BATCH TEST FOR MEASUREMENT OF ORDINARY HETEROTROPHIC ORGANISM ACTIVE BIOMASS IN ACTIVATED SLUDGE MIXED LIQUOR

by

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DECLARATION BY CANDIDATE

I, BYUNG JOON LEE, hereby declare that this thesis is my own work and it has not been submitted for a degree at another university.

Signed by candidate

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SYNOPSIS

BACKGROUND

To aid the design and operation of the single sludge activated sludge system, over the past three decades a suite of steady state design models (*e.g.* WRC, 1984; Wentzel *et al.*, 1990; Maurer and Gujer, 1994) and kinetic simulation models (*e.g.* Dold *et al.*, 1980, 1991; Van Haandel *et al.*, 1981; Henze *et al.*, 1987; Wentzel *et al.*, 1992; Henze *et al.*, 1995) have been developed. In the development of these models, it was recognised that it would not be possible to incorporate the behaviour of specific microorganism species - the mixed liquor in the activated sludge system contains a wide diversity of different micro organism species, some of whom for which identification techniques have only recently started becoming available. Instead, micro organisms that fulfil a particular function in the activated sludge system (*e.g.* aerobic degradation of organics) are grouped together as a single entity, which has been called a "surrogate" organism. This surrogate organism is assigned a set of unique characteristics that reflect the behaviour of the group, but may not reflect the characteristics of any individual organism or species of organisms in the group. A similar approach has been adopted for the "non-organism" components of the activated sludge mixed liquor, *e.g.* inert organics. Together, the surrogate organism and non-organism groups make up the activated sludge mixed liquor organic (volatile) suspended solids (MLOSS).

In terms of the models, in the non-nitrifying aerobic COD removal activated sludge system, the MLOSS is made up of three components; (1) ordinary heterotrophic organism (OHO) active biomass, (2) endogenous residue and (3) inert material. With the inclusion of nitrification in the system, a fourth component is included; (4) autotrophic organism (AO) active biomass. With the inclusion of denitrification through the incorporation of anoxic reactors, no additional surrogate organism group is included, and the OHO above are considered to be facultative mediating the denitrification process. If biological excess phosphorus removal (BEPR) is included through the incorporation of an anaerobic reactor, additionally, (5) phosphate accumulating organism (PAO) active biomass and (6) this organism group's endogenous residue contributed to the MLOSS (Wentzel *et al.*, 1992; Henze *et al.*, 1995). The active biomass components (surrogate organism groups) of the MLOSS above mediate the relevant biological processes deemed to be of importance; OHO's COD removal and denitrification, AO's nitrification and PAO's BEPR and COD removal.

Thus, in terms of the approach to modelling the activated sludge system, the activated sludge mixed liquor is made up of a number of organic components. Historically though, the MLOSS has been measured as a lumped parameter, via the VSS or COD test (Standard Methods, 1985). However, from the above, only parts of the MLOSS are active biomasses, and only these parts mediate the relevant biological processes *e.g.* OHOs for COD removal and denitrification. Acceptance of the active biomass concept has met with considerable resistance in the past. However, more recently, with the proliferation of kinetic simulation computer programmes that invariably include active biomass concentrations as parameters (*e.g.* Biowin, Simba, GPX, UCTOLD, UCTPHO), these parameters and the use of specific rates in terms of them, have become much more widely accepted. This acceptance has not been driven by sound scientific proof of the active biomass concept, but rather by the convenience of the computer programmes. It must be remembered that the active biomass concept was a hypothetical construct within the

development of the design procedures and kinetic models. For acceptance of the concept, the active biomass needs to be quantified experimentally and compared to the theoretical values of the models. If reasonable correspondence is attained, this will invest the models and the hypothetical framework on which these are based, with greater surety.

BATCH TEST METHOD TO QUANTIFY OHO ACTIVE BIOMASS

Recently a simple batch test procedure has been developed to quantify OHO active biomass concentration (Kappeler and Gujer, 1992; Wentzel *et al.*, 1995; Mbewe *et al.*, 1995). This batch test method was modified by Ubisi *et al.* (1997a,b) and Wentzel *et al.* (1998) to quantify the OHO active biomass concentration of mixed liquor samples drawn from aerobic and anoxic/aerobic activated sludge systems. In essence, in this modified method two aerobic batch tests are run in parallel; to the one batch test only unsettled wastewater is added and to the other, a mixture of wastewater and mixed liquor. Taking due account of nitrification, the difference in OUR response with time in the two batch tests can be used to derive an estimate for the OHO active biomass concentration due to the added mixed liquor. Wentzel *et al.* (1998) evaluated this batch test method, by applying it to quantify the OHO active biomass concentration of mixed liquor samples drawn from a well-defined parent laboratory-scale anoxic/aerobic activated sludge system operated at 12 and 20 d sludge age. The measured OHO active biomass concentrations were in close agreement with those calculated theoretically for the parent system at 12d sludge age, but were about ½ the theoretical values for the system at 20d sludge age.

Cronje *et al.* (2000) further evaluated the batch test method, by applying the method to mixed liquor samples drawn from a well-defined parent laboratory-scale activated sludge system operated at 10d sludge age. They found that the correlation between measured and theoretical active biomass was poor, and remarkably similar to that obtained by Wentzel *et al.* (1998) on mixed liquor samples drawn from their parent system at 20d sludge age. This prompted a detailed investigation of the batch test method. Two sources of potential error in the method were identified by Cronje *et al.*:

- In the batch test with mixed liquor + wastewater, the OHO active biomass from the wastewater has a maximum specific growth rate on RBCOD that is much larger than that of the OHO active biomass from the mixed liquor. This causes that the wastewater OHO active biomass dominates the observed OUR response in the batch tests, and thus masks the mixed liquor OHO active biomass OUR response. This introduces potential errors when the wastewater OHO active biomass is subtracted from the wastewater + mixed liquor OHO active biomass, to give the mixed liquor OHO active biomass

- In their mixed liquor + wastewater batch test Ubisi *et al.* accepted that the nitrification rate was constant, and accordingly fitted a linear line to the observed increase in nitrate concentration with time. From this linear fit, they determined the constant nitrification OUR which was subtracted from the measured OUR to give the heterotrophic OUR. In examination of their nitrate-time profiles Cronje *et al.* found that the increase could be better described by a exponential fit.

To eliminate the potential errors above, Cronje *et al.* proposed to:

- Physically remove the OHO active biomass from the wastewater. This was achieved through flocculation of the wastewater with aluminium sulphate followed by filtration.
- Using exponential fits to the nitrate-time profiles to determine nitrification OURs.

In evaluating the proposed flocculation filtration modification to the batch test procedure, Cronje *et al.* found that:

- The flocculation filtration procedure effectively removed all active biomass from the wastewater. This was demonstrated by no measurable OUR being observed in separate aerobic batch tests, conducted on the flocculated filtered wastewater only.

The flocculation filtration modification of Cronje *et al.* greatly simplified the batch test procedure - since the flocculated-filtered wastewater does not contain OHO active biomass, a parallel batch test no longer needed to be conducted to determine the wastewater OHO active biomass, which in the method of Ubisi *et al.* (1997a,b) was subtracted from the mixed liquor + wastewater OHO active biomass to give the mixed liquor OHO active biomass.

Using mixed liquor samples drawn from their parent activated sludge system at 10d sludge age, Cronje *et al.* (2000) compared the results from the modified batch test with theoretical values for OHO active biomass concentrations from the steady state design model (WRC, 1984). From this comparison they concluded that the results obtained showed good agreement. Also, there was remarkable agreement between the theoretical OHO active biomass concentration in the parent system and the mean of the measured OHO active biomass values *projected* to the parent system.

Beeharry *et al.* (2001) extensively evaluated the modified batch test procedure of Cronje *et al.* They applied the method to mixed liquor samples from two well defined parent laboratory-scale systems, both at 10d sludge age. The systems were identical, except the one (experimental) had additionally toilet paper dosed to the influent to attempt to change the relative proportions of the components making up the mixed liquor compared to the control. Beeharry *et al.* compared the measured OHO biomass concentrations to the theoretical values and found that (i) the data for the control and experimental systems were remarkably similar, and (ii) the values plot virtually parallel to the 1:1 correspondence line.

In operation of their parent systems, Beeharry *et al.* experienced severe bulking problems. To ameliorate the bulking, they changed the control system configuration from anoxic/aerobic to completely aerobic. Sequential modified batch tests on mixed liquor drawn from the control system indicated a progressive change in response: The correlation between measured and theoretical OHO active biomass concentrations moved from that noted above for the anoxic/aerobic mixed liquor, to a trend line where the measured values were 1/3 to 1/4 the theoretical values.

Thus, from the summary review above, in comparing the theoretical OHO active biomass concentration with those measured in the batch tests and modified batch tests, a variety of correlations have been found, ranging from remarkably close to 1:1 (Wentzel *et al.*, 1998 12d sludge age mixed liquor), through reasonable close to 1:1 (Cronje *et al.*, 2000 10d sludge age mixed liquor) to poor (Wentzel *et al.*, 1998 20d sludge age mixed liquor; Beeharry *et al.*, 2001 10d sludge age mixed liquor). To date, no explanation for this variability in results has been provided. ***The principle aim of this research project is to examine more thoroughly the modified batch test procedure, to explore possible explanations for the observed inconsistencies.***

RESEARCH OBJECTIVES

A weakness within the activated sludge steady state design and kinetic simulation models, is the lack of independent validation of the active biomass concept. For validation, independent quantification of active biomass and close correspondence to the theoretical values is required. In this regard, the modified batch test procedure has shown considerable promise to quantify the OHO active biomass. However, results from the batch test are variable, ranging from close correspondence with the theoretical values, to poor.

The principle aim in this research project is to more thoroughly examine the modified batch test procedure and OHO behaviour in the test, in order to explore possible explanations for the inconsistencies in results produced by the test.

To achieve this aim, three primary objectives have been identified:

(1) Re-evaluate the modified batch test method, by repeating the modified batch test procedure and comparing the measured OHO active biomass concentrations with the theoretical values predicted by the steady state model. This will establish whether the results of Cronje *et al.* or Beeharry *et al.* are reproducible, and enable an evaluation of possible causes contributing to variations in correspondence between theoretical and measured values.

(2) In addressing the aim above, it needs to be established whether discrepancies between measured and theoretical OHO active biomass concentrations arise from the activated sludge theory (*i.e.* the theoretical) or from the batch test procedure itself (*i.e.* the measured). Accordingly, the alternative more laborious batch aerobic digestion method of Marais and Ekama (1976) to quantify OHO active biomass will be applied.

(3) Should in application of the modified batch tests, an inconsistency between the measured and theoretical OHO active biomass concentrations be obtained, identify possible causes for this inconsistency. In this regard, during the investigation the importance of OHO behaviour in the modified batch tests became apparent, and the concept of substrate competition between fast and slow growing OHO population groups proposed by Novak *et al.* (1994) was found to be relevant and was examined.

RESEARCH APPROACH

Two well-defined and controlled parent laboratory-scale MLE activated sludge systems at 10 and 20 days sludge ages were operated and monitored. These parent systems provided the mixed liquor samples required for measuring OHO active biomass, by means of the modified batch test (objective (1) above) and batch aerobic digestion test (objective (2) above). The data from these tests and the analytical methods used to interpret the data were thoroughly analysed to identify possible causes for discrepancies between measured and theoretical OHO active biomass concentrations (objective (3) above); this included development of kinetic models to simulate the batch test response.

RE-EVALUATION OF MODIFIED BATCH TEST

To re-evaluate the modified batch test, the batch test was applied to mixed liquor samples drawn from two parallel well defined and controlled parent laboratory-scale anoxic/aerobic activated sludge systems, at 10 and 20 days sludge age respectively.

Parent system

Basically, both the system layout of both the10 and 20 day sludge age parent activated sludge systems constituted a Modified Ludzack-Ettinger (MLE) configuration and consisted of an anoxic reactor of 33% of the total system volume, an aerobic reactor of 67% of the total system volume and a secondary settling tank, all in series with an underflow recycle (s-recycle) from the settling tank to the anoxic reactor of 1:1 and from the aerobic reactor to the anoxic reactor (a-recycle) of 2:1 during Periods 1 and 2 or 1:1 during Periods 3 and 4. The influent for the parent laboratory-scale activated sludge systems was raw (unsettled) sewage from the Mitchell's Plain Treatment Plant in Cape Town (South Africa). This sewage is primarily domestic, with a small (< 25%) industrial component. The sewage batch was brought to the laboratory and stored in 400ℓ stainless steel tanks in a cold room at 4°C for 10 to 14 days. The total COD concentration which served as feed to both the parent laboratory-scale activated sludge systems was targeted at 750 ± 50 mgCOD/ℓ with influent flow rate of 13.3 (Period 1, 2 and 3) or 10 ℓ/d (Period 4). To maintain the pH in the aerobic reactor at ± 7.5, the alkalinity of the influent was increased by 200 mg/ℓ (as $CaCO_3$). Daily monitoring included influent COD, TKN; all reactors nitrite + nitrate; aerobic reactor TSS, VSS, COD and TKN; effluent COD, TKN, nitrate + nitrite (Standard Methods, 1985).

Both the 10 and 20 days sludge age parent systems were operated for 294 days and received 17 batches of unsettled municipal wastewater from Mitchell's Plain, Cape Town. Each wastewater batch was accepted as a steady state period, and the results for each batch were averaged (after statistical analysis for outliers). From the averaged data the following were calculated:

- System COD and N mass balances.
- Influent wastewater unbiodegradable soluble and unbiodegradable particulate COD fractions ($f_{S,us}$ and $f_{S,up}$ respectively).
- Mixed liquor COD/VSS and TKN/VSS ratios (f_{CV} and f_N respectively).
- The OHO active biomass fraction of the mixed liquor organic suspended solids (f_{av}).
- The theoretical OHO active biomass concentration in the steady state system bioreator.

From the results on the parent system:

- N mass balances were consistent and generally in the range 90 to 110%. Sewage batches rejected due to poor N mass balance were No. 15 for the 10 day sludge age system and Nos. 6 and 15 for the 20 day sludge age system.

- Generally COD mass balances were not as good as the N mass balances, with 5 of 18 sewage batches for the 10 days sludge age system and 6 of 17 sewage batches for the 20 days sludge age system giving mass balances outside the range 90 to 110%. Batch tests were conducted during 3 of these sewage batches, Nos. 5, 9 and 13. For Sewage Batch No. 9, the data were consistent with preceding and following sewage batches, and the COD mass balance was only marginally above 110% - hence this data was accepted for further analysis. For the remaining two sewage batches, the data was analyzed, but it was noted that the data should be interpreted with caution.

- The influent wastewater mean unbiodegradable soluble COD fractions ($f_{S,us}$) were determined to be 0.043 (sample standard deviation = 0.0066) and 0.040 (sample standard deviation = 0.0068) for the 10 and 20 day sludge age systems respectively. The difference between the two $f_{S,us}$ values is not statistically significant at the 95% confidence interval (t-test). However, the values are lower than the $f_{S,us}$ values obtained by both Ubisi *et al.* (1997a,b) ($f_{S,us}$ = 0.095) and Cronje *et al.* (2000) ($f_{S,us}$ = 0.085) for the same Mitchell's Plain raw wastewater; the values are similar to the $f_{S,us}$ value obtained by Beehary *et al.* (2001) ($f_{S,us}$ = 0.05). Of interest is the fact that both Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) were feeding a COD concentration of 500 ± 50 mgCOD/ℓ to their parent systems; However, Beehary *et al.* (2001) was feeding a COD concentration of 750 ± 50 mg COD/ℓ which is the same as the targeted COD concentration of this investigation. Thus, despite that the $f_{S,us}$ value would be expected to be the same, given that the influent wastewater being treated was the same and $f_{S,us}$ is a wastewater characteristic, the higher COD concentrations gave lower $f_{S,us}$ values. This observation would imply that dilution of the wastewater (with tap water) used as feed to the laboratory-scale systems has an influence on the $f_{S,us}$ value. The $f_{S,us}$ values in this experiment are, however, in the range of accepted values of 0.04 - 0.10 mgCOD/mgCOD for municipal raw wastewaters in South Africa (WRC, 1984).

- The influent wastewater mean unbiodegradable particulate COD fractions ($f_{S,up}$) were determined to be 0.165 with sample standard deviation of 0.0295 for the10 day system and 0.148 with sample standard deviation of 0.0254 for the 20 day system. The $f_{S,up}$ value of the 10 day system is slightly higher than the value of the 20 day system, similar to the $f_{S,us}$ values. However, the difference between the two $f_{S,up}$ values is not statistically significant at the 95% confidence interval (t-test). The two $f_{S,up}$ values are higher than the values observed by Ubisi *et al.* (1997a,b) ($f_{S,up}$ = 0.120) and Cronje *et al.* (2000) ($f_{S,up}$ = 0.103) and are similar to the value observed by Beehary *et al.* (2001) ($f_{S,up}$ = 0.161) for the same Mitchell's Plain raw wastewater. As noted above, both Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) were feeding a COD concentration of 500 ± 50 mgCOD/ℓ to their parent systems; however Beehary *et al.* (2001) was feeding a COD concentration of 750 ± 50 mg COD/l which is the same as the targeted COD concentration of this experiment. Thus, despite that the $f_{S,up}$ value would be expected to be the same, given that the influent wastewater being treated was the same, the higher COD concentration gave a higher $f_{S,up}$. The $f_{S,up}$ values of this experiment are, however, in the range of accepted values of 0.07 – 0.20 mgCOD/mgCOD for municipal raw wastewaters in South Africa (WRC, 1984).

The consistency in the parent systems data during which batch tests were conducted, lends support to application of the steady state design procedure to the parent systems to calculate the theoretical OHO active biomass concentrations, and to using mixed liquor from the systems in the modified batch tests to measured the OHO active biomass concentrations.

Modified batch tests

The modified batch test procedure of Cronje *et al.* (2000) to quantify the OHO active biomass concentration in mixed liquor drawn from aerobic and anoxic/aerobic activated sludge systems was used in this research. The modified batch test was done by flocculating and filtering the wastewater to remove the OHO active biomass present in the raw wastewater itself, thereby simplifying the procedure.

For flocculating and filtering the raw wastewater: 10 mℓ of stock aluminium sulphate [$A\ell(SO_4) \cdot 15\ H_2O$, stock at 50g/ℓ] were added per ℓ wastewater, the mixture was stirred rapidly (~200 rpm) for 2 minutes (rapid mix phase) and then slowly (~1 rpm) for 30 minutes (flocculation and settling phase) and then were allowed to settle (without stirring) for a further 30 minute period. The clear supernatant developed in the settling cylinders was drawn off and filtered through a glass fibre filter (Whatman's GF/C).

The modified batch tests were conducted using a mixture of flocculated and filtered wastewater and mixed liquor. The required volume of mixed liquor was harvested from the aerobic reactor of the parent system and added to the *flocculated-filtered* wastewater, giving a combined volume of 3ℓ for the mixture in the batch reactor. A sample was drawn to obtain the initial total COD concentration. The oxygen supply and OUR response in the batch test was measured using an automated technique (Randall *et al.*, 1991). At regular intervals, samples were drawn from the batch reactor, immediately filtered through 0.45 µm filter paper, 2 – 3 drops of $HgCl_2$ were added to the filtrate which was stored for subsequent nitrate and nitrite analysis. At the end of the batch tests, the final sample was drawn from the batch reactor, mascerated and the final total COD concentration measured.

The modified batch test data were analyzed and interpreted using the procedure detailed by Cronje *et al.* (2000) and Beeharry *et al.* (2001), which is based on a simplified UCT model, which consists of a single OHO population. From the batch test data the following was calculated.

- %COD recovery
- OHO active biomass concentration at the start of the batch test, $Z_{BH(0)}$
- OHO maximum specific growth rates on RBCOD (μ_H) and SBCOD (K_{MP})

In total, 35 modified batch tests were conducted on mixed liquor drawn from the 10 day sludge age parent system, and 35 on that drawn from the 20 day sludge age parent system. From the batch tests, the following conclusion were drawn:

- Nitrite concentrations in the modified batch tests were significant, and hence were taken into account in calculating the nitrification OUR.

- In general, %COD recoveries were good with only 8 out of 35 batch tests on 10 day sludge age mixed liquor yielding %COD recoveries < 90%, and only 7 out of 35 for the 20 day sludge age mixed liquor. Excluding data for those batch tests that deviated from the "true" normal probability line (4 for 10 days; 3 for 20 days), the mean %COD recoveries were 95.2 and 94.8 % for the batch tests on 10 and 20 day sludge age mixed liquor respectively, with sample standard deviations of 5.3 and 4.5% respectively. The %COD recoveries are somewhat lower than that obtained by Cronje *et al.* (2000) (100.5%), but are similar to those of Beeharry *et al.* (2001) (97.8 and 95.9 %). The good %COD recoveries lend credibility to the experimental data.

- For the OHO maximum specific growth rate on SBCOD (K_{MP}), excluding the batch tests with low %COD recoveries, statistical analysis gave mean K_{MP} of 1.37 and 1.42 /d for the 10 and 20 day sludge age mixed liquors respectively, with sample standard deviations of 0.412 and 0.428 /d respectively. The close means (difference 3.5% not statistically significant at 95% confidence interval, t-test) indicates that the sludge age did not have a significant influence on the value for this parameter. The values are larger than that measured by Cronje *et al.* (2000) (0.84 /d), but are close to the values measured by Beeharry *et al.* (2001) (1.49 and 1.38 /d). Further, the values are close to the default value for K_{MP} in the UCT kinetic simulation model of 1.35 /d (Dold *et al.*, 1991). It should be noted that there was some measure of uncertainty in the determination of K_{MP} at the relatively large and small mixed liquor volumes. However, it was concluded that the uncertainty was not large.

- For the OHO maximum specific growth rate on RBCOD (μ_H), for batch tests on mixed liquors from both parent systems, a clearly discernable trend was noted: As the volume of mixed liquor added to the batch test increased, the value for μ_H decreased. This indicates that one (or more) factor has a dominating influence, which precluded statistical analysis of the data. Re-examination of the data of Beeharry *et al.* (2001) indicated that they obtained, but did not note, a similar trend (see Cronje *et al.*, 2002). Possible reasons for this trend were examined, see below.

- In comparing the measured OHO active biomass concentration at the start of the batch test $Z_{BH(0)}$ with the theoretical value, the data for both the 10 and 20 day sludge age mixed liquor showed very similar trends. Also, superficially both comparisons bear a strong resemblance to the data of Beeharry *et al.* (2001), namely that there is a correspondence, but the values plot parallel to the 1:1 correspondence line. However, if the data is examined more closely, for both the 10 and 20 day mixed liquors three regions were identified:

  (i) Theoretical $Z_{BH(0)} < 30$ mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values decrease, to approach near zero. Beeharry *et al.* (2001) did not collect data in this region, so a comparison with their data is not possible.

  (ii) 30 mgCOD/ℓ < Theoretical $Z_{BH(0)} < 150$ mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values correspondingly increase parallel to a 1:1 correspondence line, but below it. This trend is near identical to that observed by Beeharry *et al.* (2001), whose data falls primarily in this region.

  (iii) Theoretical $Z_{BH(0)} > 150$mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values increase sharply to cross the 1:1 correspondence line. Beeharry *et al.* (2001) collected limited data in this region, but the data available indicates it is consistent with the observation here.

The close similarity in trends between the 10 and 20 day sludge age mixed liquors, and the consistency with the data of Beeharry *et al.* (2001) indicated that the observed deviation in measured and theoretical $Z_{BH(0)}$ values is not a function of sludge age, or of this investigation.

The causes for the deviation was not possible P limitation in the batch test due to pre-flocculation of the sewage with alum - parallel modified batch tests with and without P supplementation gave near identical results. This prompted a more investigation of the modified batch test. It first needed to be established whether the cause lay in the activated sludge theory (*i.e.* theoretical) or in the modified batch test procedure itself (*i.e.* the measured).

BATCH AEROBIC DIGESTION TEST

To establish whether the causes for the deviations between theoretical and measured OHO active biomass noted above lay in the activated sludge theory or in the modified batch test procedure, an alternative method to quantify OHO active biomass was investigated. As the alternative, the aerobic batch digestion method of Marais and Ekama (1976) was applied to quantify the OHO active biomass concentration of mixed liquor drawn from both the 10 and 20 day sludge age parent activated sludges systems.

1.56ℓ and 1.32ℓ of mixed liquor were drawn from the 10 and 20 days sludge age parent MLE systems respectively. The mixed liquor drawn from the parent system was placed into batch reactor and immediately the batch aerobic digestion test started. The OUR response in the batch test was measured using an automated technique (Randall *et al.*, 1991) for approximately 10 days. At the beginning of the test and at the same time on each of the following days, (i) pH was measured to ensure pH was sufficiently high for complete nitrification (pH > 7) and (ii) samples

were drawn from the batch reactor, immediately filtered through 0.45 μm filter paper, 2 - 3 drops of $HgCl_2$ were added to the filtrate which was stored for subsequent nitrate, nitrite and Free and Saline Ammonia (FSA) analysis. For all the batch aerobic digestion tests, the pH was sufficiently high to ensure complete nitrification, indicated by the fact that the FSA was constantly kept at a low concentration, *i.e.* FSA did not accumulate during the test.

The batch aerobic digestion test data were analyzed and interpreted using the procedure based on Marais and Ekama (1976). From the batch test data the following were calculated.

- Specific endogenous mass loss rate (b_{H20T}) at temperature 20 °C (/d)
- Initial OHO active biomass concentration ($X_{BH(0)}$) (mgVSS/ℓ)
- Theoretical Nitrate concentrations ($NO_{3(t)}$) with time

In total, 2 batch aerobic digestion tests were conducted on mixed liquor drawn from the 10 day sludge age parent system, and 2 on that drawn from the 20 day sludge age parent system. From the batch aerobic digestion tests, the following conclusion were drawn:

- Filtered samples taken at regular intervals during the test showed FSA concentrations were constant, at low values. This implies nitrification was complete, a pre-requisite for analysis of the data.

- Nitrate concentrations with time in the aerobic batch digestion tests were predicted with activated sludge theory. The measured nitrate concentrations were consistently higher than the predicted concentrations during the entire test. No definitive explanation for this inconsistency could be proposed, and this warrants further investigation.

- The high linear regression correlation coefficients ($R^2 > 0.97$) in the fit to the ℓn OUR_t - time plots lends credibility to the experimental data.

- For the values for the OHO specific endogenous respiration rate (b_{H20}) values, for the 20 days sludge age system mixed liquor these were estimated as 0.22/d and 0.26/d; for the 10 days sludge age system mixed liquor these were estimated as 0.31/d and 0.33/d. The values for the 10 day sludge age system are significantly higher than the default value of 0.24/d (Marais and Ekama, 1976; WRC, 1984). This would imply that sludge age influence b_{H20}, which is contrary to current activated sludge theory. This warrants further investigation.

- A remarkably close correspondence between the theoretical OHO active biomass concentration and that measured in the aerobic batch digestion test was obtained. The % differences between measured and predicted values were estimated as 1.4% and 8.2% for the 10 and 20 days sludge age parent systems respectively.

In the batch aerobic digestion tests which are based on the endogenous respiration process, remarkably good correlation between the measured and theoretical OHO active biomass values was obtained. From this observation, it was concluded that the major cause for the difference between the measured and theoretical OHO active biomass concentrations in the modified batch tests lies in the description and interpretation of the OHO growth process.

OHO BEHAVIOUR IN THE MODIFIED BATCH TESTS

The close correlation between theoretical OHO active biomass concentration and that measured in the batch aerobic digestion tests focussed attention on the behaviour of the OHOs in the batch tests.

Evaluation of OHO behaviour in the modified batch tests

A more detailed investigation into OHO behaviour within the modified batch test was conducted through a detailed analysis of the data collected above in the modified batch tests. In particular, (i) the effect of the ratio substrate concentration to OHO active biomass concentration (So/Xo) and (ii) the validity of the analytical procedures were examined. From this investigation the following general conclusions can be drawn:

- For all observations, the remarkable similarity in the data for modified batch tests on both the 10 and 20 day sludge age mixed liquors substantiates the consistency of the data and the observations made. It also excludes sludge age as the underlying causes for any deviations.

- The OHO maximum specific growth rate on RBCOD (μ_H) appears to be a function of the OHO active biomass concentration added at the start of the test ($Z_{BH(0)}$); as $Z_{BH(0)}$ decreases, μ_H increases. The OHO maximum specific growth rates on SBCOD (K_{MP}) also exhibit some variation between the different batch tests, also apparently linked to the OHO biomass concentration added.

- Similar, though reversed, trends noted above for μ_H and K_{MP} were evident for the effect of initial substrate to OHO active biomass concentration, *i.e.* So/Xo ratio.

From a plot of theoretical versus measured $Z_{BH(0)}$, the following conclusions could be drawn:

- For $Z_{BH(0)}$(Theo.) < 30 mgCOD/ℓ :
  There is uncertainty in the data, although the trends do suggest possible inhibition.

- For 30 mgCOD/ℓ < $Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ :
  In this region, the observed behaviour strongly suggests that the net OHO maximum specific growth rates change during the course of the batch test. In a single OHO population model, to interpret the batch test data, this implies that the maximum specific growth rate constants for the OHOs would need to be increased with time. A two OHO population model with fast- and slow- growing OHO groups, as proposed by Novak *et al.* (1995), was identified to be a logical alternative.

- For $Z_{BH(0)}$(Theo.) > 150 mgCOD/ℓ :
  In this region, the batch test resolution is inadequate, because the increase in OHO active biomass concentration with time is not significant compared to the initial concentration, a requirement in the batch test.

From the above, data in the range 30 mgCOD/ℓ < $Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ were identified as reasonable for further investigation. In this regard, application of the competition concept of Novak *et al.* (1994) was identified as a possible explanation for the observed behaviours.

Development and application of a competition model

In evaluating OHO behaviour in the modified batch tests above, it became apparent that the simplified UCT model which is used to analyse the batch test data could not explain the observations, in particular:

(i) The observed precipitous drop in OUR implies that the OHO specific growth rates are at their maxima, *i.e.* the changes noted below were not directly due to variations in growth rates due to varying substrate concentrations with time or between batch tests.

(ii) In a plot of ℓn OUR_H versus time, the measured data deviated from the fitted linear regression line, showing upward curvature; In plotting the OUR_H - time curve predicted by the simplified UCT model (based on a single OHO population), this deviation is accentuated. To explain these deviations, it was noted that the data implies that the overall OHO maximum specific growth rates increase during the course of the batch test. Such observations are not accommodated in the simplified UCT model used to develop the analytical procedure for the batch test.

(iii) OHO maximum specific growth rates on RBCOD as calculated from the batch test data with the simplified UCT model analytical procedure increased as the substrate (So) to OHO active biomass concentration (Xo), *i.e.* the So/Xo ratio, at the start of the batch test increased. With the single OHO population model incorporated in the analytical procedure, it would be expected that the OHO maximum specific growth rate would remain constant.

(iv) The larger OHO maximum specific growth rate on RBCOD values above, were significantly higher (up to about 7 /d) than the range of values accepted as the default for the UCT kinetic model (1.5 to 3.5 /d, Dold *et al.*, 1991).

(v) The OHO active biomass concentrations measured via the batch test procedure were consistently lower than the theoretical values. One possible explanation for this is that the OHO maximum specific growth rates increase with time in the batch tests: In terms of the batch test analytical procedure, a single constant OHO maximum specific growth is determined and applied to the start of the test to derive a value for OHO active biomass concentration. Thus, if the OHO maximum specific growth rate increases with time, then the value at the start of the test is overestimated and hence OHO active biomass concentration would be underestimated.

The observations above suggest that the OHO maximum specific growth rate, particularly on RBCOD, increases with time in the batch test. The current analytical procedure for the batch test, which is based on a single OHO population with fixed kinetics, cannot readily accommodate this observation.

To explain similar observations, Novak *et al.* (1994) and Grady *et al.* (1996) proposed substrate competition between different OHO groups as a possible cause. This possibility was investigated by developing a kinetic model for competition between two OHO populations, one a fast grower and the other a slow grower. This model was applied to both (i) the batch tests and (ii) the steady state systems.

To evaluate the competition model to be developed, the batch test data with the greatest surety was selected; these were the batch tests with theoretical OHO active biomass concentrations $\geq$ 30, but $<$ 150 mgCOD/ℓ. 11 and 12 modified batch tests respectively on mixed liquors from the 10 and 20 days sludge age parent systems (out of total of 35 modified batch tests on mixed liquors from each of the parent systems) were selected for further analysis.

Parameter estimation for the batch test data above was done with the aid of the AQUASIM 2.0 computer program (Reichert, 1998 a, b), as follows: All the parameters except the parameters related to OHO growth on RBCOD were based on the default values of UCTOLD computer program (Dold *et al.*, 1991). With regard to the OHO maximum specific growth rates and half saturation constants on RBCOD of the fast grower (μ_{H1}, K_{SH1}) and the slow grower (μ_{H2}, K_{SH2}), these were assumed as 12/d and 3 mgCOD/ℓ and 2/d and 0.1 mgCOD/ℓ respectively to ensure competition on RBCOD and that the precipitous drop in OUR could be correctly predicted. The parameters which were required to be estimated were the initial concentrations of the fast and slow growers, $Z_{BH1(0)}$ and $Z_{BH2(0)}$ respectively, and the initial "substrate" concentrations. For the initial "substrate", even though the second plateau of the OUR_H-time curve, which is assumed to be related to the "soluble" SBCOD in the analytical procedure of Wentzel *et al.* (1995), is clearly observed, to reduce the complexity of parameter estimation, the initial substrate was totally ascribed to RBCOD. This restricted the parameter estimation to the period up to the OUR precipitous drop.

The competition model was also applied to simulate the two parent activated sludge systems. The same set of kinetic and stoichiometric constants used in simulation of the batch tests were used to simulate the parent activated sludge systems. For the influent wastewater, accepting the fraction of RBCOD, f_{bs}, as 0.2, influent RBCOD and SBCOD concentrations were set as 120 and 480 mgCOD/ℓ respectively. Fast growing OHO active biomass concentration in the influent wastewater, $Z_{BH1(Inf)}$, was accepted to be 3% of total COD at most, in agreement with the observations of Wentzel *et al.* (1995). To examine the effect of variation in this parameter, $Z_{BH1(Inf)}$ was varied between 0% and 3% of the total influent COD. For the plant configuration, a simple activated sludge system configuration which consisted of a single aerobic reactor and secondary settling tank was used, because the sludge composition and production of the MLE system and the single aerobic reactor are very similar, and the application of the model to the single aerobic reactor was much simpler. The reactor volume of Period 3 was used for the simulation. For the operational parameters, 10 days and 20 days Sludge Retention Time (SRT) were used respectively. Temperature, influent flow rate and recycling flow rate were all based on the parent system conditions of Period 3.

From the results of application to the batch tests, the following conclusions could be drawn:

- The model can simulate accurately the OUR_H - time observed in the batch tests. Estimating the initial batch test OHO active biomass concentrations of the fast ($Z_{BH1(0)}$) and slow grower ($Z_{BH2(0)}$) with the parameter estimation technique in AQUASIM 2.0 gave exceptionally low $Z_{BH1(0)}/(Z_{BH1(0)}+Z_{BH2(0)})$ values, average 1%. However, with time in the batch test, the Z_{BH1} increased its proportion significantly and had a marked influence on the predicted OUR_H - time profile. This indicates that the batch test procedure is extremely sensitive to the presence of fast growing OHOs.

- The model could simulate the variety of observations made on the batch tests, including the increase in overall OHO maximum specific growth rates with increasing So/Xo and with time.

- In seeking a source for the fast growing OHOs in the batch test, it was noted that this was not the wastewater (no observable OUR after 12 hours aeration), but must be the mixed liquor drawn from the parent activated sludge systems.

In application of the model to the steady state activated sludge systems, it was found that:

- The fast growing OHO population group could only be sustained in the system if they were seeded into the system with the influent. The possibility of seeding was substantiated by the observations of Wentzel *et al.* (1995) and Cronje *et al.* (2000) who noted significant fast growing OHOs present in the same raw wastewater that was used in this investigation.

- With seeding fast growing OHO to the steady state systems at concentrations typically measured by Wentzel *et al.* (1995) (< 3% of total COD), the model predicted the fast grower could be successfully sustained in the system. However, the predicted fast growing OHO proportion of the total OHO active biomass (± 40% at seed of 3% of total COD) was significantly larger than that derived from parameter estimation of the batch test data (1%).

To address the above, the competition model was modified by removing the processes for growth of the fast growing OHOs on SBCOD. This was considered reasonable, since the original source of the fast grower is seeding with the influent wastewater to the steady state activated sludge systems - this implies growth in the sewer where RBCOD concentrations are very high, which would favour predominantly RBCOD utilization. Simulation of the batch tests and steady state systems gave results very similar to the competition only model, except that:

- The predicted proportions of Z_{BH1} in steady state system mixed liquor for were significantly lower than with the competition only model, < 3% compared to ± 40% for $Z_{BH1(Inf)}$ in the influent at 3% of total COD. These values were very close to the values determined from parameter estimation with the batch test data.

In comparing the various estimates for OHO active biomass concentrations, it was found that, compared to the theoretical concentrations calculated with the steady state model, the two OHO population models gave concentrations that were significantly superior to the single OHO population model. This would indicate that the competition hypothesis (in agreement with previous researchers) is one feasible explanation for the observations in the batch tests. However, the kinetic models developed here are largely hypothetical - insufficient information is available to separate the two OHO populations and quantify the individual kinetic processes. Furthermore, it must be remembered that the kinetic models are a gross practical simplification of the complete OHO community present in activated sludge mixed liquor. This simplification has practical benefits, *e.g.* reduced quantity of input information required, wider generality, but also has limitations. In particular, competitive interactions are difficult to accommodate, where balanced competitive populations are present. Further, hypotheses alternative to the competition one could possibly explain the observed behaviours. For example, it is possible that the batch conditions induce a change in the substrate utilization/growth kinetics of the OHOs with time (*i.e.* physiological adaptation Daigger *et al.*, 1982). Considering that the OHOs have been developed in the steady state system under substrate (organic C) limiting conditions, and are placed in the batch test with excess substrate, adaptation of the OHOs to the batch test conditions (and hence change in kinetics) is not unreasonable. Clearly, this topic requires further investigation. Such an investigation will be facilitated by the new microbiologically based analytical techniques, *e.g.* FISH.

CLOSURE

In this research project, the modified batch test, to quantify OHO active biomass has been extensively evaluated. It was hoped that the method would provide measured OHO active biomass concentrations that would compare favourably with the theoretical values predicted by the steady state design and kinetic simulation models for the activated sludge system. This would substantiate the active biomass concept incorporated in these models, and thereby promote confidence in their application. However, in this research, similarly to that previously of Beeharry *et al.* (2001), this proved not to be true: Although measured OHO active biomass concentrations were obtained that were of the same order of magnitude as the theoretical values, in general compared to the theoretical values, the measured values tended to plot on a line parallel but below the 1:1 correspondence line.

In examining possible causes for the lack of 1:1 correspondence between theoretical and measured OHO active biomass concentrations, it was noted that the modified batch test method to quantify OHO active biomass relies on a single OHO population with constant kinetics. Observations made in this research, and previously (*e.g.* Daigger *et al.*, 1982; Novak *et al.*, 1994; Grady *et al.*, 1996) suggest that this may not true, and that the batch test conditions may cause the overall OHO behaviour to deviate significantly from that in the steady state system. The batch test method, and its interpretation in terms of the procedures described in Chapter 4, is particularly sensitive to any changes in the OHO kinetics as time proceeds in the batch test, since these kinetics are applied to the start of the test to determine the OHO active biomass concentration. This sensitivity, can explain the variability in correlations between batch test measured OHO active biomass concentrations and the theoretical values. Unfortunately, the sensitivity renders the batch test as an unsuitable method to quantify the OHO active biomass

concentration with sufficient accuracy. The test does, however, hold merit as a tool to investigate OHO population dynamics, as demonstrated by Beeharry *et al.* (2001) and shown here.

The causes for the lack of a 1:1 correspondence between OHO active biomass measured in the modified batch test and that predicted theoretically with the activated sludge models was shown to lie in the modified batch test itself: The batch aerobic digestion tests and re-interpretation of the modified batch test data with the competition model both provided reasonable close 1:1 correspondence. This does provide independent evidence that substantiates the active biomass concept incorporated in the models. Further, although the competition model needed to be applied to explain the observations in the modified batch tests, it must be remembered that in the parent activated sludge systems, the OHO population is dominated by the slow growing OHO population group, to the extent of near exclusion of the fast growers. Thus, for the activated sludge system the current models incorporating a single OHO population are adequate, provided extremes in dynamic loading are not encountered (*e.g.* selector reactors).

RECOMMENDATIONS

From this investigation the following recommendations can be made:

- In operation of laboratory-scale activated sludge systems, sludge bulking may have a negative impact on N and COD mass balances. This arises because with sludge bulking, sludge can accumulate in the secondary settling tank (SST) leading to denitrification along the axis of flow through the SST. This denitrification is not fully taken into account in the mass balances, and therefore can lead to poor mass balances. According to Ekama *et al.* (1998), sludge accumulation in the SST depends on the solids loading on SST and the sludge settling characteristics. Control of the sludge settling characteristics may not always be possible. Hence, to avoid sludge accumulation in the SST for good N and COD mass balances, it is recommended that the solids loading on the SST be controlled. This is determined by the influent flow rate and the solids concentration in the biological reactor, both of which can be adjusted.

- In the modified batch test a second plateau in the OUR_H-time plot is observed. Cronje *et al.* (2000) and Beeharry *et al.* (2001) ascribed this second plateau to "soluble" SBCOD that was not removed in the flocculation and filtration of the sewage added to the batch test. In the kinetic models for activated sludge systems, a single SBCOD "type" is accepted, with the same kinetics of hydrolysis/utilization applied to all SBCOD. The existence of a soluble (*i.e.* "non-flocculatable") SBCOD need to be investigated, as this may have an impact on modelling the kinetics of SBCOD hydrolysis/utilization. Also, other possible explanations for the second OUR plateau need to be evaluated, such as intracellular substrate storage. Majone *et al.* (1999) and Carucci *et al.* (2001) reported evidence of aerobic storage under dynamic conditions. The more fundamental microbiological or biochemical analytical techniques may prove useful in this regard.

- The batch aerobic digestion test provided estimates for OHO active biomass concentrations that agree closely with the theoretical values. However, only 4 such tests were undertaken due to the time consuming nature of the tests (> 10days in duration). More such tests need to be undertaken, to confirm the results obtained here. One issue that would require resolution is that in batch aerobic digestion tests, the measured nitrate concentrations were always higher than the predicted concentrations. This was common to all the batch aerobic digestion tests. An explanation for this poor correlation could not be provided.

- To explain the behaviour observed in the modified batch tests, in this research a competition model was proposed. However, hypotheses alternative to the competition one, also could possibly explain the observed behaviour. For example, Daigger *et al.* (1982) and Grady *et al.* (1996) proposed the concept of "physiological adaptation". In this concept, the relative components of the biomass groups (fast grower and slow grower) do not change, but rather the physiological state of the biomass itself, induced by the change in conditions from the steady state system to the batch test (Grady *et al.*, 1996). Such alternatives also require evaluation.

- In this research, in calibrating the competition models, values had to be assumed for the kinetic parameters for the fast and slow growing OHO population groups (μ_{H1}, μ_{H2}, K_{SH1} and K_{SH2}). With the accepted values, the competition model could reasonably accurately simulate the diverse observed behaviour, *e.g.* change in kinetic rates with time in the batch tests, the effect of So/Xo on the kinetics. However, the values for the rate constants were not directly determined. This was not possible because the behaviour of the fast and slow growing OHO population groups could not be separated. This requires investigation.

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LIST OF SYMBOLS

AA	Anoxic-aerobic
ASM	Activated Sludge Model
BEPR	Biological excess phosphorus removal
b_{H20}	Specific endogenous mass loss rate at 20°C, death regeneration theory (/d)
b_{H20}^*	Specific endogenous mass loss rate at 20°C, endogenous respiration theory (/d)
b_{HT}	Specific endogenous mass loss rate at temperature T, death regeneration theory (/d)
b_{HT}^*	Specific endogenous mass loss rate at temp. T, endogenous respiration theory (/d)
BNR	Biological nutrient removal
C	Carbon
COD	Chemical Oxygen Demand
COD_{END}	Total unfiltered COD concentration at end of test (mgCOD/ℓ)
COD_{FE}	Total filtered effluent COD concentration (mgCOD/ℓ)
COD_{ML}	Total unfiltered mixed liquor COD concentration (mgCOD/ℓ)
COD_{START}	Total unfiltered COD concentration at start of test (mgCOD/ℓ)
$COD_{t=0}$	Total unfiltered COD concentration at start of test (t = 0) (mgCOD/ℓ)
$COD_{t=T}$	Total unfiltered COD concentration at start of test (t = T) (mgCOD/ℓ)
COD_{WW}	Total unfiltered wastewater (influent) COD concentration (mgCOD/ℓ)
d	Day
DO	Dissolved Oxygen (mgO/ℓ)
DSVI	Diluted sludge volume index (mℓ/gTSS)
e.g.	For example
EDTA	Ethylene diamine tetra acetic acid
f^*	Endogenous residue fraction, endogenous respiration theory
F/M	Food / Microorganism ratio
f_{av}	Active fraction of the volatile suspended solids (mgAVSS/mgVSS)
f_{cv}	COD to VSS ratio of the mixed liquor (mgCOD/mgVSS)
f_E^*	Endogenous residue fraction, endogenous respiration theory
f_N	Nitrogen to COD ratio of mixed liquor (mgN/mgCOD)
f_p	Endogenous residue fraction, endogenous respiration theory
FSA	Free and saline ammonia (mgN/ℓ)
$f_{S,up}$	Unbiodegradable particulate fraction of the influent (mgCOD/mgCOD)
$f_{S,us}$	Unbiodegradable soluble fraction of the influent (mgCOD/mgCOD)
h	Hour
H	Hydrogen
H^+	Hydrogen ion
H_2O	Water
$HgCl_2$	Mercuric Chloride
i.e.	That is
IAWQ	International Association of Water Quality
ISS	Inorganic suspended solids (mgISS/ℓ)
K_{MP}	OHO maximum specific growth rate on SBCOD (/d)

K_{SH}	OHO half saturation rate on RBCOD (mgCOD/ℓ)
K_{SH1}	Fast growing OHO half saturation rate on RBCOD (mgCOD/ℓ)
K_{SH2}	Slow growing OHO half saturation rate on RBCOD (mgCOD/ℓ)
K_{SP}	OHO half saturation rate on SBCOD (mgCOD/ℓ)
LR	Loading rate
ML	Mixed liquor
MLAVSS	Mixed liquor active volatile suspended solids concentration (mgVSS/ℓ)
MLE	Modified Ludzack-Ettinger
MLOSS	Mixed liquor organic suspended solids
MLSS	Mixed liquor total suspended solids concentration (mgTSS/ℓ)
MLVSS	Mixed liquor volatile suspended solids concentration (mgVSS/ℓ)
MN_{ne}	Mass of nitrate in the effluent (mgN/ℓ)
MN_{nw}	Mass of nitrate in the waste sludge (mgN/ℓ)
$MNO_{2,d}$	Mass of nitrate generated (mgN/d)
$MNO_{3,d}$	Mass of nitrate denitrified (mgN/d)
MN_{te}	Mass of effluent TKN (mgN/ℓ)
MN_{ti}	Mass of influent TKN (mgN/ℓ)
MN_{w}	Mass of TKN in the waste sludge (mgN/ℓ)
MO_{c}	Mass of carbonaceous oxygen demand (mgO/d)
MO_{d}	Equivalent mass of oxygen demand for denitrification (mgO/d)
MO_{n}	Mass of oxygen demand for nitrification (mgO/d)
MO_{t}	Mass of total oxygen demand (mgO/d)
MS_{te}	Mass of total filtered effluent COD concentration (mgCOD/d)
MS_{ti}	Mass of total unfiltered influent COD concentration (mgCOD/d)
MX_{BA}	Mass of AO active biomass (mgVSS)
MX_{BH}	Mass of OHO active biomass (mgVSS)
MX_{E}	Mass of endogenous material (mgVSS)
MX_{I}	Mass of inert material (mgVSS)
MXsvw	Mass of COD wasted (mgCOD/d)
MX_{V}	Mass of volatile suspended solids (mgVSS)
N	Nitrogen
N_2	Nitrogen gas
NaCl	Sodium chloride
$NaHCO_3$	Sodium Bicarbonate
ND	Nitrification / Denitrification
NH_3	Ammonia (mgN)
NH_4^+	Ammonium (mgN)
N_{ne}	Nitrate concentration in the effluent (mgN/ℓ)
No.	Number
NO_2^-	Nitrite (mgN)
NO_3^-	Nitrate (mgN)
N_{te}	TKN concentration in the effluent (mgN/ℓ)
O_2	Oxygen

OHO	Ordinary heterotrophic organism
OUR	Oxygen utilization rate (mgO/ℓ/h)
OUR_{ct};O_{ct}	OHO active biomass oxygen utilization rate at time t (mgO/ℓ/h)
$OUR_{H(t)}$	OHO active biomass oxygen utilization rate at time t (mgO/ℓ/h)
$OUR_{M(t)}$	OUR measured at time t (mgO/ℓ/h)
$OUR_{N(t)}$	AO oxygen utilization rate at time t (mgO/ℓ/h)
OUR_{NO2}	OUR for NO_2^- nitrification (mgO/ℓ/h)
OUR_{NO3}	OUR for NO_3^- nitrification (mgO/ℓ/h)
OUR_{nt};O_{nt}	Oxygen utilization rate by nitrification at time t (mgO/ℓ/h)
OUR_{tt};O_{tt}	Total oxygen utilization rate at time t (mgO/ℓ/h)
P	Phosphorus
PAO	Phosphate accumulating organism
polyP	Polyphosphate
Q or Qi	Influent flow (ℓ/d)
RBCOD;S_{bsi}	Readily biodegradable COD (mgCOD/ℓ)
R_S	Sludge age (d)
s	Second
S	Concentration of substrate [ML^{-3}]
S_{ads}	Adsorbed slowly biodegradable COD concentration (mgCOD/ℓ)
S_b	Biodegradable COD concentration (mgCOD/ℓ)
SBCOD;S_{bpi}	Slowly biodegradable COD (mgCOD/ℓ)
S_{bi}	Biodegradable COD concentration in the influent (mgCOD/ℓ)
S_{bp}	Biodegradable COD concentration that is particulate (mgCOD/ℓ)
S_{bpi}	Particulate biodegradable COD concentration in the influent (mgCOD/ℓ)
S_{bs}	Biodegradable COD concentration that is soluble (mgCOD/ℓ)
S_{bsi}	Soluble biodegradable COD concentration in the influent (mgCOD/ℓ)
SLR	Sludge loading rate (mgCOD/mgVSS)
So/Xo	Substrate / Biomass Ratio
SO_4	Sulphate
SSD	Sample standard deviation
S_{te}	Filtered effluent COD concentration (mgCOD/ℓ)
S_{ti}	Unfiltered influent COD concentration (mgCOD/ℓ)
S_{ui}	Unbiodegradable COD concentration in the influent (mgCOD/ℓ)
S_{up}	Unbiodegradable particulate COD concentration (mgCOD/ℓ)
S_{upi}	Unbiodegradable particulate COD conc. in the influent (mgCOD/ℓ)
S_{us}	Unbiodegradable soluble COD concentration (mgCOD/ℓ)
S_{use}	Unbiodegradable soluble COD conc. in the effluent (mgCOD/ℓ)
S_{usi}	Unbiodegradable soluble COD conc. in the influent (mgCOD/ℓ)
t	Time
TKN	Total Kjedahl Nitrogen (mgN/ℓ)
TOC	Total Organic Carbon (mg/ℓ)
TS	Total solids (mgTS/ℓ)
TSS	Total suspended solids (mgTSS/ℓ)

UCT	University of Cape Town
USCOD	Unbiodegradable soluble COD (mgCOD/ℓ)
V	System volume (ℓ)
V_{ML}	Volume of mixed liquor added to batch test (ℓ)
V_p	Volume of reactor (ℓ)
VSS	Volatile suspended solids (mgVSS/ℓ)
V_{WW}	Volume of wastewater added to batch test (ℓ)
WRC	Water Research Commission
WW	Wastewater
X	Concentration of microbiology [ML^{-3}]
X_{BA}	AO active biomass concentration (mgVSS/ℓ)
X_{BH}	OHO active biomass concentration (mgVSS/ℓ)
X_{BHi}	OHO active biomass concentration at the start (mgVSS/ℓ)
X_{BHt}	OHO active biomass concentration at time t (mgVSS/ℓ)
Xe	Endogenous material concentration (mgVSS/ℓ)
X_E	Endogenous material concentration (mgVSS/ℓ)
X_I	Inert material concentration (mgVSS/ℓ)
X_V	Volatile suspended solids concentration (mgVSS/ℓ)
X_V(PS)	Mixed liquor VSS concentration in parent system (mgVSS/ℓ)
Y_H	OHO active biomass yield, VSS units (mgVSS/mgCOD)
Y_H^*	OHO active biomass yield, VSS units (mgVSS/mgCOD)
Y_{ZA}	AO biomass yield (mgCOD/mgN)
Y_{ZH}	OHO active biomass yield, COD units (mgCOD/mgCOD)
Z_{BH}	OHO active biomass concentration (mgCOD/ℓ)
$Z_{BH(0)}$ $(WW)_D$	Heterotrophic active biomass due to waste water at start of batch test with wastewater + mixed liquor (mgCOD/ℓ)
$Z_{BH(0)}$ (WW)	Heterotrophic active biomass in the original waste water (mgCOD/ℓ)
$Z_{BH(0)}$	OHO active biomass conc. at the start of the batch test (mgCOD/ℓ)
$Z_{BH(0)}$(Meas.)	OHO active biomass conc. measured by the batch test (mgCOD/ℓ)
$Z_{BH(0)}$(Theo.)	OHO active biomass conc. calculated by the steady state model (mgCOD/ℓ)
$Z_{BH(Inf)}$	OHO active biomass conc. in influent wastewater (mgCOD/ℓ)
Z_{BH1}	Fast growing OHO active biomass concentration (mgCOD/ℓ)
$Z_{BH1(0)}$	Fast growing OHO active biomass conc. at the start of the batch test (mgCOD/ℓ)
Z_{BH2}	Slow growing OHO active biomass concentration (mgCOD/ℓ)
$Z_{BH2(0)}$	Slow growing OHO active biomass conc. at the start of the batch test (mgCOD/ℓ)
ℓ	Litre
μ_A	AO maximum specific growth rate (/d)
μ_H	OHO maximum specific growth rate on RBCOD (/d)
μ_{H1}	Fast growing OHO maximum specific growth rate on RBCOD (/d)
μ_{H2}	Slow growing OHO maximum specific growth rate on RBCOD (/d)
°C	Degrees celsius

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

To aid the design and operation of the single sludge activated sludge system, over the past three decades a suite of steady state design models (*e.g.* WRC, 1984; Wentzel *et al.*, 1990; Maurer and Gujer, 1994) and kinetic simulation models (*e.g.* Dold *et al.*, 1980, 1991; Van Haandel *et al.*, 1981; Henze *et al.*, 1987; Wentzel *et al.*, 1992; Henze *et al.*, 1995) have been developed. In the development of these models, it was recognised that it would not be possible to incorporate the behaviour of specific microorganism species - the mixed liquor in the activated sludge system contains a wide diversity of different micro organism species, some of whom for which identification techniques have only recently started becoming available. Instead, micro organisms that fulfil a particular function in the activated sludge system (*e.g.* aerobic degradation of organics) are grouped together as a single entity, which has been called a "surrogate" organism. This surrogate organism is assigned a set of unique characteristics that reflect the behaviour of the group, but may not reflect the characteristics of any individual organism or species of organisms in the group. A similar approach has been adopted for the "non-organism" components of the activated sludge mixed liquor, *e.g.* inert organics. Together, the surrogate organism and non-organism groups make up the activated sludge mixed liquor organic (volatile) suspended solids (MLOSS).

The number of surrogate organism and non-organism groups included in the models has closely mirrored the development of the activated sludge system. The functions of the activated sludge system have expanded from carbonaceous energy (measured via the chemical oxygen demand, COD) removel to progressively include nitrification, denitrification and phosphorus removal, all of these mediated biologically. These expansions have been accomplished through manipulation of the system configuration - incorporation of multiple in-series reactors, some aerated and others not, with various inter-reactor recycles. The principle objective of these manipulations is to create environmental conditions in the activated sludge system that are conducive to the growth and action of organisms that naturally perform the biological reactions (termed processes) necessary to treat the wastewater. With each expansion in function of the activated sludge system, the growth of a new group of organisms has had to be stimulated, to mediate a new set of biological processes. Consequently, not only have the system configuration and its operation progressively increased in complexity, but concomitantly the mathematical models describing the system have similarly increased in complexity - the number of surrogate organism and non-organism groups have increased, as well as the number of biological processes mediated by the surrogate organisms and the number of compounds involved in these processes. In terms of the models, in the non-nitrifying aerobic COD removal activated sludge system, the mixed liquor organic (volatile) suspended solids (MLOSS) is made up of three components; (1) ordinary heterotrophic organism (OHO) active biomass, (2) endogenous residue and (3) inert material. With the inclusion of nitrification in the system, a fourth component is included; (4) autotrophic organism (AO) active biomass. With the inclusion of denitrification through the incorporation of anoxic reactors, no additional surrogate

organism group is included, and the OHO above are considered to be facultative mediating the denitrification process. If biological excess phosphorus removal (BEPR) is included through the incorporation of an anaerobic reactor, additionally, (5) phosphate accumulating organism (PAO) active biomass and (6) this organism group's endogenous residue contributed to the MLOSS (Wentzel *et al.*, 1992; Henze *et al.*, 1995). The active biomass components (surrogate organism groups) of the MLOSS above mediate the relevant biological processes deemed to be of importance; OHO's COD removal and denitrification, AO's nitrification and PAO's BEPR and COD removal.

Thus, in terms of the approach to modelling the activated sludge system, the activated sludge mixed liquor is made up of a number of organic components. Historically though, the MLOSS has been measured as a lumped parameter, via the VSS or COD test (Standard Methods, 1985). However, from the above, only parts of the MLOSS are active biomasses, and only these parts mediate the relevant biological processes *e.g.* OHOs for COD removal and denitrification. Acceptance of the active biomass concept has met with considerable resistance in the past. However, more recently, with the proliferation of kinetic simulation computer programmes that invariably include active biomass concentrations as parameters (*e.g.* Biowin, Simba, GPX, UCTOLD, UCTPHO), these parameters and the use of specific rates in terms of them, have become much more widely accepted. This acceptance has not been driven by sound scientific proof of the active biomass concept, but rather by the convenience of the computer programmes. It must be remembered that the active biomass concept was a hypothetical construct within the development of the design procedures and kinetic models. For acceptance of the concept, the active biomass needs to be quantified experimentally and compared to the theoretical values of the models. If reasonable correspondence is attained, this will invest the models and the hypothetical framework on which these are based, with greater surety.

Recently a simple batch test procedure has been developed to quantify OHO active biomass concentration (Kappeler and Gujer, 1992; Wentzel *et al.*, 1995; Mbewe *et al.*, 1995). This batch test method was modified by Ubisi *et al.* (1997a,b) and Wentzel *et al.* (1998) to quantify the OHO active biomass concentration of mixed liquor samples drawn from aerobic and anoxic/aerobic activated sludge systems. In essence, in this modified method two aerobic batch tests are run in parallel; to the one batch test only unsettled wastewater is added and to the other, a mixture of wastewater and mixed liquor. Taking due account of nitrification, the difference in OUR response with time in the two batch tests can be used to derive an estimate for the OHO active biomass concentration due to the added mixed liquor. Wentzel *et al.* (1998) evaluated this batch test method, by applying it to quantify the OHO active biomass concentration of mixed liquor samples drawn from a well-defined parent laboratory-scale anoxic/aerobic activated sludge system operated at 12 and 20 d sludge age. The measured OHO active biomass concentrations were in close agreement with those calculated theoretically for the parent system at 12d sludge age, but were about ½ the theoretical values for the system at 20d sludge age.

Cronje *et al.* (2000) further evaluated the batch test method, by applying the method to mixed liquor samples drawn from a well-defined parent laboratory-scale activated sludge system operated at 10d sludge age. They found that the correlation between measured and theoretical active biomass was poor, and remarkably similar to that obtained by Wentzel *et al.* (1998) on mixed liquor samples drawn from their parent system at 20d sludge age. This prompted a detailed investigation of the batch test method. Two sources of potential error in the method were identified:

- In the batch test with mixed liquor + wastewater, the OHO active biomass from the wastewater has a maximum specific growth rate on RBCOD that is much larger than that of the OHO active biomass from the mixed liquor. This causes that the wastewater OHO active biomass dominates the observed OUR response in the batch tests, and thus masks the mixed liquor OHO active biomass OUR response. This introduces potential errors when the wastewater OHO active biomass is subtracted from the wastewater + mixed liquor OHO active biomass, to give the mixed liquor OHO active biomass

- In their mixed liquor + wastewater batch test Ubisi *et al.* accepted that the nitrification rate was constant, and accordingly fitted a linear line to the observed increase in nitrate concentration with time. From this linear fit, they determined the constant nitrification OUR which was subtracted from the measured OUR to give the heterotrophic OUR. Examination of the nitrate-time profiles indicated that the increase could be better described by a exponential fit.

To eliminate the potential errors above, Cronje *et al.* proposed to:

- Physically remove the OHO active biomass from the wastewater. This was achieved through flocculation of the wastewater with aluminium sulphate followed by filtration.

- Using exponential fits to the nitrate-time profiles to determine nitrification OURs.

In evaluating the proposed flocculation filtration modification to the batch test procedure, Cronje *et al.* found that:

- The flocculation filtration procedure effectively removed all active biomass from the wastewater. This was demonstrated by no measurable OUR being observed in separate aerobic batch tests, conducted on the flocculated filtered wastewater only.

The flocculation filtration modification of Cronje *et al.* greatly simplified the batch test procedure - since the flocculated-filtered wastewater does not contain OHO active biomass, a parallel batch test no longer needed to be conducted to determine the wastewater OHO active biomass, which in the method of Ubisi *et al.* (1997a,b) was subtracted from the mixed liquor + wastewater OHO active biomass to give the mixed liquor OHO active biomass.

Using mixed liquor samples drawn from their parent activated sludge system at 10d sludge age, Cronje *et al.* (2000) compared the results from the modified batch test with theoretical values for OHO active biomass concentrations from the steady state design model (WRC, 1984). From this comparison they concluded that the results obtained showed good agreement. Also, there was remarkable agreement between the theoretical OHO active biomass concentration in the parent system and the mean of the measured OHO active biomass values *projected* to the parent system.

Beeharry *et al.* (2001) extensively evaluated the modified batch test procedure of Cronje *et al.* They applied the method to mixed liquor samples from two well defined parent laboratory-scale systems, both at 10d sludge age. The systems were identical, except the one (experimental) had additionally toilet paper dosed to the influent to attempt to change the relative proportions of the components making up the mixed liquor compared to the control. Beeharry *et al.* compared the measured OHO biomass concentrations to the theoretical values and found that (i) the data for the control and experimental systems were remarkably similar, and (ii) the values plot virtually parallel to the 1:1 correspondence line.

In operation of their parent systems, Beeharry *et al.* experienced severe bulking problems. To ameliorate the bulking, they changed the control system configuration from anoxic/aerobic to completely aerobic. Sequential modified batch tests on mixed liquor drawn from the control system indicated a progressive change in response: The correlation between measured and theoretical OHO active biomass concentrations moved from that noted above for the anoxic/aerobic mixed liquor, to a trend line where the measured values were 1/3 to 1/4 the theoretical values.

Thus, from the summary review above, in comparing the theoretical OHO active biomass concentration with those measured in the batch tests and modified batch tests, a variety of correlations have been found, ranging from remarkably close to 1:1 (Wentzel *et al.*, 1998 12d sludge age mixed liquor), through reasonable close to 1:1 (Cronje *et al.*, 2000 10d sludge age mixed liquor) to poor (Wentzel *et al.*, 1998 20d sludge age mixed liquor; Beeharry *et al.*, 2001 10d sludge age mixed liquor). To date, no explanation for this variability in results has been provided. ***The principle aim of this research project is to examine more thoroughly the modified batch test procedure and the behaviour of the OHOs in the test.***

1.2 RESEARCH OBJECTIVES

A weakness within the activated sludge steady state design and kinetic simulation models, is the lack of independent validation of the active biomass concept. For validation, independent quantification of active biomass and close correspondence to the theoretical values is required. In this regard, the modified batch test procedure has shown considerable promise to quantify the OHO active biomass. However, results from the batch test are variable, ranging from close correspondence with the theoretical values, to poor.

The principle aim in this research project is to more thoroughly examine the modified batch test procedure and the OHO behaviour in the test, in order to explore possible explanations for the inconsistencies in results produced by the test.

To achieve this aim, three primary objectives have been identified. These are listed below, together with specific tasks to be completed to address the objectives:

(1) Re-evaluate the modified batch test method, by repeating the modified batch test procedure and comparing the measured OHO active biomass concentrations with the theoretical values predicted by the steady state model. This will establish whether the results of Cronje et al. or Beeharry *et al.* are reproducible, and enable an evaluation of possible causes contributing to variations in correspondence between theoretical and measured values.

To achieve the objective above, the specific tasks identified are:

- Operate and maintain a parent laboratory-scale anoxic/aerobic activated sludge system similar to that of Beeharry *et al.* (2001), at the same 10 day sludge age, which should have the same mixed liquor characteristics.

- Perform modified batch tests identical in procedure to those conducted by Cronje *et al.* (2000) and Beehary *et al.* (2001), using mixed liquor samples drawn from the parent laboratory-scale anoxic/aerobic activated sludge system at 10 day sludge age. To gather more detailed data, the modified batch tests will be conducted over a wide range of mixed liquor volume additions than of Cronje *et al.* and Beeharry *et al.*

- Compare the OHO active biomass concentrations measured with the modified batch test procedure to those calculated by the activated sludge system design model (WRC, 1984).

- Evaluate the effect of parent system sludge age on the modified batch test results, by repeating the above tasks, but with mixed liquor drawn from a parallel parent system operated at 20d sludge age.

- Thoroughly examine the batch test response, the analytical procedure used to interpret the batch test, and the data the test provides, to identify possible causes for any disagreements between measured and theoretical OHO active biomasses.

(2) In addressing the aim above, it needs to be established whether discrepancies between measured and theoretical OHO active biomass concentrations arise from the activated sludge theory (*i.e.* the theoretical) or from the batch test procedure itself (*i.e.* the measured). Accordingly, the alternative more laborious batch aerobic digestion method of Marais and Ekama (1976) to quantify OHO active biomass will be applied. Specific tasks were:

- Perform the aerobic batch digestion tests proposed by Marais and Ekama (1976) on mixed liquor samples drawn from the two parent laboratory-scale anoxic/aerobic activated sludge systems at 10 and 20 days sludge ages above.

- Compare the OHO active biomass concentrations which are measured by the aerobic batch digestion tests with values calculated by the steady state design model.

- Evaluate the applicability of the aerobic batch digestion test, and the implications on the modified batch test of the comparison between measured and theoretical OHO active biomass.

(3) Should in application of the modified batch tests, an inconsistency between the measured and theoretical OHO active biomass concentrations be obtained, identify possible causes for this inconsistency. In this regard, during investigation the importance of OHO behaviour in the modified batch tests became apparent, and the concept of substrate competition between fast and slow growing OHO population groups proposed by Novak *et al.* (1994) was found to be applicable and was examined.

1.3 RESEARCH APPROACH

Two well-defined and controlled parent laboratory-scale MLE activated sludge systems of 10 and 20 days sludge ages were operated and monitored. These parent systems provided the mixed liquor samples required for measuring OHO active biomass, by means of the modified batch test (objective (1) above) and batch aerobic digestion test (objective (2) above). The data and analytical methods were thoroughly analysed to identify possible causes for discrepancies between measured and theoretical OHO active biomass concentrations (objective (3) above); this included development of kinetic models to simulate the batch test response.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This Chapter reviews methods available to quantify ordinary heterotrophic organism (OHO) active biomass concentrations. To quantify OHO active biomass, a number of methods are available, based either in the engineering and technology field or in the microbiological and biochemical fields (Beeharry *et al.*, 2001). Since in this research project the primary focus is on the engineering and technology based methods, in this chapter the review will be restricted to this category of methods (see Beeharry *et al.*, 2001 for a review of the microbiological and biochemical based tests). The engineering and technology methods are invariably based on the batch test method approach (e.g. Kappeler and Gujer, 1992; Mbewe *et al.*, 1994). Accordingly, the development of the batch-test method will be described in this Chapter. Also, deficiencies in the batch test method will be highlighted, and possible ways to overcome those deficiencies proposed.

The batch test method introduced by Kappeler and Gujer (1992) and extended by Mbewe *et al.* (1994), Novak *et al.* (1994), Ubisi *et al.* (1997 a, b), Cronje *et al.* (2000) and Beeharry *et al.* (2001) will be described and resultant experimental data will be summarized: Kappeler and Gujer (1992) introduced the concept of the aerobic batch test; Mbewe *et al.* (1994) evaluated the applicability of the batch test to quantify readily biodegradable and OHO active biomass CODs in municipal wastewaters; Novak *et al.* (1994), Ubisi *et al.* (1997 a and b), Cronje *et al.* (2000) and Beeharry *et al.* (2001) applied the batch test to quantify OHO active biomass concentrations in the mixed liquor of the activated sludge system. This Chapter describe these developments chronologically.

2.2 MEASUREMENT OF OHO ACTIVE BIOMASS KINETIC PARAMETERS WITH THE AEROBIC BATCH TEST (Kappeler and Gujer, 1992)

Kappeler and Gujer (1992) developed the aerobic batch test method to determine values for the OHO active biomass biomass kinetic parameters required as input to 'Activated Sludge Model No.1' (Henze et al., 1987). Even though their test method was not aimed at ***the measurement of OHO active biomass in mixed liquor*** (which is the objective of this research), but rather at ***the measurement of kinetic parameters and the characterization of wastewater***, it did provide the basis for development of the batch test for measuring OHO active biomass (Novak *et al.*, 1994; Ubisi *et al.*, 1997; Wentzel *et al.*, 1998; Cronje *et al.*, 2000). Accordingly, this research is reviewed in this section, to facilitate understanding of the batch test method developed subsequently.

2.2.1 Experimental Procedure and Data Analysis

The test method is based on the measurement of the oxygen utilization rate (OUR) which yields characteristic results for the activity of OHO active biomass due to the stoichiometric relationship between substrate (electron donor) consumed, biomass growth and dissolved oxygen required as electron acceptor. The experimental apparatus consists of an airtight, circular measuring chamber, with variable height and volume, a temperature-controlling water bath surrounding the chamber, an independent stirrer, an aeration stone to increase the amount of dissolved oxygen if needed and sensors for oxygen and temperature measurement with transmitter and data logging. To estimate kinetic parameters for OHO active biomass and the COD wastewater fractions, an inhibitor of nitrification (allylthiourea) must be added (Kappleler and Gujer, 1992).

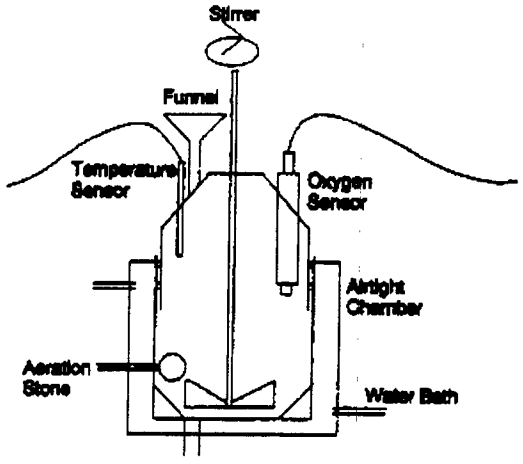


Fig. 5.1: Batch test experimental set-up (Kappleler and Gujer, 1992)

The experimental methods to quantify the various kinetic and stoichiometric parameters are described by Kappeler and Gujer (1992); of importance to this research are OHO maximum specific growth rate (μ_{max}) and the concentration of OHO active biomass in wastewater (X_{BH}) and these are summarized below.

2.2.1.1 Maximum specific growth rate (μ_{max}) and coefficient for endogenous respiration (b_H)

The aerobic batch test was carried out with a mixture of centrifuged wastewater and a small inoculum of activated sludge biomass. During the first period of the batch-test, the oxygen utilization rate (OUR) increases exponentially due to unlimited exponential OHO growth. The OUR then drops precipitously, due to depletion of readily biodegradable substrate. Thereafter, oxygen respiration is dominated by OHO growth on slowly biodegradable substrate (Kappleler and Gujer, 1992).

For the exponential increase in OUR, an equation in the logarithmic form can be derived, which relates the relative OUR to time:

$$\ln [r_{O2}(t) / r_{O2}(t_0)]=(\mu_{max} - b_H)\cdot t \qquad (2.1)$$

where
$r_{O2}(t)$ = OUR at time t ($gO_2/m^3\cdot d$)
$r_{O2}(t_0)$ = OUR at time t_0 ($gO_2/m^3\cdot d$)
μ_{max} = Maximum specific growth rate of OHOs (/d)
b_H = Specific endogenous mass loss rate of OHOs (endogenous respiration theory) (/d)

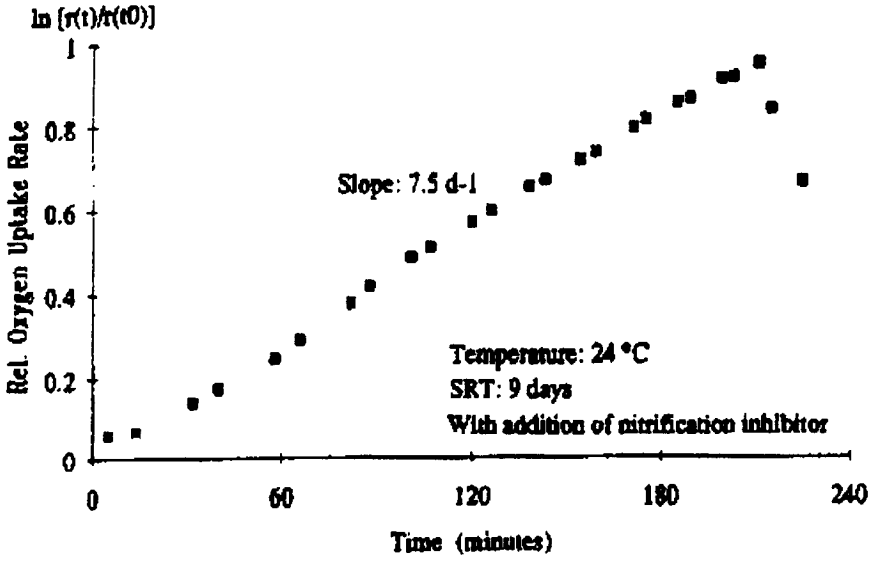


Fig. 2.2: Logarithmic plot of the relative OUR versus time in the batch test (Kappeler and Gujer, 1992).

2.2.1.2 Concentration of OHO active biomass in wastewater, X_H

Kappeler and Gujer (1992) derived the following equation to estimate X_H:

$$X_{H0} = r_{O2}(t_0)\cdot[((1-Y_H)/Y_H)\cdot\mu_{max}-(1-f_p)\cdot b_H]^{-1} \qquad (2.2)$$

Where
Y_H = Yield coefficient for OHO active biomass (0.67 g COD/g COD)
f_p = Coefficient for the production of inert COD from endogenous respiration (0.2 gCOD /gCOD)

With the commonly accepted values for the stoichiometric constants (see above), Kappeler and Gujer (1992) showed that f_p and b_H do not play an important role in estimating X_{H0} with Eq. (2.2). With the measured μ_{max} value (via Eq. (2.1) above), X_{H0} can be readily calculated.

2.2.2 Results

Several aerobic batch-tests were conducted using mixed liquor generated under different conditions, such as temperature, reactor configuration and solids retention time. The OHO maximum specific growth rate, μ_{max}, was found to vary in the range of 1 /d to 8 /d (Kappeler and Gujer, 1992) depending on temperature, reactor configuration and solids retention time. Such an influence of temperature and the reason for the temperature influence have been well documented (e.g. Still *et al.*, 1984; Cech *et al.*, 1985; Dold and Marais, 1986; Kappeler and Gujer, 1992). The influence of reactor configuration and solids retention time was also reported; however underlying causes for the observed influence of these parameters on the maximum specific growth rate, μ_{max}, are still not understood.

With the values for the maximum specific growth rate, μ_{max}, determined, the concentration of OHO active biomass in the wastewater could be calculated. In their experiments, the COD concentration of OHO active biomass in wastewater was in the range of 7% to 15% of total COD.

2.3 APPLICATION OF THE BATCH TEST TO MEASURE READILY BIODEGRADABLE COD AND OHO ACTIVE BIOMASS CONCENTRATIONS IN MUNICIPAL WASTE WATERS.

Wentzel *et al.* (1995) and Mbewe *et al.* (1995) applied the aerobic batch-test to measure the readily biodegradable COD and OHO active biomass concentrations in municipal wastewaters. In their test, raw municipal wastewater was aerated in the batch reactor with no activated sludge mixed liquor inoculum; the active biomass seed was provided by the wastewater itself. The OUR and nitrate/nitrite concentrations with time were monitored. A typical OUR-time profile is shown in Fig. 2.3; the OUR-time profle is similar to that obtained by Kappeler and Gujer (1992). No nitrification was observed in the batch tests, due to the absence of nitrifiers in the municipal wastewater. To interpret the batch test data, Wentzel *et al.* (1995) used the nitrification denitrification UCT model (Dold *et al.*, 1991) as a basis. By recognising that specific conditions apply to the batch test environment (*e.g.* aerobic conditions, excess ammonia present, no nitrification) the UCT model was simplified, by Wentzel *et al.* (1995), see Table 2.1. Wentzel *et al.* (1995) used this simplified model to develop algebraic expressions to quantify OHO active biomass, as follows: From the simplified UCT model, the rate of growth of OHO active biomass (dZ_{BH}/dt) is given by:

dZ_{BH}/dt = growth on RBCOD + growth on SBCOD - death

$$\frac{dZ_{BH}}{dt} = \mu_{H,max}\frac{S_{bs}}{K_{SH}+S_{bs}}\cdot Z_{BH} + K_{MP}\frac{S_{ads}/Z_{BH}}{K_{SP}+S_{ads}/Z_{BH}}\cdot Z_{BH} - b_H\cdot Z_{BH} \qquad (2.3)$$

where

Z_{BH} = OHO active biomass concentration (mgCOD/ℓ)
S_{bs} = RBCOD concentration (mgCOD/ℓ)
K_{SH} = half saturation constant for RBCOD = 5mgCOD/ℓ
S_{ads} = adsorbed SBCOD concentration (mgCOD/ℓ)
K_{SP} = half saturation constant for SBCOD = 0.027 mgCOD/mgCOD
b_H = specific endogenous mass loss rate (death regeneration theory) (/d)

Wentzel *et al.* (1995) accepted that during the initial stages of the batch test (before RBCOD is depleted and the OUR drops precipitously) $S_{bs} >> K_{SH}$ and $S_{ads}/Z_{BH} >> K_{SP}$, and therefore Eg. (2.3) simplifies to:

$$\frac{dZ_{BH}}{dt} = (\mu_{H,max} + K_{MP} - b_H) \cdot Z_{BH} \qquad (2.4)$$

Integrating Eq. (2.4) and solving yields the OHO active organism concentration at time t [$Z_{BH(t)}$, mgCOD/ℓ] in terms of the initial OHO active biomass concentration [$Z_{BH(0)}$, mgCOD/ℓ], time [t, in h] and the net specific growth rate [$(\mu_{H,max} + K_{MP} - b_H)$, /d] viz:

$$Z_{BH(t)} = Z_{BH(0)} \cdot e^{(\mu H,max + KMP - bH)\, t/24} \qquad (2.5)$$

The OUR at time t [OUR_t, mgO/ℓ·h] is a function of $Z_{BH(t)}$ and the net specific growth rate:

$$OUR_{(t)} = \frac{1 - Y_{ZH}}{Y_{ZH}} (\mu_{H,max} + K_{MP}) \cdot Z_{BH}/24 \qquad (2.6)$$

Substituting Eq. (2.5) for $Z_{BH(t)}$ in Eq. (2.6) and taking natural logs yields:

$$\ell n\, OUR_{(t)} = \ell n \left[\frac{1 - Y_{ZH}}{Y_{ZH}} (\mu_{H,max} + K_{MP}) \cdot Z_{BH}/24 \right] + (\mu_{H,max} + K_{MP} - b_H) \cdot t/24 \qquad (2.7)$$

Which is a straight line with:

$$\text{slope} = (\mu_{H,max} + K_{MP} - b_H)/24 \qquad (2.8)$$

$$\text{y-intercept} = \ln(OUR_{(t=0)}) = \ln \left[\frac{1 - Y_{ZH}}{Y_{ZH}} (\mu_{H,max} + K_{MP}) \cdot Z_{BH}/24 \right] \qquad (2.9)$$

Thus, to determine the OHO active biomass concentration at the start of the batch test ($Z_{BH(0)}$), Wentzel *et al.* (1995) plotted the OUR values for the data up to the precipitous drop in OUR as ℓn OUR versus time (h) (for example, the ℓn OUR from the data in Fig. 2.3 are shown plotted in Fig. 2.4). Linear regression was then applied to determine the Y-intercept, slope and correlation coefficient. From the slopes and Y-intercept, Wentzel *et al.* (1995) could determine $Z_{BH(0)}$ from Eqs. (2.8) and (2.9), as follows:

$$Z_{BH(0)} = \frac{e^{(y\text{-intercept})} \cdot 24}{\frac{1-Y_{ZH}}{Y_{ZH}} \cdot (slope \cdot 24 + b_H)} \quad (mgCOD/\ell) \qquad (2.10)$$

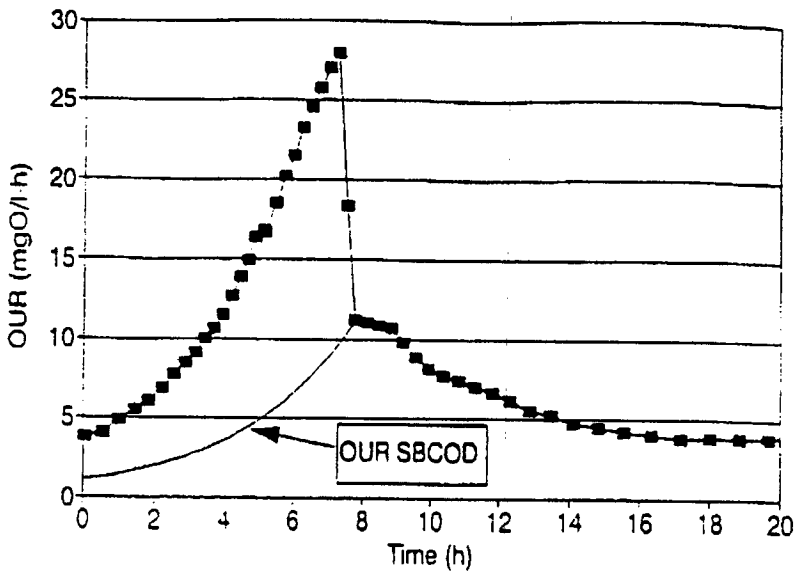


Fig. 2.3: Oxygen Utilization Rate (OUR) response with time for aerobic batch on raw municipal waste water from Mitchell's Plain (Cape Town, South Africa). Theoretical OUR for utilisation of the slowly biodegradable COD(SBCOD) (Wentzel *et al.*, 1994)

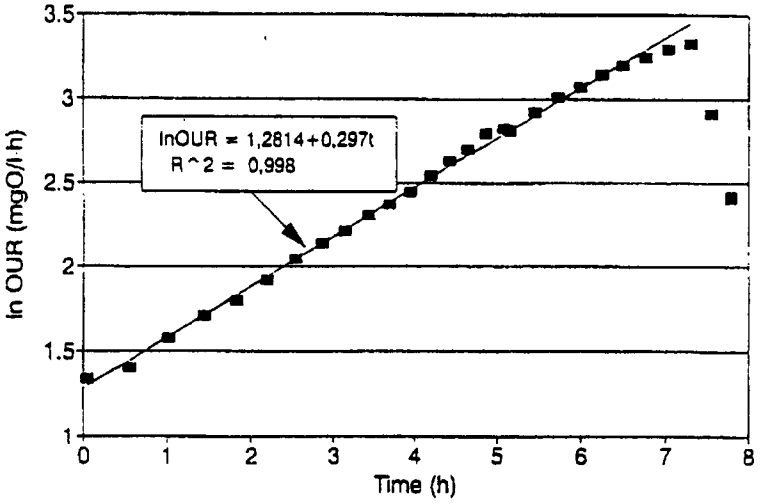


Fig. 2.4: ln Oxygen Utilization Rate (OUR) versus time for the measured OUR data in Fig. 2.3, up to the precipitous drop in OUR (Wentzel *et al.*, 1995)

With the above method, the OHO active biomass concentration, $Z_{BH(0)}$, in a wastewater can be directly measured using a simple aerobic batch test. Wentzel *et al.*(1995) applied the method to measure the OHO active biomass concentration, $Z_{BH(0)}$, in wastewaters for two treatment plants. The percentage of $Z_{BH(0)}$ in the wastewater of the treatment plant which had short retention times (±4hours) in the sewers was less than 3% of the total COD. In the case where activated sludge was recycled to the head of the plants and included in the wastewater tested, the wastewater OHO active biomass concentration was very variable, ranging from <5% to >15% of the total COD. However, Wentzel *et al.* (1995) noted that the accuracy of these measurements could not be evaluated, as no alternative conventional method for quantifying OHO active biomass existed, to cross-check the results.

2.4 APPLICATION OF THE AEROBIC BATCH TEST TO QUANTIFY OHO ACTIVE BIOMASS IN ACTIVATED SLUDGE MIXED LIQUOR AND INTRODUCTION OF A MATHEMATICAL MODEL FOR TWO HETEROTROPHIC ORGANISMS, FAST GROWER AND SLOW GROWER

Novak *et al.*(1994) applied the batch-test technique of Kappler and Gujer (1992) to determine the characteristics of activated sludge mixed liquor, including estimation of the maximum specific growth rates of OHO and autotrophic organism (AO) biomasses and quantification of the OHO and AO active biomass concentrations. Novak *et al.* (1994) accepted the linearization technique of Kappeler and Gujer (1992) (Eq. (2.1) above) to determine OHO active biomass maximum specific growth rate ($\mu_{H,max}$). Thereafter, they applied activated sludge model (ASM) No.1 (Henze *et al.*, 1987) to simulate the observed OUR-time response. They found that the fit of the simulated to experimental OUR data was poor, for example see Fig. 2.5. In particular, a major deviation between experimental and simulated data was evident at the beginning of the test. Although this possibly could be explained by a lag phase in the growth curve, nitrite oxidation in batch tests where nitrification is inhibited, or by an adaptation of OHOs to a higher energetic

substrate level resulting in an increased production of needed enzymes (*i.e.* higher specific activity), Novak *et al.* (1994) proposed that the deviation was caused by a deficiency in the single OHO population group approach followed in ASM No1. Accordingly, they investigated extension of ASM No1 to include two OHO populations/groups.

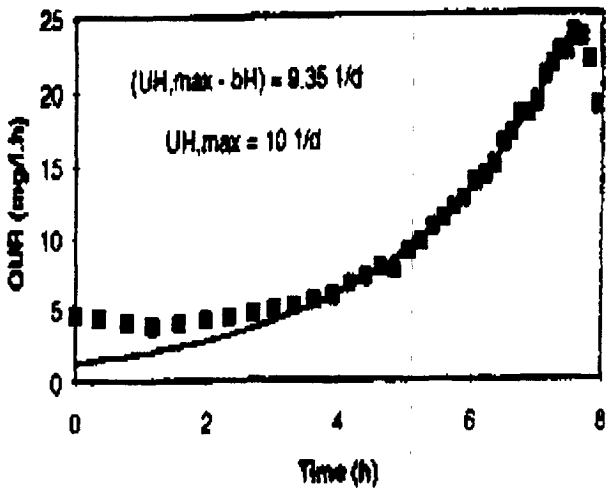


Fig. 2.5: Batch test for measurement of $\mu_{H,max}$ of OHO microorganisms. The value of $\mu_{H,max}$ is obtained from linearization of experimental points, which is modelled with ASM No.1 (Henze *et al.*, 1987). b_H considered 0.62/d (Novak *et al.*, 1994).

Hypothesis - model of two OHO organism populations (Novak et al, 1994)

Novak *et al.* (1994) hypothesized that two OHO populations were present in the batch test which have very different characteristics for growth on readily biodegradable COD - one (X_{BH1}) with low maximum specific growth rate ($\mu_{H1,max}$) and half saturation constant (K_{SH1}), and the other (X_{BH2}) with high maximum specific growth rate ($\mu_{H2,max}$) and half saturation constant (K_{SH2}). In the parent system from which the mixed liquor was drawn to innoculate the batch test, the system was continuously operated under low loaded conditions (*i.e.* long sludge age) and hence was carbon limited and consequently readily biodegradable COD concentrations would be low. Under these conditions the growth of the OHO population 1 (X_{BH1}) will be favoured due to kinetic selection theory (Chudoba *et al.*, 1973) caused by its lower K_{SH}. Consequently, the fraction of this OHO population in the mixed liquor will be higher than the fraction of the OHO population 2 ($X_{BH1} >> X_{BH2}$). Under the batch cultivation conditions described above where a high initial S_0/X_0 ratio is used, significant RBCOD concentrations are present and the conditions favour growth of OHO population 2 due to its higher $\mu_{H2,max}$. Hence, in the batch test X_{BH2} will grow faster than X_{BH1}. Although the X_{BH2} fraction in the biomass at the beginning of the test is several times lower that the fraction of X_{BH1}, the X_{BH2} growth determines the shape of the OUR exponential curve with time. The influence of X_{BH1} on the OUR is almost negligible in the exponential part of the curve. This can be best illustrated from simulations by Novak *et al.* (1994). To accommodate two OHO populations, Novak *et al.* (1994) proposed the kinetic simulation model duplicated in Table 2.1. They applied this two OHO population model to the data in Fig. 2.5, see Fig. 2.6. In Fig. 2.6,

the OURs due to the individual populations are included, as well as the combined OUR. At the start of the test, $X_{BH1} > X_{BH2}$ and hence the OUR due to X_{BH1} is greater than the OUR due to X_{BH2}. However, during the course of the test, X_{BH2} grows faster than X_{BH1} due to $\mu_{H1,max} > \mu_{H2,max}$ and hence the OUR contribution due to X_{BH2} increases to dominate the combined OUR response. The fit of the simulated OUR response to the measured data is superior for the two OHO population model compared to the single OHO population model (Fig. 2.5).

Table 2.1: Competition model Stoichiometry and Kinetics. Units: mgCOD/ℓ, oxygen (SO) mgO_2/ℓ (Novak *et al.*, 1994)

Process	SS	XS	XBH1	XBH2	XBA	SO
Growth of XBH1	$-1/Y_H$		1			$-(1-Y_H)/Y_H$
Growth of XBH2	$-1/Y_H$			1		$-(1-Y_H)/Y_H$
Decay of XBH1		1-fp	-1			
Decay of XBH2		1-fp		-1		
Hydrolysis of XS	1	-1				
Growth of XBA					1	$-(4.57-Y_A)/Y_A$
Decay of XBA		1-fp			-1	

Process	Process rate
Heterotrophic growth	$\mu_{H,max} \cdot \frac{SS}{Ks+SS} \cdot XBH$
Autotrophic growth	$\mu_{A,max} \cdot XBA$
Decay of heterotrophs	$b_H \cdot XBH$
Decay of autotrophs	$b_A \cdot XBA$
Hydrolysis	$K_h \cdot XS$

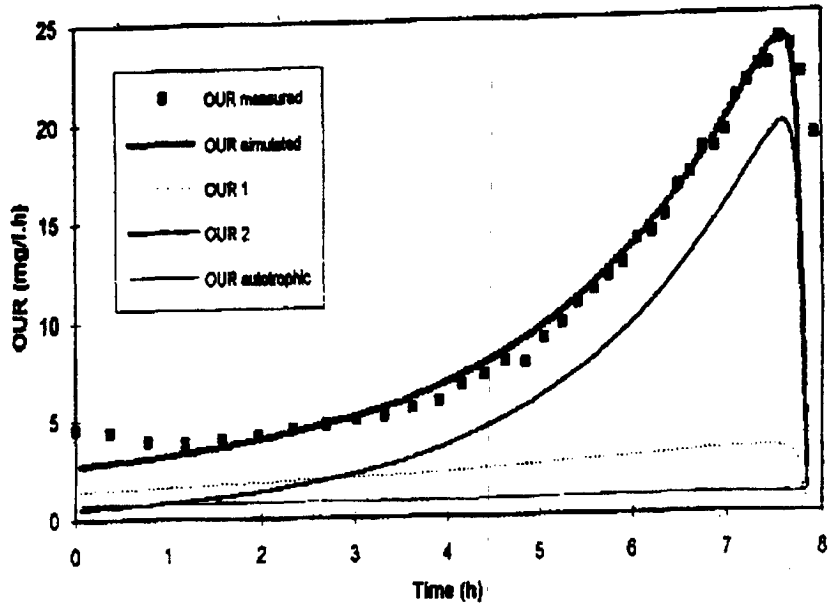


Fig. 2.6: Case simulation of experimental results plotted in Fig. 2.5 (Novak *et al.*, 1994)

If the above hypothesis is correct, it is clear that the biological response of the OHOs under the batch conditions which are S_0/X_0 ratios, is very different from the OHO response in the continuously operated systems which has lower S_0/X_0 ratios (Ghosh and Pohland, 1972; Pitter and Chudoba, 1990; Chudoba *et al.*, 1992). Hence, Novak *et al.* (1994) concluded that batch cultivation methods for determining kinetic and stiochiometric parameters for the purposes of mathematical modelling of biological wastewater treatment processes should be applied with caution.

2.5 APPLICATION OF THE AEROBIC BATCH-TEST TO QUATIFY THE OHO ACTIVE BIOMASS IN ACTIVATED SLUDGE MIXED LIQUOR

The aerobic batch-test which was developed by Wentzel *et al.* (1995) to quantify the OHO active biomass in wastewater was extended to measuring the OHO active biomass in activated sludge mixed liquor by Ubisi *et al.* (1997a, b) and Wentzel *et al.* (1998). A well-defined parent MLE activated sludge system was run. The system was monitored continuously and the reliability of the experimental measurements was checked by mass balances on COD and N (Ekama *et al.*, 1986). From the measured steady state data, theoretical values for the OHO active biomass concentration in the parent activated sludge mixed liquor were calculated. Mixed liquor samples were drawn from the parent system and the aerobic batch test method applied to determine the OHO active biomass concentration in the mixed liquor. The measured values were then compared to the theoretical values.

Although the experimental procedure and mathematical interpretation of the batch-test is similar to those of Kappler and Gujer (1992) and Wentzel *et al.* (1994) that were designed to measure the OHO active biomass in wastewater, the test was modified by running two parallel batch tests for each set of the tests (Ubisi *et al.*, 1997a,b). In the one, only unsettled municipal wastewater was added, and in the second, a mixture of wastewater and mixed liquor were added. From an analysis of the nitrate and nitrite responses in the two parallel tests, the nitrification OUR could be determined (Ubisi *et al.* (1997a,b) found that only the mixed liquor seeded batch test exhibited nitrification). By subtracting the nitrification OUR from the measured OUR, the OUR due to OHO activity only (OUR_H) could be determined. For each test, OHO active biomass concentration, $Z_{BH(0)}$, could be determined from the slopes and Y-intercepts of the $\ell n\ OUR_H$ versus time graph, with the following equation (Wentzel *et al.*, 1995);

$$Z_{BH(0)} = \frac{e^{(y\text{-intercept})} \cdot 24}{\frac{1-Y_{ZH}}{Y_{ZH}} \cdot (slope \cdot 24 + b_H)} \quad (mgCOD/\ell) \qquad (2.11)$$

where:

$Z_{BH(0)}$ = OHO active biomass concentration at the start of the batch test (mg COD/ℓ batch reactor)

Y_{ZH} = OHO active biomass yield, COD units (mgCOD/mgCOD)
= 0.666mgCOD/mgCOD (Dold et al., 1980, 1991; Wentzel *et al.*, 1995)

b_{HT} = OHO specific death rate an temperature T (/d)
= $b_{H20} \cdot 1.029^{(T-20)}$

b_{H20} = OHO specific death rate at 20°C
= 0.62/d (death/regeneration theory, Dold *et al.*, 1980; Wentzel *et al.*, 1995)

In the batch tests with both wastewater and mixed liquor present, to determine $Z_{BH(0)}$ due to the mixed liquor only [$Z_{BH(0)}$ (ML)], the $Z_{BH(0)}$ due to the waste water [$Z_{BH(0)}$ (WW)] must be subtracted from the $Z_{BH(0)}$ due to both the waste water and mixed liquor [$Z_{BH(0)}$ (WW+ML)]:

$$Z_{BH(0)}(ML) = Z_{BH(0)}(ML+WW) - Z_{BH(0)}(WW)_D \qquad (2.12)$$

where:

$Z_{BH(0)}(WW)_D$ = OHO active biomass due to waste water at start of batch test with WW+ML, taking due account of dilution (mgCOD/ℓ)
= $Z_{BH(0)}(WW) \cdot V_{WW} / (V_{ML} + V_{WW})$

$Z_{BH(0)}(WW)$ = OHO active biomass present in the original waste water (mgCOD/ℓ)

V_{WW} = volume of waste water added to batch test (ℓ)

V_{ML} = volume of mixed liquor added to batch test (ℓ)

Wentzel *et al.* (1998) evaluated this batch test method by drawing mixed liquor samples from a well defined laboratory-scale anoxic/aerobic activated sludge system operated at 12 and 20 days sludge age. They compared the results from the batch tests with theoretical values for OHO active biomass concentrations from steady state design (WRC, 1984) and kinetic simulation (Dold *et al.*, 1991) models. From the comparison they concluded that the results obtained were both encouraging and perplexing. With the parent system at 12d sludge age, the agreement between measured and theoretical values was remarkably good (see Fig. 2.7 a). However, with the parent system at 20d sludge age, the agreement was poor, with the theoretical values being about 2 times those measured (see Fig. 2.7 b). They could provide no explanation for the inconsistency in results.

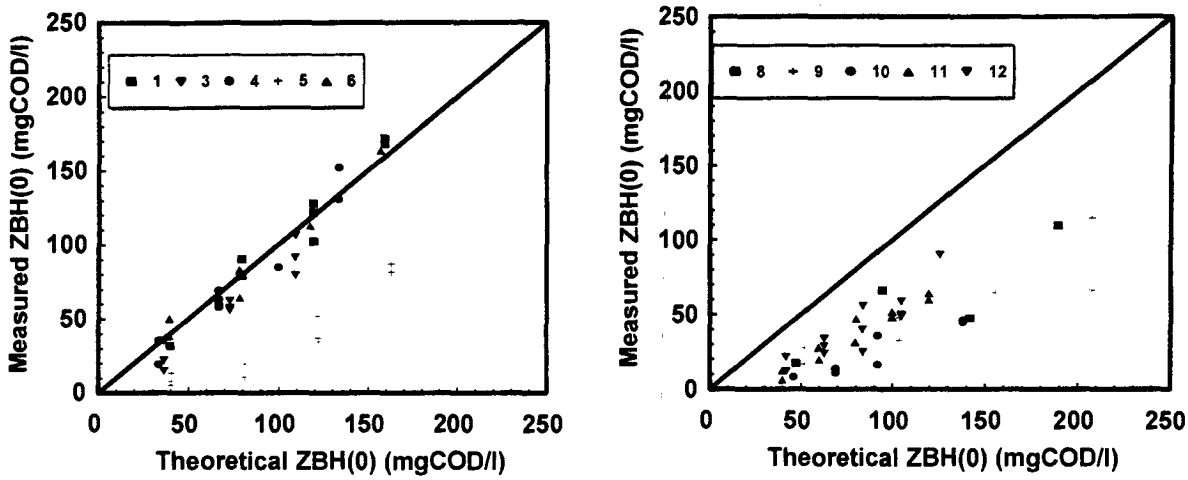


Fig. 2.7: Measured vs. theoretical OHO active biomass concentration [$Z_{BH(0)}$(ML)] in the batch test due to addition of mixed liquor drawn from the parent system at (a) 12d and (b) 20d sludge age (Wentzel *et al.*, 1998).

2.6 APPLICATION OF THE MODIFIED BATCH TEST WITH PRE-FLOCCULATION AND FILTRATION OF THE RAW WASTEWATER

The batch test method of Ubisi *et al.* (1997a,b) was further investigated by Cronje *et al.* (2000) to attempt to identify possible cause(s) for the inconsistency noted by Wentzel *et al.* (1998). Initially, they applied the batch test method of Ubisi *et al.* (1997a,b) to mixed liquor samples drawn from a well-defined parent laboratory-scale anoxic/aerobic activated sludge system operated at 10d sludge age, with one minor modification: To ensure that both parallel batch tests had equal concentrations of wastewater, the same volume of wastewater was added to the batch tests, and the total volumes made up to 3ℓ with mixed liquor added to the one batch reactor and the same volume of effluent from the parent activated sludge system to the other. This allowed Cronje *et al.* (2000) to directly compare the OUR responses in the two batch tests. In comparing the measured OHO active biomass with theoretical values, Cronje *et al.* (2000) found that the

correlation was poor (Fig. 2.8 (a)), and remarkably similar to that obtained by Wentzel *et al.* (1998) on mixed liquor samples drawn from their parent system at 20d sludge age (Fig. 2.7 (b)). From a detailed examination of the batch test procedure and data, Cronje *et al.* (2000) attributed the poor correlation between the OHO active biomass concentration measured in the batch tests and the theoretical values predicted via the steady state design model to two main factors:

(i) Being able to directly compare the OUR responses from the two parallel batch tests, they observed that the OHOs present in the wastewater exhibited a growth rate that was much faster than the growth rate exhibited by the OHOs present in the mixed liquor drawn from the parent laboratory-scale activated sludge system. In examining the OUR responses of the batch test conducted with a mixture of wastewater and mixed liquor, it was observed that the wastewater OHO active biomass partially masked the OUR response of the OHO active biomass from the mixed liquor. Accordingly, a potential source of error in the batch test procedures arose when subtracting the wastewater OHO active biomass concentration (determined from the wastewater only batch test OUR) from that for the mixed liquor plus wastewater OHO active biomass concentration, to derive the mixed liquor OHO active biomass concentration.

(ii) The premise of Ubisi *et al.* (1997a,b) that nitrification in the batch test with wastewater and mixed liquor gives rise to a linear increase in the nitrate concentration with time, proved to be unduly simplified. In agreement with the observations of Antoniou *et al.* (1990) and Sőzen *et al.* (1996), Cronje *et al.* (2000) observed that the generation of nitrate in the batch reactor was better represented by an exponential increase, than the linear increase with time followed by Ubisi *et al.* (1997a,b). Thus, in the batch test concept when the oxygen demand due to nitrification (OUR_N), with a constant value in terms of the linear approach, is subtracted from the measured OUR response to obtain the OUR response due to the OHO active biomass (OUR_H), another potential source of error is introduced.

To overcome the deficiencies identified above, Cronje *et al.* (2000) proposed two main modifications to the batch test procedure of Ubisi *et al.* (1997a,b):

- Physically remove the OHO active biomass from the wastewaters.

- Use exponential fits to the nitrate concentration - time profiles to determine nitrification OURs, as opposed to a linear increase.

To remove the OHO active biomass from the wastewater in the batch test as proposed above, Cronje *et al.* (2000), flocculated and filtered the raw wastewater; 10mℓ of stock aluminium sulphate [$Al(SO_4)_3 \cdot 15H_2O$, stock at 50g/ℓ] was added per ℓ wastewater, the mixture was stirred rapidly (~200 rpm) for 2min (rapid mix phase) and then slowly (~1 rpm) for 30 min (flocculation and settling phase). A clear liquid supernatant layer developed and this was drawn off and filtered through a glass fibre filter (Whatman's GF/C). Aerobic batch tests on the flocculated filtered wastewater only indicated that the procedure effectively removed all active biomass from the wastewater - no measurable OUR was observed. The mixed liquor drawn from the parent system was then added to flocculated filtered wastewater, and the batch test for measuring OHO active biomass concentration implemented, following the procedure set out in Wentzel *et al.* (1998) and Ubisi *et al.* (1997a, b). With this modification the OHO active biomass in the wastewater is

eliminated from the batch test and no linger contributes to the OUR, and accordingly does not have to be subtracted to give the mixed liquor OHO active biomass concentration added from the parent system. This greatly simplifies the batch test procedure in that the parallel test on wastewater only no longer needs to be conducted.

Cronje *et al.* (2000) assessed the modified batch test procedure by applying the method to mixed liquor drawn from a well-defined parent laboratory-scale MLE activated sludge system operated at 10days sludge age, and compared the measured results to those predicted theoretically, see Fig 2.8. This comparison demonstrated that the correlation between measured and theoretical OHO active biomasses was good. This indicated that the batch test method holds potential as a valuable tool that can be used to provide greater insight into the activated sludge system.

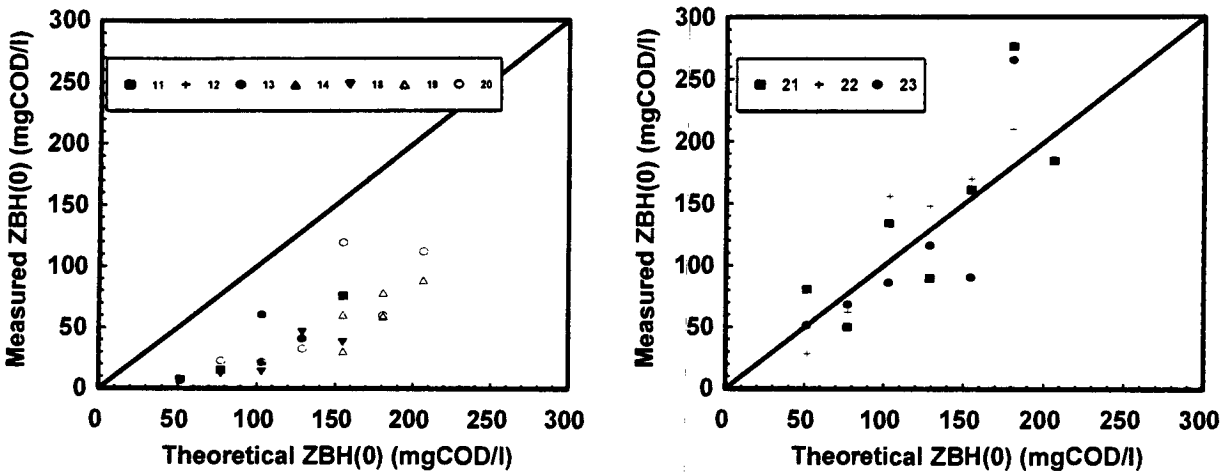


Fig. 2.8: Measured vs. theoretical heterotrophic active biomass concentration at time 0 [$Z_{BH(0)}$] in the batch test due to addition of mixed liquor drawn from the parent system at 10days sludge age with (a) raw wastewater addition and (b) flocculated filtered wastewater addition. Each data series represents batch tests conducted when the parent system received a single batch of wastewater as influent (Cronje *et al.*, 2002).

2.7 EVALUATION OF THE MODIFIED BATCH TEST METHOD

Beeharry *et al.* (2001) carried out an extensive evaluation of the modified experimental procedure proposed by Cronje *et al.* (2000). A variety of different types of parent activated sludge systems were operated, and the OHO active biomass concentration of each parent system was quntified with the modified batch test of Cronje *et al.*(2001).

At first, two parallel parent laboratory-scale MLE activated sludge systems having a different OHO active biomass fraction of the mixed liquor at the same sludge age (10days) were run. To change the OHO active biomass fraction of the mixed liquor, a known concentration of macerated toilet paper solution was dosed to the one system. Toilet paper is mainly constituted of wood pulp which is believed to be largely unbiodegradable in the activated sludge system.

Accordingly, toilet paper should contribute significantly to the inert sludge mass in the laboratory-scale MLE system, thereby significantly increasing the MLOSS concentration in the system, and reducing the OHO active biomass fraction of the MLOSS. However, from an analysis of the parent system data for the two systems, it was concluded that the unbiodegradable particulate fraction of toilet paper was only about 31% ($f_{S,up} = 0.309$), not very different from the value for the raw municipal wastewater. Thus, the initial thought that the toilet paper would contribute a high unbiodegradable particulate fraction ($f_{S,up}$) to the experimental activated sludge system did not prove true: This implies that toilet paper did not cause a large increase in inert material in the experimental activated sludge system, and thus the OHO active biomass fraction of the mixed liquor would not decrease significantly.

The modified batch test procedure above was applied to mixed liquor drawn from both parent systems, the one with influent toilet paper supplement and the other without. The measured versus theoretical OHO active biomass values for both systems are plotted in Fig. 2.9. It is apparent that the data for the both systems are remarkably similar: Both data sets appear to plot largely on a line parallel to the 1:1 correspondence (45°) line. This implies that there is a constant (*i.e.* independent of volume of mixed liquor added) difference between measured and theoretical values, of about 25mgCOD/ℓ. No explanation for this difference could be found (Beeharry *et al.*, 2001).

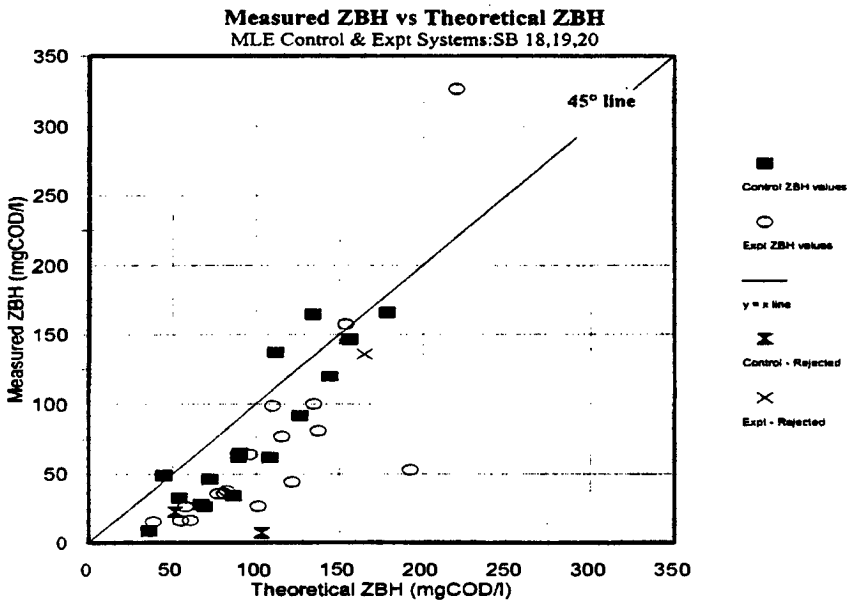


Fig. 2.9: Modified batch tests results; graph of measured versus theoretical OHO active biomass concentration at the start of the batch test ($Z_{BH(0)}$) for the various wastewater batches comparing the MLE control and experimental activated sludge systems operated at 10 days sludge age (Beeharry *et al.*, 2001).

In the second stage of the experimental investigation of Beeharry *et al.* (2001), the MLE activated sludge system was changed to a fully aerobic system (single aerobic reactor and secondary settling tank, *i.e.* the anoxic reactor was removed). The modified batch test of Cronje *et al.* (2000) was also applied to mixed liquor samples drawn from this system. The batch tests performed using mixed liquor drawn from the fully aerobic activated sludge system during all the sewage batches show a very poor agreement between the measured and the theoretical OHO active biomass concentration: There is a consistent correlation between the theoretical and measured values, but the theoretical values are approximately 3 to 4 times those measured (see Fig. 2.10). Comparing the data obtained with the mixed liquor drawn from the fully aerobic system with that from the MLE anoxic/aerobic systems, the trends are completely different: For the anoxic/aerobic system mixed liquor, there is a correlation between measured and theoretical values, but with a constant difference between the actual values (*i.e.* the values fall on a line parallel to the 1:1 correlation line). However, for the aerobic system mixed liquor, the measured values are about 1/3 to 1/4 the theoretical values (*i.e.* the values fall on a line that passes through the (0,0) origin, but the line has a reduced slope). In the investigation, during the period the system was changed from MLE system to fully aerobic system (Sewage Batch No. 23), the trend line of the theoretical versus measured graph started from the trend line for the anoxic/aerobic system mixed liquor and progressively changed to the line for the fully aerobic system mixed liquor (see SB23 A and B in Fig. 2.10). This would suggest that changing from the anoxic/aerobic to fully aerobic configuration caused a significant change in the behaviour of the mixed liquor. Such a change in population dynamics is to be expected (Beeharry *et al.*, 2001).

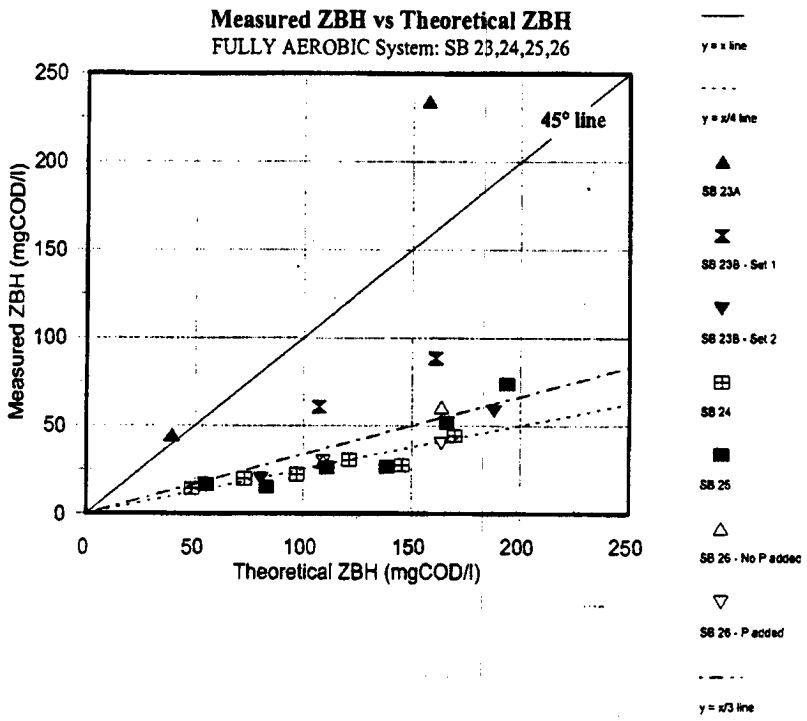


Fig. 2.10: Modified batch tests results; graph of measured versus theoretical OHO active biomass concentration at the start of the batch test ($Z_{BH(0)}$) for the various wastewater batches for the fully aerobic control activated sludge system operated at 10 days sludge age (Beeharry, *et al.*, 2001).

2.8 CONCLUSIONS

To quantify OHO active biomass, a number of methods are available, based either in the engineering and technology field or in the microbiological and biochemical fields. Since in this research project the primary focus is on the engineering and technology based methods, the review was restricted to this category of methods, which are invariably based on the batch test method approach. Accordingly, the development of the batch-test method was described in this Chapter. Also, deficiencies in the batch test method were highlighted, and possible ways to overcome those deficiencies proposed. From the previous research, the following are of significance.

- Kappeler and Gujer (1992) developed the aerobic batch test method to determine values for the OHO active biomass kinetic parameters required as input to 'Activated Sludge Model No.1' (Henze et al., 1987).

- Wentzel *et al.* (1995) and Mbewe *et al.* (1995) applied the aerobic batch-test to measure the readily biodegradable COD and OHO active biomass concentrations in municipal wastewaters. Wentzel *et al.* (1995) used the simplified UCT model to develop algebraic expressions to quantify OHO active biomass.

- Novak *et al.*(1994) found that the fit of the result simulated with ASM No1 to experimental OUR data in the aerobic batch test was poor. Novak *et al.* (1994) proposed that the deviation is caused by a deficiency in the single OHO population group approach followed in ASM No1. Accordingly, they investigated extension of ASM No1 to include two OHO populations/groups, one a fast grower and the other a slow grower.

- The aerobic batch-test which was developed by Wentzel *et al.* (1995) to quantify the OHO active biomass in wastewater was extended to measuring the OHO active biomass in activated sludge mixed liquor by Ubisi *et al.* (1997a,b). With the parent system at 12d sludge age, the agreement between measured and theoretical values was remarkably good. However, with the parent system at 20d sludge age, the agreement was poor.

- Cronje *et al.* (2000) proposed the modified batch test procedure which includes flocculation and filtration to remove OHO active biomass in raw wastewater and assessed this test procedure by comparing the measured results to that predicted theoretically for their 10 days sludge age parent system. This comparison demonstrated that the correlation between measured and theoretical OHO active biomass concentrations was good.

- Beeharry *et al.* (2001) carried out an extensive evaluation of the modified experimental procedure proposed by Cronje *et al.* (2000). A variety of different types of the parent activated sludge systems were operated, and the OHO active biomass concentration of each parent system was evaluated with the modified batch test of Cronje *et al.*(2001). However, a poor correlation between measured and theoretical OHO active biomasses were observed, and the comparison differed between mixed liquor from an anoxic/aerobic activated sludge system and from an aerobic one.

In conclusion, the batch and modified batch test methods have provided measurement for OHO active biomass concentrations that exhibit inconsistencies in comparisons with the theoretical values. This research project focuses on exploring possible explanations for these inconsistencies. In this regard, during the course of the investigation the concepts of Novak *et al.* (1994) identified as of importance require investigation.

CHAPTER 3

THE PARENT LABORATORY-SCALE NITRIFICATION / DENITRIFICATION ACTIVATED SLUDGE SYSTEM

3.1 INTRODUCTION

As described in Chapters 1 and 2, the batch test method to quantify OHO active biomass concentrations was applied by Ubisi *et al.* (1997a,b) and Cronje et al. (2000), and the modified batch tests was applied by Cronje *et al.* (2000) and Beeharry *et al.* (2001) to samples harvested from a nitrification / denitrification laboratory-scale activated sludge system operated at various sludge ages. In some cases the results from the batch test and the modified batch test showed remarkably good agreement with the theoretical OHO active biomass concentrations; however in other cases, the agreement was poor. Up to now, no explanation for this contradiction has been provided. ***The principle aim in this research project is to explore possible explanation for the inconsistency between the measured and theoretical OHO active biomass concentrations.***

To address the principle aim above, the first task in this research project was to operate and maintain a 10 days sludge age parent laboratory-scale nitrification/denitrification activated sludge system identical to that of Beeharry *et al.* (2001) which would have the same mixed liquor characteristics. Additionally, an identical parent system would be operated and maintained in parallel, but at a sludge age of 20days. Thus, the two parent systems would serve as a source of mixed liquor for the modified batch tests developed by Cronje *et al.* (2000), but would have different OHO active biomass fractions. According to Ekama *et al.* (1986) and WRC (1984), the mixed liquor OHO active biomass fraction decreases as the sludge age increases. The ability of the modified batch test to correctly detect this difference in OHO active biomass fraction would be evaluated. Accordingly, for this research project two well defined and controlled parent systems were operated and monitored closely, and provided the mixed liquor samples required for measuring OHO active biomass (see Chapter 4). This chapter describes the configuration and operation of the two parent laboratory-scale systems, and details the response of these systems.

3.2 SYSTEM LAYOUT

The system layout of the 10days and 20 days sludge age systems constituted a Modified Ludzack-Ettinger (MLE) configuration, and consisted of an anoxic reactor of 33% of the total system volume, an aerobic reactor of 67% of the total system volume and a secondary settling tank, all in series. An underflow recycle (s-recycle) from the settling tank to the anoxic reactor of 1:1 and a mixed liquor recycle from the aerobic reactor to the anoxic reactor (a-recycle) of 2:1 or 1:1 were implemented; all the recycle ratios are with respect to the influent flow. The system configuration was similar to that described by Ubisi *et al.* (1997), Cronje *et al.* (2000) and Beeharry *et al.* (2001). In their

investigations, they found that the inclusion of an unaerated zone (anoxic reactor) was essential to prevent the proliferation of the filamentous organism *Sphaerotilus natans* which caused severe sludge bulking in completely aerobic laboratory-scale activated sludge systems. A schematic layout of the system is shown in Figs. 3.1 and 3.2.

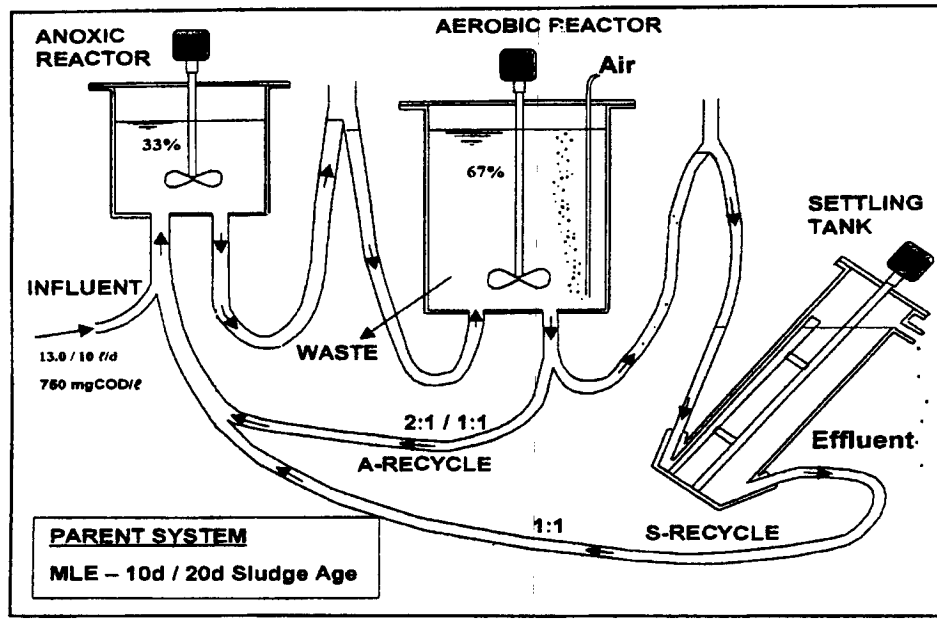


Fig. 3.1: Physical construction of parent laboratory-scale Modified Ludzack-Ettinger (MLE) anoxic/aerobic activated sludge system

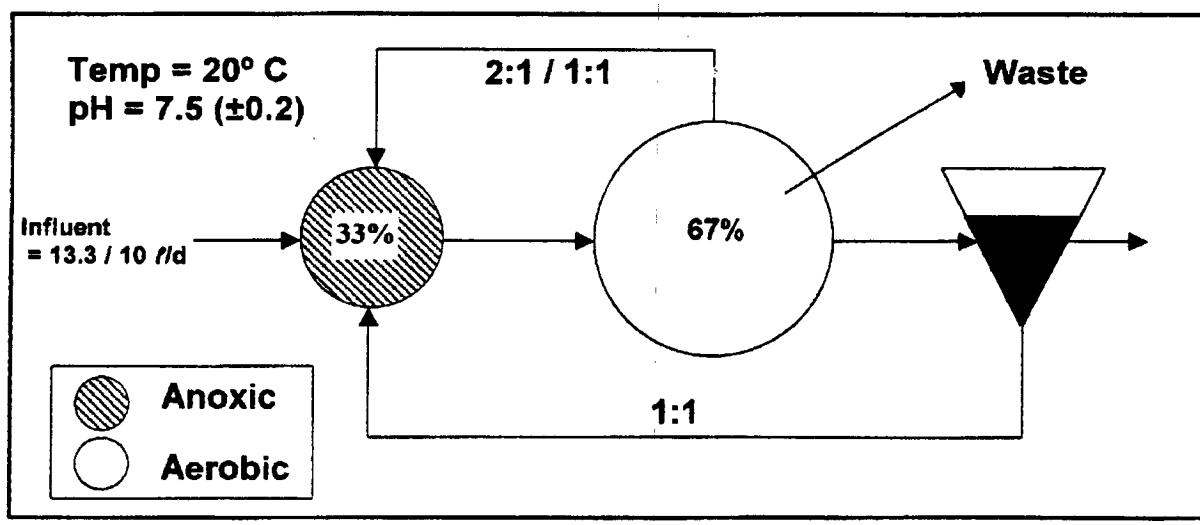


Fig. 3.2: Schematic layout and operational data for parent laboratory-scale Modified Ludzack-Ettinger (MLE) anoxic/aerobic actibated sludge system.

The contents of the anoxic and aerobic reactors were completely mixed by means of independent stirring. The aerobic reactor was aerated by passing low pressure air through a small bore Perspex tube terminating at the bottom of the tank, at the end of which was an air-stone. The secondary settling tank was an inclined tube at 60° to the horizontal fitted with an intermittent slow stirring (1.33 rpm) wiper blade. Pumping of influent feed and recycle flows was by means of a multiple channel peristaltic pump, with flow rate controlled by timers switching the pump on and off (for further details, see Burke *et al.*, 1986). The physical layout of the system is shown in Fig. 3.1.

During the experimental investigation, both systems were kept in the basic MLE system configuration as described above. However, the system layout and operation of both the 10 and 20 days sludge age systems were slightly modified several times to cope with operational problems. Table 3.1 lists these modifications to the two parent systems.

Table 3.1: Details of changes in the parent laboratory-scale system operating parameters; AX=anoxic, AE=aerobic.

Period	Dates	Day of No	Sewage Batches	Inflow Rate (Qi; ℓ/d)	Recycle ratios (With respect to Qi)		System Volume (ℓ) (33% AX, 67% AE)	
					s-recycle	a-recycle	10days	20days
1	7 Jul~19 Aug	1 ~ 42	1 ~ 3	13.3	1:1	2:1	10	10
2	20 Aug~01 Sep	43 ~ 55	4	13.3	1:1	2:1	7.8	13.2
3	02 Sep~13 Feb	56 ~ 220	5 ~ 13	13.3	1:1	1:1	7.8	13.2
4	14 Feb~28 Apr	221 ~ 294	14 ~ 17	10	1:1	1:1	7.8	13.2

3.2.1 Change from Period 1 to Period 2

During Period 1 (day 1 to 42), both the 10 days and 20 days sludge age system had the same system volume. According to Ekama *et al.*(1986) and WRC (1984), the system at 20days sludge age produces much more sludge and has a higher mixed liquor solids concentration than the 10 days sludge age system, if both systems receive the same influent and have the system volume. This was borne out in practise, in that, in Period 1 the solids concentration of the 20 days sludge age system was much higher than that of the 10 days sludge age system. Apparently as the result of the difference in the solids concentration, the fraction of the unbiodegradable soluble COD in the total influent COD ($f_{S,us}$) and the fraction of the unbiodegradable particulate COD in the total influent COD($f_{S,up}$) of the 20 days sludge age system were lower than those of the 10 days sludge age system. To carry out the batch-test evaluation of OHO active biomass in the mixed liquor, it is essential for both the 10 and 20 days sludge age system, to have identical characterization for the wastewater influent COD.

At the beginning of Period 2 (day 43 to 55), the 10 day sludge age system volume was reduced to increase the solids concentration, while the 20 day sludge age system's volume was increased. Thereafter, both systems had approximately the same mixed liquor solids concentration. The fraction of the unbiodegradable particulate COD in the total influent COD ($f_{S,up}$) of the 20 days system increased from 0.115 (which is the average value of Sewage Batch Nos. 1, 2 and 3) to 0.176 (which is the average value of Sewage Batch Nos. 4, 5 and 6). The $f_{S,up}$ of the 10days system remained at the fixed value of 0.186 which is the average value of Sewage Batch Nos. 1, 2, 3, 4, 5 and 6 (see Table 3.5). Hence, by changing the system volumes of each system, identical characterization and reasonable response for both systems could be achieved. Thus, it appeared necessary to have approximately the same mixed liquor solids concentration for the parallel systems at the different sludge ages.

3.2.2 Change from Period 2 to Period 3

From Period 3 (day 56 to 220), the a-recycle was reduced from 2:1 to 1:1 with respect to the influent flow rate to ameliorate bulking by the low F/M filaments (subsequently termed AA filaments, Casey *et al.*, 1994). In N and N&P removal systems, AA filamentous organisms proliferate when the mixed liquor is subjected to sequential anoxic-aerobic conditions in which either, or both of NO_3^- or NO_2^- are present in the anoxic zone immediately preceding the aerobic zone (Casey *et al.* 1994), at concentrations greater than about 2.0 mgNO_3^--N/ℓ or 1.0 mgNO_2^--N/ℓ (Musvoto *et al.*, 1999). (A detailed hypothesis for AA filamentous proliferation is described by Casey *et al.* (1999a, b, c)). The concentrations of NO_3^- and NO_2^- in the anoxic reactors were up to 15.0 mgNO_3^--N/ℓ and 2.0 mgNO_2^--N/ℓ respectively during Periods 1and 2 for both the 10 and 20 days sludge age systems. After the a-recycle was reduced from 2:1 to 1:1 (*i.e.* the loading of NO_3^- and NO_2^- via the a-recycle to the anoxic reactor halved) the concentrations of NO_3^- and NO_2^- in the anoxic reactors decreased into the "safe" region, less than about 2.0 mgNO_3^--N/ℓ or 1.0 mgNO_2^--N/ℓ. For a short period, reducing the nitrate and nitrite loads to the anoxic reactor succeeded in ameliorating the sludge bulking problem; however, later the AA filamentous bulking problem recurred (see Fig. 3.8 (a) and (b)).

3.2.3 Change from Period 3 to Period 4

At the start of Period 4 (day 221 to 294) the influent flow rate was reduced from 13.3 ℓ/d to 10 ℓ/d to overcome secondary settling tank failure, caused by the bulking problem. According to Ekama *et al.* (1997), sludge accumulation in the secondary settling tank (SST) depends on the solids loading on the SST and the sludge settling characteristics which can be represented via the Diluted Sludge Volume Index, DSVI. Even though the a-recycle had been reduced to reduce the NO_3^-/NO_2^- load to the anoxic reactor and hence ameliorate the bulking problem (see above), the bulking problem persisted (see Fig 3.8 (a)). The cause for the persistent bulking could not be identified. During this period the settling characteristics did not appear to conform to the AA bulking hypothesis: From Fig 3.8 (a), from day 170 the DSVI in the 10d sludge age system increased despite the negligible anoxic NO_3^- and NO_2 concentrations, a similar behavioural pattern was observed in the 20d sludge age

system (Fig 3.8 (b)), but with a smaller increase in DSVI. (This behaviour is contradictory to the earlier observations, where anoxic NO_3^-/NO_2^- concentrations and DSVI appeared to be closely linked, in conformity with the AA bulking hypothesis, see Fig. 3.8 (a and b).) The deterioration in sludge settleability led to SST failure and significant solids loss to the effluent. The only way to cope with the failure of the SST was to reduce the solids loading on the SST. The solids loading was reduced by reducing the influent flow rate. As set out in Ekama *et al.* (1986) and WRC (1984), reducing the influent flow rate in turn reduces the influent loading rate, which will reduce the mixed liquor solids concentration in the biological reactor. Thus reducing the influent flow rate has two influences on the solids loading on SST, the one is the reduced flow rate itself and the other is the reduced solids concentration in the biological reactor. In this manner, the failure of the SST was overcome. Subsequent to reducing the influent flow rates (day 221), the DSVIs in both systems improved (see Figs 3.8 (a and b)). Whether this reduction is linked to the reduced influent flow rate (and hence loading rate) is not clear, and merits future investigation.

3.3 WASTEWATER COLLECTION AND STORAGE

The influent for the two parent laboratory-scale activated sludge systems was raw (unsettled) wastewater from the Mitchell's Plain Treatment Plant in Cape Town (South Africa). This wastewater is primarily domestic, with a small (< 25%) industrial component. The wastewater was collected in batches from the head of the works, before both the course and fine screens and before grit removal and the primary sedimentation tanks. The wastewater batch was brought to the laboratory and stored in 400ℓ stainless steel tanks in a cold room at 4°C for 10 to 14 days, then discarded and a new batch of wastewater collected; experience has shown that storage of wastewater for periods longer than about 3 weeks leads to hydrogen sulphide build-up in the tanks and a change in the characteristics of the wastewater. For each new batch of wastewater, immediately after storage in the cold room a COD test was done to determine the COD concentration, which was required for subsequent dilution (see below) (COD of the undiluted wastewater ranged from 1 000 to 1 500 mgCOD/ℓ).

3.4 FEED PREPARATION

The total COD concentration which served as feed to the parent laboratory-scale activated sludge systems was targeted at 750 ± 50 mgCOD/ℓ for both the 10 days and 20 days sludge age systems. Knowing the total COD concentration of the wastewater batch collected, volumes of wastewater and tap water to dilute the wastewater to the required concentration (750 mgCOD/ℓ) could be calculated. Daily, the contents of the storage tanks were thoroughly mixed and a volume of wastewater was then drawn from the tank: The wastewater was drawn from a tap at the bottom of the tank, passed through a 1 mm sieve into a graduated 20ℓ plastic bucket. Then the appropriate volume of tap water was added to dilute the wastewater to the desired COD concentration (750 mgCOD/ℓ) and to give the required daily feed volume of 13.3ℓ during Period 1 to 3, and later 10ℓ during Period 4. Thus, the total COD load per day for each of the MLE activated sludge systems was ± 9975 mgCOD/d and 7500 mgCOD/d for Periods 1 to 3 and 4 respectively.

To maintain the pH in the aerobic reactor at ± 7.5, the alkalinity of the influent was increased by 200 mg/ℓ (as $CaCO_3$): A buffer solution was made up in a separate container by dissolving 67.2 g sodium bicarbonate ($NaHCO_3$) into 1ℓ of distilled water. By adding 100mℓ of the buffer solution to the 20ℓ diluted wastewater an increase in alkalinity of 200 mg/ℓ (as $CaCO_3$) was achieved. After thorough mixing, samples were drawn for influent analysis.

3.5 FEEDING THE SYSTEM

After thoroughly mixing the diluted wastewater above, the influent feed for each of the parent activated sludge systems over the next 24h was drawn (13.3ℓ for Period 1, 2 and 3 and 10ℓ for Period 4), and placed in a separate upright PVC bucket which had a stirrer driven at 10rpm, to keep the contents in the feed bucket completely mixed and limit settling of particulate matter. The feed buckets were placed in a large chest refrigerator at a temperature of 4-8°C to minimize biological degradation of the wastewater. The diluted wastewater was pumped at a constant rate from the feed bucket to the respective parent activated sludge system over the 24h period. The feed buckets were cleaned daily with boiling water and for each system two sets of influent feed tubes were used. One set was used for feeding and the spare influent feed tubes were washed with boiling water and stored until the following day when the two sets of tubes were swapped. This practice prevents the growth of the filamentous organism *S. natans* in the feed pipes and minimizes the build up of other organisms in the feed pipes.

The calibration of the feed pumps was checked daily through ensuring that the feed buckets were empty at exactly the same time (say 16h00) every day. The feeding rate was increased or decreased by adjusting the pumping frequency.

3.6 SYSTEM MAINTENANCE AND OPERATION

The general maintenance and operational procedures set out in detail by Burke *et al.* (1986) and Clayton *et al.* (1989) were followed.

During Period 1, the volume of mixed liquor in the anoxic reactor was maintained at 3.3ℓ and that in the aerobic reactor at 6.7ℓ (total volume 10ℓ) for both the 10 and 20 days sludge age systems, by controlling the outlet water level in the relevant reactors. The sludge ages (R_s) were controlled hydraulically at 10 days and 20 days, by wasting 1ℓ and 0.5ℓ of mixed liquor daily from the aerobic reactor (including any samples drawn for analysis) of the 10 and 20 days sludge age systems respectively. During Periods 2, 3 and 4, the volumes of mixed liquor in the anoxic reactor were maintained at 2.6ℓ and 4.4ℓ for the 10 and 20 days sludge age systems respectively and that in the aerobic reactor at 5.2ℓ and 8.8ℓ (total volume 7.8ℓ and 13.2ℓ) respectively, by controlling the outlet water level in the relevant reactors. The sludge ages (R_s) were controlled hydraulically at 10 and 20 days, by wasting 0.78ℓ and 0.66ℓ of mixed liquor daily from the aerobic reactor (including any samples drawn for analysis) of the 10 and 20 days sludge age systems respectively.

When conducting batch tests, the volume of mixed liquor drawn from the systems usually exceeded the amount to be wasted daily (depending on the volume of mixed liquor used in the batch test): To avoid over-wasting, the effluent used in diluting the mixed liquor when conducting the DSVI test was decanted, the mixed liquor rediluted to the correct volume with effluent and the appropriate volume required to avoid over-wasting was returned to the relevant system. The activated sludge systems were operated in a temperature-controlled room at 20°C. In the bioreactor, pH was controlled at 7.5 (±0.2).

The aerobic reactors' dissolved oxygen (DO) concentration was controlled between 2.0 and 4.5 mgO/ℓ, by using an automated DO meter (Randall *et al.*, 1991); this meter also recorded the oxygen utilization rate (OUR) automatically (see below). The DO meter and probe were recalibrated at least once a week.

3.7 SAMPLING AND MEASUREMENTS

Daily, for both systems the following samples were drawn for analysis:

- ***Influent***: Before the influent was poured into the two feed buckets, the feed was thoroughly mixed and a 200 mℓ sample drawn and stored at 4°C for analysis the following day. Experience showed that inaccuracies were common when the 5 mℓ or 10 mℓ volumes required for the TKN and COD tests were pipetted from the refrigerated 200 mℓ sample the following day. To avoid this, the influent sample was warmed to 20°C just prior to pipetting the samples for COD and TKN analysis.

- ***Reactors***: For each system, three 50 mℓ samples were drawn from the aerobic reactor and two from the anoxic reactor whilst the system was still feeding on the previous day's feed. When the mixed liquor samples were drawn from the reactors, care was taken not to disrupt the steady state behaviour of the system. To do this, the following sampling sequence was adopted for each system:

  - First, the two 50 mℓ samples for nitrate/nitrite analysis were drawn from the anoxic and aerobic reactors, respectively. Immediately after the samples were drawn, they were filtered separately through 0.45 μm filter paper. The filtrates of the two samples were stabilized by adding 2 drops of mercuric chloride solution (8.6 g $HgCl_2$ /ℓ, Standard Methods, 1985) to each sample and were stored at 4°C for not more than 7 days before conducting nitrate/nitrite analysis.

  - After storing the nitrate/nitrite samples, the internal surfaces of the two reactors were thoroughly brushed to dislodge sludge deposits from the tank floors and to re-introduce wall deposits below and above the water surface back into the mixed liquor; sludge particles were splashed out of solution and deposited above the surface water level of the aerobic reactor wall as a result of intermittent aeration (for measuring OUR, see below).

- After brushing, the system was allowed to operate normally for ± 30 minutes to allow sludge particles to be distributed evenly throughout the system.

- After the 30 minutes had elapsed, two 50 mℓ samples were drawn from the anoxic and aerobic reactors respectively for TSS, VSS and ISS testing (see 9. below). An additional 50 mℓ sample was drawn from the aerobic reactor, diluted in a 1:10 ratio with distilled water and homogenized in a liquidizer for mixed liquor COD and TKN testing (see 4. below).

- Lastly, a 500 mℓ mixed liquor sample was drawn from the aerobic reactor to perform the DSVI test (see 7. below).

- ***Effluent***: After thorough mixing a one litre sample was drawn from the relevant effluent bucket.

The following analyses were performed on the samples daily, and are shown in Table 3.1:

1. COD and TKN (Standard Methods, 1985) on the unfiltered influent sample.
2. COD and TKN on the unfiltered effluent sample.
3. COD and TKN on filtered effluent sample (filtered through 0.45 μm filter paper).
4. COD and TKN on the aerobic reactor mixed liquor unfiltered samples.
5. Oxygen utilization rate (OUR) in the aerobic reactor (see below).
6. pH of the aerobic reactor.
7. DSVI (Ekama and Marais, 1984) on aerobic reactor mixed liquor.
8. Nitrate and nitrite concentration (Technicon Auto Analyser) on effluent, aerobic and anoxic reactors, all samples filtered through 0.45 μm filter paper.
9. Total suspended solids (TSS), organic/volatile suspended solids (VSS) and inorganic suspended solids (ISS) on aerobic and anoxic reactor mixed liquor (Standard Methods, 1985).

Previous experience showed that varying analytical results were obtained during the first two days after the introduction of a new sewage batch. These variations were ascribed to the phenomenon that the active organisms require a short acclimatisation period to adapt to the changed wastewater characteristics of a new sewage batch. As a result no testing (apart from the influent) was done during the first two days after the introduction of a new sewage batch.

The oxygen utilization rate (OUR) in the aerobic reactor was measured continually by using an automated technique (Randall *et al.*, 1991): A dissolved oxygen (DO) probe (YSI) from an automatic DO meter/OUR logger (Hi Tech Microsystems) was immersed in the mixed liquor. The low and high DO set point of the meter were 2.0 and 5 mgO/ℓ respectively: When the DO reached ± 5mgO/ℓ the air switched off automatically and the decrease in DO with time was monitored; when the DO reached ± 2.0 mgO/ℓ, the air was switched on again automatically and the cycle repeated. Automatically, for each cycle the slope of the DO-time data during the air off period was determined by linear regression; this gives the OUR, which was stored by the meter (together with regression analysis and time data). The OUR results were downloaded from the DO meter to a PC the following

day whilst the system was still feeding on the previous day's feed. OUR results with a regression correlation coefficient less than 0.99 ($R^2 = 0.99$) were rejected, the mean OUR determined from the remaining data and recorded as the OUR for the day. The number of OUR readings ranged between 120 and 150 per day.

Table 3.2: Daily tests conducted on the two parent MLE activated sludge systems.

Test	Influent	Anoxic reactor	Aerobic reactor	Effluent
COD	◆		◆	◆○
TKN	◆		◆	◆○
Nitrate		○	○	○
Nitrite		○	○	○
OUR			❑	
TSS		✖	✖	
VSS		✖	✖	
ISS		✖	✖	
pH		❑	❑	
DSVI			❑	

◆ Unfiltered sample
○ Sample filtered through 0.45 μm filter paper
❑ Direct measurement taken
✖ Centrifuge pellet

3.8 PARENT SYSTEM CONDITIONS

As noted earlier, the parent laboratory-scale activated sludge systems were operated to supply mixed liquor samples for the batch tests, to measure OHO active biomass. This required that the conditions present in the parent systems be precisely defined. The details of the parent systems have been described above.

The wastewater used to feed the systems was collected in batches from the Mitchell's Plain Treatment Works and was changed every ± 2 weeks to prevent degradation under storage. In total 17 batches of sewage were fed to the parent systems. These sewage batches and the dates they were used as feed are listed in Table 3.3. Also indicated are the sewage batches during which mixed liquor samples were drawn from the systems for batch tests. During the periods from 17 October (day 101) to 15 November (day 130), from 18 January (day 194) to 29 January (day 205) and from 1 March

(day 236) to 15 March (day 250), no testing was done on the parent systems because of operational problems, such as the bulking problem or re-configuration of the parent systems. To contain the mixed liquor in the systems during periods of severe sludge bulking, alum was added, for Sewage Batch Nos. 2 and 8, 9 and 10. The dosage was around 50 mℓ of stock solution (50g/ℓ of $A\ell(SO_4) \cdot 15\ H_2O$) for the first 4 or 5 days and then reduced to 15 to 30 mℓ for the whole bulking period. From Sewage Batch No. 12, Alum addition was stopped, because the alum dose no longer could contain the mixed liquor in the system, and an alternative remedy was applied (reducing the influent flowrate from Sewage Batch No. 14, see above).

Table 3.3: Details of the parent laboratory-scale activated sludge systems, sewage batch number, sewage feed dates, days of operation and batch tests conducted. (* indicate Batch Test done with Aerobic Digestion)

Sewage Batch No.	Generic Sew. Batch. No	Date of tests (2001/2002)	Days of operation(d)	Alum Addition	Batch Test	Period
1	SB11/01	7 Jul -24 Jul	day 1 - 18	No	No	1
2	SB12/01	25 Jul - 03 Aug	day 19 - 28	Yes	No	
3	SB13/01	04 Aug - 19 Aug	day 29 - 42	No	No	
4	SB14/01	20 Aug - 01 Sep	day 43 - 55	No	No	2
5	SB15/01	02 Sep - 13 Sep	day 56 - 67	No	Yes	3
6	SB16/01	14 Sep - 19 Sep	day 68 - 73	No	No	
7	SB17/01	20 Sep - 07 Oct	day 74 - 91	No	Yes	
8	SB18/01	08 Oct - 16 Oct	day 92 - 100	Yes	Yes	
9	SB19/01	16 Nov - 01 Dec	day 131 - 146	Yes	Yes	
10	SB20/01	02 Dec - 17 Dec	day 147 - 162	Yes	Yes	
11	SB21/01	18 Dec - 04 Jan	day 163 - 180	No	Yes	
12	SB01/02	05 Jan - 17 Jan	day 181 - 193	No	Yes	
13	SB02/02	30 Jan - 13 Feb	day 206 - 220	No	Yes	
14	SB03/02	14 Feb - 28 Feb	day 221 - 235	No	Yes	4
15	SB04/02	16 Mar - 26 Mar	day 251 - 261	No	Yes*	
16	SB05/02	27 Mar - 12 Apr	day 262 - 278	No	Yes*	
17	SB06/02	13 Apr - 28 Apr	day 279 - 294	No	Yes	

3.9 RESULTS

3.9.1 Steady state periods

Daily results for the parent activated sludge systems at 10 days and 20 days sludge ages are listed in Appendix D, Tables D3 to D19 and Appendix E, Tables E3 to E19 respectively. Each sewage batch was accepted as a steady state period. The daily data for each sewage batch were analyzed statistically to determine outliers; data lying outside approximately the 95% confidence interval (*i.e.* data lying outside the range of mean ± 1.96* sample standard deviation) were rejected (these data are shown marked in the appropriate tables in Appendix D and E). Excluding the rejected data, for each sewage batch (steady state period) the daily data were averaged and the sample standard deviations calculated. The averages, sample standard deviations and number of data for the different wastewater batches are listed in Tables 3.4 (a and b) and 3.6 (a and b) for the 10 and 20 days sludge age systems respectively.

3.9.2 N and COD mass balances

The reliability of the experimental measurements was checked by means of COD and N mass balances on the steady state periods (Ekama *et al.*, 1986): A brief description of the method for calculating the N and COD mass balances for the two parent MLE systems, using the averaged data from Sewage Batch No.14 of the 10 days sludge age system as an example, is given below. The description is followed by an analysis of the results obtained for the various sewage batches.

3.9.2.1 Nitrogen (N) mass balance

Calculation method

In the N mass balance, the influent TKN mass must be accounted for by the sum of the mass of TKN and nitrate in the effluent, mass of nitrate denitrified to nitrogen gas in the anoxic reactor and the mass of N abstracted through the waste sludge:

mass of influent TKN	=	mass of effluent TKN	+	mass of effluent NO_3	+	mass of N denitrified	+	mass of N wasted

$$Mnti = MNte + MNne + MNd + MNw \quad (mg\ N/d) \quad (3.1)$$

The mass of nitrate denitrified (MNd) was found from NO_3^- and NO_2^- mass balances around each reactor in the system, including the settling tank. In this investigation, denitrification (indicated by a loss in nitrate across the reactor/settler) occurred primarily in the anoxic reactor, but sometimes in the Secondary Settling Tank (SST) as well. Particularly when sludge bulking was experienced, the SST contained significant sludge mass and so denitrification happened in the SST unintentionally.

The amount of nitrogen denitrified in the SST was taken into account in the N mass balance. Also, it was assumed that this denitrification happens along the axis of flow in the SST, and so the nitrate concentration in the underflow from the SST (s-recycle) is equal to the concentration in the inflow into the SST (since both inflow and underflow enter and leave the SST at closely the same height, see Fig. 3.1). This was taken into account in the N mass balance, by accepting that the nitrate concentration in the underflow of the SST was equal to the concentration in the aerobic reactor. Thus, in calculating the mass of N denitrified in Eq. (3.1), denitrification in both the anoxic reactor and SST needed to be included. Further, in this investigation, significant concentrations of nitrite were observed. This required that both nitrate and nitrite denitrification be considered. Accordingly:

$MNd = (NO_3 \text{ denitrification}) + (NO_2 \text{ denitrification})$

$= \quad MNO_{3,d} \quad + \quad MNO_{2,d}$

$MNO_{3,d}$ = anoxic NO_3 denitrification (Where SST denitrification did not occur)

= anoxic-reactor·(NO_3^- mass in - NO_3^- mass out)

$= [NO_{3(AE)} \cdot Qi \cdot a + NO_{3(FE)} \cdot Qi \cdot s] - [NO_{3(AN)} \cdot Qi \cdot (1 + a + s)]$

OR

= (anoxic + SST)·NO_3^- denitrification (Where SST denitrification did occur)

= anoxic-reactor·(NO_3^- mass in-NO_3^- mass out)+SST·(NO_3^- mass in-NO_3^- mass out)

$=[NO_{3(AE)} \cdot Qi \cdot a + \underline{NO_{3(AE)}} \cdot Qi \cdot s] - [NO_{3(AN)} \cdot Qi \cdot (1 + a + s)] + \underline{Qi \cdot [NO_{3(AE)} - NO_{3(FE)}]}$

$MNO_{2,d}$ = anoxic NO_2^- denitrification (in all cases SST NO_2^- denitrification was negligible)

= anoxic-reactor·(NO_2^- mass in - NO_2^- mass out)

$= [NO_{2(AE)} \cdot Qi \cdot a + NO_{2(FE)} \cdot Qi \cdot s] - [NO_{2(AN)} \cdot Qi \cdot (1 + a + s)]$

where

Qi = influent flow rate (10 ℓ/d or 13.3 ℓ/d)

a = a –recycle ratio = 1 or 2

s = s –recycle ratio = 1

$NO_{3(AE)}$ = NO_3 concentration in the aerobic reactor *(i.e. 12.9 mgN/ℓ for S. Batch No. 14)*

$NO_{3(FE)}$ = NO_3 concentration of the filtered effluent *(i.e. 13.4 mg N/ℓ for S. Batch No.14)*

$NO_{3(AN)}$ = NO_3 concentration in the anoxic reactor *(i.e. 0 mgN/ℓ for S. Batch No. 14)*

$NO_{2(AE)}$ = NO_2 concentration in the aerobic reactor *(i.e. 0 mgN/ℓ for S. Batch No. 14)*

$NO_{2(FE)}$ = NO_2 concentration of the filtered effluent *(i.e. 0 mg N/ℓ for S. Batch No. 14)*

$NO_{2(AN)}$ = NO_2 concentration in the anoxic reactor *(i.e. 0 mgN/ℓ for S. Batch No. 14)*

$Qi \cdot [NO_{3(AE)} - NO_{3(FE)}]$ = Only calculated when $NO_{3(AE)} > NO_{3(FE)}$
i.e. only calculated when denitrification happens in SST

For Sewage Batch No. 14: $MNO_{3,d} = [(11.5 \cdot 10 \cdot 1) + (12.6 \cdot 10 \cdot 1)] - [(0 \cdot 10 \cdot (1+1+1)]$
$= 241\ mgN/d$
$MNO_{2,d} = (0 \cdot 10 \cdot 1) + (0 \cdot 10 \cdot 1)] - [(0 \cdot 10 \cdot (1+1+1)]$
$= 0\ mgN/d$
$MNd = 241 + 0$
$= 241\ mgN/d$

The mass of effluent TKN (MNte) was taken as the unfiltered TKN concentration of the effluent (Nte) multiplied by the effluent flow rate (Qi - Qw) :

For Sewage Batch No. 14: $MNte = Nte \cdot (Qi - Qw)$
$= 4.0 \cdot (10 - 0.78) = 36.9\ mgN/d$

The mass of effluent NO_3 (MNne) was calculated as the concentration of nitrate and nitrite in the effluent ($NO_{3\,(FE)} + NO_{2\,(FE)}$) multiplied by the effluent flow rate (Qi - Qw) :

For Sewage Batch No. 14: $MNne = (NO_{3\,(FE)} + NO_{2\,(FE)}) \cdot (Qi - Qw)$
$= (12.6 + 0) \cdot (10 - 0.78) = 116.2\ mgN/d$

The mass of N in the waste sludge (MNw) was found by adding the NO_3 concentration in the aerobic reactor ($NO_{3(AE)}$) and the NO_2 concentration in the aerobic reactor ($NO_{2(AE)}$) to the measured mixed liquor TKN concentration (N_{ML}) and multiplying this value by the waste flow (Qw):

For Sewage Batch No. 5: $MNw = (N_{ML} + NO_{3(AE)} + NO_{2(AE)}) \cdot Qw$
$= (203.8 + 11.5 + 0) \cdot 0.78 = 167.9\ mgN/d$

The influent N mass (MNti) was taken as the influent TKN concentration (Nti) multiplied by the influent flow rate (Qi) :

For Sewage Batch No. 5: $MNti = Nti \cdot Qi = 59.2 \cdot 10 = 592\ mgN/d$

By substituting the masses calculated above into Eq. (3.1), the **N mass balance** is given by

$$Nbal\ (\%) = 100 \cdot (MNte + MNne + MNd + MNw) / MNti \qquad (3.2)$$

For Sewage Batch No. 5: $Nbal\ (\%) = 100 \cdot (241+36.9+116.2+167.9) / 592$
$Nbal\ (\%) = 94.9\ \%$

The data can be considered acceptable if the N mass balance falls in the range 90 – 110%.

Analysis of Nitrogen (N) mass balance results

The results of the N mass balances calculated for each sewage batch are listed in Table 3.5 and 3.7 and are shown graphically in Fig. 3.3 (a and b) for the 10 and 20 days sludge age systems. The results can be commented on as follows:

- Except for Sewage Batch Nos. 8 and 15 for the 10 days system and Nos. 6, 8 and 15 for the 20 days system, all the N mass balances fall into the range of 90 % to 110%, which indicates that further analysis is reasonable.

- For Sewage Batch Nos. 6, 7, 8, 10 and 13 for the 10 days system and 3, 6, 7, 8, 9 and 13 for the 20 days system, sludge accumulation in SST (Secondary Settling Tank) was significantly due to filamentous bulking. The N mass balance calculation method of Cronje *et al.* (2000) and Beeharry *et al.* (2001) does not consider this and produced poor N mass balances during these periods. Accordingly, the modified calculation method for N mass balances which is described above in '**calculation method**' was applied. This method notes that denitrification takes place along with direction of flow in the SST when significant sludge accumulates in the SST. Further, it accepts that the nitrate concentration in the underflow from the SST (s-recycle) is the same as the nitrate concentration in the inflow into the SST. The N mass balances were improved significantly with the modified method.

- For Sewage Batch Nos. 8 for the 10 days system and 6 and 8 for the 20 days system, the N mass balances exceeded 110% and accordingly should be rejected for further analysis. The amount of nitrite and nitrate denitrified for Sewage Batch No. 8 was excessive. The assumption that denitrification takes place linearly along the direction of flow in the SST when sludge accumulates in the SST is simplistic. The effect of the mixing imposed in the SST could introduce a certain degree of turbulence. This means that the nitrate concentration in the underflow from the SST (s-recycle) would not be exactly the same as the nitrate concentration in the SST inflow. Rather, it probably lies in the region between the nitrate concentration in inflow from the aerobic reactor and the nitrate concentration in the overflow from the SST, which is the filtered effluent concentration. Thus, for Sewage Batch No. 8, the amount of denitrification in the SST is overestimated using the above assumption. To overcome this difficulty, it is recommended that when SST sludge accumulation is significant the nitrate concentration in the s-recycle is measured to ensure greater surety in the N mass balance.

- For Sewage Batch No. 15 for both the 10 and 20 days systems, the N mass balance also exceeded 110%. For this sewage batch, the nitrate concentrations in the aerobic reactor and effluent were quite high compared to preceding and following sewage batches. Due to the high concentrations, the dilution of the samples was large in the analytical procedure for nitrate, and thus is more susceptible to dilution errors than is usual. For this reason, the nitrate concentrations of the aerobic reactor and effluent seemed to have been overestimated, resulting in high N mass balances.

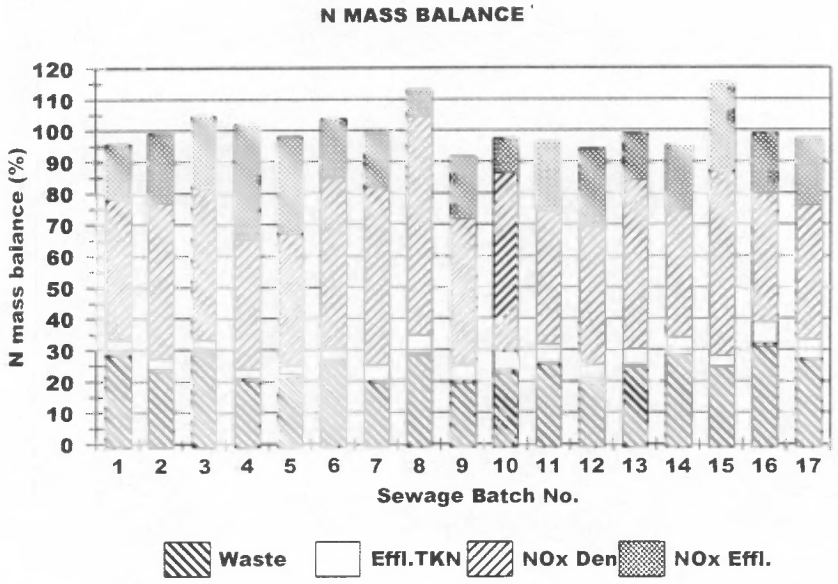


Fig. 3.3 (a): Graphical representation of the percentage Nitrogen (N) mass balance for the various wastewater batches for the10 days sludge age system. Percentages are also shown for :Nitrogen for sludge production (waste), Effluent TKN (Effl. TKN), Effluent nitrite/nitrate (NOx Effl.) and Nitrite/Nitrate for Denitrification (NOx Den.)

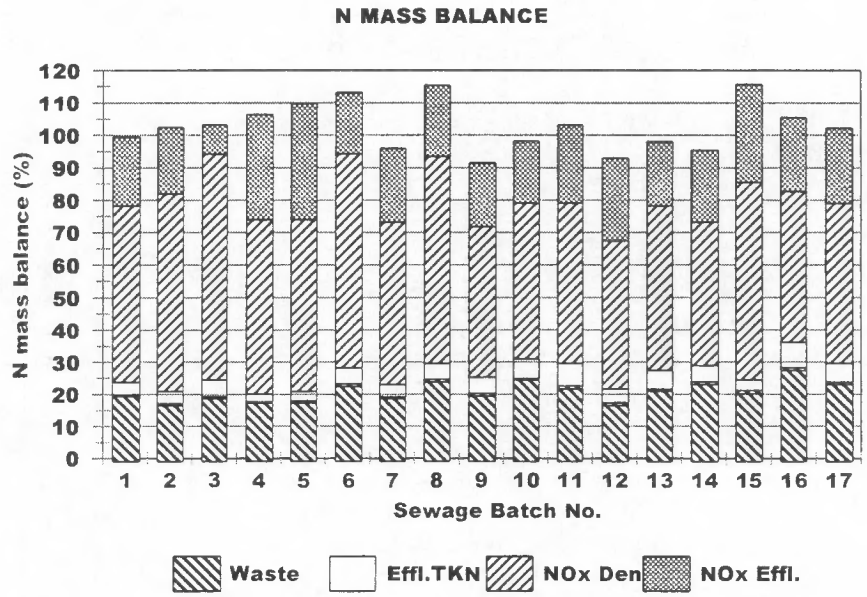


Fig. 3.3 (b): Graphical representation of the percentage Nitrogen (N) mass balance for the various wastewater batches for the 20 days sludge age system. Percentages are also shown for :Nitrogen for sludge production (waste), Effluent TKN (Effl. TKN), Effluent nitrite/nitrate (NOx Effl.) and Nitrite/Nitrate for Denitrification (NOx Den.)

3.9.2.2 COD mass balance

Calculation method

In the COD mass balance, the influent COD mass must be accounted for by the sum of the masses of effluent COD, carbonaceous oxygen demand, the equivalent oxygen demand for denitrification and the COD mass of the waste sludge:

mass of influent COD	=	mass of effluent COD	+	mass of carbonaceous oxygen demand	+	equivalent mass of oxygen demand for denitrification	+	mass of COD wasted

$$MSti = MSte + MOc + MOd + MXsvw \ (mgCOD/d) \qquad (3.3)$$

The mass of effluent COD (MSte) was taken as the unfiltered COD concentration of the effluent (Ste) multiplied by the effluent flow rate (Qi - Qw):

For Sewage Batch No. 5: MSte = 37.5 · (10 - 0.78) = 345.8 mgCOD/d

From the direct measurement of the OUR in the aerobic reactor, the total oxygen demand (MOt) can be calculated. However, the total oxygen demand is the sum of the carbonaceous oxygen demand (MOc) and the oxygen demand for nitrification (MOn):

$$MOt = 24 \cdot OUR \cdot V_{AE} = MOc + MOn \qquad (mgO/d) \qquad (3.4)$$

where

V_{AE} = volume of the aerobic reactor (ℓ)
OUR = mean oxygen utilization rate measured in the aerobic reactor (mgO/ℓ/h)

Therefore, to be able to calculate MOc, an estimate for MOn is essential. The oxygen demand for nitrification is related to the mass of nitrate generated from ammonia ($MNO_{3,g}$) and the mass of nitrite nitrified to nitrate ($MNO_{2,g}$):

$$MOn = 4.57 \cdot MNO_{3,g} - 3.43 \cdot MNO_{2,g} \qquad (mgO/d) \qquad (3.5)$$

$$= 4.57 \cdot Qi \cdot (1+a+s) \cdot [NO_{3(AE)} - NO_{3(AX)}] - 3.43 \cdot Qi \cdot (1+a+s) \cdot [NO_{2(AE)} - NO_{2(AX)}]$$

where
4.57 = mg of oxygen utilized per mg NH_4-N nitrified to NO_3-N
3.43 = mg of oxygen utilized per mg NO_2-N nitrified to NO_3-N
$MNO_{3,g} = Qi \cdot (1+a+s) \cdot [NO_{3(AE)} - NO_{3(AX)}]$
$MNO_{2,g} = Qi \cdot (1+a+s) \cdot [NO_{2(AE)} - NO_{2(AX)}]$

For Sewage Batch No. 14: $MNO_{3,g} = 10 \cdot (1+1+1) \cdot [11.5 - 0] = 345$ *mgN/d*
$MNO_{2,g} = 10 \cdot (1+1+1) \cdot [0 - 0] = 0$ *mgN/d*
$MOn = 4.57 \cdot 345 - 3.43 \cdot 0 = 1576.7$ *mgO/d*

The carbonaceous oxygen demand (MOc) was calculated by substituting Eq. (3.5) into Eq. (3.4) and solving for MOc:

$$MOc = (24 \cdot OUR \cdot V_{AE}) - MOn \quad \text{(mgO/d)} \qquad (3.6)$$

For Sewage Batch No. 14: $MOc = (24 \cdot 44.8 \cdot 5.2) - 1576.7$
$MOc = 4014.3$ *mgO/d*

The equivalent mass of oxygen demand for denitrification (MOd) was calculated from:

$$MOn = 2.86 \cdot MNO_{3,d} + 1.71 \cdot MNO_{2,d} \quad \text{(mgO/d)} \qquad (3.7)$$

where
2.86 = oxygen equivalent of nitrate as electron acceptor (mgO/mgNO_3-N) ($NO_3 \rightarrow N_2$)
1.71 = oxygen equivalent of nitrite as electron acceptor (mgO/mgNO_3-N) ($NO_2 \rightarrow N_2$)
$MNO_{3,d}$ = mass of nitrate denitrified into nitrogen gas (mgN/d)
$MNO_{2,d}$ = mass of nitrite denitrified into nitrogen gas (mgN/d)

For Sewage Batch No. 14: $MOd = 2.86 \cdot 241 + 1.71 \cdot 0$
$MOd = 689.3$ *mgO/d*

The mass of COD in the waste sludge (MX_{SVW}) was calculated by multiplying the measured mixed liquor COD concentration (COD_{ML}) by the waste flow rate (Qw):

$$MX_{SVW} = (COD_{ML}) \cdot Qw \quad \text{(mgCOD/d)} \qquad (3.9)$$

For Sewage Batch No. 14: $MX_{SVW} = (3482) \cdot 0.78$
$MX_{SVW} = 2716.0$ *mgCOD/d*

The mass of influent COD (MSti) was taken as the influent COD concentration (Sti) multiplied by the influent flowrate Qi.

For Sewage Batch No. 5: MSti = 727.2 · 10 = 7272 mgCOD/d

By substituting the masses calculated above into Eq. (3.3), the ***COD mass balance*** *is given by:*

$$\text{COD bal}(\%) = 100 \cdot (\text{MSte} + \text{MOc} + \text{MOd} + \text{MX}_{\text{svw}}) / \text{MSti} \qquad (3.10)$$

For Sewage Batch No. 14: COD bal(%) = 100 · (345.8 + 4014.3 + 689.3 + 2716.0) / 7272
COD bal(%) = 106.8 %

As with the N mass balance, the COD mass balance also should fall within the range 90 – 110% for the experimental data to be considered acceptable.

COD mass balances: Analysis of results

The results of the COD mass balances calculated for each sewage batch are listed in Table 3.5 and Table 3.7 and are shown graphically in Fig. 3.4 (a) and (b). for the 10 days sludge age system and the 20 days sludge age system respectively. The results can be commented on as follows:

- Generally, COD mass balances were poorer than the N mass balances. Only 11 out of 17 sewage batches for the 10 days sludge age system and 10 out of 17 sewage batches for the 20 days sludge age system gave COD mass balances in the range of 90% - 110%. Also, the COD mass balances showed more variation than the N mass balances.

- At the beginning of the investigation, for Sewage Batch Nos. 3 to 6 for the 10 days sludge age system and 1 to 5 for the 20 days sludge age system, poor COD mass balances were obtained. The main source of error in this startup period were caused by the need to master the experimental and analytical procedures.

- For Sewage Batch No. 13 for both the 10 and 20 days sludge age systems, the carbonaceous oxygen demand was low causing the COD mass balances to fall below 80 %. As described above for the N mass balance, severe bulking occurred during this period so that it was difficult to maintain a steady state condition.

- For Sewage Batch No. 9 for the 10 days sludge age system and 6 for the 20 days sludge age system, the COD mass balances were over 110%. In these sewage batches, the carbonaceous oxygen demand was high.

It was attempted to trace the source of the error in the COD mass balance:

- Investigations showed that the COD measurement techniques were accurate (checked with standard potassium hydrogen phthalate, Standard Methods, 1985); ***the measured COD data could be accepted.***

- Thus, the problem would appear to lie in measurement of the OUR or mixed liquor organic solids. Of particular importance to this investigation is the measurement of the mixed liquor organic solids: For the batch tests, the solids measurements are used to estimate the theoretical OHO active biomass active fraction (see Chapter 4).

- Three independent measurements were made on the mixed liquor organic solids, volatile suspended solids (VSS), COD and TKN. To check the reliability of these measurements, the ratios of COD/VSS and TKN/VSS for the parent system mixed liquor were calculated for each sewage batch, see Table 3.5 and Table 3.7. Statistical plots for these ratio's were constructed, see Figs. 3.9 and 3.10 and Figs. 3.11 and 3.11 respectively (see Appendix F for interpretation of statistical plots). The means for COD/VSS were 1.40 and 1.37 mgCOD /mgVSS with sample standard deviation 0.01 and 0.03 mgCOD/mgVSS for the 10 and 20 days sludge age systems respectively. The means for TKN/VSS were 0.083 and 0.079 mgTKN/mgVSS with sample standard deviation 0.003 and 0.003 mgTKN/mgVSS for the 10 and 20 days sludge age systems respectively. From the statistical plots it is evident that the data are normally distributed; this indicates that (i) an infinite number of parameters had an influence on the measurements (ii) each influence was small, and (iii) no single factor has had a dominating influence on the measurements. Accordingly, ***it can be accepted that the errors in the COD mass balances do not lie in the measurement of the mixed liquor organic solids.***

- Taking account of the above, it would appear that the main source of error in the COD mass balances lies in the measurement of OUR. The OUR measurement is very sensitive to temperature and humidity, especially when the DO probe is calibrated. Also, regular maintenance of the probe is required. Exact calibration and regular maintenance of the DO probe improved as the investigation proceeded, and so with time improved COD mass balances were attained. Thus, ***the measurement of OUR is critical for good COD mass balances.***

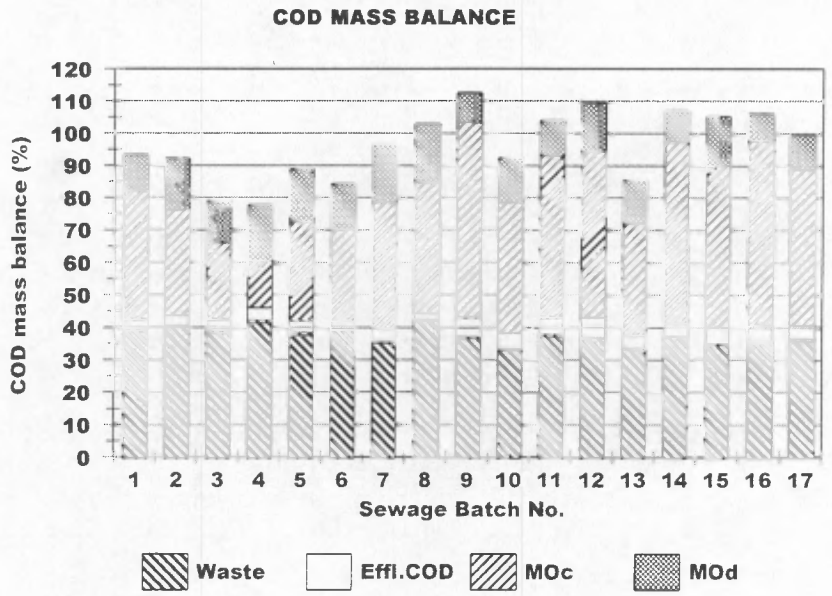


Fig. 3.4 (a) : Graphical representation of the COD mass balance for the various wastewater batches for the 10 days system. Percentages are also shown for : Waste sludge COD (Waste), Unfiltered effluent COD (Effl. COD), Carbonaceous oxygen demand (MOc) and Oxygen demand for nitrification (MOd).

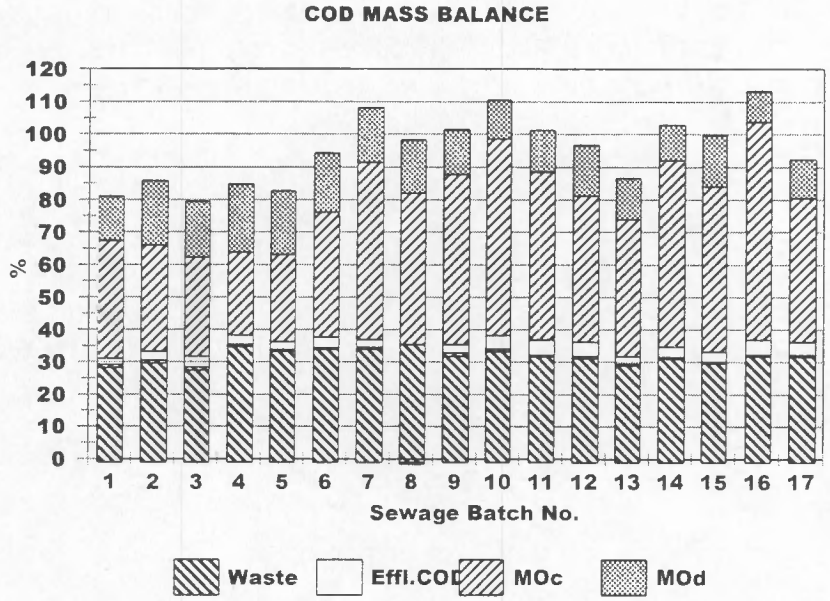


Fig. 3.4 (b) : Graphical representation of the COD mass balance for the various wastewater batches for the 20 days system. Percentages are also shown for : Waste sludge COD (Waste), Unfiltered effluent COD (Effl. COD), Carbonaceous oxygen demand (MOc) and Oxygen demand for nitrification (MOd).

3.9.2.3 Sewage Batches rejected for further analysis:

From the analysis of the N mass balances, sewage batches which yielded mass balances outside the 90% – 110% range should be rejected for further analysis. These were Sewage Batch Nos. 8 and 15 for the 10 days sludge age system and Sewage Batch Nos. 6, 8 and 15 for the 20 days sludge age system. The specific causes for the poor N mass balances for these sewage batches are discussed in Section 3.9.2.1 above. It was identified for Sewage Batch No.8, that the cause for the poor N mass balance lay in denitrification in the SST, and the difficulty in including this correctly in the mass balance calculation. Since this does not impact on the intended use for the steady state data, namely calculation of OHO active biomass, this Sewage Batch was included for further analysis.

From the analysis of the COD mass balances, Sewage Batch Nos. 3, 4, 5, 6, 9 and 13 for the 10 days sludge age system and Sewage Batch Nos. 1, 2, 3, 4, 5, 13 and 16 for the 20 days sludge age system were outside the 90% - 110% range and should be rejected for further analysis. The specific causes for the poor COD mass balances for these sewage batches are discussed in Section 3.9.2.2 above. However, the COD mass balance for Sewage Batch No. 9 for the 10 days sludge age system was only marginally greater than 110% (< 2% over). With the exception of the COD mass balance, all the other parameters are consistent with the other sewage batches. Thus, the data for this sewage batch was accepted for the further analysis. Data for the other sewage batches should be rejected.

Batch tests were conducted on the accepted Sewage Batch Nos. 7, 8, 9, 10, 11, 12, 14 and 17 and were conducted on the rejected Sewage Batch Nos. 5 and 13 for both the 10 and 20 day sludge age systems. The batch test data collected on these rejected sewage batches will be included where appropriate, and will be analyzed, but it will be noted that the data should be rejected and the data will not be used to draw conclusions. This will be done to determine the influence of poor mass balances on the test and analytical procedures.

Table 3.4 (a): Steady state data for the10 day sludge age parent system; for each sewage (Sew.) batch (steady state period, see Table 3.3) the data have been averaged and the means, sample standard deviations (SSD) and number of tests are listed.

Sew. Batch No.	TKN (mgN/l)									NITRATE (mgN/l)								
	INFLUENT			UNFILT. EFFLUENT			MIXED LIQUOR			ANOXIC			AEROBIC			EFFLUENT		
	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests
1	57.9	3.8	14	3.1	0.8	14	211.1	14.7	14	0.2	0.6	14	8.8	1.4	14	10.4	1.1	14
2	75.4	1.7	7	3.4	0.6	7	222.7	6.5	7	1.8	1.6	7	15.3	1.7	7	17.3	0.9	7
3	62.2	1.7	7	3.7	0.3	7	221.9	7.8	7	2.4	2.4	7	14.5	3.6	7	14.6	3.1	7
4	90.2	1.7	7	3.0	1.1	7	289.3	12.0	7	14.9	2.1	7	35.2	2.6	7	34.3	1.2	7
5	85.1	1.3	3	3.6	0.7	3	292.6	15.9	3	5.8	1.0	3	30.0	2.8	3	27.0	1.6	3
6	66.7	1.9	3	3.2	0.3	3	290.3	9.7	3	0.1	0.0	3	15.8	0.3	3	12.0	0.3	3
7	83.2	3.2	7	4.8	1.1	6	271.9	6.0	7	0.1	0.1	7	19.9	2.9	7	13.4	0.4	7
8	59.7	2.0	3	4.2	0.7	3	289.3	10.9	3	0.1	0.0	3	15.4	0.5	3	4.2	0.8	3
9	66.5	1.6	6	5.4	1.1	5	264.6	20.4	6	0.0	0.0	6	11.5	1.1	6	13.3	0.7	6
10	60.8	2.3	8	4.5	0.8	7	235.3	19.2	8	0.0	0.0	8	13.6	1.1	8	6.3	0.9	8
11	61.8	1.3	9	4.5	0.6	9	258.9	9.0	9	0.0	0.0	9	12.5	0.7	9	13.7	0.9	9
12	83.4	2.2	8	4.8	0.5	8	270.3	7.7	8	0.1	0.3	8	18.8	1.3	8	20.3	3.4	8
13	65.1	0.6	3	4.2	0.3	3	270.2	6.6	3	0.0	0.0	3	14.4	0.2	3	8.4	1.7	3
14	59.2	1.7	9	4.0	0.5	9	203.8	7.2	9	0.0	0.0	9	11.5	0.8	9	12.6	0.4	9
15	66.1	0.5	6	3.0	0.7	6	191.6	4.7	6	0.0	0.0	6	19.3	0.3	6	19.5	0.2	6
16	50.7	1.3	11	4.5	0.5	11	197.0	10.6	11	0.0	0.0	11	10.3	1.4	11	10.2	0.9	11
17	61.7	1.6	8	4.2	0.3	8	203.1	7.3	8	0.0	0.1	8	12.8	0.9	8	13.8	0.7	8

Table 3.4 (b): Steady state data for the10 days sludge age parent system; for each sewage (Sew.) batch (steady state period, see Table 3.3) the data have been averaged and the means, sample standard deviations (SSD) and number of tests are listed

Sew. Batch No.	COD (mgN/l)									OUR (mgO/l/h)			VSS (mgVSS/l)		
	INFLUENT			UNFILT. EFFLUENT			MIXED LIQUOR								
	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests
1	717.7	28.2	14	25.4	8.2	14	3791.4	167.8	14	36.3	1.9	14	2836.2	75.3	14
2	709.6	11.4	7	27.4	9.9	7	3813.1	113.2	7	38.6	1.2	6	2760.1	94.3	7
3	757.1	14.7	7	32.8	13.7	7	3923.4	95.6	7	32.1	1.5	7	2765.0	107.3	7
4	712.0	33.1	7	32.9	6.7	7	5105.7	140.5	7	47.5	2.9	7	3510.2	129.1	7
5	706.7	28.5	3	30.7	5.7	3	4626.7	66.0	3	55.7	0.0	3	3360.1	68.3	3
6	734.5	12.8	3	26.1	3.2	3	4892.2	90.7	3	44.6	1.3	3	3457.7	112.7	3
7	760.2	63.2	7	34.7	18.3	7	4632.8	129.5	7	60.2	3.8	7	3325.0	75.5	7
8	677.3	27.8	3	17.6	8.5	3	4897.1	315.2	3	51.2	2.8	3	3468.7	142.9	3
9	686.7	22.8	6	49.2	15.9	6	4330.6	252.0	6	60.6	6.6	4	3291.0	127.1	6
10	749.4	40.1	8	42.8	11.2	8	4251.6	225.0	8	52.0	3.9	8	3131.7	205.1	8
11	733.8	22.3	9	44.8	7.3	9	4733.1	160.1	9	57.2	4.2	9	3461.6	121.9	9
12	749.4	26.1	8	51.4	5.6	8	4711.6	188.6	8	67.8	6.1	8	3520.6	173.0	8
13	762.5	11.8	3	36.6	1.9	3	4364.6	216.4	3	48.6	7.6	3	3195.1	165.9	3
14	727.2	23.2	9	37.5	4.3	9	3482.0	72.5	9	44.8	3.2	9	2532.2	62.2	9
15	764.9	15.2	6	43.2	8.6	6	3443.0	80.6	6	51.8	2.9	6	2557.4	39.8	6
16	743.4	18.1	11	42.8	6.6	11	3416.5	354.3	11	45.1	3.9	11	2489.4	226.6	11
17	772.6	13.0	8	38.1	4.7	8	3615.5	96.7	8	43.9	1.0	8	2632.3	100.6	8

Table 3.5: Indent steady state N and COD mass balances, wastewater fractions and mixed liquor parameters for the 10 days sludge age parent system. Data calculated from Table 3.4 (* indicates data rejected as outliers at 95% confidence interval).

Sew. Batch No.	MASS BALANCE (%)		WASTEWATER FRACTIONS		MIXED LIQUOR	
	N	COD	Unbio. Soluble (fs,us) (mgCOD/mgCOD)	Unbio. Particulate (fs,up) (mgCOD/mgCOD)	COD/VSS (fcv) (mgCOD/mgVSS)	TKN/VSS (fN) (mgN/mgVSS)
1	96	93	0.0303	0.1931	1.33	0.075 *
2	99	92	0.0345	0.2046	1.34	0.080
3	104	79	0.0361	0.1654	1.40	0.081
4	102	78	0.0421	0.2037	1.44	0.083
5	98	89	0.0387	0.1703	1.37	0.088
6	104	84	0.0346	0.1739	1.44	0.086
7	99	97	0.0382	0.1345	1.42	0.085
8	113	103	0.0060 *	0.2147	1.45	0.087
9	91	113	0.0390	0.1756	1.38	0.086
10	97	92	0.0488	0.1113	1.38	0.078
11	96	104	0.0513	0.1794	1.42	0.080
12	94	110	0.0487	0.1717	1.40	0.082
13	99	85	0.0454	0.1083	1.35	0.086
14	95	107	0.0482	0.1625	1.39	0.084
15	115	105	0.0477	0.1442	1.41	0.080
16	99	106	0.0519	0.1453	1.40	0.083
17	97	99	0.0474	0.1515	1.39	0.081
MEAN			0.0427	0.1653	1.40	0.083
Std. Devation			0.0066	0.0295	0.03	0.003

Table 3.6 (a): Steady state data for the 20 days sludge age parent system; for each sewage (Sew.) batch (steady state period, see Table 3.3) the data have been averaged and the means, sample standard deviations (SSD) and number of tests are listed.

Sew. Batch No.	TKN (mgN/l)									NITRATE (mgN/l)								
	INFLUENT			UNFILT. EFFLUENT			MIXED LIQUOR			ANOXIC			AEROBIC			EFFLUENT		
	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests
1	57.9	3.8	14	2.7	0.8	14	293.2	21.1	14	1.7	2.1	14	13.2	3.5	14	12.2	3.0	14
2	75.4	1.7	7	3.3	0.5	7	327.5	5.6	7	2.8	1.4	7	20.0	1.5	7	15.1	1.5	7
3	62.2	1.7	7	3.7	0.8	7	313.8	9.1	7	0.8	0.9	7	12.7	2.0	7	4.9	1.5	7
4	90.2	1.7	7	3.2	0.7	7	290.4	6.5	7	11.4	3.0	7	33.2	4.3	7	30.3	2.3	7
5	85.1	1.3	3	3.6	0.5	3	275.6	5.5	3	4.9	1.1	3	31.4	1.8	3	31.6	2.3	3
6	66.7	1.9	3	4.0	0.1	3	300.1	6.3	3	0.0	0.1	3	18.3	0.6	3	11.7	0.5	3
7	83.2	3.1	7	3.9	0.6	6	302.3	10.0	7	0.3	0.3	7	20.2	2.6	7	18.3	2.6	7
8	59.7	2.0	3	3.7	0.2	2	283.0	6.7	3	0.1	0.1	3	16.8	0.3	3	12.9	1.0	3
9	66.5	1.6	6	4.2	0.7	6	257.7	13.0	6	0.0	0.0	6	14.6	1.0	6	12.4	2.2	6
10	60.4	2.0	8	4.3	0.9	6	291.0	16.5	8	0.0	0.0	8	14.6	1.1	8	11.6	2.3	8
11	61.8	1.3	9	5.0	0.4	9	265.8	14.0	9	0.0	0.0	9	15.0	1.0	9	15.4	0.5	9
12	83.4	2.2	8	4.3	0.8	7	269.9	9.9	8	0.7	0.6	8	21.1	0.9	8	21.6	0.8	8
13	65.1	0.6	3	4.7	0.5	3	269.3	19.2	3	0.0	0.0	3	15.1	0.3	3	12.4	1.4	3
14	59.2	1.7	9	3.8	0.4	9	200.8	3.9	9	0.0	0.0	9	12.9	1.0	9	13.4	1.3	9
15	66.1	0.5	6	2.9	0.4	6	190.6	5.7	6	0.1	0.0	6	20.7	0.3	6	20.7	0.5	6
16	50.7	1.3	11	4.5	0.5	11	204.6	5.2	11	0.0	0.0	11	11.3	1.1	11	12.3	0.8	11
17	61.7	1.6	8	4.1	0.5	8	207.3	4.8	8	0.0	0.0	8	15.3	0.4	8	15.0	0.7	8

Table 3.6 (b): Steady state for the 20 days sludge age parent system; for each sewage (Sew.) batch (steady state period, see Table 3.3) the data have been averaged and the means, sample standard deviations (SSD) and number of tests are listed.

Sew. Batch No.	COD (mgN/l)									OUR (mgO/l/h)			VSS (mgVSS/l)		
	INFLUENT			UNFILT. EFFLUENT			MIXED LIQUOR								
	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests
1	717.7	28.2	14	21.4	8.1	14	5558.6	253.8	14	38.4	1.7	14	4073.8	229.4	14
2	709.6	11.4	7	24.5	10.4	7	5737.0	137.9	7	44.5	1.6	6	4207.6	106.7	7
3	756.5	15.1	7	31.9	14.4	7	5702.6	235.3	7	38.0	1.5	7	4201.3	162.8	7
4	712.0	33.1	7	30.0	8.9	7	5071.4	159.6	7	34.9	1.9	7	3646.5	66.2	7
5	706.7	28.5	3	23.3	4.1	3	4813.3	120.4	3	34.0	1.8	3	3487.0	39.2	3
6	734.5	12.8	3	32.8	8.2	3	5086.6	175.7	3	33.4	1.6	3	3598.5	64.1	3
7	760.2	63.2	7	23.0	10.9	7	5287.9	353.0	7	43.1	3.6	7	3718.2	141.4	7
8	677.3	27.8	3	-4.7	18.9	3	4876.8	141.8	3	34.2	0.4	3	3715.2	122.6	3
9	686.7	22.8	6	23.1	10.2	6	4548.1	69.3	6	35.0	0.5	6	3308.6	68.1	6
10	747.4	41.1	8	40.8	10.5	8	5115.3	182.7	8	40.7	2.5	8	3668.3	102.5	8
11	733.8	22.3	9	42.8	5.8	9	4748.8	144.2	9	36.7	1.4	9	3351.4	62.0	9
12	749.4	26.1	8	37.3	6.0	8	4815.9	93.9	8	38.2	0.8	8	3406.6	52.6	8
13	762.5	11.8	3	26.6	2.5	3	4517.6	89.8	3	32.8	0.8	3	3272.3	48.6	3
14	727.2	23.2	9	31.5	4.9	9	3470.9	27.3	9	27.8	2.6	9	2459.8	47.5	9
15	764.9	15.2	6	34.1	4.3	6	3473.5	83.3	6	31.4	2.3	6	2507.2	49.8	6
16	743.4	18.1	11	39.9	9.2	11	3634.1	69.1	11	30.7	3.5	11	2571.8	41.2	11
17	772.6	13.0	8	35.8	4.5	8	3774.6	52.9	8	26.1	1.3	8	2666.9	70.2	8

Table 3.7: Indent steady state N and COD mass balances, wastewater fractions and mixed liquor parameters for the 20 days sludge age parent system. Data calculated from Table 3.6 (* indicates data rejected as outliers at 95% confidence interval).

Sew. Batch No.	MASS BALANCE (%)		WASTEWATER FRACTIONS		MIXED LIQUOR	
	N	COD	Unbio. Soluble (fs,us) mgCOD/mgCOD)	Unbio. Particulate (fs,up) (mgCOD/mgCOD)	COD/VSS (fcv) (mgCOD/mgVSS)	TKN/VSS (fN) (mgN/mgVSS)
1	99	81	0.0279	0.1123	1.36	0.072 *
2	102	86	0.0292	0.1280	1.35	0.078
3	103	79	0.0363	0.1056	1.35	0.075
4	106	85	0.0401	0.1870	1.37	0.079
5	110	83	0.0425	0.1716	1.37	0.080
6	113	94	0.0392	0.1702	1.39	0.083
7	96	108	0.0386	0.1707	1.39	0.081
8	115	98	-0.0190 *	0.1896	1.30 *	0.076
9	91	101	0.0331	0.1560	1.35	0.078
10	98	110	0.0523	0.1713	1.37	0.079
11	103	101	0.0513	0.1448	1.39	0.079
12	93	97	0.0471	0.1405	1.38	0.079
13	98	87	0.0332	0.1149	1.38	0.084
14	95	103	0.0427	0.1353	1.38	0.082
15	116	100	0.0415	0.1214	1.36	0.076
16	106	113	0.0454	0.1451	1.38	0.080
17	102	92	0.0382	0.1429	1.38	0.078
MEAN			0.0399	0.1475	1.37	0.079
Std. Devation			0.0068	0.0254	0.01	0.003

3.9.3 Determination of unbiodegradable soluble and particulate fractions

The unbiodegradable soluble and particulate fractions of the influent COD ($f_{S,us}$ and $f_{S,up}$ respectively) were determined using the methods of Ekama *et al.* (1986).

3.9.3.1 Unbiodegradable soluble COD fraction ($f_{S,us}$)

According to Ekama *et al.* (1986), the unbiodegradable soluble COD is given by the COD of the filtered effluent of the activated sludge system. Hence:

$$f_{S,us} = S_{te} / S_{ti} \qquad (3.11)$$

where

S_{te} = filtered effluent COD concentration (mgCOD/ℓ)
S_{ti} = unfiltered influent COD concentration (mgCOD/ℓ)

For the average data on each sewage batch (Tables 3.4 and 3.6), the $f_{S,us}$ values were calculated using Eq.(3.11), and the values are listed in Tables 3.5 and 3.7 for the 10 and 20 days sludge age systems respectively. The $f_{S,us}$ data from all the sewage batches were analysed using a statistical plot, see Fig. 3.5 (a) and (b) for the 10 and 20 days sludge age systems respectively (for interpretation of the statistical plot, see Appendix F). Accepting the procedures above, ***for the 10 day sludge age system*** one outlier was identified, $f_{S,us} = 0.006$, see Fig. 3.5 (a). Rejecting this point, the data are replotted in Fig. 3.6 (a). The data are normally distributed, giving for Mitchell's Plain raw wastewater a mean $f_{S,us} = 0.043$ and sample standard deviation of 0.0066. ***For the 20 day sludge age system*** one outlier was identified, $f_{S,us} = -0.0190$, see Fig. 3.5 (a). Rejecting this point, the data are replotted in Fig. 3.6 (b). The data are normally distributed, giving for Mitchell's Plain raw wastewater a mean $f_{S,us} = 0.040$ and sample standard deviation of 0.0068. The $f_{S,us}$ value of the 10 day sludge age system is slightly higher than the value of the 20 day sludge age system. However, this difference is not statistically significant at the 95% confidence interval (t-test). The values are lower than the $f_{S,us}$ values obtained by both Ubisi *et al.* (1997a,b) ($f_{S,us} = 0.095$) and Cronje *et al.* (2000) ($f_{S,us} = 0.085$) for the same Mitchell's Plain raw wastewater; However they are quite similar to the $f_{S,us}$ value obtained by Beeharry *et al.* (2001) ($f_{S,us} = 0.05$). Of interest is the fact that both Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) were feeding a COD concentration of 500 ± 50 mgCOD/ℓ to their parent systems; However, Beeharry *et al.* (2001) was feeding a COD concentration of 750 ± 50 mg COD/l which is the same as the targeted COD concentration of this investigation. Thus, despite that the $f_{S,us}$ values would be expected to be the same, given that the influent wastewater being treated was the same, the higher COD concentration gave a lower $f_{S,us}$. This observation would imply that the concentration of the wastewater used as feed to the laboratory-scale systems has an influence on the $f_{S,us}$ values. The $f_{S,us}$ values in this investigation are, however, in the range of accepted values of 0.04 – 0.10 mgCOD/mgCOD for municipal raw wastewaters in South Africa (WRC, 1984).

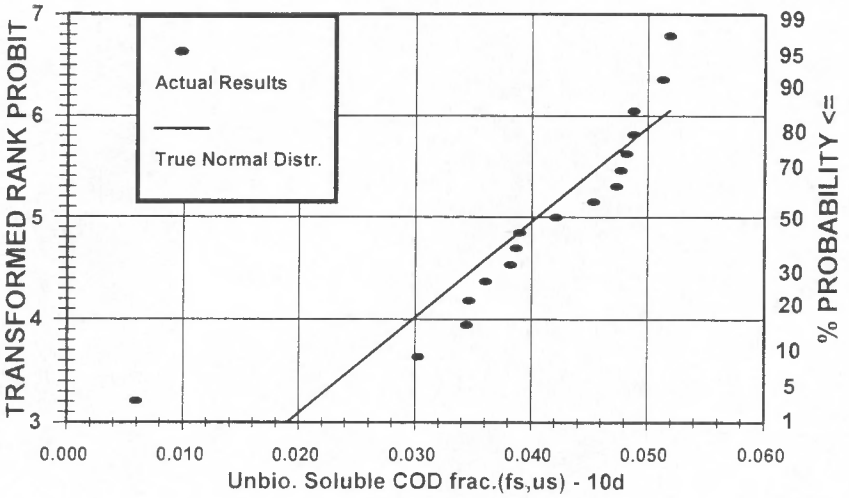


Fig. 3.5 (a): Statistical plot of influent unbiodegradable soluble COD fractions ($f_{S,us}$) for the 10 day sludge age parent laboratory-scale activated sludge system fed with municipal wastewater from Mitchell's Plain (Cape Town, South Africa).

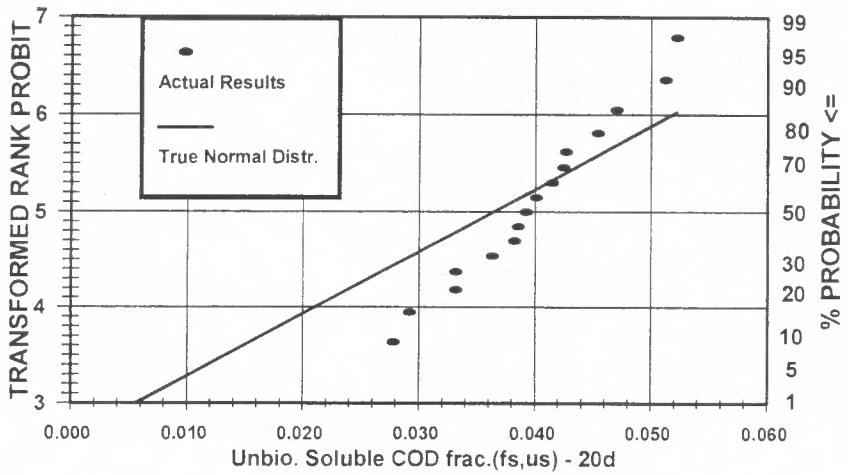


Fig. 3.5 (b): Statistical plot of influent unbiodegradable soluble COD fractions ($f_{S,us}$) for the 20 day sludge age parent laboratory-scale activated sludge system fed with municipal wastewater from Mitchell's Plain (Cape Town, South Africa).

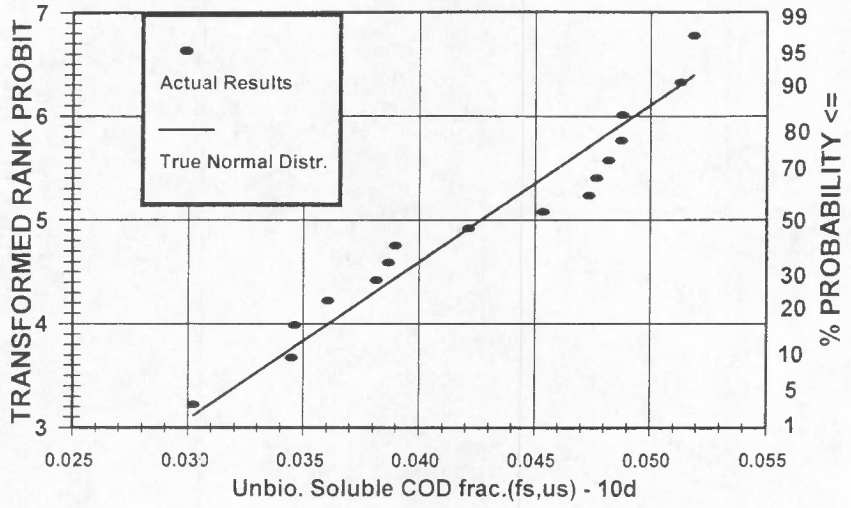


Fig. 3.6 (a): Statistical plot of influent unbiodegradable soluble COD fractions ($f_{S,us}$) for the 10 days sludge age parent laboratory-scale activated sludge system fed with municipal wastewater from Mitchell's Plain (Cape Town, South Africa) - rejected outliers omitted.

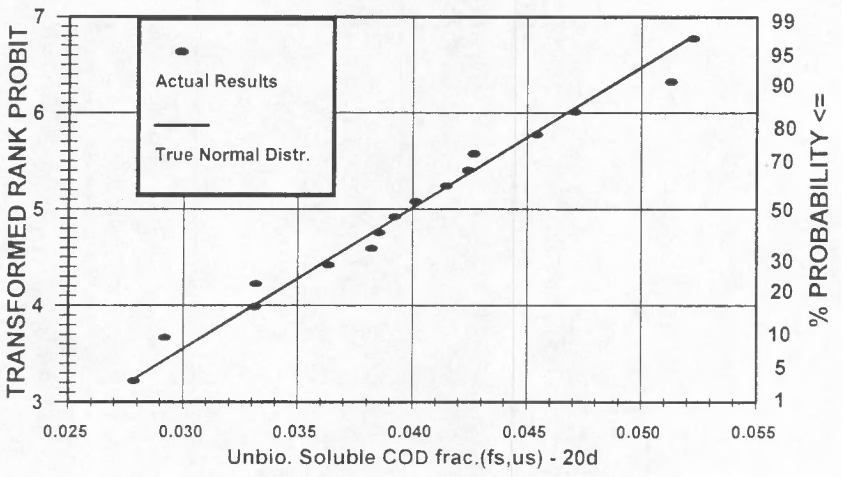


Fig. 3.6 (b): Statistical plot of influent unbiodegradable soluble COD fractions ($f_{S,us}$) for the 20 days sludge age parent laboratory-scale activated sludge system fed with municipal wastewater from Mitchell's Plain (Cape Town, South Africa) - rejected outliers omitted.

3.9.3.2 Unbiodegradable particulate COD fractions ($f_{S,up}$):

Following the method of Ekama *et al.* (1986), the measured mixed liquor volatile suspended solids (MLVSS) was used to determine the influent unbiodegradable particulate COD fraction, $f_{S,up}$. From the average data on each sewage batch (Tables 3.4 and 3.6) and the calculated $f_{S,us}$ (Tables3.5 and 3.7), the $f_{S,up}$ values were calculated using the following equation (Ekama *et al.*, 1986):

$$MX_V = \frac{MS_{ti}(1 - f_{S,us} - f_{S,up})\, Y_H^* R_S}{(1 + b_H^* R_S)} (1 + f^* b_H^* R_S) + f_{S,up}\, MS_{ti}\, R_S / f_{cv} \qquad (3.12)$$

MX_V = total volatile solids mass (mgVSS)
= $X_V \cdot V_P$
X_V = MLVSS concentration (mgVSS/ℓ)
= measured value (Tables 3.4 and 3.6)
V_P = System volume
= 10 ℓ for Period 1 and 7.8ℓ / 13.2ℓ(10 / 20days systems) for Periods 2, 3 and 4
Y_H^* = OHO active biomass yield (VSS units)
= 0.45 mgVSS/mgCOD
R_S = sludge age (d)
= 10 d / 20 d
b_H^* = net specific endogenous mass loss rate (endogenous mass loss theory, WRC, 1984)
= 0.24 / d at 20°C
f^* = endogenous residue fraction
= 0.20
f_{cv} = COD/VSS ratio of mixed liquor (mgCOD/mgVSS)
= 1.40 and 1.37 mgCOD/mgVSS for 10 and 20 day systems respectively
MS_{ti} = total influent COD mass fed per day (mgCOD/d)
= Qi · Sti
Qi = influent flow rate
= 13.3 ℓ/d for Period 1, 2 and 3 and 10.0 ℓ/d for Period 4.
S_{ti} = influent COD concentration (mgCOD/ℓ)
= measured value (Table 3.3)

For each batch of sewage tested, successive values for $f_{S,up}$ were substituted into Eq. (3.12); the $f_{S,up}$ value that gave a theoretical MLVSS mass (MX_V) equal to the measured value was accepted. The $f_{S,up}$ values for the different wastewater batches are listed in Tables 3.5 and Tables 3.7 for the 10 and 20 day sludge age systems respectively.

The $f_{S,up}$ data for all the wastewater batches were analysed using a statistical plot, see Fig. 3.7 (a) and Fig. 3.7 (b) for the 10 and 20 day systems respectively. No outliers were identified at the 95% confidence interval. *i.e.* no data were rejected. The data are normally distributed, giving for Mitchell's Plain raw wastewater a mean $f_{S,up} = 0.165$ with sample standard deviation of 0.0295 for the 10 day

sludge age system and $f_{S,up}$ = 0.148 with sample standard deviation of 0.0254 for the 20 day system. It is apparent that the value for the 10 day system is slightly higher than the value for the 20 day system, which is similar to the $f_{S,us}$ values. Hence, the differences in $f_{S,up}$ are not statistically significant at the 95% confidence interval (t-test). The $f_{S,up}$ values are higher than the values observed by Ubisi *et al.* (1997a,b) ($f_{S,up}$ = 0.120) and Cronje *et al.* (2000) ($f_{S,up}$ = 0.103) but are similar to the value observed by Beeharry *et al.* (2001) ($f_{S,up}$ = 0.161) for the same Mitchell's Plain raw wastewater. Both Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) were feeding a COD concentration of 500 ± 50 mgCOD/ℓ to their parent systems; however Beeharry *et al.* (2001) was feeding a COD concentration of 750 ± 50 mg COD/l which is the same as the targeted COD concentration of this experiment. Thus, despite that the $f_{S,up}$ value would be expected to be the same, given that the influent wastewater being treated was the same, the higher COD concentration gave a higher $f_{S,up}$. The $f_{S,up}$ values of this experiment are, however, in the range of accepted values of 0.07 – 0.20 mgCOD/mgCOD for municipal raw wastewaters in South Africa (WRC, 1984).

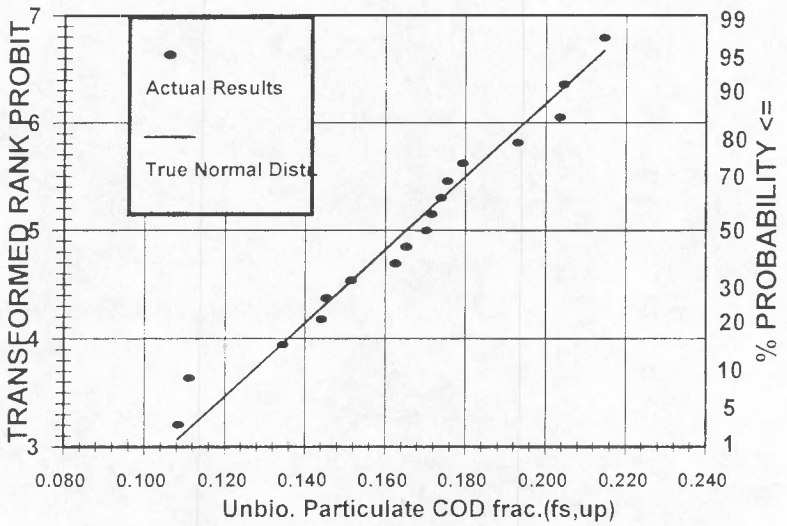


Fig. 3.7 (a): Statistical plot of influent unbiodegradable soluble COD fractions ($f_{S,up}$) for the 10 day sludge age parent laboratory-scale activated sludge system fed with municipal wastewater from Mitchell's Plain (Cape Town, South Africa).

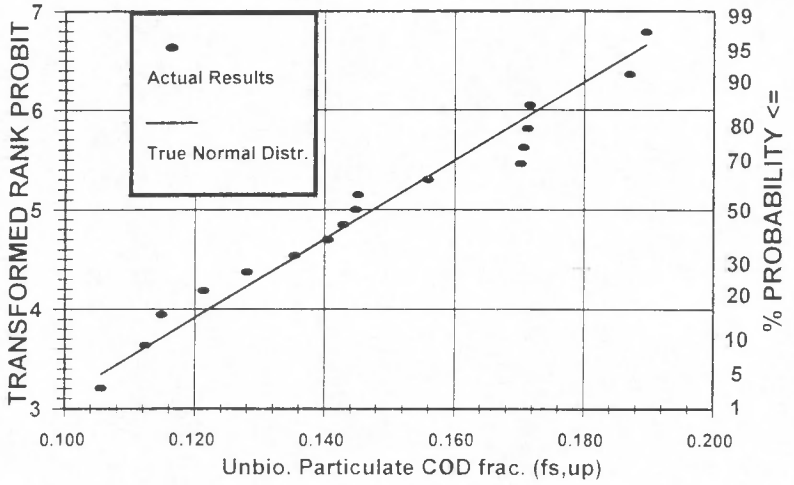


Fig. 3.7 (b): Statistical plot of influent unbiodegradable soluble COD fractions ($f_{S,up}$) for the 20 day sludge age parent laboratory-scale activated sludge system fed with municipal wastewater from Mitchell's Plain (Cape Town, South Africa).

3.9.4 Sludge settleability

Although not explicitly part of this research project, the sludge settleabilities of the two parent systems were monitored daily by means of the Diluted Sludge Volume Index (DSVI). On a number of different occasions, the DSVI increased to values above 150 mℓ/g (indicating a bulking sludge): Microscopic identification implicated the filamentous organism *Microthrix parvicella*. According to the hypothesis of Casey *et al.* (1999a, b, c) which explains the proliferation of the anoxic/aerobic (AA) group of filaments, the nitrate/nitrite concentration in the primary anoxic reactor preceding the aerobic reactor is of fundamental importance: If the nitrate/nitrite concentration is high, the growth of AA filaments is stimulated and *vice versa*. In Fig. 3.8 (a) and (b) for the 10 and 20 day sludge age systems respectively, the primary anoxic reactor nitrate concentrations are shown plotted on the same graph as the DSVI versus day of operation.

From about day 20 to day 50, the primary anoxic reactor nitrate concentration increased to 15 mgN/ℓ for both the 10 and 20 day sludge age systems. Concomitantly, the DSVI increased to over 150 mℓ/g with the dominant filamentous organism identified as *M.parvicella* belongs to the anoxic/aerobic (AA) group of filaments. This behaviour of filament proliferation is in direct agreement with the hypothesis of Casey *et al.* (1999 a, b, c). From day 56, Sewage Batch No.5, the a-recycle was reduced from 2:1 to 1:1 to reduce the nitrate load on the primary anoxic reactor. This caused an

immediate decrease in the nitrate concentration in the anoxic reactor to below 1 to 2 mgN/ℓ. However, the DSVIs of the both 10 and 20 days sludge age systems continue increasing until about day 80, whereafter, the DSVIs decreased. This lag in DSVI response is indicative of a population shift, and is in agreement with the bulking hypothesis. However, from about day 170 the DSVI in both systems increased without a concomitant increase in anoxic nitrate/nitrite concentrations. This increase in DSVI was also caused by the AA group of filaments. However, it is contradictory to the hypothesis of Casey *et al.* (1999 a, b, c). No definitive cause for the increase in DSVI could be identified. Thus, as described in Section 3.2 above, from day 220, the influent flow rate was reduced from 13.3 ℓ/d to 10.0 ℓ/d. This appeared to ameliorate the AA filament bulking problem.

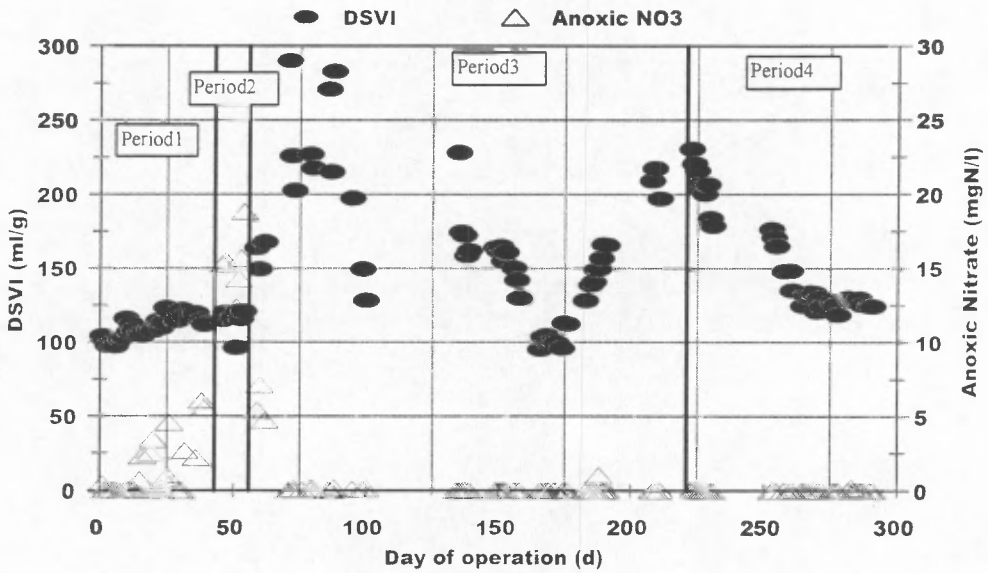


Fig. 3.8 (a): Daily Diluted Sludge Volume Index (DSVI) and anoxic nitrate (NO_3) concentration versus day of operation for the 10 days sludge age parent lab-scale activated sludge system.

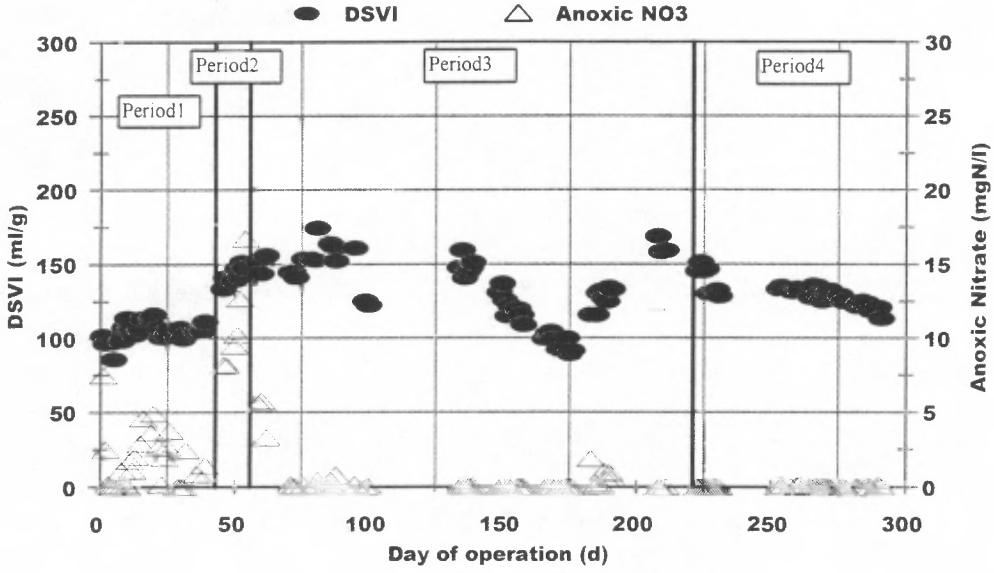


Fig. 3.8 (b): Daily Diluted Sludge Volume Index (DSVI) and anoxic nitrate (NO_3) concentration versus day of operation for the 20 days sludge age parent lab-scale activated sludge system.

3.9.5 Operational problems

Occasional pipeline blockages, caused by lumps of sludge which settled in the outlet pipelines of the reactors, resulted in sludge losses from overflowing reactors. During the day following a sludge spillage, the reactors were drained and the mixed liquor was screened through a 1 mm sieve to remove sludge lumps. All pipelines were removed, cleaned and replaced and no testing was done on the system for that day. The volume of sludge wasted for that day was also decreased to account for the lost sludge.

Sludge losses could well account for the poor mass balances observed in the initial sewage batches. To prevent pipeline blockages and consequent sludge losses, towards the latter part of the experimental investigation an improved version of Y over flow connectors were implemented at the outflow of the aerobic reactor into the secondary settling tank. Inconsequential sludge overflows were experienced after this measure was introduced.

3. 10 CONCLUSIONS

The two parent systems were operated for 294 days each and each received as influent 17 batches of raw municipal wastewater from the Mitchell's Plain Treatment Plant in Cape Town. From the results obtained from the systems:

- N mass balances were consistent and generally in the range 90 to 110%. Sewage batches that gave mass balances falling outside this range were Nos. 8 and 15 for the 10 day sludge age system and Nos. 6, 8 and 15 for the 20 day sludge age system. Batch tests were conducted during Sewage Batch No. 8. From an analysis of the data, it was concluded that the poor N mass balance for this sewage batch arose from the difficulty in correctly incorporating SST denitrification in the mass balance calculation. Since this does not impact on the calculation of OHO active biomass (required for the batch tests), the data from this sewage batch was not excluded.

- Generally COD mass balances were not as good as the N mass balances, with 5 of 17 sewage batches for the 10 days sludge age system and 6 of 17 sewage batches for the 20 days sludge age system giving mass balances outside the range 90 to 110%. Sewage batches that gave COD mass balances falling outside this range were No. 3, 4, 5, 6 and 13 for the 10 days system and 1, 2, 3, 4, 5, 13 and 16 for the 20 days system. Examining the data more closely showed that for Sewage Batch No.9 for the 10 day sludge age system, the COD mass balance was only marginally above 110% (around 2%) and that all the other parameters were consistent with the proceeding and following sewage batches. Accordingly, the data for this sewage batch was retained. For the other sewage batches, batch tests were conducted during Sewage Batch Nos. 5 and 13 on mixed liquors from both the 10 and 20 day sludge age systems. From statistical plots of the ratios between mixed liquor organic solids parameters, *i.e.* volatile suspended solids(VSS), COD and TKN, it is evident that the data are normally distributed. Accordingly, it could be accepted that the errors in the COD mass balances do not lie in the measurement of the mixed liquor organic solids, the parameter of importance in the measurement of OHO active biomass, but probably lies in the measurement of the OUR. Accordingly, the batch test data collected on Sewage Batch Nos. 5 and 13 will be included where appropriate, and will be analysed, but it will be noted that the data should be interpreted with caution.

- The influent wastewater mean unbiodegradable soluble COD fractions ($f_{S,us}$) were determined to be 0.043 (sample standard deviation = 0.0066) and 0.040 (sample standard deviation = 0.0068) for the 10 and 20 day sludge age systems respectively. The difference between the two $f_{S,us}$ values is not statistically significant at the 95% confidence interval (t-test). However, the values are lower than the $f_{S,us}$ values obtained by both Ubisi *et al.* (1997a,b) ($f_{S,us}$ = 0.095) and Cronje *et al.* (2000) ($f_{S,us}$ = 0.085) for the same Mitchell's Plain raw wastewater; the values are similar to the $f_{S,us}$ value obtained by Beeharry *et al.* (2001) ($f_{S,us}$ = 0.05). Of interest is the fact that both Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) were feeding a COD concentration of 500 ± 50 mgCOD/ℓ to their parent systems; However, Beeharry *et al.* (2001) was feeding a COD concentration of 750 ± 50 mg COD/ℓ which is the same as the targeted COD

concentration of this investigation. Thus, despite that the $f_{S,us}$ value would be expected to be the same, given that the influent wastewater being treated was the same and $f_{S,us}$ is a wastewater characteristic, the higher COD concentrations gave lower $f_{S,us}$ values. This observation would imply that dilution of the wastewater (with tap water) used as feed to the laboratory-scale systems has an influence on the $f_{S,us}$ value. The $f_{S,us}$ values in this experiment are, however, in the range of accepted values of 0.04 - 0.10 mgCOD/mgCOD for municipal raw wastewaters in South Africa (WRC, 1984).

- The influent wastewater mean unbiodegradable particulate COD fractions ($f_{S,up}$) were determined to be 0.165 with sample standard deviation of 0.0295 for the10 day system sludge age and 0.148 with sample standard deviation of 0.0254 for the 20 day sludge age system. It is apparent that the $f_{S,up}$ value of the 10 day system is slightly higher than the value of the 20 day system, similar to the $f_{S,us}$ values. However, the difference between the two $f_{S,up}$ values is not statistically significant at the 95% confidence interval (t-test). The two $f_{S,up}$ values are higher than the values observed by Ubisi *et al.* (1997a,b) ($f_{S,up}$ = 0.120) and Cronje *et al.* (2000) ($f_{S,up}$ = 0.103) and are similar to the value observed by Beeharry *et al.* (2001) ($f_{S,up}$ = 0.161) for the same Mitchell's Plain raw wastewater. As noted above both Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) were feeding a COD concentration of 500 ± 50 mgCOD/ℓ to their parent systems; however Beeharry *et al.* (2001) was feeding a COD concentration of 750 ± 50 mg COD/l which is the same as the targeted COD concentration of this experiment. Thus, despite that the $f_{S,up}$ value would be expected to be the same, given that the influent wastewater being treated was the same, the higher COD concentration gave a higher $f_{S,up}$. The $f_{S,up}$ values of this experiment are, however, in the range of accepted values of 0.07 - 0.20 mgCOD/mgCOD for municipal raw wastewaters in South Africa (WRC, 1984).

- Minor sludge losses did occur during the investigation, but did not impact significantly on the steady state behaviour of the parent system, nor on the batch test data analysis since no batch tests were conducted during the periods when the losses occurred.

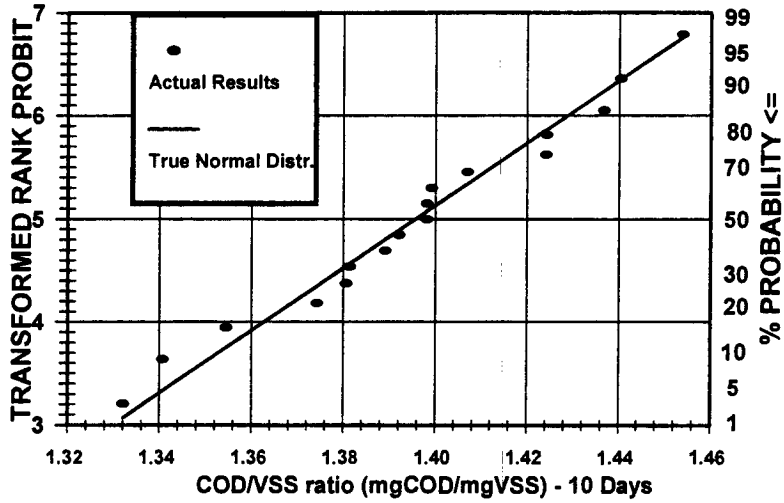


Fig. 3.9 (a): Statistical plot of COD/VSS ratio for the 10 days sludge age parent laboratory-scale activated sludge system.

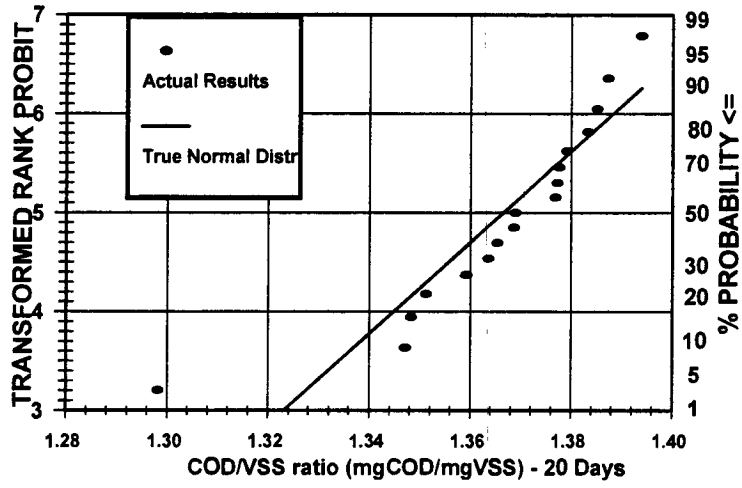


Fig. 3.9 (b): Statistical plot of COD/VSS ratio for the 20 days sludge age parent laboratory-scale activated sludge system.

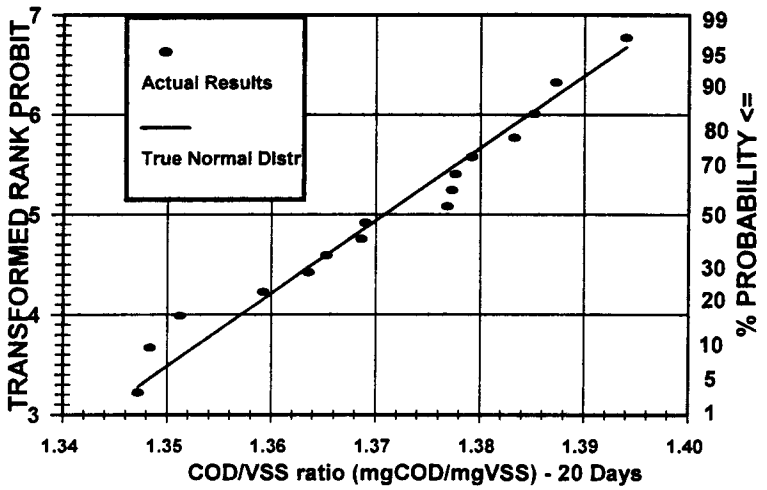


Fig. 3.10: Statistical plot of COD/VSS ratio for the 20 days sludge age parent laboratory-scale activated sludge system- rejected outliers omitted.

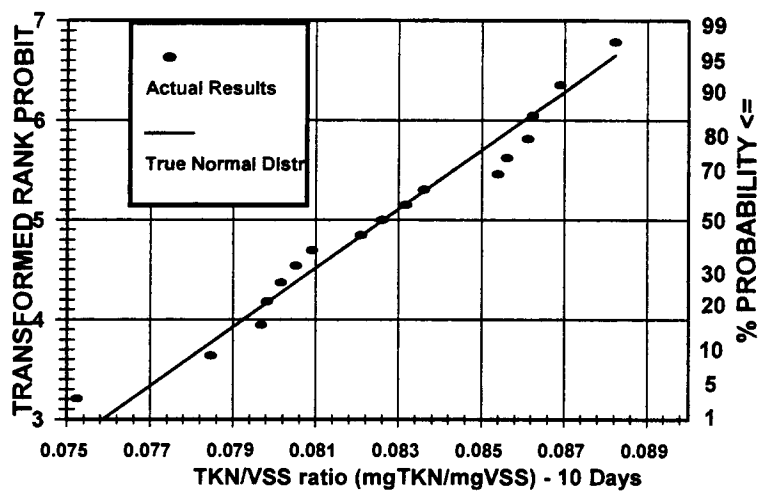


Fig. 3.11 (a): Statistical plot of TKN/VSS ratio for the 10 days sludge age parent laboratory-scale activated sludge system.

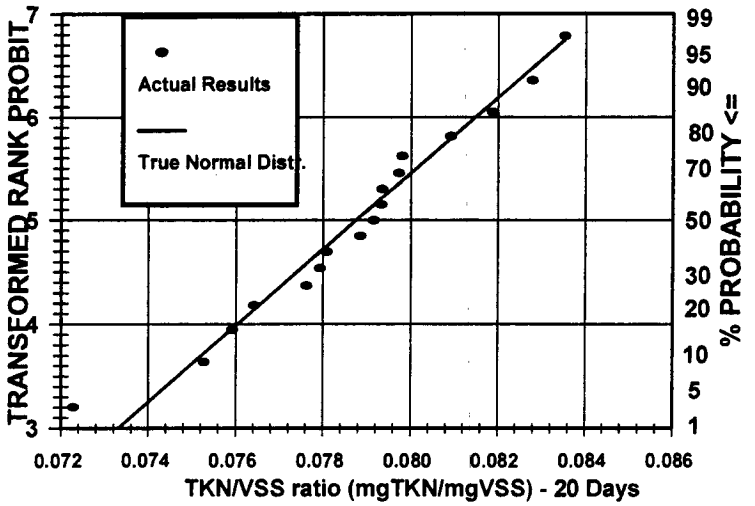


Fig. 3.11 (b): Statistical plot of TKN/VSS ratio for the 20 days sludge age parent laboratory-scale activated sludge system.

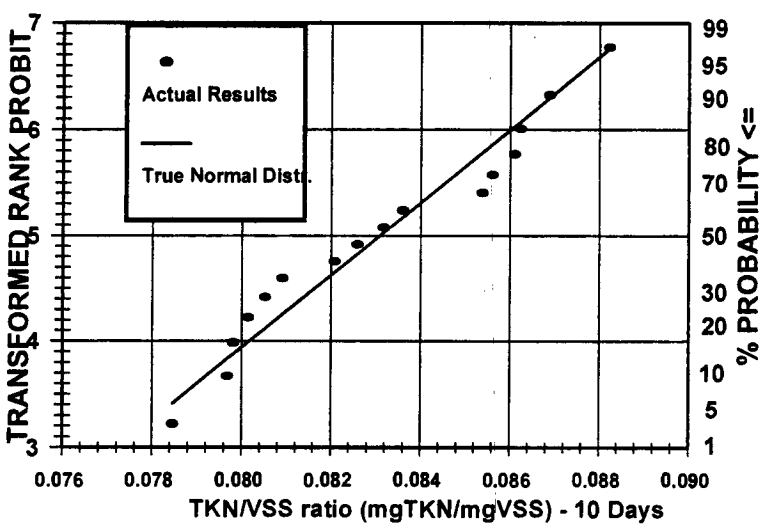


Fig. 3.12 (a): Statistical plot of TKN/VSS ratio for the 10 days sludge age parent laboratory-scalactivated sludge system - rejected outliers omitted.

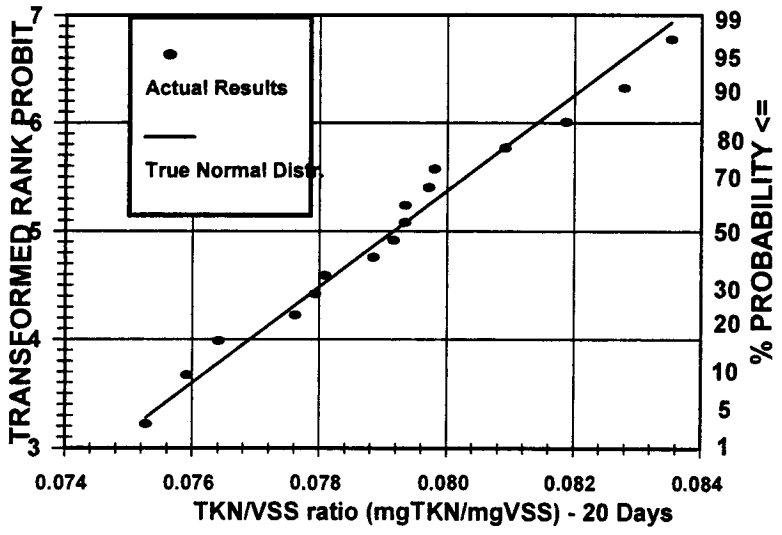


Fig. 3.12 (b): Statistical plot of TKN/VSS ratio for the 20 days sludge age parent laboratory-scale activated sludge system - rejected outliers omitted.

CHAPTER 4

EVALUATION OF THE MODIFIED BATCH TEST PROCEDURE TO QUANTIFY HETEROTROPHIC ACTIVE BIOMASS

4.1 INTRODUCTION

The batch test procedure to quantify the OHO active biomass concentration in mixed liquor drawn from aerobic and anoxic/aerobic activated sludge systems was developed by Ubisi *et al.* (1997a,b). Cronje *et al.* (2000) modified this batch test procedure by flocculating and filtering the wastewater to remove the OHO active biomass present in the raw wastewater itself, thereby simplifying the procedure (see Chapter 2).

With the modified batch test, Cronje *et al.* (2000) and Beeharry *et al.* (2001) measured the OHO active biomass concentration in mixed liquors drawn from a variety of parent activated sludge systems. In some cases, good correlation was found between the theoretical and measured OHO active biomass concentrations; however, in other cases, the correlation was poor. Possible reasons for the variations in agreement were not provided. In this research, the causes for this disagreement, between the measured and theoretical values, were sought and the applicability of the modified batch test was examined.

In identifying possible causes for the disagreement above, the batch test was applied to measure the OHO active biomass concentrations of the parent systems operated at two different sludge ages. This was because Ubisi *et al.* (1997 a, b) and Wentzel *et al.* (1998) had noted a sludge age effect: They applied the batch test method to mixed liquor drawn from laboratory-scale ND activated systems operated at sludge ages of 12 and 20 days respectively. The theoretical OHO active biomass concentrations for the two activated sludge systems were calculated with the current steady state design model (WRC, 1984) and compared to the measured values obtained through the batch test. The comparisons showed that for the 12 day sludge age system, good agreement existed between the measured and theoretical values. For the 20 days sludge age system, however, the values compared poorly, with the theoretical values being approximately 2 times those measured. Thus, to examine this inconsistency, two parallel parent systems of 10 and 20 days sludge age were operated and the modified batch test was conducted on mixed liquor drawn from each system.

In this Chapter, the experimental procedure and interpretation of data obtained from the modified batch test will be described. The results from the various modified batch tests will be presented and interpreted, and general trends in the batch test results will be examined intensively.

4.2 EXPERIMENTAL PROCEDURE

4.2.1 Experimental approach

The application of the modified batch test to quantify the OHO active biomass concentration hinges around the capacity of the OHO organisms to utilize oxygen as final electron acceptor in the process of aerobic degradation of substrate (COD) present in the wastewater. In the aerobic batch test environment, the active organisms present in the mixed liquor sample drawn from the parent system are mixed with *flocculated-filtered* wastewater. In a series of such tests, different volumes of mixed liquor and flocculated-filtered wastewater are mixed, and thus the OHO active biomass is surrounded by different concentrations of substrate in the form of readily biodegradable COD (RBCOD) and slowly biodegradable COD (SBCOD). The wastewater to be added into the batch reactor is preflocculated and filtered, to remove any OHO active biomass present in the wastewater itself.

According to Cronje *et al.* (2000) and Beeharry *et al.* (2001), under the above conditions in the batch test, the OHO organisms are present at low concentrations (low volumes added) and accordingly could be assumed to utilize the substrates at a maximum rate, for the synthesis of new cell mass, with associated consumption of oxygen. Thus, within the framework of current kinetic simulation models (e.g. UCTOLD, Dold *et al.*, 1991; IAWQ ASM No. 1, Henze *et al.*, 1987), with growth/substrate utilization rates at maxima, the oxygen utilization rate (OUR) is independent of the substrate concentration and directly related, *inter alia*, to the OHO active biomass concentration. Through monitoring the OUR for the duration of the batch test, and interpreting the data in terms of the kinetic simulation models, the OUR response can serve as a means to quantify the OHO active biomass concentration present at the start of the test. (That the growth/substrate utilization rates are at maxima in the substrate-rich conditions is an assumption which will be investigated further in Chapter 6.) In analysis of the batch test data, due consideration must be taken of the OUR for nitrification and this must be subtracted from the total OUR to give the OUR for OHOs only. Cronje *et al.* (2000) and Beeharry *et al.* (2001) describe the batch test procedures in detail, but this is repeated below for elucidation purposes.

4.2.2 Wastewater preparation

The preparation of the wastewater for the modified batch test incorporates flocculating and filtering the raw wastewater. Because these processes tend to be time-consuming, the wastewater preparation was performed the day before the batch test was conducted. The raw wastewater was drawn from the storage tanks according to the same procedure described for the parent system feed preparation in Chapter 3. The wastewater was diluted to approximately the same COD concentration (± 750 mgCOD/ℓ) as that fed to the parent system. A sufficient volume of diluted wastewater (± 8ℓ) was measured and placed in a separate bucket which served as the wastewater source for the two separate batch tests to be performed on the next day.

Flocculation / settling

To expedite the filtration process, the diluted wastewater was subjected to flocculation prior to filtration; 10 mℓ of stock aluminium sulphate [Aℓ(SO_4)·15 H_2O, stock at 50g/ℓ] were added per ℓ wastewater, the mixture was stirred rapidly (~200 rpm) for 2 minutes (rapid mix phase) and then slowly (~1 rpm) for 30 minutes (flocculation and settling phase). The flocculation and settling phase was conducted in custom-built settling cylinders of 3ℓ capacity each. The settling cylinders (110 mm dia.) were equipped with magnetic stirring arms regulated to achieve the slow rotational speed of 1 rpm. Enhanced settling was observed when the stirring was discontinued after the 30 minute period and the contents of the cylinder were allowed to settle (without stirring) for a further 30 minute period.

Filtration

The clear supernatant developed in the settling cylinders was drawn off and filtered through a glass fibre filter (Whatman's GF/C). Although filtering through a 0.45μm filter is the accepted requirement to remove almost all the particulate material in the wastewater, this procedure proved to be unduly laborious, considering that ± 8ℓ of wastewater had to be filtered at a time. In any event, with a preflocculation step, using a glass fibre filter met the requirement in that it effectively removed all active biomass from the wastewater - no measurable OUR on the *flocculated-filtered* wastewater only was observed (Cronje *et al.*, 2000).

The *flocculated-filtered* wastewater was stored overnight in the cold room at 4°C. All containers used were thoroughly cleaned with boiling water beforehand to ensure that no contamination occurred.

4.2.3 Filtered wastewater and mixed liquor batch tests

As described above, the modified batch tests were conducted using a mixture of *flocculated-filtered* wastewater and mixed liquor drawn from the parent system. The single batch reactor configuration is illustrated in Fig. 4.1.

After retrieving the stored *flocculated-filtered* wastewater from the cold room, the required volume of wastewater (for example, 2.9ℓ in Fig. 4.1) was carefully measured, preheated to 20°C in a warm water bath and placed in the continually stirred batch reactor maintained at a constant temperature of 20°C. To account for the reduction in pH during the flocculation phase, the pH of the *flocculated-filtered* wastewater was raised to pH ~ 7.8 prior to the commencement of each batch test. This was done by adding the required amount of the sodium bicarbonate ($NaHCO_3$) solution (see Chapter 3, Section 3.4) to the wastewater. The required volume of mixed liquor (0.1ℓ in Fig. 4.1) was harvested from the aerobic reactor of the parent system and added to the *flocculated-filtered* wastewater, giving a combined volume of 3ℓ for the mixture in the batch reactor. The volume of mixed liquor added was varied between 30 mℓ and 600 mℓ for the 10 day sludge age parent system and between 50 mℓ and 660 mℓ for the 20 day sludge age parent system for all the modified batch tests conducted, with the

volume of *flocculated-filtered* wastewater being concomitantly varied from 2.97ℓ to 2.4ℓ and from 2.95ℓ to 2.34ℓ for the 10 and 20 day systems respectively. Immediately after the mixed liquor was added to the *flocculated-filtered* wastewater, a sample was drawn to obtain the initial total COD concentration (Standard Methods, 1985).

The reactor was aerated by passing low pressure air through a small bore Perspex tube termination at the bottom of the reactor, at the end of which was an air-stone (see Fig. 4.1). A dissolved oxygen (DO) probe (YSI) from an automatic DO meter/OUR logger was immersed in the solution. The oxygen supply and OUR response in the batch test was measured using an automated technique (Randall *et al.*, 1991). The DO was raised to ± 5 mgO/ℓ, the air was switched off automatically and the decrease in DO with time was monitored; when the DO reached ± 3 mgO/ℓ, the air was switched on again automatically and the cycle repeated (the exact values for the high and low DO set points were varied depending on the OUR – if the OUR was low, the high and low DO set points were moved closer together and *vise versa*). Automatically, for each cycle the slope of the DO-time data during the air off period was determined by linear regression; this gives the OUR, which was stored by the meter (together with the regression analyses and time data). OUR data with a regression correlation coefficient, $R^2 < 0.95$ were rejected for OUR analysis. A typical OUR (mgO/ℓ/h) versus time (h) response is shown plotted in Fig. 4.3. During the first period of the batch test (<11h) the OUR exhibits an exponential increase due to OHO active biomass growth on both RBCOD and SBCOD added with the wastewater. After ± 11 h the OUR drops precipitously due to the depletion of the wastewater RBCOD, and the subsequent OUR reflects OHO active biomass growth on SBCOD only. Concomitantly, over the entire batch test, there is a OUR due to nitrification. Even though the first period is the important part for subsequent analysis, the batch tests were generally continued for approximately 2 or 3 more hours to identify the second plateau caused by SBCOD after the precipitous drop in OUR was observed. The duration of the batch tests depends on the volume of mixed liquor added into the batch reactor. In general, the duration of the batch tests varied between 6 and 15 hours.

At regular intervals, samples were drawn from the batch reactor, immediately filtered through 0.45 μm filter paper, 2 – 3 drops of $HgCl_2$ were added to the filtrate which was stored for subsequent nitrate and nitrite analysis. At the end of the batch tests, a final sample was drawn from the batch reactor by pipetting, the sample was homogenized in a liquidizer and the final total COD concentration measured. The OUR results were downloaded from the DO meter to a PC.

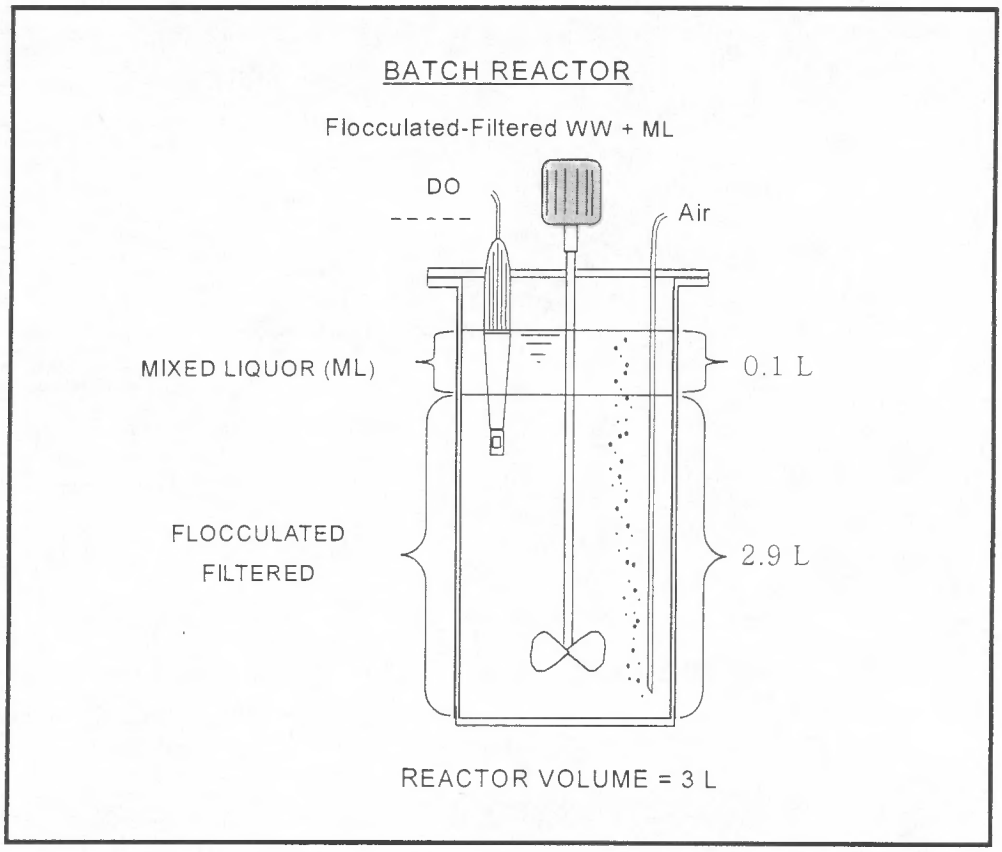


Fig. 4.1: Single batch reactor arrangement used to conduct batch tests with mixed liquor added to flocculated-filtered wastewater.

4.2.4 Experimental cautions for the modified batch test

During the investigation it was found that the air bubble supplied by aeration via the air stone (see Fig. 4.1) must be coarse. For the first set of batch tests, fine bubble aeration was used. This appeared to cause considerable variability in the recorded OUR data, so much so that further analysis of the data was not possible. In examining possible reasons for this variability, it was noted that the fine air bubbles supplied via the aeration device adhered to the solid flocs in the reactor. Thus, these bubbles would still supply oxygen when the aeration is stopped to measure OUR. After the air-stone was changed from a fine one to a coarse one, the variability in the OUR data was largely eliminated (see Fig. 4.2). Also, it was found that the aeration should not be over-vigorous, otherwise the DO probe would not detect the Dissolved Oxygen (DO) concentration in the solution, but rather would detect directly the DO concentration in the bubbles supplied by aeration.

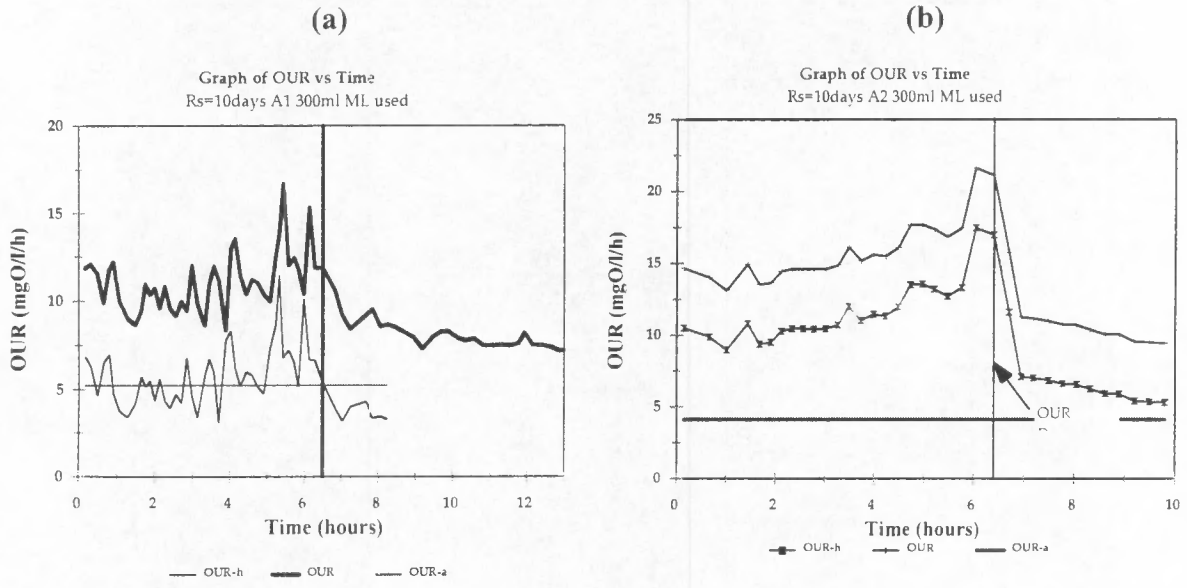


Fig. 4.2: Oxygen Utilization Rate (OUR) response with time for a modified batch tests of Batch Test No. A1 and No. A2 which was done (a) before and (b) after changing the air-stone respectively.

A further problem experienced was that the solids tended to stick onto the wall of the batch reactor: As a result of the intermittent aeration process, particulate matter and organisms were frequently splashed out of solution and deposited on the batch reactor walls, above the water surface. Because these organisms would cease to contribute to the OUR measured in the solution, the walls of the reactor were regularly brushed (during every aeration cycle) to return the organisms back into the solution.

4.3 DATA INTERPRETATION

In this section, the calculation procedures for the modified batch test will be described. Following the procedures set out by Wentzel *et al.* (1995) and Mbewe *et al.* (1995), the batch tests will be analysed to determine:

- COD recovery (%)
- OHO active biomass concentration at the start of the batch test, $Z_{BH(0)}$ (mgCOD/ℓ)

Additionally, if required the maximum specific growth rates as formulated in the UCT model will be determined from the batch test data for growth of OHOs on:

- RBCOD, μ_H (/d), and
- SBCOD, K_{MP} (/d)

Then, to evaluate the measured OHO active biomass concentrations determined in the batch tests, the theoretical values for the parent system from which the mixed liquor was drawn will be calculated. Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) found that the steady state theory (WRC, 1984) and the kinetic simulation models (Dold *et al.*, 1991) for anoxic/aerobic activated sludge systems gave theoretical OHO active biomass concentrations that were in close agreement. Since the steady state theory is simpler and provides a direct analytical solution, this will be used to calculate the theoretical OHO active biomass concentration in the parent system, and compared to the batch test measured concentrations. Below, the data from one batch test (Batch Test No. A35, Sewage Batch No. 17, 10 Days system) will be used as an example to illustrate the calculation procedures, see from Figs. 4.3 to 4.5.

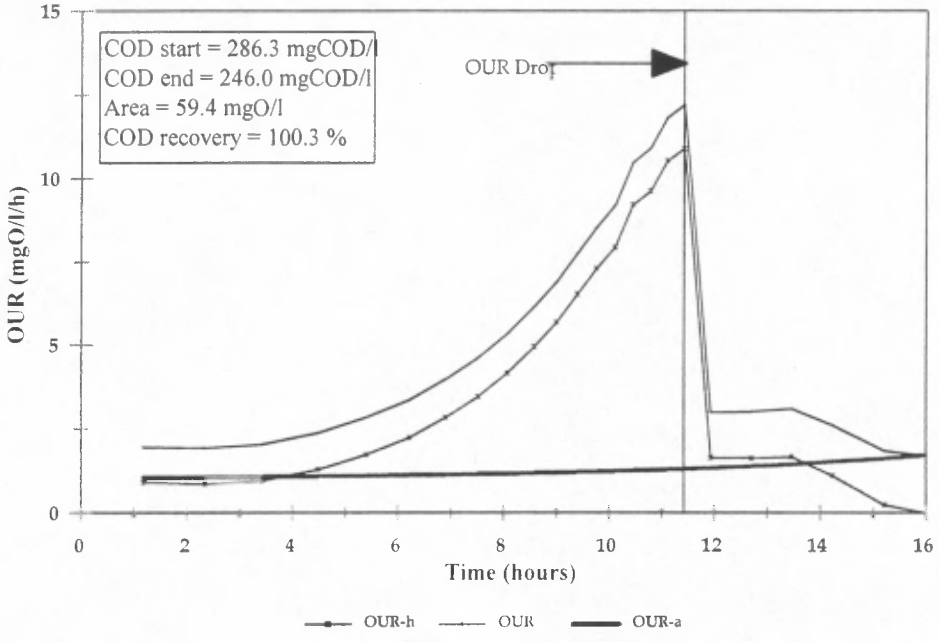


Fig. 4.3: Oxygen Utilization Rate (OUR) response with time for a modified batch test on a mixture of flocculated-filtered wastewater (2.9 ℓ) and mixed liquor (0.1ℓ) drawn from the aerobic reactor of the 10 days sludge age system. Batch Test No. A35, Sewage Batch No. 17.

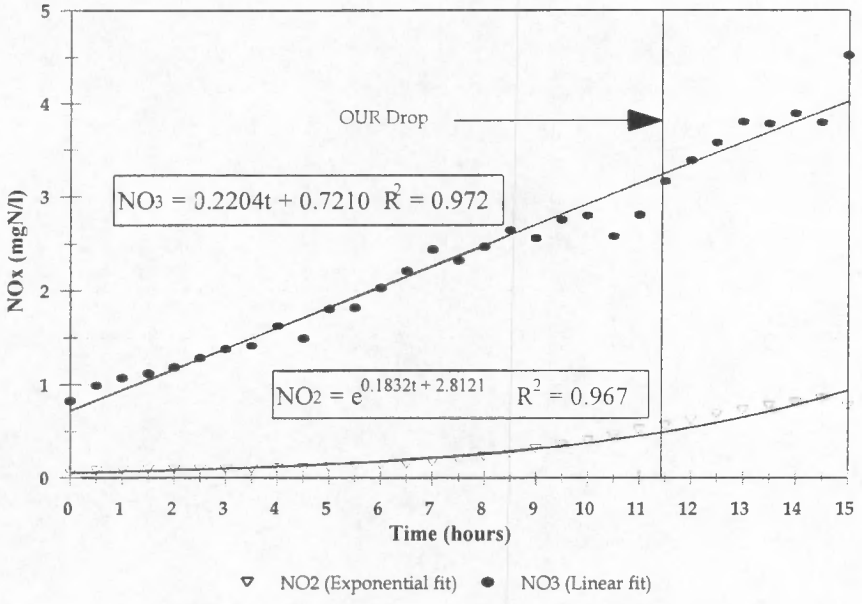


Fig. 4.4 : Nitrate and nitrite concentrations with time for the modified batch test in Fig. 4.3. Also shown are the linear and exponential best fit expressions and correlation coefficients, obtained through regression. The nitrification OUR is shown in Fig. 4.3.

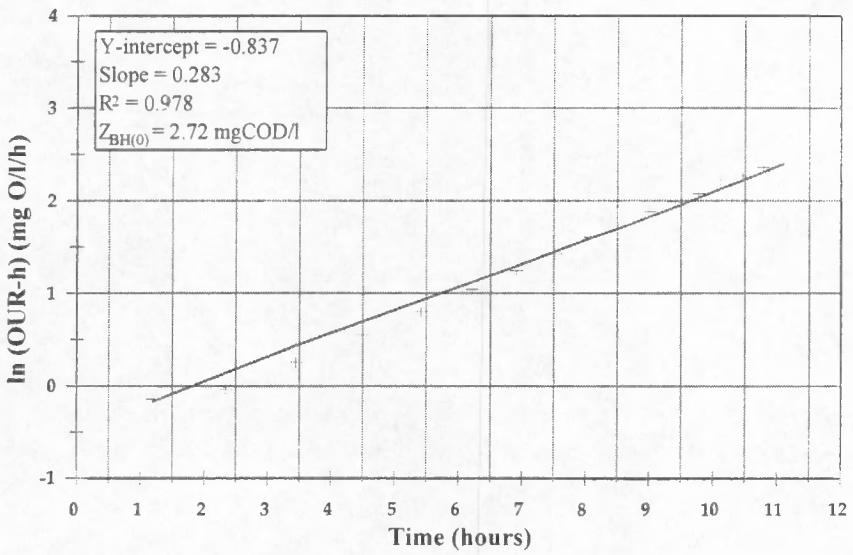


Fig 4.5: ℓn Oxygen Utilization Rate (OUR) due to OHO active biomass (ℓn OUR_H) versus time for the OUR data in Fig. 4.3 up to the precipitous drop OUR. Batch Test No. A35, Sewage Batch No. 17.

4.3.1 Batch test data

4.3.1.1 Separating the OUR into its OHO and nitrification components

In the batch test, mixed liquor is drawn from a nitrifying activated sludge system and thus nitrification can be expected and indeed was observed, see Fig. 4.4. The OUR due to nitrification must be taken into account in deriving estimates for %COD recovery and $Z_{BH(0)}$ since both parameters are determined from the OUR for OHOs only ($OUR_{H(t)}$). This can be done by noting that the measured OUR at any time t ($OUR_{M(t)}$) is made up of the OUR due to OHO growth ($OUR_{H(t)}$) and due to nitrification by autotrophic organisms (AO) ($OUR_{N(t)}$), *i.e.*

$$OUR_{M(t)} = OUR_{H(t)} + OUR_{N(t)} \qquad (mgO/\ell/h) \qquad (4.1)$$

Rearranging Eq. (4.1):

$$OUR_{H(t)} = OUR_{M(t)} - OUR_{N(t)} \qquad (mgO/\ell/h) \qquad (4.2)$$

Accordingly, to determine $OUR_{H(t)}$, an estimate for $OUR_{N(t)}$ is essential. The $OUR_{N(t)}$ can be determined from the nitrite/nitrate concentration – time profile (for example Fig. 4.4). In determining $OUR_{N(t)}$ from the nitrate concentration – time profile, Ubisi *et al.* (1997a,b) noted that for the batch tests, ammonia-N is available in excess and nitrification proceeds at the maximum rate. Further, they noted that since the yield and maximum specific growth rate of the AOs are relatively low, the nitrification rate can be assumed to be constant within the time scale of the batch test. Accepting a constant nitrification rate, the slope of a "best-fit" linear line to the nitrate (mgN/ℓ) time (hour) profile is the constant nitrification rate ($d(NO_3^-)/d\,t$, mgN/ℓ/h), and the $OUR_{N(t)}$ is given by:

$$OUR_{N(t)} = 4.57 \cdot [\, d\,(NO_3^-) / d\,t\,] \qquad (mgO/\ell/h) \qquad (4.3)$$

However, in their evaluation of the batch test method, Cronje *et al.* (2000) proposed that the nitrification rate is not constant, but is better approximated by an exponential fit to the measured NO_3^- concentration - time data, which is verified by the observations of Antoniou *et al.* (1990) and Sözen *et al.* (1996). From such an exponential fit, the nitrification rate can be found at each time interval from the slope of the exponential equation, *i.e.* from the differential of the exponential equation, and the corresponding $OUR_{N(t)}$ can be determined via Eq. (4.3).

Beeharry *et al.*(2001) found that apart from the generation of nitrate with time, a detectable amount of nitrite was also generated in all the batch tests and also found that the nitrate/nitrite concentrations could be best represented by either a linear or an exponential increase. Thus, for their investigation, increases in both the nitrate and nitrite concentrations had to be taken into account when analyzing the results of the batch tests. Also, to select the best type of fit for a particular batch test, they visually checked which of the linear or exponential lines best fitted the data, and confirmed the best-fit line by doing a regression analysis and noting the correlation coefficient. A reasonable correlation coefficient ($R^2 > 0.90$) implies that the selected best-fit line gives a good approximation of the

experimental data. For the various batch tests, both linear and exponential fits were used case by case. Thus, they concluded that selecting the type of fit is not general, but must be based on the data for a particular batch test.

In this investigation, similarly to Beeharry *et al.* (2001) significant nitrite concentrations were observed in the batch tests so that separate nitrite and nitrate nitrification had to be taken into account. To accommodate both nitrite and nitrate nitrification, the following stiochiometry was accepted:

$$NH_4^+ + 3/2\ O_2 \rightarrow NO_2^- + H_2O + 2H^+ \qquad (4.4)$$

$$NO_2^- + 1/2\ O_2 \rightarrow NO_3^- \qquad (4.5)$$

From the stoichiometric equations above, for every 1 mg NH_4^+ - N nitrified to 1 mg NO_2^- - N, 3.43 mg O are required, and for 1 mg NO_2^- - N nitrified to 1 mg NO_3^- - N, 1.14 mg O are required. Thus, for nitrification of NH_4^+ - N to NO_3^- - N, 4.57 mgO/mgN are required.

As mentioned above, in this investigation the nitrate and nitrite concentrations were separated, and "best-fit" lines fitted to the individual profiles, linear or exponential to be evaluated. For the example, in Fig. 4.4, exponential fit and linear fit to nitrite and nitrate concentration - time profiles respectively gave good correlation to the experimental data: From regression analysis of the data in Fig. 4.4,

$$NO_{2(t)} = e^{0.1832\,t\,-\,2.8121} \qquad [R^2 = 0.967] \qquad (mgN/\ell) \qquad (4.6)$$

$$NO_{3(t)} = 0.2204\,t + 0.7210 \qquad [R^2 = 0.972] \qquad (mgN/\ell) \qquad (4.7)$$

Hence, differenting the equations to determine an expression for the appropriate nitrification rate yields for Batch Test No. A35:

$$d(NO_2^-)/dt = 0.1832 \cdot e^{0.1832\,t\,-\,2.8121} \qquad (mgN/\ell/h) \qquad (4.8)$$

$$d(NO_3^-)/dt = 0.2204 \qquad (mgN/\ell/h) \qquad (4.9)$$

From the individual profile fits, the OUR for NO_2^- nitrification (OUR_{NO2}) and NO_3^- nitrification (OUR_{NO3}) could be determined:

$$OUR_{NO2} = 3.43 \cdot [d(NO_2^-)/dt] \qquad (mgO/\ell/h) \qquad (4.10)$$

$$OUR_{NO3} = 4.57 \cdot [d(NO_3^-)/dt] \qquad (mgO/\ell/h) \qquad (4.11)$$

and

$$OUR_N = OUR_{NO2} + OUR_{NO3} \qquad (mgO/\ell/h) \qquad (4.12)$$

For the example here, this gives respectively.

$$OUR_{NO2} = 0.6284 \cdot e^{0.1832\,t\,-\,2.8121} \quad (mgO/\ell/h)$$

$$OUR_{NO3} = 1.0072 \quad (mgO/\ell/h)$$

$$OUR_{N} = 1.0072 + 0.6284 \cdot e^{0.1832\,t\,-\,2.8121} \quad (mgO/\ell/h)$$

These two OURs were subtracted from the measured OUR_M (Fig. 4.3) at each time interval, to give the OUR_H for OHOs only (Fig. 4.3).

4.3.1.2 Derivation of equations for COD recovery

The acceptability of the data from the batch test can be evaluated by doing a COD mass balance, as follows (Wentzel *et al.*, 1995) :

$$\%\ \text{COD recovery} = \frac{COD_{t=T} + \int_{t=0}^{t=T} OUR_{H(t)} \cdot dt}{COD_{t=0}} \cdot 100 \qquad (4.13)$$

where

t	= time (h)
$COD_{t=0}$	= total unfiltered COD concentration at start of test (t = 0) (mgCOD/ℓ).
$COD_{t=T}$	= total unfiltered COD concentration at end of test (t = T) (mgCOD/ℓ).
$OUR_{H(t)}$	= OHO active biomass oxygen utilization rate at time t (mgO/ℓ/h).
$\int_{t=0}^{t=T} OUR_{H(t)} \cdot dt$	= integral (area) under the OHO OUR versus time plot between start and end of test (mgO/ℓ). = oxygen consumed over the test by OHO active biomass.

The integration of the $OUR_{M(t)}$ in the batch test can be calculated directly using an automated technique (Randall *et al.*, 1991). In Eq. (4.2), the OUR due to OHO growth only ($OUR_{H(t)}$) equals the measured total OUR ($OUR_{M(t)}$) minus the OUR due to nitrification ($OUR_{N(t)}$), see Section 4.3.1.1 above. The $OUR_{N(t)}$ is made up of the nitrate and nitrite nitrification OURs (OUR_{NO3} and OUR_{NO2} respectively). Thus, the integration of the $OUR_{H(t)}$ can be calculated as follows;

$$\int_{t=0}^{t=T} OUR_{H(t)} \cdot dt = \int_{t=0}^{t=T} OUR_{M(t)} \cdot dt - \int_{t=0}^{t=T} OUR_{NO3(t)} \cdot dt - \int_{t=0}^{t=T} OUR_{NO2(t)} \cdot dt \qquad (4.14)$$

Using the data in Figs. 4.3 and 4.4 as an example, $COD_{t=0}$ = 286.27 mgCOD/ℓ ; $COD_{t=T}$ = 245.95 mgCOD/ℓ ; T (time when the last sample is taken) = 15 hr; and the expressions developed above for OUR_{NO2} and OUR_{NO3}:

$$\int_{t=0}^{t=T} OUR_{M(t)} \cdot dt = 59.4 \text{ mgO/ℓ}$$

$$\int_{t=0}^{t=T} OUR_{NO3(t)} \cdot dt = \int_{t=0}^{t=T} 1.0072 \cdot dt = 1.0072 \cdot T = 15.11 \text{ mgO/ℓ}$$

$$\int_{t=0}^{t=T} OUR_{NO2(t)} \cdot dt = \int_{t=0}^{t=T} 0.6284 \cdot \exp(0.1832 \cdot t - 2.8121) \cdot dt$$

$$= 3.43 \cdot (e^{0.1832 \cdot T - 2.8121} - e^{-2.8121}) = 3.01 \text{ mgO/ℓ}$$

$$\int_{t=0}^{t=T} OUR_{H(t)} \cdot dt = 59.4 - 3.01 - 15.11 = 41.28 \text{ mgO/ℓ}$$

$$\% \text{ COD recovery} = \frac{245.95 + 41.28}{286.27} \cdot 100 = 100.3 \%$$

COD recoveries between 90 – 110% indicate that the test results are acceptable.

Table 4.1: Matrix representation of the UCT model (Dold *et al.*, 1991), simplified for conditions present in the batch test.

COMPOUND i → / j ↓ PROCESS	1 Z_{BH}	2 Z_E	3 Z_I	4 S_{ads}	5 S_{enm}	6 S_{bs}	7 S_{us}	8 O	PROCESS RATE, ρ_j
1 Aerobic growth of Z_{BH} on S_{bs}	1					$-1/Y_{ZH}$		$\frac{1-Y_{ZH}}{Y_{ZH}}$	$\mu_H \left[\frac{S_{bs}}{K_{SH}+S_{bs}}\right] Z_{BH}$
2 Acrobic growth of Z_{BH} on S_{ads}	1			$-1/Y_{ZH}$				$\frac{1-Y_{ZH}}{Y_{ZH}}$	$K_{MP} \left[\frac{(S_{ads}/Z_{BH})}{K_{SP}+(S_{ads}/Z_{bh})}\right] Z_{BH}$
3 Death of Z_{BH}	-1	f_E			$1-f_E$				$b_H Z_{BH}$
4 Adsorption of S_{enm}				1	-1				$K_A S_{enm} Z_{BH} (f_{MA} - S_{ads}/Z_{BH})$
Stoichiometric constants Y_{ZH} = Heterotroph yield f_E = Endogenous residue f_{MA} = Max. ratio S_{ads}/Z_{BH}	Biological (active) heterotrophic mass M (COD) L^{-3}	Endogenous mass M (COD) L^{-3}	Inert mass M (COD) L^{-3}	Adsorbed slowly biodegradable substrate M (COD) L^{-3}	Enmeshed slowly biodegradable substrate M (COD) L^{-3}	Readily biodegradable (soluble) substrate M (COD) L^{-3}	Unbiodegradable soluble substrate M (COD) L^{-3}	Oxygen M (-COD) L^{-3}	Kinetic constants μ_H = Heterotroph max. specific growth rate on S_{bs} K_{SH} = Heterotroph 1/2 saturation on S_{bs} K_{MP} = Heterotroph max. specific growth rate on S_{ads} K_{SP} = Heterotroph 1/2 sat. on S_{ads} b_H = Heterotroph specific death rate K_A = S_{enm} specific adsorption rate

4.3.1.3 Derivation of equations for OHO active biomass concentration, $Z_{BH(0)}$

The simplified UCT model to describe the processes in the batch tests presented in Table 1 of Wentzel *et al.* (1995) is duplicated in Table 4.1. From the simplified UCT model, the rate of growth of OHO active biomass (dZ_{BH}/dt) is given by:

dZ_{BH}/dt = growth on RBCOD + growth on SBCOD - death

$$\frac{dZ_{BH}}{dt} = \mu_{HT}\frac{S_{bs}}{K_{SH}+S_{bs}}\cdot Z_{BH} + K_{MPT}\frac{S_{ads}/Z_{BH}}{K_{SP}+S_{ads}/Z_{BH}}\cdot Z_{BH} - b_{HT}\cdot Z_{BH} \qquad (4.15)$$

where

Z_{BH}	=	OHO active biomass concentration (mgCOD/ℓ)
μ_{HT} *	=	maximum specific growth rate of OHO on RBCOD at temperature T (/d)
S_{bs}	=	RBCOD concentration (mgCOD/ℓ)
K_{SH}	=	half saturation constant for RBCOD
	=	5 mgCOD/ℓ
K_{MPT} *	=	maximum specific growth rate of OHO on SBCOD at temperature T (/d)
S_{ads}	=	adsorbed SBCOD concentration (mgCOD/ℓ)
K_{SP}	=	half saturation constant for SBCOD
	=	0.027 mgCOD/mgCOD
b_{HT} *	=	OHO specific death rate at temperature T (/d)

* *μ_{HT}, K_{MPT} and b_{HT} are temperature dependent.*

It can be accepted that during the initial stages of the batch test (before RBCOD is depleted and the OUR drops precipitously) $S_{bs} >> K_{SH}$ and $S_{ads} / Z_{BH} >> K_{SP}$, and therefore,

$$\frac{dZ_{BH}}{dt} = (\mu_{HT} + K_{MPT} - b_{HT})\cdot Z_{BH} \qquad (4.16)$$

Integrating Eq (4.16) and solving yields the OHO active biomass concentration at time t [$Z_{BH(t)}$, mgCOD/ℓ] in terms of the initial OHO active biomass concentration [$Z_{BH(0)}$, mgCOD/ℓ], time (t, in h) and the net specific growth rate ($\mu_{HT} + K_{MPT} - b_{HT}$) viz;

$$Z_{BH(t)} = Z_{BH(0)}\, e^{(\mu_{HT}+K_{MPT}-b_{HT})t/24} \qquad (4.17)$$

The OUR at time t ($OUR_{(t)}$, mgO/ℓ) is a function of $Z_{BH(t)}$, the net specific growth rate and OHO yield coefficient, Y_{ZH} = 0.666 mgCOD/mgCOD:

$$OUR_{(t)} = \frac{1-Y_{ZH}}{Y_{ZH}} (\mu_{HT} + K_{MPT}) Z_{BH(t)}/24 \quad (4.18)$$

Substituting Eq. (4.17) for $Z_{BH(t)}$ in Eq. (4.18) and taking natural logs yields

$$\ell nOUR_{(t)} = \ell n\left[\frac{1-Y_{ZH}}{Y_{ZH}} (\mu_{HT} + K_{MPT}) Z_{BH(0)}/24\right] + (\mu_{HT} + K_{MPT} - b_{HT})t/24 \quad (4.19)$$

which is a straight line with,

$$\text{slope} = (\mu_H + K_{MP} - b_H)/24 \quad (4.20)$$

$$\text{y-intercept} = \ell nOUR_{(t=0)} = \ell n\left[\frac{1-Y_{ZH}}{Y_{ZH}} (\mu_{HT} + K_{MPT}) Z_{BH(0)}/24\right] \quad (4.21)$$

To determine the OHO active biomass concentration at the start of the batch test ($Z_{BH(0)}$), the OHO active biomass OUR (OUR_H) values for the data up to the precipitous drop in OUR were plotted as ℓn (OUR_H) versus time (for the example, the ℓn (OUR_H) from the data from Fig. 4.3 are plotted in Fig. 4.5), and linear regression applied to determine the y-intercept, slope and correlation coefficient. For the example, these are listed in Table 4.2. From the slopes and y-intercepts, Eqs. (4.20) and (4.21) respectively, $Z_{BH(0)}$ can be determined from (Wentzel *et al.*, 1995):

$$Z_{BH(0)} = \frac{e^{\text{y-intercept}} \cdot 24}{\frac{1-Y_{ZH}}{Y_{ZH}} \cdot (\text{slope} \cdot 24 + b_{HT})} \quad (4.22)$$

where

$Z_{BH(0)}$ = OHO active biomass concentration at the start of the batch test (mgCOD/ℓ batch reactor)

Y_{ZH} = OHO active biomass yield, COD units (mgCOD/mgCOD)
= 0.666 mgCOD/mgCOD (Dold *et al.*, 1980, 1991; Wentzel *et al.*, 1995)

b_{HT} = OHO specific death rate at temperature T (/d)
= b_{H20} $1.029^{(T-20)}$

b_{H20} = heterotrophic specific death rate at 20°C
= 0.62/d (death/regeneration theory, Dold *et al.*, 1980; Wentzel *et al.*, 1995).

Note that in Eq. (4.15) for the batch tests, the death regeneration theory (Dold *et al.*, 1980) is used (with $b_{H20} = 0.62$/d), whereas in the Eq. (4.27) below for the steady state system, the endogenous respiration theory (Dold *et al.*, 1980; WRC, 1984) is used (with $b_{H20}^{*} = 0.24$/d). In the death regeneration theory, the OHO active biomass dies at a certain rate; of the biomass lost, the biodegradable portion adds to the slowly biodegradable COD which passes through the various stages to be utilized for OHO active biomass synthesis with associated oxygen utilization [*i.e.* the oxygen demand arises, in fact, from the energy requirements for resynthesis of OHO active biomass (regeneration) from the slowly biodegradable substrate liberated from organism death]; the unbiodegradable portion adds to the endogenous residue. In the endogenous respiration theory, the OHO active biomass dies at a certain rate; of the biomass lost, the biodegradable portion gives rise *directly* to oxygen utilization (there is no slowly biodegradable substrate intermediate) and the unbiodegradable portion adds to endogenous residue. For the steady state parent system where all the biodegradable COD has been depleted, with the appropriate selection of constants the two approaches give the same nett result, *i.e.* same loss of OHO active biomass, utilization of oxygen and generation of endogenous residue (Dold *et al.*, 1980). However, the endogenous respiration approach allows a simple analytical procedure to be developed to provide a solution for the steady state system (WRC, 1984); accordingly, the endogenous respiration approach is followed here for the steady state parent system. For the batch tests, the conditions are transient (*e.g.* the wastewater biodegradable COD has not been depleted, and is utilized over the course of the batch tests). Thus, to interpret the batch test results, a full kinetic model should be used (*e.g.* UCTOLD, Dold *et al.*, 1991). In the kinetic models the death regeneration approach has been adopted (for reasons see Dold *et al.*, 1980), and thus this approach is followed here for analysis of the batch tests. However, the endogenous respiration theory can be used to derive an equation that is numerically identical to Eq. (4.15). Thus, the choice of using the death regeneration theory over the endogenous respiration theory does not influence the results.

Accepting Eq. (4.22) and substituting into the equation the regression data listed in Table 4.2 for the example batch test, the value for $Z_{BH(0)}$ for Batch Test No. A35 is calculated and is shown in Table 4.2 as a COD concentration.

Table 4.2: Batch Test No. A35: COD recovery, regression data from $\ell n(OUR_H)$ versus time plot and measured/theoretical OHO active biomass at the start of the batch test [$Z_{BH(0)}$].

BATCH TEST : FLOCCULATED-FILTERED WASTEWATER (WW) AND MIXED LIQUOR (ML)										
Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		COD Recov. (%)	Regression			ZBH(0)	
			WW	ML		Y-int	Slope	R2	mgCOD/l	
									Measured	Theoretical
17	A35	24 04	2.9	0.1	100.3	-0.8368	0.283	0.978	2.7	47.6

4.3.1.4 Derivation of equations for maximum specific growth rates

From the analysis of an $OUR_{H(t)}$ (mgO/ℓ/h) versus time (h) response obtained in the batch test, valuable information pertaining to the OHO active biomass growth rates can also be determined. Wentzel *et al.* (1995) and Mbewe *et al.* (1995) concluded that the $OUR_{H(t)}$ before the precipitous drop could be separated into the OUR contribution due to RBCOD degradation and the OUR contribution due to SBCOD degradation (see Fig. 4.3). This is equivalent to separating the overall growth rate ($\mu_{HT} + K_{MPT}$) into its μ_{HT} and K_{MPT} components. The derived equation for K_{MPT} - OHO maximum specific growth rate on SBCOD and μ_{HT} - OHO maximum specific growth rate on RBCOD will be repeated here to illustrate the calculation procedures.

In terms of the UCT model, growth of OHO active biomass on RBCOD and SBCOD is independent and concomitant (see Table 4.1). The OUR's (mgO/ℓ/h) associated with these two growth processes are given by Eq. (4.15), which can be separated to give:

$$(1)\quad OUR_{RBCOD(t)} \cdot 24 = \frac{1-Y_{ZH}}{Y_{ZH}} \cdot \mu_{HT} \cdot Z_{BH(0)} \cdot e^{(\mu_{HT} + K_{MPT} - b_{HT})t/24} \qquad (4.23)$$

$$(2)\quad OUR_{SBCOD(t)} \cdot 24 = \frac{1-Y_{ZH}}{Y_{ZH}} \cdot K_{MPT} \cdot Z_{BH(0)} e^{(\mu_{HT} + K_{MPT} - b_{HT})t/24} \qquad (4.24)$$

Heterotroph maximum specific growth rate on SBCOD, K_{MPT}

Up to the precipitous decrease, the OUR is the sum of the OURs associated with the RBCOD and SBCOD utilization [Eq. (4.23) + Eq. (4.24)]. Once the RBCOD is depleted, which causes the precipitous OUR decrease, the OUR is that for SBCOD only [Eq. (4.24)]. If the precipitous decrease occurs at t=s hours at which time the OUR is $OUR_{SBCOD(t)}$, then from Eq. (4.24) K_{MPT} is given by:

$$K_{MPT} = \frac{OUR_{SBCOD(t=s)} \cdot 24}{\frac{1-Y_{ZH}}{Y_{ZH}} \cdot Z_{BH(0)}\ e^{(\mu_{HT} + K_{MPT} - b_{HT}) \cdot (t=s)/24}} \qquad (4.25)$$

where

$OUR_{SBCOD(t=s)}$	=	OUR due to SBCOD only, *i.e.* observed OUR immediately following the precipitous drop in OUR (mgO/ℓ/h).
(t=s)	=	time immediately following the precipitous drop in OUR (h)
$(\mu_{HT}+K_{MPT}-b_{HT})/24$	=	slope of ℓn $OUR_{(t)}$ versus time (h) plot.
T	=	Temperature (°C)

Using the data from Figs. 4.3 and 4.5 as an example, time s = 11.4h; $OUR_{SBCOD(t=11.4h)}$ = 1.656 mgO/ℓ/h; slope of ℓn $OUR_{(t)}$ vs time plot = 0.283 (Fig. 4.5); $Z_{BH(0)}$ = 2.72 mgCOD/ℓ; T = 20°C:

$$K_{MP20} = \frac{1.656 \cdot 24}{\frac{1-0.666}{0.666} \cdot 2.72 \cdot e^{0.283 \cdot 11.45}} = 1.15/d$$

Heterotroph maximum specific growth rate on RBCOD, μ_{HT}

For the UCT model, the value for μ_{HT} can be calculated from the value for K_{MPT} derived above and the slope of the ℓn OUR versus time plot, as follows

$$\mu_{HT} = Slope \cdot 24 - K_{MPT} + b_{HT} \qquad (4.26)$$

For the example above,

$$\mu_{H20} = 0.283 \cdot 24 - 1.15 + 0.62 = 6.262/d$$

4.3.2 Theoretical OHO active biomass concentration in the parent system

To evaluate the measured OHO active biomass concentrations determined in the batch tests, these will be compared with the theoretical values for the parent system from which the mixed liquor is drawn. Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) found that the steady state theory (WRC, 1984) and the kinetic simulation models (Dold *et al.*, 1991) for anoxic/aerobic activated sludge systems gave theoretical OHO active biomass concentrations that were in close agreement. Since the steady state theory is simpler and provides a direct analytical solution, this will be used to calculate the theoretical OHO active biomass concentration in the parent system, and added to the batch test. This calculation procedure is summarized below.

From WRC (1984), the OHO active biomass fraction of the mixed liquor volatile suspended solids (VSS) (f_{av}) can be determined from:

$$f_{av} = MX_{BH}/MX_V$$

$$= MX_{BH}/(MX_{BH} + MX_E + MX_I + MX_{BA}) \qquad (4.26)$$

where

MX_V = mass of volatile suspended solids = $V \cdot X_V$, VSS units (mg VSS)
MX_{BH} = mass of OHO active biomass = $V \cdot X_{BH}$, VSS units (mgVSS)
MX_E = mass of endogenous material = $V \cdot X_E$, VSS units (mgVSS)
MX_I = mass of inert material = $V \cdot X_I$, VSS units (mgVSS)
MX_{BA} = mass of AO active biomass = $V \cdot X_{BA}$, VSS units (mgVSS)
V = system volume (ℓ)
X_{BH} = OHO active biomass concentration, VSS units (mgVSS/ℓ)
X_E = endogenous material concentration, VSS units (mgVSS/ℓ)
X_I = inert material concentration, VSS units (mgVSS/ℓ)
X_V = volatile suspended solids concentration, VSS units (mg VSS/ℓ)

In Eq. (4.26), for activated sludge systems receiving "normal" municipal wastewaters (influent TKN/COD ratio < 0.12 mgN/mgCOD) the AO active biomass (MX_{BA}) component of the mixed liquor organic suspended solids is very small compared to the other three components (< 2% of the total for the parent system here). Thus, with very little error, the AO active biomass can be neglected when calculating the mixed liquor VSS. Accordingly, from WRC (1984), substituting in Eq. (4.26) for $MX_{BA} = 0$ and $MX_V = (MX_{BH} + MX_E + MX_I)$:

$$\frac{1}{f_{av}} = 1 + f_E^* b_{HT}^* R_S + \frac{f_{S,up}(1 + b_{HT}^* R_S)}{f_{cv} Y_H^* (1 - f_{S,us} - f_{S,up})} \qquad (4.27)$$

where

f_E^* = fraction of OHO active biomass that is endogenous residue
= 0.2 (endogenous respiration theory, Dold *et al.*, 1980).
b_{HT}^* = specific endogenous mass loss rate at temperature T (/d)
= $b_{H20}^* 1.029^{(T-20)}$
b_{H20}^* = specific endogenous mass loss rate at 20ºC
= 0.24/d at 20ºC (endogenous respiration theory, Dold *et al.*, 1980)
R_S = system sludge age (d)
= 10d or 20d
$f_{S,up}$ = fraction of influent substrate that is unbiodegradable particulate
$f_{S,us}$ = fraction of influent substrate that is unbiodegradable soluble
f_{cv} = COD to VSS ratio of mixed liquor organic suspended solids (mgCOD/mgVSS)
Y_H^* = OHO active biomass yield, VSS units (mgVSS/mgCOD)
= 0.45 mgVSS/mgCOD (WRC, 1984)

Accepting each sewage batch as a steady state period, values for $f_{S,us}$ and $f_{S,up}$ have been determined for both the *10 days* (Table 3.5) and *20 days* (Table 3.7) sludge age parent systems. Also, f_{cv} values were measured and averaged for each sewage batch (Tables 3.5 and 3.7). Hence, values for f_{av} for each sewage batch could be calculated using Eq. (4.27). For the example Sewage Batch No. 17, for the *10 days* parent system Rs = 10d, $f_{S,us} = 0.0474$, $f_{S,up} = 0.1515$, $f_{cv} = 1.39$ and T = 20°C (Table 4.4). Substituting these values in Eq. (4.27) gives $f_{av} = 0.399$.

Now, knowing f_{av} and the concentration of the mixed liquor VSS that was drawn from the aerobic reactor of the parent system [X_V(PS)] to be added to the batch tests (available from the steady state VSS concentration of the aerobic reactor, measured in the parent system and averaged for each sewage batch; Table 3.4 and 3.6 for 10 and 20 day systems respectively), the *theoretical* OHO active biomass concentration in the batch reactor due to the added mixed liquor [$X_{BH(0)}(\text{Theo.})_{BT}$, COD units] is given by:

$$Z_{BH(0)}(\text{Theo.})_{BT} = [X_V(PS) \cdot f_{av} \cdot f_{cv} \cdot V_{ML}] / (V_{ML}+V_{WW}) \qquad (4.28)$$

where

$Z_{BH(0)}(\text{Theo.})_{BT}$ = theoretical OHO active biomass concentration in batch test reactor due to added mixed liquor, COD units (mgCOD/ℓ batch reactor)

X_V(PS) = mixed liquor VSS concentration measured in the aerobic reactor of the parent system, from Table 3.4 and 3.6 for 10 and 20 day systems respectively (mgVSS/ℓ)

V_{ML} = volume of mixed liquor from parent system added to batch test (ℓ)

V_{WW} = volume of wastewater added to batch test (ℓ).

As an illustration, for Batch Test No. A35 conducted with Sewage Batch No.17 the *theoretical* OHO active biomass concentration in the batch reactor due to the addition of the mixed liquor sample drawn from the parent system was calculated as follows:

The average VSS concentration for the *10 day* sludge age parent system during Sewage Batch No. 17 is X_V(PS) = 2570.7 mgVSS/ℓ [Table A1 and A2, Appendix A for 10 and 20 day systems respectively]. For Sewage Batch No. 17, $f_{av} = 0.399$ from above; f_{cv} for this sewage batch = 1.39 mgCOD/mgVSS and the volumes used in Batch Test No. A35, $V_{ML} = 0.1$ℓ ; $V_{WW} = 2.9$ℓ. Substituting these values into Eq. (4.28):

$$Z_{BH}(\text{theor})_{BT} = \frac{(2570.7 \cdot 0.399 \cdot 1.39 \cdot 0.1)}{(0.1 + 2.9)} = 47.5 \text{ mgCOD/ℓ}$$

Note that in Eq. (4.28) the parent system mixed liquor organic suspended solids are expressed in VSS units [X_V(PS)], whereas the OHO active biomass is expressed in COD units. This is done because conventionally the mixed liquor organic suspended solids in activated sludge systems are measured via the VSS test, whereas the kinetic model used to develop the batch test are in terms of the COD parameter. However, the two units of measure are directly related through the COD/VSS ratio of the mixed liquor organic suspended solids (f_{cv}), which was available from direct measurements.

4.4 RESULTS FOR THE 10DAYS SLUDGE AGE MLE ACTIVATED SLUDGE SYSTEM

This section deals with the interpretation of the results calculated for both the parent system and the batch test analysis. Also, a comparison between the theoretical OHO active biomass concentration in the parent system [$Z_{BH(0)}$(Theo.)] and the OHO active biomass concentration measured at the start of batch tests [$Z_{BH(0)}$(Meas.)] will be describe. The calculation procedures for both analyses were as set out in detail in Sections 4.3.1 and 4.3.2 above.

The parent laboratory-scale nitrification/denitrification system was operated at 10 days sludge age and was continually monitored; the sewage was fed to the parent system in batches which lasted for approximately 2 weeks and each sewage batch constituted a steady state period. A total of 35 batch tests were conducted using mixed liquor drawn from the 10 days MLE activated sludge system.

4.4.1 Parent system data

As described in Chapter 3, the sewage that was fed to the parent system was changed every ±2 weeks to prevent degradation under storage and to minimize changes in the nature of the wastewater. Although the intention was to keep the wastewater feed as consistent as possible throughout the investigation period, invariably the wastewater characteristics changed for each sewage batch. Each sewage batch therefore constituted a steady state period during which the characteristics of the sewage batch governed the parent system behaviour. For this reason, the approach adopted was to analyze each sewage batch separately to determine the various parent system parameters, as set out in Chapters 3. During 10 out of a total of 17 sewage batches, modified batch tests were conducted. For these sewage batches the various parent system parameters and the averaged data (from Table 3.4 (a) and (b), Chapter 3) are listed in Table 4.3.

Table 4.3: Steady state results for 10 days sludge age parent laboratory-scale anoxic/aerobic activated sludge system for those sewage (Sew.) batches during which batch tests were performed. Averages are listed with sample standard deviations in the second row (Inf. = influent, Eff = effluent, ML = mixed liquor, AX = anoxic and AE = aerobic).

10DAY SLUDGE AGE PARENT ANOXIC/AEROBIC STEADY STATE SYSTEM													
Sew. Batch No.	No. of tests	TKN (mgN/l)			NITRATE (mgN/l)			COD (mgN/l)			OUR (mgO/l/h)	VSS (mgVSS/l)	pH
		Inf	Eff	ML	AX	AE	Eff	Inf	Eff	ML			
5	3	85.1	3.6	292.6	5.76	30.0	27.0	706.7	30.7	4626.7	55.7	3360.1	7.72
	(SSD)	1.3	0.7	15.9	1.01	2.8	1.6	28.5	5.7	66.0	0.0	68.3	0.08
7	7	83.2	4.8	271.9	0.08	19.9	13.4	760.2	34.7	4632.8	60.2	3325.0	7.68
	(SSD)	3.2	1.1	6.0	0.07	2.9	0.4	63.2	18.3	129.5	3.8	75.5	0.19
8	3	59.7	4.2	289.3	0.12	15.4	4.2	677.3	17.6	4897.1	51.2	3468.7	7.69
	(SSD)	2.0	0.7	10.9	0.02	0.5	0.8	27.8	8.5	315.2	2.8	142.9	0.06
9	6	66.5	5.4	264.6	0.05	11.5	13.3	686.7	49.2	4330.6	60.6	3291.0	7.74
	(SSD)	1.6	1.1	20.4	0.03	1.1	0.7	22.8	15.9	252.0	6.6	127.1	0.02
10	8	60.8	4.5	235.3	0.00	13.6	6.3	749.4	42.8	4251.6	52.0	3131.7	7.75
	(SSD)	2.3	0.8	19.2	0.00	1.1	0.9	40.1	11.2	225.0	3.9	205.1	0.11
11	9	61.8	4.5	258.9	0.00	12.5	13.7	733.8	44.8	4733.1	57.2	3461.6	7.74
	(SSD)	1.3	0.6	9.0	0.00	0.7	0.9	22.3	7.3	160.1	4.2	121.9	0.07
12	8	83.4	4.8	270.3	0.13	18.8	20.3	749.4	51.4	4711.6	67.8	3520.6	7.67
	(SSD)	2.2	0.5	7.7	0.34	1.3	3.4	26.1	5.6	188.6	6.1	173.0	0.04
13	3	65.1	4.2	270.2	0.00	14.4	8.4	762.5	36.6	4364.6	48.6	3195.1	7.74
	(SSD)	0.6	0.3	6.6	0.00	0.2	1.7	11.8	1.9	216.4	7.6	165.9	0.03
14	9	59.2	4.0	203.8	0.00	11.5	12.6	727.2	37.5	3482.0	44.8	2532.2	7.77
	(SSD)	1.7	0.5	7.2	0.00	0.8	0.4	23.2	4.3	72.5	3.2	62.2	0.04
17	8	61.7	4.2	203.1	0.03	12.8	13.8	772.6	38.1	3615.5	43.9	2632.3	7.92
	(SSD)	1.6	0.3	7.3	0.07	0.9	0.7	13.0	4.7	96.7	1.0	100.6	0.06

In accordance with the steady state design (and kinetic simulation) theory, the OHO active biomass performs an integral role in the behaviour of the activated sludge system. The theoretical mass of OHO active organisms would invariably fluctuate as the wastewater characteristics change from one sewage batch to the next. As the OHO active biomass forms the focal point of this investigation, it was imperative to monitor these variations in key system parameters between sewage batches. To formulate a theoretical estimate for the OHO active biomass concentration present in the parent system during each sewage batch period, the following were determined from the data in Table 4.2:

- Influent wastewater unbiodegradable soluble and particulate COD fractions ($f_{S,us}$ and $f_{S,up}$ respectively); system COD and N mass balances (Ekama *et al.* 1986) and the COD and TKN to VSS ratios for the mixed liquor (f_{CV} and f_N respectively). The calculation procedures are set out in detail in Chapter 3 and the results for each sewage batch during which modified batch tests were conducted are listed in Table 4.4.

- The OHO active biomass fractions of the mixed liquor organic suspended solids (f_{av}) were determined for each sewage batch using the steady state design model [Eq. (4.27)]. As noted above Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) applied both the steady state design model and the UCTOLD kinetic simulation computer programme to determine the OHO active biomass fraction (f_{av}) and found that reasonably close agreement was obtained between the steady state and kinetically simulated predictions (average difference = 2.2%). Thus due to its simpler and more direct calculation procedure, in this investigation the steady state design model the OHO active biomass fractions (f_{av}) were used.

Table 4.4: Steady state COD and N mass balances, wastewater fractions and mixed liquor parameters for the 10 days sludge age parent laboratory-scale anoxic/aerobic activated sludge system. Data calculated from data in Table 4.3 using the steady state (SS) design model (WRC, 1984).

10 DAYS SLUDGE AGE PARENT ANOXIC/AEROBIC STEADY STATE SYSTEM								
Sew. Batch No.	No. of Test	MASS BALANCE (%)		WASTEWATER FRACTIONS		MIXED LIQUOR		
		N	COD	Unbio. Soluble COD (fs,us)	Unbio. Particulate COD (fs,up)	COD/VSS ratio (fcv)	TKN/VSS ratio (fN)	Active Fraction (fav)
5**	3	98	89	0.0387	0.1703	1.37	0.088	0.375
7	7	99	97	0.0382	0.1345	1.42	0.085	0.427
8	3	112	103	0.0060	0.2147	1.45	0.087	0.343
9	6	91	113	0.0390	0.1756	1.38	0.086	0.370
10	8	97	92	0.0488	0.1113	1.38	0.078	0.454
11	9	96	104	0.0513	0.1794	1.42	0.080	0.368
12	8	94	110	0.0487	0.1717	1.40	0.082	0.374
13**	3	99	85	0.0454	0.1083	1.35	0.086	0.456
14	9	95	107	0.0482	0.1625	1.39	0.084	0.385
17	8	97	99	0.0474	0.1515	1.39	0.081	0.399

* Shaded blocks rejected as outliers

** Rejected on COD and N mass balances

From the analysis of the N mass balances (Chapter3), sewage batches which yielded mass balances outside the 90% – 110% range should be rejected for further analysis; this was Sewage Batch No. 8. From the analysis of the COD mass balances, Sewage Batch Nos. 5, 9 and 13 were outside the 90% - 110% range and should be rejected for further analysis. The specific causes for the poor N and COD mass balances for these sewage batches were discussed in Chapter 3. There it was noted that Sewage Batch Nos. 8 and 9 should be retained for further analysis and Sewage Batch Nos. 5 and 13 rejected.

Thus, batch tests were conducted on the accepted Sewage Batch Nos. 7, 8, 9, 10, 11, 12, 14 & 17 and were conducted on the rejected Sewage Batch Nos. 5 and 13. The batch test data collected on these rejected sewage batches will be included where appropriate, and will be analyzed, but it will be noted that the data should be rejected and the data will not be used to draw conclusions. This will be done to determine the influence of poor mass balances on the test and analytical procedures.

4.4.2 Batch test data

For the batch tests, measured OUR, NO_3 and NO_2 – time data are shown graphically in Appendix A. Following the procedures set out in Section 4.3.1 above, the OHO active biomass concentrations measured at the start of each batch test were calculated and are listed in Appendix A. The results are summarized in Table 4.5.

The R^2 values obtained by linear regression of the $\ell n(OUR_H)$ – time data in the batch tests are also listed in Table 4.5. For the batch tests where relatively large volumes of mixed liquor were added to the batch reactor (over 0.3ℓ), the R^2 values were less than 0.90. In these batch tests, the slope of the $\ell n\ (OUR_{H(t)})$ - time plot was relatively flat. In the calculation procedure for the R^2 values, it is difficult to get a high R^2 value with a flat slope, even though the deviations of the data points from the fitted line are small. In this investigation, despite the low R^2 values, the deviations of the data points from the fitted line were considered sufficiently small to accept the data for the further analysis (for example, see Fig. 4.6). The reason for the flat slope of the $\ell n(OUR_H)$ – time curve will be more investigated further in Chapter 6.

(a) (b)

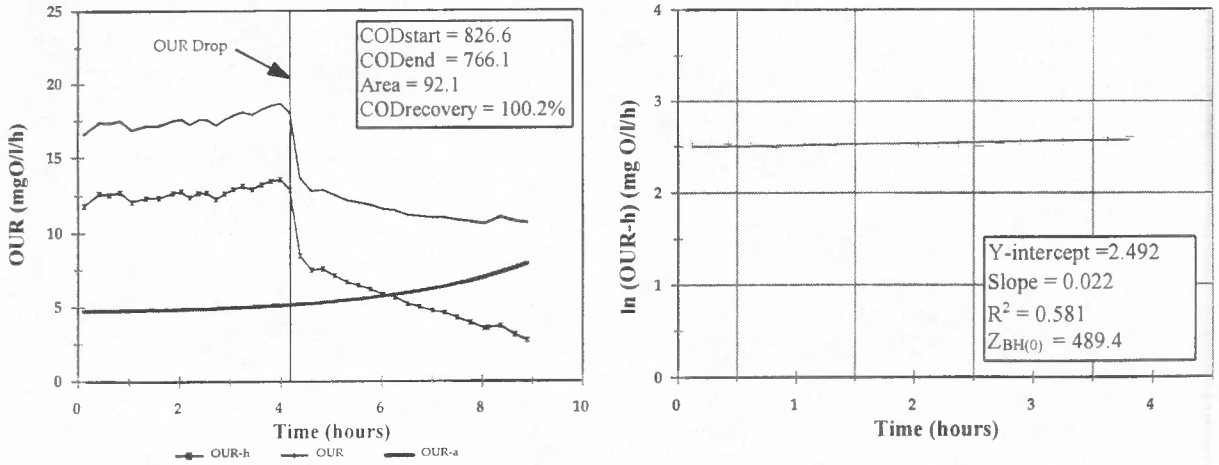


Fig. 4.6: (a) Oxygen Utilization Rate (OUR) response with time for a modified batch test on a mixture of flocculated-filtered wastewater (2.6 ℓ) and mixed liquor (0.4 ℓ) drawn from the aerobic reactor of the 10 days sludge age system and (b) ℓn Oxygen Utilization Rate (OUR) due to OHO active biomass (ℓn OUR_H) versus time for the OUR data up to the precipitous drop OUR. Batch Test No. A15, Sewage Batch No. 11.

% COD recoveries

The %COD recoveries for all the batch tests were calculated using Eq. (4.13) and the results are listed in Appendix A. The %COD recovery for each batch test is summarized in Table 4.5 below.

In general, %COD recoveries were good, with only 8 out of 35 batch tests yielding %COD recoveries < 90%; no % COD recoveries > 105% were obtained. In examining those batch tests with % COD recoveries < 90% (Batch Test Nos. A19, A24, A25, A26, A30, A31, A32 and A33), it was noted that for these batch tests small mixed liquor volumes were added, ≤0.05ℓ. Particularly noticeable was that for Sewage Batch No.14, as the mixed liquor volume added to the batch test decreased, so did the %COD recovery. To determine whether these low %COD recoveries arose from random effects, or whether they were a discernable trend, a statistical plot of the %COD recovery for all the modified batch tests was constructed, see Fig. 4.7(a). From 4.7(a), the mean %COD recovery was 93.2% with sample standard deviation of 7.7%. From the statistical plot, it is evident that the lower 4 %COD recovery data points deviate significantly from the "true" normal distribution line. This would indicate that the low % COD recoveries for these data did not arise from random effects. Most likely, the dominating cause was the difficulty in accurately measuring

the low OUR values arising from the small mixed liquor volume additions. Accordingly, the 4 data points (Batch test Nos. A25, A31, A32 and A33 in Table 4.5) were rejected for further analysis. Excluding the rejected data, the statistical plot for %COD recoveries was reconstructed, see Fig. 4.7(b). This gave mean %COD recovery of 95.2% with sample standard deviation 5.3%. From the statistical plot, the remaining 4 data points < 90% do deviate from the "true" normal plot, but this deviation is relatively small (< 1% to 2%). Hence, it was decided to retain these data points. Thus, effectively a lower cut off limit of 83% was accepted.

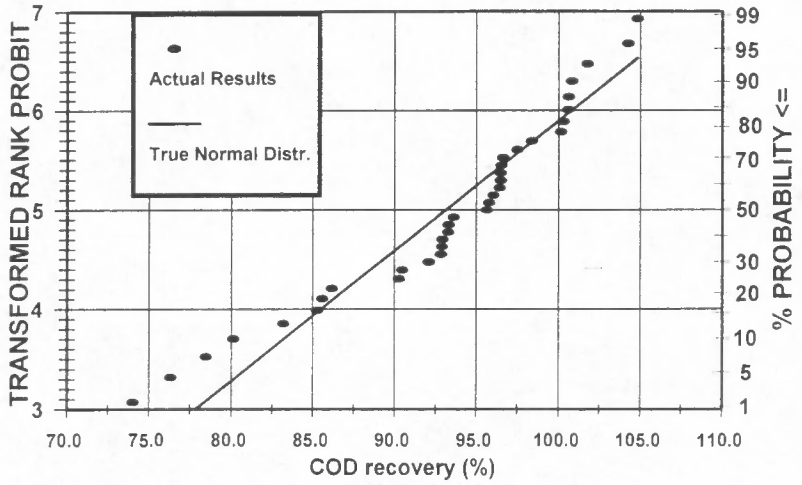


Fig. 4.7 (a) : Statistical plot of %COD recovery for all the modified batch tests conducted with flocculated-filtered wastewater and mixed liquor drawn from the 10 days sludge age MLE activated sludge system

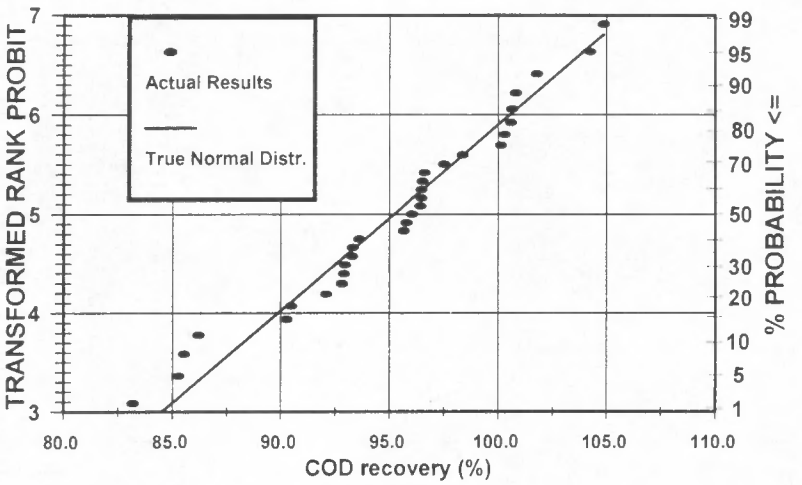


Fig. 4.7 (b) : Statistical plot of %COD recovery for all the modified batch tests conducted with flocculated-filtered wastewater and mixed liquor drawn from the 10 days sludge age MLE activated sludge system: * outliers rejected

Table 4.5: Results for batch tests with a mixture of *flocculated-filtered* wastewater (WW) and mixed liquor (ML): Batch test numbers, dates of batch tests, volumes added, COD recoveries, *measured* OHO active biomass present the start of the batch test ($Z_{BH(0)}$) and the *projected* parent system mixed liquor (ML) active biomass. The *theoretical* parent system mixed liquor (ML) OHO active biomass and the *projected* active biomass present the start of the batch test are also given.

Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		COD Recov. (%)	Regression			Growth Rate (/d)		ZBH(0) (mgCOD/l)			
			WW	ML		Y-int	Slope	R2			Measured		Theoretical	
									K_{MP}	μ_H	Batch	ML	Batch	ML
5	A1	11 09	2.70	0.30	92.8	1.542	0.1	0.15	1.18	0.46	108.1	1081	172.7	1726.8
7	A2	24 09	2.70	0.30	90.3	2.162	0.083	0.761	1.3	1.3	154.4	1543.6	196.5	1965.1
	A3	2909	2.8	0.20	104.3	1.714	0.106	0.891	1.51	1.65	81.9	1228.0	131.0	1965.1
	A4	0510	2.90	0.10	93.6	1.263	0.215	0.923	1.23	4.55	28.5	854.5	65.5	1965.1
8	A5	12 10	2.70	0.30	96.5	1.987	0.125	0.979	1.93	1.69	93.9	938.6	166.3	1663.3
	A6	1910	2.80	0.20	100.7	1.854	0.080	0.925	1.18	1.35	117.5	1763.0	110.9	1663.3
	A7	2310	2.90	0.10	95.7	0.861	0.235	0.962	1.58	4.67	17.6	528.3	55.4	1663.3
9	A8	26 11	2.70	0.30	93.0	2.482	0.133	0.964	1.76	2.04	146.4	1463.8	159.2	1591.8
	A9	2711	2.80	0.20	96.5	2.190	0.167	0.928	1.68	2.95	89.8	1346.4	106.1	1591.8
	A10	2811	2.90	0.10	100.6	1.769	0.218	0.988	1.77	4.08	46.7	1400.2	53.1	1591.8
10	A11	10 12	2.70	0.30	95.8	2.227	0.022	0.379	0.54	0.6	377.6	3776.1	191.2	1912.0
	A12	1112	2.80	0.20	104.9	1.733	0.155	0.954	1.65	2.67	60.9	913.1	127.5	1912.0
	A13	1212	2.90	0.10	100.8	1.031	0.266	0.993	1.65	5.35	18.7	560.2	63.7	1912.0
	A14	1312	2.95	0.05	96.5	0.807	0.266	0.999	1.1	5.91	14.9	893.4	31.9	1912
11	A15	26 12	2.60	0.40	100.2	2.492	0.022	0.581	0.67	0.48	489.4	3670.4	230.4	1728.2
	A16	2912	2.70	0.30	98.4	1.974	0.077	0.877	1.26	1.21	136.3	1362.5	172.8	1728.2
	A17	3012	2.80	0.20	93.3	1.381	0.146	0.926	1.51	2.61	45.0	675.2	115.2	1728.2
	A18	3112	2.90	0.10	90.5	0.459	0.225	0.967	1.86	4.16	12.2	366.9	57.6	1728.2
	A19	0501	2.95	0.05	85.6	0.878	0.315	0.997	0.9	7.28	13.7	822.1	28.8	1728.2
12	A20	09 01	2.60	0.40	101.8	2.476	0.029	0.594	0.8	0.51	421.6	3161.7	233.4	1750.8
	A21	1001	2.70	0.30	92.9	2.203	0.044	0.852	0.84	0.84	252.0	2519.8	175.1	1750.8
	A22	1101	2.80	0.20	93.3	1.538	0.152	0.982	1.9	2.38	50.7	760.5	116.7	1750.8
	A23	1401	2.90	0.10	92.1	0.759	0.173	0.950	1.58	3.18	20.9	626.4	58.4	1750.8
	A24	1501	2.95	0.05	83.2	0.306	0.221	0.992	1.65	4.28	10.7	640.4	29.2	1750.8
13	A25	01 02	2.95	0.05	80.2 *	-0.536	0.252	0.992	0.64	6.03	4.1	245.2	32.9	1973.5
	A26	0402	2.96	0.04	85.3	0.197	0.189	0.951	1.59	3.56	11.0	825.6	26.3	1973.5
14	A27	15 02	2.40	0.60	96.4	2.688	0**	0***	0.42	0.2	1093.8	5469.0	265.2	1325.9
	A28	1702	2.60	0.40	96.6	2.085	0.078	0.985	1.35	1.14	150.8	1131.3	176.8	1325.9
	A29	1802	2.80	0.20	96.1	0.896	0.178	0.962	1.9	3	23.3	349.4	88.4	1325.9
	A30	2002	2.90	0.10	86.2	0.301	0.275	0.978	1.79	5.42	8.7	261.6	44.2	1325.9
	A31	2202	2.93	0.07	78.5*	0.438	0.261	0.994	0.97	5.91	10.5	449.7	30.9	1325.9
	A32	2402	2.95	0.05	76.3*	1.085	0.172	0.995	0.6	4.14	29.0	1742.8	22.1	1325.9
	A33	2502	2.97	0.03	74.0*	1.362	0.161	0.989	0.62	3.87	40.5	4049.4	13.3	1325.9
17	A34	2204	2.80	0.20	97.5	0.967	0.128	0.958	1.38	2.31	33.2	497.5	95.2	1427.9
	A35	2404	2.90	0.10	100.3	-0.837	0.283	0.978	1.14	6.27	2.7	81.6	47.6	1427.9

* Rejected on poor COD mass balance.

** Approached almost zero.

*** Approached almost zero due to a very low slope.

Maximum specific growth rates on SBCOD (K_{MP}) and RBCOD (μ_H)

For each batch test, the values for K_{MP} and μ_H were calculated using Eq. (4.25) and Eq. (4.26) respectively. The results are given in Table A1, Appendix A, and are summarized in Table 4.5 below. Although a significant fraction of the slowly biodegradable COD (SBCOD) is associated with the particulate matter that was removed through flocculation and filtering the wastewater, it was assumed that the filtered wastewater would still contain some SBCOD. Thus, up to the precipitous drop in OUR_H, the OUR is the sum of both the SBCOD and RBCOD utilization. When the precipitous drop in OUR_H occurs, the RBCOD is depleted and the OUR is that for SBCOD only. The experimental data tended to support the assumption that SBCOD remains after flocculation and filtration; following the precipitous drop in OUR (when RBCOD is depleted), an OUR plateau was observed, presumably associated with SBCOD utilization.

For K_{MP}, a statistical plot of the K_{MP} values for all the modified batch tests was constructed, see Fig. 4.8(a). From Fig. 4.8 (a), the mean K_{MP} was 1.30 /d with sample standard deviation of 0.445 /d. A further statistical plot of K_{MP} was constructed, excluding those batch tests with low %COD recoveries (A25, A31, A32 and A33, see above), see Fig 4.8(b). From Fig. 4.8(b), mean K_{MP} was 1.37/d with sample standard deviation 0.412/d. This is significantly larger than the K_{MP} value measured by Cronje *et al.* (2000) (0.84 /d), but close to the values measured by Beeharry *et al.* (2001) (1.49 and 1.38 /d). Further, this value is close to the default value for K_{MP} in the UCT kinetic simulation model of 1.35 /d (Dold *et al.*, 1991). However, in examining the statistical plot it is evident that the lower K_{MP} value deviate somewhat from the "true" normal distribution line. These data tend to be associated with batch tests where relatively low or high volumes of mixed liquor were added. For those cases where low mixed liquor volumes were added (0.05ℓ, Table 4.5), the second OUR plateau associated with SBCOD utilization was low and difficult to isolate exactly. This introduced a measure of uncertainty into the K_{MP} determination. For those cases where high mixed liquor volume were added (>0.4ℓ, Table 4.5), it is probable that the utilization of SBCOD was no longer at a maximum when RBCOD was depleted, and hence K_{MP} was underestimated. However, these effects do not appear that large, with maximum deviation from the true normal distribution line of about 0.06 /d (see Fig. 4.8(b)), and their effect on the mean value is small due to the large sample size.

For the values of μ_H, a clearly discernable trend was noted for the data, see Table 4.5. As the volume of mixed liquor added to the batch test increased, the value for μ_H decreased. This is clearly demonstrated in Fig. 4.8(c) where μ_H is plotted against mixed liquor volume added. This indicates that one factor (namely mixed liquor added) has a dominating influence, which precluded statistical analysis of the data. Re-examination of the data of Beeharry *et al.* (2001) indicates that they obtained, but did not note, a similar trend, see Cronje *et al.* (2002). Possible reasons for this trend will be examined in Chapter 6.

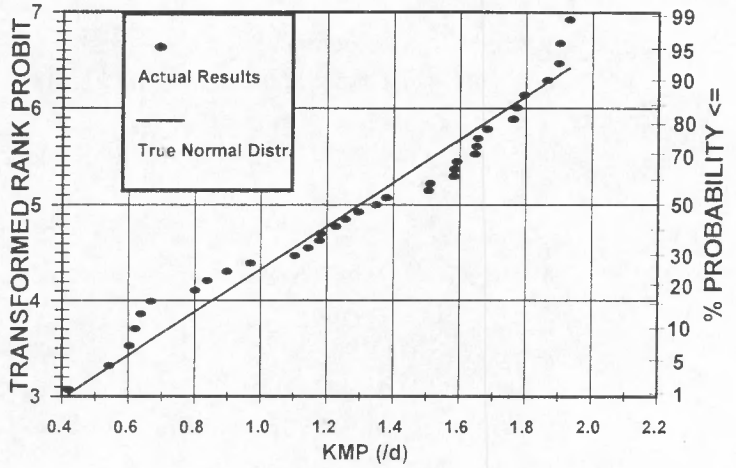


Fig. 4.8 (a) : Statistical plot of K_{MP} recovery for all the modified batch tests conducted with flocculated-filtered wastewater and mixed liquor performed on the 10 days sludge age MLE activated sludge system.

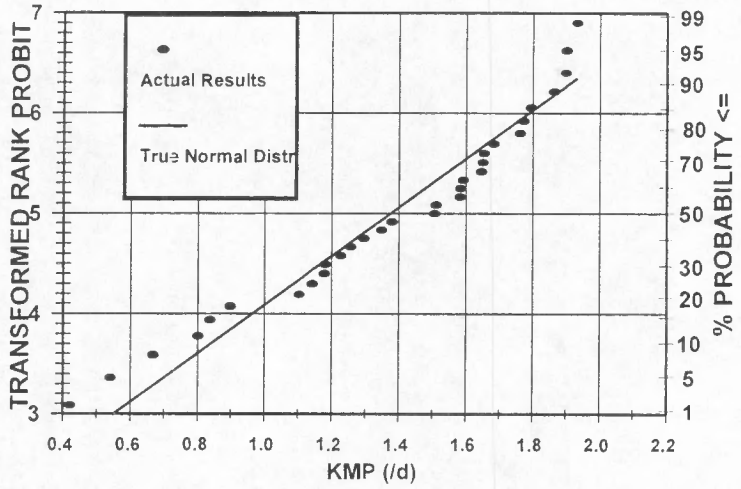


Fig. 4.8 (b) : Statistical plot of K_{MP} recovery for the modified batch tests conducted with flocculated-filtered wastewater and mixed liquor performed on the 10 days sludge age MLE activated sludge system * Low %COD recoveries rejected.

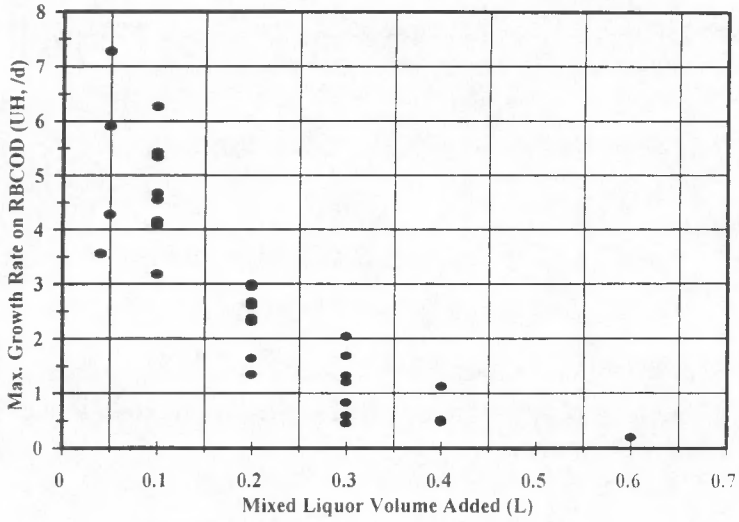


Fig. 4.8 (c) : Maximum specific growth rate on RBCOD (μ_H; /d)) versus mixed liquor volume added to batch reactor (V_{ML}; ℓ) for modified batch tests on mixed liquor drawn from the 10 days sludge age MLE activated sludge system * Low %COD recoveries rejected.

4.4.3 Comparison between measured and theoretical OHO active biomass for the *10days sludge age* MLE activated sludge system

In Table 4.5, the measured OHO active biomass concentration at the start of each batch test [$Z_{BH(0)}$(Meas.)] is compared to the theoretical OHO active biomass concentration at the start of the batch test due to the mixed liquor sample which was drawn from the parent system and added to the batch test [$Z_{BH(0)}$(Theo.)]; theoretical values were predicted via the steady state design model (see above). To illustrate the comparison, the measured versus theoretical mixed liquor OHO active biomass data for all the batch tests are shown in Fig. 4.9 (a) and (b). In Fig. 4.9 (a) and (b), the comparative data for the batch test results that should be rejected on the basis of poor N and COD mass balances for the parent system (Sewage Batch Nos. 5 and 13, see Chapter 3) are also shown, but are appropriately marked.

From Fig. 4.9, superficially the correlation between measured and theoretical $Z_{BH(0)}$ is very similar to that obtained by Beeharry *et al.* (2001) (see Chapter 2, Fig. 2.9), namely there is a correspondence, but the values plot parallel to the 1:1 correspondence line. However, in contrast to the investigation of Beeharry *et al.* (2001), in this investigation considerably more data was obtained at the lower and upper ranges for $Z_{BH(0)}$. Examining the data in more detail, in Fig 4.9, three trend regions can be identified. The first, in the region of the theoretical $Z_{BH(0)}$ from 0 to about 30 mgCOD/ℓ as the theoretical $Z_{BH(0)}$ increases, the measured values decrease, to approach near zero; Beeharry *et al.*

(2001) did not collect data in this region so a comparison with their data is not possible. The second, in the region from about 30 to 150 mgCOD/ℓ theoretical $Z_{BH(0)}$, as the theoretical $Z_{BH(0)}$ increases, the measured values increase parallel to the 1:1 correspondence line between the measured values and the theoretical values; this trend is near identical to that observed by Beeharry *et al.* (2001) whose data falls primarily in this region. The third, above about 150 mgCOD/ℓ theoretical $Z_{BH(0)}$, as the theoretical $Z_{BH(0)}$ increases further the measured $Z_{BH(0)}$ values increase sharply; Beeharry *et al.* (2001) collected limited data in this region, but re-examining the data available indicates it is consistent with the observation here. Thus, it is evident that the trends observed in this investigation are consistent with those of Beeharry *et al.* (2001). Possible reasons for these trends will be discussed in Chapter 6 in detail.

Comparing the measured and the theoretical OHO active biomass concentrations for Sewage Batch No. 9, it would seem that for this sewage batch there is closer correspondence between theoretical and measured OHO active biomass concentrations than for the other sewage batches; The RBCOD fraction of Sewage Batch No.9 was very low and thus the batch tests on this sewage batch were conducted with an initial low COD concentration. Thus, it would seem that the initial COD concentration of the batch test may play an important role in determining the OUR response. This aspect will also be examined in detail in Chapter 6.

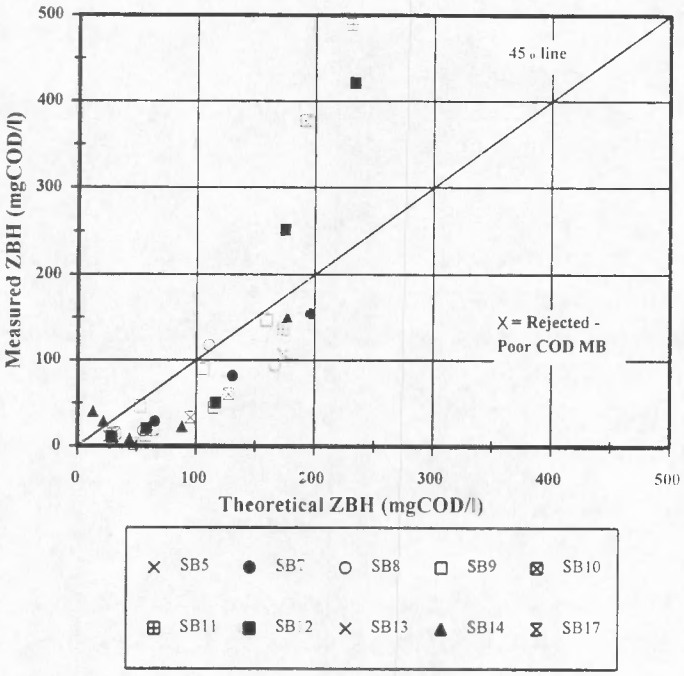


Fig. 4.9 (a) : Modified batch tests results; graph of measured versus theoretical OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] for the various sewage batches (SB) for the 10 days MLE activated sludge system; Scale 500 × 500 mgCOD/ℓ.

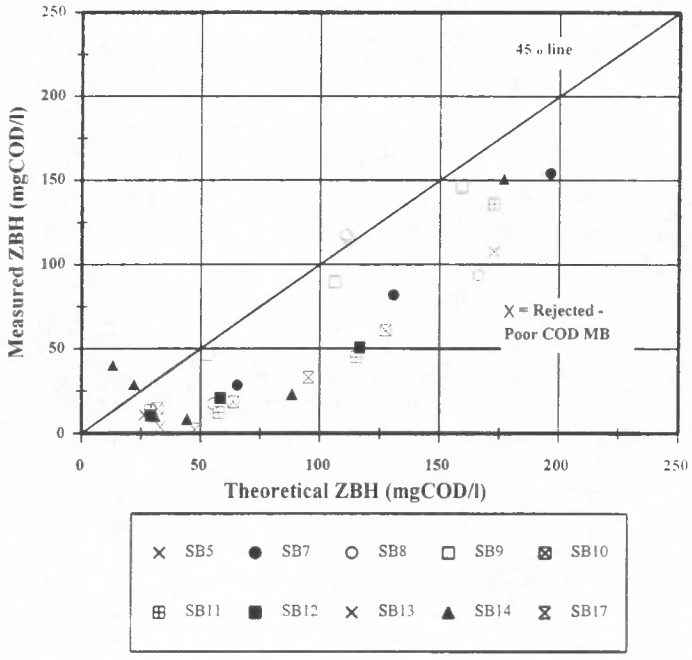


Fig. 4.9 (b) : Modified batch tests results; graph of measured versus theoretical OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] for the various sewage batches (SB) for the 10 days MLE activated sludge system; Scale 250 × 250 mgCOD/ℓ.

4.5 RESULTS FOR THE 20 DAYS SLUDGE AGE MLE ACTIVATED SLUDGE SYSTEM

This section deals with the interpretation of the results calculated for both the parent system and the batch test analysis. Also, a comparison between the theoretical OHO active biomass concentration in the parent system [$Z_{BH(0)}$(Theor.)] and the OHO active biomass concentration measured at the start of batch tests [$Z_{BH(0)}$(ML)] will be described. The calculation procedure for the both analyses were set out in detail in Section 4.3.1 and 4.3.2 above.

The parent laboratory-scale nitrification/denitrification system was operated at 20 days sludge age and was continually monitored; the sewage was fed to the parent system in batches which lasted for approximately 2 weeks and each sewage batch constituted a steady state period. A total of 35 batch tests were conducted using mixed liquor drawn from the 20 days MLE activated sludge system.

4.5.1 Parent system data

As for the 10 day sludge age parent system (Section 4.4.1), modified batch tests were conducted during 10 out of a total of 17 sewage batches. For these sewage batches the various parent system parameters and the averaged data (from Table 3.6 (a) and (b), Chapter 3) are listed in Table 4.6.

Table 4.6: Steady state results for 20 days sludge age parent laboratory-scale anoxic/aerobic activated sludge system for those sewage (Sew.) batches during which batch tests were performed. Averages are listed with sample standard deviations in the second row. (Inf. = influent, Eff = effluent, ML = mixed liquor, AX = anoxic and AE = aerobic.)

20 DAY SLUDGE AGE PARENT ANOXIC/AEROBIC STEADY STATE SYSTEM													
Sew. Batch No	No. of tests	TKN (mgN/l)			NITRATE (mgN/l)			COD (mgN/l)			OUR (mgO/l/h)	VSS (mgVSS/l)	pH
		Inf	Eff	ML	AX	AE	Eff	Inf	Eff	ML			
5	3	85.1	3.6	275.6	4.9	31.4	31.6	706.7	23.3	4813.3	34.0	3487.0	7.70
	(SSD)	1.3	0.5	5.5	1.1	1.8	2.3	28.5	4.1	120.4	1.8	39.2	0.08
7	7	83.2	3.9	302.3	0.3	20.2	18.3	760.2	23.0	5287.9	43.1	3718.2	7.65
	(SSD)	3.1	0.6	10.0	0.3	2.6	2.6	63.2	10.9	353.0	3.6	141.4	0.18
8	3	59.7	3.7	283.0	0.1	16.8	12.9	677.3	-4.7	4876.8	34.2	3715.2	7.70
	(SSD)	2.0	0.2	6.7	0.1	0.3	1.0	27.8	18.9	141.8	0.4	122.6	0.04
9	6	66.5	4.2	257.7	0.0	14.6	12.4	686.7	23.1	4548.1	35.0	3308.6	7.77
	(SSD)	1.6	0.7	13.0	0.0	1.0	2.2	22.8	10.2	69.3	0.5	68.1	0.03
10	8	60.4	4.3	291.0	0.0	14.6	11.6	747.4	40.8	5115.3	40.7	3668.3	7.68
	(SSD)	2.0	0.9	16.5	0.0	1.1	2.3	41.1	10.5	182.7	2.5	102.5	0.08
11	9	61.8	5.0	265.8	0.0	15.0	15.4	733.8	42.8	4748.8	36.7	3351.4	7.74
	(SSD)	1.3	0.4	14.0	0.0	1.0	0.5	22.3	5.8	144.2	1.4	62.0	0.07
12	8	83.4	4.3	269.9	0.7	21.1	21.6	749.4	37.3	4815.9	38.2	3406.6	7.67
	(SSD)	2.2	0.8	9.9	0.6	0.9	0.8	26.1	6.0	93.9	0.8	52.6	0.04
13	3	65.1	4.7	259.3	0.0	15.1	12.4	762.5	26.6	4517.6	32.8	3272.3	7.67
	(SSD)	0.6	0.5	19.2	0.0	0.3	1.4	11.8	2.5	89.8	0.8	48.6	0.04
14	9	59.2	3.8	200.8	0.0	12.9	13.4	727.2	31.5	3470.9	27.8	2459.8	7.77
	(SSD)	1.7	0.4	3.9	0.0	1.0	1.3	23.2	4.9	27.3	2.6	47.5	0.04
17	8	61.7	4.1	207.3	0.0	15.3	15.0	772.6	35.8	3774.6	26.1	2666.9	7.92
	(SSD)	1.6	0.5	4.8	0.0	0.4	0.7	13.0	4.5	52.9	1.3	70.2	0.06

As for the 10day sludge age parent system, to formulate a theoretical estimate for the OHO active biomass concentration present in the 20 days sludge age parent system during each sewage batch period, the following were determined from the data in Table 4.6:

- Influent wastewater unbiodegradable soluble and particulate COD fractions ($f_{S,us}$ and $f_{S,up}$ respectively); system COD and N mass balances (Ekama *et al.* 1986) and the COD and TKN to VSS ratios for the mixed liquor (f_{CV} and f_N respectively). The calculation procedures are set out in detail in Chapter 3 and the results for each sewage batch during which modified batch tests were conducted are listed in Table 4.7.

- The OHO active biomass fractions of the mixed liquor organic suspended solids (f_{av}) were determined for each sewage batch using the steady state design model [Eq. (4.27)], for reasons set out in Section 4.1.1 above.

Table 4.7: Steady state COD and N mass balances, wastewater fractions and mixed liquor parameters for the 20 days sludge age parent laboratory-scale anoxic/aerobic activated sludge system. Data calculated from data in Table 4.6 using the steady state (SS) design model (WRC, 1984).

10 DAYS SLUDGE AGE PARENT ANOXIC/AEROBIC STEADY STATE SYSTEM								
Sew. Batch No.	No. of Test	MASS BALANCE (%)		WASTEWATER FRACTIONS		MIXED LIQUOR		
		N	COD	Unbio. Soluble (fs,us)	Unbio.Particulate (fs,up)	COD/VSS (fcv)	TKN/VSS (fN)	Active Fraction (fav)
5 **	3	110	83	0.0425	0.1716	1.37	0.080	0.249
7	7	96	108	0.0386	0.1707	1.39	0.081	0.253
8	3	115	98	-0.0190 *	0.1896	1.30*	0.076	0.236
9	6	91	101	0.0331	0.1560	1.35	0.078	0.263
10	8	98	110	0.0523	0.1713	1.37	0.079	0.247
11	9	103	101	0.0513	0.1448	1.39	0.079	0.275
12	8	93	97	0.0471	0.1405	1.38	0.079	0.279
13 **	3	98	87	0.0332	0.1149	1.38	0.084	0.310
14	9	95	103	0.0427	0.1353	1.38	0.082	0.286
17	8	102	92	0.0382	0.1429	1.38	0.078	0.279

* Shaded areas rejected as outliers

** Rejected on COD and N mass balances

From the analysis of the N mass balances (Chapter 3), sewage batches which yielded mass balances outside the 90% - 110% range should be rejected for further analysis; this was Sewage Batch No. 8. From the analysis of the COD mass balances, Sewage Batch Nos. 5 and 13 were outside the 90% - 110% range and were rejected for further analysis. The specific causes for the poor N and COD mass balances for these sewage batches were discussed in Chapter 3. There it was noted that Sewage batch No.8 should be retained and Sewage Batch Nos. 5 and 13 rejected.

Thus, batch tests were conducted on the accepted Sewage Batch Nos. 7, 8, 9, 10, 11, 12, 14 & 17 and were conducted on the rejected Sewage Batches Nos. 5 and 13. The batch test data collected on these rejected sewage batches will be included where appropriate, and will be analyzed, but it will be noted that the data should be rejected and the data will not be used to draw conclusions. This will be done to determine the influence of poor mass balances on the test and analytical procedures.

4.5.2 Batch test data

For the batch tests, measured OUR, NO_3^- and NO_2^- – time data are shown graphically in Appendix A. Following the procedures set out in Section 4.3.1 above, the OHO active biomass concentrations measured at the start of each batch test were calculated and are listed in Table A2, Appendix A. The results are summarized in Table 4.8.

The R^2 values obtained by linear regression of the $\ell n(OUR_H)$ – time data in the batch tests are also listed in Table 4.8. As noted for the batch tests on mixed liquor drawn from the 10 day sludge age parent system (Section 4.1.1), a number (5) of R^2 values were less than 0.90. As noted previously, these low values are associated with low values for the slope of the ℓn OUR - time plot, caused by larger volumes of mixed liquor addition. As for the 10day system batch tests, examination of the data indicated that despite the low R^2 values the data points did not deviate significantly from the fitted line. Accordingly, the data with low R^2 values were accepted for the further analysis (see Fig. 4.6).

%COD recoveries

The %COD recoveries for all the batch tests were calculated using Eq. (4.13) and the results are listed in Table A2, Appendix A. The %COD recovery for each batch test is summarized in Table 4.8 below.

As for the batch tests on mixed liquor drawn from the 10day sludge age parent system, in general %COD recoveries were good with only 7 out of 35 batch tests yielding %COD recoveries <90%; no COD recoveries >105% were obtained. Again these low %COD recovery batch tests (B24, B25, B26, B30, B32 and B33, Table 4.8) tended to be associated with low mixed liquor volumes added. To determine whether these low %COD recoveries arose from random effects, or whether these was a discernable trend, a statistical plot of the %COD recovery for all the modified batch tests was constructed, see Fig. 4.10(a). From Fig. 4.10 (a) the mean %COD recovery was 93.2 % with sample standard deviation of 6.8 %. From the statistical plot, it is evident that the lower 3 data points deviate significantly from the "true" normal distribution line. This would indicate that the low %COD recoveries for these data did not arise from random effects. Most likely, the dominating cause was the difficulty in accurately measuring the low OUR values arising from the small mixed liquor volume additions. Accordingly, the 3 data points (Batch Test Nos. B26, B32 and B33, Table 4.8) were rejected for further analysis. Excluding the rejected data, the statistical plot for %COD recoveries was reconstructed, see Fig. 4.10(b). This gave mean %COD recovery of 94.8% with sample standard deviation 4.5%. This mean %COD recovery is very close to that obtained for the batch tests on the 10 day sludge age parent system mixed liquor (95.2%).

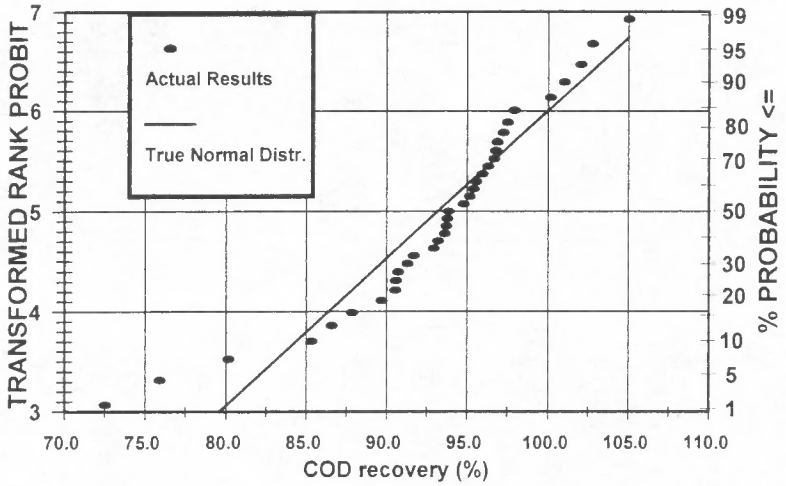


Fig. 4.10 (a) : Statistical plot of %COD recovery for all the modified batch tests conducted with flocculated-filtered wastewater and mixed liquor drawn from the 20 days sludge age MLE activated sludge system.

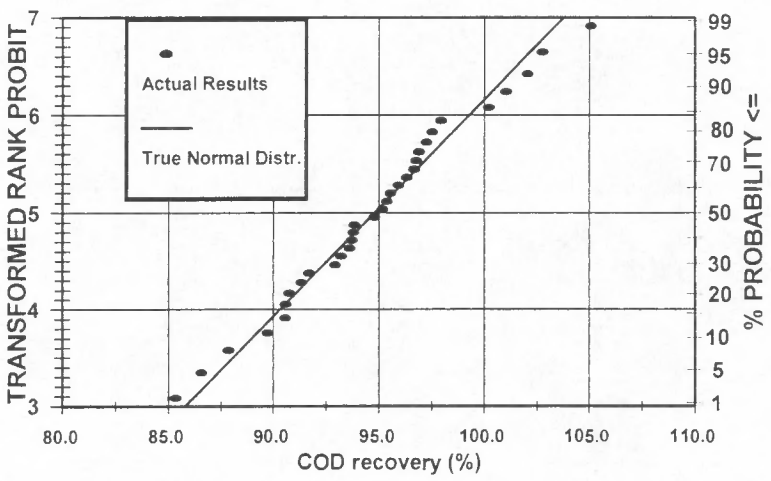


Fig. 4.10 (b) : Statistical plot of %COD recovery for all the modified batch tests conducted with flocculated-filtered wastewater and mixed liquor drawn from the 20 days sludge age MLE activated sludge system: * outliers rejected.

Table 4.8: Results for batch tests with a mixture of *flocculated-filtered* wastewater (WW) and mixed liquor (ML): Batch test numbers, dates of batch tests, volumes added, COD recoveries, *measured* OHO active biomass concentration present at the start of the batch test ($Z_{BH(0)}$) and the measured value *projected* to the parent system mixed liquor (ML) concentration. The *theoretical* parent system mixed liquor (ML) OHO active biomass concentration and the theoretical value *projected* to that present at the start of the batch test are also given.

Sew. Batch No.	Batch test No.	Batch test date	Volume(l)		COD Recov. (%)	Regression			Growth Rate (/d)		ZBH(0) (mgCOD/l)			
			WW	ML		Y-int	Slope	R2			Measured		Theoretical	
									K_{MP}	μ_H	Batch	ML	Batch	ML
5	B1	11 09	2.70	0.30	96.8	1.573	0.027	0.131	0.51	0.77	175.5	1755.2	119.1	1191.2
7	B2	24 09	2.70	0.30	92.9	1.641	0.129	0.908	1.89	1.84	64.6	645.7	131.5	1315.0
	B3	2909	2.8	0.20	97.5	1.321	0.141	0.957	1.11	2.89	43.7	654.8	87.7	1315.0
	B4	0510	2.90	0.10	91.3	0.916	0.217	0.965	0.56	5.26	20.0	599.9	44.3	1329.1
8	B5	12 10	2.60	0.4	93.7	2.093	0.108	0.972	1.83	1.38	117.7	882.9	151.8	1138.5
	B6	1910	2.70	0.30	93.9	1.797	0.089	0.906	1.65	1.11	101.8	1018	113.9	1138.5
	B7	2310	2.80	0.20	91.7	1.489	0.182	0.971	1.8	3.18	41.4	621.2	75.9	1138.5
9	B8	26 11	2.60	0.40	93.8	2.437	0.112	0.979	1.58	1.72	161.6	1212	158.8	1190.8
	B9	2711	2.70	0.30	96.7	2.112	0.172	0.996	1.77	2.99	81.0	810	119.1	1190.8
	B10	2811	2.80	0.20	97.3	1.970	0.079	0.654	0.93	1.59	132.7	1991	79.4	1190.8
10	B11	10 12	2.60	0.40	100.2	2.379	0.024	0.674	0.74	0.44	424.5	3183.6	167.4	1255.5
	B12	1112	2.70	0.30	105.1	2.099	0.104	0.958	1.44	1.68	121.6	1216.2	125.6	1255.5
	B13	1212	2.80	0.20	95.6	1.647	0.174	0.992	1.62	3.18	50.3	755.0	83.7	1255.5
	B14	1312	2.90	0.10	93.6	1.136	0.217	0.996	1.45	4.38	24.9	746.3	41.9	1255.5
11	B15	26 12	2.50	0.50	97.9	2.209	0.043	0.860	0.92	0.72	258.4	1550.2	216.1	1296.6
	B16	2912	2.60	0.40	96.9	1.948	0.128	0.968	1.83	1.85	88.7	664.9	172.9	1296.6
	B17	3012	2.70	0.30	93.2	1.530	0.148	0.957	1.92	2.26	51.4	514.5	129.7	1296.6
	B18	3112	2.80	0.20	102.1	0.962	0.178	0.962	1.86	3.02	25.0	374.5	86.4	1296.6
	B19	0501	2.90	0.10	90.6	1.043	0.282	0.995	1.55	5.82	17.9	537.5	43.2	1296.6
12	B20	09 01	2.50	0.50	90.6	2.268	0.050	0.941	1.22	0.6	247.7	1486.0	222.6	1335.8
	B21	1001	2.60	0.40	90.8	2.196	0.045	0.867	1.04	0.66	247.5	1856.6	178.1	1335.8
	B22	1101	2.70	0.30	95.9	1.637	0.113	0.971	1.8	1.54	71.8	717.7	133.6	1335.8
	B23	1401	2.80	0.20	94.8	1.252	0.114	0.916	1.37	1.99	48.5	727.0	89.1	1335.8
	B24	1501	2.90	0.10	86.6	0.545	0.213	0.967	1.61	4.13	14.0	420.4	44.5	1335.8
13	B25	01 02	2.93	0.07	85.4	-0.752	0.276	0.976	0.67	6.57	3.0	129.9	32.5	1394.3
	B26	0402	2.95	0.05	80.2*	0.027	0.209	0.962	1.58	4.05	8.5	509.8	23.2	1394.3
14	B27	15 02	2.34	0.66	95.4	2.247	0.083	0.984	1.44	1.16	169.2	769.2	216.2	982.7
	B28	1702	2.50	0.50	95.2	1.945	0.064	0.941	0.92	1.24	150.7	904.5	163.8	982.7
	B29	1802	2.70	0.30	96.3	1.000	0.157	0.945	1.69	2.71	28.8	288.0	98.3	982.7
	B30	2002	2.80	0.20	89.7	0.591	0.238	0.974	1.84	4.51	13.3	198.9	65.5	982.7
	B31	2202	2.90	0.10	87.9	-0.320	0.307	0.994	2.06	5.92	4.2	127.2	32.8	982.7
	B32	2402	2.93	0.07	75.9*	0.115	0.265	0.971	0.99	5.98	7.5	321.3	22.9	982.7
	B33	2502	2.95	0.05	72.5*	0.929	0.237	0.990	0.81	5.49	18.7	1122.7	16.4	982.7
17	B34	2204	2.70	0.30	101.0	1.165	0.118	0.945	1.34	2.13	43.1	431.4	104.4	1044.4
	B35	2404	2.80	0.20	102.8	0.167	0.200	0.953	1.34	4.07	10.2	152.5	69.6	1044.4

* Rejected on COD mass balance

Maximum specific growth rates on SBCOD (K_{MP}) and RBCOD (μ_H)

As for the batch tests on the 10day sludge age parent system mixed liquor, for each batch test, the values for K_{MP} and μ_H were calculated using Eq. (4.25) and Eq. (4.26) respectively. The results are given in Table A2, Appendix A, and are summarized in Table 4.8. As noted previously (Section 4.1.1), up to the precipitous drop in OUR_H, the OUR is the sum of both the SBCOD and RBCOD utilization. When the precipitous drop in OUR_H occurs, the RBCOD is depleted and the OUR is that for SBCOD only. Again, the experimental data tended to support the presence of SBCOD; following the precipitous drop in OUR (when RBCOD is depleted) an OUR plateau associated with SBCOD utilization was observed.

For K_{MP}, a statistical plot of the K_{MP} for all the modified batch tests was constructed, see Fig. 4.11(a). From Fig. 4.11 (a), the mean K_{MP} was 1.39 /d with sample standard deviation of 0.428 /d. A further statistical plot of K_{MP} was constructed, excluding those batch tests with low %COD recoveries (B26, B32 and B33, Table 4.8), see Fig. 4.11(b). From Fig. 4.11(b), mean K_{MP} was 1.42/d with sample standard deviation 0.428 /d. As for the K_{MP} value for the 10day sludge age parent system mixed liquor, this is significantly larger than the K_{MP} value measured by Cronje *et al.* (2000) (0.84 /d), but close to the values measured by Beeharry *et al.* (2001) (1.49 and 1.38 /d). Further, the value is close to the value derived for the 10day sludge age parent system mixed liquor (1.37 /d), and both values measured in this investigation are close to the default value for K_{MP} in the UCT kinetic simulation model of 1.35 /d (Dold *et al.*, 1992). However, as was noted for the batch tests with 10days sludge age mixed liquor, for the batch tests with (i) low volumes of mixed liquor added it was difficult to clearly define the second OUR plateau associated with SBCOD utilization, and (ii) high volumes of mixed liquor added, it is possible that the utilization of SBCOD was no longer at a maximum when RBCOD was depleted. These two effects bring a measure of uncertainty to estimation of K_{MP}, causing the observed deviation in data points from the "true" normal distribution line, Fig. 4.11(b). However, these effects do not appear that large - the maximum deviation from the true normal distribution line is about 0.1/d (see Fig 4.11(b)), and their effect on the mean value is small due to the large sample size.

For the values of μ_H, as was noted for the batch tests on the 10day sludge age mixed liquor, a clearly discernable trend was noted for the data, see Table 4.8. As the volume of mixed liquor added to the batch test increased, the value for μ_H decreased; this is clearly demonstrated in Fig. 4.11(c). Again, this indicates that one factor has a dominating influence, which precludes statistical analysis of the data. Possible reasons for this trend will be examined in Chapter 6 in detail.

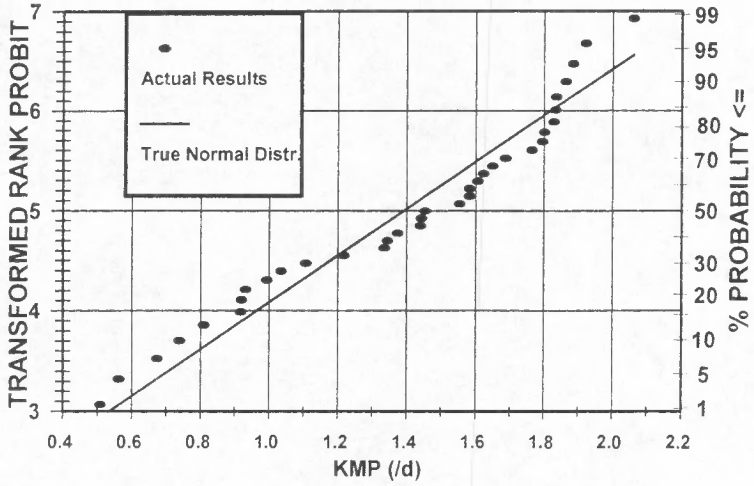


Fig. 4.11 (a) : Statistical plot of K_{MP} recovery for all the modified batch tests conducted with flocculated-filtered wastewater and mixed liquor drawn from the 20 days sludge age MLE activated sludge system.

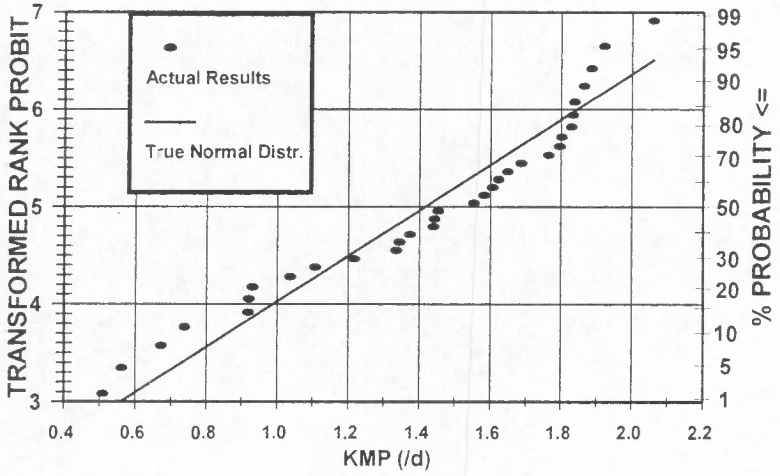


Fig. 4.11 (b) : Statistical plot of K_{MP} recovery for all the modified batch tests conducted with flocculated-filtered wastewater and mixed liquor drawn from the 20 days sludge age MLE activated sludge system. *Low %COD recoveries rejected.

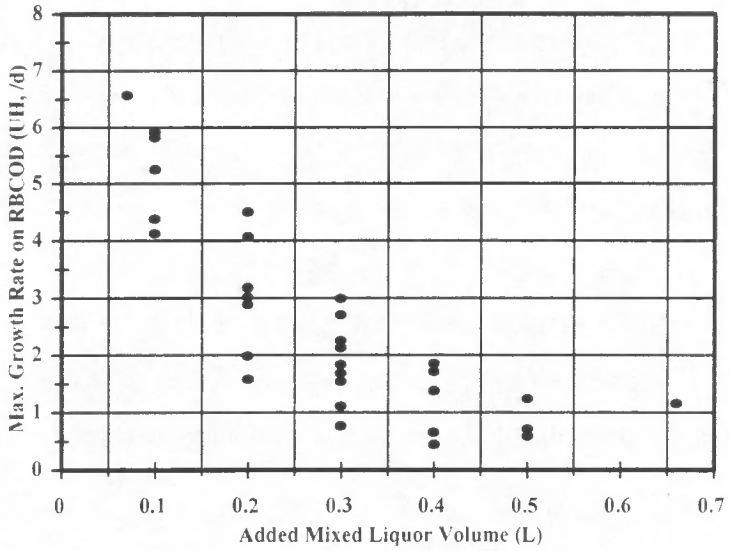


Fig. 4.8 (c) : Maximum specific growth rate on RBCOD (μ_H; /d)) versus mixed liquor volume added to batch reactor (V_{ML}; ℓ) for modified batch tests on mixed liquor drawn from the 20 days sludge age MLE activated sludge system. * Low %COD recoveries rejected.

4.5.3 Comparison between measured and theoretical OHO active biomass for the *20 days sludge age* MLE activated sludge system

In Table 4.8, the measured OHO active biomass concentration at the start of each batch test is compared with the theoretical OHO active biomass concentration at the start of the batch test due to the mixed liquor sample drawn from the parent system and added to the batch test; theoretical values predicted via the steady state design model. To illustrate the comparison, the measured versus theoretical mixed liquor OHO active biomass data for all the batch tests are shown plotted in Fig. 4.12 (a) and (b). In Fig. 4.12 (a) and (b), the comparative data for the batch test results that should be rejected on the basis of poor N and COD mass balances for the parent system (Sewage Batch Nos. 5 and 13) are also shown, but are appropriately marked.

From Fig. 4.12, the data for the batch tests on the 20 day sludge age mixed liquor are very similar to that for the batch tests on the 10 day sludge age mixed liquor (Fig. 4.9), where it was noted that superficially the data bears a strong resemblance to that of Beeharry *et al.* (2001), namely that there is a correspondence, but the values tend to plot parallel to the 1:1 correspondence line. However, as noted for the 10day sludge age mixed liquor, if the data is examined in more detail three trend regions can be identified.

(i) Theoretical $Z_{BH(0)}$ < 30mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values decrease, to approach near zero.

(ii) 30mgCOD/ℓ < Theoretical $Z_{BH(0)}$ < 150 mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values increase parallel the 1:1 correspondence line.

(iii) Theoretical $Z_{BH(0)}$ > 150 mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values increase sharply to cross the 1:1 correspondence line.

This behaviour is identical to that for the 10day sludge age mixed liquor, and the comparison with the data of Beeharry *et al.* (2001) made in the section dealing with the 10 day mixed liquor applies here also. Possible reasons for the observed trend will be discussed in Chapter 6.

As for the 10 day sludge age mixed liquor system, for Sewage Batch No. 9, the points deviate from the trend above, and appear randomly scattered. For this Sewage Batch, it should be noted that the RBCOD fraction was very low and thus the batch tests on this sewage batch were conducted with a low initial COD concentration. The OUR precipitous drop in the batch tests on Sewage Batch No.9 occurred earlier than usual, and the slopes of the $\ell n(OUR_H)$ - time curves were flatter. Thus, it was difficult to estimate correctly the measured $Z_{BH(0)}$ at the start of the batch test. As noted for the 10 day sludge age mixed liquor, it appears that the initial COD concentration in the batch test plays an important role in the OUR response. This aspect will also be examined in detail in Chapter 6.

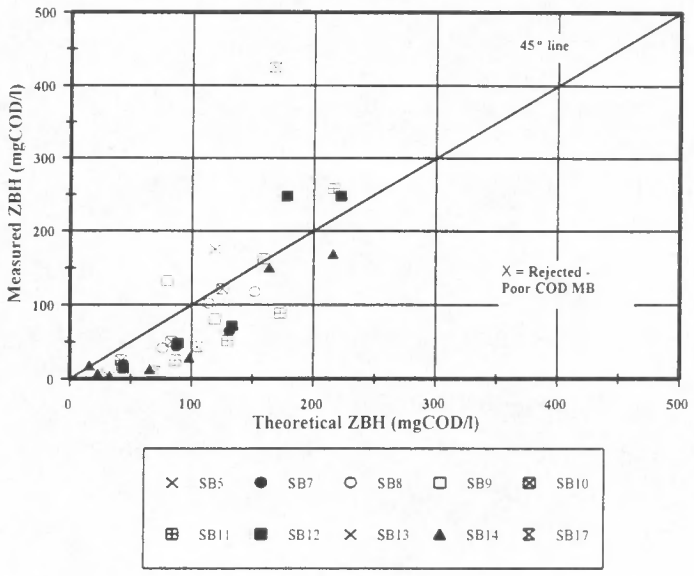


Fig. 4.12(a): Modified batch tests results; graph of measured versus theoretical OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] for the various sewage batches (SB) for the 20 days MLE activated sludge system; Scale 500 × 500 mgCOD/ℓ.

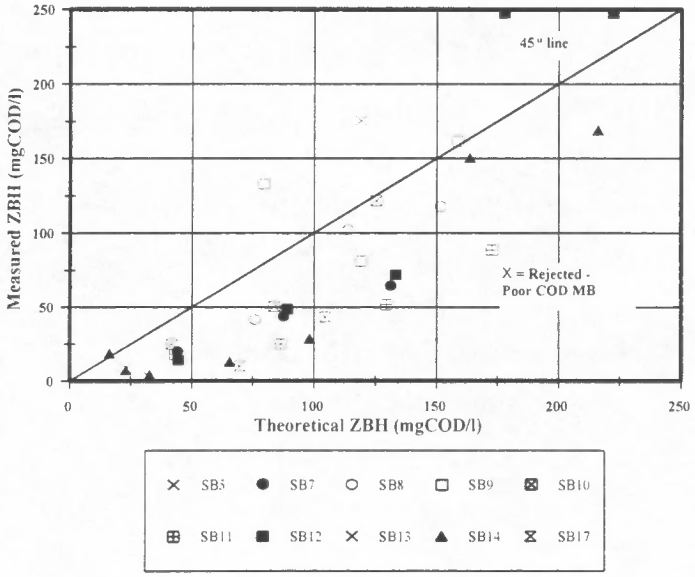


Fig. 4.12 (b): Modified batch tests results; graph of measured versus theoretical OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] for the various sewage batches (SB) for the 20 days MLE activated sludge system; Scale 250 × 250 mgCOD/ℓ.

4.6 COMPARISON BETWEEN OHO ACTIVE BIOMASS BETWEEN THE 10 AND 20 DAY SLUDGE AGE SYSTEMS

With the batch test method, Wentzel *et al.* (1998) and Ubisi *et al.* (1997a,b) measured OHO active biomass in mixed liquor from parent systems at sludge ages 12 and 20 days. With the parent system at 12days sludge age, the agreement between measured and theoretical values was remarkably good. However, with the parent system at 20 days sludge age the agreement was poor, with the theoretical values being about 2 times those measured. No explanation could be found for this inconsistency.

In this research, a similar experimental approach was followed, to attempt to provide an explanation for the above inconsistency. Two parallel parent MLE systems at 10 and 20 days sludge age were run and the modified batch tests (Cronje *et al.*, 2001; see Section 4.2 and 4.3) were conducted on mixed liquor drawn from the two parent systems. In Section 4.4 and 4.5, separate comparisons were made between the measured and theoretical values of OHO active biomass concentrations for the 10 and 20 days sludge age systems respectively. A combined comparison between the 10 and 20 days sludge age system mixed liquor is shown in Fig. 4.13.

In Fig. 4.13, the batch test data for Sewage Batch No.9 are marked rejected even though acceptable parent system N and COD mass balances, %COD recoveries and R^2 were obtained, for reasons described in Sections 4.4 and 4.5.

From Fig. 4.13(a and b), the general trends for the 10 and 20 day sludge age mixed liquors show remarkable similarity. As described in the individual comparisons above, for both sets of batch tests three regions can be identified (see Sections 4.4 and 4.5) which correspond closely. Further, as noted above, there is close similarity between the data obtained in this investigation and that of Beeharry *et al.* (2001). This similarity in the OHO active organism's behaviour in the 10 and 20 day sludge age mixed liquors and in the investigation of Beeharry *et al.* would suggest that the difference in the correspondence between theoretical and measured OHO biomass concentration observed by Wentzel *et al.* (1998) at the different sludge ages is not caused by the sludge age itself. The poor agreement between the measured and theoretical OHO active biomass for the 20 days sludge age mixed liquor of Wentzel *et al.* (1998) and Ubisi *et al.* (1997) appears to be caused by some factor(s) which does not depend on sludge age. Possible reasons for the poor agreement that is common for both the 10 and 20 days sludge age MLE system mixed liquors will be provided in Chapter6.

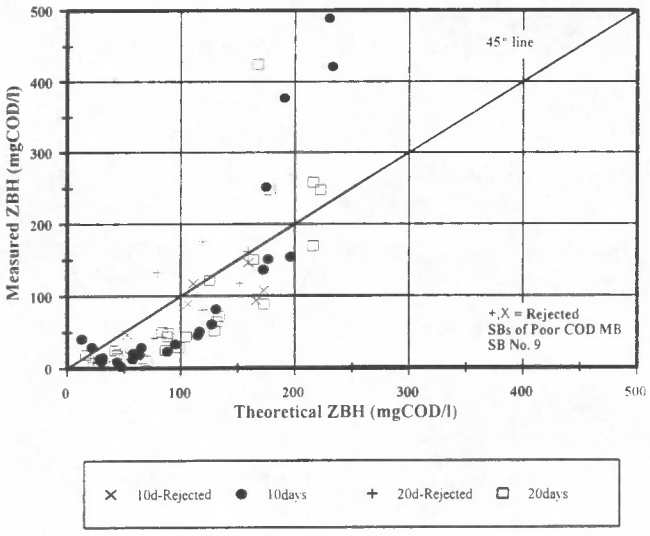


Fig. 4.13(a): Modified batch tests results; graph of measured versus theoretical OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] for the various sewage batches for the 10 and 20 days MLE activated sludge system; Scale 500 × 500 mgCOD/ℓ.

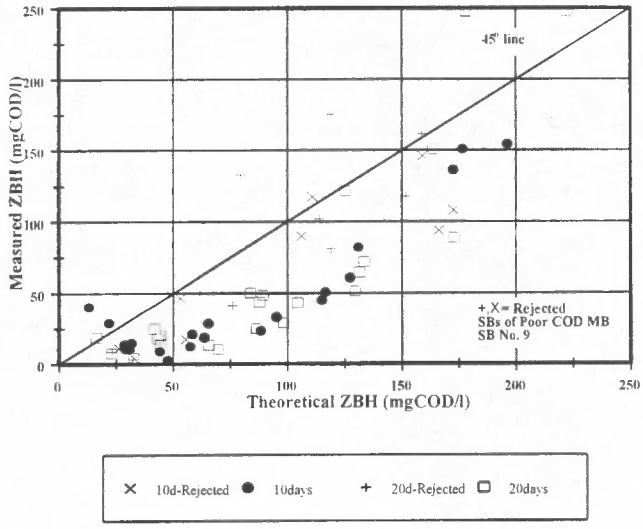


Fig. 4.13(b): Modified batch tests results; graph of measured versus theoretical OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] for the various sewage batches for the 10 and 20 days MLE activated sludge system; Scale 250 × 250 mgCOD/ℓ.

4.7 EFFECT OF ALUMINIUM SULPHATE

Beeharry *et al.* (2001) investigated the effect on the batch test results of the precipitation of the phosphorus by aluminium sulphate during flocculating and filtering the wastewater. It was noted that the use of aluminium sulphate as a flocculent possibly removes a large fraction of the available phosphorus required for the growth of the OHO active biomass. Thus, this would have a direct impact on the OHO active biomass concentration measured in the batch tests, since the growth of OHOs would be restricted by non-availability of phosphorus. It was postulated that this may be the reason for the deviation from the 1:1 correlation line observed; however from the results of Beeharry *et al.*, (2001), it seemed that the effect of adding P to the batch test was inconsistent, and not entirely conclusive.

In this research, the effect of the alumunium sulphate was again investigated. Two parallel batch tests were done, with the same volume of mixed liquor (200mℓ) drawn from the same 20 day sludge age parent system added to the batch tests. To one batch reactor, *flocculated-filtered* wastewater plus mixed liquor were added and to the other, *flocculated-filtered* wastewater plus mixed liquor and 5 mℓ of stock potassium hydrogen phosphate (K_2HPO_4, stock at 33.68 g/ℓ) were added per ℓ of wastewater (10 mgP/ℓ *batch reactor*).

The OHO active biomass values measured at the start of each batch test are summarized in Table 4.9. The R^2 values obtained for the batch tests were reasonable, with R^2 value of 0.941 and 0.947 for the batch tests with and without phosphorus addition respectively and the %COD recoveries were 93.2% and 96.3% respectively. The high R^2 values and %COD recoveries lend credibility to the batch tests.

Table 4.9: Results for batch tests with a mixture of *flocculated-filtered* wastewater (WW) and mixed liquor (ML) {and phosphorus, P}: Batch test numbers, dates of batch tests, volumes added, COD recoveries, *measured* OHO active biomass present the start of the batch test ($Z_{BH(0)}$) and the *projected* parent system mixed liquor (ML) active biomass.

Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		COD Recov. (%)	Regression			ZBH(0) (mgCOD/l)	
			WW	ML		Y-int	Slope	R2	Measured	
									Batch Test	ML
-	P-added	26 01	2.8	0.2	93.2	1.0984	0.162	0.941	31.1	466.2
-	P-non	26 01	2.8	0.2	96.3	1.2053	0.154	0.947	36.0	539.4

* Evaluated with the previous sewage batch, Sewage Batch No. 12

In Table 4.9, the measured OHO active biomass concentrations at the start of each batch test with and without phosphorus addition are shown; the concentrations with and without phosphorus addition were determined as 31.1 and 36.0 mgCOD/ℓ respectively. The difference in OHO acitive biomass concentrations between the batch tests with and without phosphorus addition is small (~ 14%) and can be ascribed to differ to experimental error. From the above experimental results, it could be concluded that phosphorus is not limiting in the batch tests.

Fig. 4.14 (a) and (b) shows the OUR - time curves for the batch tests with and without phosphorus addition respectively. The OUR profiles are near exact duplicates, *i.e.* the OHOs behave identically whether the batch test contained the excess phosphorus or not.

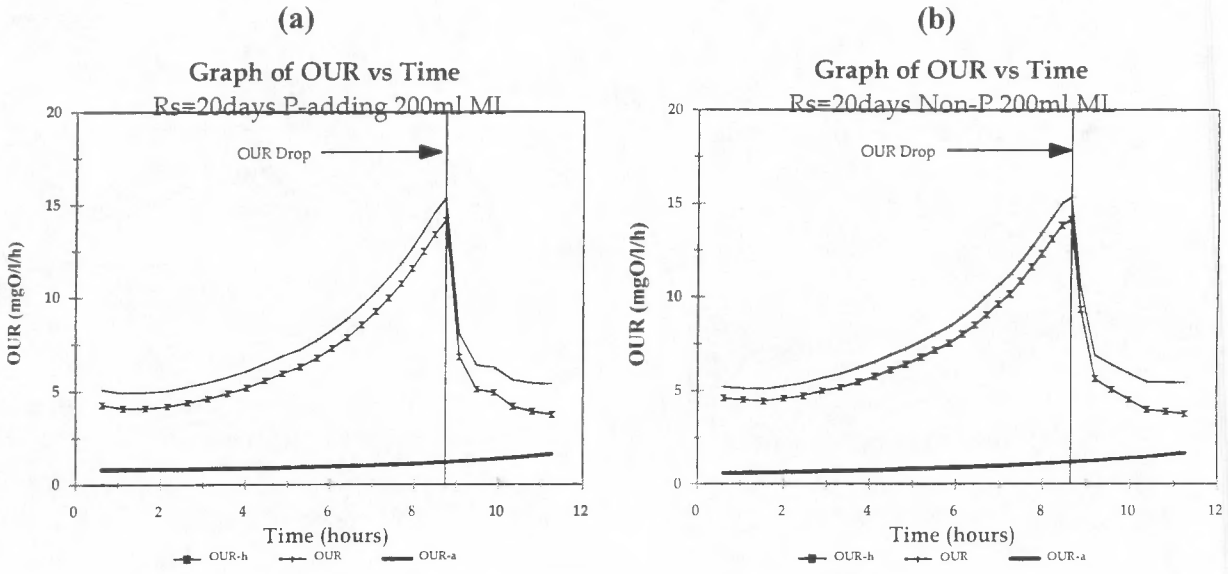


Fig. 4.14 : Oxygen Utilization Rate (OUR) response with time for a modified batch test on a mixture of flocculated-filtered wastewater (2.8ℓ) and mixed liquor (0.2ℓ) drawn from the aerobic reactor of the 20 days sludge age parent system (a) *with* and (b) *without* phosphorus addition.

A further uncertainty in the investigation of Beeharry *et al.* (2001) was the effect of aluminium sulphate (alum) addition to the parent systems on the data analysis. In their investigation, Beeharry *et al.* (2001) added alum to the parent systems to contain the mixed liquor in the systems, which was being lost due to secondary settling tank failure. They speculated that possibly the alum addition influenced the analysis of the parent systems, to calculate the theoretical $Z_{BH(0)}$, and hence caused the deviation between measured and theoretical $Z_{BH(0)}$ that they observed. In this investigation, alum was also added, but only during some of the sewage batches when batch tests were conducted (see Chapter 3, Table 3.3). However, no difference in the batch test data between periods when alum was added and when it was not was discernable.

Thus, addition of alum either to the parent system or to the wastewater in preparation for the batch tests had no significant effect on the results. It can be concluded, therefore, that the alum was not the cause for the deviation between theoretical and measured $Z_{BH(0)}$.

4. 9 DILUTION EFFECT

In measuring nitrate and nitrite concentrations, Beeharry *et al.* (2001) observed that, whenever sample dilution was increased to bring the nitrate concentrations into the range that can be measured (*Technicon Auto Analyser* method), for example, increasing dilution of samples from two times dilution to five times dilution, there was always a step increase in the nitrate/nitrite concentration. In interpretation and analysis of the batch test, the best exponential or linear fit to the nitrate/nitrite experimental data was of crucial importance, as this impacted on the OUR due to nitrification, and consequently on OUR due to OHO growth. This in turn influenced, to a large extent, the slope and the y-intercept value required to calculate the OHO active biomass concentration at the start of a batch test. To take account of this effect, Beeharry *et al.* made up the nitrate standards in the same background matrix as in the batch tests, i.e. flocculated filtered wastewater.

In this investigation, the dilution of samples for nitrate/nitrite analysis was kept at a fixed value for all samples collected during the whole batch test period, to prevent the step change in the nitrate/nitrite concentration. In addition, the interference of the sample matrix on nitrate determination was investigated to ensure accuracy in the measured nitrate concentration. The interference on nitrite determination was not investigated in this research, because Beeharry *et al.* (2001) had already concluded that sample matrix does not interfere in measuring nitrite. The extent of sample matrix interference on nitrate measurement at various dilutions was investigated, and is shown graphically in Fig. 4.15. The method followed was as set out by Beeharry *et al.* (2001).

From Fig. 4.15, it is clear that the more the samples were diluted, the less the interference on nitrate determination, with the undiluted samples having the largest impact. As an example, a sample giving a peak height 50 mm in the method, diluted in *distilled water* would apparently have a nitrate concentration of about 0.5 mgN/ℓ, whereas in *undiluted flocculated-filtered wastewater*, the nitrate concentration would be as high as 1.1 mgN/ℓ. This is a significant difference, when considering the sensitivity of the batch test analysis. Accordingly, for all the batch test, nitrate data were corrected using appropriate nitrate standard curves for the specific dilution.

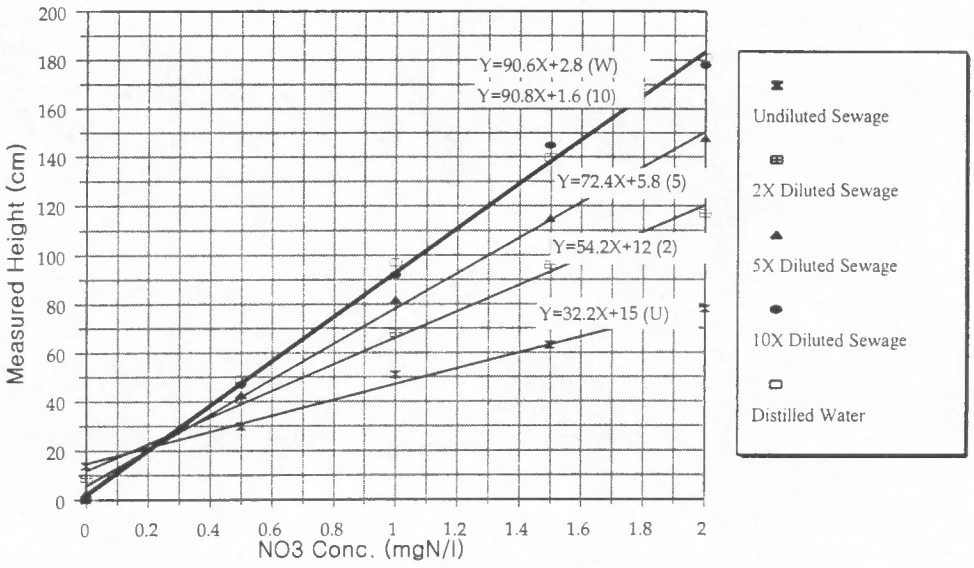


Fig. 5.20 : Nitrate standard curves developed for various dilutions of flocculated-filtered wastewater; measured height is the height of the peak generated in the *Technicon Auto Analyzer* method.

4.9 CONCLUSIONS

This Chapter describes the modified batch test procedure, the interpretation of the recorded data and the evaluation of the batch test results for modified batch tests conducted on mixed liquor drawn from two parent laboratory-scale MLE activated sludge systems operated in parallel at 10 and 20 days sludge ages respectively. In total, 35 batch tests were conducted on mixed liquor drawn from the 10 day sludge age parent system, and 35 on that drawn from the 20 day sludge age parent system. From the investigation, the following aspects and conclusions are of significance:

- Beeharry *et al.* (2001) found that apart from the generation of nitrate with time, a detectable amount of nitrite was also generated in the batch tests. They also found that the nitrate/nitrite concentration - time profiles could be represented by either a linear or an exponential increase, the selection depending on the fit to the data. In this investigation, similar observations were made. Accordingly increases in both the nitrate and nitrite concentrations had to be taken into account when analyzing the results of the batch tests. Further, for the various batch tests, both linear and exponential fits were used, with the best fit selected case by case. Thus, selecting the types of fits to the nitrate / nitrite time profiles is not general, but must be based on the data for a particular batch test.

- In general, %COD recoveries were good with only 8 out of 35 batch tests on 10 day sludge age mixed liquor yielding %COD recoveries < 90%, and only 7 out of 35 for the 20 day sludge age mixed liquor. Excluding data for those batch tests that deviated from the "true" normal probability line (4 for 10 days; 3 for 20 days), the mean %COD recoveries were 95.2 and 94.8 % for the batch tests on 10 and 20 day sludge age mixed liquor respectively, with sample standard deviations of 5.3 and 4.5 % respectively. The %COD recoveries are somewhat lower than that obtained by Cronje *et al.* (2000) (100.5%), but are similar to those of Beeharry *et al.* (2001) (97.8 and 95.9 %). The good %COD recoveries lend credibility to the experimental data.

- For the OHO maximum specific growth rate on SBCOD (K_{MP}), excluding the batch tests with low %COD recoveries, statistical analysis gave mean K_{MP} of 1.37 and 1.42 /d for the 10 and 20 day sludge age mixed liquors respectively, with sample standard deviations of 0.412 and 0.428 /d respectively. The close means (difference 3.5% not statistically significant at 95% confidence interval, t-test) indicates that the sludge age did not have a significant influence on the value for this parameter. The values are larger than that measured by Cronje *et al.* (2000) (0.84 /d), but are close to the values measured by Beeharry *et al.* (2001) (1.49 and 1.38 /d). Further, the values are close to the default value for K_{MP} in the UCT kinetic simulation model, of 1.35 /d (Dold *et al.*, 1991). It should be noted that there was some measure of uncertainty in the determination of K_{MP} at the relatively large and small mixed liquor volumes (see Section 4.4.2 and 4.5.2). However, it was concluded that the uncertainty was not large.

- For the OHO maximum specific growth rate on RBCOD (μ_H), for batch tests on mixed liquors from both parent systems, a clearly discernable trend was noted: As the volume of mixed liquor added to the batch test increased, the value for μ_H decreased. This indicates that one (or more) factor has a dominating influence, which precluded statistical analysis of the data. Re-examination of the data of Beeharry *et al.* (2001) indicated that they obtained, but did not note, a similar trend (see Cronje *et al.*, 2002). Possible reasons for this trend will be examined in Chapter 6.

- In comparing the measured OHO active biomass concentration at the start of the batch test $Z_{BH(0)}$ with the theoretical value, the data for both the 10 and 20 day sludge age mixed liquor showed very similar trends. Also, superficially both comparisons bear a strong resemblance to the data of Beeharry *et al.* (2001), namely that there is a correspondence, but the values plot parallel to the 1:1 correspondence line. However, if the data is examined more closely, for both the 10 and 20 day mixed liquors three regions can be identified:

  (i) Theoretical $Z_{BH(0)} < 30$ mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values decrease, to approach near zero. Beeharry *et al.* (2001) did not collect data in this region, so a comparison with their data is not possible.

  (ii) 30 mgCOD/ℓ < Theoretical $Z_{BH(0)} < 150$ mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values correspondingly increase parallel to a 1:1 correspondence line, but below it. This trend is near identical to that observed by Beeharry *et al.* (2001), whose data falls primarily in this region.

  (iii) Theoretical $Z_{BH(0)} > 150$mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values increase sharply to cross the 1:1 correspondence line. Beeharry *et al.* (2001) collected limited data in this region, but the data available indicates it is consistent with the observation here.

  The close similarity in trends between the 10 and 20 day sludge age mixed liquors, and the consistency with the data of Beeharry *et al.* (2001) indicate that the observed deviation in measured and theoretical $Z_{BH(0)}$ values is not a function of sludge age, or of this investigation.

In this research, the effect of the alumunium sulphate (alum) addition to the wastewater in preparation for the batch test and to the parent system to contain the mixed liquor, were examined. For alum addition to the wastewater for the batch tests, Beeharry *et al.* (2001) had noted that this may cause precipitation of phosphorus (P), and hence P limitation in the batch test. Their experiments in this regard were inconclusive, and hence this possibility was investigated:

- Parallel batch tests identical except that P was supplemented to the one and not the other, gave virtually identical results - OUR profiles were virtually identical and the measured $Z_{BH(0)}$ values were very similar (14% difference).

In their investigation, Beeharry *et al.* (2001) added alum to their parent system to contain the mixed liquor. They speculated that this possibly could be the causes for deviation between measured and theoretical $Z_{BH(0)}$ values. In this investigation, alum was also added to the parent systems, but only during some of the sewage batches (3 out of 10) when batch tests were conducted:

- No difference in the batch test data between periods when alum was added and when it was not was discernable.

Hence, it could be concluded that:

- Addition of alum, either to the parent system or to the wastewater in preparation for the batch tests, had no discernable influence on the batch test results. Alum addition did not cause the observed deviation between theoretical and measured $Z_{BH(0)}$ values.

The sample matrix interference on nitrate measurement reported by Beeharry *et al.* (2001) was observed in this investigation also. To counter this, in this research:

- The dilution of nitrate/nitrite samples was kept at a fixed value during the entire batch test period and the nitrate standards were prepared in the same background matrix as the samples and diluted with distilled water in the same ratio as the samples.

In the research of Ubisi *et al.* (1997 a,b) and Wentzel *et al.* (1998), the measured and theoretical OHO active biomass concentrations of mixed liquor from the 12 day sludge age parent system showed a close 1:1 correlation while those for mixed liquor from the 20 day sludge age parent system showed poor correlation. Ubisi *et al.* (1997a,b) and Wentzel *et al.* (1998) did not provided any explanation for this inconsistency. In the investigation of Cronje et al. on mixed liquor drawn from a 10 day sludge age parent system, a reasonably close 1:1 correlation was found. In contrast, in the investigation of Beeharry *et al.* (2001) on mixed liquor from a 10 day sludge age parent system, the correspondence line between measured and theoretical $Z_{BH(0)}$ fell parallel to the 1:1 correspondence. In this investigation on mixed liquors from 10 and 20 day sludge age parent systems, the correspondence was similar to that of Beeharry *et al.* (2001) (but did show differences due to the larger range of data collected). Clearly, sludge age is not the factor causing the various observed deviations. The causes remain to be identified and will be investigated further in Chapters 5 and 6. At this stage, it is possible to conclude that the batch test method does provide insight into the OHO active fraction of activated sludge mixed liquor (consistency in data at two very different sludge ages), but as constituted does not provide a sufficiently accurate measure of this parameter.

CHAPTER 5

BATCH AEROBIC DIGESTION TEST TO QUANTIFY OHO ACTIVE BIOMASS

5.1 INTRODUCTION

The applicability of the modified batch test to quantify OHO active biomass was investigated in Chapter 4. The modified batch test was applied to mixed liquors drawn from both the 10 and 20 days parent MLE systems. From a comparison of the modified batch test measured to the theoretical OHO active biomass concentrations, it was concluded that there is a remarkable similarity in the data for the two parent systems' mixed liquors, but that the agreement of the measured with the theoretical values was poor. No immediate explanation for this poor agreement was evident, and this was further investigated. This further investigation proceeded in two directions: In one, an alternative method to quantify OHO active biomass was applied, to determine whether the poor correspondence was due to the batch test method itself, or due to an inconsistency in the theoretical models applied to N removal activated sludge systems. In the second, the microbial OHO behaviour in the modified batch test were investigated further, to evaluate whether the batch test conditions induced OHO behaviour that possibly deviated from that in the steady state parent system. In this Chapter, the first direction is explored with the batch aerobic digestion test investigated as an alternative method to quantify OHO active biomass, and the applicability of the test evaluated by comparing the measured and theoretical OHO active biomass concentrations.

The batch aerobic digestion test was first proposed by Marais and Ekama (1976). In this test, mixed liquor is drawn from an activated sludge system and batch aerobically digested (no substrate supplied) for a period of about 10 days. By monitoring the Oxygen Utilization Rate (OUR) in the test, Marais and Ekama were able to determine the net specific OHO endogenous respiration rate (b_{HT}), the main focus of their study. They also noted, but did not investigate in any depth, that the OHO active biomass concentration at the start of the test can be quantified. Thus, this test method provides an independent means to quantify the OHO active biomass concentration in activated sludge mixed liquor, and hence should provide further insight into the data obtained from the modified batch test above.

In this Chapter, the derivation and application of the equations describing the aerobic batch digestion of mixed liquor proposed by Marais and Ekama (1976) will be set out. The aerobic batch digestion test will be applied to mixed liquors drawn from the two parent systems described in Chapter 3. From these tests and the measured OHO active biomass concentrations calculated with the derived equations, the measured values will be compared with the theoretical OHO active biomass concentrations. From this comparison and the information obtained from the batch aerobic digestion test, possible explanations will be sought for the poor correlation between the theoretical OHO active biomass concentrations and the values measured in the modified batch test (Chapter 4).

5.2 EXPERIMENTAL PROCEDURE

5.2.1 Experimental approach

In this experimental investigation, the aerobic batch digestion method of Marais and Ekama (1976) will be applied to quantify the OHO active biomass concentration of mixed liquor drawn from the two parent activated sludges systems described in Chapter 3. These measured values then will be compared to the theoretical OHO active biomass concentrations for the two parent systems as determined via the procedures set out in Chapter 3.

In developing a mathematical model to describe the aerobic batch digestion test, Marais and Ekama (1976) noted that the OHO active biomass principally mediates the two biological processes of growth and endogenous respiration. Both processes are directly related to the carbonaceous oxygen consumption. However, one of the processes, growth, can be excluded from the aerobic digestion description because external substrate for growth of OHO active biomass is not supplied under the conditions present in aerobic digestion and the endogenous respiration approach is followed (see below). Thus, the carbonaceous oxygen consumption in the aerobic digestion is attributed solely to the process of endogenous respiration. Accepting endogenous respiration as the dominant OHO mediated process, Marais and Ekama formulated a mathematical model describing OHO behaviour in the aerobic batch digestion. In terms of this model, the initial concentration of OHO active biomass (X_{BHi}) and the specific endogenous respiration rate (b_{HT}) can be calculated from the carbonaceous Oxygen Utilization Rate (OUR_{ct}). Marais and Ekama noted that if the mixed liquor for the digestion test is drawn from a nitrifying activated sludge system, nitrification will take place in the digestion test on the ammonia released in the endogenous respiration processes, giving rise to a nitrification OUR (OUR_{nt}). Hence, the measured OUR (OUR_{tt}) is the sum of the OUR_{ct} and OUR_{nt}. Accordingly, to determine the OUR_{ct}, from which X_{BHi} is determined (since b_{HT} is determined from the slope of a OUR - time plot which is not affected by nitrification, OUR_{nt} does not influence the estimate of b_{HT}, see Marais and Ekama, 1976), the OUR_{nt} needs to be determined and subtracted from OUR_{tt}. Accepting complete nitrification Marais and Ekama formulated equations to determine OUR_{nt} and hence OUR_{ct}.

Thus, in the aerobic batch digestion test, the OUR with time needs to be monitored (for OUR_{tt}). Additionally, pH, nitrate, nitrite, and free and saline ammonia (FSA) with time need to be monitored to ensure that nitrification is complete. From this data, with the theory of Marais and Ekama, OUR_{nt} can be calculated, and hence OUR_{ct}. From OUR_{ct}, the X_{BHi} can be calculated.

Note that in the batch aerobic digestion tests, the endogenous respiration theory (Dold *et al.*, 1980; WRC, 1984) is used, not the death regeneration theory (Dold *et al.*, 1980). For the batch aerobic digestion test, as for the steady state parent system, where all the biodegradable COD has been depleted, the two approaches of endogenous respiration and death regeneration give the same nett result with the appropriate selection of constants, *i.e.* both approaches produce the same loss of OHO active biomass, utilization of oxygen and generation of endogenous residue (Dold *et al.*, 1980). However, the endogenous respiration approach allows a simple analytical procedure to be developed

to provide a solution; accordingly, the endogenous respiration approach is applied in the batch aerobic digestion test.

5.2.2 Batch aerobic digestion test

1.56ℓ and 1.32ℓ of mixed liquor were drawn from the aerobic reactors of the 10 and 20 days sludge age parent MLE systems respectively. The quantity of mixed liquor drawn for the batch aerobic digestion test is the same amount of mixed liquor wasted from the respective parent system for 2 days to maintain the sludge age *i.e.* the amount of mixed liquor is twice the daily mixed liquor wastage from the parent system: Although it may be preferable to carry out the batch test on a larger mixed liquor volume, the volume of mixed liquor was restricted to prevent the negative impact on the steady state parent system of over wasting. The mixed liquors drawn from the two parent systems were placed into separate batch reactors and immediately the batch aerobic digestion tests started.

The batch reactor was aerated by passing low pressure air through a small bore Perspex tube terminating at the bottom of the reactor, at the end of which was an air-stone (see Fig. 5.1). A dissolved oxygen (DO) probe (YSI) from an automatic DO meter/OUR logger was immersed in the solution. The oxygen supply and OUR response in the batch test were measured using an automated technique (Randall *et al.*, 1991). The DO was raised to ± 5 mgO/ℓ, the air was switched off automatically and the decrease in DO with time was monitored; when the DO reached ± 3 mgO/ℓ, the air was switched on again automatically and the cycle repeated. Automatically, for each cycle the slope of the DO-time data during the air off period was determined by linear regression; this gives the OUR, which was stored by the meter (together with regression analyses and time data). OUR data with linear correlation coefficient (R^2) < 0.95 were rejected. A typical OUR (mgO/ℓ/h) versus time (h) response is shown plotted in Fig. 5.2; the OUR decreased steadily due to the endogenous respiration process. The batch aerobic digestion tests were carried out for about 10days, until the OUR values were too low to get the interpretable data. The batch tests were carried in a laboratory with the temperature controlled to 20°C, the same temperature as for the two parent systems.

At the beginning of the test and at the same time on each of the following days, (i) pH was measured to ensure pH was sufficiently high for complete nitrification (pH > 7) and (ii) samples were drawn from the batch reactor, immediately filtered through 0.45 μm filter paper, 2 - 3 drops of $HgCl_2$ were added to the filtrate which was stored for subsequent nitrate, nitrite and Free and Saline Ammonia (FSA) analysis. For all the batch aerobic digestion tests, the pH was sufficiently high to ensure complete nitrification, indicated by the fact that the FSA was constantly kept at a low concentration (see Fig. 5.5), *i.e.* FSA did not accumulate during the test.

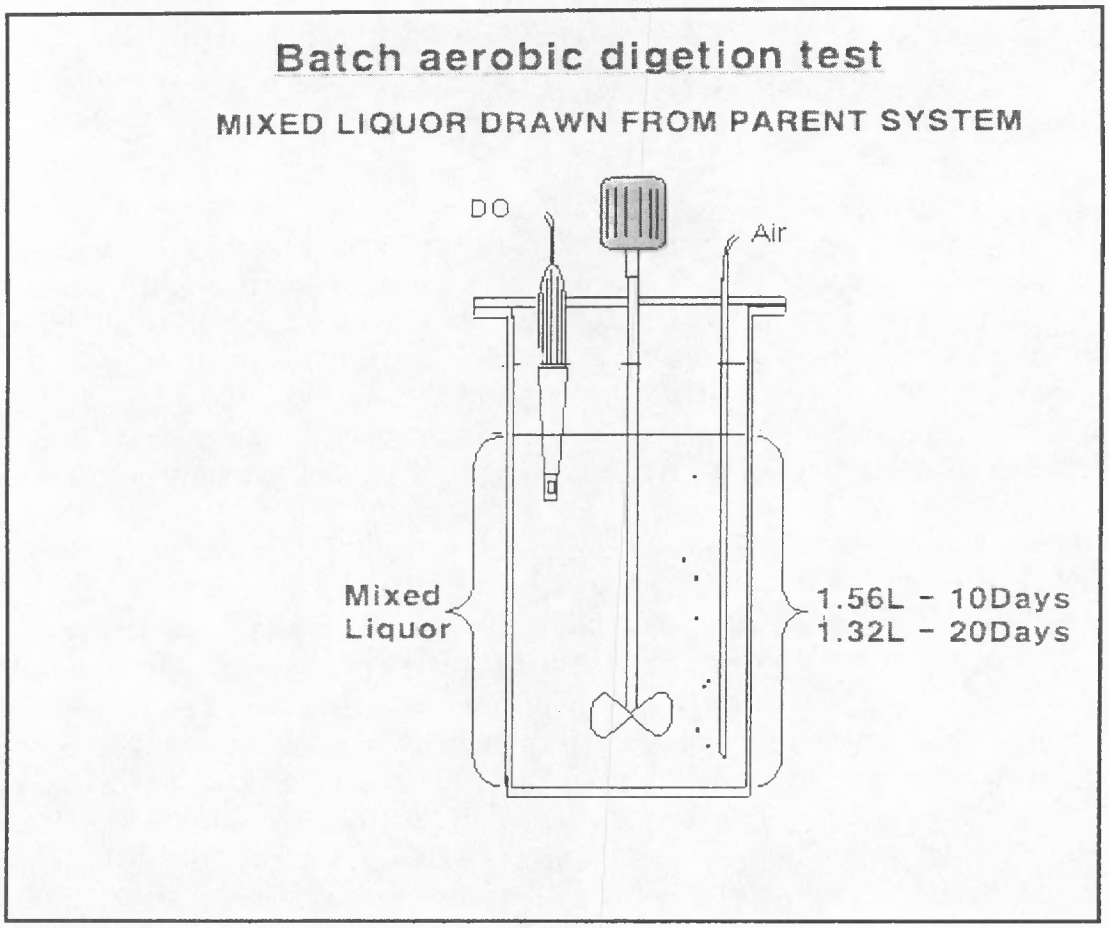


Fig. 5.1: Single batch reactor arrangement used to conduct batch aerobic digestion tests with mixed liquor drawn from the 10 and 20 days sludge age MLE parent systems (Chapter 3).

5.3 DATA INTERPRETATION AND ANALYSIS

5.3.1 Derivation and application of the equations of Marais & Ekama (1976) and WRC (1984)

Marais and Ekama (1976) have developed a conceptual framework and mathematical model describing the aerobic batch digestion test, that is consistent with activated sludge theory (Dold *et al.*, 1980; WRC, 1984). According to Marais and Ekama (1976), sludge entering an aerobic digestor can be characterized by division into two fractions : (1) inert and (2) active fractions. The inert material entering the aerobic digestor is composed of the inert and endogenous fractions of the waste

sludge and the active material is the OHO active fraction of the waste sludge from the activated sludge process (the nitrifying autotrophic organism (AO) active biomass can be considered negligible compared to the other two fractions). Both of these fractions can be expressed in terms of either the volatile settleable solids (VSS) or total settlable solids (TSS) (or the COD). During digestion one may assume that the inert mass in the influent into the digestor remains unaffected; the OHO active biomass reduces by endogenous respiration (see 5.2 above), and gives rise to two ancillary effects: (1) generation of unbiodegradable settleable organic solids (endogenous residue) and (2) oxygen demand for endogenous respiration. For these basic processes, Marais and Ekama formulated mathematical expressions as follows:

(1) Inert organic solid material (X_I) in the influent is unaffected by digestion:

$$X_{I(t)} = X_{Ii} \qquad \text{(mgVSS/}\ell\text{)} \qquad (5.1)$$

where

$X_{I(t)}$ = inert organic particulate concentration at time t (mgVSS/ℓ)
X_{Ii} = initial inert organic particulate concentration (mgVSS/ℓ)

(2) OHO active biomass degrades according to:

$$\frac{dX_{BH(t)}}{dt} = -b_{HT} \cdot X_{BH(t)} \qquad (5.2)$$

where

b_{HT} = specific endogenous mass loss rate at temperature T°C (/d)
$X_{BH(t)}$ = OHO active biomass concentration at time t (mgVSS/ℓ)

(3) A fraction, f, of the OHO active mass which disappears, remains as unbiodegradable solid material termed endogenous residue, according to:

$$\frac{dX_{E(t)}}{dt} = f \cdot b_{HT} \cdot X_{BH(t)} \qquad (5.3)$$

where

f = unbiodegradable particulate fraction of OHO active biomass (mgCOD/mgVSS)
$X_{E(t)}$ = endogenous residue concentration at any time (t)

(4) Oxygen requirement for endogenous respiration is given by:

$$O_{e(t)} = f_{cv} \cdot (1 - f) \cdot b_{HT} \cdot X_{BH(t)} \qquad (5.4)$$

where

f_{cv} = COD/VSS ratio for OHO active biomass (mgCOD/mgVSS)
$O_{e(t)}$ = OHO endogenous respiration oxygen demand at time t (mgO/ℓ/hr)

In the equations above, the mass of the various sludge components are defined in terms of the VSS instead of the TSS. Both can be used if VSS/TSS remains constant, but the ratio often changes, particularly if nitrification occurs. Hence, it is more usual to express the components with respect to the VSS parameter. With little difficulty, the components can be similarly expressed in terms of the COD parameter if required.

In the aerobic batch digestion test, two possible methods can be used to determine X_{BHi} and b_{HT}. The one method determines the parameters from Volatile Solids measurements with time, while the other method uses Oxygen Utilization Rates (OURs). According to Marais and Ekama (1976), the latter is recommended because of its ease of measurement and accuracy. Thus, in this investigation, the method using OURs was applied to interpret the data from the batch aerobic digestion test, as follows:

The carbonaceous OUR (OUR_{ct}) at time t in the batch digestor is equivalent to $O_{e(t)}$ in Eq. (5.4) above, *i.e.*:

$$O_{c(t)} = f_{cv} \cdot (1 - f) \cdot b_{HT} \cdot X_{BH(t)} \qquad (mgO/\ell/d) \qquad (5.5)$$

Integrating Eq. (5.2) above, an expression can be derived for the OHO active biomass concentration at any time t in the test:

$$X_{BH(t)} = X_{BHi} \cdot e^{-b_{HT} \cdot t} \qquad (mgVSS/\ell) \qquad (5.6)$$

Substituting Eq. (5.6) for $X_{BH(t)}$ in Eq. (5.5):

$$O_{c(t)} = f_{cv} \cdot (1 - f) \cdot b_{H} \cdot X_{BHi} \cdot e^{-b_{H} \cdot t} \qquad (mgO/\ell/d) \qquad (5.7)$$

Equation (5.7) does not take into account the nitrification of the nitrogen released through endogenous respiration. Accordingly, Eq. (5.7) must be modified to incorporated the oxygen demand for nitrification.

The rate of loss of OHO active biomass is given by Eq. (5.2). Of this mass loss, only a fraction (1-f) is biodegradable. If it is accepted that a fraction (f_n) of this biodegradable material is nitrogen available for nitrification and is subsequently completely nitrified, the nitrification oxygen demand, O_{nt} is given by:

$$O_{n(t)} = 4.57 \cdot f_n \cdot (1 - f) \cdot b_{HT} \cdot X_{BH(t)} \qquad (mgO/\ell/d) \qquad (5.8)$$

where

$O_{n(t)}$ = nitrification oxygen demand (mgO/ℓ/d) at any time t
f_n = fraction of nitrogen in the OHO active biomass (mgN/mgVSS)
4.57 = oxygen required to nitrify 1 mgN to nitrate (mgO/mgN)

Substituting Eq. (5.6) for $X_{BH(t)}$ in Eq. (5.8) gives:

$$O_{n(t)} = 4.57 \cdot f_n \cdot (1 - f) \cdot b_{HT} \cdot X_{BHi} \cdot e^{-b_{HT} \cdot t} \qquad (mgO/\ell/d) \qquad (5.9)$$

The total oxygen demand ($O_{t(t)}$) at any time t in a batch digestion is given by the sum of the OHO (carbonaceous) and AO (nitrification) oxygen demands.

$$O_{t(t)} = O_{c(t)} + O_{n(t)} \qquad (mgO/\ell/d) \qquad (5.10)$$

$$= f_{cv} \cdot (1 - f) \cdot b_{HT} \cdot X_{BHi} \cdot e^{-b_{HT} \cdot t} + 4.57 \cdot f_n \cdot (1 - f) \cdot b_{HT} \cdot X_{BHi} \cdot e^{-b_{HT} \cdot t}$$

$$= (f_{cv} + 4.57 \cdot f_n) \cdot (1 - f) \cdot b_{HT} \cdot X_{BHi} \cdot e^{-b_{HT} \cdot t}$$

Eq. (5.7) or Eq. (5.10) for the OUR in an aerobic digestor under batch conditions without or with nitrification respectively provide a convenient experimental procedure to determine X_{BHi} and b_{HT}, *i.e.* the OHO active biomass concentration in an activated sludge mixed liquor and the specific endogenous respiration rate of the OHO active biomass, as follows:

Accepting nitrification will be present in the aerobic batch digestion tests to be conducted in this investigation, Eq. (5.10) is applicable. Taking natural log (ℓn) of Eq. (5.10):

$$\ell n O_{t(t)} = \ell n[(f_{cv} + 4.57 f_n) \cdot (1 - f) \cdot X_{BHi} \cdot b_{HT}] - b_{HT} \cdot t \qquad (5.11a)$$

In Eq. (5.11a) above, the time related units ($O_{t(t)}$, b_{HT}, t) need to be consistent. Since b_{HT} conventionally has time units (/d), the other two parameters are also in terms of days. However, $O_{t(t)}$ usually is measured in mgO/ℓ/h. Thus, the plot would be of $O_{t(t)}$ in mgO/ℓ/h versus time in h. With this plot, to resolve the time inconsistency with b_{HT}, Eq. (5.11a) can be re-expressed as:

$$\ell nO_{t(t)} = \ell n[(f_{cv} + 4.57 f_n) \cdot (1 - f) \cdot X_{BHi} \cdot b_{HT} / 24] - b_{HT} / 24 \cdot t \qquad (5.11b)$$

Hence, plotting $\ell n(O_{t(t)})$ (mgO/ℓ/h) versus time (h) (see Fig. 5.3) yields a straight line with a slope of $b_{HT}/24$. Since the slope is independent of nitrification, the value for b_{HT} can be determined from the slope of the measured OUR from a batch aerobic digestion test.

$$\text{Slope} = -b_{HT} / 24 \qquad (5.12)$$

In contrast, the y-intercept is dependent on nitrification. However, this is taken into account in Eq. (5.11a,b) and hence the initial OHO active biomass concentration can be determined directly from the y-intercept value:

$$\text{Y - intercept} = \ell n[(f_{cv} + 4.57 f_n) \cdot (1 - f) \cdot X_{BHi} \cdot b_{HT} / 24] \qquad (5.13)$$

Thus, X_{BHi} can be determined as follow:

$$X_{BHi} = \frac{e^{\text{Y-intercept}}}{(f_{cv} + 4.57 \cdot f_n) \cdot (1 - f) \cdot (-\text{Slope})} \qquad (5.14)$$

Hence, by monitoring the OUR in the aerobic batch digestion of activated sludge mixed liquor, following the procedures above the specific endogenous mass loss rate and the OHO active biomass concentration in the mixed liquor can be determined. It should be noted that these procedures accept complete nitrification; if nitrification is incomplete, the procedures are invalid and cannot be applied. Accordingly, the batch test needs to be monitored to ensure nitrification is complete.

To illustrate the calculation procedure, the data from batch aerobic digestion test No. D2 will be used as an example. This test was conducted on mixed liquor drawn from the aerobic reactor of the 20 days sludge age parent system (described in Chapter 3), while this system was receiving Sewage Batch No. 16 as influent (see Chapter 3, Tables 3.6 and 3.7). For this sewage batch, the characteristics of the parent system mixed liquor were measured as f_{cv} = 1.379 and f_n = 0.080 (Chapter 3, Table 3.7). The aerobic batch digestion data are shown plotted in Figs. 5.2, 5.3, 5.4 and 5.5. From Fig. 5.5, it is evident that the FSA concentration remained approximately constant at a relatively low value. Thus, it could be accepted that nitrification was complete and the procedure described above could be applied. From the ℓn OUR versus time plot (Fig. 5.3):

Slope = -0.01099 /h

Y-intercept = 2.4741

Hence, from Eq. (5.12) and noting the temperature of 20°C:

b_{H20} = - Slope/24 = 0.26 /d

Substituting the measured f_{cv} and f_n values above into Eq. (5.14), and the slope and y-intercept determined from the ℓn OUR versus time plot (Fig 5.3):

$$X_{BHi} = \frac{e^{2.4741}}{(1.379 + 4.57 \cdot 0.080) \cdot (1 - 0.2) \cdot 0.01019} = 774 \text{ mgVSS/ℓ}$$

The value for X_{BHi} above is in terms of VSS units. This can be readily converted to COD units with the measured COD/VSS ratio for the mixed liquor (f_{cv} = 1.379 mgCOD/mgVSS):

$$Z_{BHi} = f_{cv} \cdot X_{BHi}$$
$$= 1.379 \cdot 774$$
$$= 1076 \text{ mgCOD/ℓ}$$

Knowing values for b_{HT} and X_{BHi} determined from the batch test data, the theoretical carbonaceous OUR ($O_{c(t)}$) and nitrification OUR ($O_{n(t)}$) with time could be calculated with Eqs. (5.7) and (5.8) respectively, and hence the total OUR ($O_{t(t)}$). For the example, these are shown plotted in Fig. 5.2, together with the measured OUR. There is a consistent close fit of predicted total OUR to the measured OUR, indicating consistency in the data.

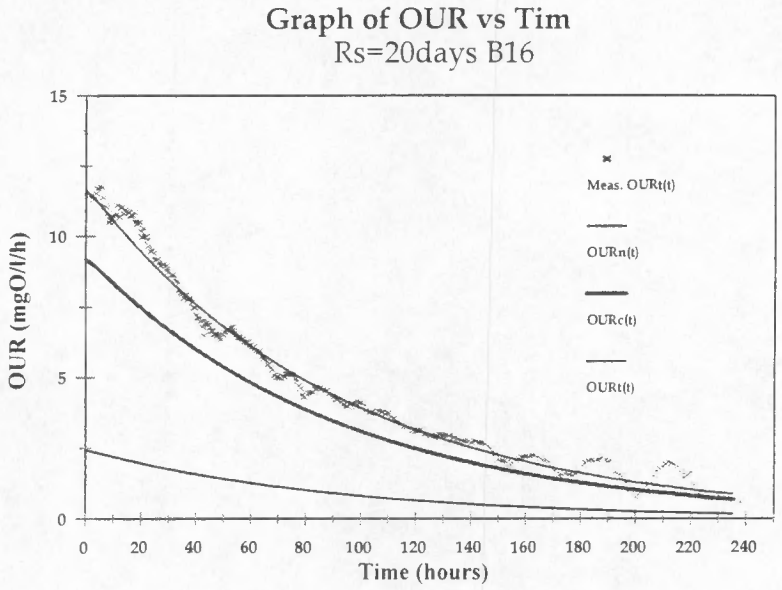


Fig. 5.2: Measured Oxygen Utilization Rate ($OUR_{t(t)}$) and predicted $OUR_{t(t)}$, $OUR_{c(t)}$ and $OUR_{n(t)}$ responses with time for a batch aerobic digestion test on mixed liquor (1.32ℓ) drawn from the aerobic reactor of the 20 days sludge age system. Batch Aerobic Digestion Test No. D2, Sewage Batch No. 16.

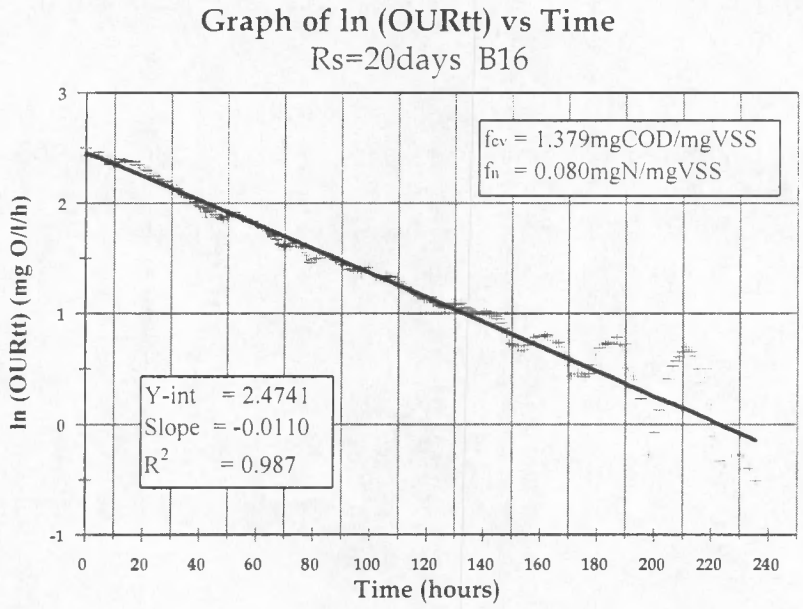


Fig. 5.3: ℓn [total Oxygen Utilization Rate ($OUR_{t(t)}$)] versus time for the OUR data in Fig. 5.2. Batch Aerobic Digestion Test No. D2, Sewage Batch No. 16.

5.3.2 Comparison between theoretical and measured Nitrate

As was shown in Section 5.3.1 above, in the derivation of the equations, nitrification influences the determination of X_{BHi}. This was taken into account by accepting that OUR_{tt} includes complete nitrification. During the batch aerobic digestion tests, nitrate, nitrite and Free and Saline Ammonia (FSA) concentrations were measured regularly to check whether the ammonia released from the endogenous respiration process is directly and completely nitrified or not. From the experiment data (for example, see Figs. 5.4 and 5.5), the nitrate concentration increased continually during the entire period of the batch aerobic digestion test. Nitrite concentrations were negligible and thus did not need to be taken into account. Also, the FSA concentrations of the filtered samples during the test were constantly at low values. This indicates that all the ammonia released from the endogenous respiration process is directly converted into nitrate *i.e.* ammonia accumulation in the reactor did not occur (see Fig. 5.5 for batch aerobic digestion test No. D2 and Appendix B for the other batch tests).

To further examine the nitrification process, equations to predict the theoretical nitrate concentrations were derived. Accepting that all the released ammonia from the endogenous respiration is nitrified into Nitrate by nitrification, the rate of generation of nitrate ($dNO_{3(t)}/dt$) can be expressed by the following equation:

$$\frac{dNO_3}{dt} = f_n \cdot \left(-\frac{dX_{BH}}{dt} - \frac{dX_E}{dt}\right) \qquad (5.15)$$

$$= f_n \cdot (\text{ The rate of OHO active biomass loss - The rate of endogenous residue generation})$$

Substituting Eqs. (5.2) and (5.3) for dX_{BH}/dt and dX_E/dt respectively into Eq. (5.15):

$$\frac{dNO_{3(t)}}{dt} = f_n \cdot (b_{HT} \cdot X_{BH(t)} - f \cdot b_{HT} \cdot X_{BH(t)}) \qquad (5.16)$$

Substituting Eq. (5.6) for $X_{BH(t)}$ into Eq. (5.16)

$$\frac{dNO_{3(t)}}{dt} = f_n \cdot b_{HT} \cdot (1 - f) \cdot X_{BH(t)} \cdot e^{-b_{HT} \cdot t} \qquad (5.17)$$

Integrating Eq. (5.17) above from time = 0 to time = t:

$$NO_{3(t)} = NO_{3(t\,=\,0)} + f_n \cdot (1 - f) \cdot X_{BHi} \cdot (1 - e^{-b_{HT} \cdot t}) \qquad (5.18)$$

where

$NO_{3(t)}$ = Nitrate concentration, at time = t (mgN/ℓ)
$NO_{3(t=0)}$ = Nitrate concentration, at time = 0 (mgN/ℓ)
X_{BHi} = Measured OHO active biomass at the beginning of the test (mgVSS/ℓ)
b_{HT} = Measured endogenous respiration rate (/d) at temperature T°C

Eq. (5.18) above allows the theoretical nitrate concentration profile to be predicted. Fig. 5.4 shows both measured and theoretical nitrate concentrations for batch aerobic digestion test No. D2, Sewage Batch No. 16. As shown in Fig. 5.4, the correlation between the measured and predicted Nitrate concentrations during the period of the batch aerobic digestion test was poor. The measured nitrate concentrations were consistently higher than the predicted concentrations during the entire test. This behaviour was common for all the batch aerobic digestion tests (see Appendix B).

Thus, although the experimental data does confirm complete nitrification, there is an inconsistency between predicted and measured nitrate concentrations for all aerobic batch digestion tests. Within the conceptual framework for the aerobic batch digestion described above, it is difficult to explain the poor correlation between the measured and predicted nitrate concentrations. If it is accepted that the measured nitrate concentrations are accurate, this implies that an additional source of ammonia-N is being released in the digestion which is not accounted for within the conceptual framework. However, in assessing the reliability of the measured nitrate concentrations, it should be noted that these samples had to be highly diluted to get the concentrations to fall within the range of standard in the analytical method *(Technicon Auto Analyser* method), by up to 50 times. Such high dilution introduces large multiplication of any errors. At this stage, a definitive reason for the above poor correlation between the measured and predicted nitrate cannot be provided. More extensive experiments are required to identify whether the error comes from unknown biological reactions or from experimental error, or even some other causes.

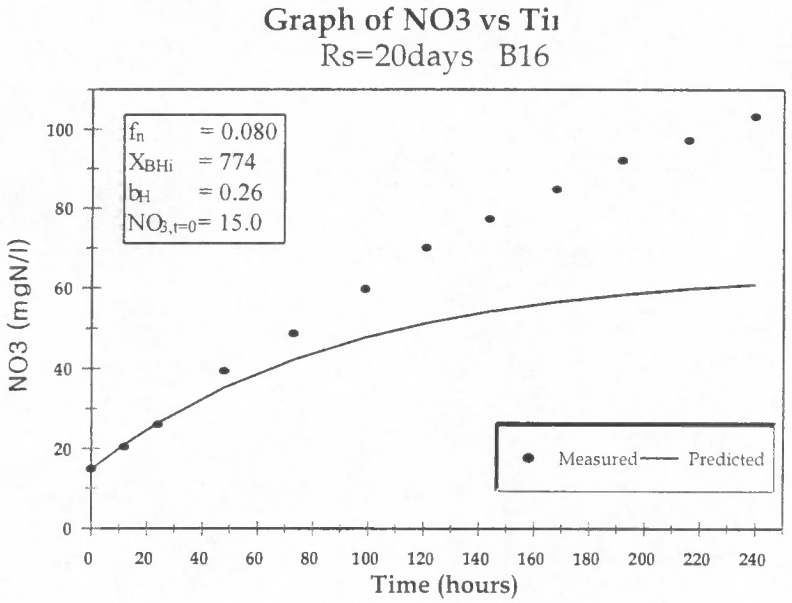


Fig. 5.4: Measured and theoretically calculated Nitrate (NO_3) concentrations versus time. Batch Aerobic Digestion Test No. D2, Sewage Batch No. 16.

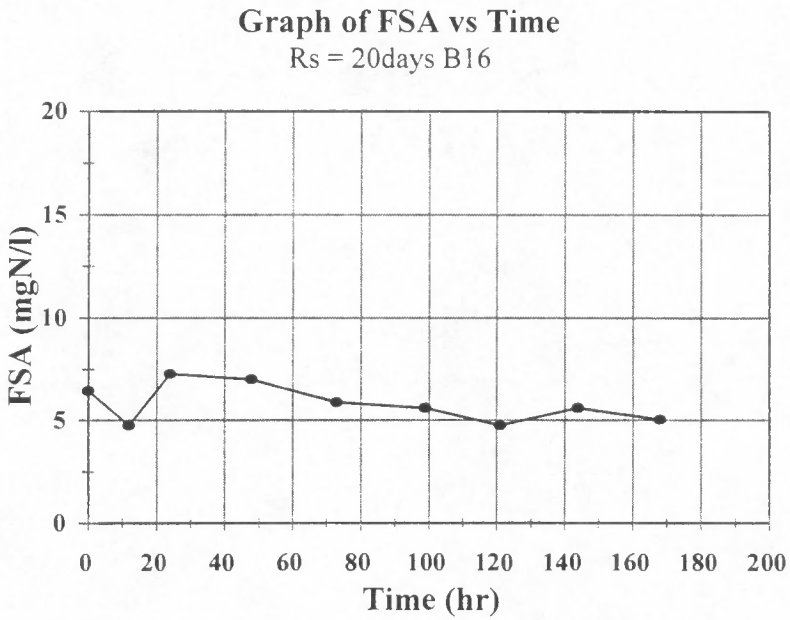


Fig. 5.5: Meaured Free and Saline Ammonia (FSA) concentrations versus time. Batch Aerobic Digestion Test No. D2, Sewage Batch No. 16.

5.4 RESULTS OF THE BATCH AEROBIC DIGESTION TESTS

5.4.1 Parent system data

As noted in Chapter 3, the sewage that was fed to the parent systems was changed every ±2 weeks to prevent degradation under storage and to minimize changes in the nature of the wastewater. Although the intention was to keep the wastewater feed as consistent as possible throughout the investigation period, invariably the wastewater characteristics changed for each sewage batch. Each sewage batch therefore constituted a steady state period during which the characteristics of the wastewater governed the parent system behaviour. For this reason, the approach adopted was to analyze each sewage batch separately to determine the various parent system parameters, as set out in Chapters 3 and 4. During the 2 sewage batch periods when the batch aerobic digestion tests were conducted the various parent system parameters were monitored, and the averaged data (from Table 3.4 (a) and (b), Chapter 3) are listed in Table 5.1.

Table 5.1: Steady state results for the 10 and 20 days sludge age parent laboratory-scale anoxic/aerobic activated sludge system receiving sewage batches during which batch aerobic digestion tests were performed. Averages are listed with sample standard deviations in the second row.

10 AND 20 DAYS PARENT ANOXIC/AEROBIC STEADY STATE SYSTEM														
System	Sew. Batch No.	No. of tests	TKN (mgN/l)			NITRATE (mgN/l)			COD (mgN/l)			OUR (mgO/l/h)	VSS (mgVSS/l)	pH
			Inf	Eff	ML	AX	AE	Eff	Inf	Eff	ML			
10 days	15	6	66.1	3	191.6	0	19.3	20	764.9	43.2	3443	51.8	2557.4	7.88
		(SSD)	0.5	0.7	4.7	0	0.3	1	15.2	8.6	80.6	2.9	39.8	0.11
	16	11	50.7	4.5	197	0	10.3	10.2	743.4	42.8	3416.5	45.1	2489.4	7.93
		(SSD)	1.3	0.5	10.6	0	1.4	0.9	18.1	6.6	354.3	3.9	226.6	0.03
20 days	15	6	66.1	2.9	190.6	0.08	20.7	20.7	764.9	34.1	3473.5	31.4	2507.2	7.87
		(SSD)	0.5	0.4	5.7	0.04	0.3	0.5	15.2	4.3	83.3	2.3	49.8	0.1
	16	11	50.7	4.5	204.6	0	11.3	12.3	743.4	39.9	3634.1	30.7	2571.8	7.93
		(SSD)	1.3	0.5	5.2	0	1.1	0.8	18.1	9.2	69.1	3.5	41.2	0.03

According to activated sludge theory, the OHO active biomass plays an integral role in the behaviour of the activated sludge system. The theoretical mass of OHO active biomass would invariably fluctuated as the wastewater characteristics change from one sewage batch to the next. As the OHO active biomass forms the focal point of this investigation, it was imperative to monitor this variation in key system parameters. To formulate a theoretical estimate for the OHO active biomass concentration present in the parent system, for each sewage batch period the following were determined from the data in Table 5.2:

- Influent wastewater unbiodegradable soluble and particulate COD fractions ($f_{S,us}$ and $f_{S,up}$ respectively); system COD and N mass balances (Ekama *et al.* 1986) and the COD and TKN to VSS ratios for the mixed liquor (f_{cv} and f_N respectively). The calculation procedures are set out in detail in Chapter 3 and the results for each sewage batch in which the aerobic digestion batch tests were done are listed in Table 5.2.

- The OHO active biomass fractions of the mixed liquor organic suspended solids (f_{av}) were determined for each sewage batch using the steady state design model [Eq. (4.27)]. Ubisi *et al.* (1997) and Cronje *et al.* (2000) applied both the steady state design model and the UCTOLD kinetic simulation computer programme to measure the OHO active biomass fractions (f_{av}) and found that reasonably close agreement was obtained between the steady state and kinetically simulated predictions (average difference = 2.2%). Thus, in this investigation, the steady state design model only is used to calculate the OHO active biomass fractions (f_{av}) in this investigation because of its simpler and more direct procedure. In the steady state calculation procedure, a value for the OHO specific endogenous mass loss rate (b_{HT}) is required. For this, the default value was used (0.24/d, WRC, 1984).

Table 5.2: Steady state COD and N mass balances, wastewater fractions and mixed liquor parameters for the 10 and 20 days sludge age parent laboratory-scale anoxic/aerobic activated sludge system. Data calculated from data Table 5.1 using the steady state (SS) design model (WRC, 1984).

10 AND 20 DAYS SLUDGE AGE PARENT ANOXIC/AEROBIC STEADY STATE SYSTEM									
System	Sew. Batch No.	No. of Test	MASS BALANCE (%)		WASTEWATER FRACTIONS		MIXED LIQUOR		
			N	COD	Unbio. Soluble COD (fs,us)	Unbio. Particulate COD (fs,up)	COD/VSS ratio (fcv)	TKN/VSS ratio (fN)	Active Fraction (fav)
10 days	15	6	115	105.3	0.048	0.144	1.407	0.08	0.41
	16	11	99	106.2	0.052	0.145	1.398	0.083	0.407
20 days	15	6	115.6	99.8	0.041	0.121	1.364	0.076	0.3
	16	11	105.5	113.3	0.045	0.145	1.379	0.08	0.275

From an analysis of the N mass balances, for Sewage Batch No.15 both the 10 and 20 days parent systems have poor mass balances which are outside the 90% - 110% range. In the examining the measured data for Sewage Batch No.15 (Table D17 and E17, Appendix D and E for 10 and 20 days parent systems respectively), it was noted that the nitrate concentrations of the effluent and aerobic reactor, and the mass of nitrified N were considerably higher than for the other sewage batches. Due to the higher nitrate concentrations, for Sewage Batch No.15, the dilution factor to ensure that the nitrate concentrations fell into the measurable range was larger than for the other sewage batches. With higher dilution, any experimental errors are magnified. However, in this investigation the principle parameter of concern is the OHO active biomass fraction. Since this is not affected by nitrate concentration measurement errors, the data were accepted.

From an analysis of the COD mass balances, for the Sewage Batch No.16, the 20 days sludge age parent system gave a COD mass balance marginally outside the 90% - 110% range. The specific reason of the poor COD mass balance for the 20 days parent system of Sewage Batch No.16 could not be readily identified. However, since the mass balance was only marginally above the acceptable range, and the other calculated data appeared consistent with that for the other sewage batches (Table 5.2), the data were not rejected.

5.4.2 Batch aerobic digestion test data

For the batch aerobic digestion tests, measured and predicted OUR and NO_3 – time data are shown graphically in Appendix B. Following the procedures set out in Section 5.3 above, the OHO active biomass concentrations measured at the start of each test (X_{BHi}) were calculated and are listed in Appendix B. The results are summarized in Table 5.3.

In Table 5.3, for all the batch aerobic digestion tests the R^2 values for the linear regression of the ℓn OUR - time plots were remarkably good. All the R^2 values were > 0.97 which lends credibility to the tests. Also the experimental responses of two batch aerobic digestion tests which were done with the same mixed liquor drawn from the same parent system, were very similar. These similarities also lend credibility to the experimental data.

Of particular interest in the results, is the determined values for the specific OHO endogenous respiration rate (b_{H20}). For the 20 days sludge age system mixed liquor these values were determined as 0.22/d and 0.26/d which are very similar to the default value of 0.24/d proposed by WRC (1984) and Marais and Ekama (1976). For the 10 days sludge age system mixed liquor the values were estimated as 0.31/d and 0.33/d, which are significantly higher than the proposed default value (0.24/d). Thus, in this investigation the value for b_{H20} for the 20 day sludge age system is consistent with the current default value. However, the value for b_{H20} for the 10 day sludge age system is significantly higher than the default value. This indicates that sludge age appears to influence the b_{H20} value. This is contrary to the current activated sludge theory, where it is accepted that the b_{H20} value is independent of sludge age, and previous investigations (Marais and Ekama, 1976). Due to time constraints this aspect could not be further investigated, but does warrant future attention.

Table 5.3: Results for batch aerobic digestion tests: Sewage (Sew.) batch number, Batch test numbers, dates of batch tests, regression data, measured specific endogenous respiration rate (b_{H20}), *measured* OHO active biomass concentration present the start of the batch test (X_{BHi}) and the *theoretical* parent system mixed liquor (ML) OHO active biomass concentration.

System	Sew. Batch No.	Batch test No.	Date of Test	Regression data			b_{H20} (/d)	X_{BHi} (mgVSS/l)	
				Y-int	Slope	R^2		Meas.	Theo.
10days	15	C1	27 03	2.9029	-0.0129	0.971	0.31	996	993
	16	C2	08 04	2.9768	-0.0137	0.987	0.33	1008	983
20days	15	D1	27 03	2.3453	-0.009	0.979	0.22	834	758
	16	D2	08 04	2.4741	-0.011	0.987	0.26	774	718

5.4.3 Comparison between measured and theoretical OHO active biomass concentration

In Table 5.3 the measured OHO active biomass concentration at the start of each batch test is compared to the theoretical OHO active biomass concentration which were predicted via the steady state design model (WRC, 1984). To illustrate the comparison, the measured versus theoretical mixed liquor OHO active biomass data for all the batch tests are shown in Fig. 5.6.

From Fig. 5.6, the correlation between the measured and theoretical OHO active biomass concentrations is remarkably good. The % differences between the measured and theoretical values were estimated as 1.4% and 8.2% for the 10 days and 20 days sludge age parent systems respectively.

This close correlation provides substantive support for the OHO active biomass concept incorporated in activated sludge theory. In the previous modified batch tests which are based on the growth process of OHO active biomass, the differences between the measured and theoretical values were large. However, in the batch aerobic digestion tests which are based on the endogenous respiration process, the results show remarkably good correlation between the measured and theoretical values. From this observation, it appears that the major cause for the difference between the measured and theoretical OHO active biomass concentrations in the modified batch tests lies in the description and interpretation of the OHO growth process within the modified batch test itself. Further investigations on the growth process in the modified batch tests will be described in Chapter 6.

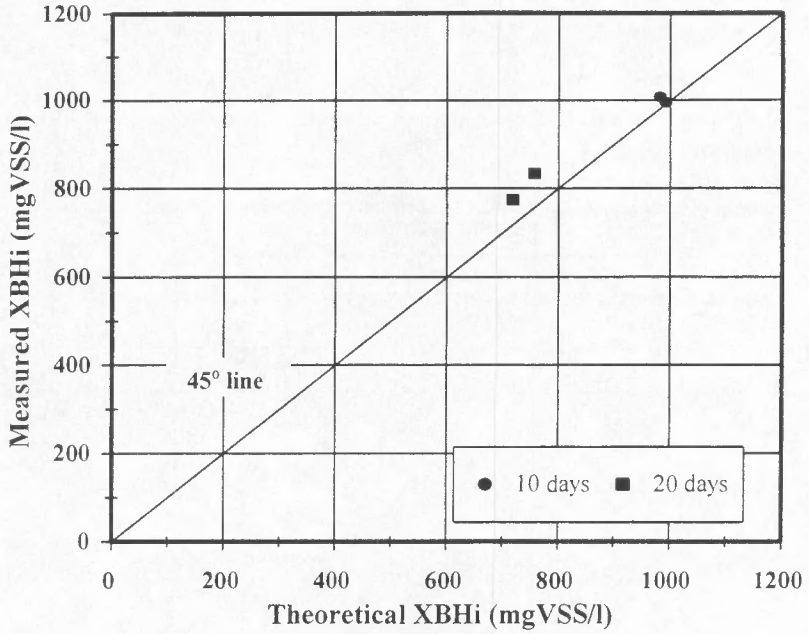


Fig. 5.6 Measured versus theoretical OHO active biomass concentration at the start of the batch aerobic digestion tests [X_{BHi}] for the 10 and 20 days sludge age parent MLE activated sludge systems.

5.5 CONCLUSIONS

In this Chapter, the aerobic batch digestion test has been applied to quantify OHO active biomass concentrations. From this investigation, the following aspects and conclusions are of significance:

- Plotting natural log of the total measured OUR ($\ell n(O_{ti})$) versus time (for example see Fig. 5.3) yields a straight line with a slope of b_{HT}. Thus, from a batch aerobic digestion test the b_{HT} value can be determined. The y-intercept is a function *inter alia* of the initial OHO active biomass concentration and can be used to determine the initial OHO active biomass concentration, provided nitrification is complete.

- Filtered samples taken at regular intervals during the test showed FSA concentrations were constant, at low values. This indicates that all ammonia released from the endogenous respiration process was directly nitrified to nitrate, *i.e.* ammonia did not accumulate. This implies nitrification was complete.

- Nitrate concentrations with time in the aerobic batch digestion tests were predicted with activated sludge theory. The correlation between the measured and predicted nitrate concentrations was poor. The measured nitrate concentrations were consistently higher than the predicted concentrations during the entire test. No definitive explanation for this inconsistency could be proposed, and this warrants further investigation.

- Linear regression of the $\ell n(O_{t(t)})$ versus time plots gave high correlation coefficient (R^2) values (> 0.97) which lends credibility to the tests. Also, the experimental responses of two batch aerobic digestion tests which were done with the same mixed liquor drawn from the same parent system, were very similar. These similarities also lend credibility to the experimental data.

- For the values for the specific endogenous respiration rate (b_{H20}), for the 20 days sludge age system these were estimated as 0.22/d and 0.26/d; for the 10 days sludge age system these were estimated as 0.31/d and 0.33/d. The b_{H20} values for the 20 day sludge age system are close to the default value of 0.24/d (Marais and Ekama, 1976; WRC, 1984), but the values for the 10 day sludge age system are significantly higher. This indicates that sludge age appears to influence the b_{H20} value. This is contrary to the current activated sludge theory, and previous investigations (*e.g.* Marais and Ekama, 1976). This aspect warrants further investigation.

- There is a remarkably close correspondence between the theoretical OHO active biomass concentration and that measured in the aerobic batch digestion test. The % differences between measured and predicted values were estimated as 1.4% and 8.2% for the 10 and 20 days sludge age parent systems respectively. This close correlation provides substantive support for the OHO active biomass concept incorporated in activated sludge theory.

In closure, in the previous modified batch tests (Chapter 4) which are based on the growth process of OHO active biomass, the differences between the measured and theoretical values were large. However, in the batch aerobic digestion tests which are based on the endogenous respiration process, remarkably good correlation between the measured and theoretical values was obtained. From this observation, it is clear that the major cause for the difference between the measured and theoretical OHO active biomass concentrations in the modified batch tests lies in the description and interpretation of the OHO growth process within the modified batch test itself. In the next chapter, the growth of OHO active biomass in the modified batch test will be investigated intensively.

CHAPTER 6

FURTHER INVESTIGATION INTO THE MICROBIOLOGICAL BEHAVIOUR OF OHOs IN THE MODIFIED BATCH TEST

6.1 INTRODUCTION

The modified batch test to quantify OHO active biomass developed by Cronje *et al.* (2000) was evaluated by Beeharry *et al.* (2001). While, for mixed liquor drawn from a parent activated sludge system at 10 day sludge age, Cronje *et al.* (2000) obtained reasonable agreement between the theoretical OHO active biomass concentrations and that measured in the modified batch test, Beeharry *et al.* (2001) found for mixed liquor drawn from similar parent systems at 10 day sludge age a constant difference between the theoretical and measured values; in a plot of measured versus theoretical OHO active biomass concentration, the data plotted parallel to the 1:1 correspondence line. Beeharry *et al.* could provide no explanation for this deviation.

In this investigation, the modified batch test has been evaluated further (Chapter 4), to attempt to seek an explanation for the observations of Beeharry *et al.* (2001), and the inconsistency between the results obtained in their investigation and that of Cronje *et al.* (2000). This was done by applying the modified batch test to mixed liquor drawn from two parallel parent MLE activated sludge systems, at 10 and 20 day sludge ages (Chapter 4). From a comparison of the measured to the theoretical OHO active biomass concentrations, it was found that, for the range of concentrations corresponding to that of Beeharry *et al.*, the results for the mixed liquors from the parent systems at both sludge ages were remarkably similar, and also remarkably similar to the results of Beeharry *et al.* This excluded sludge age as the cause for the observations above. Additionally, data was collected outside the data range of Beeharry *et al.*, at both higher and lower OHO active biomass concentrations. This data did not conform to that described above, see Chapter 4. It was concluded that three distinct regions could be identified in the comparison of the measured with theoretical OHO active biomass concentrations:

(i) Theoretical $Z_{BH(0)} < 30$ mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values decrease, to approach near zero. Beeharry *et al.* (2001) did not collect data in this region, so a comparison with their data is not possible.

(ii) 30 mgCOD/ℓ < Theoretical $Z_{BH(0)} < 150$ mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values correspondingly increase parallel to a 1:1 correspondence line, but below it. This trend is near identical to that observed by Beeharry *et al.* (2001), whose data falls primarily in this region.

(iii) Theoretical $Z_{BH(0)} > 150$mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values increase sharply to cross the 1:1 correspondence line. Beeharry *et al.* (2001) collected limited data in the region, but the data available indicates it is consistent with the observation here.

To evaluate whether the cause for these observations lay in the activated sludge theory or in the modified batch test method, in Chapter 5 the OHO active biomass concentrations in the two parallel parent systems were measured by means of aerobic batch digestion. Remarkably close agreement between theoretical and measured OHO active biomass concentrations was obtained for the mixed liquors at both sludge ages. This indicated that, most likely, the cause for the non-agreement with the modified batch test lay in the batch test itself. This prompted a more detailed investigation into OHO behaviour within the modified batch test, through a detailed analysis of the data collected in Chapter 4. In particular, (i) the effect of the ratio substrate concentration to OHO active biomass concentration (So/Xo) and (ii) the validity of the analytical procedures were examined. This investigation is described in this Chapter. In Chapter 7, the information and data gathered in this investigation will be used to develop a mathematical model to describe the OHO behaviour in the modified batch tests.

6.2 MAXIMUM SPECIFIC GROWTH RATES, μ_H AND K_{MP}

In examining the OHO maximum specific growth rates calculated from the modified batch test data, in Chapter 4 a clear trend in OHO maximum specific growth rate on RBCOD (μ_H) with volume of mixed liquor added to the batch test was noted - as the volume of mixed liquor added increased, the value for μ_H decreased, see Figs. 4.8 (c) and 4.11 (c). For the OHO maximum specific growth rate on SBCOD (K_{MP}), no such clear trend was noted. However, re-examination of the statistical probability plots for the K_{MP} values with the 10 and 20 day sludge age mixed liquors (Figs. 4.8 and 4.11 respectively), it is noticeable that for both plots the data does deviate from the "true" normal probability line at the upper and lower K_{MP} values. Thus, attention was focussed on the variation in μ_H and K_{MP} values.

6.2.1 Maximum specific growth rates, μ_H and K_{MP}, versus $Z_{BH(0)}$(Theo.)

Figs. 6.1 and 6.2 show plots of the OHO maximum specific growth rates on RBCOD (μ_H) and SBCOD (K_{MP}) respectively versus the theoretical OHO active biomass concentration in the modified batch test as calculated with the steady state model, $Z_{BH(0)}$(Theo.). The parameter $Z_{BH(0)}$ was selected instead of volume of mixed liquor added, as this would eliminate variations caused by changes in wastewater characteristics from one sewage batch to another, which would directly influence the parent system mixed liquor characteristics. Also, sludge age effects on $Z_{BH(0)}$ would be eliminated. In these plots, the modified batch tests calculated during Sewage Batch Nos.5 and 13 were rejected because of the poor parent system mass balances, and the tests during Sewage Batch No.9 were also rejected because of the noted difference in behaviour with these tests compared with the rest, proposed to be due to a shortage of substrates; reasons for these rejections were described in detail in Chapter 4. The OHO maximum specific growth rates for the modified batch tests were calculated with the analytical procedure of Wentzel *et al.* (1995).

For OHO maximum specific growth rate on RBCOD (μ_H), from Fig. 6.1, there is remarkable similarity in the data for the 10 and 20 day sludge age mixed liquors. Further, a consistent trend is evident. As the $Z_{BH(0)}$(Theo.) decreases, the values of μ_H increase to reach a maximum at $Z_{BH(0)}$(Theo.) of approximately 30 mgCOD/ℓ (at $Z_{BH(0)}$(Theo.) < 30 mgCOD/ℓ, there is uncertainty in the data due to rejection of these batch tests on the basis of %COD recovery). This effect is

not due to the OHO growth rate on RBCOD not being at its maximum: For all the modified batch tests, a precipitous OUR drop in the OUR-time profile was clearly present. This substantiates that the OHO growth rates of RBCOD were at their maximum values in all the modified batch tests conducted; if this was not so, the precipitous OUR drop would not be evident. Thus, it can be concluded that the OHO maximum specific growth rate on RBCOD (μ_H) is not a constant value between the different modified batch tests, but appears to be a function of the OHO active biomass concentration added at the start of the test.

For the OHO maximum specific growth rate on slowly biodegradable COD (K_{MP}), from Fig. 6.2 again there is remarkable similarity in the data for the 10 and 20 day sludge age mixed liquors. Also, the K_{MP} value does not appear to be a constant, and there is variation with $Z_{BH(0)}$(Theo.). However, this variation is very different from that described above for μ_H. For K_{MP}, it would appear that three possible regions can be identified (which is in agreement with analysis of measured versus theoretical $Z_{BH(0)}$, see Chapter 5):

- $Z_{BH(0)}$(Theo.) < 30 mgCOD/ℓ : There is uncertainty in this data, as the modified batch tests were rejected on the basis of poor %COD recoveries.

- 30 mgCOD/ℓ < $Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ : Reasonably constant (though scattered) values for K_{MP}, higher than the mean value for K_{MP} determined in Chapter 4. For these batch tests, the second plateau in the OUR-time profile used to determine K_{MP} (see Chapter 4) was clear and readily identifiable.

- $Z_{BH(0)}$(Theo.) > 150 mgCOD/ℓ : Values for K_{MP}, that are lower than the mean K_{MP} value determined in Chapter 4, with a tendency for K_{MP} to decrease as $Z_{BH(0)}$(Theo.) increases.

In seeking possible explanations for the behaviours described above, it was noted that the variation in theoretical OHO active biomass concentration ($Z_{BH(0)}$(Theo.)) would imply a concomitant variation in the ratio of the initial substrate to OHO active biomass concentrations in the batch test (*i.e.*, the So/Xo ratio). Accordingly to Grady *et al.* (1996), it has been observed frequently that different OHO maximum specific growth rates can be obtained under different So/Xo conditions. Accordingly, this aspect is examined further in the sections that follow.

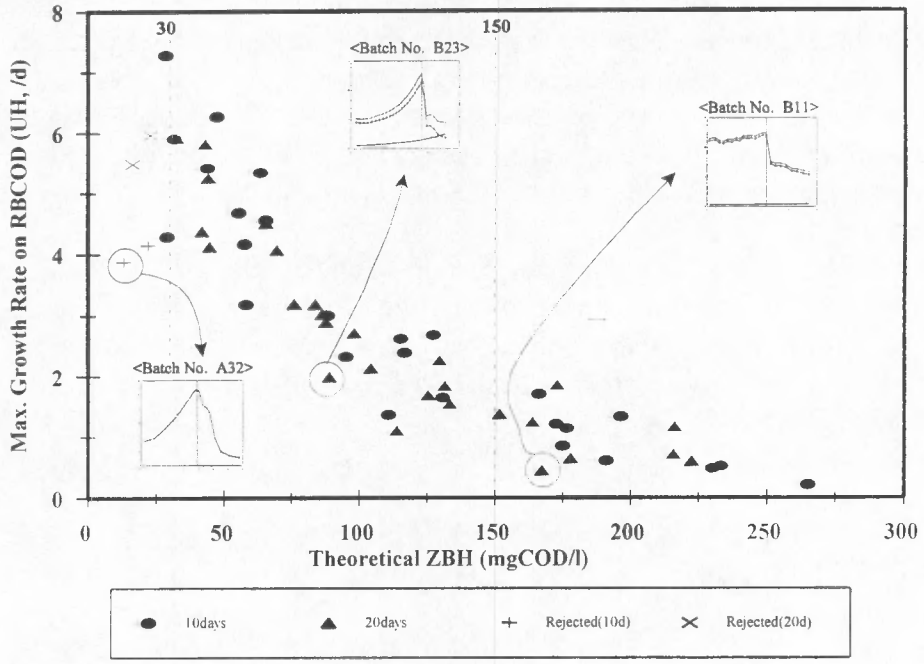


Fig. 6.1: OHO maximum specific growth rate on readily biodegradable COD (μ_H) versus the theoretical OHO active biomass concentration at the start of the batch test, $Z_{BH(0)}$. Representative OUR versus time profiles for different regions are shown inside the graph.

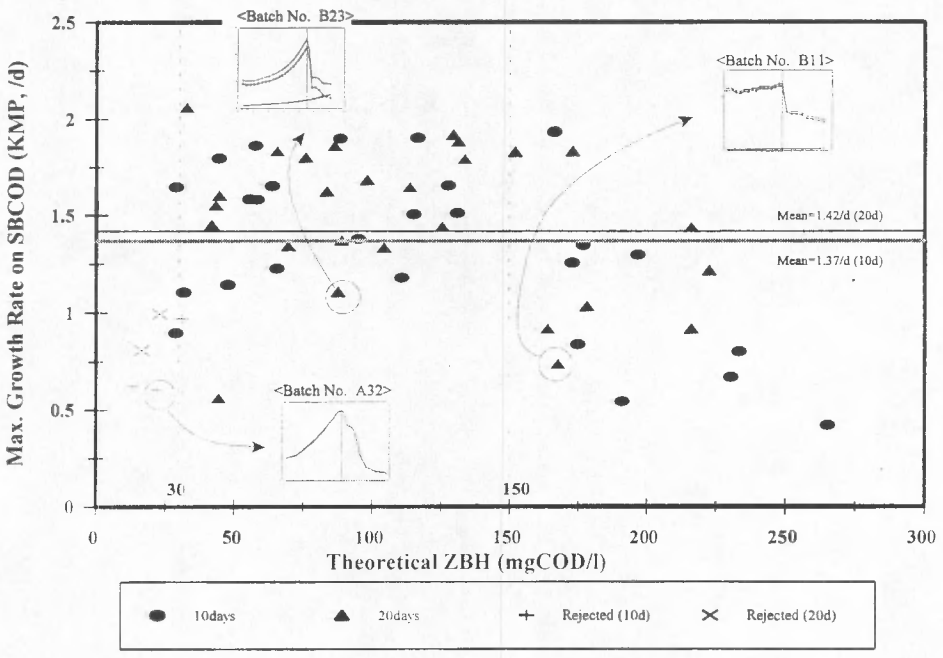


Fig. 6.2: OHO maximum specific growth rate on slowly biodegradable COD (K_{MP}) versus the theoretical OHO active biomass concentration at the start of the batch test, $Z_{BH(0)}$. Representative OUR versus time profiles for different regions are shown inside the graph.

6.2.2 Growth rates, μ_H and K_{MP}, under various S_o/X_o conditions

Chudoba *et al.* (1992) and Novak *et al.* (1994) have investigated the effect of So/Xo on microbiological behaviour under batch conditions. Chudoba *et al.* (1992) noted that the So/Xo ratio is extremely important in any biodegradation studies carried out with the objective of quantifying kinetic constants. According to Novak *et al.* (1994), in batch cultivation two different cases must be distinguished: (1) high So/Xo ratio, and (2) low So/Xo ratio, based on initial batch test conditions. At low So/Xo ratios, substrate storage and accumulation phenomena dominate with cell multiplication (growth) secondary, whereas at higher So/Xo ratios the microorganisms have sufficient substrate (energy) for growth and cell multiplication and these dominate with substrate storage and accumulation phenomena as secondary. The former So/Xo conditions are unlikely to be encountered in the batch tests conducted here - in none of the batch tests is substrate limiting during the first few hours (indicated by the precipitous drop in OUR being observed). However, from the work of Grady *et al.* (1996) noted above, it is possible that So/Xo has an effect on these maximum specific growth rates. Accordingly, in this research, the OHO maximum specific growth rates at the various So/Xo will be examined, to identify possible trends. Unfortunately, the initial substrate concentrations were not measured for all batch tests, only for those conducted during Sewage Batch No. 14. Thus, analysis will be restricted to this batches. However, the notable consistency in the data means that any conclusions drawn will be generally applicable.

The ratio So/Xo can have a number of interpretations, *e.g.* So = total, biodegradable or biodegradable soluble COD; Xo = TSS, VSS or OHO active biomass. In this investigation, the initial substrate concentrations, So, were determined by measuring the COD concentrations of the flocculated and filtered sewage before addition to the batch reactor and taking due account of dilution by addition of mixed liquor. This interpretation of So is not equal to the biodegradable substrate concentration on which OHO active biomass would grow since some portion of this So would be unbiodegradable. However, since the sewage is flocculated and filtered which would remove virtually all unbiodegradable particulates, it can be regarded as reasonably representative of the biodegradable substrate concentration. The initial biomass concentration (Xo) was calculated from the parent system analysis with the steady state model (WRC, 1984). Thus, in this research, Xo is not represented by VSS or TSS concentration, but is represented by the OHO active biomass concentration calculated by the steady state model. This approach is superior, since it is the growth and activity of the OHO active biomass that is monitored in the batch test and this was demonstrated by the greater consistency in the results for both the 10 and 20 days sludge age systems.

From the above, formulations for So and Xo were as follows:

$$So = COD_{filt} \cdot \frac{V_{reactor} - V_{ML}}{V_{reactor}} \qquad (mgCOD/\ell) \qquad (6.1)$$

$$Xo = f_{av} \cdot X_v \cdot \frac{V_{ML}}{V_{reactor}} \qquad (mgMLAVSS/\ell) \qquad (6.2)$$

where:

$COD_{filt.}$ = COD concentration of flocculated and filtered sewage (mgCOD/ℓ)
$V_{reactor}$ = Volume of the batch reactor = 3 ℓ
V_{ML} = Volume of the mixed liquor added into the batch reactor (ℓ)
f_{av} = OHO active fraction of VSS, calculated with Eqn. (4.27)
X_v = VSS concentration of the parent system (mgVSS/ℓ)

Accepting the formulations above, the ratio So/Xo was calculated for all modified batch tests conducted during Sewage Batch No. 14, on both the 10 and 20 day sludge age mixed liquors. In Figs. 6.3, 6.4 and 6.5 the slope of the ℓn OUR_H - time plot, the OHO maximum specific growth rates on SBCOD (K_{MP}) and RBCOD (μ_H) respectively are shown plotted against So/Xo. From Figs. 6.3, 6.4 and 6.5, in all plots there is remarkable consistency between the data for the 10 and 20 days sludge age mixed liquors. In examining the trends in the various plots it should be noted that the 5 batch tests at So/Xo > 15 mgCOD/mgMLAVSS should be rejected on the basis of %COD recovery, and are so marked. From Figs. 6.3, 6.4 and 6.5, the maximum specific growth rates, as calculated from the batch test data with the analytical procedure of Wentzel *et al.* (1995), do not remain constant. As So/Xo increases, the rates increase steadily up to So/Xo equal to about 5 and 10 gCOD/gMLAVSS for K_{MP} and μ_H respectively, where the plots tend to level off. In this region, the plots are reminiscent of Monod type kinetics. However, it must be remembered that the data are maximum specific growth rates, confirmed for μ_H by the precipitous drop in OUR observed in all batch tests; as noted earlier, the precipitous OUR can occur only if μ_H is at a maximum. Also, from Fig. 6.5 the highest values for μ_H exceed the μ_H values usually used in design of activated sludge systems (1.5 - 3.5 /d, Dold *et al.*, 1991). Under batch conditions with high So/Xo, Chudoba *et al.* (1992) and Novak *et al.* (1994) found much higher μ_H values than the usual μ_H values. As a possible reason, they suggested that mixed cultures of microorganisms (*e.g.* activated sludge) usually contains different bacterial species and predators (protozoa, rotifers, etc.) which differ in their growth rate constants. In a batch test at a high So/Xo ratio, the fast-growing population group in the activated sludge most likely will be favoured. Grady *et al.* (1996) also provided a similar explanation for the observed increase in the maximum specific growth rate as the So/Xo ratio increases. According to Grady *et al.* (1996), the larger the So/Xo, the greater the change in the community structure and the more the batch test measured kinetics will reflect the characteristics of the fastest growing population group, rather than the characteristics of the original culture. Similarly, the greater the number of sequential enrichments performed, the more the measured parameters will reflect the kinetics of the fastest growing population group.

For So/Xo > 15 mgCOD/mgMLAVSS, the data are uncertain due to these batch tests being rejected on the basis of poor %COD recoveries. However, accepting this uncertainty the trend does appear to be for both K_{MP} and μ_H to decrease. A possible explanation for this trend may be that of Blanch *et al.* (1996). According to Blanch *et al.* (1996), most substrates, if present at sufficiently high concentrations, can inhibit microbial growth by one or more mechanisms. Any changes in the physicochemical properties of the medium by high substrate concentrations might be expected to have some effect on cell growth. These properties include the osmotic pressure, ionic strength, dielectric constant and activity of solutes present, any one of which might result in an alteration of membrane fluidity. In addition, overproduction of a metabolite by one pathway

may result in inhibition of another pathway. Thus, possibly the OHO growth processes in the batch test were inhibited by a sufficiently high substrate concentration.

In summary, it would appear that the batch test conditions, particularly the So/Xo ratio, could have a significant impact on the maximum specific growth rates K_{MP} and μ_H. Significantly, the conditions may favour the growth of one part of the OHO community over another, causing a change in the microbial OHO community structure with time in the batch test. Since interpretation of the batch test data is based on a single consistent OHO population representing the entire OHO community, change in community structure with time will reflect as changes in the behavioural characteristics of the single surrogate OHO population group. For example, if the fast growing group of the OHO community is favoured and their proportion of the OHO population increases with time in the batch test, this will reflect as an increase with time of the maximum specific growth rate of the entire OHO population. These changes with time in the batch test are not taken into account in the current analytical and calculation procedure, because a single OHO population with fixed constant kinetics is accepted (see Chapter 4). This aspect will be examined further in Chapter 7.

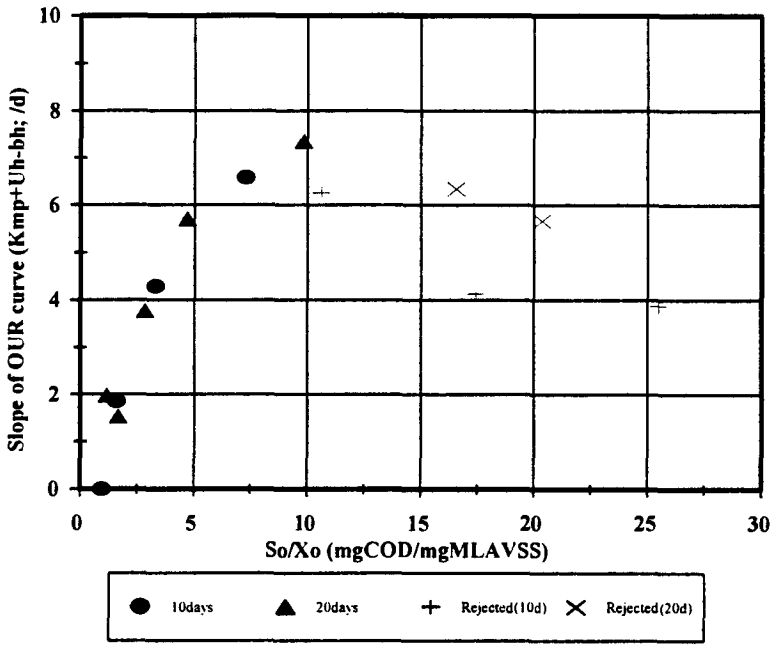


Fig. 6.3: Slope of ℓn OUR_H - time plot ($K_{MP}+\mu_H-b_H$) versus So/Xo ratio (mgCOD/mgMLAVSS) for the set of the modified batch tests conducted during Sewage Batch No. 14.

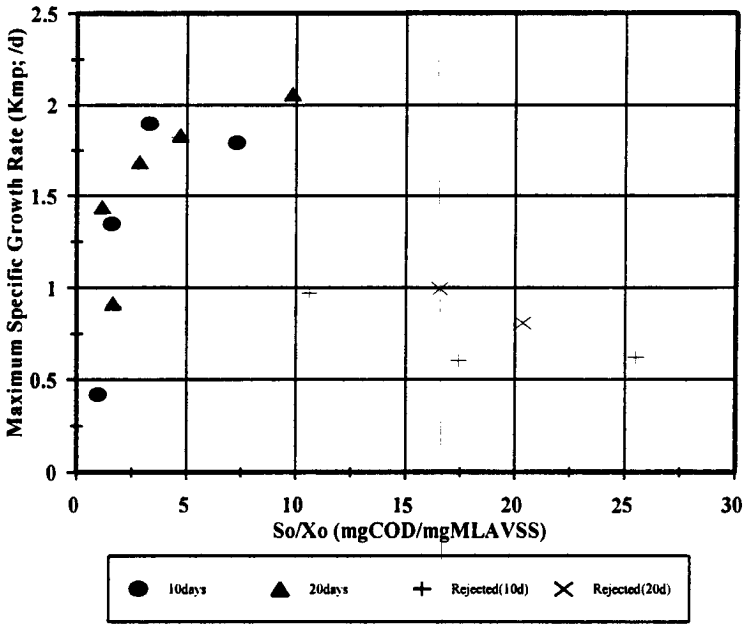


Fig. 6.4: OHO maximum specific growth rate on slowly biodegradable COD (K_{MP}) versus So/Xo ratio (mgCOD/mgMLAVSS) for the set of the modified batch tests conducted during Sewage Batch No.14.

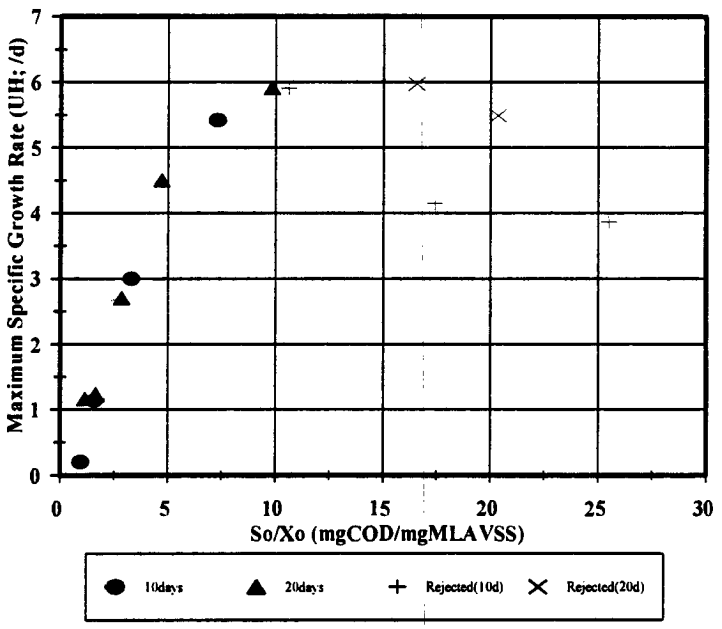


Fig. 6.5: OHO maximum specific growth rate on readily biodegradable COD (μ_H) versus So/Xo ratio (mgCOD/mgMLAVSS) for the set of the modified batch tests conducted during Sewage Batch No.14.

6.3 THE THREE REGIONS IN THE $Z_{BH(0)}$(Meas.) VERSUS $Z_{BH(0)}$(Theo.) GRAPH

As described in Chapter 4, in the plot of $Z_{BH(0)}$(Meas.) versus $Z_{BH(0)}$(Theo.) three prominent regions can be identified. From the discussion above, possible explanation for each region can be provided. Fig. 6.6 shows the $Z_{BH(0)}$(Meas.) versus $Z_{BH(0)}$(Theo.) plot, and the representative OUR - time profiles for each prominent region.

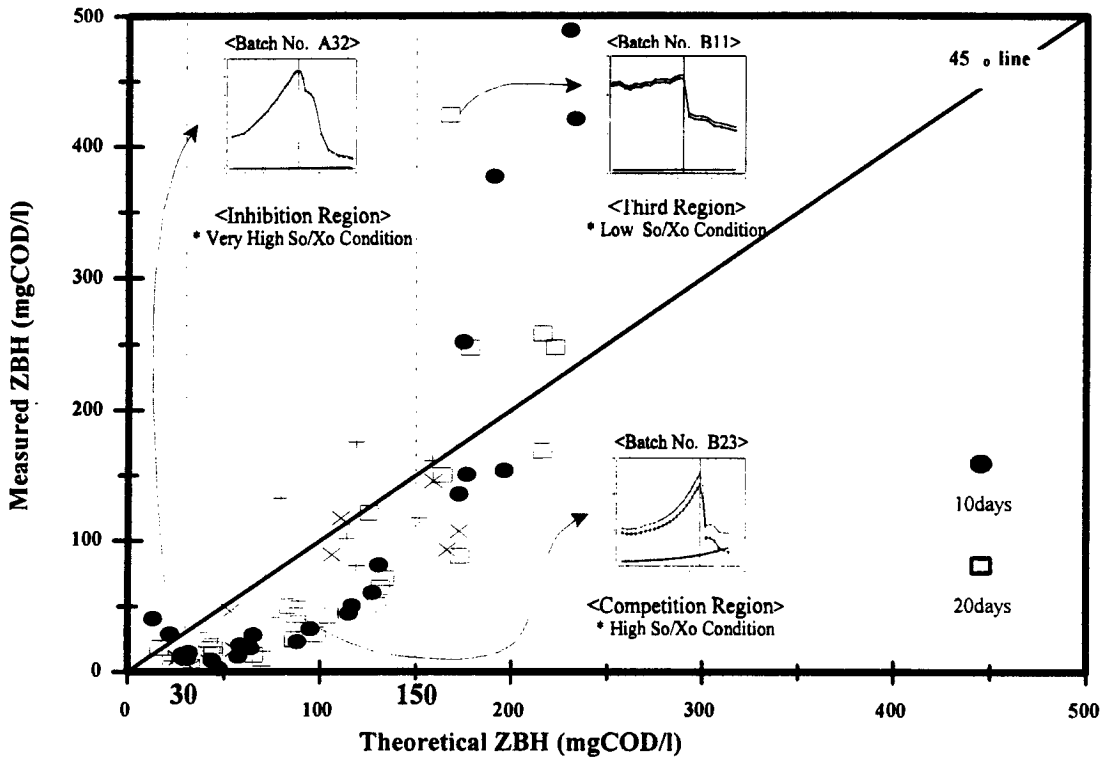


Fig. 6.6: Measured $Z_{BH(0)}$(Theo.) versus theoretical $Z_{BH(0)}$(Meas.) OHO active biomass concentrations showing the three regions. Representative OUR versus time profiles for modified batch tests conducted in each of the three prominent regions are shown inside the graph.

6.3.1 Inhibition region: $0 < Z_{BH(0)}$(Theo.) < 30 mgCOD/ℓ

From Figs. 6.1 and 6.2 (and 6.4 and 6.5), although there is some uncertainty in the data (see above) in this region the OHO maximum specific growth rates on both RBCOD and SBCOD tend to be lower than the average, even though the So/Xo is higher. As mentioned in Section 6.2.2, according to Blanch *et al.* (1996), most substrates, if present at sufficiently high concentrations, can inhibit microbial growth by one or more mechanisms. Thus, it appears possible that in this region substrate inhibition occurred and accordingly it is named the inhibition region.

Fig. 6.7 shows the representative OUR versus time profile for a typical batch conducted in this inhibition region. In Fig. 6.7, it is noteworthy that the precipitous drop in OUR is not as marked as in the batch tests conducted in the other regions (*e.g.* Fig. 6.8). Rather, there is a curved (though sharp) time dependent drop in OUR. This would suggest that some intermediate products are generated from the sewage substrates and accumulate inside the cell and then are utilized slowly during the test. The accumulation of the intermediate products seems to act as an inhibitor of cell growth, which is directly related to the OUR response before the precipitous drop of OUR. With the depletion of wastewater RBCOD, the drop in OUR, although sharp, is not precipitous. This possibly could be due to continued utilization of the generated intermediate. Accumulation of an inhibitory intermediate during the batch test would cause the maximum specific growth rates to be reduced, which in turn would cause the OHO active biomass concentration to be overestimated in the batch test calculation procedures, as is evident in Fig. 6.6. However, since there is uncertainty in the data, this explanation must be regarded as tenuous at best, and accordingly was not investigated further.

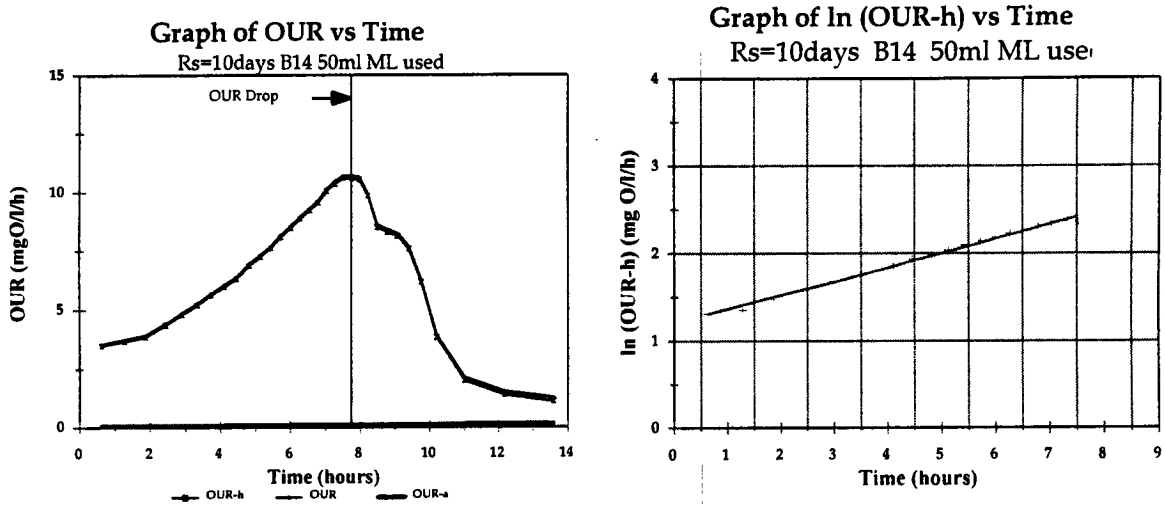


Fig. 6.7: OUR (OHO, h; AO, a and measured) versus time and $\ell n(OUR_H)$ versus time profile for a representative modified batch test in the inhibition region. Modified Batch Test No. A32, Sewage Batch Test No. 14.

6.3.2 Competition region: $30 < Z_{BH(0)}(Theo.) < 150$ mgCOD/ℓ

In this region, Fig. 6.6 shows poor agreement between $Z_{BH(0)}$(Meas.) and $Z_{BH(0)}$(Theo.). The data plots approximately parallel to but below the 1:1 correspondence line. In determining the initial OHO active biomass in the batch test, $Z_{BH(0)}$(Meas.), the calculated μ_H value has a significant impact. As the μ_H value increases, the $Z_{BH(0)}$(Meas.) calculated according to Eq. (4.22) decreases. As described in Section 6.2.2 above, the μ_H values in this region are larger than the usual values. This suggests that μ_H is overestimated which leads to underestimation of $Z_{BH(0)}$(Meas.). Also, it is apparent that the μ_H values calculated via the analytical procedure of Wentzel *et al.* (1995) increase as $Z_{BH(0)}$(Theo.) decreases, *i.e.* So/Xo ratio increases. To explain similar observations

to those noted above, Novak *et al.* (1994) suggested a competition model, between fast-growing and slow-growing OHO population groups. The model development will be explained in detail at Chapter 7, but the basic equations are presented below to assist the discussion. The growth rates on RBCOD for the fast and slow-growing population groups are given in Eqs. (6.3) and (6.4) respectively. Noting that at the high substrate concentrations present in the batch tests, S >> K_{SH} and hence $S/(S+K_{SH}) \approx 1$, the equations can be simplified as below:

$$\frac{dX_1}{dt} = \mu_{H1}\frac{S \cdot X_1}{S+K_{SH1}} \simeq \mu_{H1} \cdot X_1 \qquad \text{(fast-grower)} \tag{6.3}$$

$$\frac{dX_2}{dt} = \mu_{H2}\frac{S \cdot X_2}{S+K_{SH2}} \simeq \mu_{H2} \cdot X_2 \qquad \text{(slow-grower)} \tag{6.4}$$

From Eqs. (6.3) and (6.4), as the batch test proceeds it can be expected that the fast grower (X_1) will increase their relative proportion in the total OHO population, while the slow growers (X_2) will decrease their relative proportion (even though their actual concentration may increase). Since the OUR monitored in the batch test is the combined effect, in terms of the single OHO population approach used to analyse the batch test data, this would cause an increase in the maximum specific growth rates as the batch test proceeds. This will reflect in an upward curvature in the plot of $\ell n\ OUR_H$ versus time. Fig. 6.8 shows a typical OHO OUR versus time profile in the competition region of $30 < Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ as well as the $\ell n\ OUR_H$ versus time profile. From this latter profile it is evident that the $\ell n\ OUR_H$ data indeed does have an upward curvature relative to the fitted linear regression line. This deviation shows clearly that the conventional single OHO population model cannot depict the reality of the modified batch test at high So/Xo conditions. Novak *et al.* (1995) reported a similar deviation and proposed the two OHO population model in terms of which during the batch test under high So/Xo conditions the fast-growing group in the activated sludge are favoured (Ghosh and Pohland, 1972; Pitter and Chudoba, 1990; Chudoba *et al.*, 1992).

From the above, in this region the observed behaviour strongly suggests that the net OHO maximum specific growth rates change during the course of the batch test. In a single OHO population model, as applied in Chapter 4 to interpret the batch test data, this implies that the maximum specific growth rate constants for the OHO would need to be increased with time. A two OHO population model with fast- and slow- growing OHO groups, as proposed by Novak *et al.* (1995), would seem to be a logical alternative. Conceptually, such a model can provide a rational explanation for the observed behaviour. Accordingly this will be investigated further in Chapter 7.

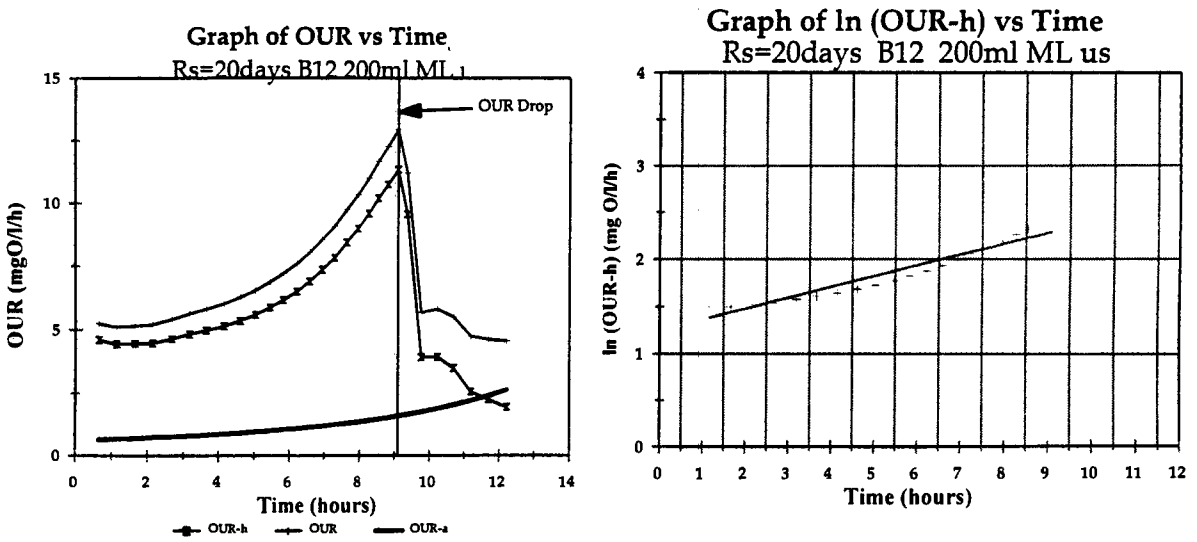


Fig. 6.8: OUR (OHO, h; AO, a; and measured) versus time and $\ell n(OUR_H)$ versus time profile for a representative modified batch test in the competition region. Modified Batch Test No. B23, Sewage Batch Test No. 12.

6.3.3 Third region: 150 mgCOD/ℓ < $Z_{BH(0)}$(Theo.)

In the region of theoretical $Z_{BH(0)}$ > 150 mgCOD/ℓ, which represents a relatively low So/Xo ratio (for the batch test), the measured $Z_{BH(0)}$ were significantly larger than the theoretical $Z_{BH(0)}$ and the data are very scattered. Additionally, in this region the values for the maximum specific growth rates were low.

Fig. 6.9 shows typical OUR and $\ell n(OUR_H)$ versus time profiles for batch tests in the region 150 mgCOD/ℓ < $Z_{BH(0)}$(Theo.). Particularly evident is that the slope of the $\ell n(OUR_{H(t)})$-time plot is almost flat, which is a reflection of the low maximum specific growth rates. Thus, any small errors in measuring the OUR or in fitting the linear regression line to the $\ell n\ OUR_H$ - time plot, would have a significant impact on the slope. Since the OHO maximum specific growth rates are determined from the slope, the error in slope would be carried to the maximum specific growth rates and hence to the estimate for $Z_{BH(0)}$ also. Thus, in this region the batch test resolution is inadequate; in the batch test, the increase in OHO active biomass concentration with time needs to be significant compared to the initial concentration, in order to obtain a reasonable value for the slope of the $\ell n\ OUR_H$ - time plot, and hence for initial OHO active biomass concentration. In this region this did not happen - the data lies outside the range of sensitivity for the modified batch test method. Further, at low So/Xo values there is a possibility of substrate storage (Chudoba *et al.*, 1992). To investigate this possibility, the RBCOD recovered from the area under the OUR_H - time profile was determined (Mbewe *et al.* 1995), and is shown plotted as a fraction of the initial batch test total COD versus So/Xo in Fig. 6.9. Since the wastewater added to the batch tests is the same (taking account of dilution), it can be expected the RBCOD fraction of the total COD should stay constant. However, at the very low So/Xo value (± 1 mgCOD/mgMLAVSS) a lower recovery was obtained, suggesting substrate storage. Such a process is not included in the data analysis. Accordingly, for these reasons the behaviour in this

region was not investigated further.

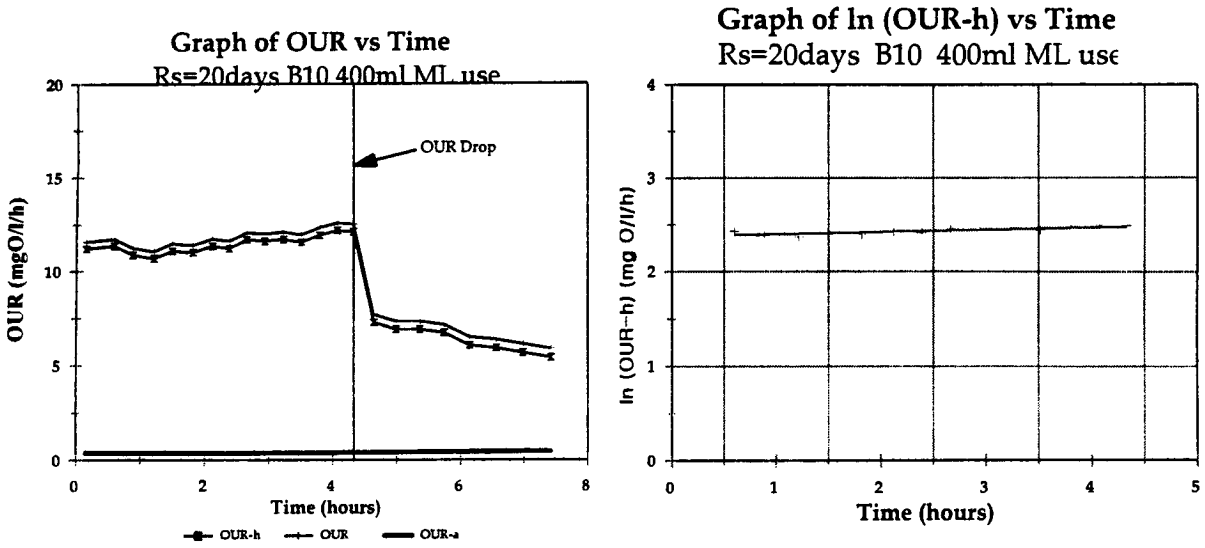


Fig. 6.9: OUR (OHO, h; AO, a; and measured) versus time and $\ell n(OUR_H)$ versus time profile for a representative modified batch test in the inhibition region. Modified Batch Test No. B11, Sewage Batch Test No. 10.

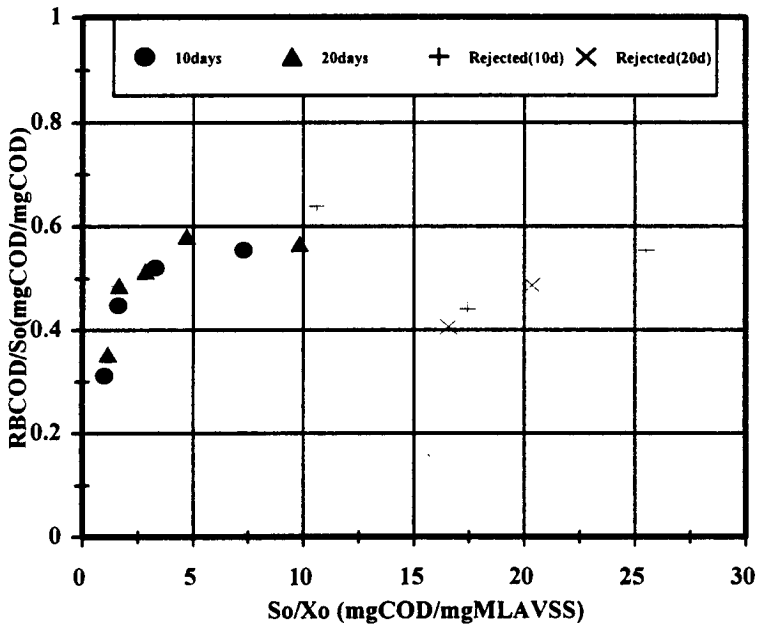


Fig. 6.10: RBCOD as a fraction of total wastewater COD (So) determined from the area under the OUR_H-time profile (Mbewe *et al.* 1995) in the initial batch test versus So/Xo ratio.

6.4 SECOND PLATEAU OF OUR RESPONSE

In analysis of the batch test data, the OUR_H plateau immediately following the precipitous OUR drop is assumed to be due to SBCOD hydrolysis/utilization. Further, it is assumed that this SBCOD hydrolysis/utilization proceeds at a maximum rate (K_{MP}) from the start of the batch test till after the precipitous OUR drop. These assumptions are necessary since the kinetic behaviour in the batch test is interpreted in terms of the UCT kinetic model for activated sludge systems (Dold *et al.*, 1980, 1991). In this model the substrate utilization is divided into separate, but simultaneous, RBCOD and SBCOD utilization. (In contrast, in the IWA Task Group model (Henze *et al.*, 1987), this division is not necessary since substrate utilization and growth occur only on RBCOD; SBCOD is hydrolysed to RBCOD for subsequent utilization and growth).

By assuming the OUR_H immediately following the precipitous OUR drop is due to SBCOD hydrolysis/utilization, a value for the OHO maximum specific growth rate on SBCOD (K_{MP}) can be derived and hence a value for the OHO maximum specific growth rate on RBCOD (μ_H). Separate values for these kinetic constants are not required to determine the OHO active biomass concentration at the start of the batch test, but rather a lumped parameter which is the net OHO maximum specific growth rate, *i.e.* ($\mu_H + K_{MP} - b_H$) = slope of the $\ell n\ OUR_H$ - time plot. However, what is of importance is that the OHO specific growth rates are at their maxima. Should the specific growth rates not be at their maxima, then these will change with time in the batch test as the substrate concentrations change with time due to utilization. With regard to μ_H, the observed precipitous drop in OUR would substantiate that these are at maxima. With regard to K_{MP}, (i) that an OUR plateau following the precipitous drop is observed, and (ii) that the values for K_{MP} derived in this investigation (K_{MP} = 1.37 and 1.42 /d) are close to the default value for the UCT kinetic model (K_{MP} = 1.35 /d, Dold *et al.*, 1991), would suggest that the SBCOD hydrolysis/ utilization rate is close to a maximum immediately following the precipitous OUR drop. What is not clear, however, is the source of the SBCOD. In preparation of the wastewater for the modified batch test, alum is added as flocculent and the supernatant after settling is filtered (see Chapter 4). This should remove most, if not all the SBCOD. Accordingly, this aspect was investigated further.

For the modified batch tests conducted during Sewage Batch No.17, soluble Total Organic Carbon (TOC) concentrations with time were monitored. Substrate concentrations usually are quantified by COD measurements; however, in the modified batch test, COD concentrations were too low to measure accurately and precisely. Samples were taken from the batch reactor at regular intervals, every 2 hours before OUR drop and every 0.5 hour after the OUR drop. The samples were immediately filtered through 0.45 μm filter paper, 2 - 3 drops of $HgCl_2$ were added to the filtrate which was stored for subsequent TOC analysis.

Fig. 6.11 shows a typical plot of soluble TOC concentration with time during Batch Test No. A34, Sewage Batch No.17 (see Appendix A for the Batch Test Nos. A35, B34 and B35). Up to the precipitous OUR drop, the soluble TOC concentration decreases. To examine the rate of soluble TOC removal, this is shown plotted with time in Fig. 6.11. The rate of TOC removal closely follows the OUR, increasing with time. This substantiates that the observed OUR response is directly linked to the rate of substrate removal. Both rates increase with time, due to the increase in OHO active biomass concentration, due to the growth process. Following the precipitous drop in OUR, the rate of TOC removal decreases sharply, but continues for

approximately 2 hours before the TOC concentration levels off at the unbiodegradable soluble TOC concentration.

The continuation of soluble TOC uptake after the precipitous drop in OUR, would suggest that a "soluble" SBCOD remains after flocculation and filtration of the wastewater. Further, during the course of the batch test additional SBCOD will be generated, through the death regeneration process. This would tend to substantiate the assumption of maximum SBCOD utilization. However, the information available is not sufficient to make a definitive judgement on this aspect. What is clear, however, is that any uncertainties in quantifying K_{MP} do not cause the definite trend in μ_H with theoretical OHO active biomass concentration (Fig. 6.1) or So/Xo (Fig. 6.5).

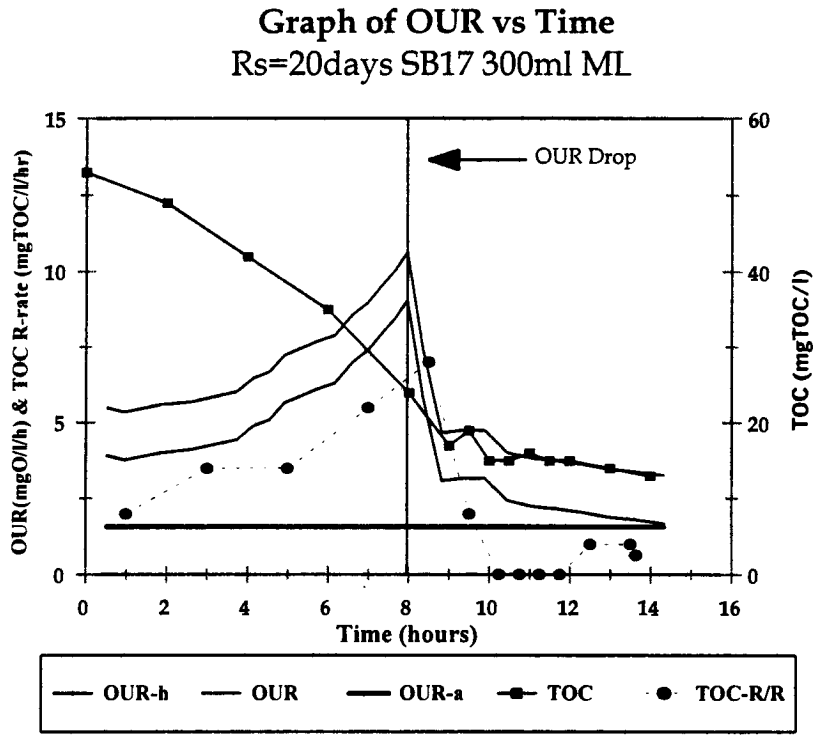


Fig. 6.11: OUR (OHO, h; AO, a; and measured), soluble Total Organic Carbon (TOC) concentrations and TOC removal rate (TOC-R/R, mgTOC/ℓ/hr) versus time. Modified Batch Test No. B34, Sewage Batch No. 17.

6.5 CONCLUSIONS

To attempt to identify possible causes for the deviations between measured and theoretical OHO active biomass concentrations (see Chapter 4), in this Chapter OHO behaviour in the modified batch tests has been examined in more detail, through a detailed analysis of the data collected in Chapter 4. From this investigation the following general conclusion can be drawn:

- For all observations, there is remarkable similarity in the data for modified batch tests on both the 10 and 20 day sludge age mixed liquors. This substantiates the consistency of the data and the observations made. It also excludes sludge age as the underlying cause for any deviations

In examining the variations in OHO maximum specific growth rates with the theoretical OHO active biomass added to the batch test ($Z_{BH(0)}$(Theo.)), it was noted that:

- The OHO maximum specific growth rate on RBCOD (μ_H) is not a constant value between the different modified batch tests, but appears to be a function of the OHO active biomass concentration added at the start of the test ($Z_{BH(0)}$); as $Z_{BH(0)}$ decreases, μ_H increases.

- The OHO maximum specific growth rates on SBCOD (K_{MP}) also exhibit some variation between the different batch tests, also linked to the OHO biomass concentration added. However, the trend here differs from that for μ_H. Three regions can be identified: (i) $Z_{BH(0)}$(Theo.) < 30 mgCOD/ℓ - there is uncertainty in this data as this was rejected on the basis of poor %COD recovery; (ii) 30 mgCOD/ℓ < $Z_{BH(0)}$ < 150 mgCOD/ℓ - reasonably constant normally distributed values for K_{MP}, with average value higher than in the other two regions; (iii) $Z_{BH(0)}$(Theo.) > 150 mgCOD/ℓ - tendency for K_{MP} to decrease as $Z_{BH(0)}$(Theo.) increases.

In seeking an explanation for the behaviour described above, it was noted that the variation in $Z_{BH(0)}$(Theo.) would imply a concomitant variation in the ratio initial substrate to OHO active biomass concentration (*i.e.* the So/Xo ratio). Grady *et al.* (1996) has previously noted that different maximum specific growth rates can be obtained at different So/Xo. This was investigated, and the following conclusions can be drawn:

- Similar, though reversed, trends noted above for μ_H and K_{MP} were evident for the effect of So/Xo.

- To explain similar observations, Novak *et al.* (1994) proposed that the batch conditions may favour the growth of sections of the OHO population (*e.g.* fast growing OHOs), causing the OHO community structure to change with time in the batch test. This change in community structure will effect a change in the observed response, which is not taken into account in the batch test analysis; this would require the single OHO population to be divided into sub populations.

With the information above, the plot of theoretical versus measured $Z_{BH(0)}$ plot was re-examined, and the following conclusions can be drawn:

- For $Z_{BH(0)}$(Theo.) < 30 mgCOD/ℓ : There is uncertainty in the data although the trends do suggest possible inhibition. However, due to the uncertainty this will not be investigated further.

- For 30 mgCOD/ℓ < $Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ : In this region, the observed behaviour strongly suggests that the net OHO maximum specific growth rates change during the course of the batch test. In a single OHO population model, as applied in Chapter 4 to interpret the batch test data, this implies that the maximum specific growth rate constants for the OHO would need to be increased with time. A two OHO population model with fast- and slow-growing OHO groups, as proposed by Novak *et al.* (1995), would seem to be a logical alternative. Conceptually, such a model can provide a rational explanation for the observed behaviour.

- For $Z_{BH(0)}$(Theo.) > 150 mgCOD/ℓ : In this region, the batch test resolution is inadequate, because the increase in OHO active biomass concentration with time is not significant compared to the initial concentration, a requirement in the batch test. Accordingly this data will not be investigated further.

From the above, the region of 30 mgCOD/ℓ < $Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ will be investigated further in Chapter 7. In this regard the concepts of Novak *et al.* (1994) appear to hold promise, in which subdivision of the single OHO population group into subpopulations which compete for substrate is proposed.

CHAPTER 7

KINETIC MODEL FOR COMPETITION BETWEEN FAST- AND SLOW-GROWING OHO ACTIVE BIOMASS GROUPS

7.1 INTRODUCTION

In Chapter 4, the analytical procedure of Wentzel *et al.* (1995) for the modified batch test was applied to interpret the batch test data and to quantify the measured OHO active biomass concentration. The results showed very poor correlation between the theoretical OHO active biomass concentration calculated with the conventional steady state model and that measured with the modified batch test method. In Chapter 5, the aerobic batch digestion method was applied to quantify OHO active biomass concentration and close correlation between theoretical and measured was obtained. This indicated that for the modified batch test the cause for the divergence between theoretical and measured values lay in the modified batch test method and data interpretation procedures. This was substantiated in Chapter 6, where the modified batch test data collected in Chapter 4 and the behaviour of OHOs under the batch test conditions were examined in greater detail. It was concluded that the observed response and OHO behavioural patterns can not be explained in terms of the single OHO population kinetic model accepted as the convention in modelling of aerobic and anoxic/aerobic activated sludge systems (e.g. Dold *et al.*, 1991; Henze *et al.*, 1987), and used by Wentzel *et al.* (1995) to interpret the batch test data. Accordingly, in this Chapter, the single OHO population kinetic model will be modified to develop a new kinetic model(s) to describe the observed batch test and parent activated sludge system behaviours The developed kinetic model(s) must be able to correctly describe the OHO microbiological behaviour observed in both the modified batch tests and in the parent steady activate sludge systems. Thus, applicability of the developed models will be evaluated through simulation of the modified batch test and parent steady state systems. Application to the modified batch tests will be restricted to those batch tests in which there is greater certainty in the data as set out in Chapter 6, *i.e.* 30 mgCOD/ℓ < $Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ Fig.6.6.

7.2 DEFICIENCIES OF THE CURRENT MODEL AND POSSIBLE ALTERNATIVES

7.2.1 Deficiency of the simplified UCT model (Wentzel *et al.*, 1995)

As noted in previous chapters, the simplified UCT model cannot correctly describe the OUR-time curve observed in the modified batch test. Particularly for the competition region (as named in Chapter 6), the deficiency of the simplified UCT model was clearly demonstrated.

Specifically, in this region it was noted in Chapter 6 that:

(i) The observed precipitous drop in OUR implies that the OHO specific growth rates are at their maxima, *i.e.* the changes noted below were not directly due to variations in growth rates due to varying substrate concentrations with time or between batch tests.

(ii) In a plot of $\ell n\ OUR_H$ versus time, the measured data deviated from the fitted linear regression line, showing upward curvature; for example see Fig. 6.8. In plotting the OUR_H - time curve predicted by the simplified UCT model (based on a single OHO population), this deviation is accentuated; for example see Fig. 7.2. To explain these deviations, in Chapter 6 it was noted that the data implies that the overall OHO maximum specific growth rates increase during the course of the batch test. An increase in OHO maximum specific growth rates with time under batch test conditions has been directly observed by Pollard *et al.* (1998). Such observations are not accommodated in the simplified UCT model used to develop the analytical procedure for the batch test.

(iii) OHO maximum specific growth rates on RBCOD as calculated from the batch test data with the simplified UCT model analytical procedure increased as the substrate (So) to OHO active biomass concentration (Xo), *i.e.* the So/Xo ratio, at the start of the batch test increased. With the single OHO population model incorporated in the analytical procedure, it would be expected that the OHO maximum specific growth rate would remain constant.

(iv) The larger OHO maximum specific growth rate on RBCOD values above, were significantly higher (up to about 7 /d) than the range of values accepted as the default for the UCT kinetic model (1.5 to 3.5 /d, Dold *et al.*, 1991). Such high values usually are only encountered in systems in which the "selector effect" has been stimulated (Chudoba *et al.*, 1973). For the parent systems operated here as source of mixed liquor for the batch tests, reactors were completely mixed and the loading rates low and hence the selector effect was not induced.

(v) The OHO active biomass concentrations measured via the batch test procedure were consistently lower than the theoretical values. One possible explanation for this is that the OHO maximum specific growth rates increase with time in the batch tests: In terms of the batch test analytical procedure, a single constant OHO maximum specific growth is determined and applied to the start of the test to derive a value for OHO active biomass concentration. Thus, if the OHO maximum specific growth rate increases with time, then the value at the start of the test is overestimated and hence OHO active biomass concentration would be underestimated.

The observations above suggest that the OHO maximum specific growth rate, particularly on RBCOD, increases with time in the batch test. The current analytical procedure for the batch test, which is based on a single OHO population with fixed kinetics, cannot readily accommodate this observation.

To overcome this and to explain similar observations, Novak *et al.* (1995) proposed a competition model. In this model, two OHO populations groups in activated sludge are distinguished, one a slow growing group and the other a fast growing group. During the batch test under high So/Xo ratio the fast-growing group in the activated sludge are favoured (Ghosh and Pohland, 1972; Pitter and Chudoba, 1990; Chudoba *et al.*, 1992), causing their relative proportion of the OHO population to increase. The change in the relative proportions of the fast and slow growing groups (*i.e.* change in OHO community structure) in the batch test would account for the observed change in overall OHO maximum specific growth rates. Similarly, Grady *et al.* (1996) proposed competition as one of the reasons for the above observations and noted that the larger So/Xo, the greater the change in the community structure and the more the measured kinetics will reflect the characteristics of the fastest growing species rather than the characteristics of the original culture. Further, the greater the number of sequential enrichments performed, the more the measured parameters will reflect the kinetics of the fastest growing species.

In contrast, Daigger *et al.* (1982) and Grady *et al.* (1996), proposed that the change in the OHO maximum specific growth rate could be ascribed more to "physiological adaptation" than to a competition. In "physiological adaptation", when the biomass is subjected to a new environment, such as different So/Xo conditions, the protein synthesizing system (PSS) adapts to the new environmental conditions such that the cell maximizes the use of organic monomers and energy for synthesis of new cell mass and hence different maximum specific growth rates can be yielded under different environmental conditions. Thus, it is not the relative proportions of the biomass groups that change, but rather the change is in the physiological state of the biomass itself (Grady *et al.*, 1996).

In this research, even though it remains a point of contention, the competition model will be selected for development rather than the physiological adaptation model. From a practical point of view, the competition model can be more readily transformed to a mathematical form. Thus, for this research a kinetic model for competition between two OHO population groups will be developed, and the model validated against the experimental data collected here. The physiological adaptation model development can be a topic for further research. In any event, it is expected the overall observable predictions of the two approaches will be similar.

7.2.2 Data for evaluation of the competition model

To evaluate the competition model to be developed, the batch test data with the greatest surety was selected. From Chapter 6, these were the batch tests with theoretical OHO active biomass concentrations > 30, but < 150 mgCOD/ℓ; in Chapter 6, this was termed the competition region. Table 7.1 lists the sewage batches and batch tests in the competition region selected for the evaluation of the competition model. 11 and 12 modified batch tests respectively on mixed liquors from the 10 and 20 days sludge age parent systems (out of total of 35 modified batch tests on mixed liquors from each of the parent systems) were selected for further analysis. All these batch test data have shown poor agreement between the measured OHO active biomass concentration ($Z_{BH(0)}$) and the theoretical $Z_{BH(0)}$. The OUR_H-time plots of the individual batch tests all show the representative

trend of the competition region (see Appendix A, and Fig. 6.8). Fig. 7.1 shows the measured $Z_{BH(0)}$ versus theoretical $Z_{BH(0)}$ plot for the selected data set, as determined in Chapter 4; as noted previously, the measured values are consistently lower than the theoretical values.

Table 7.1: Modified batch test experimental data in the competition region selected for evaluation of the proposed models.

Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		COD Recov. (%)	Regression			Growth Rate (/d)		$Z_{BH(0)}$ (mgCOD/l)			
											Measured		Theoretical	
			WW	ML		Y-int	Slope	R2	K_{MP}	μ_H	Batch	ML	Batch	ML
10	A12	1112	2.80	0.20	104.9	1.733	0.155	0.954	1.65	2.67	60.9	913.1	127.5	1912.0
	A13	1212	2.90	0.10	100.8	1.031	0.266	0.993	1.65	5.35	18.7	560.2	63.7	1912.0
	A14	1312	2.95	0.05	96.5	0.807	0.266	0.999	1.10	5.91	14.9	893.4	31.9	1912.0
11	A17	3012	2.80	0.20	93.3	1.381	0.146	0.926	1.51	2.61	45.0	675.2	115.2	1728.2
	A18	3112	2.90	0.10	90.5	0.459	0.225	0.967	1.86	4.16	12.2	366.9	57.6	1728.2
12	A22	1101	2.80	0.20	93.3	1.538	0.152	0.982	1.90	2.38	50.7	760.5	116.7	1750.8
	A23	1401	2.90	0.10	92.1	0.759	0.173	0.950	1.58	3.18	20.9	626.4	58.4	1750.8
14	A29	1802	2.80	0.20	96.1	0.896	0.178	0.962	1.90	3.00	23.3	349.4	88.4	1325.9
	A30	2002	2.90	0.10	86.2*	0.301	0.275	0.978	1.79	5.42	8.7	261.6	44.2	1325.9
17	A34	2204	2.80	0.20	97.5	0.967	0.128	0.958	1.38	2.31	33.2	497.5	95.2	1427.9
	A35	2404	2.90	0.10	100.3	-0.837	0.283	0.978	1.14	6.27	2.7	81.6	47.6	1427.9
10	B13	1212	2.80	0.20	95.6	1.647	0.174	0.992	1.62	3.18	50.3	755.0	83.7	1255.5
	B14	1312	2.90	0.10	93.6	1.136	0.217	0.996	1.45	4.38	24.9	746.3	41.9	1255.5
11	B17	3012	2.70	0.30	93.2	1.530	0.148	0.957	1.92	2.26	51.4	514.5	129.7	1296.6
	B18	3112	2.80	0.20	102.1	0.962	0.178	0.962	1.86	3.02	25.0	374.5	86.4	1296.6
	B19	0501	2.90	0.10	90.6	1.043	0.282	0.995	1.55	5.82	17.9	537.5	43.2	1296.6
12	B22	1101	2.70	0.30	95.9	1.637	0.113	0.971	1.80	1.54	71.8	717.7	133.6	1335.8
	B23	1401	2.80	0.20	94.8	1.252	0.114	0.916	1.37	1.99	48.5	727.0	89.1	1335.8
	B24	1501	2.90	0.10	86.6*	0.545	0.213	0.967	1.61	4.13	14.0	420.4	44.5	1335.8
14	B29	1802	2.70	0.30	96.3	1.000	0.157	0.945	1.69	2.71	28.8	288.0	98.3	982.7
	B30	2002	2.80	0.20	89.7*	0.591	0.238	0.974	1.84	4.51	13.3	198.9	65.5	982.7
17	B34	2204	2.70	0.30	101.0	1.165	0.118	0.945	1.34	2.13	43.1	431.4	104.4	1044.4
	B35	2404	2.80	0.20	102.8	0.167	0.200	0.953	1.34	4.07	10.2	152.5	69.6	1044.4

Note) A : 10 days sludge age system, B : 20 days sludge age system

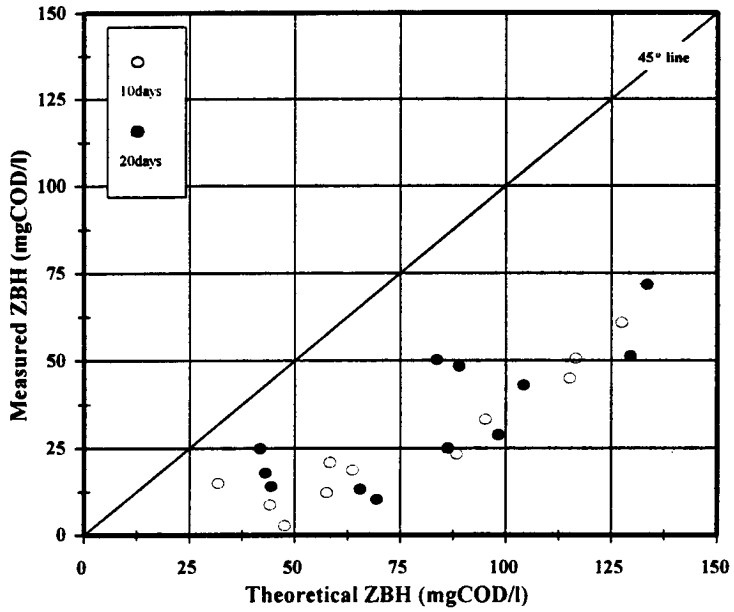


Fig. 7.1 : The graph of measured versus theoretical OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] for the selected data of the modified batch tests in the competition region.

7.3 DEVELOPMENT OF THE COMPETITION MODEL - CONCEPT AND HYPOTHESIS

Novak *et al.* (1994) formulated the hypothesis for the competition model as follows: In the competition model, it is assumed that an activated sludge OHO biomass is composed of two different OHO population groups, X_{BH1} (fast grower) and X_{BH2} (slow grower), which are significantly different in their maximum specific growth rates ($\mu_{H1} >> \mu_{H2}$). In the case where the sludge is developed in a continuously operated low loaded system where lower growth rates are expected, the growth of the slow grower (X_{BH2}) will be favoured. Consequently, for this case the fraction of the slow grower in the sludge will be higher than the fraction of the fast grower ($X_{BH1} << X_{BH2}$). In contrast, under batch cultivation conditions when very high initial S_0/X_0 ratios are used, the fast grower (X_{BH1}) will be favoured because of its higher maximum specific growth rate. Although the fast grower (X_{BH1}) fraction in the biomass at the start of the batch test may be several times lower than that of the slow grower (X_{BH2}), the fast grower rapidly increases its relative proportion in the biomass, to the extent the growth of the fast grower (X_{BH1}) determines the shape of the OUR exponential curve with time; the influence on the OUR of the slow grower (X_{BH2}) may be almost negligible in the exponential part of the curve.

The proposals above requires that both slow and fast growing OHO population groups are present at the start of the batch test. With regard to the source of the slow grower, the slow grower appears to originate and dominate within the parent system, and thus would be present in the parent system mixed liquor added to the batch test. Thus, this OHO group would be acclimatized to the conditions of the parent system which has a low So/Xo ratio. Sokol (1987) reported on the acclimatization of biomass. In his experiment, continuous parent systems were run at various "dilution rate" (0.13 to 0.52d), which equals the specific growth rate (flow through system). The biomass from each continuous parent system was transferred to a batch reactor to measure the removal rate for a substrate . The measured removal rates in the batch reactor were closely related to the condition of the parent continuous system. As the fixed specific growth rate (dilution rate) of the continuous parent system increased, the measured removal rate in the batch test also increased, *i.e.* the condition of the parent system influences the measured maximum specific growth rate in the batch test. The activated sludge systems of this research were run at very low specific growth rates (*i.e.* dilution rates), so it is reasonable to expect that the maximum specific growth rate of OHO active biomass in the activated sludge system would be low.

With regard to the source of the fast grower, Wentzel *et al.* (1995) applied the batch test with wastewater only to measure the RBCOD in the wastewater. From their observations, it was found that OHO active biomass definitely exists in the wastewater and has much higher maximum specific growth rates than the rate in the activated sludge system. Cronje *et al.* (2000) in applying the batch test to mixtures of activated sludge mixed liquor and raw wastewater reported that the wastewater OHO active biomass dominates the OUR response and masks the mixed liquor OHO active biomass OUR response. To eliminate the wastewater OHO active biomass, Cronje *et al.* developed the modified batch test, in which they successfully removed all the active biomass from wastewater with flocculation and filtration. This enabled them to isolate the mixed liquor OHO active biomass, for which they determined very low maximum specific growth rates, of less than 2/d. Cronje *et al.* verified that the flocculation filtration procedure effectively removed all OHO active biomass from the wastewater by running aerobic batch tests on flocculated filtered wastewater - no observable OUR was obtained. This would tend to indicate that the mixed liquor in the Cronje *et al.* investigation contained slow growing OHOs. In this research, the flocculation filtration procedure of Cronje *et al.* was followed. Aerobic batch tests on the flocculated filtered wastewater similarly indicated no observable OUR even after 12 hours. Clearly, the source of fast growing OHO active biomass in the batch test was not the flocculated filtered wastewater added to the test. The only alternative source is the mixed liquor. Thus, in contrast to the investigation of Cronje *et al.*, it would appear that the mixed liquor in this investigation contained both fast and slow growing OHOs. An explanation for the existence of fast growing OHOs in the mixed liquor can be provided as follows.

From the investigations of Wentzel *et al.* and Cronje *et al.* above, fast growing OHO are present in the raw sewage, and hence enter (are seeded into) the activated sludge system with the wastewater feed. Even though this OHO group has a capacity for fast growth, it does not grow significantly in the activated sludge system, and is kept at a very low or negligible concentrations by either "kinetic selection" (Section 7.4) or "process selection" (Section 7.5). In brief, in kinetic selection the fast and slow growing OHO groups have a different set of Monod kinetic parameters (μ_H and K_{SH}), see Fig

7.2. From Fig. 7.2, at high substrate concentration (B) the fast grower has higher specific growth rates and will out-compete the slow grower for substrate, and *visa versa* at low substrate concentrations (A). The net effect of this competition is that one OHO group dominates and the other becomes negligible. The conditions present in the parent activated sludge system are low substrate concentrations (A), and hence the slow growing OHO group should grow to dominate, and the fast growers become negligible. However, since the fast grower are seeded into the system with the wastewater, they can become established in the system at low concentrations. Kinetic selection has been proposed as a mechanism to explain the growth of filamentous organisms in sludge bulking of activated sludge systems (Chudoba *et al.*, 1973; Rittmann *et al.*, 1996; and Chantal *et al.*, 1999 a, b). In process selection, one OHO group does not have a substrate utilization process that the other OHO group does. Thus the former OHO group (which does not have the process) is at a competitive disadvantage to the latter OHO group, reducing its proportion in the mixed liquor. Both kinetic and process selection will be described in more detail later in the chapter, and the applicability of the two types of competition will be assessed.

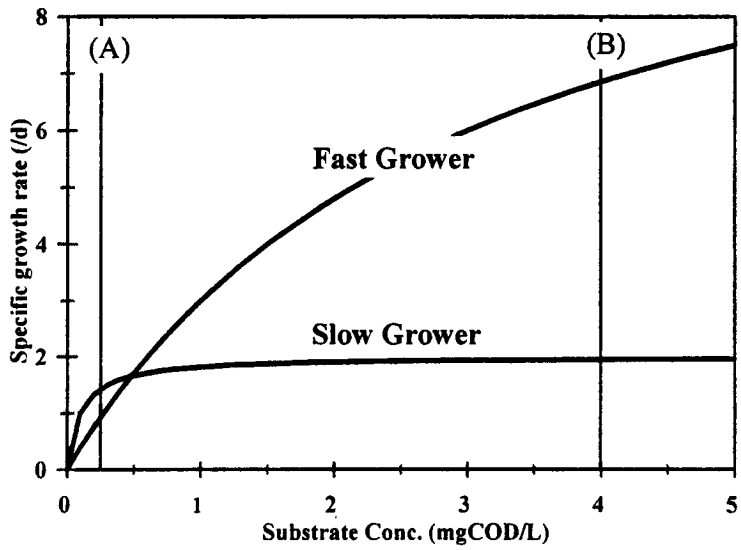


Fig. 7.2: Qualitative behaviour of the growth kinetics for fast grower (Z_{BH1}) and slow grower (Z_{BH2}): μ_{H1} (=12) > μ_{H2} (=2) and K_{SH1} (=3) > K_{SH2} (=0.1).

Both the approaches of kinetic selection and process selection are competition models. Thus, these models will be named as "competition model of kinetic selection" and "competition model of process selection" respectively. In the sections that follow, mathematical kinetic models incorporating these approaches will be developed, values for parameters will be estimated with the data from the modified batch tests, and simulation of both the modified batch tests and parent steady state systems will be investigated.

7.4 COMPETITION MODEL OF KINETIC SELECTION

In concept from the above, in "competition model of kinetic selection", the fast growing OHO group has a higher maximum specific growth rate on RBCOD (μ_{H1}) and a higher half saturation coefficient (K_{SH1}) than the slow growing OHO group (see Fig. 7.2). This proposal must be able to account for the observations made on both the modified batch tests and the parent steady state systems. Under the conditions present in the modified batch test, which contains a significant amount of RBCOD and a small amount of SBCOD, both the fast grower and slow grower can grow at their maximum specific growth rates until all the available RBCOD is depleted. Thus, the observed OUR_H - time plot is the net effect of the interaction between the fast grower and the slow grower (see Fig. 7.3). Since the fast grower has a higher maximum specific growth rate, it relative proportion in the OHO active biomass will increase, causing an increase in the overall specific growth rate with time in the batch test; this is in agreement with the observations above. In the steady state activated sludge system, in which the RBCOD is kept at a very low concentration, the fast grower would be washed out by kinetic selection: Under conditions of very low RBCOD concentrations, the growth rates of both the fast and slow grower do not reach their maxima and, due to its higher half saturation coefficient, the specific growth rate on RBCOD of the fast grower should be lower than that of the slow grower (Kinetic selection theory - Chudoba *et al.*, 1973), to the extent washout of the fast grower occurs. To ensure that the fast growing OHO group remains viable in the steady state system (for transfer to the start of the batch test), seeding with the influent wastewater has been proposed (see above).

In this section, a mathematical kinetic model based on the concepts above is developed, and it validity assessed through application to both the modified batch test and parent steady state systems.

7.4.1 Mathematical model

In this research, the competition model of kinetic selection is based on the simplified UCT kinetic model (Wentzel *et al.*, 1995). This simplified kinetic model included only one OHO group. Accordingly, a second OHO group needed to be incorporated. This was accomplished as follows (Table 7.2):

- The single OHO active biomass was subdivided into two OHO active biomasses, a fast grower (Z_{BH1}) and a slow grower (Z_{BH2}).

- All processes of the simplified UCT kinetic model were duplicated, with the new processes allocated to the second OHO group.

- In the duplication above, the absorbed COD (S_{ads}) was subdivided into absorbed COD for the fast grower (S_{ads1}) and absorbed COD for the slow grower (S_{ads2}). According to Dold *et al.* (1991), the enmeshed COD (S_{enm}), which consists of SBCOD, is adsorbed onto the surface of the OHO active biomass, forms the adsorbed COD (S_{ads}) and finally is hydrolysed and directly utilized by the OHO active biomass. In terms of this proposal, with two OHO groups, each can only utilize the adsorbed COD which is on its own surface. Thus, the adsorbed COD was split into two groups, S_{ads1} and S_{ads2}, which are then utilized by the fast grower (Z_{BH1}) and the slow grower (Z_{BH2}) respectively.

- The proposals above required that each OHO group had individual SBCOD adsorption and hydrolysis/utilization processes, and hence the duplication.

The complete competition model is presented in matrix format in Table 7.2. Modelling of the nitrification processes is not included, as the focus is on OHO mediated processes. This obviates the need to include nitrogen transformations - adequate nitrogen for OHO growth is always available.

In selecting values for the stiochiometric and kinetic constants, values for all constants (including duplicated constants) from the simplified UCT kinetic model were accepted, except for:

- Maximum specific growth rates (μ_{H1} and μ_{H2}) and half saturation coefficients (K_{SH1} and K_{SH2}) for OHO growth on RBCOD; for the competition model, the two OHO population groups were to be given different values for these constants.

- Maximum specific growth rates for OHO growth on SBCOD (K_{MP}); both OHO population groups were given the same value, which was the default value (K_{MP} = 1.35) for the UCT model (Dold *et al.*, 1991), which is very close to the average K_{MP} values measured in this investigation (Chapter 4).

The above implies direct kinetic competition for RBCOD substrate between the two OHO groups. However, direct competition for SBCOD substrate is not explicitly included - the SBCOD related process are duplicated for both OHO groups and the values for the constants are the same. There is, however, implicit competition for SBCOD - the rate formulations for SBCOD adsorption, and hydrolysis/utilization include the relevant OHO active biomass concentrations.

Table 7.2: Matrix representation of competition model of kinetic selection.

COMPOUND i → / j ↓ PROCESS	1 Z_{BH1}	2 Z_{BH2}	3 Z_E	4 Z_I	5 S_{ads1}	6 S_{ads2}	7 S_{enm}	8 S_{bs}	9 S_{us}	10 O	PROCESS RATE, ρ_j
1 Aerobic growth of Z_{BH1} on S_{bs}	1							$-1/Y_{ZH}$		$-\frac{1-Y_{ZH}}{Y_{ZH}}$	$\mu_{H1}\left[\frac{S_{bs}}{K_{SH1}+S_{bs}}\right]Z_{BH1}$
2 Aerobic growth of Z_{BH2} on S_{bs}		1						$-1/Y_{ZH}$		$-\frac{1-Y_{ZH}}{Y_{ZH}}$	$\mu_{H2}\left[\frac{S_{bs}}{K_{SH2}+S_{bs}}\right]Z_{BH2}$
3 Aerobic growth of Z_{BH1} on S_{ads1}	1				$-1/Y_{ZH}$					$-\frac{1-Y_{ZH}}{Y_{ZH}}$	$K_{MP}\left[\frac{(S_{ads1}/Z_{BH1})}{K_{SP}+(S_{ads1}/Z_{BH1})}\right]Z_{BH1}$
4 Aerobic growth of Z_{BH2} on S_{ads2}		1				$-1/Y_{ZH}$				$-\frac{1-Y_{ZH}}{Y_{ZH}}$	$K_{MP}\left[\frac{(S_{ads2}/Z_{BH2})}{K_{SP}+(S_{ads2}/Z_{BH2})}\right]Z_{BH2}$
5 Death of Z_{BH1}	-1		f_E				$1-f_E$				$b_H Z_{BH1}$
6 Death of Z_{BH2}		-1	f_E				$1-f_E$				$b_H Z_{BH2}$
7 Adsorption of S_{enm} by Z_{BH1}					1		-1				$K_A S_{enm} Z_{BH1}(f_{MA} - S_{ads1}/Z_{BH1})$
8 Adsorption of S_{enm} by Z_{BH2}						1	-1				$K_A S_{enm} Z_{BH2}(f_{MA} - S_{ads2}/Z_{BH2})$
Stoichiometric constants Y_{ZH} = Heterotroph yield f_E = Endogenous residue f_{MA} = Max. ratio S_{ads}/Z_{BH}	Fast grow (active) heterotrophic mass M (COD) L^{-3}	Slow grow (active) heterotrophic mass M (COD) L^{-3}	Endogenous mass M (COD) L^{-3}	Inert mass M (COD) L^{-3}	Adsorbed slowly biodegradable substrate M (COD) L^{-3}	Adsorbed slowly biodegradable substrate M (COD) L^{-3}	Enmeshed slowly biodegradable substrate M (COD) L^{-3}	Readily biodegradable (soluble) substrate M (COD) L^{-3}	Unbiodegradable soluble substrate M (COD) L^{-3}	Oxygen M (-COD) L^{-3}	Kinetic constants μ_{H1} = Heterotroph max. specific growth rate on S_{bs} of Fast Grower μ_{H2} = Heterotroph max. specific growth rate on S_{bs} of Slow Grower K_{SH1} = Heterotroph 1/2 saturation on S_{bs} K_{SH2} = Heterotroph 1/2 saturation on S_{bs} K_{MP} = Heterotroph max. specific growth rate on S_{ads} K_{SP} = Heterotroph 1/2 sat. on S_{ads} b_H = Heterotroph specific death rate K_A = S_{enm} specific adsorption rate

From the above, values need to be determined for the maximum specific growth rates on RBCOD of the fast grower (μ_{H1}) and the slow grower (μ_{H2}) and the respective half saturation coefficients (K_{SH1} and K_{SH2}). With regard to μ_{H1} and μ_{H2}, these were assumed as 12/d and 2/d respectively. These values cannot be directly determined in this research, because methods to separate the two maximum specific growth rates are not available. The maximum specific growth rate of the slow grower (μ_{H2}) is based on the value which was determined by Cronje *et al.* (2000), since their data for the modified batch test showed very low maximum specific growth rates, which probably represents the maximum specific growth rate of the slow grower. The value for the maximum specific growth rate of the fast grower is based on inspection of the parameter estimation results and selection of the value that appeared to best describe the observations.

The values for the half saturation coefficients on RBCOD of the fast grower (K_{SH1}) and the slow grower (K_{SH2}) determine the sharpness of the OUR drop in the OUR_H-time plot when RBCOD becomes depleted. The value of K_{SH1} should be kept low in order to reproduce the observed precipitous drop of the OUR_H-time plot. Thus, K_{SH1} for the fast grower was set as 3 mgCOD/ℓ from inspection of the OUR_H-time curves. Even though it may be unrealistic, K_{SH2} of the slow grower was set as 0.1, which is far lower than the value of K_{SH1} to ensure the appropriate kinetic selection in steady state system modelling. Uncertainty in values for the kinetic parameters are not of major concern since, in this research, emphasis is on evaluation of the competition model concept, rather than on finding the exact model structure and values for constants. Table 7.3 shows the kinetic and stoichiometric parameters which are used in this parameter estimation.

Table 7.3: Kinetic and stoichiometric parameters for the non-linear regression of competition model for 'competition model of kinetic selection'.

PARAMETERS	UNIT	VALUE	NOTE
μ_{H1}	/d	12	Max. specific growth rate for Fast grower
μ_{H2}	/d	2	Max. specific growth rate for Slow grower
K_{SH1}	mg/l	3	Half saturation coeff. for Fast grower
K_{SH2}	mg/l	0.1	Half saturation coeff. for slow grower
K_{MP}	mgCOD/mgcellCOD/d	1.35	Max. specific growth rate on SBCOD
K_{SP}	mgCOD/mgcellCOD	0.027	Half saturation coeff. on SBCOD
b_H	/d	0.62	Death rate
K_A	mgCOD/mgcellCOD/d	0.17	Adsorption Rate
Y_{ZH}	mgcellCOD/mgCODutilized	0.666	Yield coeff.
f_E	-	0.08	Fraction of the endogenous residue
f_{MA}	mgCOD/mgcellCOD	1	Max. ratio of S_{enm}/Z_{BH}

7.4.2 Application of the proposed model to the modified batch tests

The model proposed above, was applied to the modified batch tests listed in Table 7.1. In this application, the values for kinetic and stiochiometric constants listed in Table 7.3 were accepted. In the application, what is not known are the initial conditions present at the start of the batch tests. These were determined using the parameter estimation facility in the AQUASIM 2.0 computer programme (Reichert 1998 a, b).

7.4.2.1 Parameter estimation procedure

The parameter estimation was done with the aid of the AQUASIM 2.0 computer program (Reichert, 1998 a, b). All the parameters except the parameters related to the growth on RBCOD are based on the default values of the UCTOLD computer program (Dold *et al.*, 1991). Accepting the values for the kinetic and stoichiometric parameters in Table 7.3, the parameters which were required to be estimated are:

- The initial concentrations of the fast grower and the slow grower, $Z_{BH1(0)}$ and $Z_{BH2(0)}$ respectively which are the main concern of this research.

- The initial "substrate" concentrations.

In the parameter estimation, values for the maximum specific growth rates were not included in order to reduce the complexity of the procedure; as the number of parameters to be estimated increases, it is becomes more feasible for the solution to fall into a local minimized solution instead of a global minimized solution.

In the parameter estimation it was assumed that the influent substrate consists only of RBCOD, and does not contain any SBCOD in any form, "soluble" or otherwise. Even though the second plateau of the OUR_H-time curve, which is assumed to be related to the "soluble" SBCOD in the analytical procedure of Wentzel *et al.* (1995), is clearly observed, the parameter estimation could not be done with incorporating "soluble" SBCOD because of the added complexity. As mentioned above, the main purpose of this parameter estimation was not to produce exact values for parameters, but rather to evaluate the competition model concept. Thus, to reduce complexity of parameter estimation, the initial substrate was totally ascribed to RBCOD; thus, the parameter estimation was applied to the period up to the OUR precipitous drop. This clearly is a simplification of the actual behaviour, and would require future attention.

The above mathematical model and the values for the parameters were input into AQUASIM 2.0 computer program, and the parameter estimation procedure set out in the manual for the AQUASIM 2.0 computer program (Reichert, 1998 a, b) followed. The batch test data sets of OUR_H versus time listed in Table 7.1 were used for parameter estimation: The OUR due to nitrification was not included.

7.4.2.2 Simulation results

Fig. 7.3 shows typical examples of the fit of predicted to the experimentally "measured" OUR_H- time profile in the batch tests for modified batch tests with relatively high and low volumes of mixed liquor added, *i.e.* relatively low and high So/Xo ratios (see Appendix C for other batch tests). For both cases, and for all batch tests in general remarkably close agreement was obtained between predicted and measured OUR_H, for the data up to the precipitous OUR drop. Particularly evident are that:

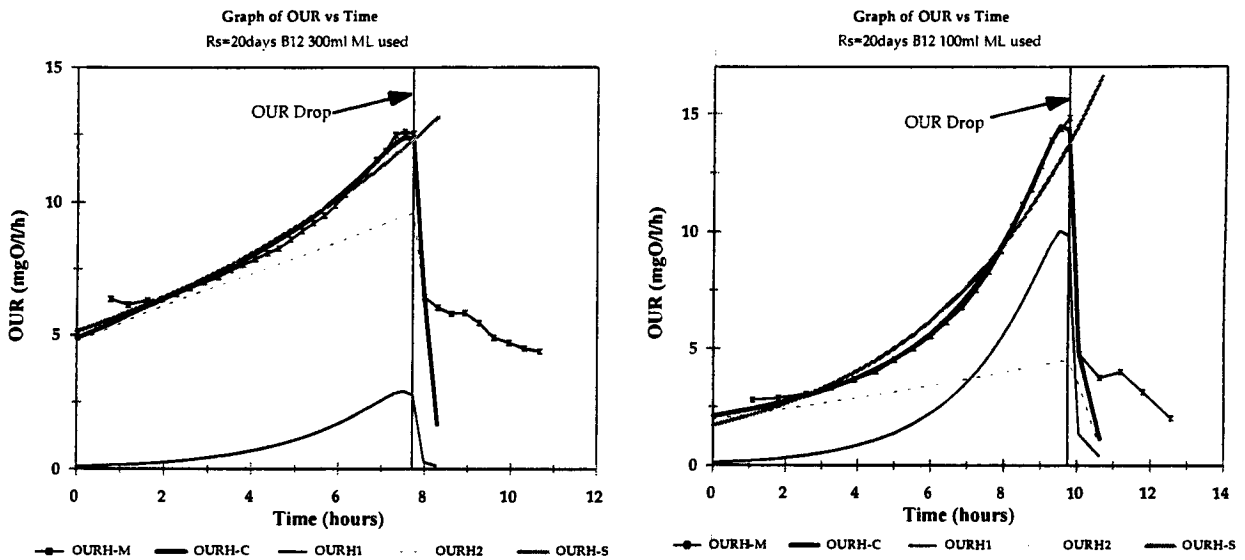
- The curvature of the OUR_H - time profile can be correctly predicted. For comparative purposes, the OUR_H - time profiles predicted with the single OHO population model (Chapter 4) are also shown plotted. The two OHO population model OUR_H predictions are clearly superior, and can account for the increase in the overall net OHO maximum specific growth rate on RBCOD noted in Chapter 6. This is because the fast grower increase their relative proportion in the OHO population with time.

- The observed precipitous drop in OUR can be correctly predicted by the proposed model. The OUR response following the precipitous drop in OUR cannot be correctly predicted. This OUR represents the OUR associated with SBCOD hydrolysis/utilization, and is not the main focus of the research, as noted above. Clearly this is an aspect that requires future attention.

- The OUR_H contributions by the two OHO population groups are also shown plotted in Fig. 7.3. From this, initially in the batch test the slow grower dominates the OUR_H response, with the fast grower making a minor contribution. However, as the test procedure, since they have a higher maximum specific growth rate, the fast grower increase their relative proportion in the OHO active biomass, and correspondingly increase their relative contribution to OUR_H.

- The proposed model can correctly predict the observed effect of So/Xo on the OUR_H, *i.e.* the increase in overall OHO maximum specific growth rate as So/Xo increases (see Chapter 6). From Fig. 7.3 and Appendix C of the other simulation results, it is clear that the influence on the OUR response of the fast grower increases as the So/Xo ratio increases, causing the increase in the overall OHO maximum specific growth rate. However, because parameter estimation was used to determine the initial Z_{BH1} and Z_{BH2} concentrations in the batch tests, there was some uncertainty as to whether the effect of So/Xo was real, or simply an artifact of selecting different initial Z_{BH1} concentrations. To evaluate this, a hypothetical mixed liquor of 0.5%, 1% and 1.5% $Z_{BH1(0)}$ and the balance $Z_{BH2(0)}$ was added to the modified batch tests at different So/Xo ratios and the OUR_H - time profile simulated. The simulated OUR_H - time profiles were plotted ln OUR_H versus time and the slope determined - this is equivalent to determining the overall net maximum specific OHO growth rate in Chapter 4 and 6, see Fig 7.4. From Fig. 7.4, it is evident that the influence of So/Xo on the overall nett maximum specific OHO growth rate is a function of the model itself, and not an artifact of the parameter estimation: with a fixed initial Z_{BH1}/Z_{BH2}, as So/Xo increases the overall nett maximum specific OHO growth rate increases, in agreement with the observations. These observations are in agreement with the hypothesis of Grady *et al.* (1996),

where it is proposed that the larger So/Xo, the greater the change in the community structure and the more the measured kinetics will reflect the characteristics of the fastest growing species rather than the characteristics of the original culture. Similarly, the greater the number of sequential enrichments performed, the more the measured parameters will reflect the kinetics of the fastest growing species.



(a) (b)

Fig. 7.3 : Measured Oxygen Uptake Rate of Heterotrophic organisms ($OUR_{H\text{-}M}$), OUR calculated by the analytical procedure of Wentzel *et al.* (1995) ($OUR_{H\text{-}S}$), OUR simulated by the competition model of kinetic selection ($OUR_{H\text{-}C}$), OUR of the fast grower (OUR_{H1}) and OUR of the slow grower (OUR_{H2}) at different So/Xo conditions; (a) represents low So/Xo condition, $Z_{BH(0)}$(Theo.) = 133.6 and (b) represents high So/Xo condition, $Z_{BH(0)}$(Theo.) = 44.5. Modified batch tests on mixed liquor drawn from the OHOs 20 days sludge age system, Sewage Batch No.12, Batch Test Nos. B22 and B24 for (a) and (b) respectively.

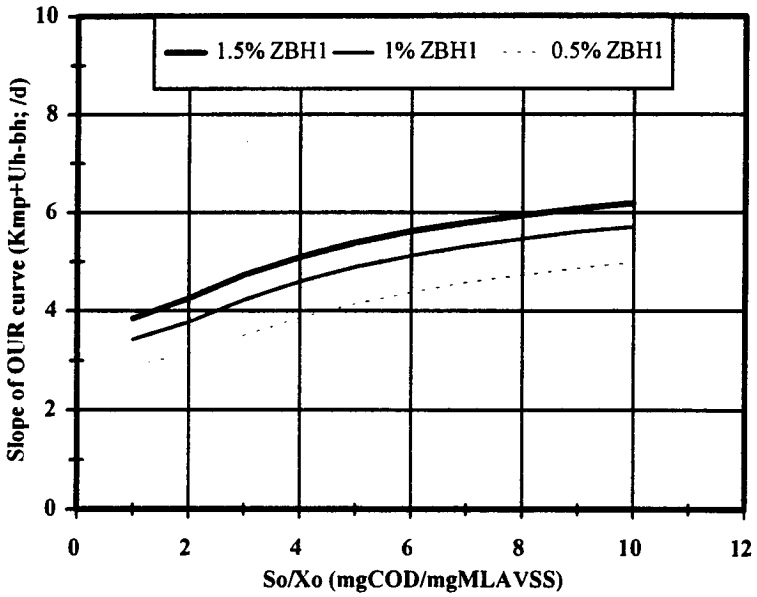


Fig. 7.4: Slopes of OUR curve simulated with different Z_{BH1} proportions (0.5%, 1% and 1.5%) versus various substrate/biomass concentration ratio (So/Xo)

7.4.2.3 Parameter estimation results

As noted above, values for some parameters were determined by the parameter estimation technique, namely initial substrate concentration and initial fast and slow growing OHO active biomass concentrations. The results of the parameter estimation are summarized in Table 7.4. The initial substrate concentration, S_{bi}, which is assumed to be RBCOD (see above), varies between the different batch tests. The variation of the initial substrate concentration may be caused by the differences in the RBCOD fraction of the different sewage batches, the different volumes of sewage added to the batch tests, and the different dilutions applied to attempt to ensure constant COD concentration in the sewage. Also, it is noteworthy that the second OUR plateau could not be simulated with the competition model, and this would influence the estimated S_{bi}. Even though it is still not clear whether the COD causing the second plateau derives from 'soluble SBCOD' or from 'storage of RBCOD', it definitely constitutes biodegradable COD.

The initial concentrations of the fast growing OHO population group, $Z_{BH1(0)}$, are estimated to be very low for all the batch tests and are almost negligible compared to the slow growing OHO population group ($Z_{BH2(0)}$). Even though the concentrations of the fast grower are negligible compared to those of the slower grower ($Z_{BH2(0)}$), the effect of the fast grower on the OUR response is marked, as shown in Fig. 7.3 and Appendix C. The total initial OHO active biomass concentrations predicted with the competition model (*i.e.* $Z_{BH1(0)} + Z_{BH2(0)}$) are significantly higher

than the values obtained with the analytical procedure in Chapter 4, and, in fact, are quite similar to the concentrations calculated theoretically with the steady state model for the parent system. A more in depth comparison is made in Section 7.6 below.

Table 7.4: Results for the parameter estimation with the aid of AQUASIM 2.0 computer program for the modified batch test data listed in Table 7.1. Also shown are the total OHO active biomass concentrations at the start of the batch test, ($Z_{BH(0)}$) predicted by competition model, from analysis using the procedure in chapter 4 (UCT model), and predicted by application of the steady state model to the parent system (taking due account of dilution)

Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		Parameter Estimation				$Z_{BH(0)}$ (mgCOD/l)		
			WW	ML	S_{bi}	$Z_{BH1(0)}$	$Z_{BH2(0)}$	χ^2	Competition Model	UCT Model	Steady-state Model
					mgCOD/ℓ						
10	A12	11 12	2.80	0.20	150.84	1.77	119.97	16.39	121.74	60.9	127.5
	A13	12 12	2.90	0.10	111.69	3.09	53.89	1.93	56.98	18.7	63.7
	A14	13 12	2.95	0.05	70.91	3.20	36.97	0.05	40.17	14.9	31.9
11	A17	30 12	2.80	0.20	137.95	0.94	85.47	3.43	86.41	45.0	115.2
	A18	31 12	2.90	0.10	135.56	0.70	40.39	5.86	41.09	12.2	57.6
12	A22	11 01	2.80	0.20	193.02	0.81	110.38	46.85	111.19	50.7	116.7
	A23	14 01	2.90	0.10	172.44	0.31	57.69	4.65	58	20.9	58.4
14	A29	18 02	2.80	0.20	184.53	0.46	63.71	15.18	64.17	23.3	88.4
	A30	20 02	2.90	0.10	182.07	0.84	41.95	19.57	42.79	8.7	44.2
17	A34	22 04	2.80	0.20	126.64	0.36	58.91	4.88	59.27	33.2	95.2
	A35	24 04	2.90	0.10	121.40	0.23	19.52	1.24	19.75	2.7	47.6
10	B13	12 12	2.80	0.20	109.96	2.43	110.06	5.86	112.49	50.3	83.7
	B14	13 12	2.90	0.10	72.28	2.95	58.30	0.09	61.25	24.9	41.9
11	B17	30 12	2.70	0.30	141.44	1.23	98.25	2.67	99.48	51.4	129.7
	B18	31 12	2.80	0.20	137.33	0.74	61.50	9.97	62.24	25.0	86.4
	B19	05 01	2.90	0.10	89.29	4.55	42.79	3.26	47.34	17.9	43.2
12	B22	11 01	2.70	0.30	175.02	0.41	114.31	21.20	114.72	71.8	133.6
	B23	14 01	2.80	0.20	162.99	0.22	77.55	6.28	77.77	48.5	89.1
	B24	15 01	2.90	0.10	166.27	0.52	47.30	7.66	47.82	14.0	44.5
14	B29	18 02	2.70	0.30	171.32	0.40	65.50	12.07	65.9	28.8	98.3
	B30	20 02	2.80	0.20	198.91	0.71	51.79	1.87	52.5	13.3	65.5
17	B34	22 04	2.70	0.30	121.04	0.33	71.39	5.59	71.72	43.1	104.4
	B35	24 04	2.80	0.20	117.18	0.32	30.71	3.22	31.03	10.2	69.6

Note) A : 10 days sludge age system, B : 20 days sludge age system

7.4.3 Modelling the steady state activated sludge systems

In the section above, the competition model has been shown to be able to predict the observed OUR_H response observed in the modified batch tests accurately. Further, the OHO active biomass concentrations at the start of the batch test determined by parameter estimation with the competition model are in reasonable agreement with the theoretical values calculated from application of the steady state model to the parent activated sludge systems, taking due account of dilution of the mixed liquor in the batch tests. In the parameter estimation, the relative proportion of the fast growing OHO in the total OHO active biomass concentration was estimated to be very low, excluding outliers average = 1% with sample standard deviation 0.44%. This implies that in the parent activated sludge systems used as source for the mixed liquor added to the batch tests, the slow growing OHO population must be dominant. The competition model in application to the parent activated sludge systems, should be able to predict this dominance. Accordingly, this was evaluated.

7.4.3.1 Modelling procedure

The competition model in Table 7.2 used to simulated the batch test was also used to simulate the two parent activated sludge systems. The same set of kinetic and stoichiometric constants used in simulation of the batch tests was used to simulate the parent activated sludge systems. As described above, these values for the kinetic and stoichiometric constants were the same as the default values in the simplified UCT model (Wentzel *et al.*, 1995), except for the kinetic parameters which are related to the growth processes on RBCOD for reasons set out above. Again it is noteworthy that the values for K_{SH1} and K_{SH2} were set as 3 and 0.1 mgCOD/ℓ respectively. With these K_{SH} values, kinetic selection which favours the slow grower in the activated sludge system could be achieved, even though from values reported by other researchers, the value of K_{SH2} would seem unrealistically low.

For the influent wastewater, the influent COD consists of various fractions. For each sewage batch, the total COD concentration was available from measurement (see Chapter 3). Further, from analysis of the parent systems response with the steady state model (WRC, 1984), in Chapter 3 the influent average unbiodegradable soluble and particulate COD concentrations (and fractions) have been calculated. Hence, the biodegradable COD could be calculated by difference. To split the biodegradable COD into RBCOD and SBCOD, the default value for f_{bs} in the UCTOLD computer program, which is equal to 0.2, was used.

From Chapter 3, the target total influent COD was set at 750mgCOD/ℓ. The influent unbiodegradable particulate and soluble COD fractions, f_{up} and f_{us}, were estimated as 0.1564 and 0.0413 respectively which are the mean values for both the 10 and 20 days systems. Thus, the total unbiodegradable COD and biodegradable COD of the influent was found by difference, as 150 and 600 mgCOD/ℓ respectively. Accepting the fraction of RBCOD, f_{bs}, as 0.2, RBCOD and SBCOD concentrations of influent were set as 120 and 480 mgCOD/ℓ respectively.

In Section 4.3 above, it was hypothesized that the fast growing OHO population group originates from the influent. This is substantiated by the observations of Wentzel *et al.* (1995), who conducted the batch test with wastewater only to measure RBCOD. From their results, it was found that OHO active biomass definitely exists in the wastewater, and has maximum specific growth rates which are higher than those in the activated sludge system. They also reported that OHO active biomass, fast grower, was found to be present at low concentrations, <3% of total COD for Mitchell's Plain wastewater when no waste activated sludge is recycled to the head of the works and mixed with the influent. This wastewater is the same as the wastewater in this research. Thus, fast growing OHO active biomass concentration in the influent wastewater, $Z_{BH1(Inf)}$, was accepted to be 3% of total COD at most. To examine the effect of variation in this parameter, $Z_{BH1(Inf)}$ was varied between 0% and 3% of the total influent COD. When a $Z_{BH1(Inf)}$ concentration is incorporated into the total influent COD, an amount of COD must be subtracted from the influent SBCOD. Accepting that $Z_{BH1(Inf)}$ consists of 80% SBCOD and 20% UPCOD (Unbiodegradable Particulate COD), when a concentration of $Z_{BH1(Inf)}$ is included in the influent, to compensate 80% of the $Z_{BH1(Inf)}$ concentration should be subtracted from the SBCOD concentration. This ensures that the total SBCOD concentration (which includes $Z_{BH1(Inf)}$) remains the same, 480mgCOD/ℓ. Table 7.6 shows the various influent substrate concentrations used in the simulations together with the percentage $Z_{BH1(Inf)}$ of the influent total COD.

For the plant configuration, a simple activated sludge system configuration which consisted of a single aerobic reactor and secondary settling tank was used. Even though a MLE system (anoxic/aerobic) was used as the parent system, the single aerobic reactor was used for the simulation, because the sludge composition and production of the MLE system and the single aerobic reactor are very similar, and the application of the model to the single aerobic reactor was much simpler. The reactor volume of Period 3 (see Chapter 3) was used for the simulation. For the operation parameters, 10 days and 20 days Sludge Retention Time (SRT) were used respectively. Temperature, influent flow rate and recycling flow rate were all based on the system conditions of Period 3 (see Chapter 3). Table 7.5 lists the parameters used in the simulation of the activated sludge systems.

Table 7.5: Influent Characteristics, System configuration and operation parameters for simulation of the continuous steady state system with the competition model of kinetic selection (Table 7.2).

	PARAMETER	UNIT	VALUE	NOTE
Influent Data	SBCOD	mgCOD/l	462~480	dependent on the various $Z_{BH1(Inf)}$ conc.
	RBCOD	mgCOD/l	120	set by f_{bs}=0.2
	$Z_{BH1(Inf)}$	mgCOD/l	0~22.5	0~3% of total influent COD
	$Z_{BH2(Inf)}$	mgCOD/l	0	0% of total influent COD
Plant Configuration	Volume	l	7.8/13.2	10/20 days systems
	No. of Reactor	-	1	Aerated reactor
Operational Parameters	SRT	d	10/20	10/20 days systems
	Temperature	°C	20	-
	Influent flow rate	l/d	13.3	Based on Period 3
	Recycle flow rate	l/d	13.3	Based on Period 3

7.4.3.2 Modelling of the steady state systems - results

The simulation of the steady state parent systems was done over the range of influent wastewater fast growing OHO active biomass concentration ($Z_{BH1(Inf)}$) of 0% to 3%. These simulations were to evaluate:

(i) Whether with no seeding the fast growing OHO population group (Z_{BH1}) is eliminated from the system due to kinetic selection at the low substrate concentrations present in the bioreactors.

(ii) Whether seeding Z_{BH1} into the system with the influent wastewater allows Z_{BH1} to become established, and

(iii) With (ii) above, what are the relative proportions of the two types of OHOs, *i.e.* fast and slow grower, and whether these proportions are in agreement with the values obtained from parameter estimation in the modified batch tests.

Table 7.6 and Fig. 7.5 show the COD concentrations of the fast grower, slow grower and endogenous biomass for the various influent wastewater fast grower OHO active biomass concentrations, $Z_{BH1(Inf)}$.

From Table 7.6 and Fig. 7.5:

- For $Z_{BH1(Inf)} = 0$, for both parent activated sludge systems (10 and 20 days sludge age), the fast grower (Z_{BH1}) is eliminated from the system, and the slow grower (Z_{BH2}) is completely dominant. Thus, with the competition model, the fast grower can not be sustained in the system (and hence will not be present in the mixed liquor used in the batch tests), unless it is provided with some competitive advantage, such as seeding (see below). This arises because the substrate concentrations in the steady state system are low, and under these conditions the specific growth rate of Z_{BH2} is greater than Z_{BH1} (see Fig. 7.2).

- With seeding, Z_{BH1} can be successfully maintained in the system. The seeding provides Z_{BH1} with a competitive advantage.

- As the % $Z_{BH1(Inf)}$ increases, so the concentration of Z_{BH1} increases, at the expense of Z_{BH2}, and hence the relative proportion of Z_{BH1} increases.

- With Z_{BH1} seeded into the system, the relative proportion of Z_{BH1} approaches 40% for only 3% of the total influent COD as Z_{BH1}. This is significantly higher than that determined in parameter estimation from the batch test data, average 1%.

Thus, the proposed competition model of kinetic selection can predict that both fast and slow growing OHO populations groups can be maintained in the steady state parent activated sludge systems, provided seeding with the influent is included. However, for values for influent fast grower concentrations ($Z_{BH1(Inf)}$) typical for the wastewater used in this investigation (< 3% of total COD, Mbewe *et al.* 1995), there is an inconsistency in the simulations of the batch test data and the steady state system; the steady state systems yield proportions of fast grower in the mixed liquor that are significantly higher than those in the mixed liquor added to the batch tests. What is required is to reduce, in some fashion, the concentration of fast growers in the steady state systems. One way to do this is to reduce the amount of substrate available to the fast growers in the steady state system.

In selection of the kinetic parameters, the parameters related to the OHO growth on RBCOD were chosen to reflect and ensure kinetic selection in both the batch tests and steady state systems (see Section 7.4.1). However, for OHO growth on SBCOD, the same kinetic parameters were used for both the fast and slow growers. While the flocculated and filtered influent of the modified batch test largely consists of RBCOD, the influent to the steady state system consists of 80% SBCOD and 20% RBCOD. Thus, the fast grower, if seeded into the system will obtain in addition to RBCOD, significant SBCOD enabling them to proliferate in the continuous steady state system. Thus, utilization of SBCOD was examined.

Table 7.6: Model inputs and results from simulations of the 10 and 20 days sludge age steady state activated systems with the competition model of kinetic selection.

No. of Simulation	% of $Z_{BH1(Inf)}$ in Inf. CODt	Input data mgCOD/l			Simulation Results - 10days system mgCOD/l			%	Simulation Results -20days system mgCOD/l			%
		Z_{BH1}	S_{bs}	S_{bs}	Z_{BH1}	Z_{BH2}	Z_E	Z_{BH1}/Z_{BH2}	Z_{BH1}	Z_{BH2}	Z_E	Z_{BH1}/Z_{BH2}
1	0	0	120	480	0.1	1992	988	0.0	0.2	1383	1366	0.0
2	0.2	1.5	120	478.8	46.3	1950	990	2.4	32.0	1354	1369	2.4
3	0.4	3	120	477.6	91.0	1908	992	4.8	62.8	1326	1371	4.7
4	0.6	4.5	120	476.4	134.3	1896	993	7.2	92.7	1298	1373	7.1
5	0.8	6	120	475.2	176.3	1830	995	9.6	121.7	1272	1376	9.6
6	1	7.5	120	474	217.0	1793	997	12.1	149.9	1246	1378	12.0
7	1.2	9	120	472.8	256.5	1757	999	14.6	177.2	1221	1381	14.5
8	1.4	10.5	120	471.6	294.9	1722	1000	17.1	203.7	1197	1383	17.0
9	1.6	12	120	470.4	332.2	1688	1002	19.7	229.5	1174	1385	19.5
10	1.8	13.5	120	469.2	368.5	1656	1004	22.3	254.6	1151	1388	22.1
11	2	15	120	468	403.7	1624	1006	24.9	279.0	1129	1390	24.7
12	2.2	16.5	120	466.8	438.1	1593	1007	27.5	302.8	1108	1393	27.3
13	2.4	18	120	465.6	471.5	1563	1009	30.2	325.9	1087	1395	30.0
14	2.6	19.5	120	464.4	504.1	1534	1011	32.9	348.4	1067	1397	32.7
15	2.8	21	120	463.2	535.9	1506	1013	35.6	370.4	1047	1400	35.4
16	3	22.5	120	462	566.8	1478	1014	38.3	391.9	1028	1402	38.1

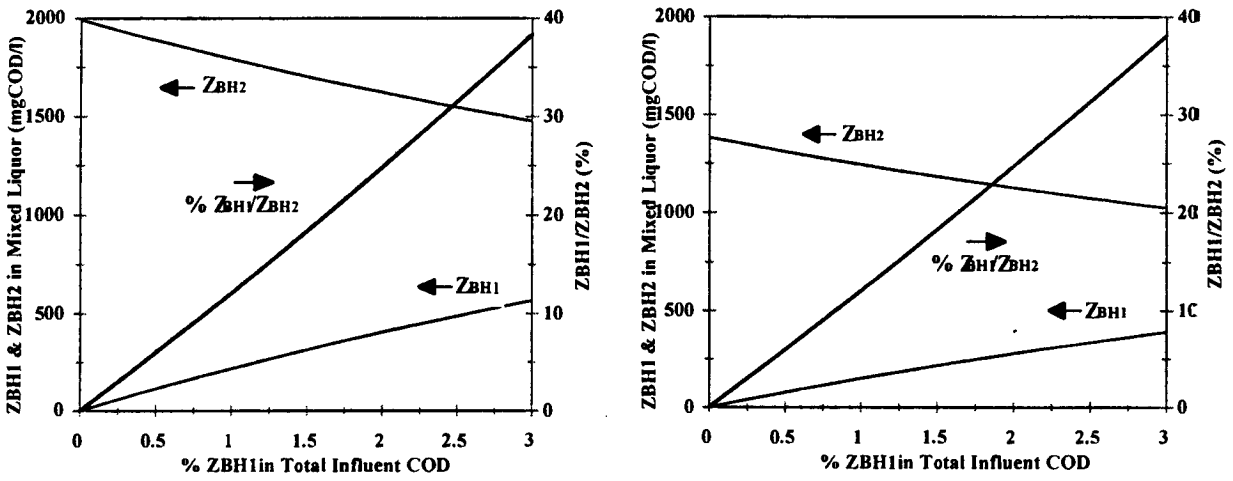


Fig. 7.5: Simulated fast grower (Z_{BH1}) and slow grower (Z_{BH2}) concentrations in mixed liquor and the percentage of Z_{BH1}/Z_{BH2} versus fast grower concentration in the influent, $Z_{BH1(Inf)}$, as a percentage of total influent total COD, for both (a) 10 days sludge age system and (b) 20 days sludge age system, using competition model of kinetic selection.

7.5 COMPETITION MODEL OF PROCESS SELECTION

In application of the 'competition model of kinetic selection' above, it was noted that the model could successfully simulate the modified batch test behaviour which has a high initial RBCOD concentration. However, it could not simulate sufficiently the suppression of the fast grower in the steady state activated system, which has low RBCOD and high SBCOD concentrations. It was identified that in the steady state system, the fast grower should obtain less substrate for growth. To achieve this, without causing the quality of the batch test simulation to deteriorate, it was proposed to prevent growth of the fast grower on SBCOD. This proposal is not unreasonable because it has been hypothesized that the origin of the fast grower is seeding into the steady state system with the influent. This implies that the fast grower develop in the sewer, where conditions of high RBCOD concentrations and limited oxygen are present. These conditions would promote growth on RBCOD. This model will be called the 'competition model of process selection'. Its development and application to simulating the modified batch test and the steady state activated systems will be described in this section.

7.5.1 Mathematical model

The mathematical kinetic model developed above for the "competition model of kinetic selection" (Table 7.2) was used as a basis. The model was modified by:

- Removing those processes for growth of the fast grower on SBCOD (Process 3 for SBCOD hydrolysis/growth and process 7 for SBCOD adsorption, Table 7.2)

- Removing compound Sads1 (component 5, Table 7.2); since only the slow grower utilization SBCOD, an adsorbed SBCOD for the fast grower is not required.

Table 7.7 shows the matrix form of the competition model.

Table 7.7: Matrix representation of competition model of process selection.

COMPOUND i → / j ↓ PROCESS	1 Z_{BH1}	2 Z_{BH2}	3 Z_E	4 Z_I	5 S_{ads}	6 S_{enm}	7 S_{bs}	8 S_{us}	9 O	PROCESS RATE, ρ_j
1 Aerobic growth of Z_{BH1} on S_{bs}	1						$-1/Y_{ZH}$		$-\frac{1-Y_{ZH}}{Y_{ZH}}$	$\mu_{H1}\left[\frac{S_{bs}}{K_{SH1}+S_{bs}}\right]Z_{BH1}$
2 Aerobic growth of Z_{BH2} on S_{bs}		1					$-1/Y_{ZH}$		$-\frac{1-Y_{ZH}}{Y_{ZH}}$	$\mu_{H2}\left[\frac{S_{bs}}{K_{SH2}+S_{bs}}\right]Z_{BH2}$
3 Aerobic growth of Z_{BH2} on S_{ads}		1			$-1/Y_{ZH}$				$-\frac{1-Y_{ZH}}{Y_{ZH}}$	$K_{MP}\left[\frac{(S_{ads}/Z_{BH2})}{K_{SP}+(S_{ads}/Z_{BH2})}\right]Z_{BH2}$
4 Death of Z_{BH1}	-1		f_E			1-f_E				$b_H Z_{BH1}$
5 Death of Z_{BH2}		-1	f_E			1-f_E				$b_H Z_{BH2}$
6 Adsorption of S_{enm} by Z_{BH2}					1	-1				$K_A S_{enm} Z_{BH2}(f_{MA} - S_{ads}/Z_{BH2})$
Stoichiometric constants Y_{ZH} = Heterotroph yield f_E = Endogenous residue f_{MA} = Max. ratio S_{ads}/Z_{BH}	Fast grow (active) heterotrophic mass M (COD) L^{-3}	Slow grow (active) heterotrophic mass M (COD) L^{-3}	Endogenous mass M (COD) L^{-3}	Inert mass M (COD) L^{-3}	Adsorbed slowly biodegradable substrate M (COD) L^{-3}	Enmeshed slowly biodegradable substrate M (COD) L^{-3}	Readily biodegradable (soluble) substrate M (COD) L^{-3}	Unbiodegradable soluble substrate M (COD) L^{-3}	Oxygen M (-COD) L^{-3}	Kinetic constants μ_{H1} = Heterotroph max. specific growth rate on S_{bs} of Fast Grower μ_{H2} = Heterotroph max. specific growth rate on S_{bs} of Slow Grower K_{SH1} = Heterotroph 1/2 saturation on S_{bs} K_{SH2} = Heterotroph 1/2 saturation on S_{bs} K_{MP} = Heterotroph max. specific growth rate on S_{ads} K_{SP} = Heterotroph 1/2 sat. on S_{ads} b_H = Heterotroph specific death rate K_A = S_{enm} specific adsorption rate

The values for the kinetic and stiochiometric constants were taken unmodified from the "competition model for kinetic selection" (Table 7.3). As noted in Section 7.4.1 the majority of values for the constants have their origin in the default values for the UCT kinetic model; detailed discussion on selecting values for the other constants is given in section 7.4.1.

Table 7.8: The kinetic and stoichiometric parameters for the non-linear regression of competition model of process selection.

PARAMETERS	UNIT	VALUE	NOTE
μ_{H1}	/d	12	Max. specific growth rate for FG
μ_{H2x}	/d	2	Max. specific growth rate for SG
K_{SH1}	mg/l	3	Half saturation coeff. for FG
K_{SH2}	mg/l	0.1	Half saturation coeff. for SG
K_{MP}	mgCOD/mgcellCOD/d	1.35	Max. specific growth rate on SBCOD for SG
K_{SP}	mgCOD/mgcellCOD	0.027	Half saturation coeff. on SBCOD for SG
b_H	/d	0.62	Death rate for FG & SG
K_A	mgCOD/mgcellCOD/d	0.17	Adsorption Rate for SG
Y_{ZH}	mgcellCOD/mgCODutilized	0.666	Yield coeff. for FG & SG
f_E	-	0.08	Fraction of the endogenous residue for FG&SG
f_{MA}	mgCOD/mgcellCOD	1	Max. ratio of S_{enm}/Z_{BH} for SG

* FG = fast grower and SG = slow grower

7.5.2 Parameter estimation with data from the modified batch test

7.5.2.1 Parameter estimation procedure

Parameter estimation was done with the aid of the AQUASIM 2.0 computer program (Reichert, 1998 a, b). The procedure for parameter estimation was exactly the same as followed for the previous competition model of kinetic selection, except that the mathematical model differed (*i.e.* Table 7.7).

Again, the parameters which were required to be determined were:

- The initial concentrations of the fast grower and the slow grower, $Z_{BH1(0)}$ and $Z_{BH2(0)}$ respectively.
- The initial "substrate" concentration; as explained in Section 7.4.2.1, it was assumed that the initial substrate consists only of the RBCOD, and does not contain any SBCOD.

The batch test data sets of OUR_H versus time listed in Table 7.1 were used for parameter estimation; to derive OUR_H the OUR due to nitrification was subtracted from the measured OUR - following the procedure described in Chapter 4.

7.5.2.2 Simulation results

Typical examples of the predicted and experimentally "measured" OUR_H - time profiles for the batch test are shown in Fig. 7.6. The predicted profiles are near identical to those with the competition model of kinetic selection above (Fig. 7.3), and the fit to the experimental data at both high and low So/Xo ratios is good. This is not unexpected, since the competition for RBCOD between the two OHO population groups (Z_{BH1} and Z_{BH2}) is the same in the two models. Again the fit with the model presented here is far superior to that with the single OHO population model.

In selecting values for the kinetic constants, a very low value for the RBCOD half saturation coefficient for the slow growers (K_{SH2}) was used (0.1 mgCOD/ℓ, Tables 7.3 and 7.4). This was to ensure that at low RBCOD substrate concentrations, the slow growers would have higher specific growth rates than the fast grower and *visa versa.* It was, however, noted that this value is significantly lower than conventionally accepted (5 mgCOD/ℓ, Henze *et al.*, 1987; Dold *et al.*, 1991). To evaluate the value selected, K_{SH2} was increased to 3 mgCOD/ℓ, the same value as for the fast grower. Typical predicted OUR_H-time profiles are shown in Fig. 7.7. From Fig. 7.7 it is apparent that:

- At relatively high So/Xo (Fig 7.7 b), close correlation between predicted and measured OUR_H is obtained, including correct prediction of the precipitous drop in OUR_H.

- At relatively low So/Xo, the fit of predicted to measured OUR_H is worse than with the lower K_{SH2} value. Particularly, the precipitous drop in OUR_H is not corrected predicted.

This difference above arises because at relatively low So/Xo, the slow growers make a significant contribution to the OUR, but much less so at high So/Xo, see Fig. 7.7. Considering that in the previous investigations to determine K_{SH} values, the data resolution probably was insufficient to obtain an accurate value, the K_{SH2} value here (0.1 mgCOD/ℓ) will be accepted as reasonable.

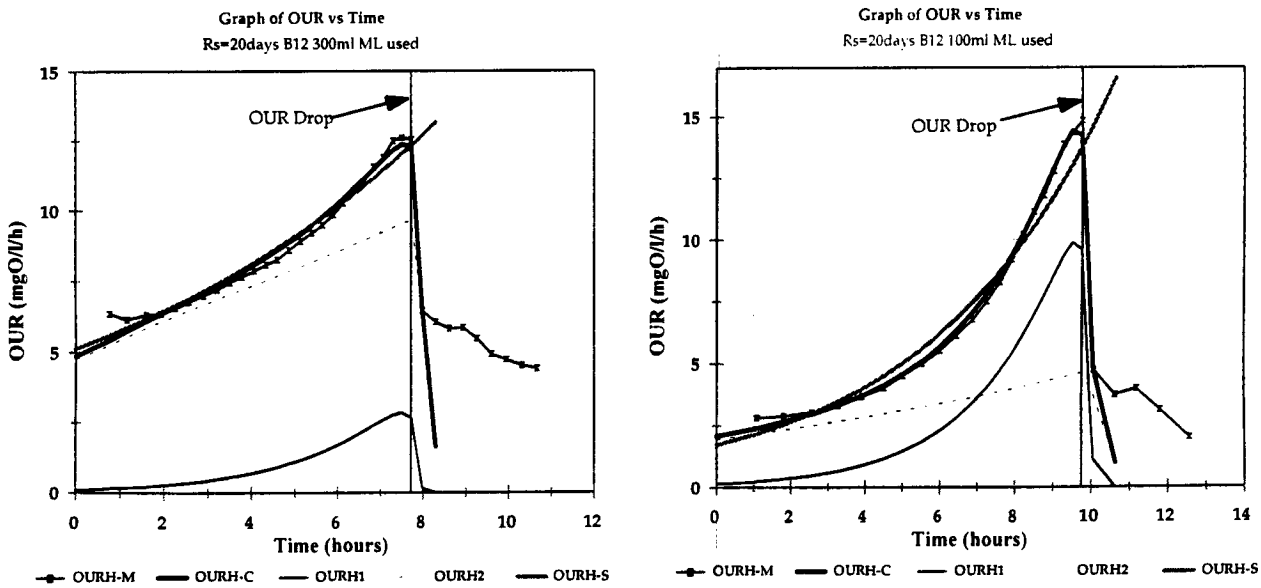
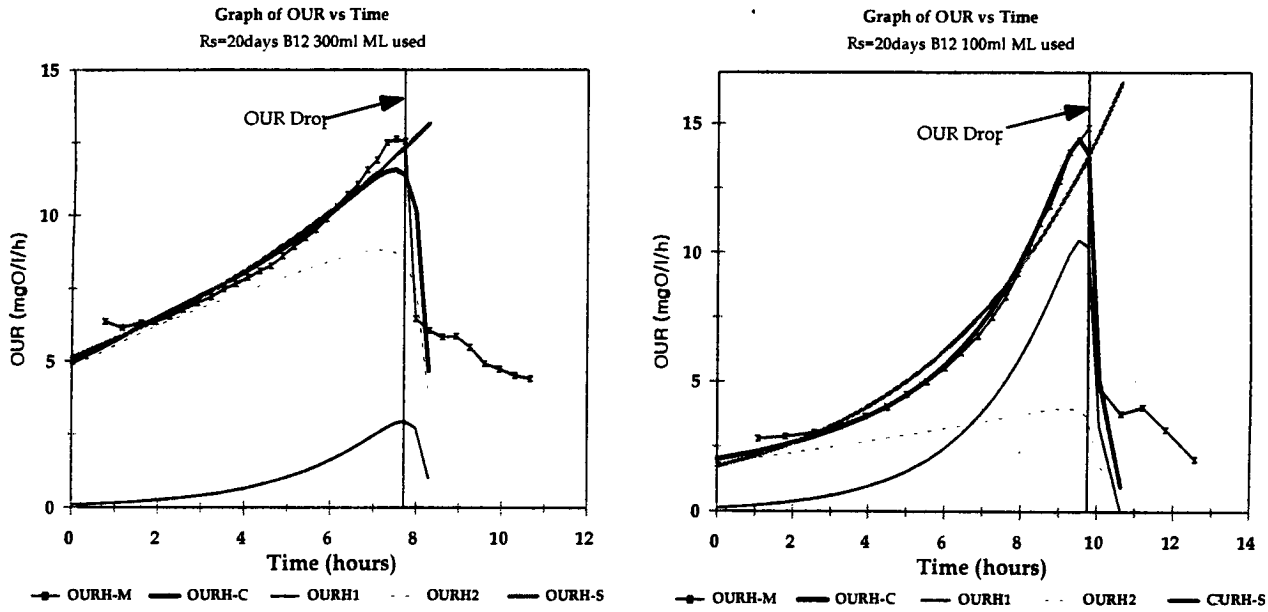


Fig. 7.6 : Measured Oxygen Uptake Rate of OHO ($OUR_{H\text{-}M}$), OUR calculated by the analytical procedure of Wentzel *et al.* (1995) ($OUR_{H\text{-}S}$), OUR simulated by the competition model of process selection ($OUR_{H\text{-}C}$), OUR of the fast grower (OUR_{H1}) and OUR of the slow grower (OUR_{H2}) at the different So/Xo conditions. (a) represents low So/Xo condition, $Z_{BH(0)}$(Theo.) = 133.6 and (b) represents high So/Xo condition, $Z_{BH(0)}$(Theo.) = 44.5. Modified batch tests on mixed liquor drawn from the 20 days sludge age system, Sewage Batch No.12, Batch Test Nos. B22 and B24 for (a) and (b) respectively ***(* K_{SH2} = 0.1 mgCOD/ℓ)***.



(a) (b)

Fig. 7.7 : Measured Oxygen Uptake Rate of OHO ($OUR_{H\text{-}M}$), OUR calculated by the analytical procedure of Wentzel *et al.* (1995) ($OUR_{H\text{-}S}$), OUR simulated by the competition model of process selection ($OUR_{H\text{-}C}$), OUR of the fast grower (OUR_{H1}) and OUR of the slow grower (OUR_{H2}) at the different So/Xo conditions. (a) represents low So/Xo condition, $Z_{BH(0)}$(Theo.) = 133.6 and (b) represents high So/Xo condition, $Z_{BH(0)}$(Theo.) = 44.5. Modified batch tests on mixed liquor drawn from the 20 days sludge age system, Sewage Batch No.12, Batch Test Nos. B22 and B24 for (a) and (b) respectively ($^*K_{SH2}$ = *3 mgCOD/ℓ*).

7.5.2.3 Parameter estimation results

The results of the parameter estimation are summarized in Table 7.9. Similarly to the results with the competition model of kinetic selection, the initial substrate concentration, S_{bi}, which was assumed to be RBCOD, varies between the different batch tests for reason described in Section 7.4.2.3. The initial concentrations of the fast grower, $Z_{BH1(0)}$, are estimated to be very low for all the batch tests. This observation is very similar to that with the competition model of kinetic selection. Also, even though the concentrations of the fast grower are negligible compared those of the slower grower ($Z_{BH2(0)}$), the effect of the fast grower on the OUR response is marked, as shown in Fig. 7.6 and Appendix C. Further, similarly to the results with the competition model of kinetic selection, the total initial OHO active biomass concentrations predicted with the competition model (*i.e.* $Z_{BH1(0)} + Z_{BH2\ 0)}$) are significantly higher than the values obtained with the analytical procedure in Chapter 4, and, in fact, are quite similar to those concentrations calculated theoretically with the steady state model for

the parent system. In summary, the changes made to the competition model of kinetic selection to develop the competition model of process selection (*i.e.* excluding SBCOD hydrolysis/ utilization by fast growers) had very little influence on the simulated results for the batch tests. This is not unexpected since in the batch test simulations no SBCOD is present at the start, and the only available SBCOD is that produced through the death regeneration process - the OUR_H associated with this process is negligible compared to that for RBCOD utilization. For RBCOD utilization, the process have remained unchanged.

Table 7.9: Results for the parameter estimation with the aid of AQUASIM 2.0 computer program for the modified batch test data listed in Table 7.1. Also shown are the total OHO active biomass concentrations at the start of the batch test, ($Z_{BH(0)}$) predicted by competition model, from analysis using the procedure in chapter 4 (UCT model), and predicted by application of the steady state model to the parent system (taking due account of dilution).

Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		Parameter Estimation				$Z_{BH(0)}$ (mgCOD/l)		
			WW	ML	Sti	$Z_{BH1(0)}$	$Z_{BH2(0)}$	χ^2	Competition Model	UCT Model	Steady-state Model
					mgCOD/ℓ						
10	A12	11 12	2.80	0.20	151.44	1.88	119.53	16.92	121.41	60.9	127.5
	A13	12 12	2.90	0.10	113.20	3.25	53.20	2.39	56.45	18.7	63.7
	A14	13 12	2.95	0.05	71.62	3.39	35.39	0.06	38.78	14.9	31.9
11	A17	30 12	2.80	0.20	138.48	1.02	84.65	3.52	85.67	45.0	115.2
	A18	31 12	2.90	0.10	137.02	0.77	39.60	6.77	40.37	12.2	57.6
12	A22	11 01	2.80	0.20	193.72	0.88	109.94	48.05	110.82	50.7	116.7
	A23	14 01	2.90	0.10	166.84	0.39	54.73	8.57	55.12	20.9	58.4
14	A29	18 02	2.80	0.20	185.68	0.51	62.93	16.21	63.44	23.3	88.4
	A30	20 02	2.90	0.10	184.78	0.91	41.43	22.63	42.34	8.7	44.2
17	A34	22 04	2.80	0.20	127.22	0.39	58.56	5.22	58.95	33.2	95.2
	A35	24 04	2.90	0.10	122.88	0.25	18.56	1.03	18.81	2.7	47.6
10	B13	12 12	2.80	0.20	110.38	2.54	109.68	6.11	112.22	50.3	83.7
	B14	13 12	2.90	0.10	72.76	3.14	56.96	0.10	60.1	24.9	41.9
11	B17	30 12	2.70	0.30	141.93	1.33	97.39	2.82	98.72	51.4	129.7
	B18	31 12	2.80	0.20	138.44	0.80	61.16	10.67	61.96	25.0	86.4
	B19	05 01	2.90	0.10	90.44	4.74	42.17	3.85	46.91	17.9	43.2
12	B22	11 01	2.70	0.30	175.32	0.44	114.11	21.54	114.55	71.8	133.6
	B23	14 01	2.80	0.20	163.57	0.25	77.18	5.12	77.43	48.5	89.1
	B24	15 01	2.90	0.10	167.80	0.58	46.44	8.72	47.02	14.0	44.5
14	B29	18 02	2.70	0.30	172.26	0.45	64.89	12.90	65.34	28.8	98.3
	B30	20 02	2.80	0.20	200.42	0.79	50.01	1.87	50.8	13.3	65.5
17	B34	22 04	2.70	0.30	121.48	0.36	71.35	5.78	71.71	43.1	104.4
	B35	24 04	2.80	0.20	118.57	0.35	30.30	3.79	30.65	10.2	69.6

Note) A : 10 days sludge age system, B : 20 days sludge age system

7.5.3 Modelling of the steady state systems - Results

The previous 'competition model of kinetic selection' could simulate the modified batch tests well but could not adequately describe the suppression of fast growers in the steady state systems. Thus, the 'competition model of process selection' was developed in which growth of the fast grower on SBCOD was eliminated. This model provided good agreement between the measured and the predicted data for the batch tests. In this section, the competition model of process selection will be applied to the steady state systems, to evaluate whether the changes adequately suppress the fast grower in the steady state system.

7.5.3.1 Modelling procedure

For simulating the two steady state parent activated sludge systems, the procedures detailed in Section 7.4.3.1 above were followed, except that the mathematical model in Table 7.4 was used. The systems simulated were again completely aerobic activated sludge systems, for reasons described previously. Table 7.10 lists the parameters used to simulate the simple activated sludge systems.

Table 7.10: Influent Characteristics, System configuration and operation parameters for the simulation of the steady state system with the competition model of process selection (Table 7.4).

	ITEM	UNIT	VALUE	NOTE
Influent Data	SBCOD	mgCOD/l	462~480	dependent on the various $Z_{BH1(Inf)}$ conc.
	RBCOD	mgCOD/l	120	set by f_{bs}=0.2
	$Z_{BH1(Inf)}$	mgCOD/l	0~22.5	0~3% of total influent COD
	$Z_{BH2(Inf)}$	mgCOD/l	0	0% of total influent COD
Plant Configuration	Volume	l	7.8/13.2	10/20 days systems
	No. of Reactor	-	1	Aerated reactor
Operational Parameters	SRT	d	10/20	10/20 days systems
	Temperature	°C	20	-
	Influent flow rate	l/d	13.3	Based on Period 3
	Recycle flow rate	l/d	13.3	Based on Period 3

7.5.3.2 Modelling of steady state systems - Results

As for the previous model, the simulation of the steady state parent system was done over the range of influent wastewater fast growing OHO active biomass concentrations ($Z_{BH1(Inf)}$) of 0% to 3%. These simulations were to evaluate:

(i) Whether with no seeding the fast growing OHO population group (Z_{BH1}) is eliminated from the system due to process selection at the low substrate concentrations present in the bioreacotrs.

(ii) Whether seeding Z_{BH1} into the system with the influent wastewater allows Z_{BH1} to become established, and

(iii) With (ii) above, what are the relative proportions of the two types of OHOs, *i.e.* fast and slow grower, and whether these proportions are in agreement with the values obtained from parameter estimation in the modified batch tests.

Table 7.11 and Fig. 7.8 show the COD concentrations of the fast grower, slow grower and endogenous biomass in the mixed liquor of the systems for the various influent wastewater fast grower OHO active biomass concentrations, $Z_{BH1(Inf)}$.

From Table 7.11 and Fig. 7.8:

- For $Z_{BH1(Inf)} = 0$, for both parent activated sludge systems, the fast grower (Z_{BH1}) is eliminated from the system and the slow grower (Z_{BH2}) is completely dominant. This is exactly the same as for the previous model, and again implies the fast grower requires some competitive advantage to be sustained in the system, such as seeding.

- With seeding, again Z_{BH1} can be successfully maintained in the system.

- Again, as the % $Z_{BH1(Inf)}$ increases, the relative proportion of Z_{BH1} in the mixed liquor increases at the expenses of Z_{BH2}. However, compared to the previous model, the proportion of Z_{BH1} in the mixed liquor is significantly lower (± 3% versus ± 40% at $Z_{BH1(Inf)} = 3\%$ of total COD). The lower proportion of Z_{BH1} in the mixed liquor more closely reflects the results from parameter estimation of the modified batch test data.

Thus, modifying the proposed model by removing SBCOD hydrolysis/utilization by the fast growers, can successfully suppress the fast grower concentrations in the mixed liquor of the steady state system to levels similar to those derived from parameter estimation of the modified batch tests, *i.e.* there is now consistency in the simulated results for both the steady state systems and the batch tests.

Table 7.11: Model inputs and results from simulations of the 10 and 20 days sludge age steady state activated systems with the competition model of process selection.

No. of Simulation	% of $Z_{BH1(Inf)}$ in Inf. CODt	Input data mgCOD/l			Simulation Results - 10days system mgCOD/l			Simulation Results - 10days system %	Simulation Results -20days system mgCOD/l			Simulation Results -20days system %
		Z_{BH1}	S_{bs}	S_{bs}	Z_{BH1}	Z_{BH2}	Z_E	Z_{BH1}/Z_{BH2}	Z_{BH1}	Z_{BH2}	Z_E	Z_{BH1}/Z_{BH2}
1	0	0	120	480	0	1992	988	0.0	0	1384	1366	0.0
2	0.2	1.5	120	478.8	3.6	1992	990	0.2	2.3	1384	1369	0.2
3	0.4	3	120	477.6	7.2	1992	992	0.4	4.6	1384	1371	0.3
4	0.6	4.5	120	476.4	10.9	1992	993	0.5	6.9	1384	1373	0.5
5	0.8	6	120	475.2	14.5	1992	995	0.7	9.2	1384	1376	0.7
6	1	7.5	120	474	18.1	1992	997	0.9	11.5	1384	1378	0.8
7	1.2	9	120	472.8	21.7	1992	999	1.1	13.8	1384	1380	1.0
8	1.4	10.5	120	471.6	25.4	1992	1000	1.3	16.1	1385	1383	1.2
9	1.6	12	120	470.4	29.0	1991	1002	1.5	18.4	1385	1385	1.3
10	1.8	13.5	120	469.2	32.6	1991	1004	1.6	20.7	1385	1388	1.5
11	2	15	120	468	36.2	1991	1006	1.8	23.0	1385	1390	1.7
12	2.2	16.5	120	466.8	40.0	1991	1007	2.0	25.3	1385	1392	1.8
13	2.4	18	120	465.6	43.5	1991	1009	2.2	27.6	1385	1395	2.0
14	2.6	19.5	120	464.4	47.1	1991	1011	2.4	29.9	1385	1397	2.2
15	2.8	21	120	463.2	50.7	1991	1013	2.5	32.2	1386	1400	2.3
16	3	22.5	120	462	54.4	1991	1014	2.7	34.5	1386	1402	2.5

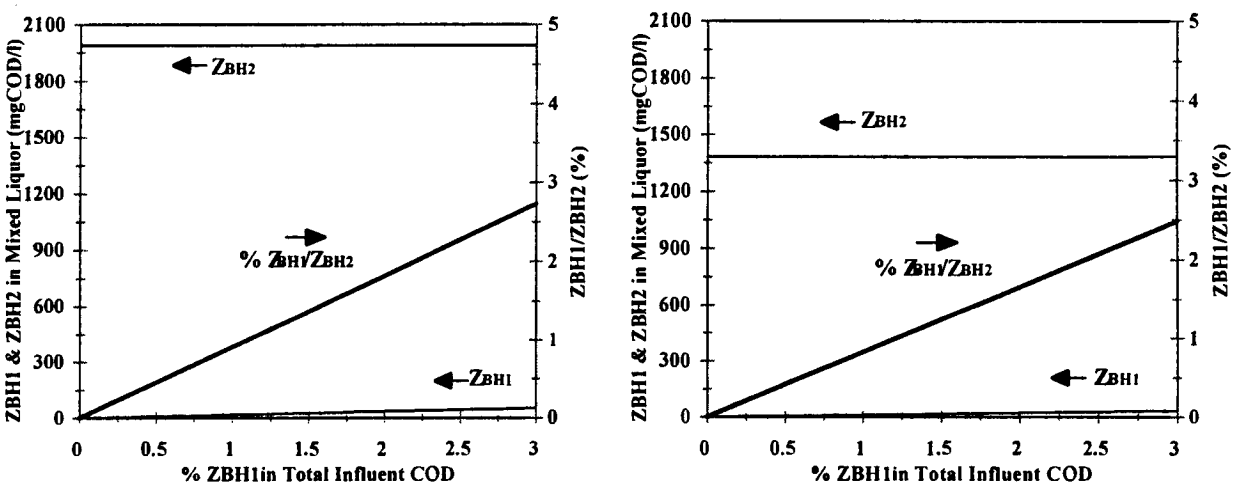


Fig. 7.8: Simulated fast grower (Z_{BH1}) and slow grower (Z_{BH2}) concentrations in mixed liquor and the percentage of Z_{BH1}/Z_{BH2} versus fast grower concentration in the influent, $Z_{BH1(Inf)}$, as a percentage of total influent COD, for both (a) 10 days sludge age system and (b) 20 days sludge age system, with competition model of process selection.

7.6 COMPARISON OF THE OHO ACTIVE BIOMASS CONCENTRATIONS ESTIMATED WITH THE VARIOUS MODELS

The initial OHO active biomass concentrations estimated by the parameter estimation technique for the competition models of kinetic selection and process selection are compared in Fig. 7.9. From Fig. 7.9, near identical initial OHO active biomass concentrations are determined with the two competition models. This is not unexpected since both models include the same concept of and formulation for competition on RBCOD and the same OHO maximum specific growth rates on RBCOD (μ_{H1} and μ_{H2}) and the same half saturation coefficients (K_{SH1} and K_{SH2}). In the modified batch tests, due to the pre- flocculation and filtration of the wastewater, RBCOD is the dominant substrate (and in the simulations was assumed to be the only substrate present at the start of the batch tests, see Section 7.4.2.1) and hence RBCOD utilization dominates the OUR_H response. Whether SBCOD is utilized by the fast growers (competition model of kinetic selection) or not (competition model of process selection) is of little consequence to the batch test simulations, and hence to the estimation of OHO active biomass concentration.

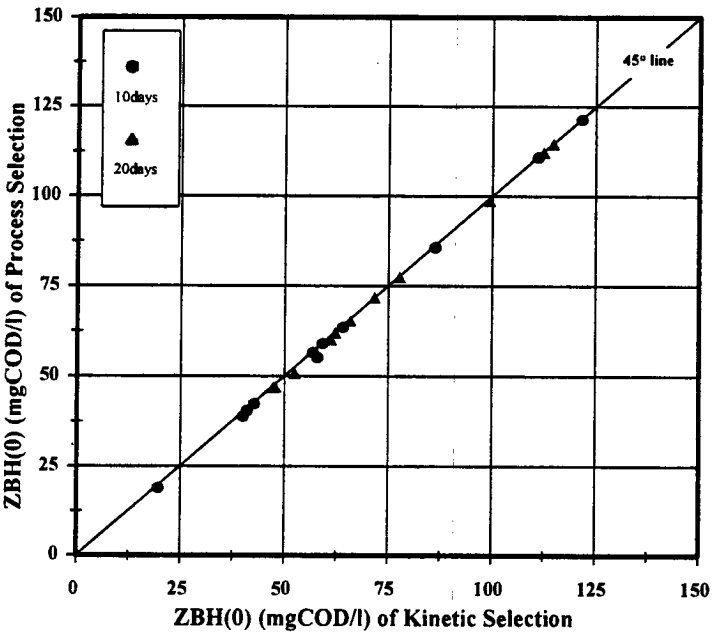


Fig. 7.9 : Plot of the OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] determined by the parameter estimation with 'competition model of kinetic selection' versus that determined by the parameter estimation with 'competition model of process selection', for the selected modified batch test data (Table 7.1).

The "estimated" OHO active biomass concentrations determined by parameter estimation with the two kinetic models developed in this Chapter were compared to the theoretical OHO active biomass concentrations calculated with the steady state model applied to the parent activated sludge systems. From this comparison it is evident that:

- The correlation between the theoretical OHO active biomass concentration and that estimated with both models is reasonable, and reasonably close to 1:1.

- The models with two OHO populations provide estimates from the batch tests for OHO active biomass concentrations that are superior to the analytical technique based on a single OHO population (Figs. 4.9, 4.12 and 4.13 in Chapter 4).

Thus, development of the two OHO population models has significantly improved the correspondence between "measured" and theoretical OHO active biomass concentrations. This would indicate that the competition hypothesis (in agreement with previous researchers) is a feasible explanation for the observations in the batch tests. However, it should be remembered that the models developed are largely speculative - insufficient information is available to separate the two OHO populations and quantify the individual kinetic processes.

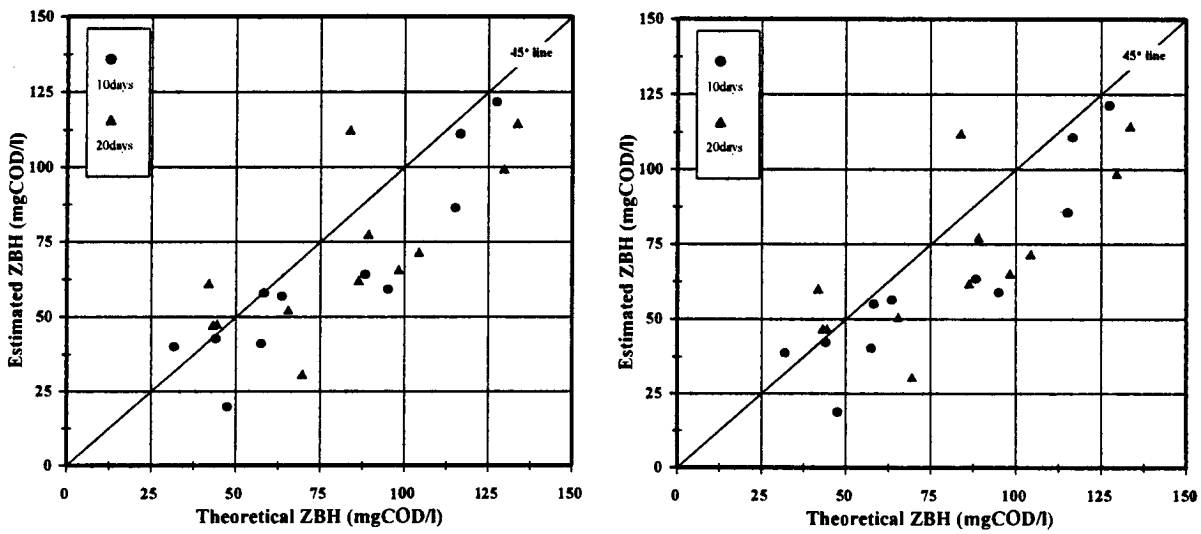


Fig. 7.10 : Plot of the OHO active biomass concentration at the start of the batch test [$Z_{BH(0)}$] determined by the parameter estimation with the competition model of (a) kinetic selection and (b) process selection versus the theoretical $Z_{BH(0)}$ concentration calculated with the steady-state model for the selected modified batch test data in the competition region (Table 7.1).

7.7 CONCLUSIONS

In this chapter, deficiencies in the single OHO population model used to interpret the batch test data (Chapter 4) that caused deviations between predicted and observed behaviours, were identified. In particular, it was noted that the observations indicated an increase in overall OHO maximum specific growth rate with time in the batch tests. To explain similar observations, Novak *et al.* (1994) and Grady *et al.* (1996) proposed substrate competition between different OHO group as a possible cause. This possibility was investigated, by developing a kinetic model for competition between two OHO populations, one a fast grower and the other a slow grower. This model was applied to both the batch test and the steady state systems. From the results of application to the batch tests, the following conclusions can be drawn:

- The model can simulate accurately the OUR_H - time observed in the batch tests.

- Estimating the initial batch test OHO active biomass concentrations of the fast ($Z_{BH1(0)}$) and slow grower ($Z_{BH2(0)}$) with the parameter estimation technique in AQUASIM 2.0, gave exceptionally low $Z_{BH1(0)}/(Z_{BH1(0)}+Z_{BH2(0)})$ values, average 1%. However, with time in the batch test, the Z_{BH1} increased its proportion significantly and had a marked influence on the predicted OUR_H - time profile. This indicates that the batch test procedure is extremely sensitive to the presence of fast growing OHOs.

- The model could simulate the variety of observations made on the batch tests, including the increase in overall OHO maximum specific growth rates with increasing So/Xo and with time.

- In seeking a source for the fast growing OHOs in the batch test, it was noted that this was not the wastewater (no observable OUR after 12 hours aeration), but must be the mixed liquor drawn from the parent activated sludge systems.

In application of the model to the steady state activated sludge systems, it was found that:

- The fast growing OHO population group could only be sustained in the system if they were seeded into the system with the influent. The possibility of seeding was substantiated by the observations of Wentzel *et al.* (1995) and Cronje *et al.* (2000) who noted significant fast growing OHOs present in the same raw wastewater used in this investigation.

- With seeding fast growing OHO to the steady state systems at concentrations typically measured by Wentzel *et al.* (1995) (< 3% of total COD), the model predicted the fast grower could be successfully sustained in the system. However, the predicted fast growing OHO proportion of the total OHO active biomass (± 40% at seed of 3% of total COD) was significantly larger than that derived from parameter estimation of the batch test data (1%).

To address the above, the competition model was modified by removing the processes for growth of the fast growing OHOs on SBCOD. This was considered reasonable, since the original source of

the fast grower is seeding with the influent wastewater to the steady state activated sludge systems - this implies growth in the sewer where RBCOD concentrations are very high, which would favour predominantly RBCOD utilization. Simulation of the batch tests and steady state systems gave results very similar to the competition only model, except that:

- The predicted proportions of Z_{BH1} in steady state system mixed liquor were significantly lower than with the competition only model, < 3% compared to ± 40% for $Z_{BH1(Inf)}$ in the influent at 3% of total COD. These values were very close to the values determined from parameter estimation with the batch test data. This indicated greater consistency in the simulations of the batch tests and steady state systems.

In comparing the various estimates for OHO active biomass concentrations, it was found that, compared to the theoretical concentrations calculated with the steady state model, the two OHO population models gave concentrations that were significantly superior to the single OHO population model. This would indicate that the competition hypothesis (in agreement with previous researchers) is one feasible explanation for the observations in the batch tests. However, the kinetic models developed here are largely hypothetical - insufficient information is available to separate the two OHO populations and quantify the individual kinetic processes. Furthermore, it must be remembered that the kinetic models are a gross practical simplification of the complete OHO community present in activated sludge mixed liquor. This simplification has practical benefits, *e.g.* reduced quantity of input information required, wider generality, but also has limitations. In particular, competitive interactions are difficult to accommodate, where balanced competitive populations are present. Further, hypotheses alternative to the competition one could possibly explain the observed behaviours. For example, it is possible that the batch conditions induce a change in the substrate utilization/growth kinetics of the OHOs with time (*e.g.* Daigger *et al.*, 1982). Considering that the OHOs have been developed in the steady state system under substrate (organic C) limiting conditions, and are placed in the batch test with excess substrate, adaptation of the OHOs to the batch test conditions (and hence change in kinetics) is not unreasonable. Clearly, this topic requires further investigation. Such an investigation will be facilitated by the new microbiologically based analytical techniques, *e.g.* FISH.

In conclusion, the modified batch test method to quantify OHO active biomass relies on a single OHO population with constant kinetics. Observations made in this research, and previously (*e.g.* Daigger *et al.*, 1982; Novak *et al.*, 1994; Grady *et al.*, 1996) suggest that this may not true, and that the batch test conditions cause the overall OHO behaviour to deviate from that in the steady state system. The batch test method, and its interpretation in terms of the procedures described in Chapter 4, is particularly sensitive to any changes in the OHO kinetics as the time proceeds in the batch test, since there kinetics are applied to the start of the test to determine the OHO active biomass concentration. This sensitivity, can explain the variability in correlations between batch test measured OHO active biomass concentrations and the theoretical values. Unfortunately, the sensitivity renders the batch test as an unsuitable method to consistently quantify the OHO active biomass concentration with sufficient accuracy. The test does, however, hold merit as a tool to investigate OHO population dynamics, as demonstrated by Beeharry *et al.* (2001) and shown here.

CHAPTER 8

CONCLUSION AND RECOMMENDATION

8.1 OBJECTIVE

The steady state design and kinetic simulation models for activated sludges systems have gained widespread acceptance through successful application to a range of activated sludge systems. This acceptance has been promoted by the convenience of the computer programmes incorporating the models, rather than by a rigorous scientific validation of the concepts on the which the models are based. One such concept is that of active biomass. In the models, the parameter Ordinary Heterotrophic Organism (OHO) active biomass is fundamental. This mixed liquor organic suspended solids mediates the biodegradation processes of COD removal and denitrification (and associated processes). In addition, in the models all the relevant specific process rates are expressed in terms of it. However, due to the lack of suitable experimental measurement techniques, the OHO active biomass exists only hypothetically within the structure of the steady state design and dynamic simulation models; this casts a measure of uncertainty on the entire framework within which the models have been developed, and is a weakness in the models. To promote further confidence in the application of the models, and indeed in the models themselves, the OHO active biomass concept needs to be validated by experimental measurement.

Recently, a batch test procedure to quantify the OHO active biomass concentration in mixed liquor drawn from aerobic and anoxic/aerobic activated sludge systems has been developed by Ubisi *et al.* (1997a,b). Cronje *et al.* (2000) modified this batch test procedure by flocculating and filtering the wastewater to remove the OHO active biomass present in the raw wastewater itself, thereby simplifying the procedure. With the modified batch test, Cronje *et al.* (2000) and Beeharry *et al.* (2001) measured the OHO active biomass concentration in mixed liquors drawn from a variety of parent activated sludge systems, and compared the batch test measured values with the model predicted theoretical values. In the comparison of Cronje *et al.*, the correlation between the theoretical and measured OHO active biomass concentrations was reasonably close to 1:1; however, in the more extensive comparison of Beeharry *et al.*, the correlation was not 1:1. Beeharry *et al.* (2001) could provide no explanation for this variation in results. Thus, ***the principle aim of this research project was to examine more thoroughly the modified batch procedure and the behaviour of the OHOs in the test, in order to explore possible explanations for the inconsistencies in results produced by the test.*** To address this aim, three primary objectives were identified:

(1) Re-evaluate the modified batch test method, by repeating the modified batch test procedure and comparing the measured OHO active biomass concentrations with the theoretical values predicted by the steady state model. This would establish whether the results of Cronje *et al.* or Beeharry *et al.* are reproducible, and enable an evaluation of possible causes contributing to variations in correspondence between theoretical and measured values.

(2) In addressing the aim above, it needed to be established whether discrepancies between measured and theoretical OHO active biomass concentrations arise from the activated sludge theory (*i.e.* the theoretical) or from the batch test procedure itself (*i.e.* the measured). Accordingly, the alternative more laborious batch aerobic digestion method of Marais and Ekama (1976) to quantify OHO active biomass were applied.

(3) Should in application of the modified batch tests, an inconsistency between the measured and theoretical OHO active biomass concentrations be obtained, identify possible causes for this inconsistency. In this regard, during the investigation the importance of OHO behaviour in the modified batch tests became apparent, and the concept of substrate competition between fast and slow growing OHO population groups proposed by Novak *et al.* (1994) was found to be relevant and was examined.

8.2 RESEARCH APPROACH

Two well-defined and controlled parent laboratory-scale MLE activated sludge systems at 10 and 20 days sludge ages were operated and monitored. These parent systems provided the mixed liquor samples required for measuring OHO active biomass, by means of the modified batch test (objective (1) above) and batch aerobic digestion test (objective (2) above). The data from these tests and the analytical methods used to interpret the data were thoroughly analysed to identify possible causes for discrepancies between measured and theoretical OHO active biomass concentrations (objective (3) above); this included development of kinetic models to simulate the batch test response.

8.3 RE-EVALUATION OF MODIFIED BATCH TEST

To re-evaluate the modified batch test, the batch test was applied to mixed liquor samples drawn from two parallel well defined and controlled parent laboratory-scale anoxic/aerobic activated sludge systems, at 10 and 20 days sludge age respectively.

8.3.1 Parent system

Two well-defined and controlled parent laboratory-scale nitrification/denitrification activated sludge systems were operated, at 10 and 20 days sludge ages respectively. The systems were monitored closely, and provided the mixed liquor samples required for measuring OHO active biomass. From the results obtained for the 10 and 20 days sludge age parent systems:

- N mass balances were consistent and generally in the range 90 to 110%. Sewage batches rejected due to poor N mass balance were No. 15 for the 10 day sludge age system and Nos. 6 and 15 for the 20 day sludge age system.

- Generally COD mass balances were not as good as the N mass balances, with 5 of 18 sewage batches for the 10 days sludge age system and 6 of 17 sewage batches for the 20 days sludge age system giving mass balances outside the range 90 to 110%. Batch tests

were conducted during 3 of these sewage batches, Nos. 5, 9 and 13. For Sewage Batch No. 9, the data were consistent with preceding and following sewage batches, and the COD mass balance was only marginally above 110% - hence this data was accepted for further analysis. For the remaining two sewage batches, the data was analyzed, but it was noted that the data should be interpreted with caution.

- The influent wastewater mean unbiodegradable soluble COD fractions ($f_{S,us}$) were determined to be 0.043 (sample standard deviation = 0.0066) and 0.040 (sample standard deviation = 0.0068) for the 10 and 20 day sludge age systems respectively. The difference between the two $f_{S,us}$ values is not statistically significant at the 95% confidence interval (t-test). However, the values are lower than the $f_{S,us}$ values obtained by both Ubisi *et al.* (1997a,b) ($f_{S,us}$ = 0.095) and Cronje *et al.* (2000) ($f_{S,us}$ = 0.085) for the same Mitchell's Plain raw wastewater; the values are similar to the $f_{S,us}$ value obtained by Beehary *et al.* (2001) ($f_{S,us}$ = 0.05). Of interest is the fact that both Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) were feeding a COD concentration of 500 ± 50 mgCOD/ℓ to their parent systems; However, Beehary *et al.* (2001) was feeding a COD concentration of 750 ± 50 mg COD/ℓ which is the same as the targeted COD concentration of this investigation. Thus, despite that the $f_{S,us}$ value would be expected to be the same, given that the influent wastewater being treated was the same and $f_{S,us}$ is a wastewater characteristic, the higher COD concentrations gave lower $f_{S,us}$ values. This observation would imply that dilution of the wastewater (with tap water) used as feed to the laboratory-scale systems has an influence on the $f_{S,us}$ value. The $f_{S,us}$ values in this experiment are, however, in the range of accepted values of 0.04 - 0.10 mgCOD/mgCOD for municipal raw wastewaters in South Africa (WRC, 1984).

- The influent wastewater mean unbiodegradable particulate COD fractions ($f_{S,up}$) were determined to be 0.165 with sample standard deviation of 0.0295 for the 10 day system and 0.148 with sample standard deviation of 0.0254 for the 20 day system. The $f_{S,up}$ value of the 10 day system is slightly higher than the value of the 20 day system, similar to the $f_{S,us}$ values. However, the difference between the two $f_{S,up}$ values is not statistically significant at the 95% confidence interval (t-test). The two $f_{S,up}$ values are higher than the values observed by Ubisi *et al.* (1997a,b) ($f_{S,up}$ = 0.120) and Cronje *et al.* (2000) ($f_{S,up}$ = 0.103) and are similar to the value observed by Beehary *et al.* (2001) ($f_{S,up}$ = 0.161) for the same Mitchell's Plain raw wastewater. As noted above, both Ubisi *et al.* (1997a,b) and Cronje *et al.* (2000) were feeding a COD concentration of 500 ± 50 mgCOD/ℓ to their parent systems; however Beehary *et al.* (2001) was feeding a COD concentration of 750 ± 50 mg COD/l which is the same as the targeted COD concentration of this experiment. Thus, despite that the $f_{S,up}$ value would be expected to be the same, given that the influent wastewater being treated was the same, the higher COD concentration gave a higher $f_{S,up}$. The $f_{S,up}$ values of this experiment are, however, in the range of accepted values of 0.07 - 0.20 mgCOD/mgCOD for municipal raw wastewaters in South Africa (WRC, 1984).

The consistency in the parent systems data during which batch tests were conducted, lends support to application of the steady state design procedure to the parent systems to calculate the theoretical OHO active biomass concentrations, and to using mixed liquor from the systems in the modified batch tests to measured the OHO active biomass concentrations.

8.3.2 Modified batch tests

In total, 35 modified batch tests were conducted on mixed liquor drawn from the 10 day sludge age parent system, and 35 on that drawn from the 20 day sludge age parent system. The modified batch test data were analyzed and interpreted using the procedure detailed by Cronje *et al.* (2000) and Beeharry *et al.* (2001), which is based on a simplified UCT model, which consists of a single OHO population. From this analysis, the following conclusion can be drawn:

- Nitrite concentrations in the modified batch tests were significant, and hence were taken into account in calculating the nitrification OUR.

- In general, %COD recoveries were good with only 8 out of 35 batch tests on 10 day sludge age mixed liquor yielding %COD recoveries < 90%, and only 7 out of 35 for the 20 day sludge age mixed liquor. Excluding data for those batch tests that deviated from the "true" normal probability line (4 for 10 days; 3 for 20 days), the mean %COD recoveries were 95.2 and 94.8 % for the batch tests on 10 and 20 day sludge age mixed liquor respectively, with sample standard deviations of 5.3 and 4.5% respectively. The %COD recoveries are somewhat lower than that obtained by Cronje *et al.* (2000) (100.5%), but are similar to those of Beeharry *et al.* (2001) (97.8 and 95.9 %). The good %COD recoveries lend credibility to the experimental data.

- For the OHO maximum specific growth rate on SBCOD (K_{MP}), excluding the batch tests with low %COD recoveries, statistical analysis gave mean K_{MP} of 1.37 and 1.42 /d for the 10 and 20 day sludge age mixed liquors respectively, with sample standard deviations of 0.412 and 0.428 /d respectively. The close means (difference 3.5% not statistically significant at 95% confidence interval, t-test) indicates that the sludge age did not have a significant influence on the value for this parameter. The values are larger than that measured by Cronje *et al.* (2000) (0.84 /d), but are close to the values measured by Beeharry *et al.* (2001) (1.49 and 1.38 /d). Further, the values are close to the default value for K_{MP} in the UCT kinetic simulation model of 1.35 /d (Dold *et al.*, 1991). It should be noted that there was some measure of uncertainty in the determination of K_{MP} at the relatively large and small mixed liquor volumes. However, it was concluded that the uncertainty was not large.

- For the OHO maximum specific growth rate on RBCOD (μ_H), for batch tests on mixed liquors from both parent systems, a clearly discernable trend was noted: As the volume of mixed liquor added to the batch test increased, the value for μ_H decreased. This indicates that one (or more) factor has a dominating influence, which precluded statistical analysis of the data. Re-examination of the data of Beeharry *et al.* (2001) indicated that they obtained, but did not note, a similar trend (see Cronje *et al.*, 2002). Possible reasons for this trend will be examined.

- In comparing the measured OHO active biomass concentration at the start of the batch test $Z_{BH(0)}$ with the theoretical value, the data for both the 10 and 20 day sludge age mixed liquor showed very similar trends. Also, superficially both comparisons bear a strong resemblance to the data of Beeharry *et al.* (2001), namely that there is a correspondence, but the values plot parallel to the 1:1 correspondence line. However, if the data is examined more closely, for both the 10 and 20 day mixed liquors three regions can be identified:

(i) Theoretical $Z_{BH(0)}$ < 30 mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values decrease, to approach near zero. Beeharry *et al.* (2001) did not collect data in this region, so a comparison with their data is not possible.

(ii) 30 mgCOD/ℓ < Theoretical $Z_{BH(0)}$ < 150 mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values correspondingly increase parallel to a 1:1 correspondence line, but below it. This trend is near identical to that observed by Beeharry *et al.* (2001), whose data falls primarily in this region.

(iii) Theoretical $Z_{BH(0)}$ > 150mgCOD/ℓ : As the theoretical $Z_{BH(0)}$ increases, the measured values increase sharply to cross the 1:1 correspondence line. Beeharry *et al.* (2001) collected limited data in this region, but the data available indicates it is consistent with the observation here.

The close similarity in trends between the 10 and 20 day sludge age mixed liquors, and the consistency with the data of Beeharry *et al.* (2001) indicated that the observed deviation in measured and theoretical $Z_{BH(0)}$ values is not a function of sludge age, or of this investigation.

The causes for the deviation was not possible P limitation in the batch test due to pre-flocculation of the sewage with alum - parallel modified batch tests with and without P supplementation gave near identical results. This prompted a more investigation of the modified batch test. It first needed to be established whether the cause lay in the activated sludge theory (*i.e.* theoretical) or in the modified batch test procedure itself (*i.e.* the measured).

8.4 BATCH AEROBIC DIGESTION TEST

In application of the modified batch tests above, deviation between the theoretical and measured OHO active biomass concentrations was observed. To determined whether the poor correspondence was due to the batch test method itself, or due to an inconsistency in the theoretical models applied to N removal systems, an alternative method to quantify OHO active biomass concentrations was applied. This alternative method was the batch aerobic digestion test. Two batch aerobic digestion tests were conducted on mixed liquor samples drawn from each of the two parent activated sludge systems (4 tests in total). From the results, it can be concluded that:

- Filtered samples taken at regular intervals during the test showed FSA concentrations were constant, at low values. This implies nitrification was complete, a pre-requisite for analysis of the data.

- Nitrate concentrations with time in the aerobic batch digestion tests were predicted with activated sludge theory. The measured nitrate concentrations were consistently higher than the predicted concentrations during the entire test. No definitive explanation for this inconsistency could be proposed, and this warrants further investigation.

- The high linear regression correlation coefficients (R^2 > 0.97) in the fit to the ℓn OUR_t - time plots lends credibility to the experimental data.

- For the values for the OHO specific endogenous respiration rate (b_{H20}) values, for the 20 days sludge age system mixed liquor these were estimated as 0.22/d and 0.26/d; for the 10 days sludge age system mixed liquor these were estimated as 0.31/d and 0.33/d. The values for the 10 day sludge age system are significantly higher than the default value of 0.24/d (Marais and Ekama, 1976; WRC, 1984). This would imply that sludge age influences $b_{H,20}$, which is contrary to current activated sludge theory. This warrants further investigation.

- A remarkably close correspondence between the theoretical OHO active biomass concentration and that measured in the aerobic batch digestion test was obtained. The % differences between measured and predicted values were estimated as 1.4% and 8.2% for the 10 and 20 days sludge age parent systems respectively.

In the batch aerobic digestion tests which are based on the endogenous respiration process, remarkably good correlation between the measured and theoretical OHO active biomass values was obtained. From this observation, it was concluded that:

- The major cause for the difference between the measured and theoretical OHO active biomass concentrations in the modified batch tests lies in the description and interpretation of the OHO growth process.

This prompted a more in-depth investigation into OHO growth behaviour in the modified batch test.

8.5 OHO BEHAVIOUR IN THE MODIFIED BATCH TESTS

The close correlation between theoretical OHO active biomass concentration and that measured in the batch aerobic digestion tests focussed attention on the behaviour of the OHOs in the batch tests.

8.5.1 Evaluation of OHO behaviour in the modified batch tests

Initially OHO behaviour in the modified batch tests was investigated through a more detailed analysis of the modified batch test data collected. From this investigation the following general conclusions could be drawn:

- For all observations, the remarkable similarity in the data for modified batch tests on both the 10 and 20 day sludge age mixed liquors substantiates the consistency of the data and the observations made. It also excludes sludge age as the underlying cause for any deviations.

- The OHO maximum specific growth rate on RBCOD (μ_H) appears to be a function of the OHO active biomass concentration added at the start of the test ($Z_{BH(0)}$); as $Z_{BH(0)}$ decreases, μ_H increases. The OHO maximum specific growth rates on SBCOD (K_{MP}) also exhibit some variation between the different batch tests, also apparently linked to the OHO biomass concentration added.

- Similar, though reversed, trends noted above for μ_H and K_{MP} were evident for the effect of initial substrate to OHO active biomass concentration, *i.e.* So/Xo ratio.

From a plot of theoretical versus measured $Z_{BH(0)}$, the following conclusions could be drawn:

- For $Z_{BH(0)}$(Theo.) < 30 mgCOD/ℓ :
  There is uncertainty in the data, although the trends do suggest possible inhibition.

- For 30 mgCOD/ℓ < $Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ :
  In this region, the observed behaviour strongly suggests that the net OHO maximum specific growth rates change during the course of the batch test. In a single OHO population model, to interpret the batch test data, this implies that the maximum specific growth rate constants for the OHOs would need to be increased with time. A two OHO population model with fast- and slow- growing OHO groups, as proposed by Novak *et al.* (1995), was identified to be a logical alternative.

- For $Z_{BH(0)}$(Theo.) > 150 mgCOD/ℓ :
  In this region, the batch test resolution is inadequate, because the increase in OHO active biomass concentration with time is not significant compared to the initial concentration, a requirement in the batch test.

From the above, data in the range 30 mgCOD/ℓ < $Z_{BH(0)}$(Theo.) < 150 mgCOD/ℓ were identified as reasonable for further investigation. In this regard, application of the competition concept of Novak *et al.* (1994) was identified as a possible explanation for the observed behaviours.

8.5.2 Development and application of a competition model

It was noted from the above that the observations made on the modified batch tests indicated an increase in overall OHO maximum specific growth rate with time in the batch tests. To explain similar observations, Novak *et al.* (1994) and Grady *et al.* (1996) proposed substrate competition between different OHO groups as a possible cause. This possibility was investigated, by developing a kinetic model for competition between two OHO populations, one a fast grower and the other a slow grower. This model was applied to both the batch test and the parent steady state systems.

From the results of application to the batch tests, the following conclusions can be drawn:

- The model can simulate accurately the OUR_H - time observed in the batch tests. Estimating the initial batch test OHO active biomass concentrations of the fast ($Z_{BH1(0)}$) and slow grower ($Z_{BH2(0)}$) with the parameter estimation technique in AQUASIM 2.0 gave exceptionally low $Z_{BH1(0)}/(Z_{BH1(0)}+Z_{BH2(0)})$ values, average 1%. However, with time in the batch test, the Z_{BH1} increased its proportion significantly and had a marked influence on the predicted OUR_H - time profile. This indicates that the batch test procedure is extremely sensitive to the presence of fast growing OHOs.

- The model could simulate the variety of observations made on the batch tests, including the increase in overall OHO maximum specific growth rates with increasing So/Xo and with time.

- In seeking a source for the fast growing OHOs in the batch test, it was noted that this was not the wastewater (no observable OUR after 12 hours aeration), but must be the mixed liquor drawn from the parent activated sludge systems.

In application of the model to the steady state activated sludge systems, it was found that:

- The fast growing OHO population group could only be sustained in the system if they were seeded into the system with the influent. The possibility of seeding was substantiated by the observations of Wentzel *et al.* (1995) and Cronje *et al.* (2000) who noted significant fast growing OHOs present in the same raw wastewater that was used in this investigation.

- With seeding fast growing OHO to the steady state systems at concentrations typically measured by Wentzel *et al.* (1995) (< 3% of total COD), the model predicted the fast grower could be successfully sustained in the system. However, the predicted fast growing OHO proportion of the total OHO active biomass (± 40% at seed of 3% of total COD) was significantly larger than that derived from parameter estimation of the batch test data (1%).

To address the above, the competition model was modified by removing the processes for growth of the fast growing OHOs on SBCOD. This was considered reasonable, since the original source of the fast grower is seeding with the influent wastewater to the steady state activated sludge systems - this implies growth in the sewer where RBCOD concentrations are very high, which would favour predominantly RBCOD utilization. Simulation of the batch tests and steady state systems gave results very similar to the competition only model, except that:

- The predicted proportions of Z_{BH1} in steady state system mixed liquor were significantly lower than with the competition only model, < 3% compared to ± 40% for $Z_{BH1(Inf)}$ in the influent at 3% of total COD. These values were very close to the values determined from parameter estimation with the batch test data.

In comparing the various estimates for OHO active biomass concentrations, it was found that, compared to the theoretical concentrations calculated with the steady state model, the two OHO population models gave concentrations that were significantly superior to the single OHO population model. This would indicate that the competition hypothesis (in agreement with previous researchers) is one feasible explanation for the observations in the batch tests. However, the kinetic models developed here are largely hypothetical - insufficient information is available to separate the two OHO populations and quantify the individual kinetic processes. Furthermore, it must be remembered that the kinetic models are a gross practical simplification of the complete OHO community present in activated sludge mixed liquor. This simplification has practical benefits, *e.g.* reduced quantity of input information required, wider generality, but also has limitations. In particular, competitive interactions are difficult to accommodate, where balanced competitive populations are present. Further, hypotheses alternative to the competition one could possibly explain the observed behaviours. For example, it is possible that the batch conditions induce a change in the substrate utilization/growth kinetics of the OHOs with time (*i.e.*

physiological adaptation, Daigger *et al.*, 1982). Considering that the OHOs have been developed in the steady state system under substrate (organic C) limiting conditions, and are placed in the batch test with excess substrate, adaptation of the OHOs to the batch test conditions (and hence change in kinetics) is not unreasonable. Clearly, this topic requires further investigation. Such an investigation will be facilitated by the new microbiologically based analytical techniques, *e.g.* FISH.

8.6 CONCLUSIONS

In this research project, the modified batch test, to quantify OHO active biomass has been extensively evaluated. It was hoped that the method would provide measured OHO active biomass concentrations that would compare favourably with the theoretical values predicted by the steady state design and kinetic simulation models for the activated sludge system. This would substantiate the active biomass concept incorporated in these models, and thereby promote confidence in their application. However, in this research, similarly to that previously of Beeharry *et al.* (2001), this proved not to be true: Although measured OHO active biomass concentrations were obtained that were of the same order of magnitude as the theoretical values, in general compared to the theoretical values, the measured values tended to plot on a line parallel but below the 1:1 correspondence line.

In examining possible causes for the lack of 1:1 correspondence between theoretical and measured OHO active biomass concentrations, it was noted that the modified batch test method to quantify OHO active biomass relies on a single OHO population with constant kinetics. Observations made in this research, and previously (*e.g.* Daigger *et al.*, 1982; Novak *et al.*, 1994; Grady *et al.*, 1996) suggest that this may not true, and that the batch test conditions may cause the overall OHO behaviour to deviate significantly from that in the steady state system. The batch test method, and its interpretation in terms of the procedures described in Chapter 4, is particularly sensitive to any changes in the OHO kinetics as time proceeds in the batch test, since these kinetics are applied to the start of the test to determine the OHO active biomass concentration. This sensitivity, can explain the variability in correlations between batch test measured OHO active biomass concentrations and the theoretical values. Unfortunately, the sensitivity renders the batch test as an unsuitable method to quantify the OHO active biomass concentration with sufficient accuracy. The test does, however, hold merit as a tool to investigate OHO population dynamics, as demonstrated by Beeharry *et al.* (2001) and shown here.

The causes for the lack of a 1:1 correspondence between OHO active biomass measured in the modified batch test and that predicted theoretically with the activated sludge models was shown to lie in the modified batch test itself: The batch aerobic digestion tests and re-interpretation of the modified batch test data with the competition model both provided reasonable close 1:1 correspondence. This does provide independent evidence that substantiates the active biomass concept incorporated in the models. Further, although the competition model needed to be applied to explain the observations in the modified batch tests, it must be remembered that in the parent activated sludge systems, the OHO population is dominated by the slow growing OHO population group, to the extent of near exclusion of the fast growers. Thus, for the activated sludge system the current models incorporating a single OHO population are adequate, provided extremes in dynamic loading are not encountered (*e.g.* selector reactors).

8.7 RECOMMENDATIONS

From this investigation the following recommendations can be made:

- In operation of laboratory-scale activated sludge systems, sludge bulking may have a negative impact on N and COD mass balances. This arises because with sludge bulking, sludge can accumulate in the secondary settling tank (SST) leading to denitrification along the axis of flow through the SST. This denitrification is not fully taken into account in the mass balances, and therefore can lead to poor mass balances. According to Ekama *et al.* (1998), sludge accumulation in the SST depends on the solids loading on SST and the sludge settling characteristics. Control of the sludge settling characteristics may not always be possible. Hence, to avoid sludge accumulation in the SST for good N and COD mass balances, it is recommended that the solids loading on the SST be controlled. This is determined by the influent flow rate and the solids concentration in the biological reactor, both of which can be adjusted.

- In the modified batch test a second plateau in the OUR_H-time plot is observed. Cronje *et al.* (2000) and Beeharry *et al.* (2001) ascribed this second plateau to "soluble" SBCOD that was not removed in the flocculation and filtration of the sewage added to the batch test. In the kinetic models for activated sludge systems, a single SBCOD "type" is accepted, with the same kinetics of hydrolysis/utilization applied to all SBCOD. The existence of a soluble (*i.e.* "non-flocculatable") SBCOD need to be investigated, as this may have an impact on modelling the kinetics of SBCOD hydrolysis/utilization. Also, other possible explanations for the second OUR plateau need to be evaluated, such as intracellular substrate storage. Majone *et al.* (1999) and Carucci *et al.* (2001) reported evidence of aerobic storage under dynamic conditions. The more fundamental microbiological or biochemical analytical techniques may prove useful in this regard.

- The batch aerobic digestion test provided estimates for OHO active biomass concentrations that agree closely with the theoretical values. However, only 4 such tests were undertaken due to the time consuming nature of the tests (> 10days in duration). More such tests need to be undertaken, to confirm the results obtained here. One issue that would require resolution is that in batch aerobic digestion tests, the measured nitrate concentrations were always higher than the predicted concentrations. This was common to all the batch aerobic digestion tests. An explanation for this poor correlation could not be provided.

- To explain the behaviour observed in the modified batch tests, in this research a competition model was proposed. However, hypotheses alternative to the competition one, also could possibly explain the observed behaviour. For example, Daigger *et al.* (1982) and Grady *et al.* (1996) proposed the concept of "physiological adaptation". In this concept, the relative components of the biomass groups (fast grower and slow grower) do not change, but rather the physiological state of the biomass itself, induced by the change in conditions from the steady state system to the batch test (Grady *et al.*, 1996). Such alternatives also require evaluation.

- In this research, in calibrating the competition models, values had to be assumed for the kinetic parameters for the fast and slow growing OHO population groups (μ_{H1}, μ_{H2}, K_{SH1} and K_{SH2}). With the accepted values, the competition model could reasonably accurately simulate the diverse observed behaviour, *e.g.* change in kinetic rates with time in the batch tests, the effect of So/Xo on the kinetics. However, the values for the rate constants were not directly determined. This was not possible because the behaviour of the fast and slow growing OHO population groups could not be separated. This requires investigation.

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APPENDIX A

OUR vs TIME PLOTS FOR MODIFIED BATCH TESTS CONDUCTED WITH FLOCCULATED-FILTERED WASTEWATER PLUS MIXED LIQUOR

TABLE OF CONTENTS

Table A1 Results for batch tests with a mixture of *flocculated-filtered* wastewater (WW) and mixed liquor (ML)drawn from the **10 days sludge age parent activated sludge system**: Batch test numbers, dates of batch tests, volumes added, COD recoveries, *measured* OHO active biomass present at the start of the batch test ($Z_{BH(0)}$) and the *projected* parent system mixed liquor (ML) active biomass. The *theoretical* parent system mixed liquor (ML) OHO active biomass and the *projected* active biomass present the start of the batch test are also given.

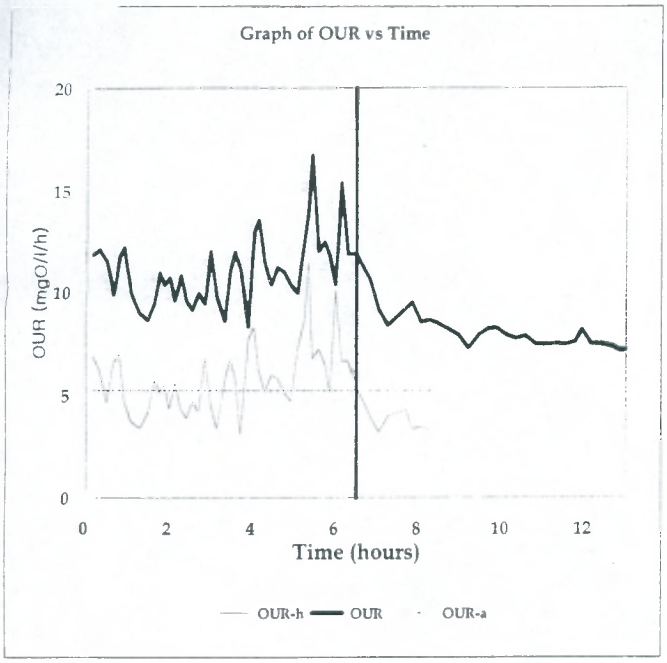
- OUR vs time and ℓn(OUR) vs time profiles for modified batch tests No. A1 - A35. The nitrate/nitrite concentration vs time profiles recorded during each batch test are also given.

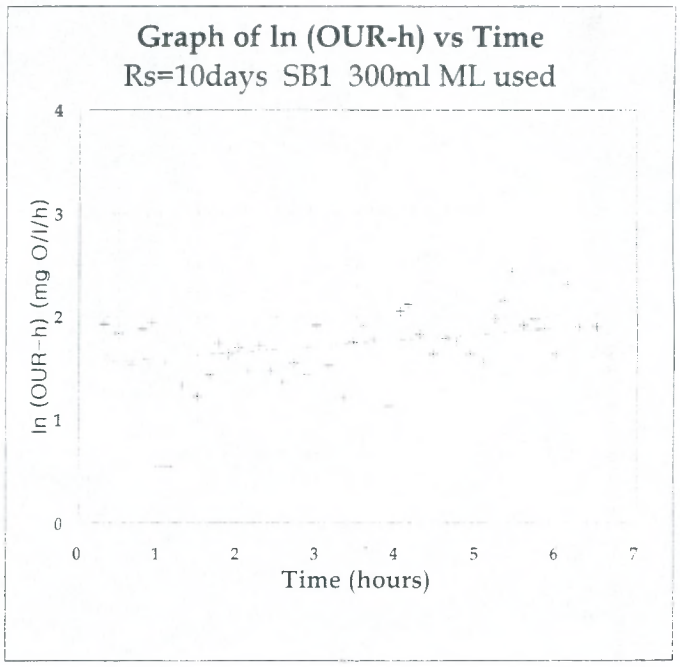
Table A2 Results for batch tests with a mixture of *flocculated-filtered* wastewater (WW) and mixed liquor (ML)drawn from the **20 days sludge age parent activated sludge system**: Batch test numbers, dates of batch tests, volumes added, COD recoveries, *measured* OHO active biomass present at the start of the batch test ($Z_{BH(0)}$) and the *projected* parent system mixed liquor (ML) active biomass. The *theoretical* parent system mixed liquor (ML) OHO active biomass and the *projected* active biomass present the start of the batch test are also given.

- OUR vs time and ℓn(OUR) vs time profiles for modified batch tests No. B1 - B35. The nitrate/nitrite concentration vs time profiles recorded during each batch test are also given.

Table A1: Results for batch tests with a mixture of flocculated-filtered wastewater (WW) and mixed liquor (ML)drawn from the 10 days sludge age parent activated sludge system: Batch test numbers, dates of batch tests, volumes added, COD recoveries, measured OHO active biomass present at the start of the batch test (ZBH(0)) and the projected parent system mixed liquor (ML) active biomass. The theoretical parent system mixed liquor (ML) O active biomass and the projected active biomass present the start of the batch test are also give

Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		COD Recov. (%)	Regression			K_{MP}	u_H	ZBH(0) (mgCOD/l)			
			WW	ML		Y-int	Slope	R^2			Measured		Theoretical	
											Batch Test	ML	Batch Test	ML
5	A1	11 09	2.70	0.30	92.8	1.5423	0.058	0.146	1.18	0.46	108.1	1080.6	172.7	1726.8
7	A2	24 09	2.70	0.30	90.3	2.1615	0.083	0.761	1.30	1.32	154.4	1543.6	196.5	1965.1
	A3	29 09	2.80	0.20	104.3	1.7136	0.106	0.891	1.51	1.65	81.9	1228.0	131.0	1965.1
	A4	05 10	2.90	0.10	93.6	1.2628	0.215	0.923	1.23	4.55	28.5	854.5	65.5	1965.1
8	A5	12 10	2.70	0.30	96.5	1.9874	0.125	0.979	1.93	1.69	93.9	938.6	166.3	1663.3
	A6	19 10	2.80	0.20	100.7	1.8539	0.080	0.925	1.18	1.35	117.5	1763.0	110.9	1663.3
	A7	23 10	2.90	0.10	95.7	0.8606	0.235	0.962	1.58	4.67	17.6	528.3	55.4	1663.3
9	A8	26 11	2.70	0.30	93.0	2.4815	0.133	0.964	1.76	2.04	146.4	1463.8	159.2	1591.8
	A9	27 11	2.80	0.20	96.5	2.1895	0.167	0.928	1.68	2.95	89.8	1346.4	106.1	1591.8
	A10	28 11	2.90	0.10	100.6	1.7688	0.218	0.988	1.77	4.08	46.7	1400.2	53.1	1591.8
10	A11	10 12	2.70	0.30	95.8	2.2268	0.022	0.379	0.54	0.60	377.6	3776.1	191.2	1912.0
	A12	11 12	2.80	0.20	104.9	1.7326	0.155	0.954	1.65	2.67	60.9	913.1	127.5	1912.0
	A13	12 12	2.90	0.10	100.8	1.0313	0.266	0.993	1.65	5.35	18.7	560.2	63.7	1912.0
	A14	13 12	2.95	0.05	96.5	0.8067	0.266	0.999	1.10	5.91	14.9	893.4	31.9	1912.0
11	A15	26 12	2.60	0.40	100.2	2.4917	0.022	0.581	0.67	0.48	489.4	3670.4	230.4	1728.2
	A16	29 12	2.70	0.30	98.4	1.9744	0.077	0.877	1.26	1.21	136.3	1362.5	172.8	1728.2
	A17	30 12	2.80	0.20	93.3	1.3810	0.146	0.926	1.51	2.61	45.0	675.2	115.2	1728.2
	A18	31 12	2.90	0.10	90.5	0.4588	0.225	0.967	1.86	4.16	12.2	366.9	57.6	1728.2
	A19	05 01	2.95	0.05	85.6	0.8782	0.315	0.997	0.90	7.28	13.7	822.1	28.8	1728.2
12	A20	09 01	2.60	0.40	101.8	2.4762	0.029	0.594	0.80	0.51	421.6	3161.7	233.4	1750.8
	A21	10 01	2.70	0.30	92.9	2.2033	0.044	0.852	0.84	0.84	252.0	2519.8	175.1	1750.8
	A22	11 01	2.80	0.20	93.3	1.5381	0.152	0.982	1.90	2.38	50.7	760.5	116.7	1750.8
	A23	14 01	2.90	0.10	92.1	0.7585	0.173	0.950	1.58	3.18	20.9	626.4	58.4	1750.8
	A24	15 01	2.95	0.05	83.2	0.3058	0.221	0.992	1.65	4.28	10.7	640.4	29.2	1750.8
13	A25	01 02	2.95	0.05	80.2	-0.5355	0.252	0.992	0.64	6.03	4.1	245.2	32.9	1973.5
	A26	04 02	2.96	0.04	85.3	0.1968	0.189	0.951	1.59	3.56	11.0	825.6	26.3	1973.5
14	A27	15 02	2.40	0.60	96.4	2.6878	0.000	0.000	0.42	0.20	1093.8	5469.0	265.2	1325.9
	A28	17 02	2.60	0.40	96.6	2.0849	0.078	0.985	1.35	1.14	150.8	1131.3	176.8	1325.9
	A29	18 02	2.80	0.20	96.1	0.8955	0.178	0.962	1.90	3.00	23.3	349.4	88.4	1325.9
	A30	20 02	2.90	0.10	86.2	0.3006	0.275	0.978	1.79	5.42	8.7	261.6	44.2	1325.9
	A31	22 02	2.93	0.07	78.5	0.4377	0.261	0.994	0.97	5.91	10.5	449.7	30.9	1325.9
	A32	24 02	2.95	0.05	76.3	1.0853	0.172	0.995	0.60	4.14	29.0	1742.8	22.1	1325.9
	A33	25 02	2.97	0.03	74.0	1.3622	0.161	0.989	0.62	3.87	40.5	4049.4	13.3	1325.9
17	A34	22 04	2.80	0.20	97.5	0.9671	0.128	0.958	1.38	2.31	33.2	497.5	95.2	1427.9
	A35	24 04	2.90	0.10	100.3	-0.8368	0.283	0.978	1.14	6.27	2.7	81.6	47.6	1427.9

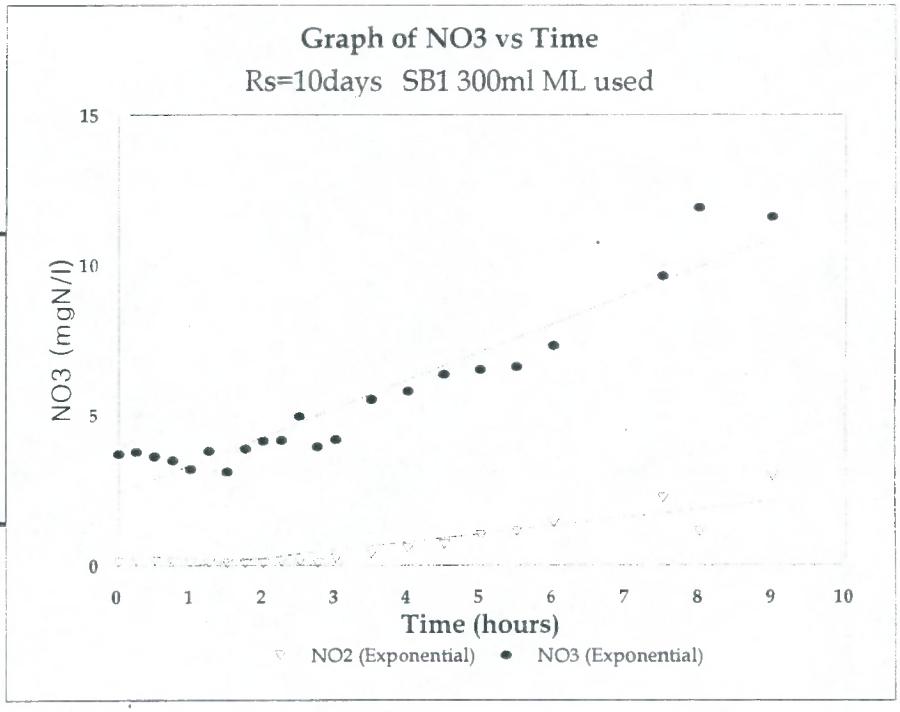


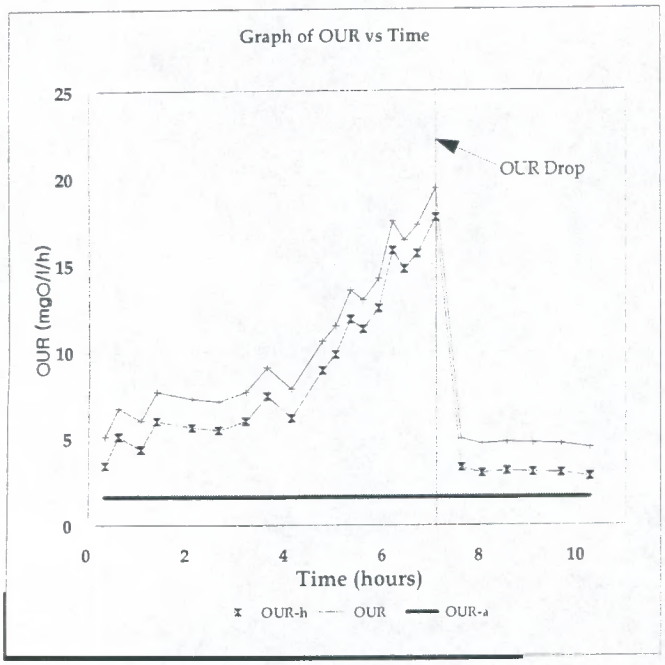


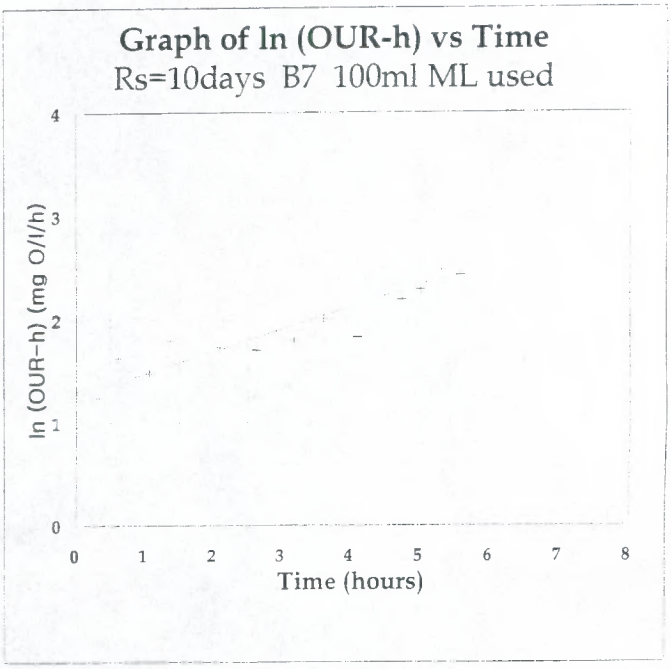
% COD Recovery		End Point=	13.20				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
692.00	588.00	123.60	12.23	56.86	69.09	54.51	92.85

Parent System		fcv=	1.374	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.375	3346.7	300	172.68195	108.06	3.98573830233	1.18	0.46	6.5

Regression Output:	
Constant	1.542261359
Std Err of Y Est	0.264466608
R Squared	0.145985994
No. of Observations	44
Degrees of Freedom	42
X Coefficient(s)	0.058147989
Std Err of Coef.	0.02170136

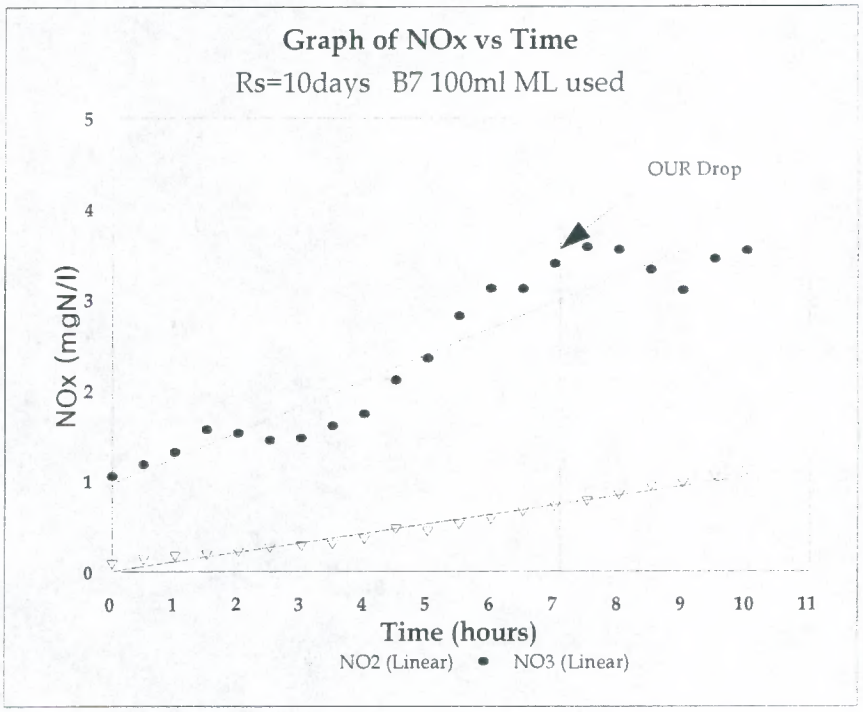




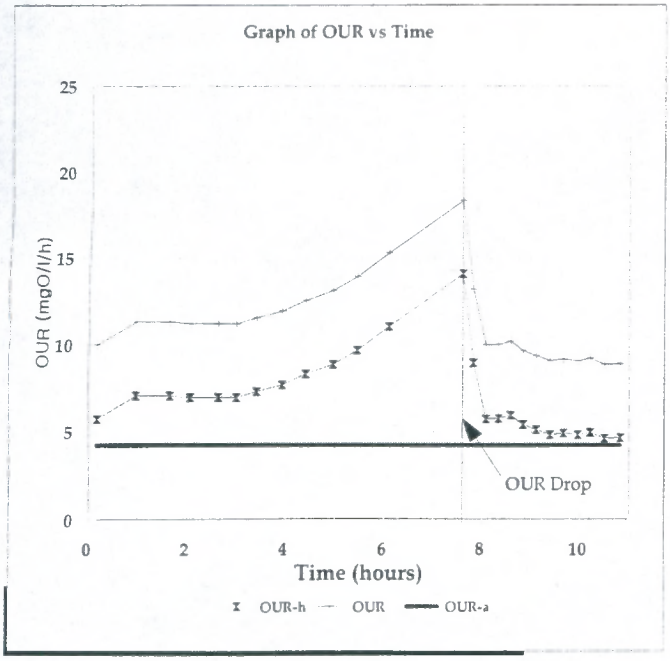


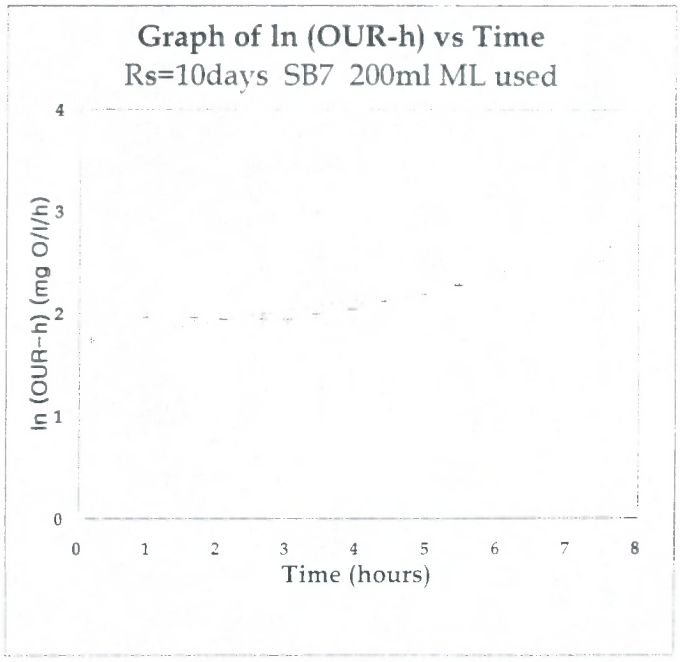
% COD Recovery		End Point=	10.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
344.00	288.00	84.70	3.58	13.03	16.60	68.10	103.52

Parent System		fcv=	1.424	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.427	3232	100	65.502885	28.48	3.34957555954	1.23	4.55	7.08



Regression Output:	
Constant	1.26275734
Std Err of Y Est	0.141618765
R Squared	0.923352701
No. of Observations	18
Degrees of Freedom	16
X Coefficient(s)	0.215084884
Std Err of Coef.	0.015492251

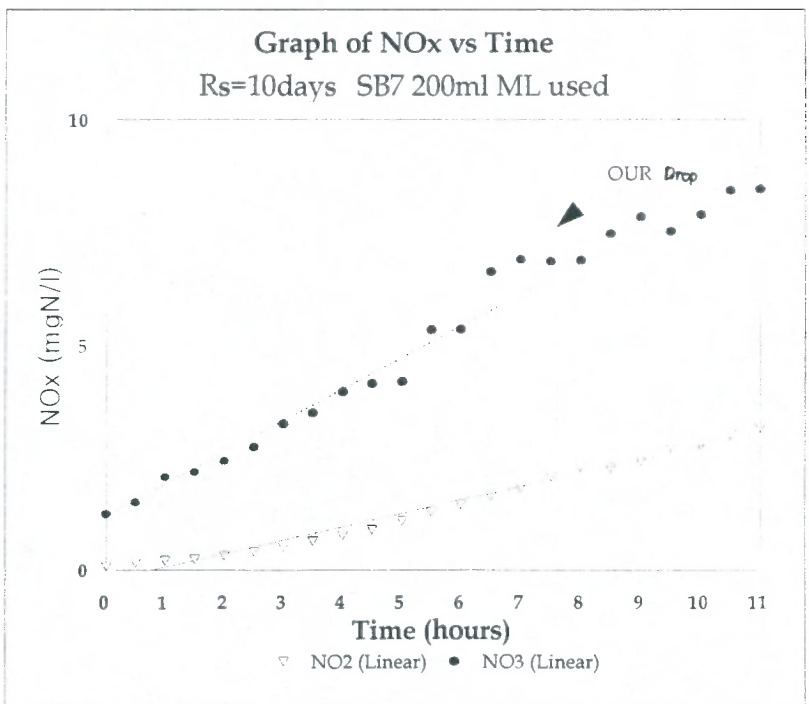


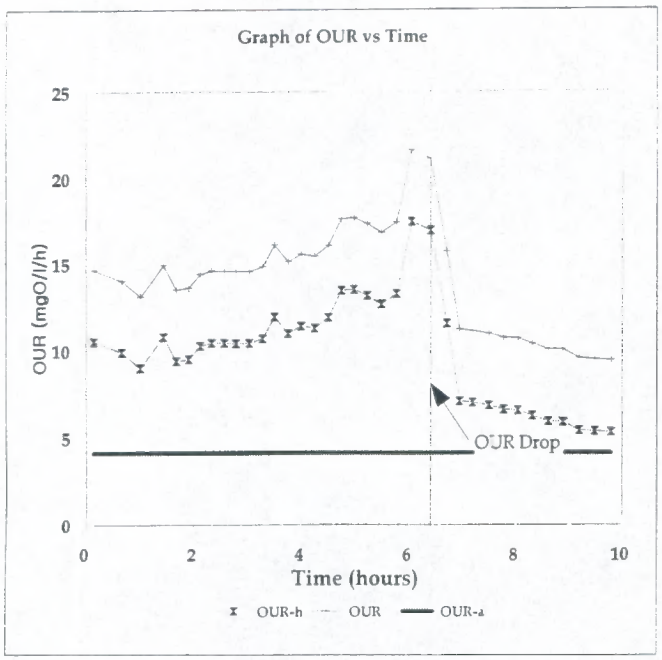


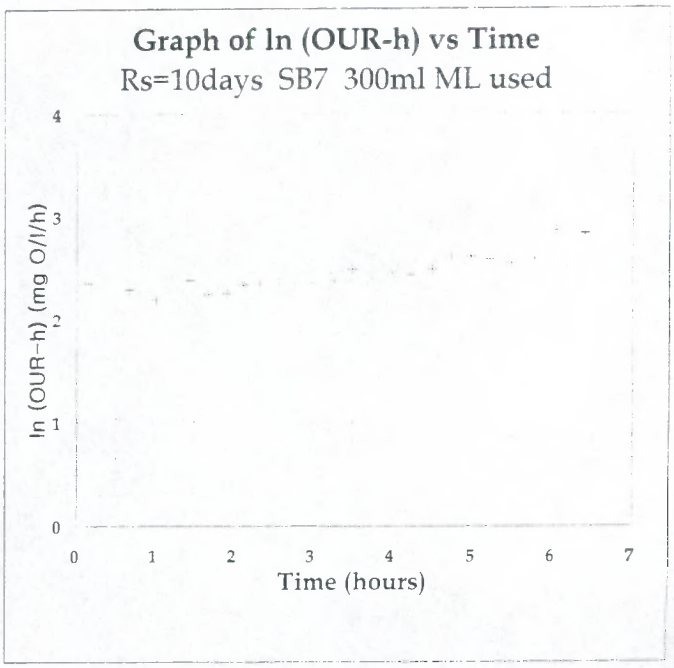
% COD Recovery		End Point=	10.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
504.00	444.00	126.20	10.75	33.93	44.68	81.52	104.27

Parent System		fcv=	1.424	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.427	3232	200	131.00577	81.87	5.77501063205	1.51	1.65	7.6

Regression Output:	
Constant	1.713616242
Std Err of Y Est	0.08229141
R Squared	0.890708354
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.105737929
Std Err of Coef.	0.011167608



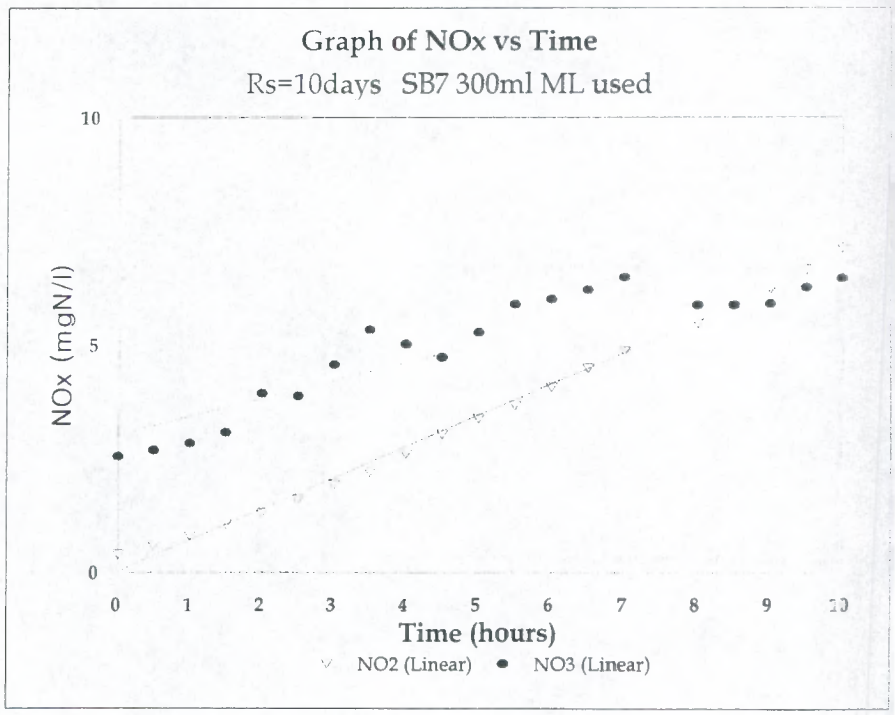


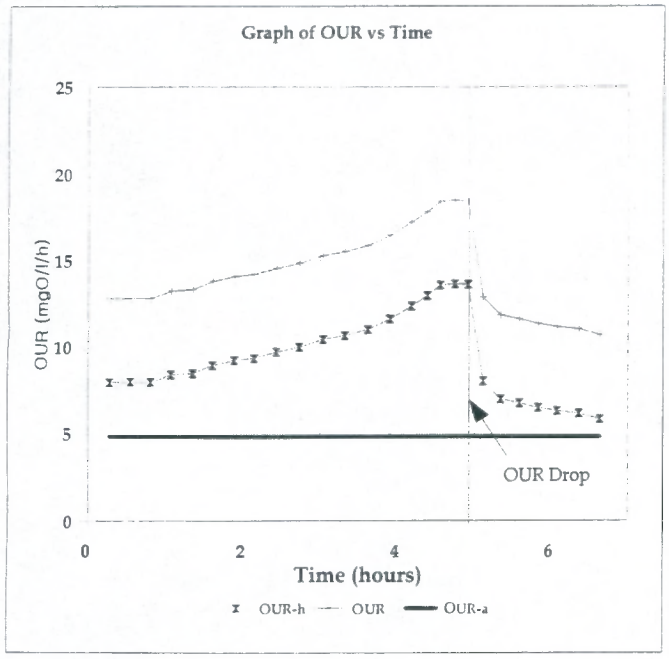


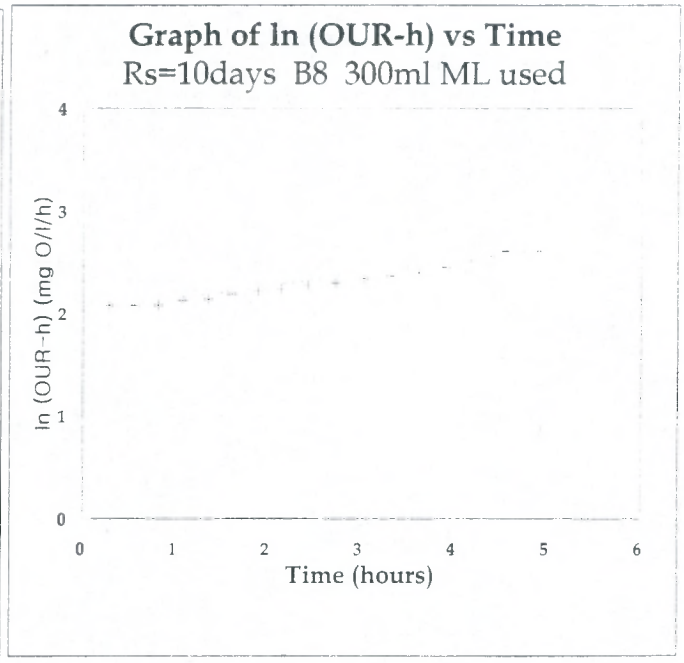
% COD Recovery		End Point=	10.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
673.30	512.10	137.30	23.54	17.95	41.48	95.82	90.29

Parent System		fcv=	1.424	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.427	3232	300	196.50866	154.36	7.13154678824	1.30	1.32	6.4

Regression Output:	
Constant	2.161517148
Std Err of Y Est	0.084853029
R Squared	0.761135721
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	0.08337499
Std Err of Coef.	0.009957929





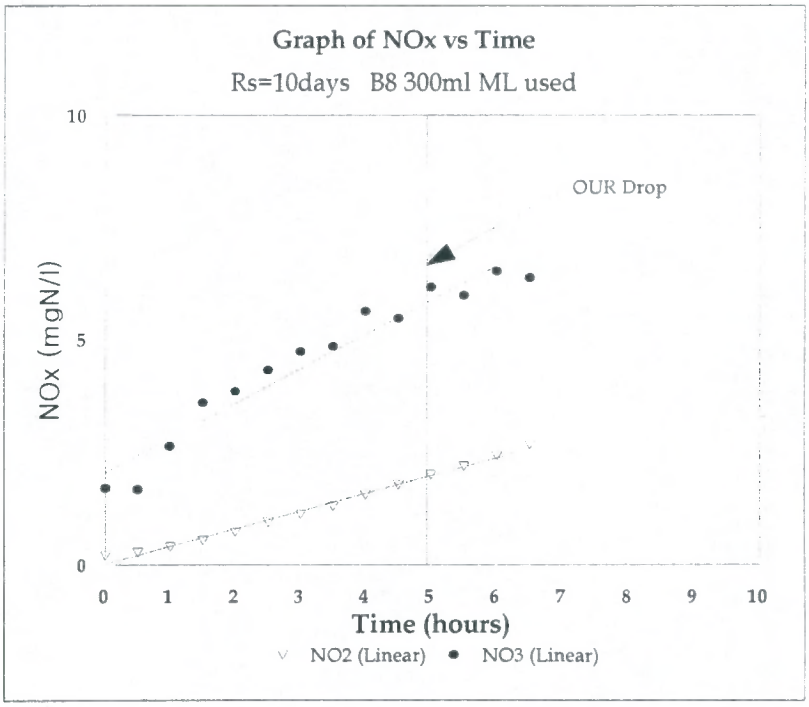


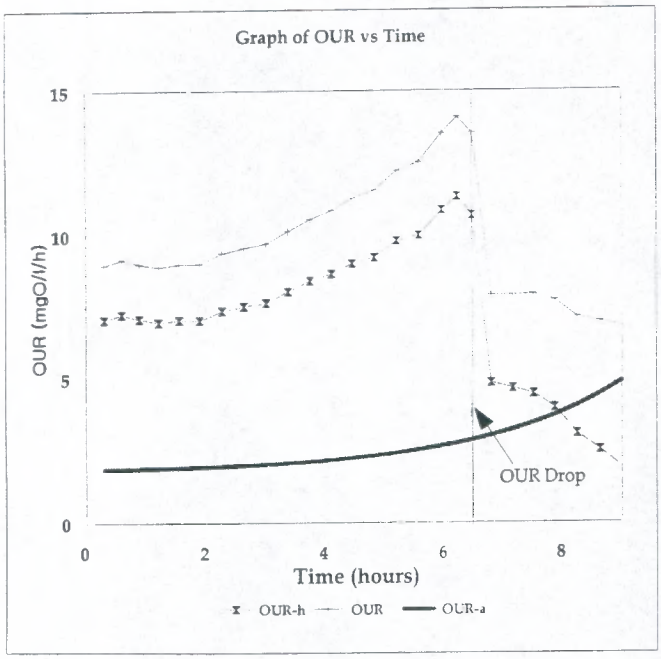
% COD Recovery		End Point=	6.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
707.14	629.92	83.80	8.74	22.75	31.49	52.31	96.48

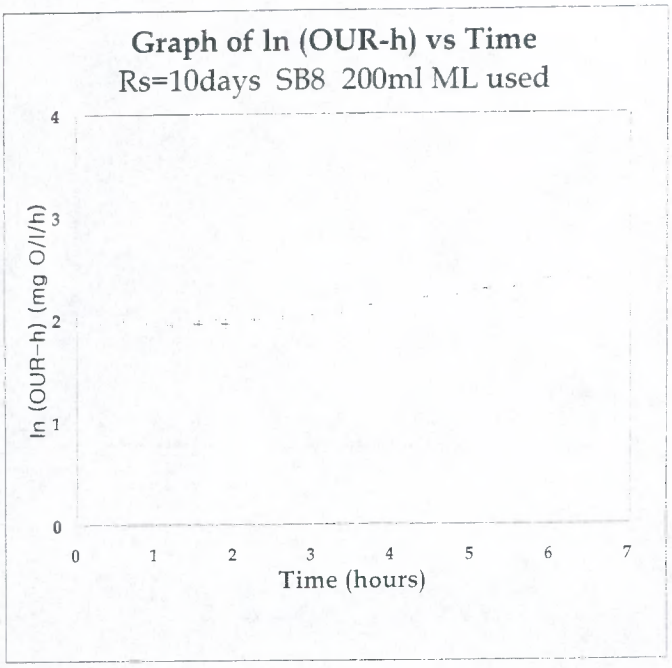
Parent System		fcv=	1.454	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.332	3448.5	300	166.33229	93.86	7.0160562819	1.93	1.69	4.93

0.387	3140.0	300	179.73261
0.317	3472.0	300	162.88898
0.330	3484.0	300	170.36511
0.310	3698.0	300	169.82023

Regression Output:	
Constant	1.987417571
Std Err of Y Est	0.028440294
R Squared	0.979063421
No. of Observations	19
Degrees of Freedom	17
X Coefficient(s)	0.12508018
Std Err of Coef.	0.004436204





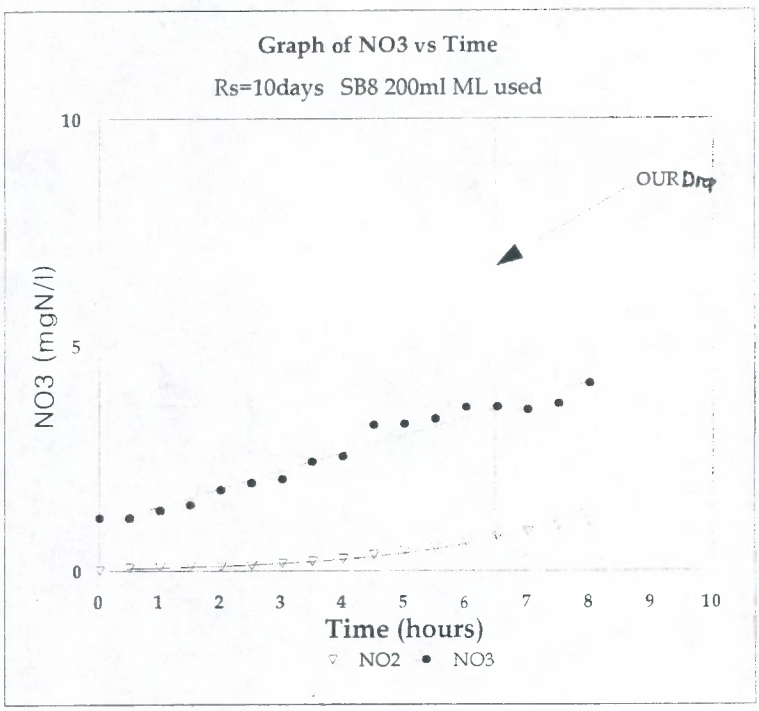


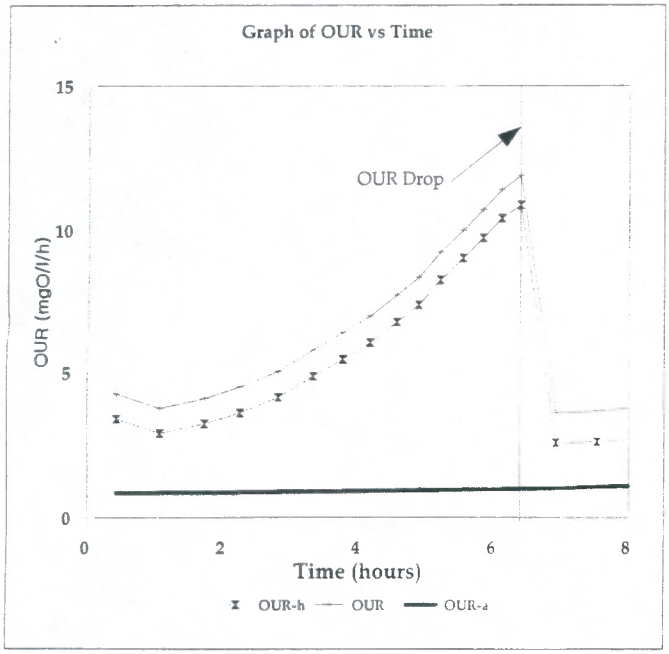
% COD Recovery		End Point=	8.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
479.55	424.53	77.20	4.69	14.36	19.05	58.15	100.65

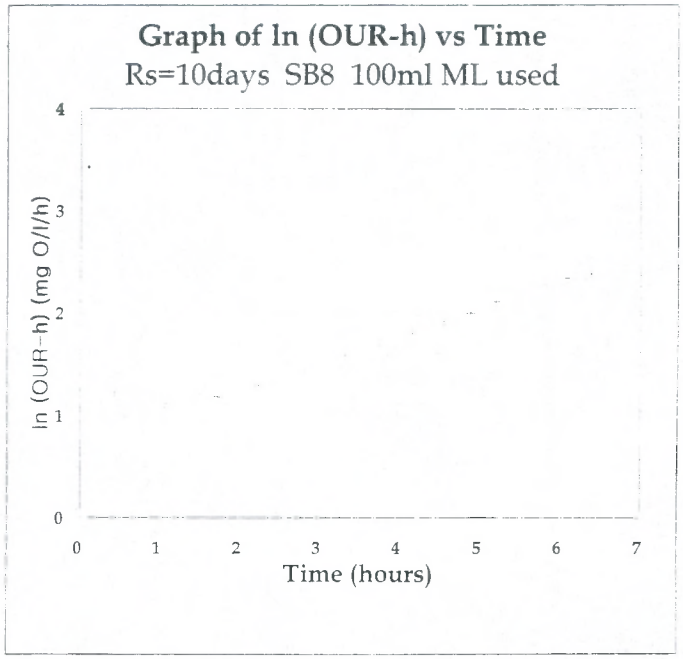
Parent System		fcv=	1.454	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.332	3448.5	200	110.88819	117.53	4.85470050586	1.18	1.35	6.47

0.387	3140.0	200	119.82174
0.317	3472.0	200	108.59265
0.330	3484.0	200	113.57674
0.310	3698.0	200	113.21348

Regression Output:		
Constant		1.853882948
Std Err of Y Est		0.046470614
R Squared		0.925303254
No. of Observations		19
Degrees of Freedom		17
X Coefficient(s)	0.079615555	
Std Err of Coef.	0.005486334	





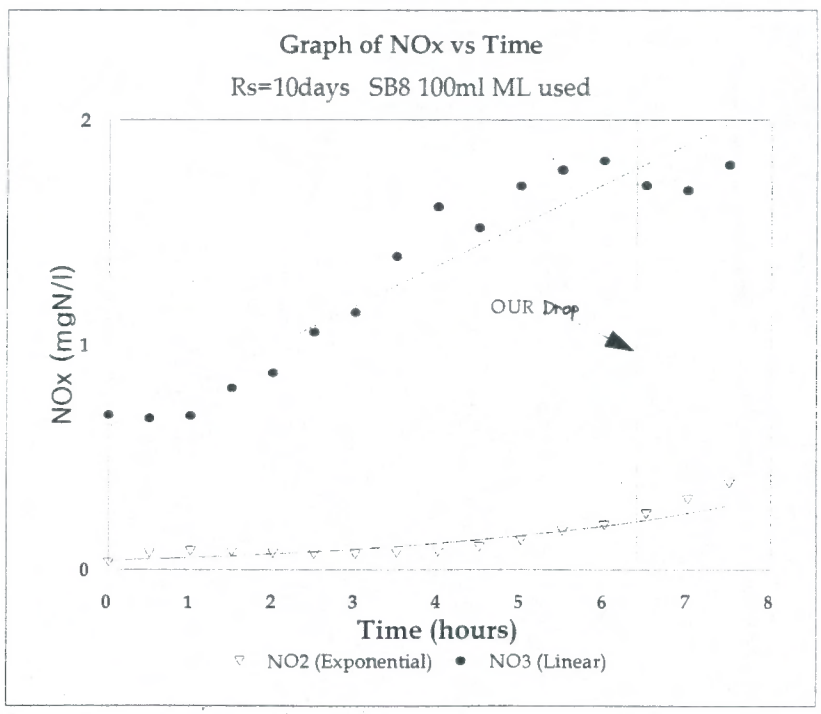


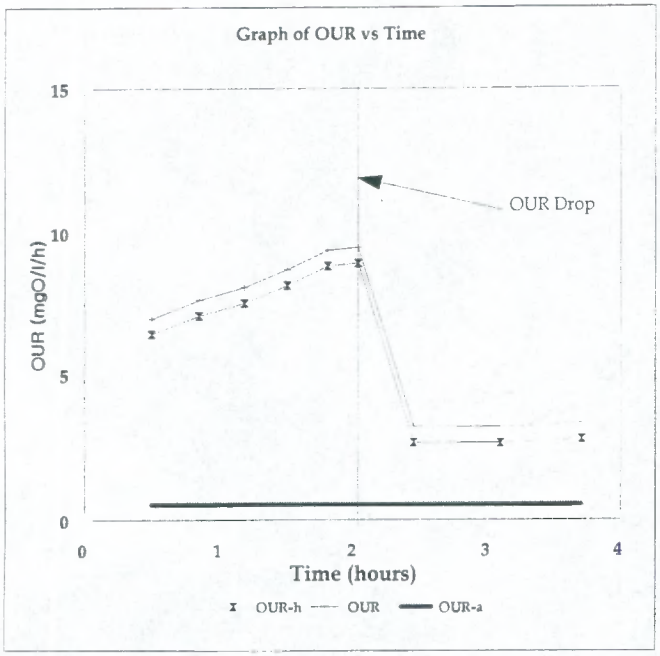
% COD Recovery		End Point=	7.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
350.15	283.36	58.60	0.83	6.17	7.00	51.60	95.66

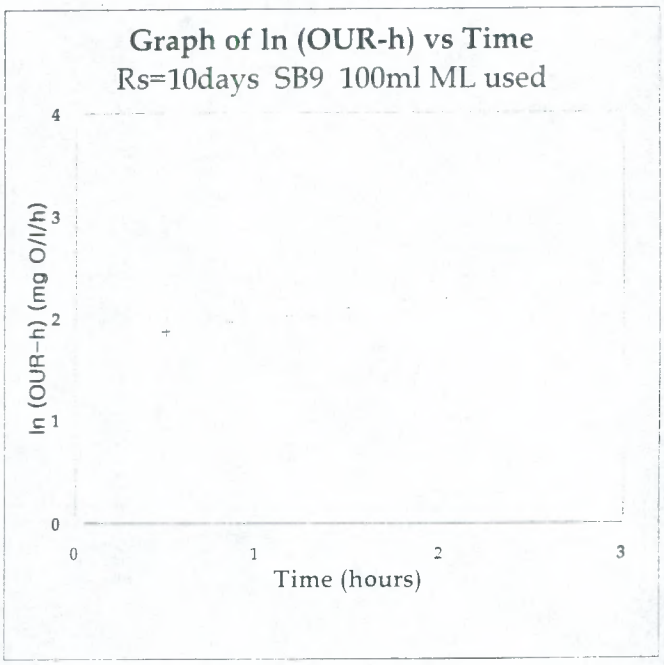
Parent System		fcv=	1.454	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.332	3448.5	100	55.444095	17.61	2.6141818952	1.58	4.67	6.39

0.387	3140.0	100	59.910871
0.317	3472.0	100	54.296326
0.330	3484.0	100	56.78837
0.310	3698.0	100	56.606742

Regression Output:		
Constant		0.860571093
Std Err of Y Est		0.091608193
R Squared		0.961628498
No. of Observations		15
Degrees of Freedom		13
X Coefficient(s)	0.234810442	
Std Err of Coef.	0.013009076	





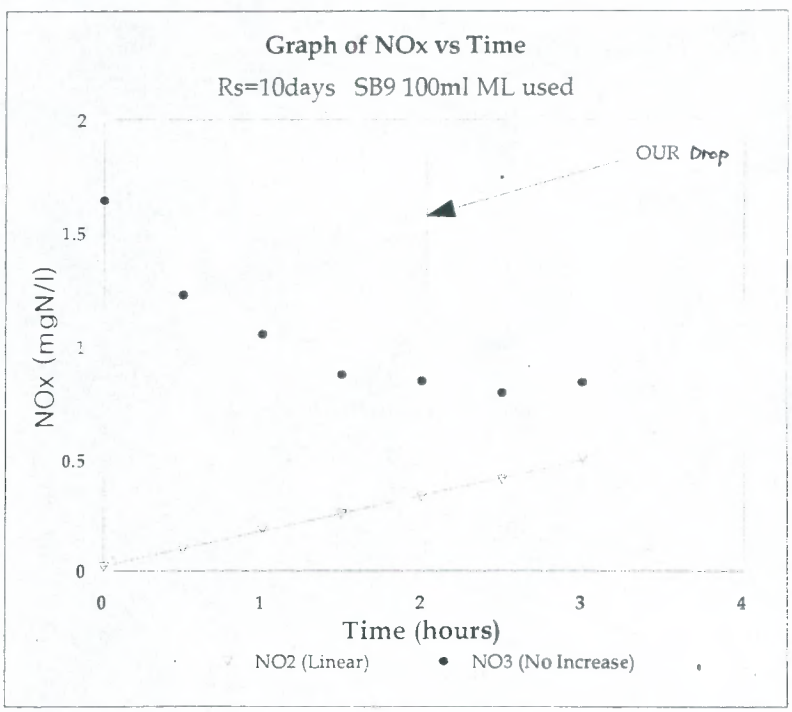


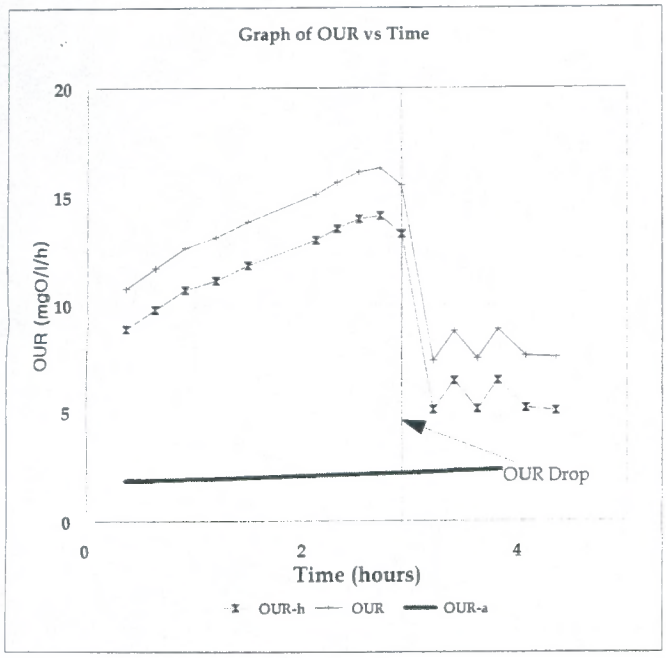
% COD Recovery		End Point=	3.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
272.16	260.06	15.40	1.65	0.00	1.65	13.75	100.61

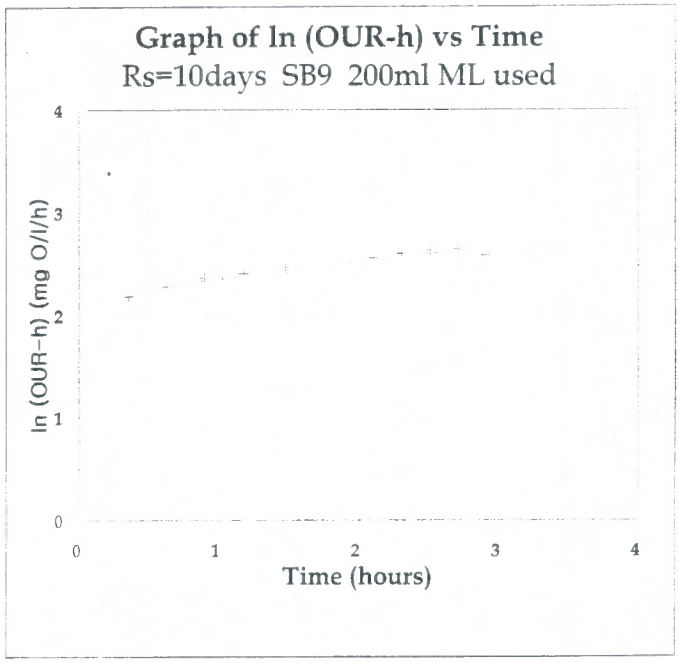
Parent System		fcv=	1.381	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(TI:eo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.370	3117.0	100	53.058482	46.67	2.69158748561	1.77	4.08	2.03

0.390	3150.0	100	60.537541
0.327	3222.0	100	52.01423
0.440	2874.0	100	62.426605
0.329	3306.0	100	53.723617
0.351	3036.0	100	52.502816
0.390	3114.0	100	59.845144

Regression Output:	
Constant	1.768767267
Std Err of Y Est	0.015557007
R Squared	0.988086226
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	0.218030757
Std Err of Coef.	0.011970575





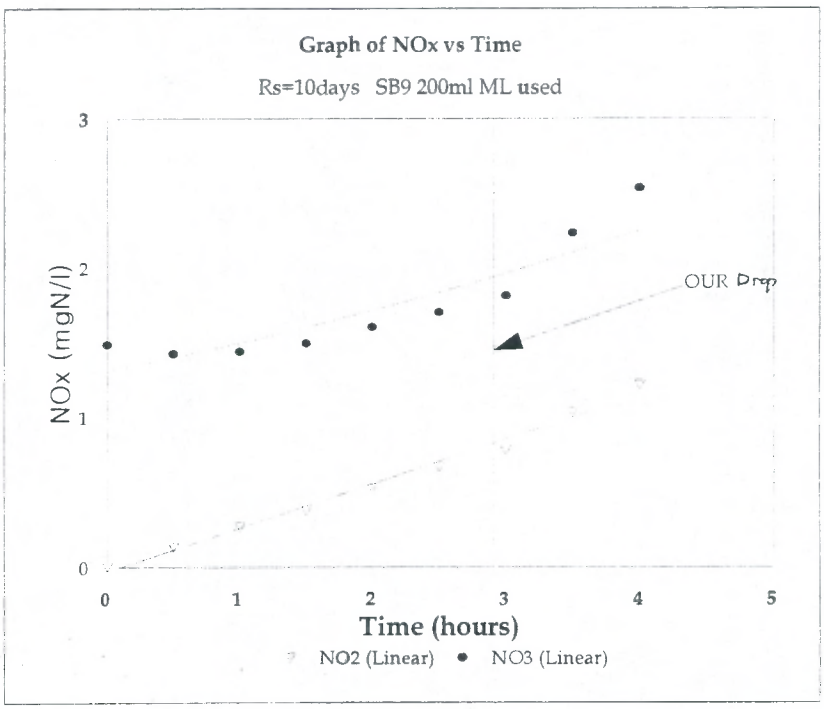


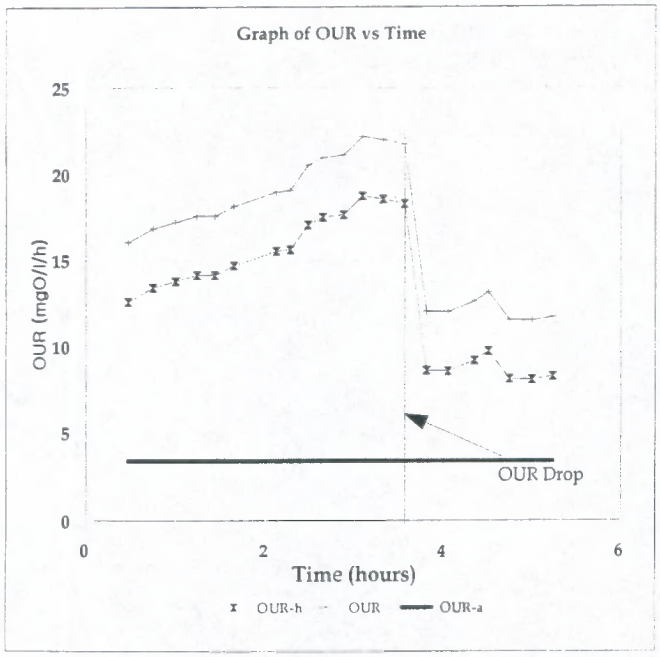
% COD Recovery		End Point=	4.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
483.84	431.41	44.00	4.05	4.33	8.38	35.62	96.53

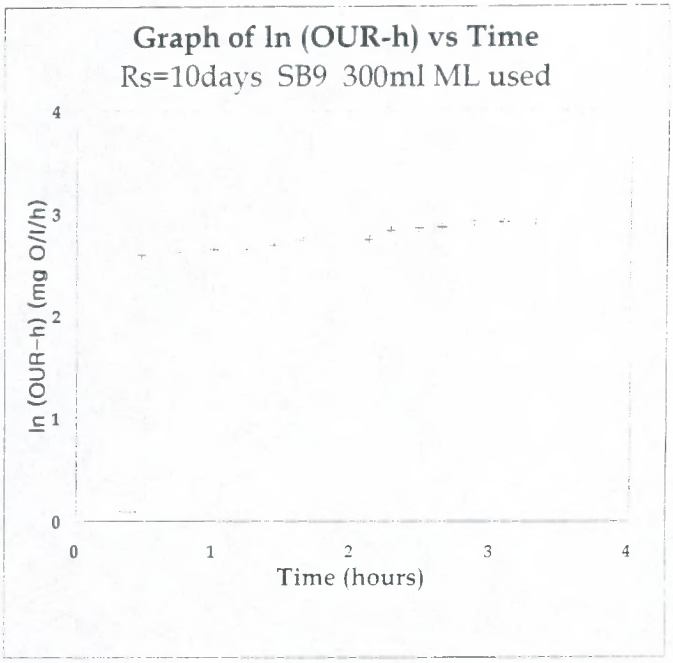
Parent System		fcv=	1.381	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.370	3117.0	200	106.11696	89.76	5.13780688452	1.68	2.95	2.91

0.390	3150.0	200	121.07508
0.327	3222.0	200	104.02846
0.440	2874.0	200	124.85321
0.329	3306.0	200	107.44723
0.351	3036.0	200	105.00563
0.390	3114.0	200	119.69029

Regression Output:		
Constant		2.189475218
Std Err of Y Est		0.045420226
R Squared		0.927890115
No. of Observations		10
Degrees of Freedom		8
X Coefficient(s)	0.167294781	
Std Err of Coef.	0.016488704	





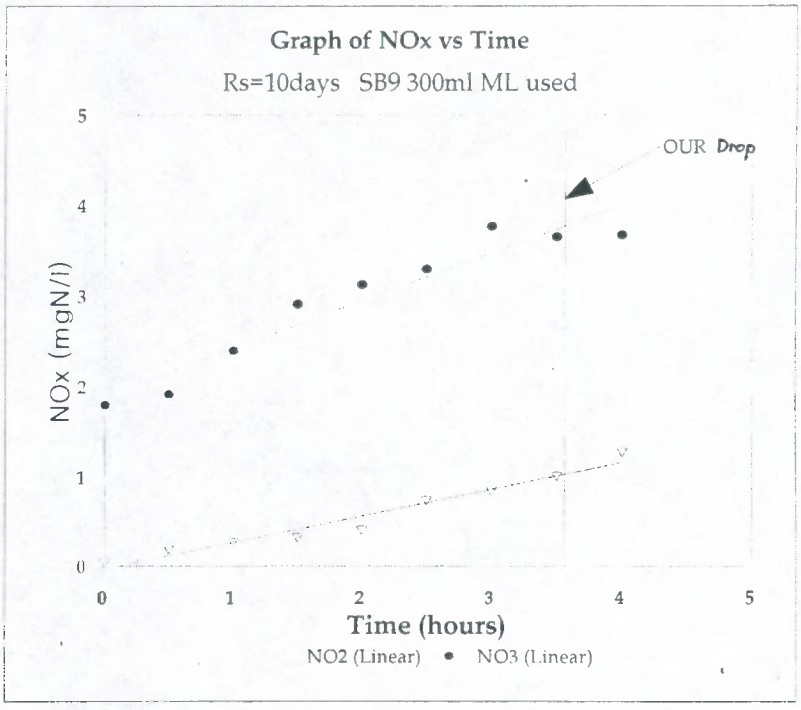


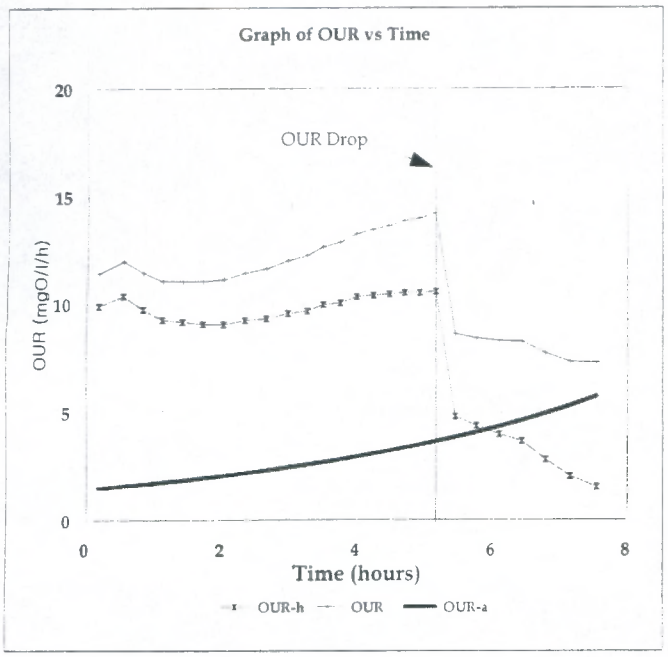
% COD Recovery		End Point=	4.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
657.22	556.42	70.00	4.62	10.83	15.45	54.55	92.96

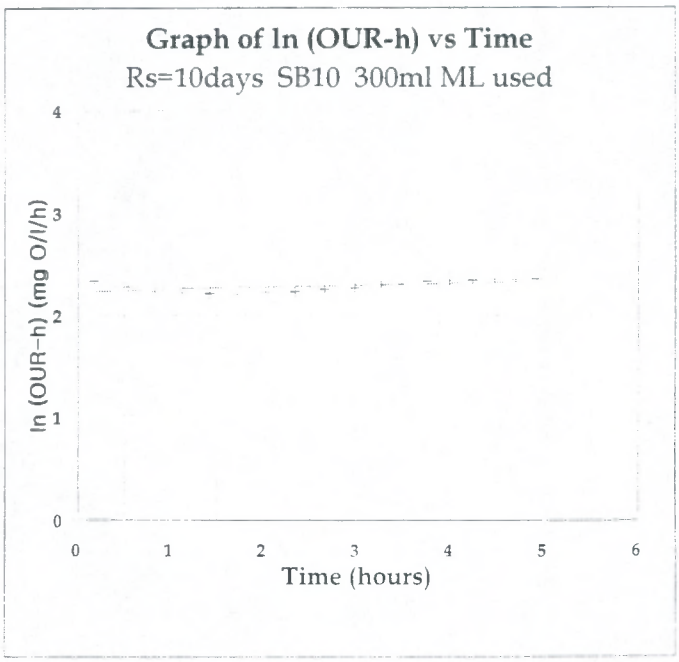
Parent System		fcv=	1.381	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.370	3117.0	300	159.17544	146.38	8.64609293798	1.76	2.04	3.56

0.390	3150.0	300	181.61262
0.327	3222.0	300	156.04269
0.440	2874.0	300	187.27982
0.329	3306.0	300	161.17085
0.351	3036.0	300	157.50845
0.390	3114.0	300	179.53543

Regression Output:	
Constant	2.48149935
Std Err of Y Est	0.026276204
R Squared	0.964259745
No. of Observations	14
Degrees of Freedom	12
X Coefficient(s)	0.132755694
Std Err of Coef.	0.007378097





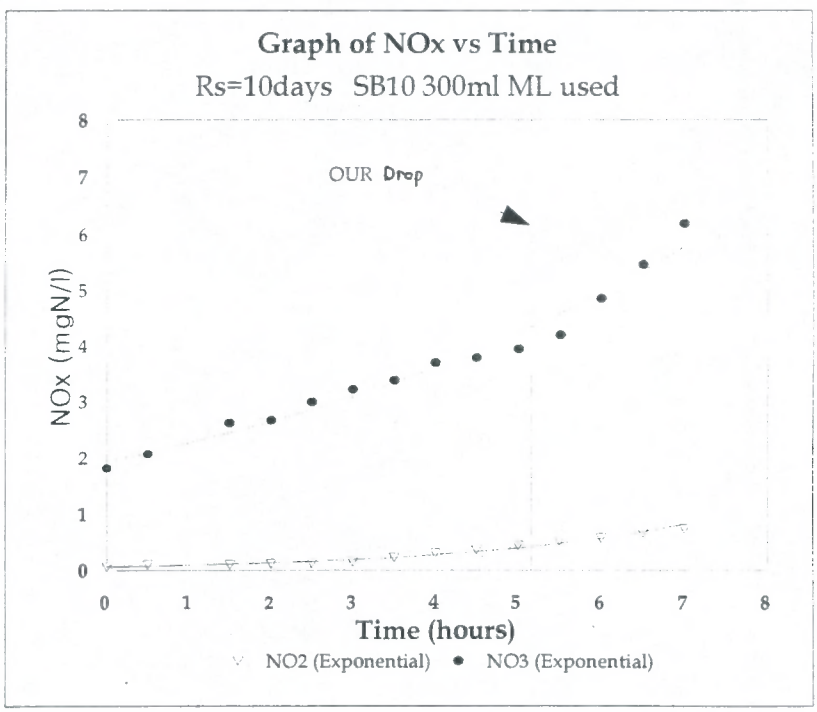


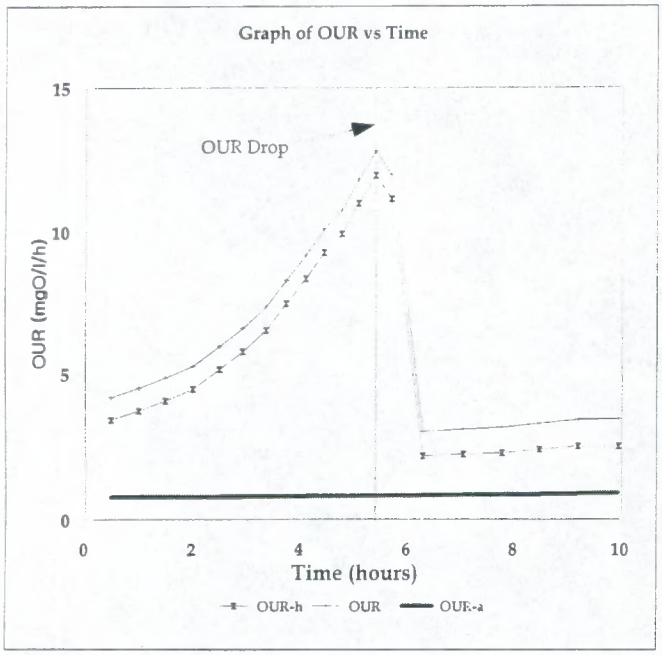
% COD Recovery		End Point=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
592.00	512.00	75.30	2.59	17.62	20.21	55.09	95.79

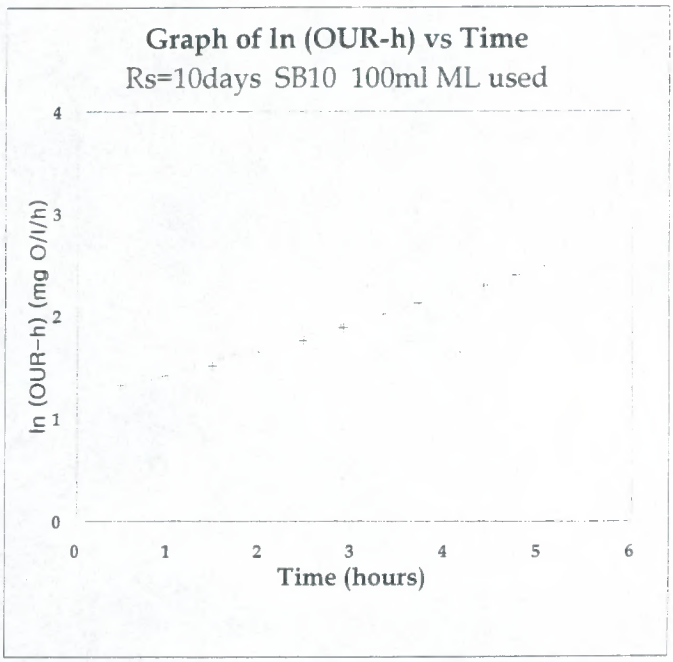
Parent System		fcv=	1.381	Batch Result				
fav	Xv	VML	ZBH(Theo),BT	ZBH(O)	OURSBCOD	KMP	UH	t=s
0.453626446	3051.25	300	191.203	377.61	4.80152532206	0.54	0.60	5.16

0.4344314	3204	300	206.00389
0.491395441	3032	300	220.50682
0.447625731	3156	300	209.08061
0.603960899	2744	300	245.27577
0.53505438	2812	300	222.67679
0.401917946	3158	300	187.85002
0.40420218	3090	300	184.84974
0.348444164	3214	300	165.74513

Regression Output:	
Constant	2.226779077
Std Err of Y Est	0.045060231
R Squared	0.378716165
No. of Observations	19
Degrees of Freedom	17
X Coefficient(s)	0.021820379
Std Err of Coef.	0.00677838





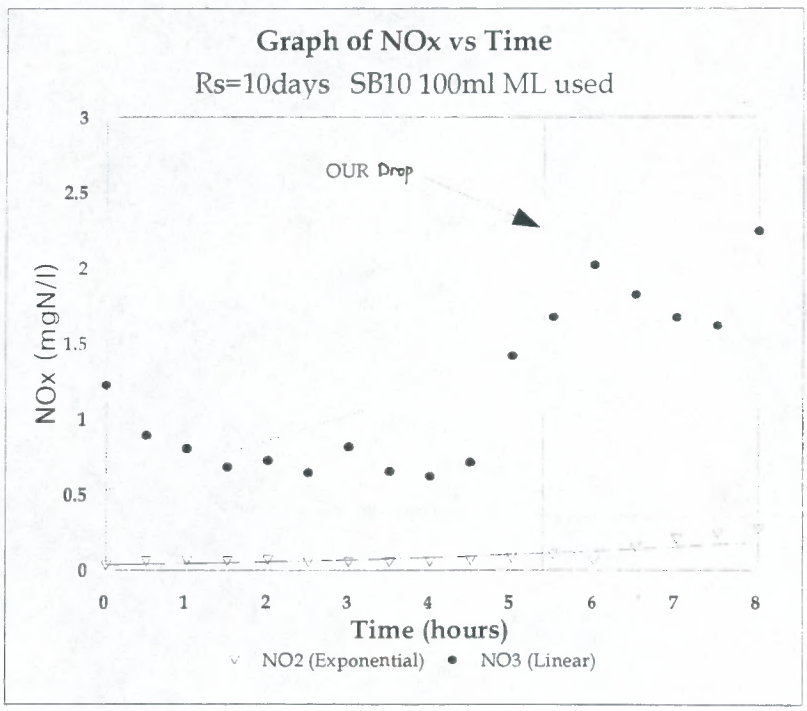


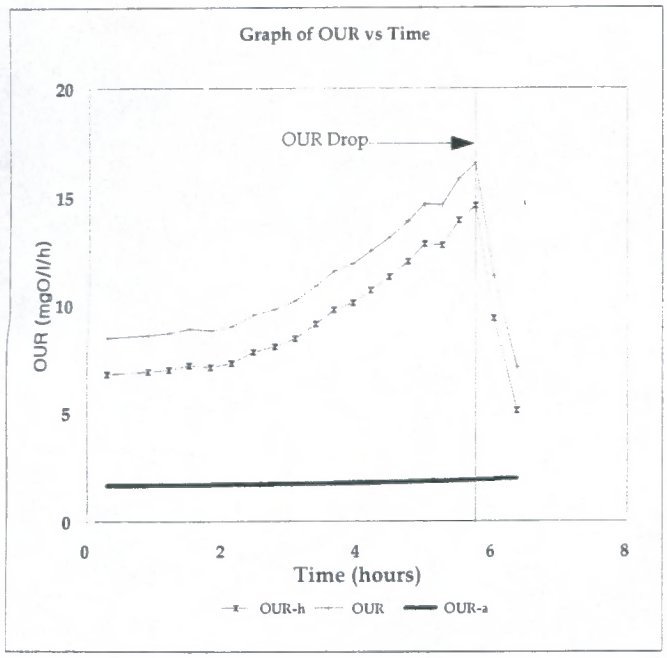
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
328.00	290.00	46.40	0.39	5.29	5.69	40.71	100.83

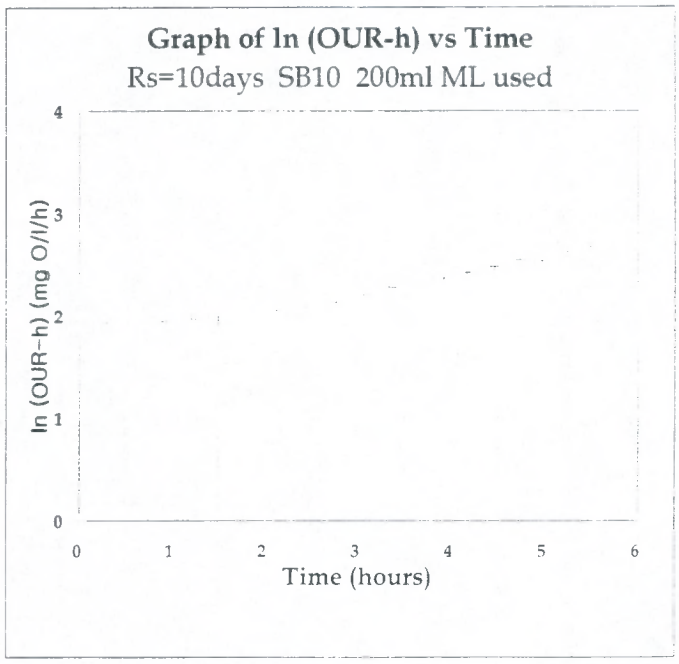
Parent System		fcv=	1.381	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(The),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.453626446	3051.25	100	63.734334	18.67	2.6923172301	1.65	5.35	5.38

0.4344314	3204	100	68.667965
0.491395441	3032	100	73.502275
0.447625731	3156	100	69.693536
0.603960899	2744	100	81.758589
0.53505438	2812	100	74.225597
0.401917946	3158	100	62.616672
0.40420218	3090	100	61.61658
0.348444164	3214	100	55.248377

Regression Output:	
Constant	1.031239883
Std Err of Y Est	0.037172761
R Squared	0.992956176
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.265721722
Std Err of Coef.	0.00674792





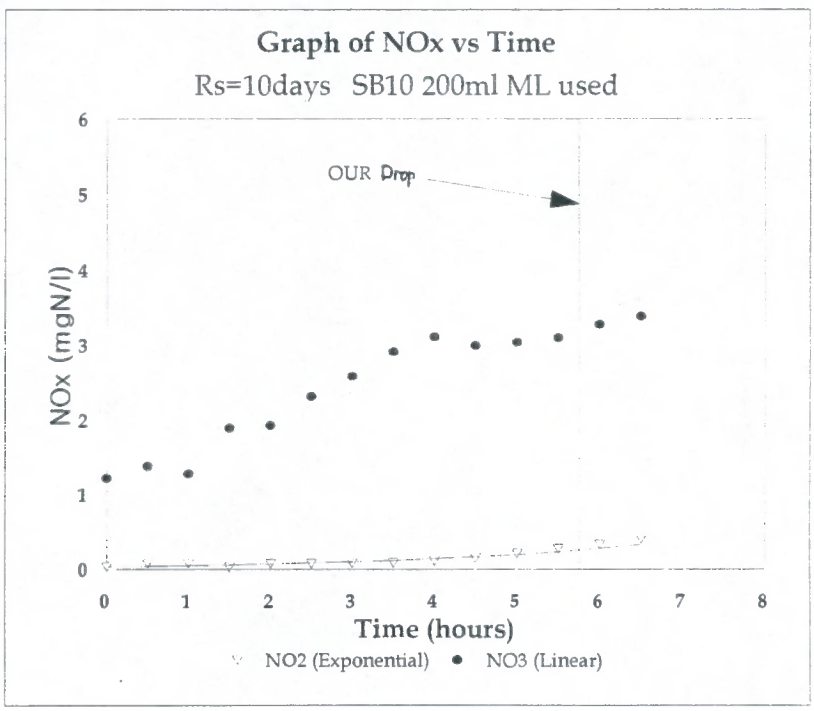


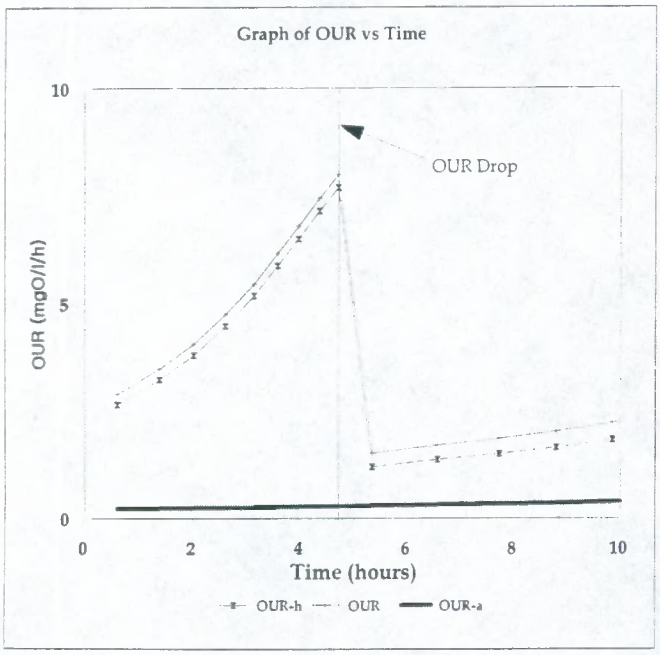
% COD Recovery		End Time=	6.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
484.00	452.00	67.20	1.01	10.63	11.64	55.56	104.87

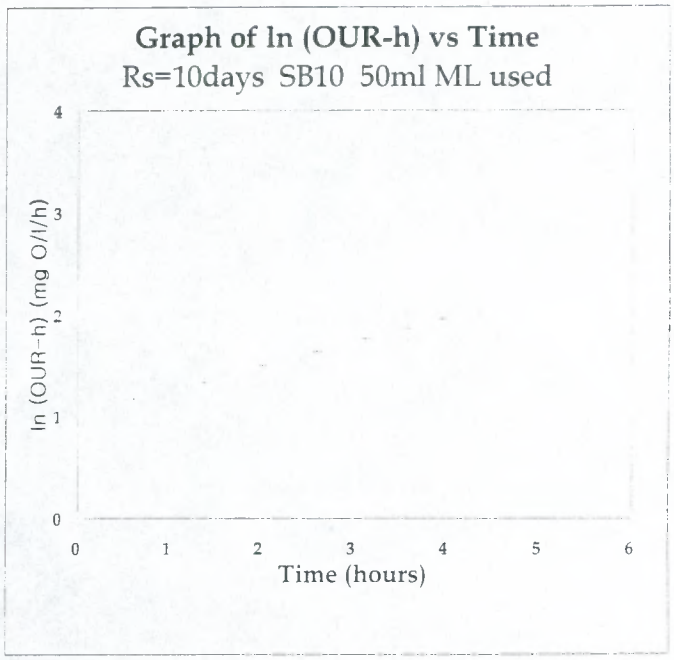
Parent System		fcv=	1.381	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.453626446	3051.25	200	127.46867	60.87	5.11497648758	1.65	2.67	5.75

0.4344314	3204	200	137.33593
0.491395441	3032	200	147.00455
0.447625731	3156	200	139.38707
0.603960899	2744	200	163.51718
0.53505438	2812	200	148.45119
0.401917946	3158	200	125.23334
0.40420218	3090	200	123.23316
0.348444164	3214	200	110.49675

Regression Output:	
Constant	1.73255253
Std Err of Y Est	0.057825076
R Squared	0.953725841
No. of Observations	19
Degrees of Freedom	17
X Coefficient(s)	0.154508357
Std Err of Coef.	0.00825439





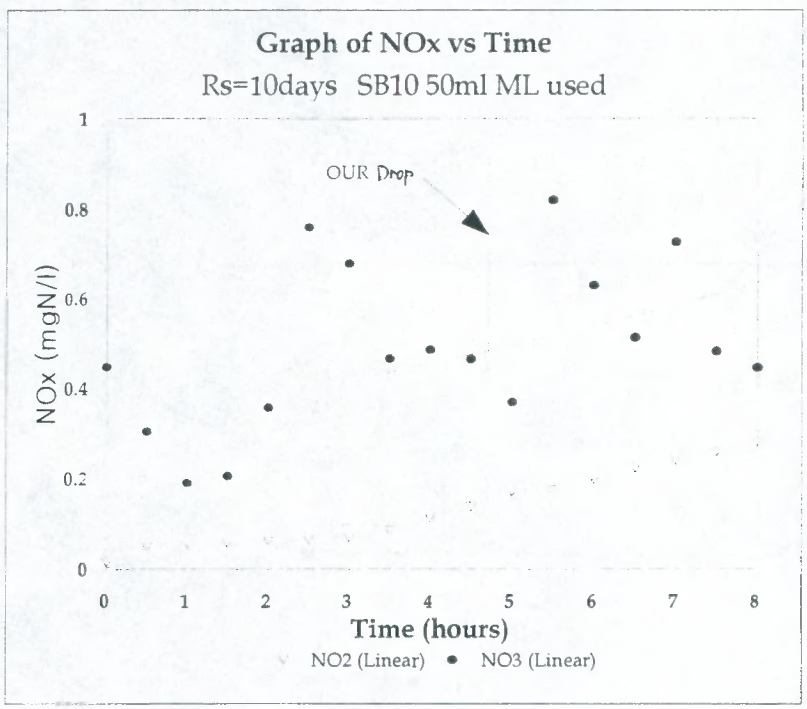


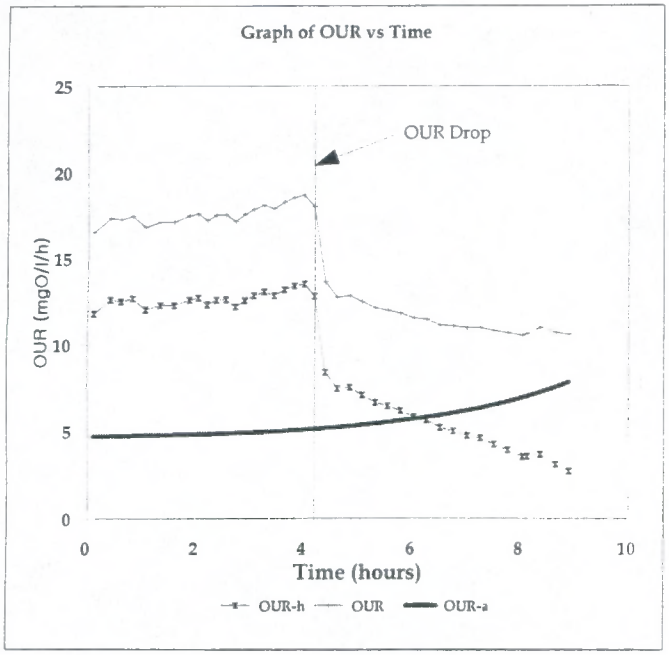
% COD Recovery		End Time=	6.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
230.00	200.00	23.70	0.73	1.07	1.80	21.90	96.48

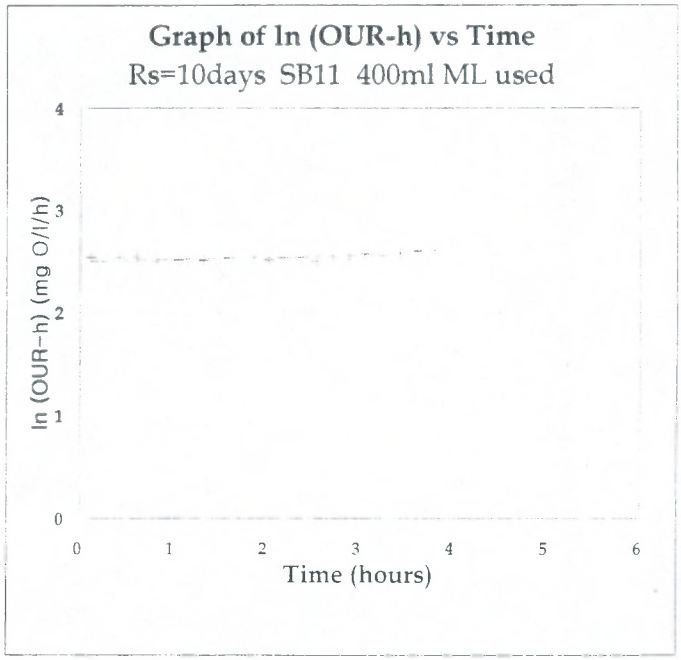
Parent System		fcv=	1.381	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.453626446	3051.25	50	31.867167	14.89	1.20347773633	1.10	5.91	4.71

0.4344314	3204	50	34.333982
0.491395441	3032	50	36.751137
0.447625731	3156	50	34.846768
0.603960899	2744	50	40.879295
0.53505438	2812	50	37.112799
0.401917946	3158	50	31.308336
0.40420218	3090	50	30.80829
0.348444164	3214	50	27.624189

Regression Output:		
Constant		0.806656158
Std Err of Y Est		0.010705209
R Squared		0.999265536
No. of Observations		9
Degrees of Freedom		7
X Coefficient(s)	0.266243771	
Std Err of Coef.	0.002728194	





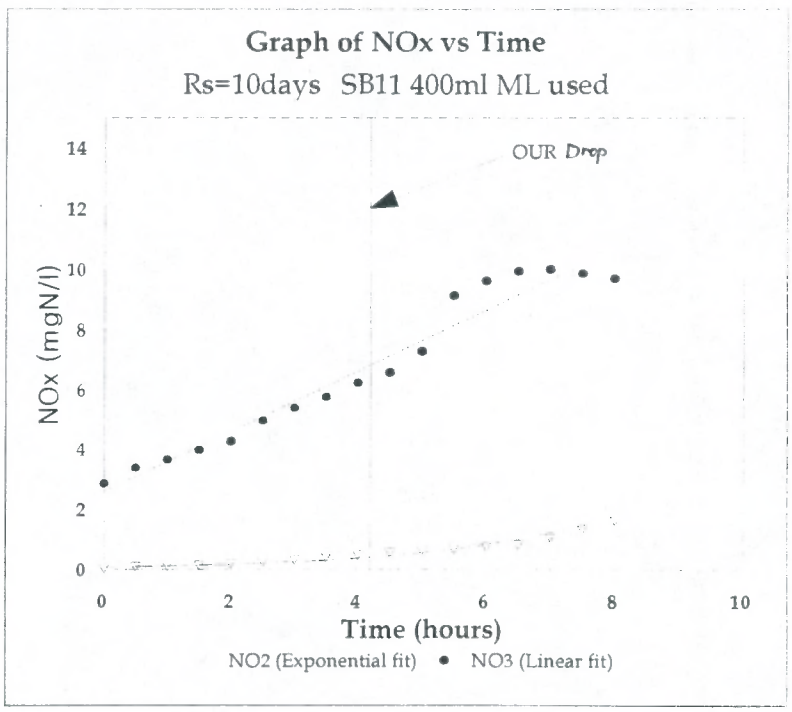


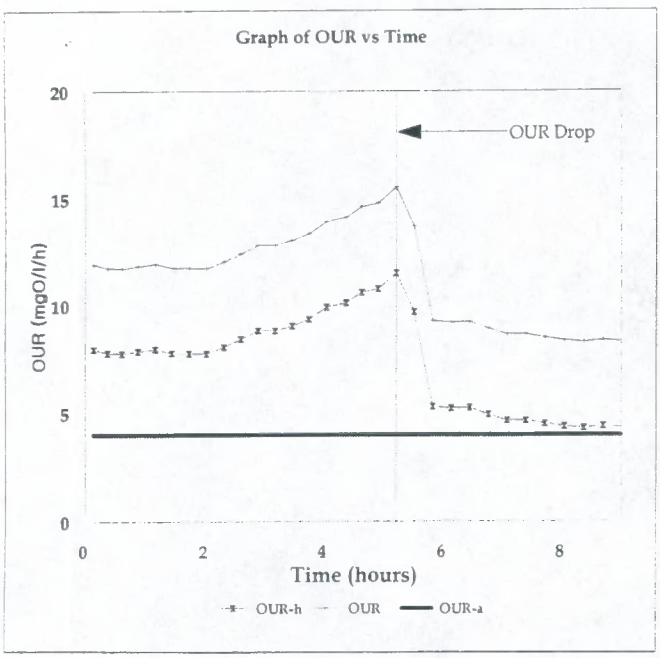
% COD Recovery		End Time=	6.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
826.56	766.08	92.10	2.57	27.77	30.34	61.76	100.15

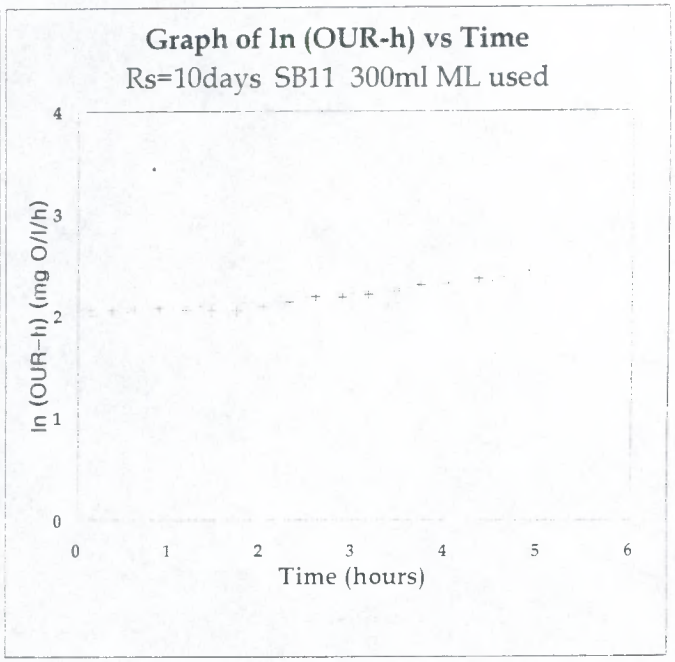
Parent System		fcv=	1.424217848	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.3680656010053	3296.888889	400	230.43302	489.39	7.51002959018	0.67	0.48	4.19

0.3906152711085	3404	400	262.38513
0.4367805894677	3160	400	272.36473
0.4020793715902	3110	400	246.75879
0.3732739806518	3192	400	235.1208
0.3434349787735	3378	400	228.93101
0.35656594976	3414	400	240.21705
0.3345372817424	3252	400	214.68194
0.3588826852155	3350	400	237.24538
0.327259329602	3412	400	220.34414

Regression Output:		
Constant		2.491671631
Std Err of Y Est		0.022763895
R Squared		0.581141386
No. of Observations		20
Degrees of Freedom		18
X Coefficient(s)	0.022088071	
Std Err of Coef.	0.004419919	





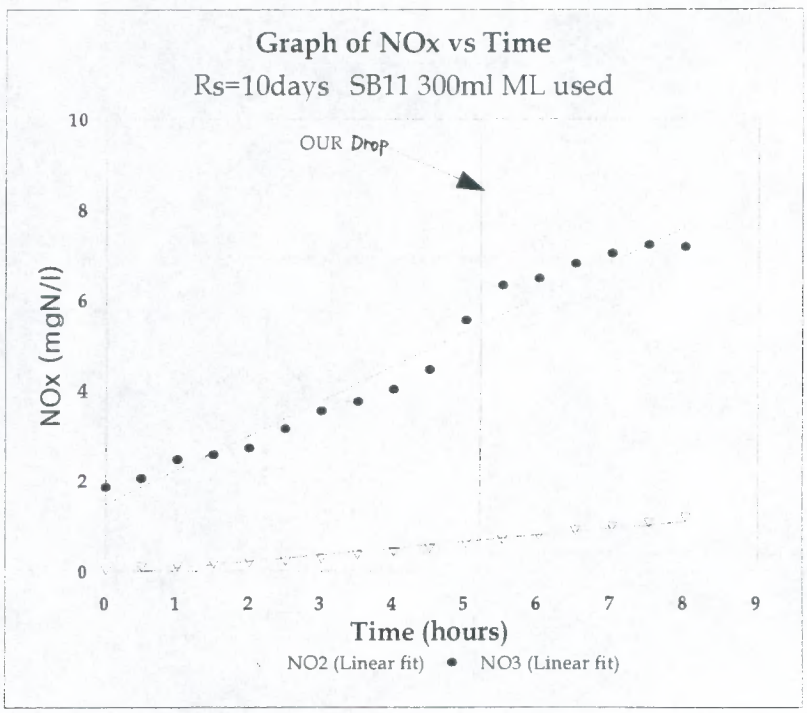


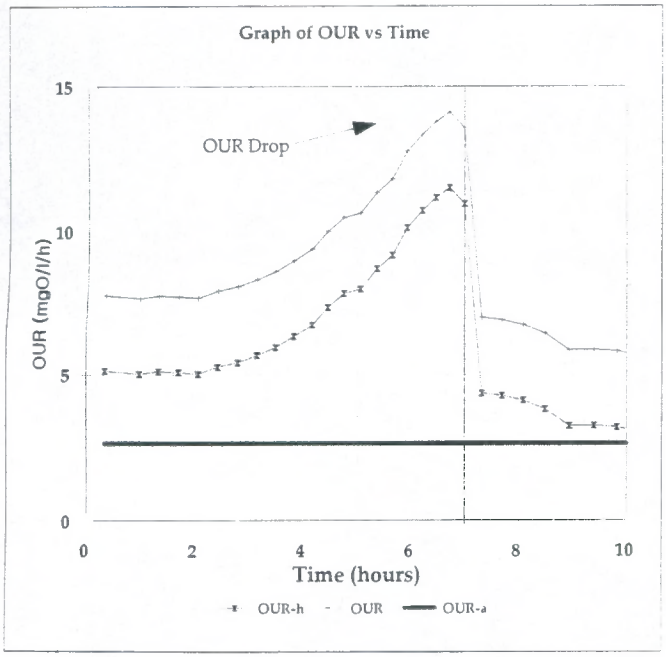
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
661.25	596.74	81.70	3.48	24.50	27.98	53.72	98.37

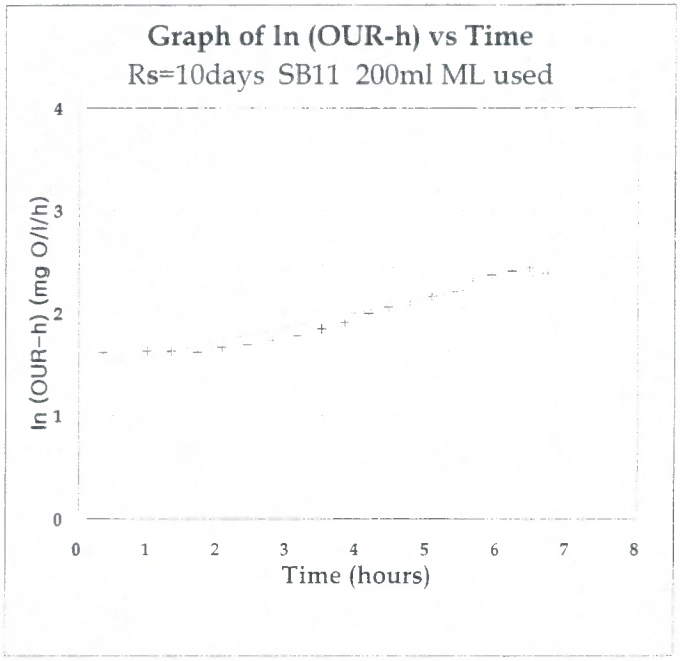
Parent System		fcv=	1.424217848	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.3680656	3296.888889	300	172.82476	136.25	5.33263706768	1.26	1.21	5.2

0.39061527	3404	300	196.78885
0.43678059	3160	300	204.27355
0.40207937	3110	300	185.06909
0.37327398	3192	300	176.3406
0.34343498	3378	300	171.69826
0.35656595	3414	300	180.16279
0.33453728	3252	300	161.01146
0.35888269	3350	300	177.93404
0.32725933	3412	300	165.25811

Regression Output:		
Constant		1.974439197
Std Err of Y Est		0.047179948
R Squared		0.877454781
No. of Observations		19
Degrees of Freedom		17
X Coefficient(s)	0.076782284	
Std Err of Coef.	0.006959409	





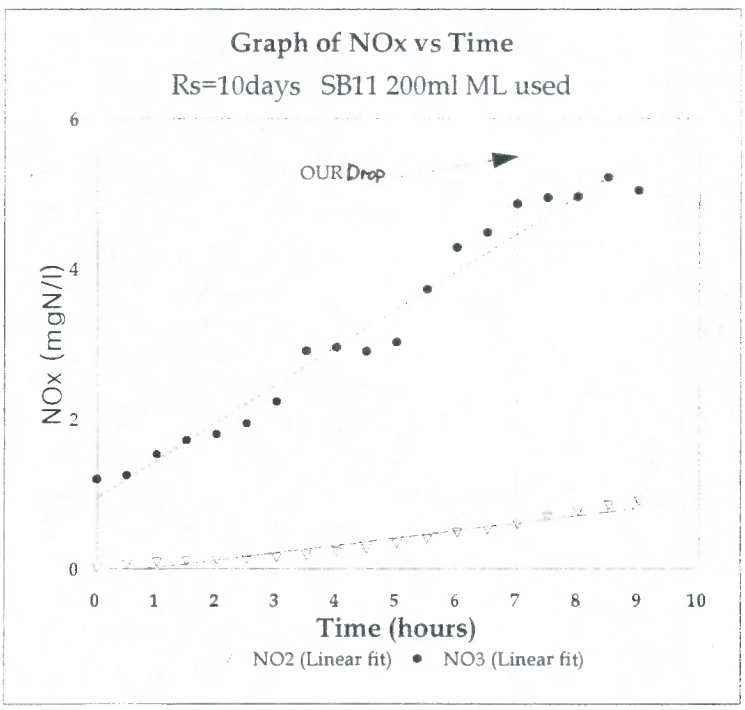


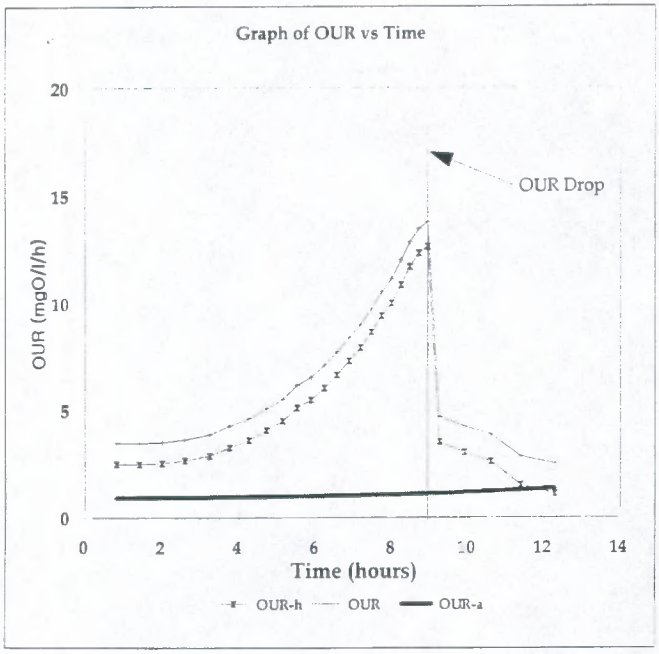
% COD Recovery		End Time=	8.00				
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Recovery
528.19	443.52	70.40	2.70	18.36	21.06	49.34	93.31

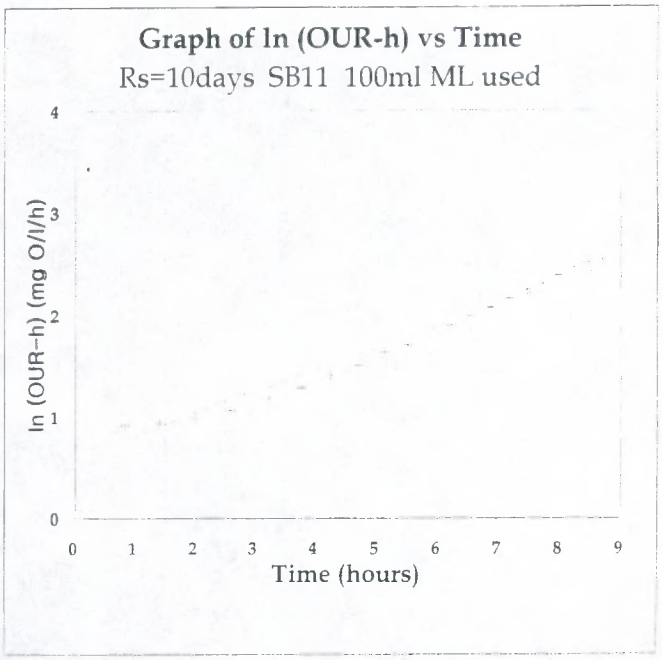
Parent System		fcv=	1.424217848	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.36806560100534	3296.888889	200	115.21651	45.02	3.92522347711	1.51	2.61	6.99

0.39061527110849	3404	200	131.19257
0.4367805894677	3160	200	136.18236
0.40207937159022	3110	200	123.3794
0.37327398065176	3192	200	117.5604
0.34343497877347	3378	200	114.4655
0.35656594976001	3414	200	120.10853
0.33453728174245	3252	200	107.34097
0.3588826852155	3350	200	118.62269
0.32725932960203	3412	200	110.17207

Regression Output:		
Constant		1.381013799
Std Err of Y Est		0.085089606
R Squared		0.925895462
No. of Observations		21
Degrees of Freedom		19
X Coefficient(s)	0.145745259	
Std Err of Coef.	0.009459301	







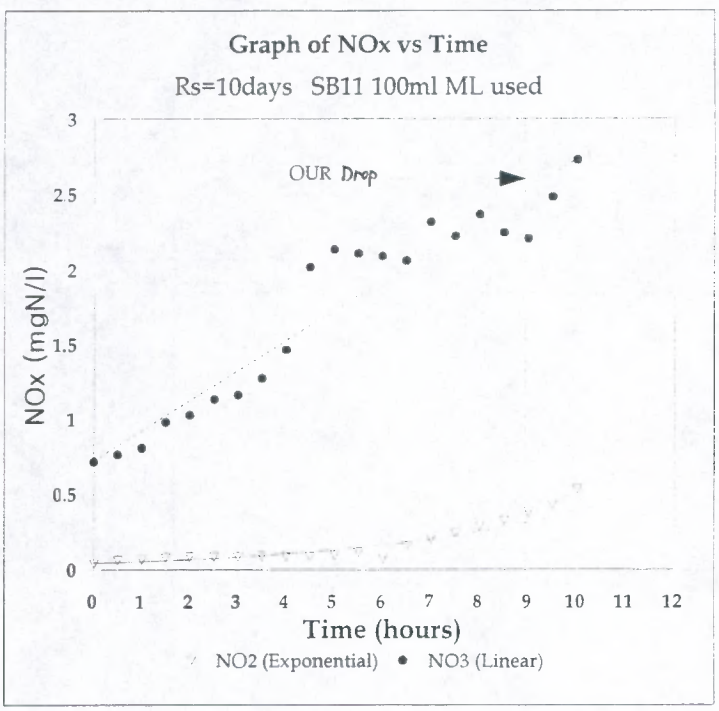
% COD Recovery		End Time=	9.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
370.94	290.30	55.10	1.06	8.74	9.80	45.30	90.47

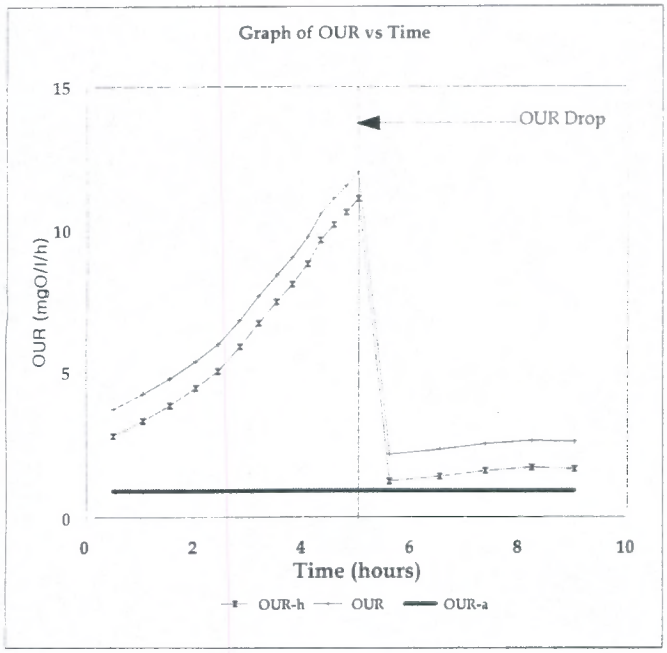
Parent System		fcv=	1.424217848	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.36806560100534	3296.888889	100	57.608254	12.23	3.56164544645	1.86	4.16	8.93

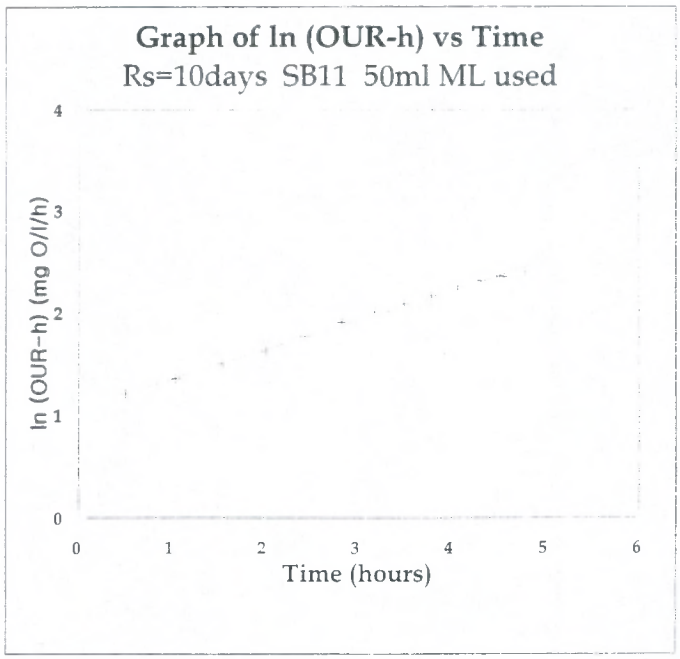
0.390615271108488	3404	100	65.596283
0.4367805894677	3160	100	68.091182
0.402079371590219	3110	100	61.689698
0.373273980651758	3192	100	58.7802
0.343434978773466	3378	100	57.232752
0.356565949760015	3414	100	60.054264
0.334537281742449	3252	100	53.670485
0.358882685215503	3350	100	59.311345
0.327259329602033	3412	100	55.086036

Regression Output:

Constant		0.458820093
Std Err of Y Est		0.1050392
R Squared		0.967348945
No. of Observations		22
Degrees of Freedom		20
X Coefficient(s)	0.225267074	
Std Err of Coef.	0.009254218	





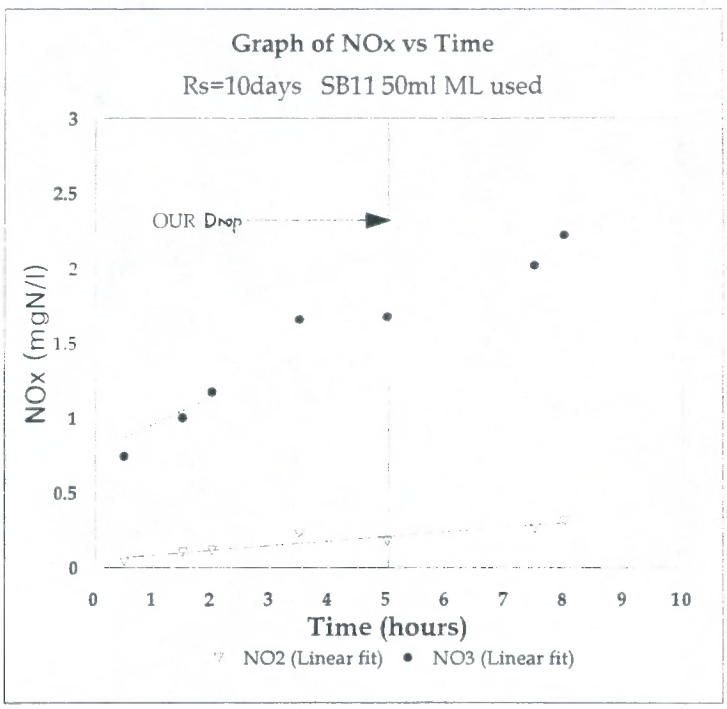


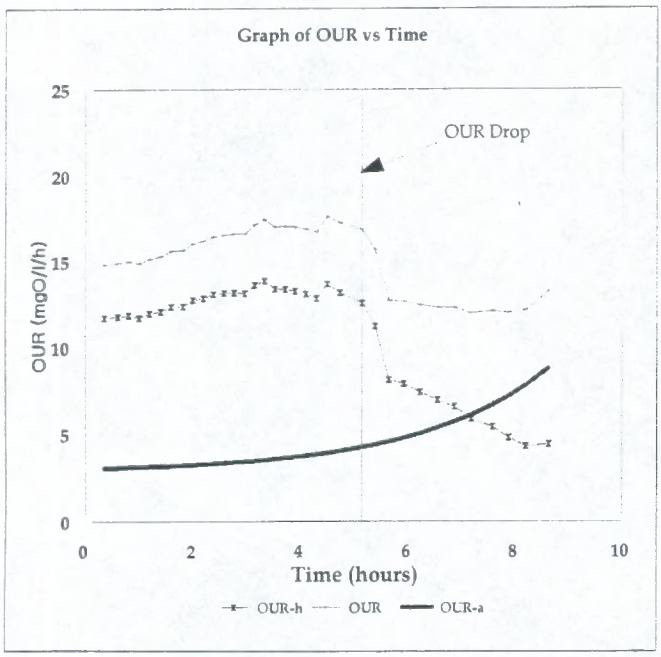
% COD Recovery		End Time=	6.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
235.87	171.36	36.50	0.69	5.35	6.04	30.46	85.56

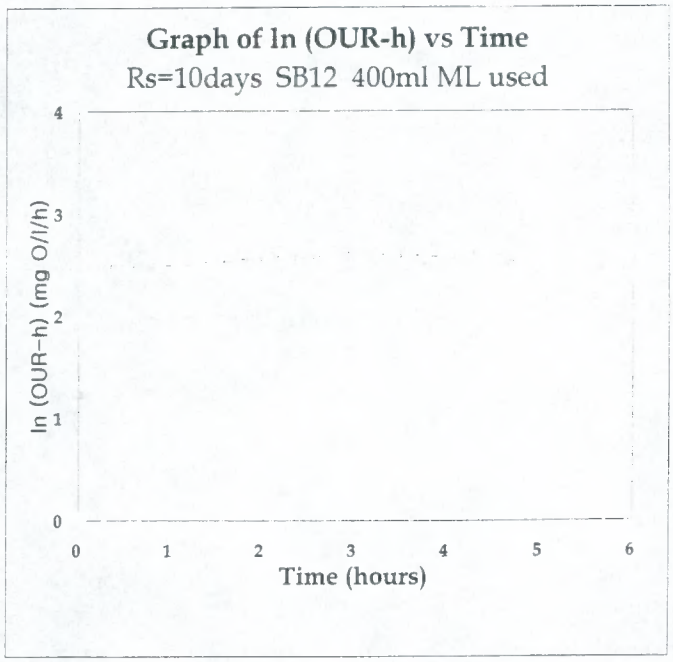
Parent System		fcv=	1.424217848	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.36806560100534	3296.888889	50	28.804127	13.70	1.25108870694	0.90	7.28	5.02

0.390615271108488	3404	50	32.798141
0.4367805894677	3160	50	34.045591
0.402079371590219	3110	50	30.844849
0.373273980651758	3192	50	29.3901
0.343434978773466	3378	50	28.616376
0.356565949760015	3414	50	30.027132
0.334537281742449	3252	50	26.835243
0.358882685215503	3350	50	29.655673
0.327259329602033	3412	50	27.543018

Regression Output:		
Constant		0.878182865
Std Err of Y Est		0.024399679
R Squared		0.997318843
No. of Observations		14
Degrees of Freedom		12
X Coefficient(s)	0.315094463	
Std Err of Coef.	0.004716223	





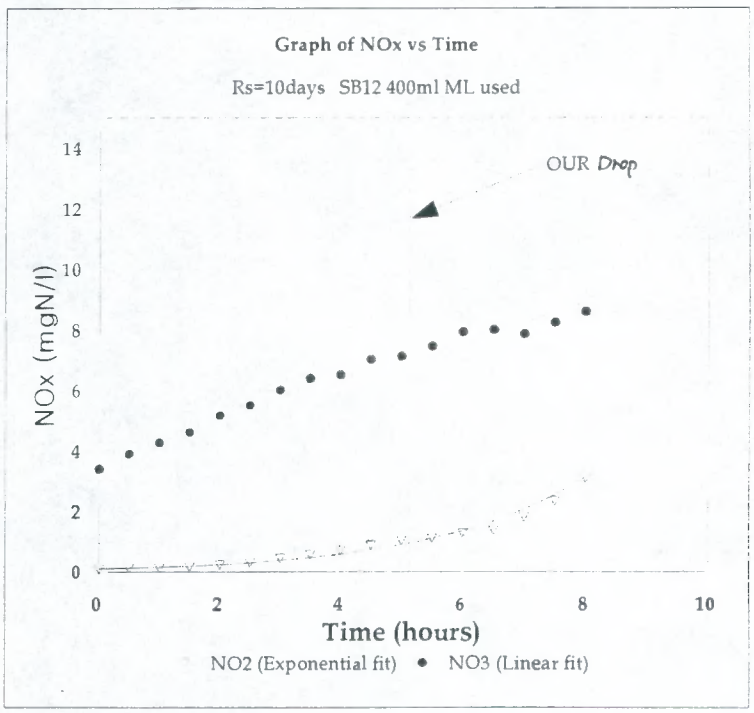


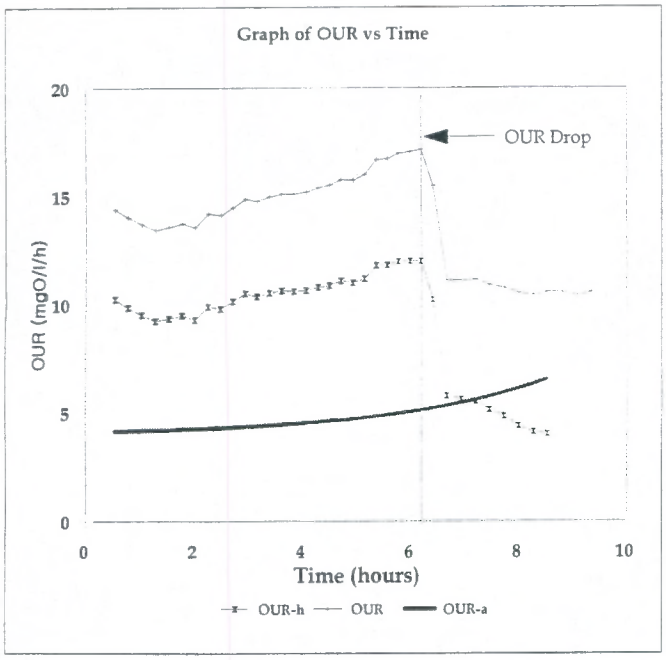
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
813.44	753.92	101.30	6.74	20.43	27.17	74.13	101.80

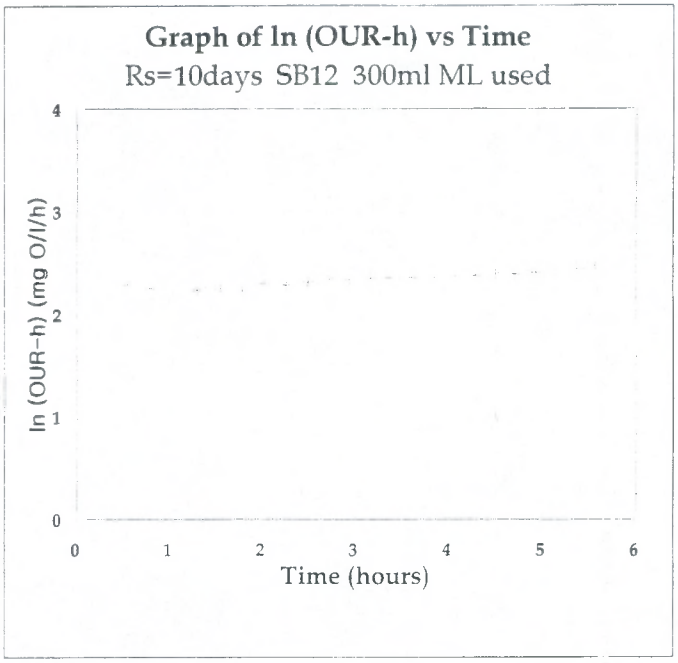
Parent System		fcv=	1.398255122	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.3744907781318	3343.5	400	233.43588	421.56	8.19952617118	0.80	0.51	5.13

0.325766584416	3298	400	212.01063
0.3545854929965	3510	400	245.6001
0.3444360528164	3444	400	234.08425
0.4170722936844	3244	400	266.98855
0.4714023315314	3148	400	292.83764
0.3935747057854	3326	400	258.31515
0.330620233603	3436	400	224.17286
0.3754316988097	3342	400	247.5927

Regression Output:	
Constant	2.476165753
Std Err of Y Est	0.033999159
R Squared	0.594078844
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	0.028942368
Std Err of Coef.	0.005100603







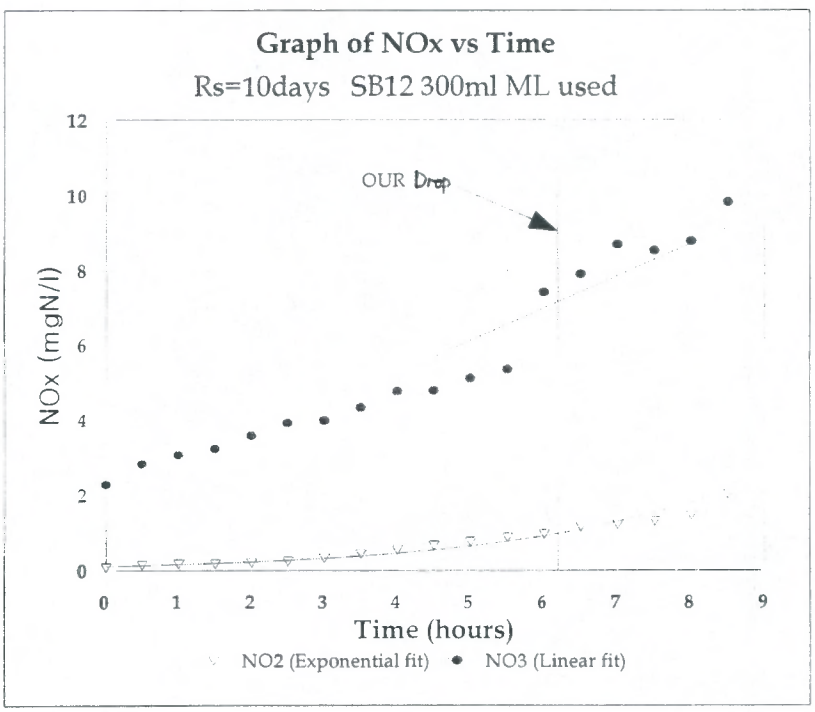
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
738.05	622.98	94.60	4.05	27.86	31.90	62.70	92.90

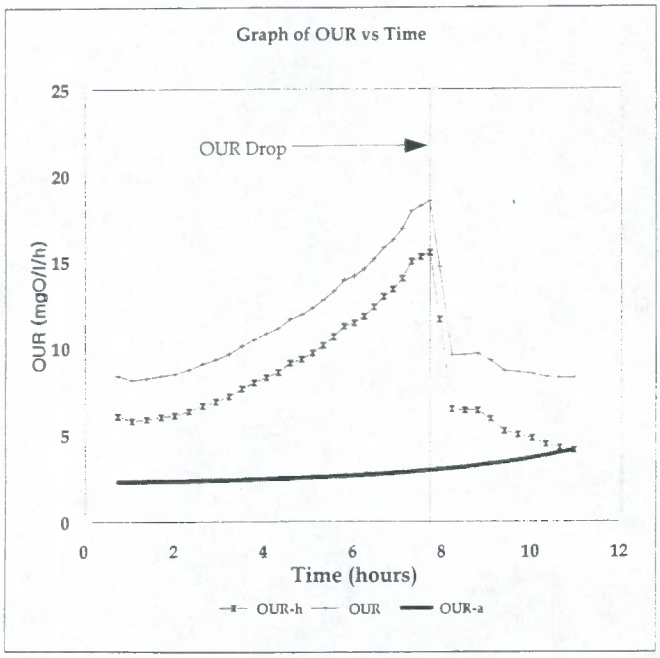
Parent System		fcv=	1.398255122	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.37449078	3343.5	300	175.07691	251.98	5.79169922552	0.84	0.84	6.19

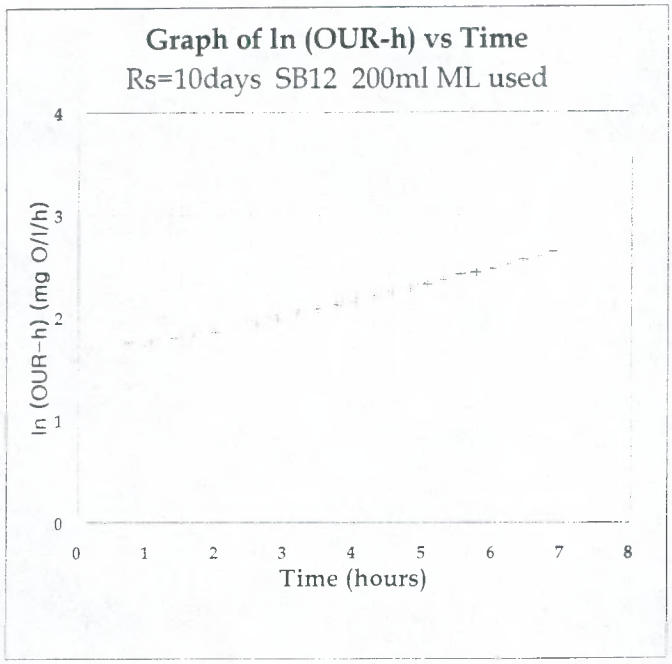
0.32576658	3298	300	159.00797
0.35458549	3510	300	184.20007
0.34443605	3444	300	175.56319
0.41707229	3244	300	200.24141
0.47140233	3148	300	219.62823
0.39357471	3326	300	193.73636
0.33062023	3436	300	168.12965
0.3754317	3342	300	185.69453

Regression Output:

Constant	2.203303852
Std Err of Y Est	0.032111583
R Squared	0.852425995
No. of Observations	26
Degrees of Freedom	24
X Coefficient(s)	0.043923332
Std Err of Coef.	0.003730493





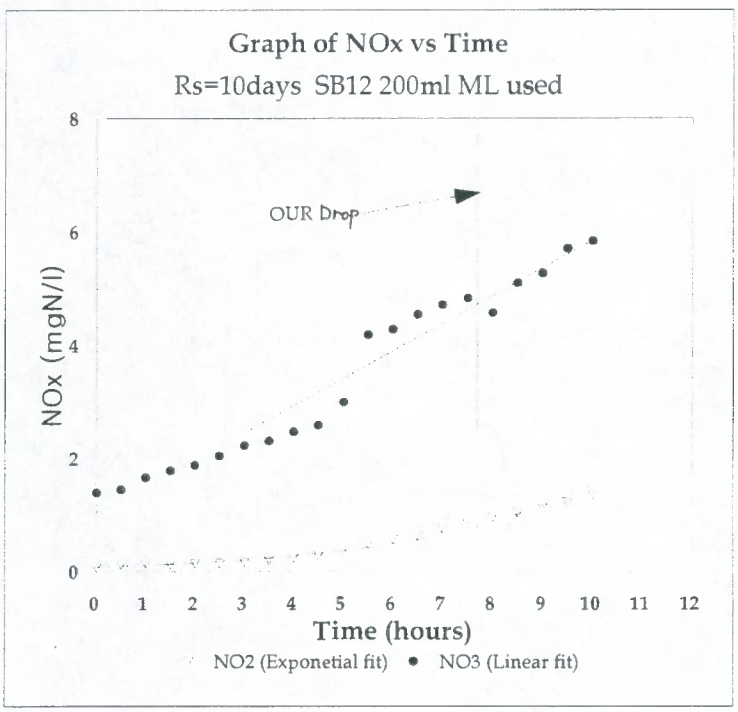


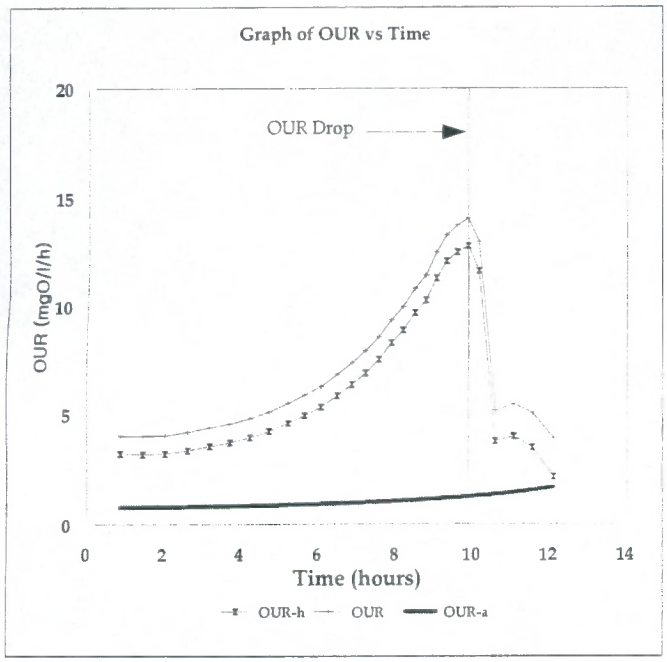
% COD Recovery		End Time=	8.00				
COD t=o	COD$t=_T$	MOt	MOno2	MOno3	MOn	MOc	% Recovery
503.94	404.74	85.80	2.70	17.75	20.45	65.35	93.28

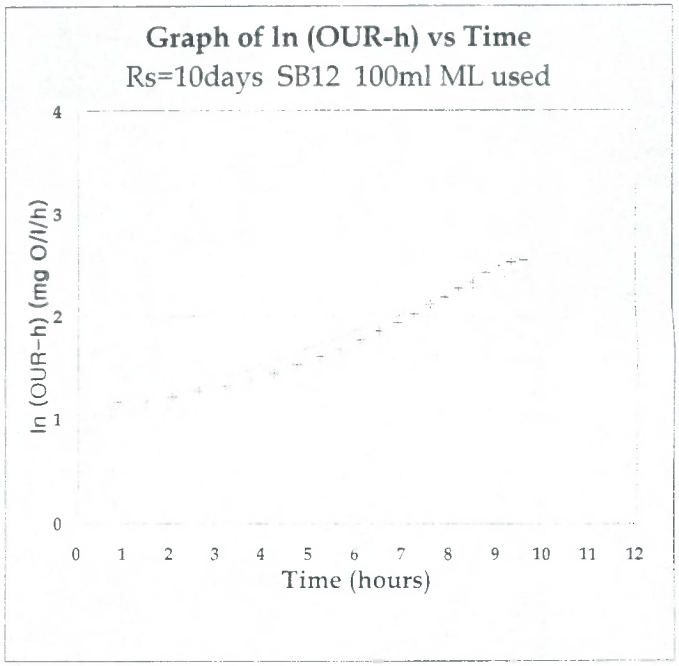
Parent System		fcv=	1.398255122	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.37449077813184	3343.5	200	116.71794	50.70	6.50589267099	1.90	2.38	7.69

0.32576658441596	3298	200	106.00532
0.3545854929965	3510	200	122.80005
0.34443605281643	3444	200	117.04213
0.41707229368436	3244	200	133.49428
0.47140233153141	3148	200	146.41882
0.39357470578537	3326	200	129.15757
0.33062023360303	3436	200	112.08643
0.37543169880967	3342	200	123.79635

Regression Output:		
Constant		1.538112683
Std Err of Y Est		0.044776017
R Squared		0.981754054
No. of Observations		28
Degrees of Freedom		26
X Coefficient(s)	0.152416842	
Std Err of Coef.	0.004075005	







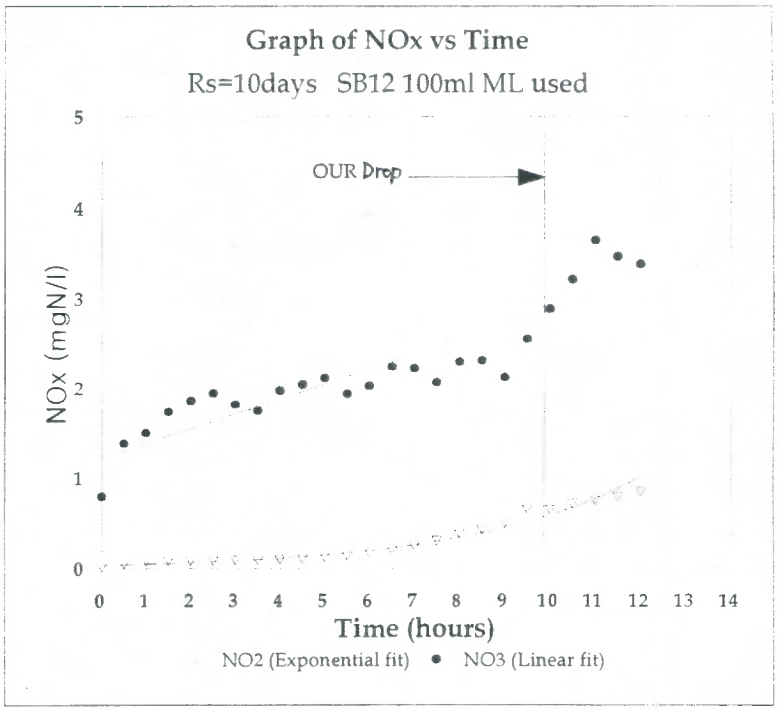
% COD Recovery		End Time=	11.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
370.00	282.00	69.60	2.52	8.34	10.86	58.74	92.09

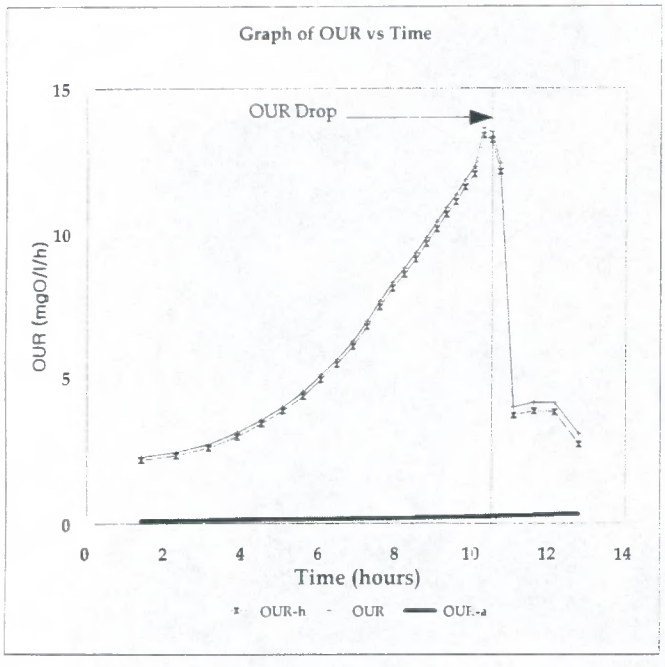
Parent System		fcv=	1.398255122	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.374490778131838	3343.5	100	58.35897	20.88	3.79567339229	1.58	3.18	9.87

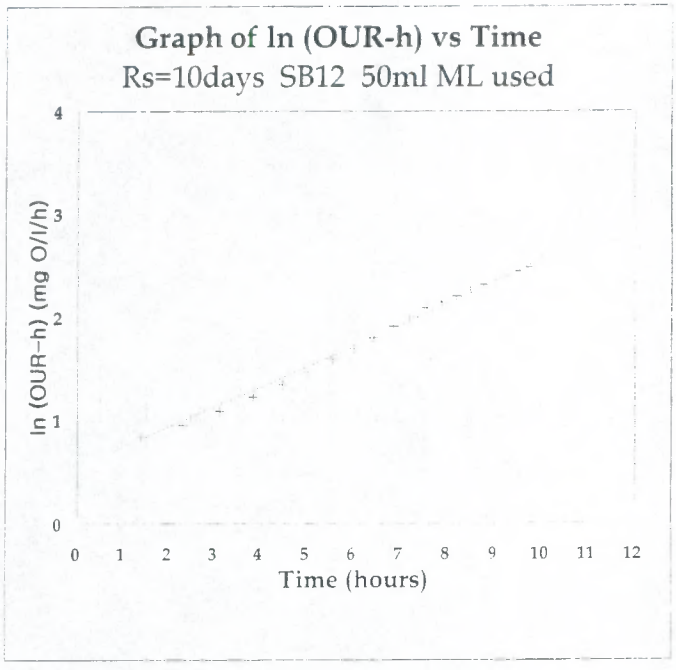
0.325766584415963	3298	100	53.002658
0.354585492996503	3510	100	61.400024
0.344436052816429	3444	100	58.521063
0.417072293684358	3244	100	66.747138
0.471402331531408	3148	100	73.209411
0.393574705785369	3326	100	64.578787
0.33062023360303	3436	100	56.043215
0.37543169880967	3342	100	61.898175

Regression Output:

Constant		0.75848642
Std Err of Y Est		0.111684223
R Squared		0.950287758
No. of Observations		23
Degrees of Freedom		21
X Coefficient(s)	0.172642172	
Std Err of Coef.	0.008616708	





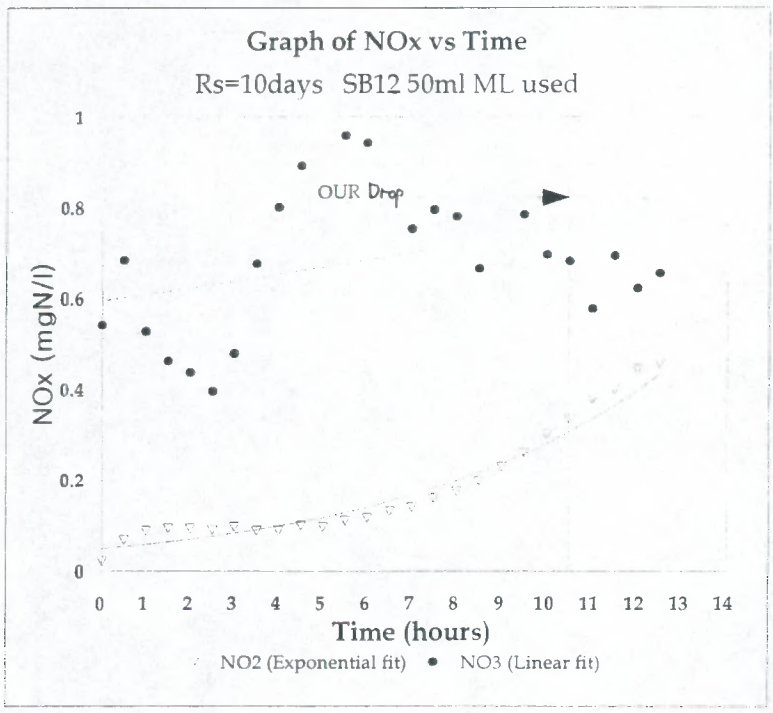


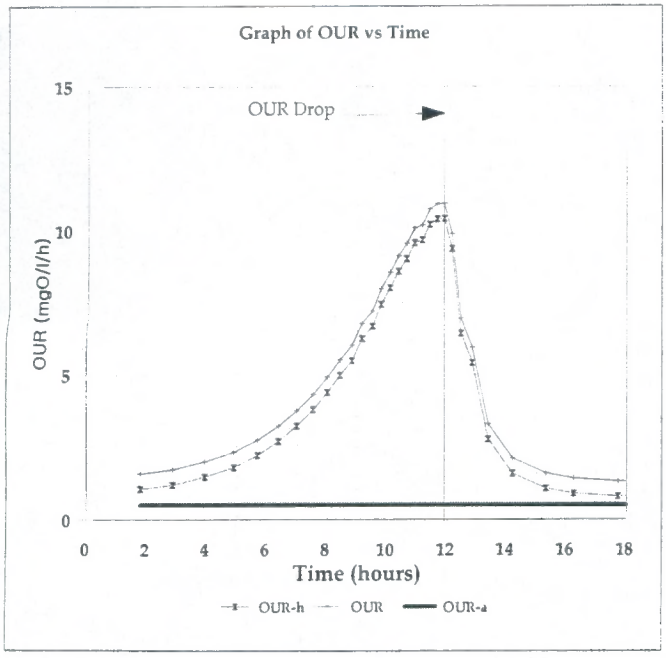
% COD Recovery		End Time=	12.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
314.00	200.00	63.30	1.19	0.89	2.08	61.22	83.19

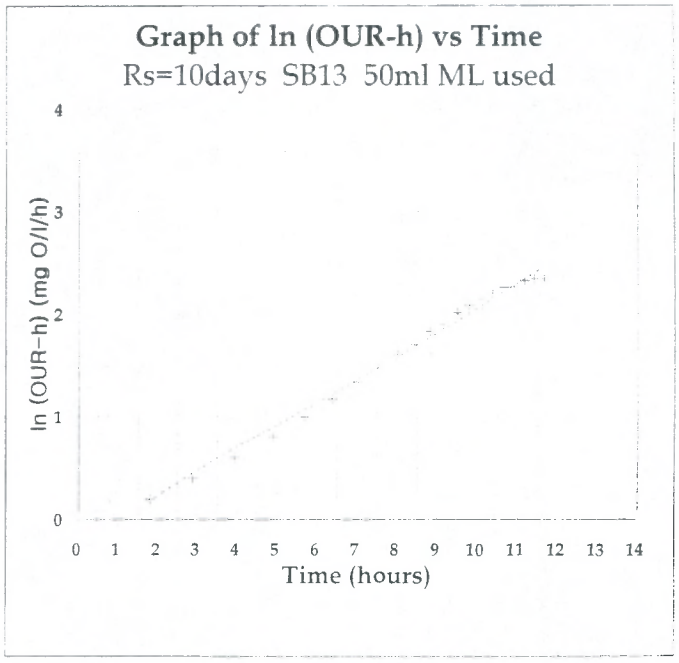
Parent System		fcv=	1.398255122	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.374490778131838	3343.5	50	29.179485	10.67	3.72735765888	1.65	4.28	10.48

0.325766584415963	3298	50	26.501329
0.354585492996503	3510	50	30.700012
0.344436052816429	3444	50	29.260532
0.417072293684358	3244	50	33.373569
0.471402331531408	3148	50	36.604705
0.393574705785369	3326	50	32.289394
0.33062023360303	3436	50	28.021608
0.37543169880967	3342	50	30.949088

Regression Output:		
Constant		0.305802578
Std Err of Y Est		0.054313518
R Squared		0.991620443
No. of Observations		22
Degrees of Freedom		20
X Coefficient(s)	0.221115611	
Std Err of Coef.	0.004545087	





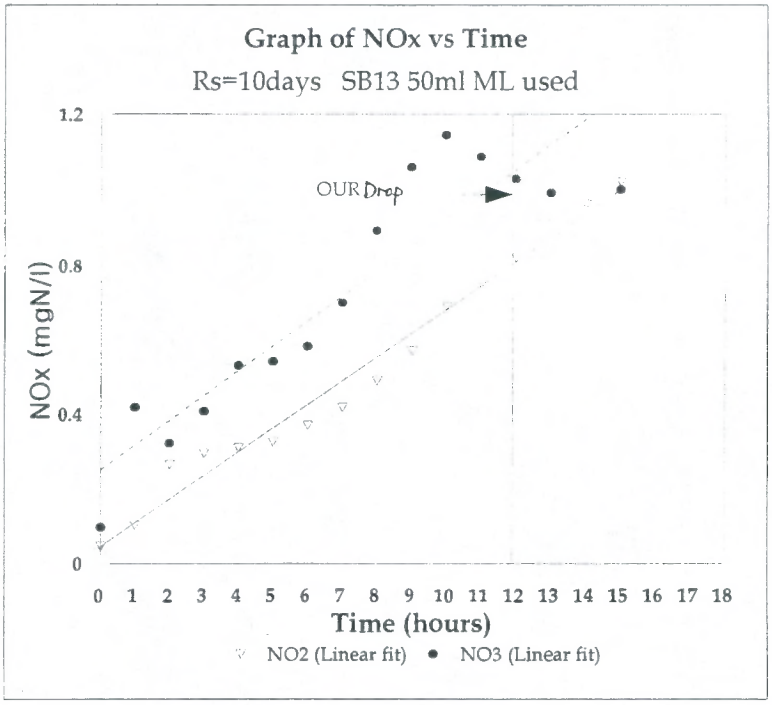


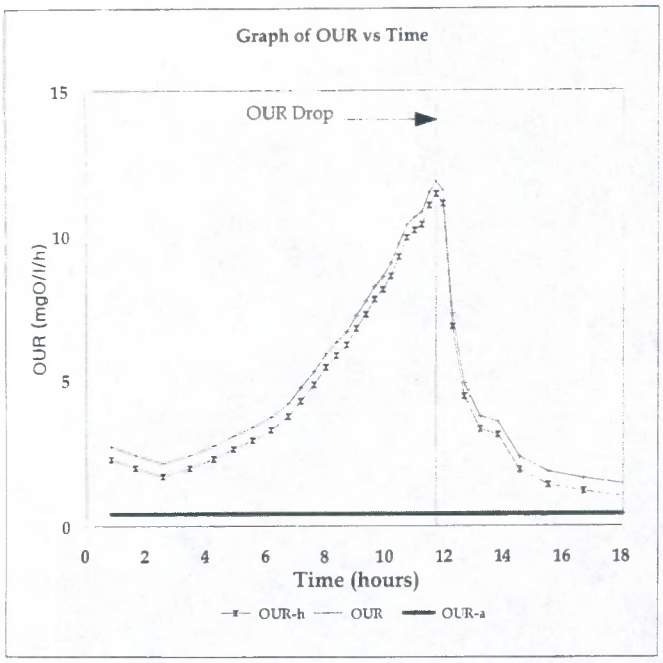
% COD Recovery		End Time=	14.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
279.44	177.64	53.70	3.06	4.28	7.34	46.36	80.16

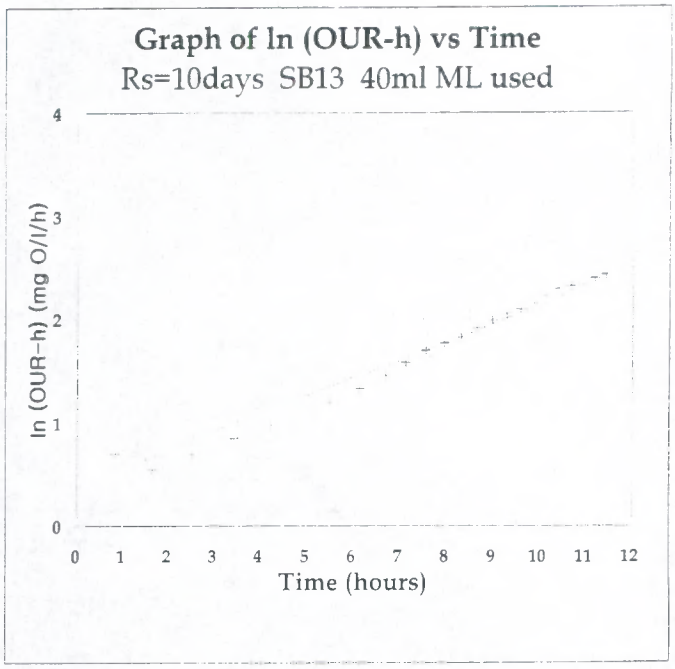
Parent System		fcv=	1.354532638	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.455764987166789	3196.666667	50	32.890959	4.09	1.09587463733	0.64	6.03	11.908

0.506153381132806	3038	50	37.929785
0.456593522996536	3100	50	34.914185
0.410755370080843	3452	50	34.975546

Regression Output:		
Constant		-0.53550177
Std Err of Y Est		0.070377681
R Squared		0.991516701
No. of Observations		22
Degrees of Freedom		20
X Coefficient(s)	0.252165846	
Std Err of Coef.	0.005215592	





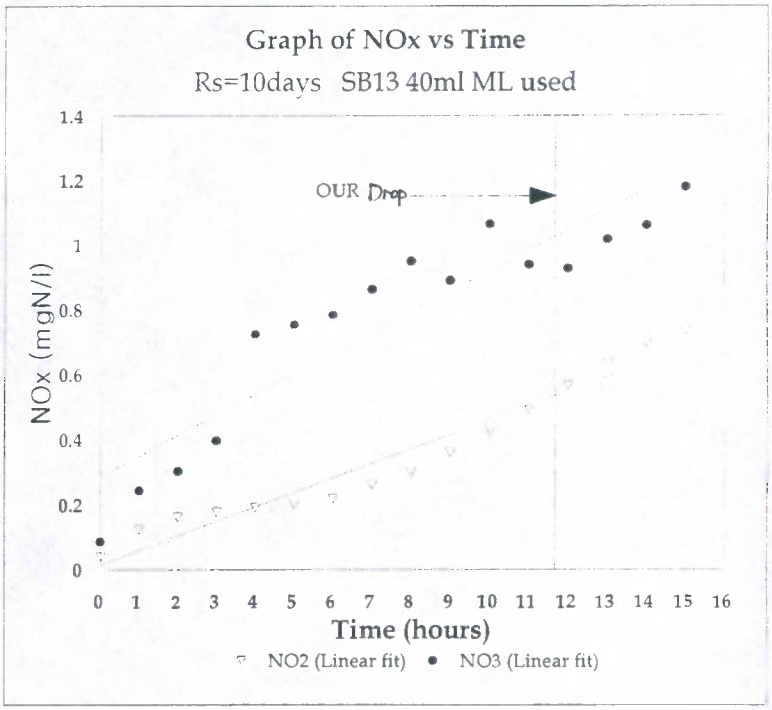


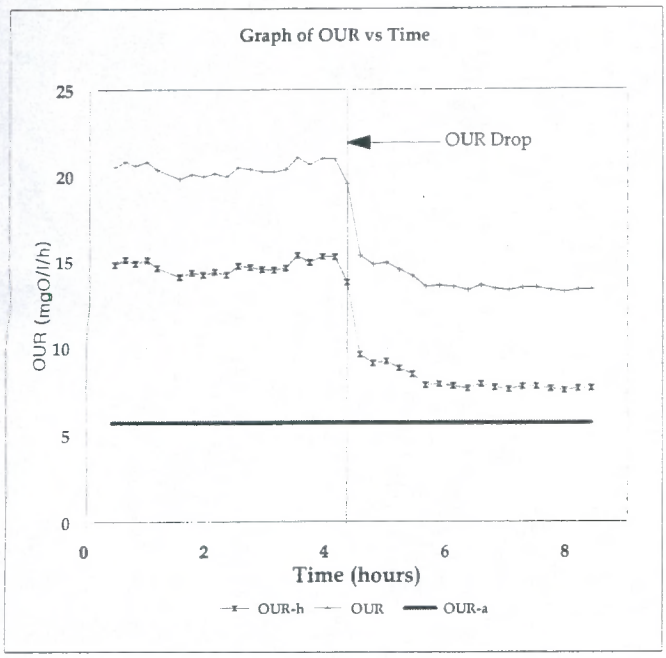
% COD Recovery		End Time=	14.00				
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Recovery
285.43	181.64	68.00	2.14	4.06	6.20	61.80	85.29

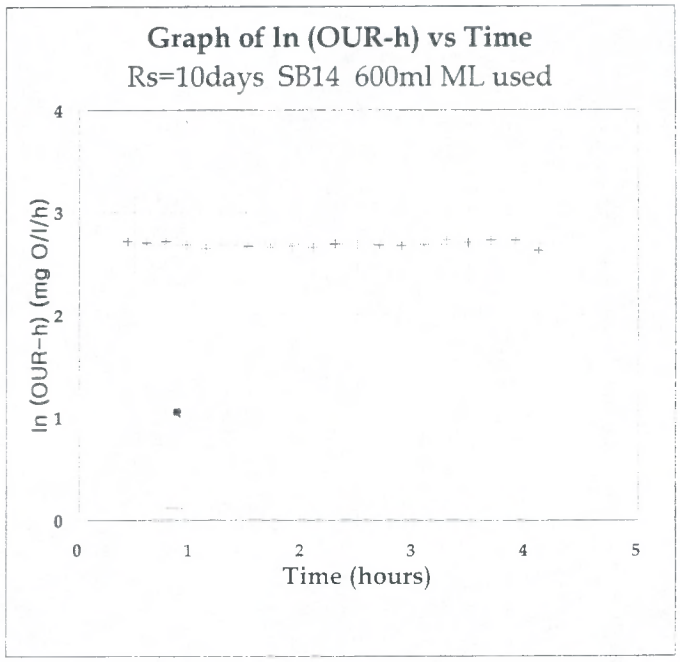
Parent System		fcv=	1.354532638	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.455764987166789	3196.666667	40	26.312767	11.01	3.31687577196	1.59	3.56	11.668

0.506153381132806	3038	40	30.343828
0.456593522996536	3100	40	27.931348
0.410755370080843	3452	40	27.980437

Regression Output:		
Constant		0.196751448
Std Err of Y Est		0.139754033
R Squared		0.951161066
No. of Observations		25
Degrees of Freedom		23
X Coefficient(s)	0.188860083	
Std Err of Coef.	0.00892344	



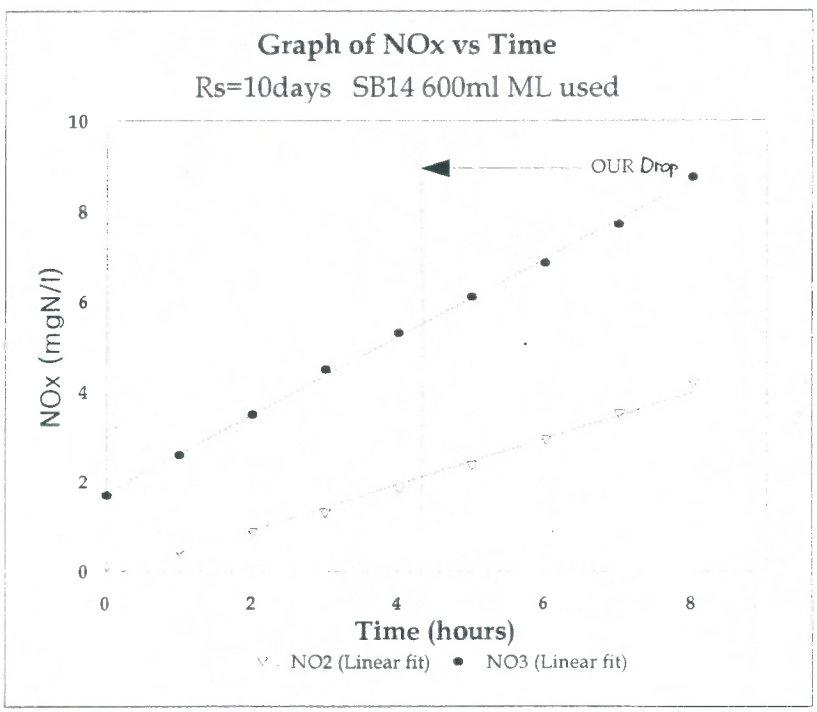


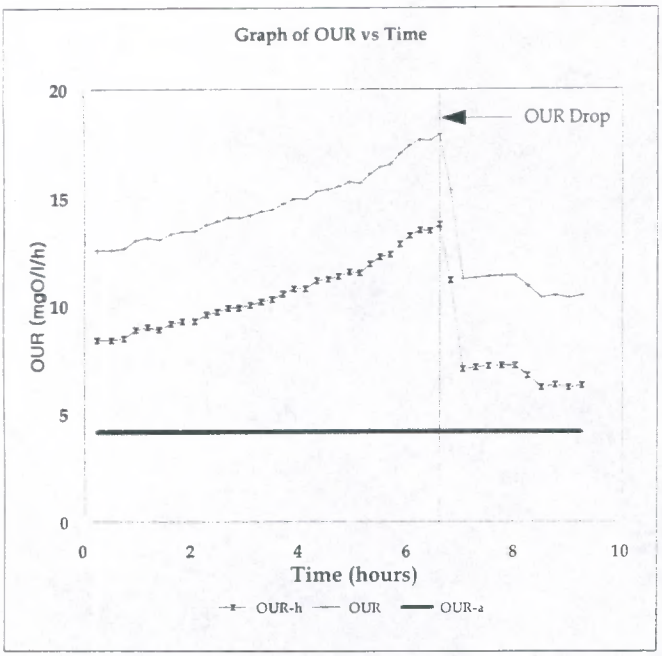


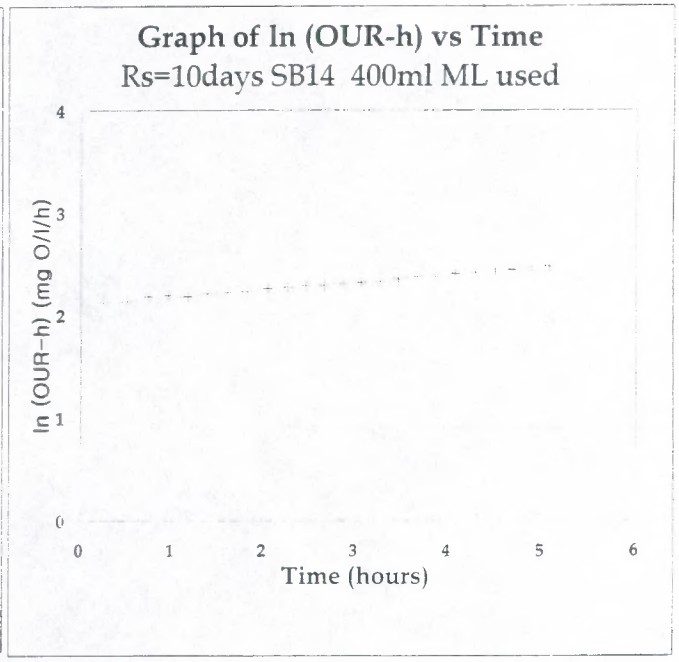
% COD Recovery		End Time=	8.00					CODfilt.	241.92	
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery	So(mgCOD/	Xo(mgMLVSS/l)	So/Xo
888.00	764.00	138.00	14.01	31.66	45.67	92.33	96.43	193.54	496.27	0.38998
								So(mgCOD/	Xo(mgMLAVSS/	So/Xo
Parent System		fcv=	1.389	Batch Result				193.54	190.90	1.01381
fav	Xv	VML	ZBH(Theo),BT	ZBH(O)	OURSBCOD	KMP	UH	t=s		
0.385	2481.333333	600	265.18635	1093.79	9.66151069587	0.42	0.20	4.32		

0.378	2450	600	273.95657
0.390	2398	600	277.08834
0.359	2456	600	260.90316
0.431	2416	600	308.56574
0.402	2464	600	293.26052
0.384	2526	600	287.4748
0.398	2476	600	292.01415
0.361	2576	600	275.1249
0.360	2570	600	274.05643

Regression Output:		
Constant		2.687834873
Std Err of Y Est		0.029639162
R Squared		0.000115931
No. of Observations		20
Degrees of Freedom		18
X Coefficient(s)	0.000254696	
Std Err of Coef.	0.005575198	





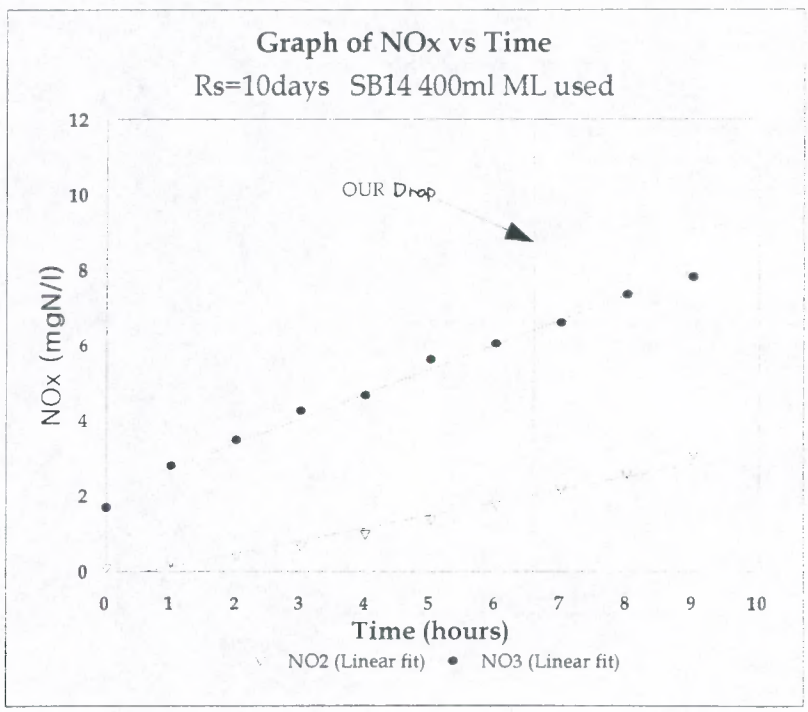


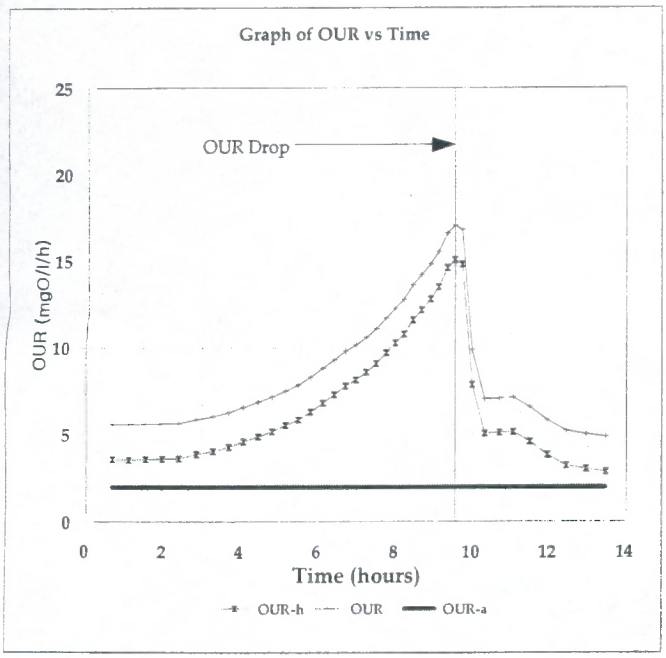
% COD Recovery		End Time=	9.00					CODfilt.	236	
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery	So(mgCOD/l	Xo(mgMLVSS/l	So/Xo
668.00	564.00	119.00	10.44	27.07	37.51	81.49	96.63	204.53	330.84	0.618216
								So(mgCOD/l	Xo(mgMLAVSS/l	So/Xo
								204.53	127.27	1.607126

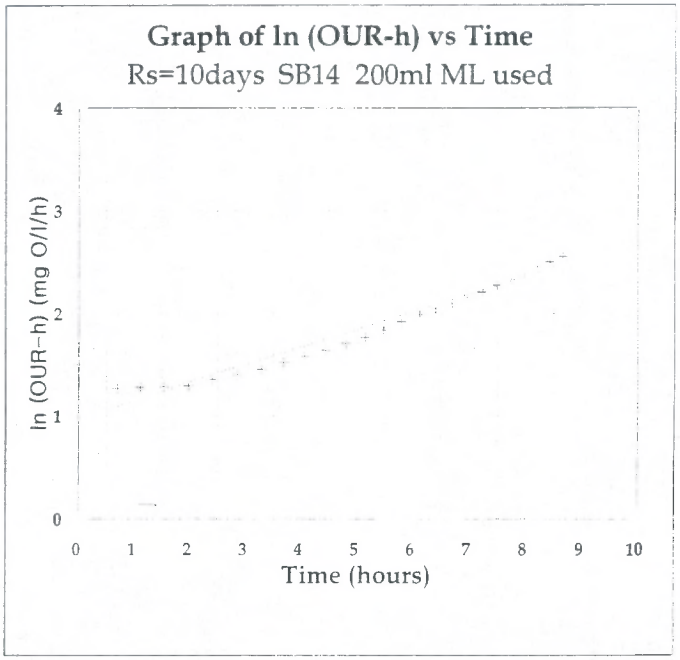
Parent System		fcv=	1.389	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.385	2481.333333	400	176.7909	150.84	7.08234273836	1.35	1.14	6.57

0.378	2450	400	182.63771
0.390	2398	400	184.72556
0.359	2456	400	173.93544
0.431	2416	400	205.71049
0.402	2464	400	195.50701
0.384	2526	400	191.64987
0.398	2476	400	194.6761
0.361	2576	400	183.4166
0.360	2570	400	182.70429

Regression Output:	
Constant	2.084865375
Std Err of Y Est	0.018700855
R Squared	0.984761074
No. of Observations	32
Degrees of Freedom	30
X Coefficient(s)	0.077677193
Std Err of Coef.	0.001764187







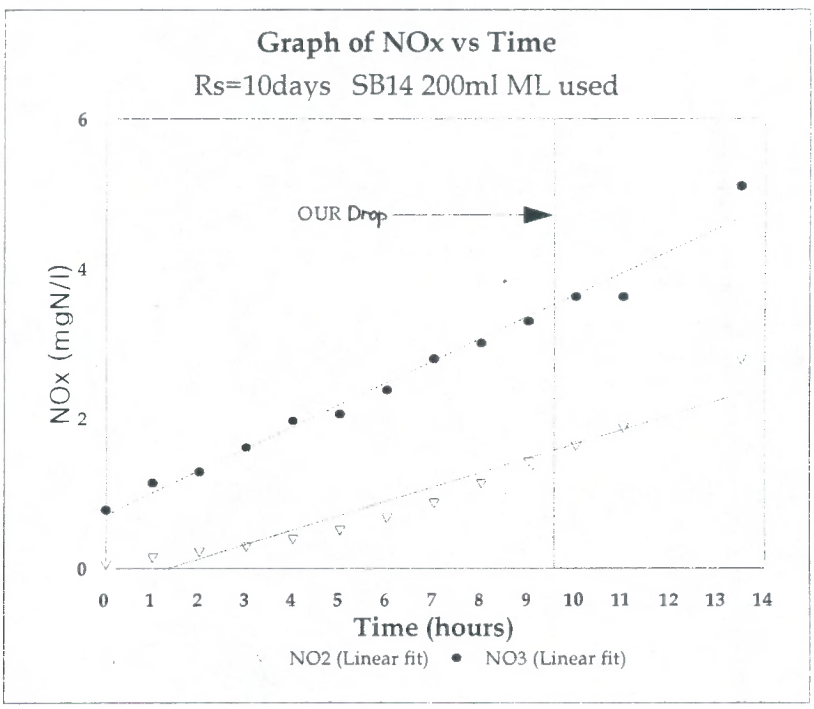
% COD Recovery		End Time=	10.50					$COD_{filt.}$	225.792	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Recov.	So(mgCOD/	Xo(mgMLVSS/l)	So/Xo
433.44	350.78	86.60	6.88	14.14	21.02	65.58	96.06	210.7392	165.42222222222	1.27395
								So(mgCOD/	Xo(mgMLAVSS/	So/Xo
								210.7392	63.633257823951	3.31178

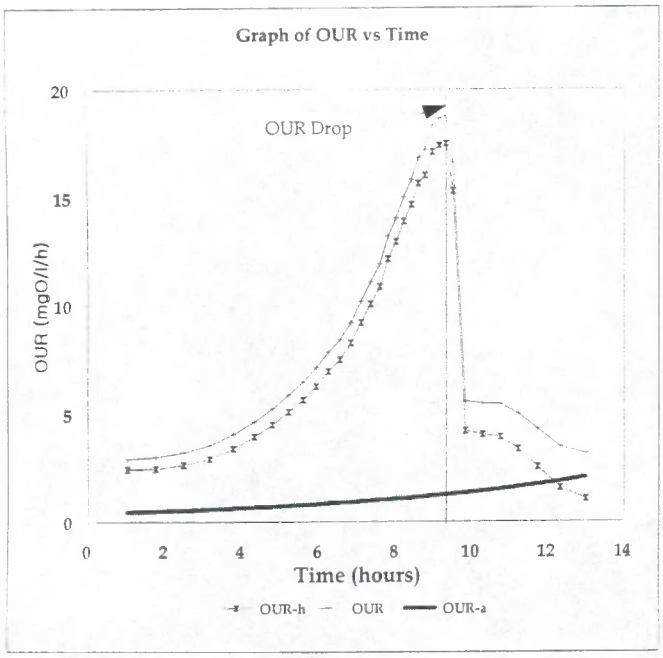
Parent System		fcv=	1.389	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.385	2481.333333	200	88.395451	23.29	5.05809296928	1.90	3.00	9.538

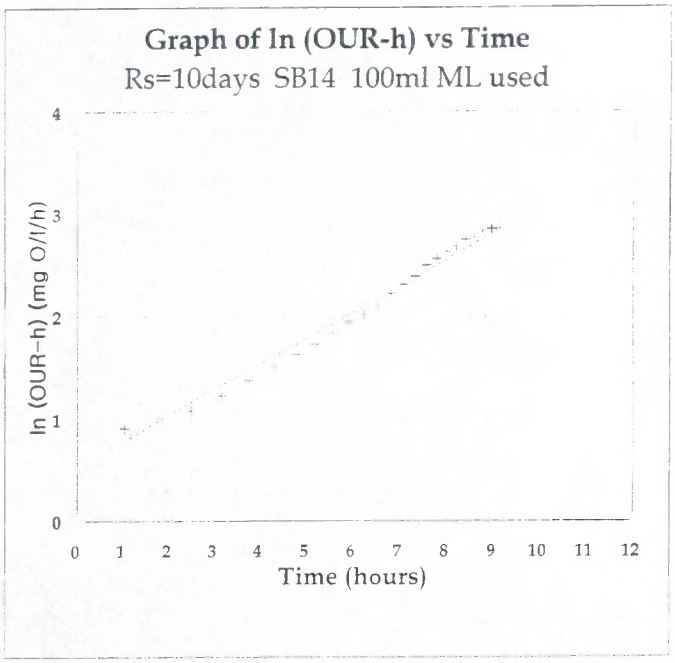
0.378	2450	200	91.318856
0.390	2398	200	92.362779
0.359	2456	200	86.967719
0.431	2416	200	102.85525
0.402	2464	200	97.753505
0.384	2526	200	95.824933
0.398	2476	200	97.338051
0.361	2576	200	91.708299
0.360	2570	200	91.352144

Regression Output:

Constant	0.89554114
Std Err of Y Est	0.096625143
R Squared	0.962254125
No. of Observations	29
Degrees of Freedom	27
X Coefficient(s)	0.17824437
Std Err of Coef.	0.006793973







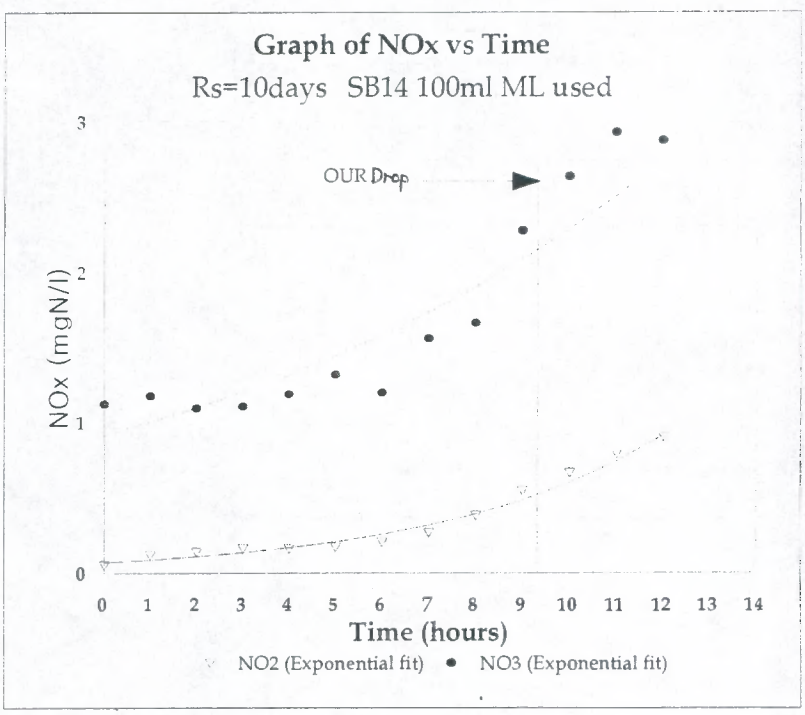
% COD Recovery		End Time=	12.00					$COD_{filt.}$	239.904	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Recov.	So(mgCOD/	Xo(mgMLVSS/l)	So/Xo
344.74	227.81	80.60	2.90	8.40	11.29	69.31	86.19	231.9072	82.71111111111	2.8038
								So(mgCOD/	Xo(mgMLAVSS/	So/Xo
								231.9072	31.81662891198	7.2889

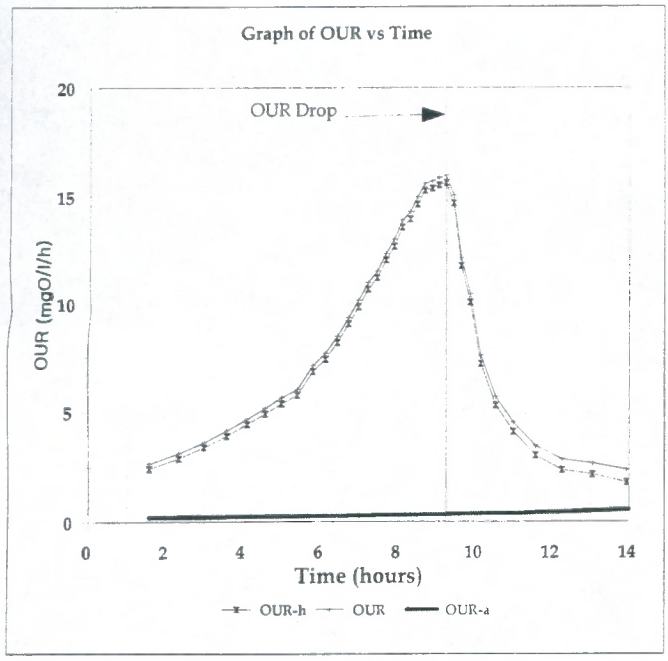
Parent System		fcv=	1.389	Batch Result				
fav	Xv	V_{ML}	$Z_{3H(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.385	2481.333333	100	44.197726	8.72	4.23455788798	1.79	5.42	9.32

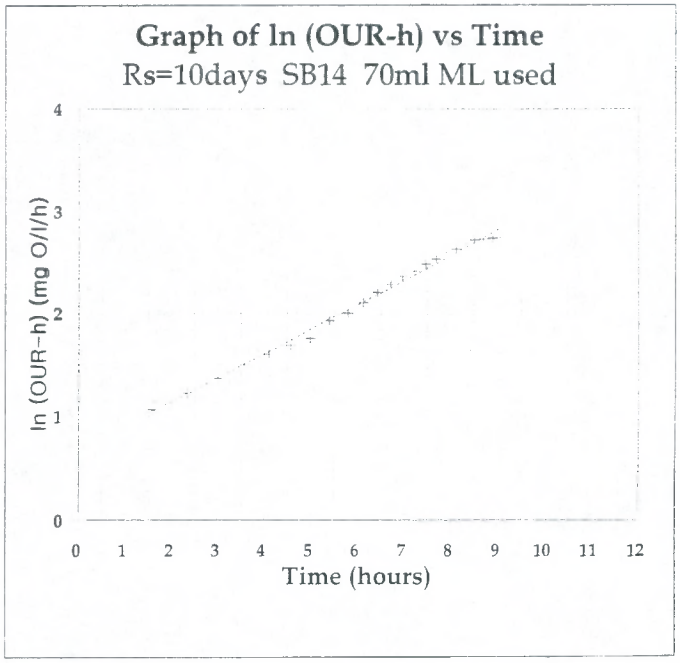
0.378	2450	100	45.659428
0.390	2398	100	46.181389
0.359	2456	100	43.48386
0.431	2416	100	51.427624
0.402	2464	100	48.876753
0.384	2526	100	47.912467
0.398	2476	100	48.669025
0.361	2576	100	45.85415
0.360	2570	100	45.676072

Regression Output:

Constant	0.300615496
Std Err of Y Est	0.101445933
R Squared	0.978090177
No. of Observations	25
Degrees of Freedom	23
X Coefficient(s)	0.274837822
Std Err of Coef.	0.008577141





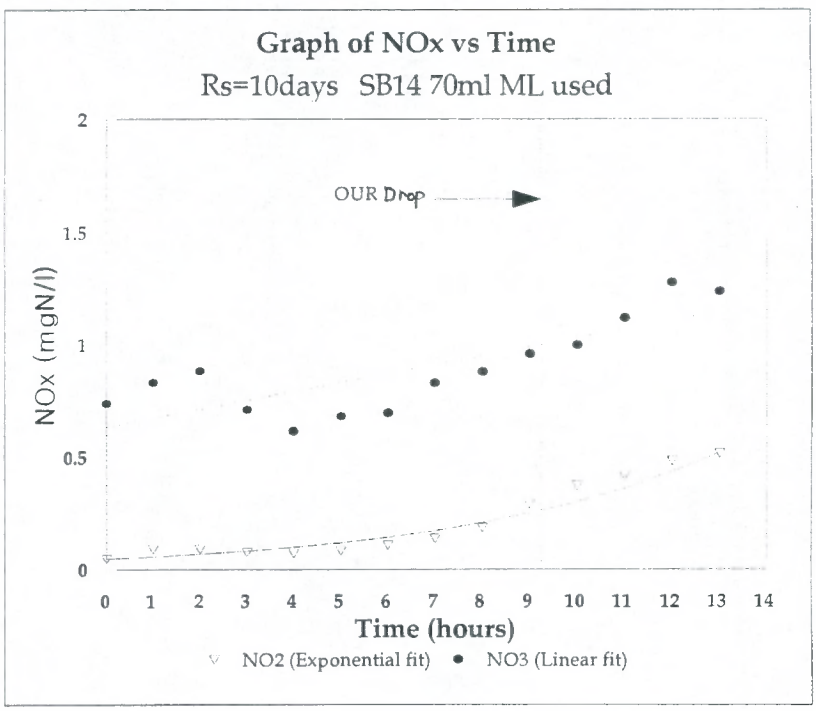


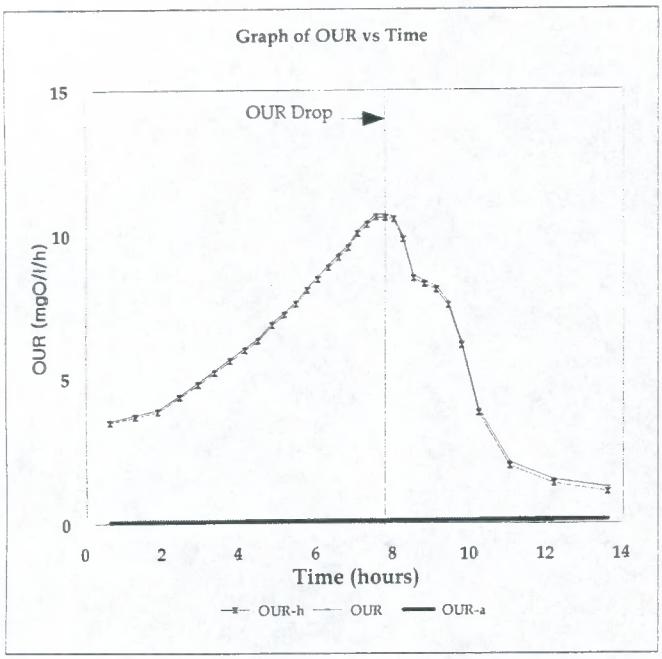
% COD Recovery		End Time=	12.00					$COD_{filt.}$	241.92	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Rec.	So(mgCOD/	Xo(mgMLVSS/l)	So/Xo
330.62	185.47	77.50	1.33	2.17	3.50	74.00	78.48	236.28	57.90	4.0809
								So(mgCOD/	Xo(mgMLAVSS/	So/Xo
Parent System		fcv=	1.389	Batch Result				236.28	22.27	10.6088
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s		
0.385	2481.333333	70	30.938408	10.49	2.37244774636	0.97	5.91	9.249		

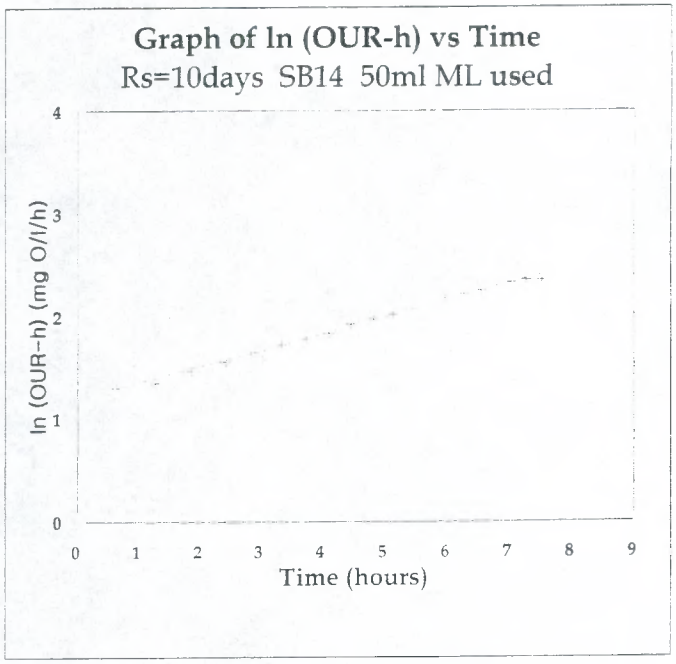
0.378	2450	70	31.961599
0.390	2398	70	32.326972
0.359	2456	70	30.438702
0.431	2416	70	35.999337
0.402	2464	70	34.213727
0.384	2526	70	33.538727
0.398	2476	70	34.068318
0.361	2576	70	32.097905
0.360	2570	70	31.97325

Regression Output:

Constant	0.437685498
Std Err of Y Est	0.044674985
R Squared	0.994404284
No. of Observations	24
Degrees of Freedom	22
X Coefficient(s)	0.260762859
Std Err of Coef.	0.004170429







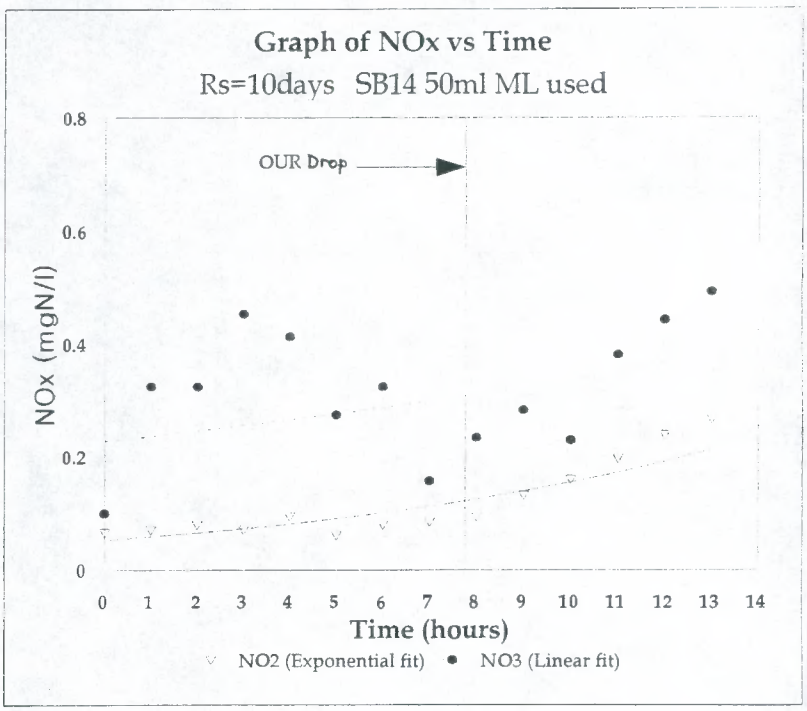
% COD Recovery		End Time=	13.00					$COD_{filt.}$	282	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/	Xo(mgMLVSS/l)	So/Xo
364.00	208.00	71.10	0.55	0.69	1.24	69.86	76.34	277.30	41.36	6.70527
								So(mgCOD/	Xo(mgMLAVSS/	So/Xo
								277.30	15.91	17.4311

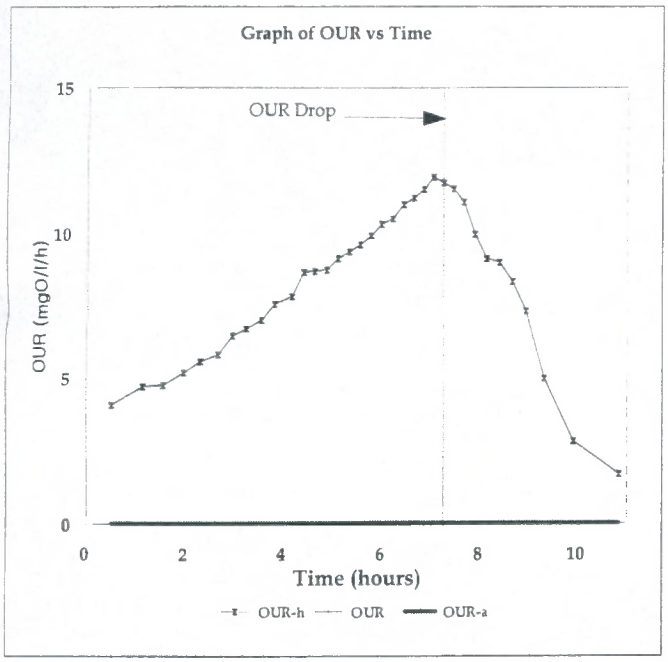
Parent System		fcv=	1.389	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.385	2481.333333	50	22.098863	29.05	1.39304346466	0.60	4.14	7.755

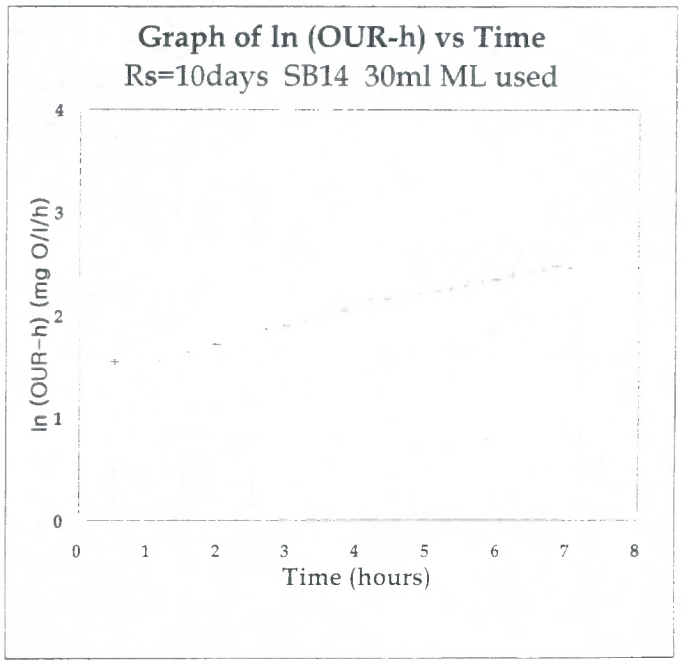
0.378	2450	50	22.829714
0.390	2398	50	23.090695
0.359	2456	50	21.74193
0.431	2416	50	25.713812
0.402	2464	50	24.438376
0.384	2526	50	23.956233
0.398	2476	50	24.334513
0.361	2576	50	22.927075
0.360	2570	50	22.838036

Regression Output:

Constant	1.085289421
Std Err of Y Est	0.026648049
R Squared	0.994993437
No. of Observations	21
Degrees of Freedom	19
X Coefficient(s)	0.171996361
Std Err of Coef.	0.002798995







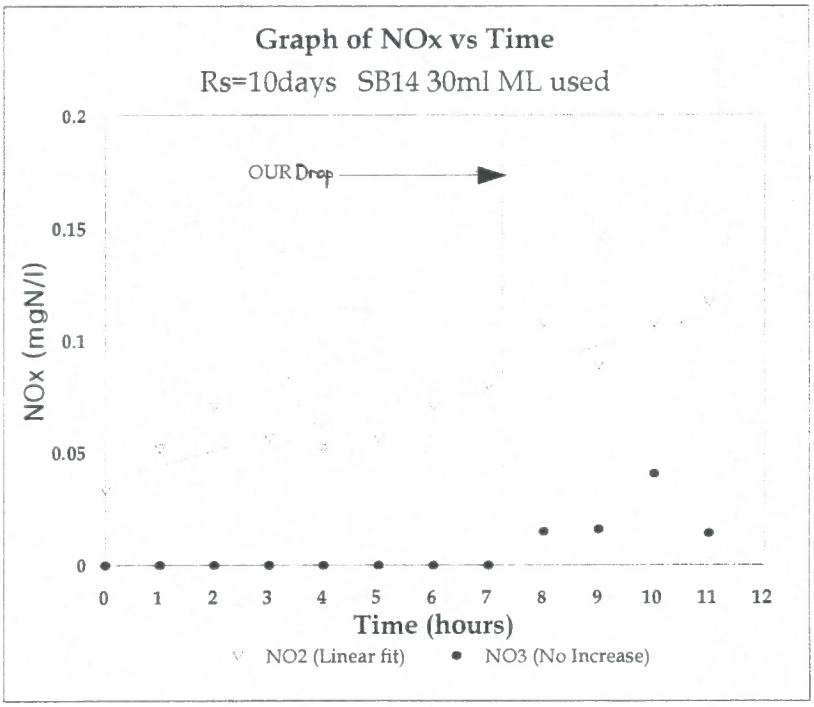
% COD Recovery		End Time=	11.00					$COD_{filt.}$	246	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/	Xo(mgMLVSS/l)	So/Xo
282.00	134.00	75.00	0.25	0.00	0.25	74.75	74.02	243.54	24.813333333333	9.81488
								So(mgCOD/	Xo(mgMLAVSS/	So/Xo
								243.54	9.5449886735927	25.515

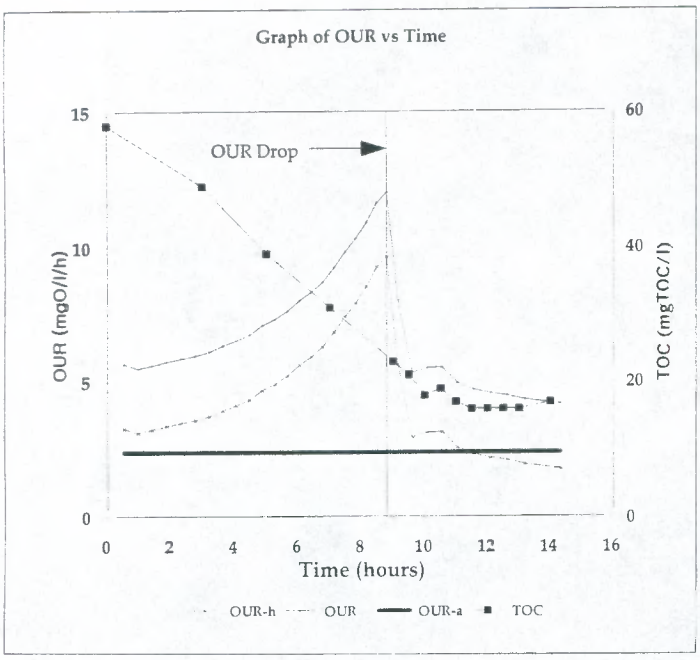
Parent System		fcv=	1.389	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.385	2481.333333	30	13.259318	40.49	1.69699490177	0.62	3.87	7.25

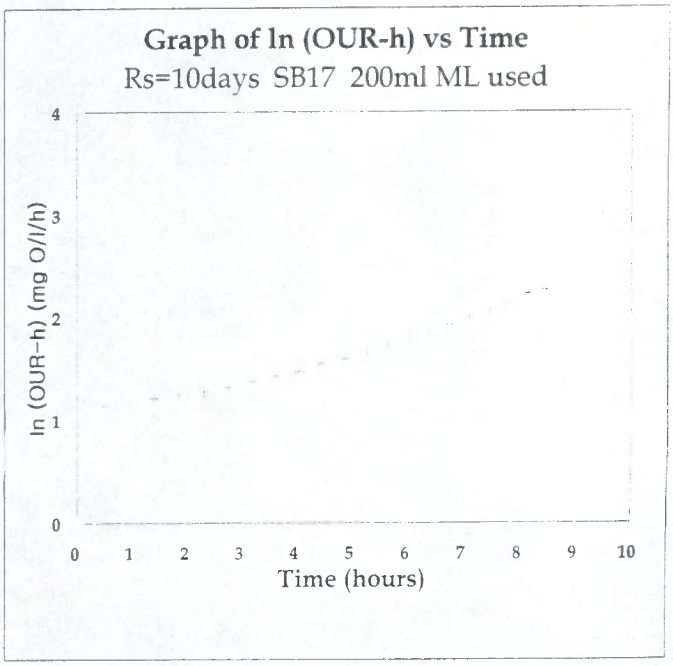
0.378	2450	30	13.697828
0.390	2398	30	13.854417
0.359	2456	30	13.045158
0.431	2416	30	15.428287
0.402	2464	30	14.663026
0.384	2526	30	14.37374
0.398	2476	30	14.600708
0.361	2576	30	13.756245
0.360	2570	30	13.702822

Regression Output:

Constant	1.362246287
Std Err of Y Est	0.034775187
R Squared	0.988537527
No. of Observations	25
Degrees of Freedom	23
X Coefficient(s)	0.16136159
Std Err of Coef.	0.003623087





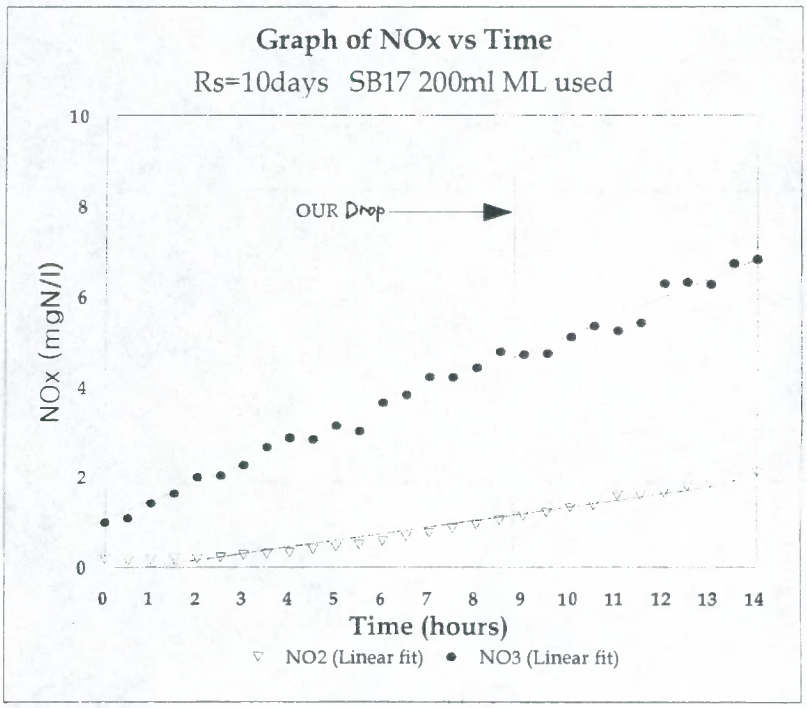


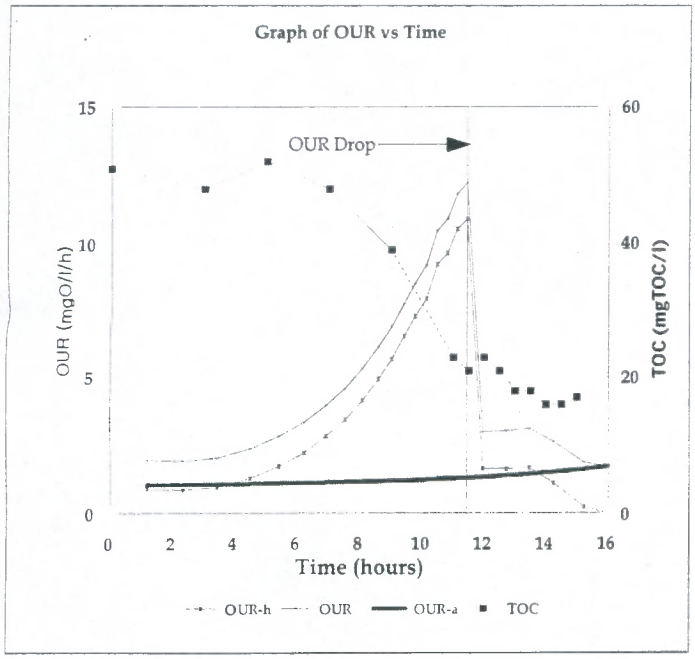
% COD Recovery		End Time=	13.50							
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/	Xo(mgMLVSS)	So/Xo
421.34	356.83	86.30	6.84	25.42	32.26	54.04	97.51	193.50	514.15	1.0538
								So(mgCOD/	Xo(mgMLAVSS	So/Xo
								193.50	205.14	2.6412

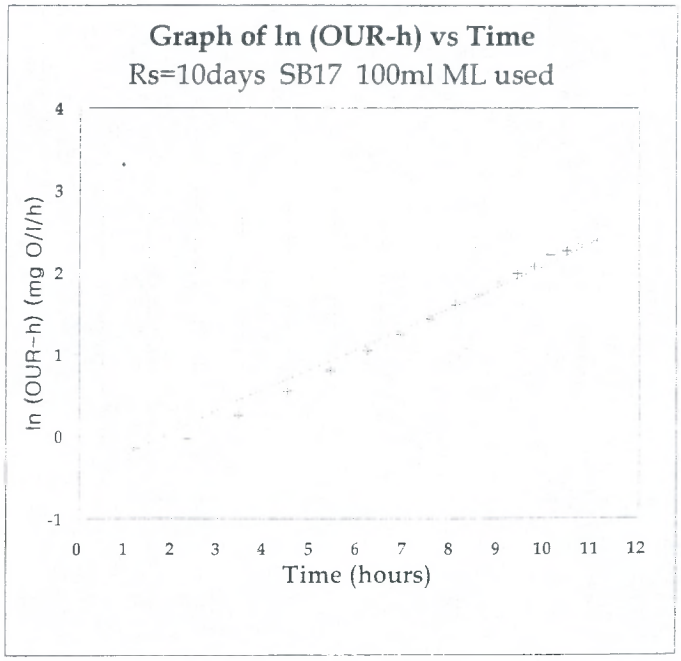
Parent System		fcv=	1.392	Batch Result				
fav	Xv	VML	ZBH(Theo),BT	ZBH(O)	OURSBCOD	KMP	UH	t=s
0.399	2570.75	200	95.194926	29.56	2.9501590838	1.39	2.60	8.794

0.397	2622	200	102.65054
0.385	2614	200	99.40052
0.380	2602	200	97.518137
0.447	2500	200	110.2512
0.397	2608	200	102.25166
0.359	2718	200	96.397296
0.428	2452	200	103.57606
0.406	2450	200	98.077533

Regression Output:	
Constant	0.928465851
Std Err of Y Est	0.075026085
R Squared	0.96040607
No. of Observations	22
Degrees of Freedom	20
X Coefficient(s)	0.140367666
Std Err of Coef.	0.006372927







% COD Recovery		End Time=	15.00							
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/	Xo(mgMLVSS)	So/Xo
286.27	245.95	59.40	3.01	15.11	18.12	41.28	100.34	183.5	257.075	2.07002
								So(mgCOD/	Xo(mgMLAVSS)	So/Xo
								183.5	102.5677404482	5.18828

Parent System		fcv=	1.392	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.399	2570.75	100	47.597463	2.72	1.65590271764	1.14	6.27	11.434

0.397	2622	100	51.325269
0.385	2614	100	49.70026
0.380	2602	100	48.759068
0.447	2500	100	55.125602
0.397	2608	100	51.125832
0.359	2718	100	48.198648
0.428	2452	100	51.78803
0.406	2450	100	49.038766

Regression Output:	
Constant	-0.83677448
Std Err of Y Est	0.135707056
R Squared	0.978328884
No. of Observations	18
Degrees of Freedom	16
X Coefficient(s)	0.28314212
Std Err of Coef.	0.010535198

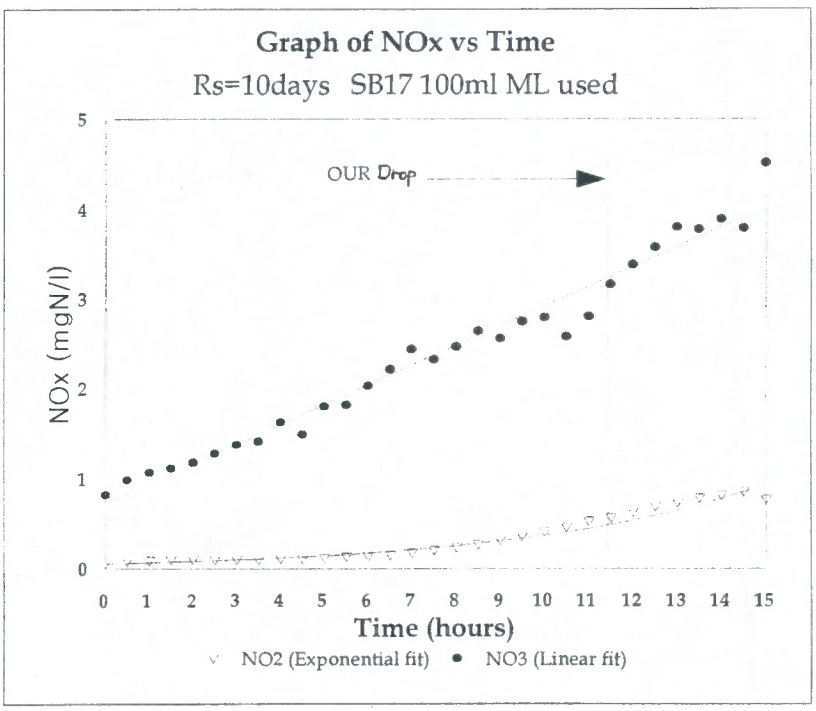
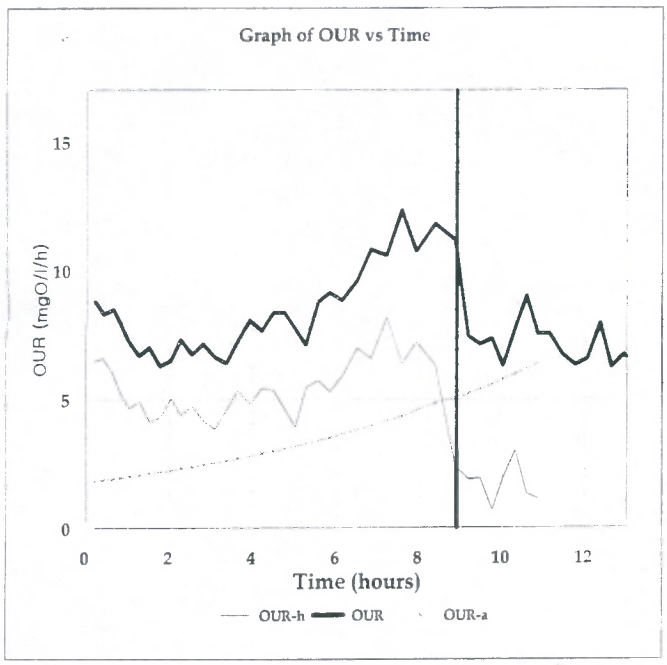
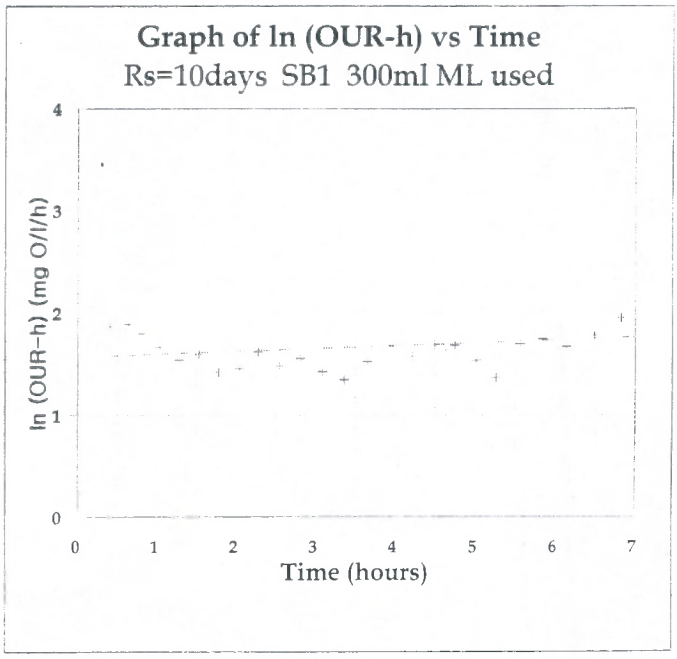


Table A2: Results for batch tests with a mixture of flocculated-filtered wastewater (WW) and mixed liquor (ML)drawn from the 20 days sludge age parent activated sludge system: Batch test numbers, dates of batch tests, volumes added, COD recoveries, measured OHO active biomass present at the start of the batch test (ZBH(0)) and the projected parent system mixed liquor (ML) active biomass. The theoretical parent system mixed liquor (ML) OHO active biomass and the projected active biomass present the start of the batch test are also given.

Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		COD Recov. (%)	Regression			K_{MP}	U_H	ZBH(0) (mgCOD/l)			
											Measured		Theoretical	
			WW	ML		Y-int	Slope	R^2			Batch Test	ML	Batch Test	ML
5	B1	11 09	2.70	0.30	96.8	1.5726	0.027	0.131	0.51	0.77	175.5	1755.2	119.1	1191.2
7	B2	24 09	2.70	0.30	92.9	1.6405	0.129	0.908	1.89	1.84	64.6	645.7	131.5	1315.0
	B3	29 09	2.80	0.20	97.5	1.3207	0.141	0.957	1.11	2.89	43.7	654.8	87.7	1315.0
	B4	05 10	2.90	0.10	91.3	0.9156	0.217	0.965	0.56	5.26	20.0	599.9	44.3	1329.1
8	B5	12 10	2.60	0.40	93.7	2.0928	0.108	0.972	1.83	1.38	117.7	882.9	151.8	1138.5
	B6	19 10	2.70	0.30	93.9	1.7966	0.089	0.906	1.65	1.11	101.8	1018.0	113.9	1138.5
	B7	23 10	2.80	0.20	91.7	1.4889	0.182	0.971	1.80	3.18	41.4	621.2	75.9	1138.5
9	B8	26 11	2.60	0.40	93.8	2.4367	0.112	0.979	1.58	1.72	161.6	1211.8	158.8	1190.8
	B9	27 11	2.70	0.30	96.7	2.1122	0.172	0.996	1.77	2.99	81.0	810.0	119.1	1190.8
	B10	28 11	2.80	0.20	97.3	1.9700	0.079	0.654	0.93	1.59	132.7	1991.0	79.4	1190.8
10	B11	10 12	2.60	0.40	100.2	2.3792	0.024	0.674	0.74	0.44	424.5	3183.6	167.4	1255.5
	B12	11 12	2.70	0.30	105.1	2.0990	0.104	0.958	1.44	1.68	121.6	1216.2	125.6	1255.5
	B13	12 12	2.80	0.20	95.6	1.6471	0.174	0.992	1.62	3.18	50.3	755.0	83.7	1255.5
	B14	13 12	2.90	0.10	93.6	1.1357	0.217	0.996	1.45	4.38	24.9	746.3	41.9	1255.5
11	B15	26 12	2.50	0.50	97.9	2.2090	0.043	0.860	0.92	0.72	258.4	1550.2	216.1	1296.6
	B16	29 12	2.60	0.40	96.9	1.9480	0.128	0.968	1.83	1.85	88.7	664.9	172.9	1296.6
	B17	30 12	2.70	0.30	93.2	1.5298	0.148	0.957	1.92	2.26	51.4	514.5	129.7	1296.6
	B18	31 12	2.80	0.20	102.1	0.9618	0.178	0.962	1.86	3.02	25.0	374.5	86.4	1296.6
	B19	05 01	2.90	0.10	90.6	1.0426	0.282	0.995	1.55	5.82	17.9	537.5	43.2	1296.6
12	B20	09 01	2.50	0.50	90.6	2.2682	0.050	0.941	1.22	0.60	247.7	1486.0	222.6	1335.8
	B21	10 01	2.60	0.40	90.8	2.1960	0.045	0.867	1.04	0.66	247.5	1856.6	178.1	1335.8
	B22	11 01	2.70	0.30	95 9	1.6373	0.113	0.971	1.80	1.54	71.8	717.7	133.6	1335.8
	B23	14 01	2.80	0.20	94.8	1.2516	0.114	0.916	1.37	1.99	48.5	727.0	89.1	1335.8
	B24	15 01	2.90	0.10	86.6	0.5448	0.213	0.967	1.61	4.13	14.0	420.4	44.5	1335.8
13	B25	01 02	2.93	0.07	85.4	-0.7524	0.276	0.976	0.67	6.57	3.0	129.9	32.5	1394.3
	B26	04 02	2.95	0.05	80.2	0.0269	0.209	0.962	1.58	4.05	8.5	509.8	23.2	1394.3
14	B27	15 02	2.34	0.66	95.4	2.2471	0.083	0.984	1.44	1.16	169.2	769.2	216.2	982.7
	B28	17 02	2.50	0.50	95.2	1.9448	0.064	0.941	0.92	1.24	150.7	904.5	163.8	982.7
	B29	18 02	2.70	0.30	96.3	1.0002	0.157	0.945	1.69	2.71	28.8	288.0	98.3	982.7
	B30	20 02	2.80	0.20	89.7	0.5908	0.238	0.974	1.84	4.51	13.3	198.9	65.5	982.7
	B31	22 02	2.90	0.10	87.9	-0.3202	0.307	0.994	2.06	5.92	4.2	127.2	32.8	982.7
	B32	24 02	2.93	0.07	75.9	0.1148	0.265	0.971	0.99	5.98	7.5	321.3	22.9	982.7
	B33	25 02	2.95	0.05	72.5	0.9285	0.237	0.990	0.81	5.49	18.7	1122.7	16.4	982.7
17	B34	22 04	2.70	0.30	101.0	1.1647	0.118	0.945	1.34	2.13	43.1	431.4	104.4	1044.4
	B35	24 04	2.80	0.20	102.8	0.1665	0.200	0.953	1.34	4.07	10.2	152.5	69.6	1044.4

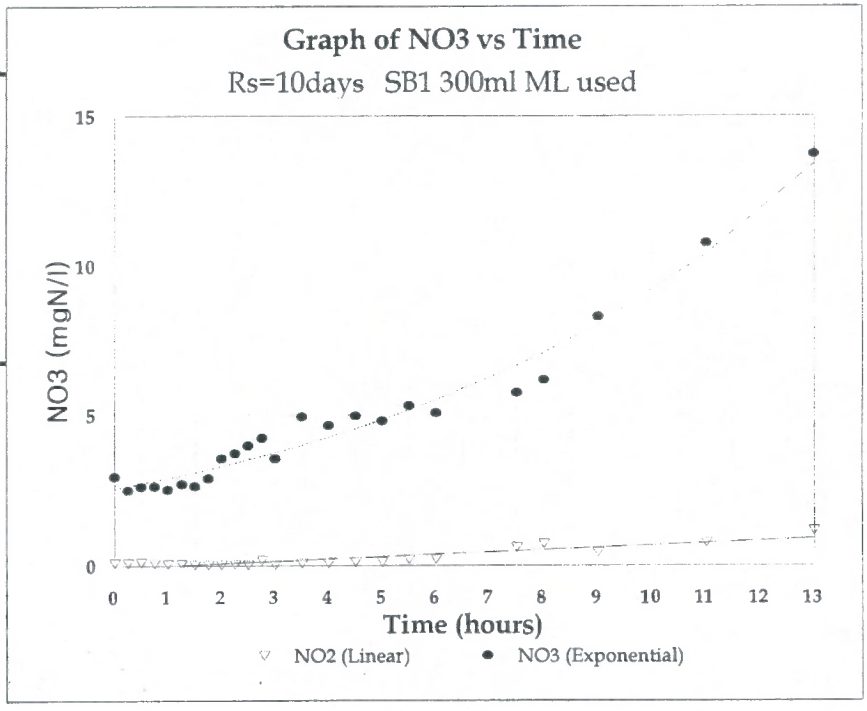


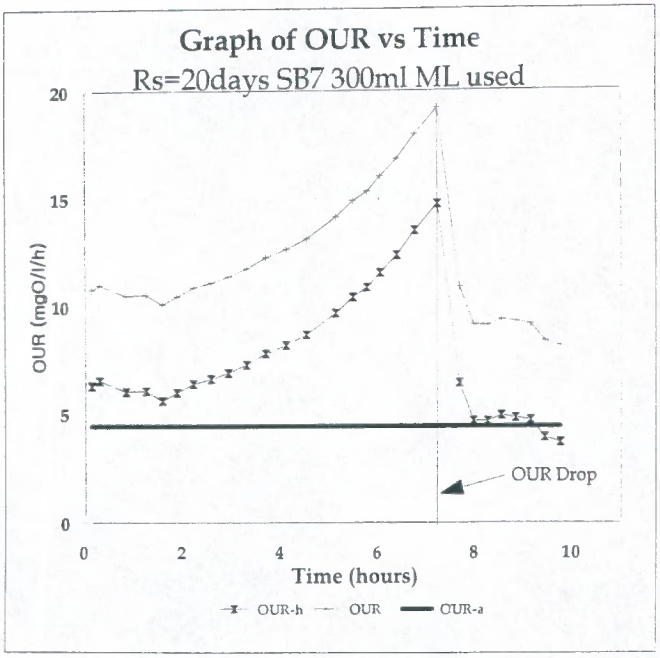


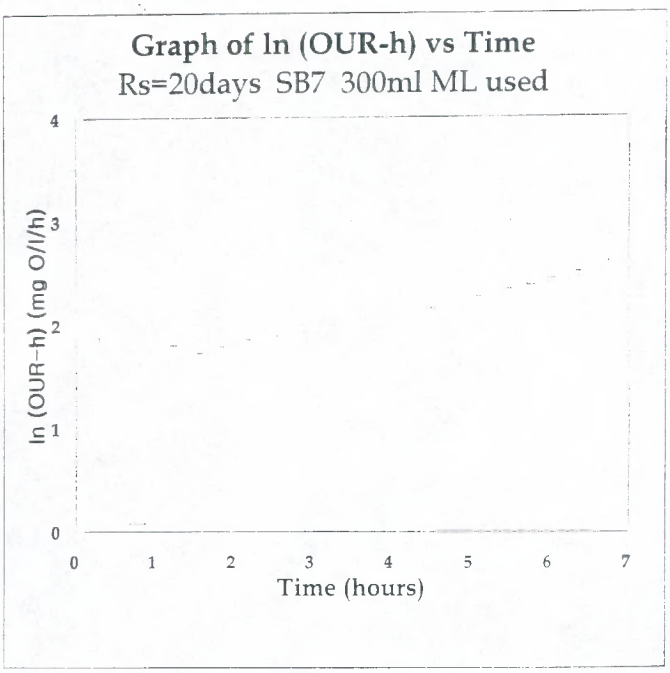
% COD Recovery		End Point=	13.20				
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Recovery
716.00	624.00	123.60	3.48	51.09	54.57	69.03	96.79

Parent System		fcv=	1.369	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.2490309	3494	300	119.11979	175.52	2.39	0.51	0.77	8.9

Regression Output:		
Constant		1.572571501
Std Err of Y Est		0.184163187
R Squared		0.13096501
No. of Observations		31
Degrees of Freedom		29
X Coefficient(s)	0.027463618	
Std Err of Coef.	0.013137107	



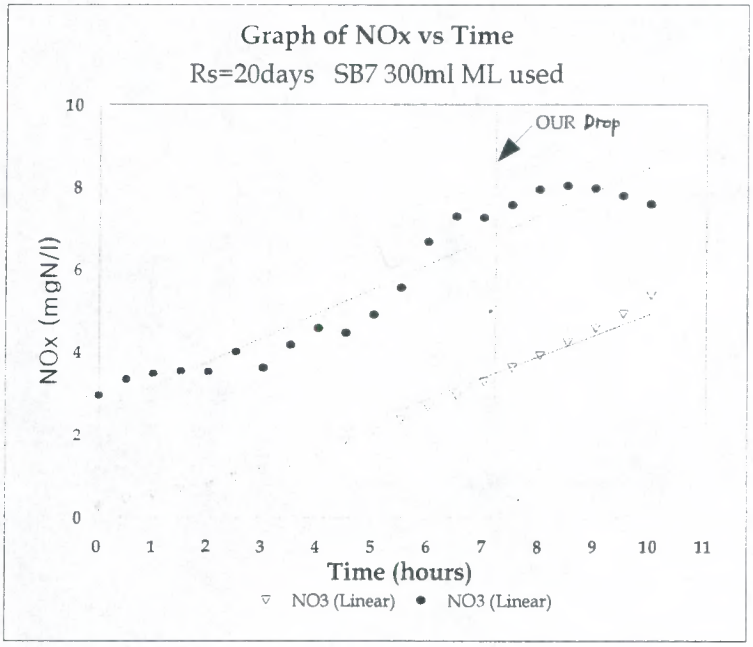


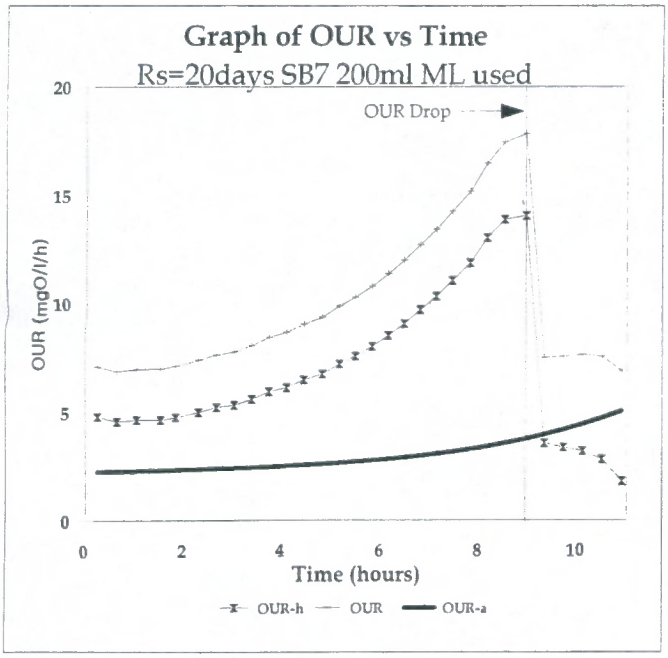


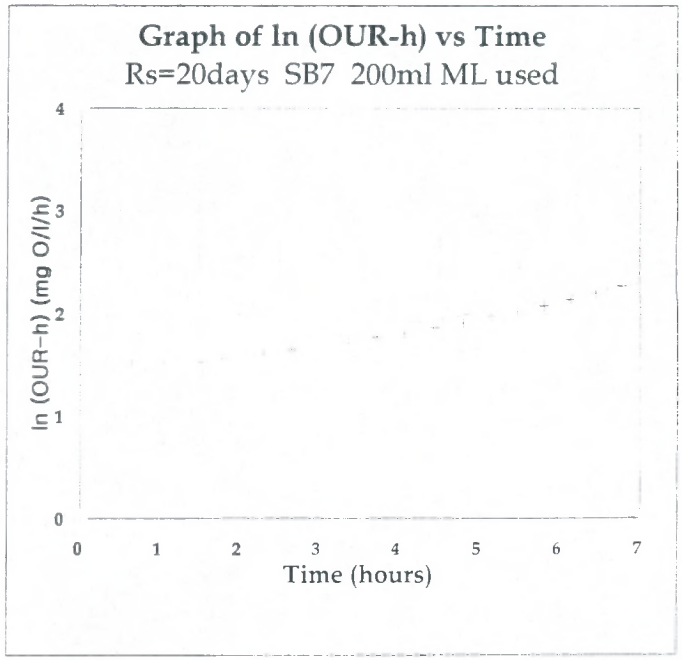
% COD Recovery		End Point=	10.00				
COD t=o	CODt=T	MOt	MOr.o2	MOno3	MOn	MOc	% Recovery
729.80	604.80	118.00	17.51	27.00	44.51	73.49	92.94

Parent System		fcv=	1.394	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.2524507	3736.6667	300	131.49976	64.57	6.45877523504	1.89	1.84	7.21

Regression Output:	
Constant	1.64046005
Std Err of Y Est	0.094579279
R Squared	0.907589792
No. of Observations	20
Degrees of Freedom	18
X Coefficient(s)	0.129221885
Std Err of Coef.	0.009718852



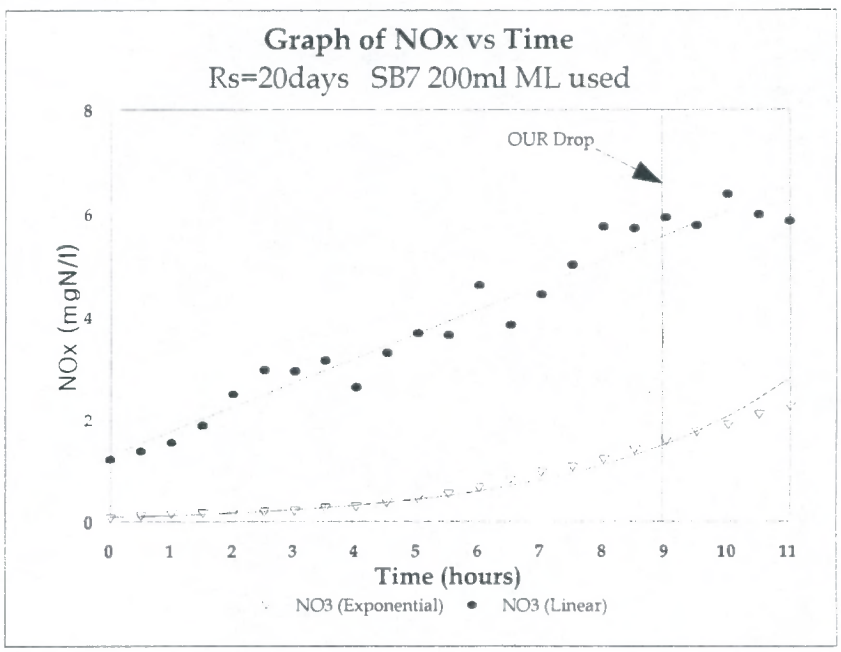


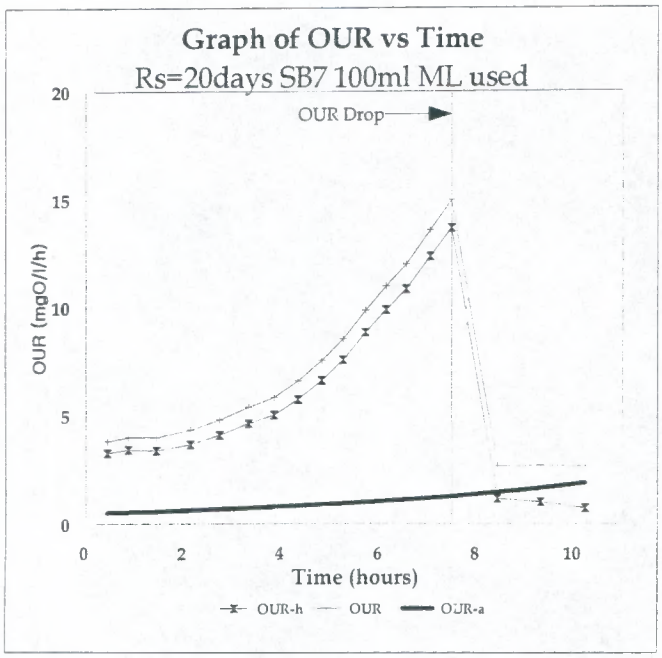


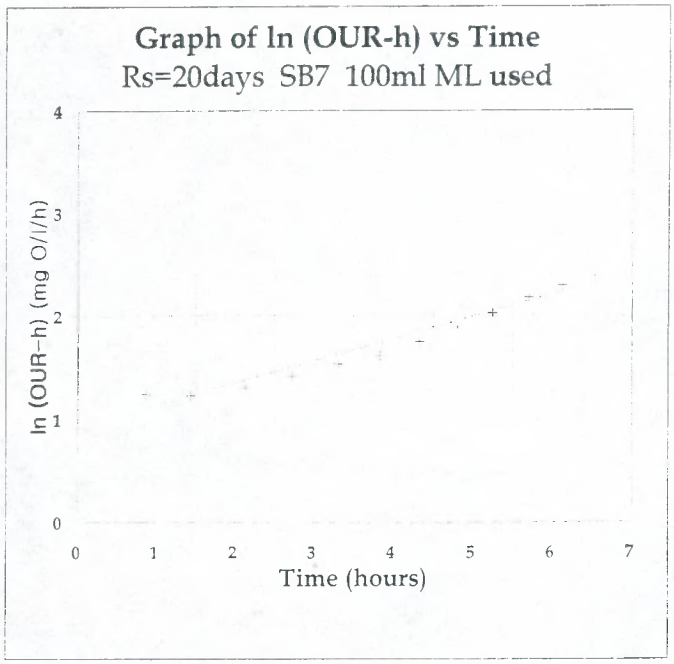
% COD Recovery		End Point=	10.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
556.00	472.00	101.10	7.95	22.88	30.83	70.27	97.53

Parent System		fcv=	1.394	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.2524507	3736.6667	200	87.666506	43.65	3.55512101162	1.11	2.89	8.94

Regression Output:	
Constant	1.320701087
Std Err of Y Est	0.079073047
R Squared	0.95721344
No. of Observations	25
Degrees of Freedom	23
X Coefficient(s)	0.14074536
Std Err of Coef.	0.006204681



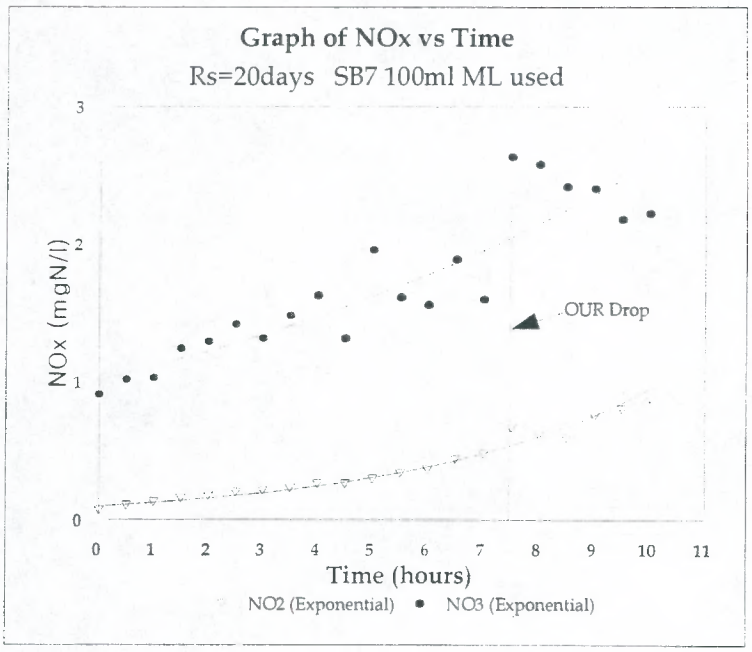


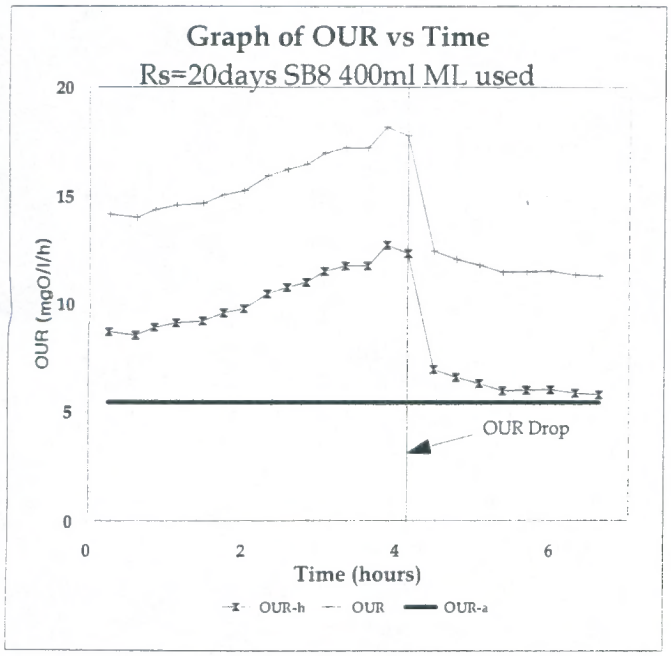


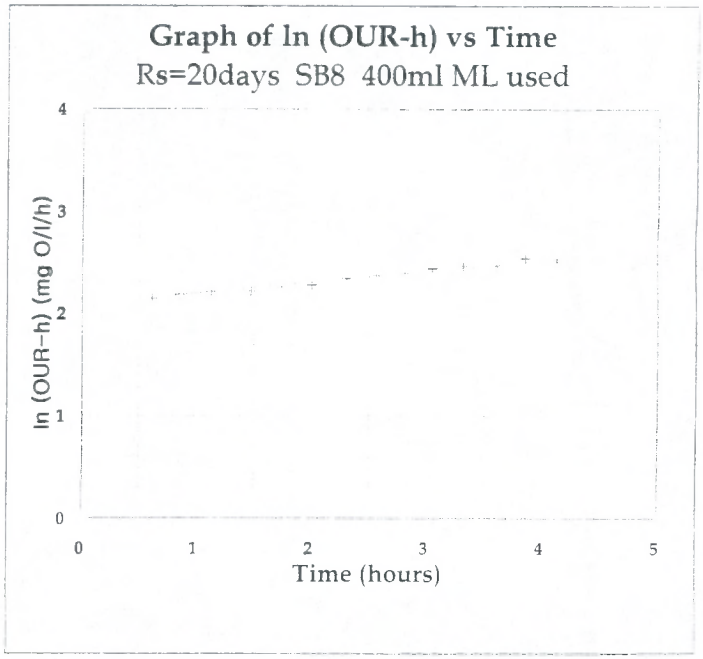
% COD Recovery		End Point=	10.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
346.00	290.00	62.20	2 93	7.20	10.13	52.07	98.87

Parent System		fcv=	1.394	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.253	3772	100	44.304014	20.00	1.18708385556	0.56	5.26	7.47

Regression Output:	
Constant	0.915574754
Std Err of Y Est	0.097286349
R Squared	0.964717001
No. of Observations	15
Degrees of Freedom	13
X Coefficient(s)	0.216687344
Std Err of Coef.	0.011493298



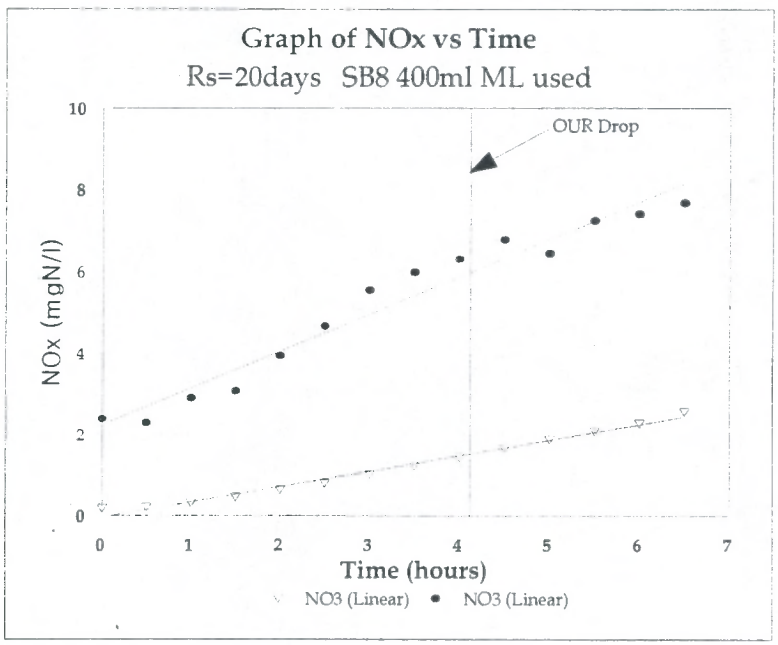


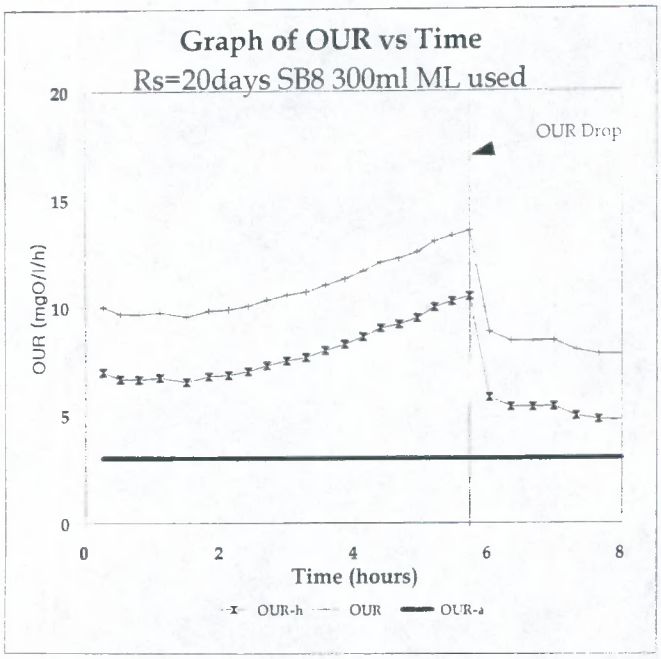


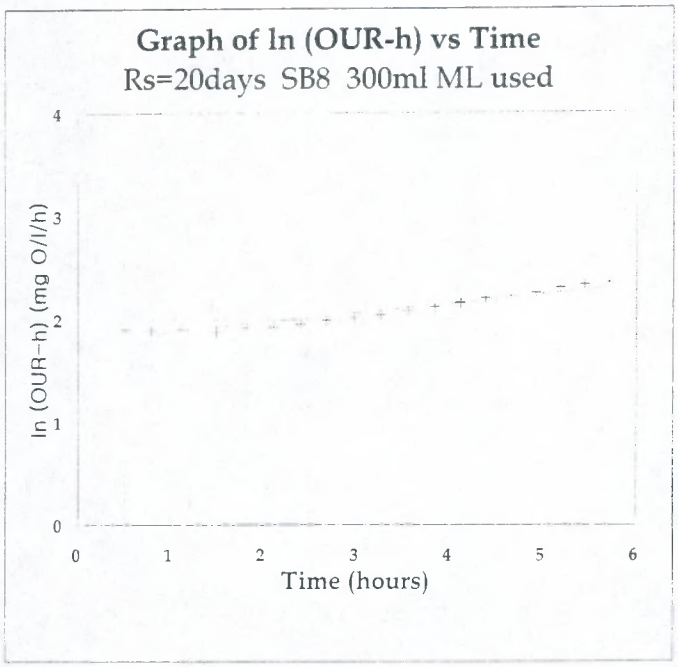
% COD Recovery		End Point=	6.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
930.66	824.99	82.80	8.47	27.04	35.51	47.29	93.73

Parent System		fcv=	1.298	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.229	3829.6	400	151.80618	117.72	7.0160562819	1.83	1.38	4.12
0.241	3614.0	400	172.08148					
0.231	3738.0	400	170.6267					
0.237	3948.0	400	184.44621					
0.206	3972.0	400	161.48958					
0.231	3876.0	400	176.79291					

Regression Output:	
Constant	2.092809674
Std Err of Y Est	0.023327409
R Squared	0.971609352
No. of Observations	15
Degrees of Freedom	13
X Coefficient(s)	0.107865172
Std Err of Coef.	0.00511389





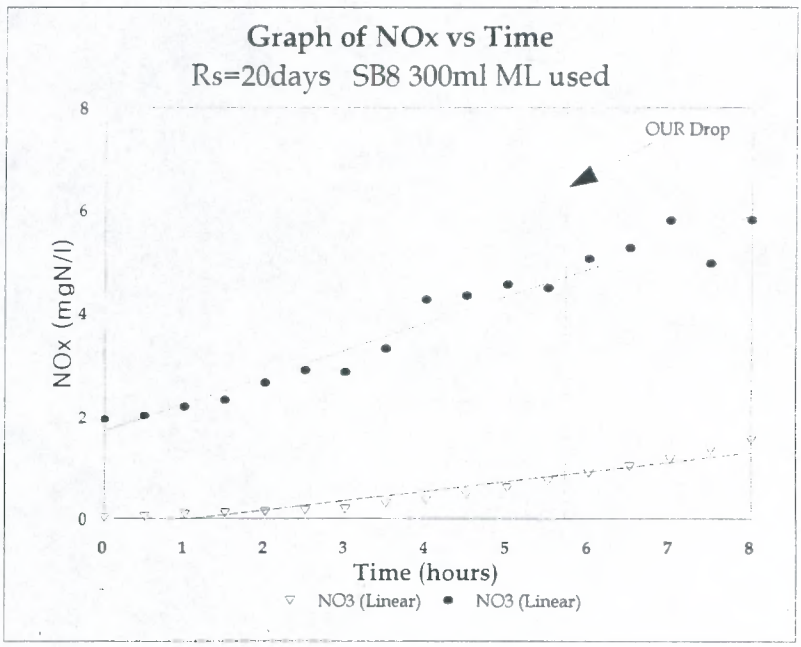


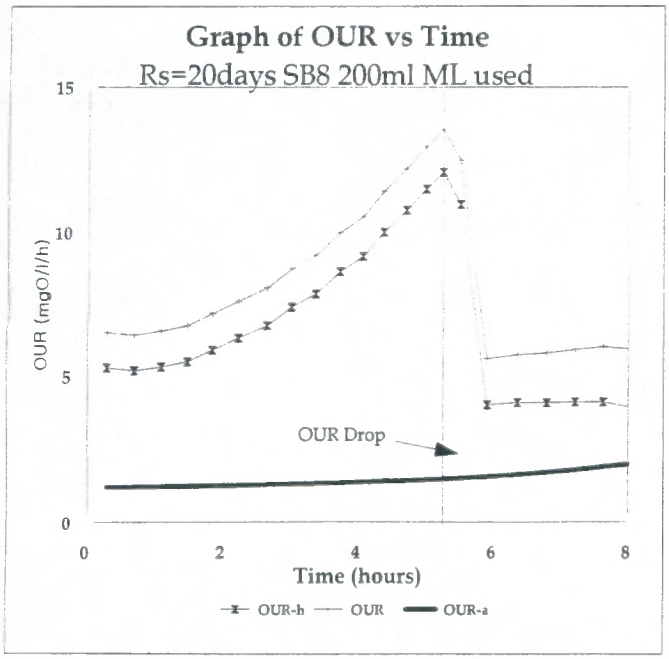
% COD Recovery		End Point=	8.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
755.90	654.30	79.40	5.19	19.05	24.24	55.16	93.86

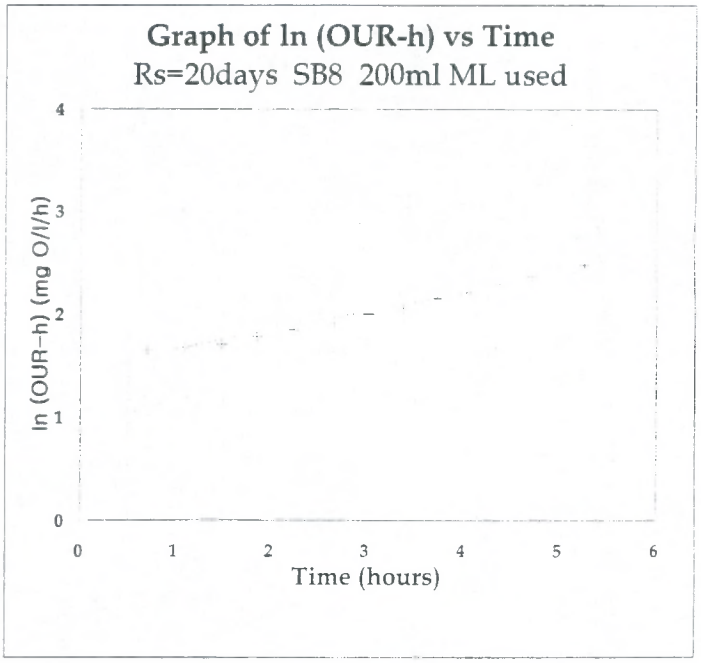
Parent System		fcv=	1.298	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Tzeo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.229	3829.6	300	113.85464	101.80	5.83983029164	1.65	1.11	5.71

0.241	3614.0	300	129.06111
0.231	3738.0	300	127.97003
0.237	3948.0	300	138.33466
0.206	3972.0	300	121.11719
0.231	3876.0	300	132.59468

Regression Output:	
Constant	1.796617508
Std Err of Y Est	0.050512622
R Squared	0.90598355
No. of Observations	20
Degrees of Freedom	18
X Coefficient(s)	0.089133321
Std Err of Coef.	0.00676777





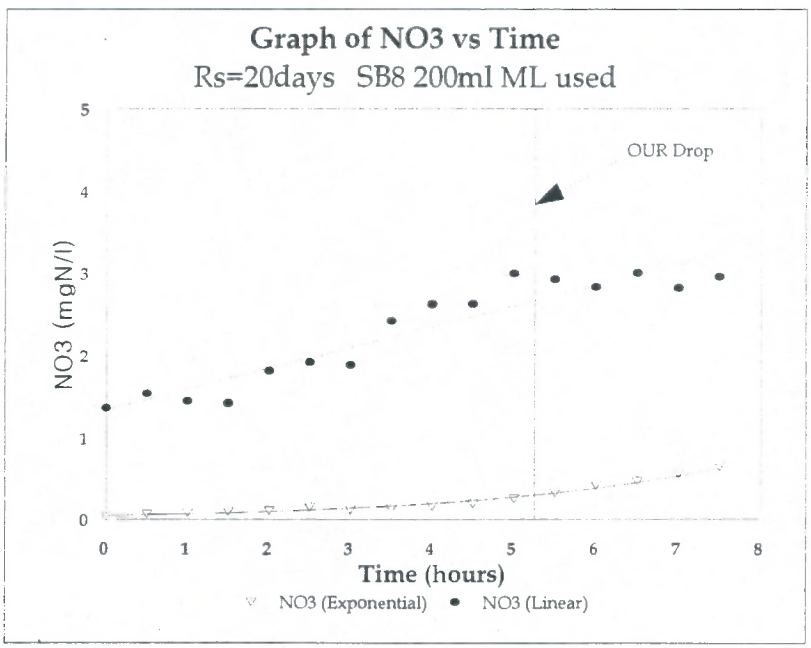


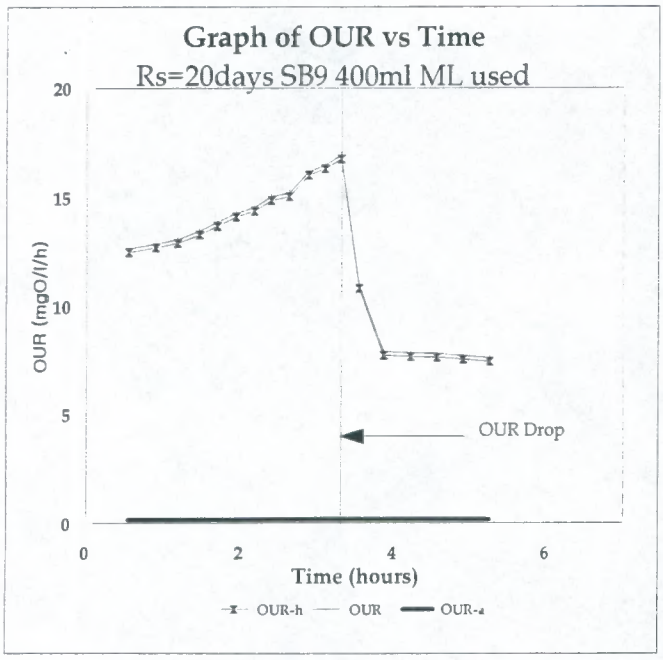
% COD Recovery		End Point=	7.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
530.29	451.35	45.60	1.98	8.65	10.63	34.97	91.71

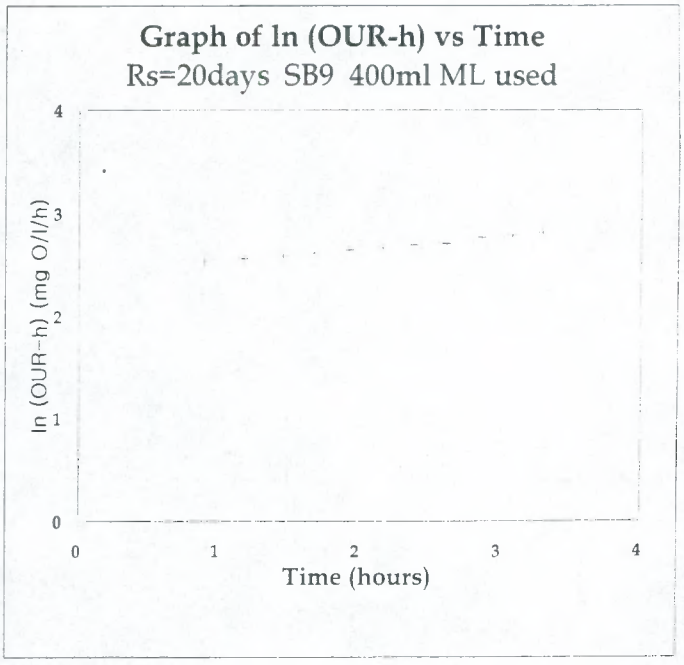
Parent System		fcv=	1.298	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.229	3829.6	200	75.903092	41.41	4.05557324687	1.80	3.18	5.253

0.241	3614.0	200	83.265234
0.231	3738.0	200	82.561307
0.237	3948.0	200	89.248167
0.206	3972.0	200	78.140121
0.231	3876.0	200	85.544957

Regression Output:		
Constant		1.488891315
Std Err of Y Est		0.052869802
R Squared		0.97055409
No. of Observations		15
Degrees of Freedom		13
X Coefficient(s)	0.181912225	
Std Err of Coef.	0.008788056	





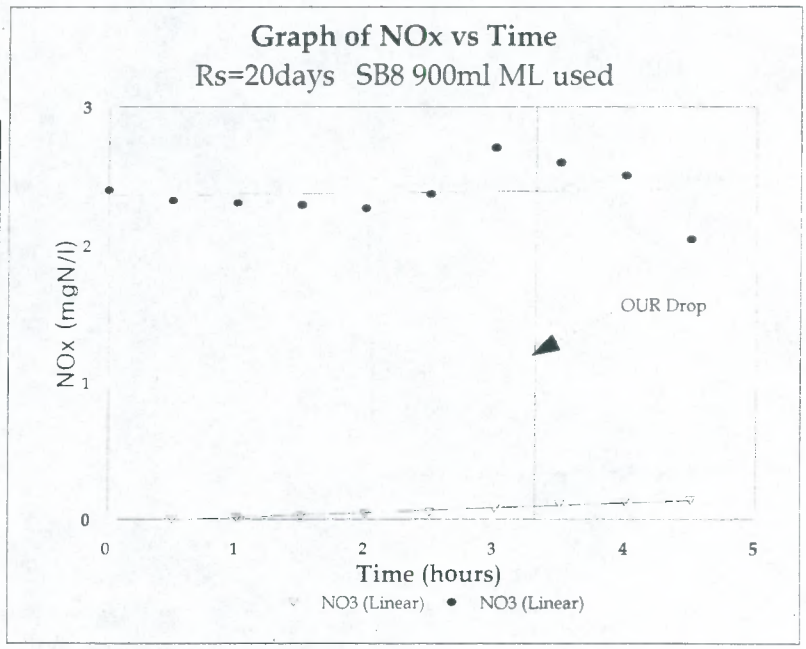


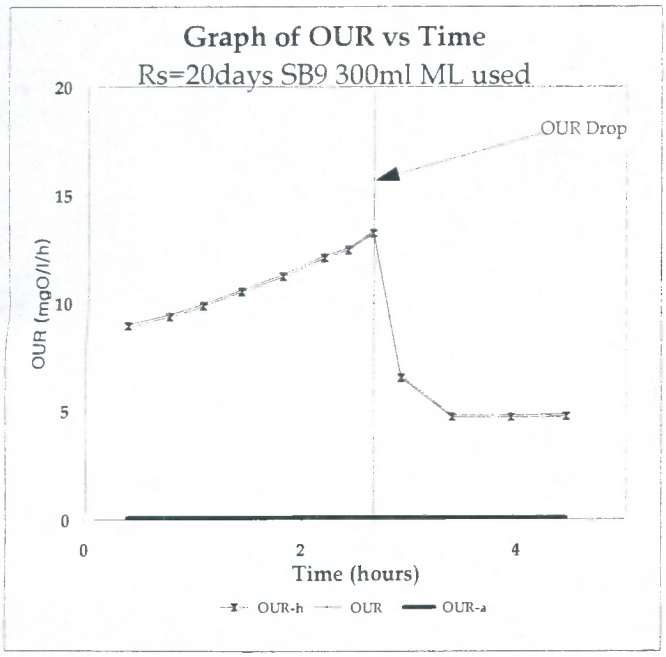
% COD Recovery		End Point=	4.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
930.66	824.99	48.70	0.55	0.22	0.77	47.93	93.80

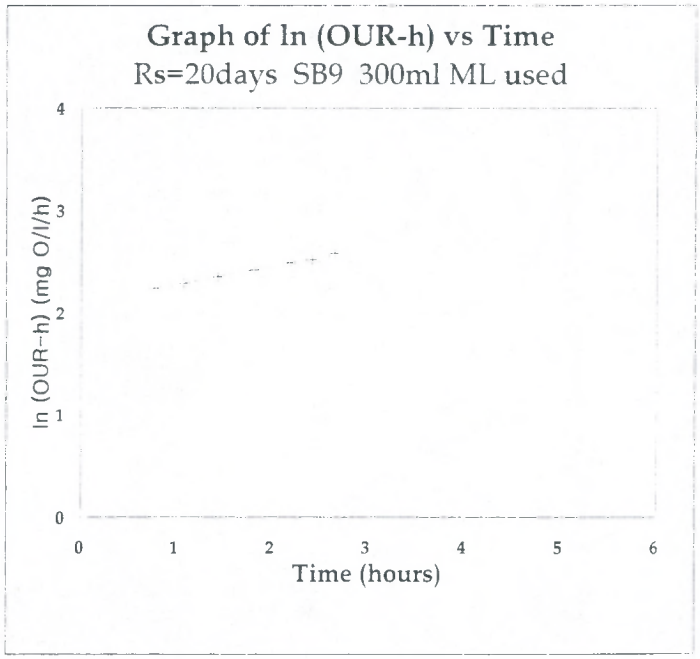
Parent System		fcv=	1.347	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.263	3359.0	400	158.77742	161.57	7.72852744078	1.58	1.72	3.31

0.251	3472.0	400	171.75407
0.246	3450.0	400	167.44188
0.291	3324.0	400	190.94818
0.267	3376.0	400	178.03248
0.238	3296.0	400	154.48222
0.287	3236.0	400	183.49318

Regression Output:	
Constant	2.436732636
Std Err of Y Est	0.015214059
R Squared	0.978764868
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.111559672
Std Err of Coef.	0.005196316





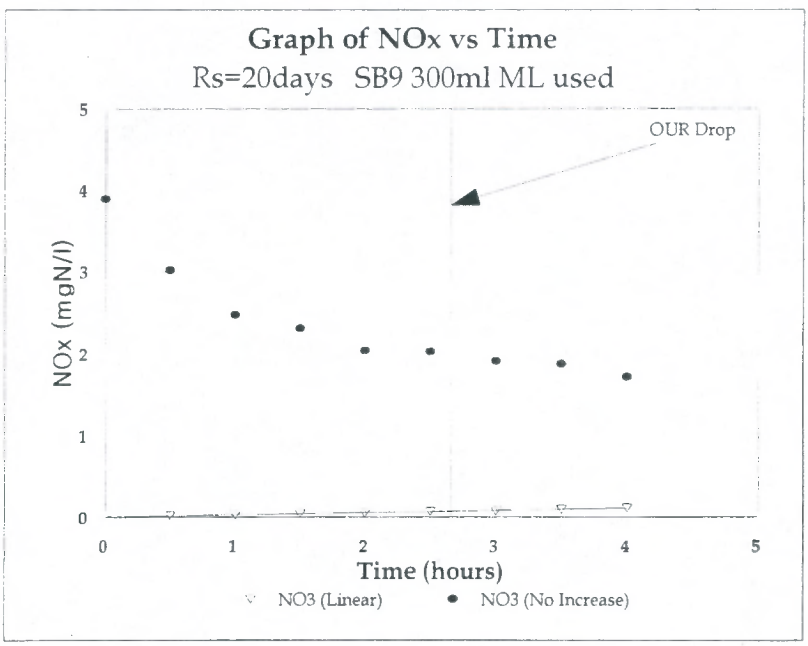


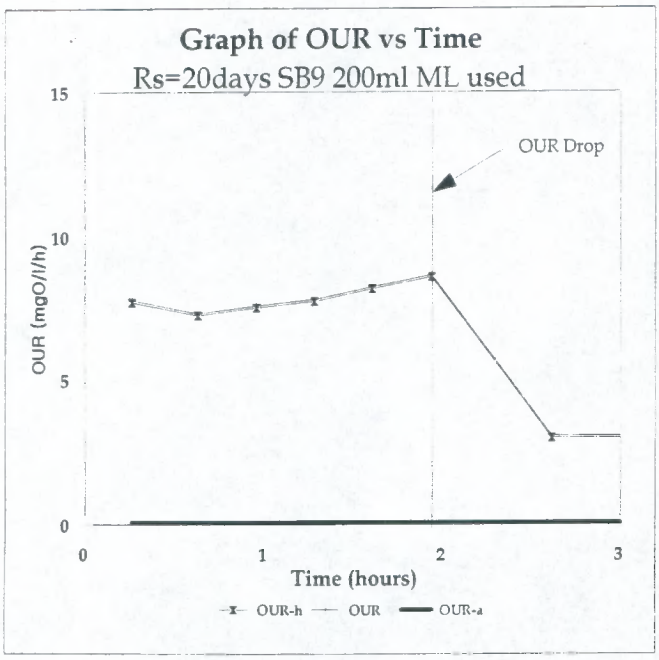
% COD Recovery		End Point=	4.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
608.83	556.42	32.60	0.38	0.00	0.38	32.22	96.68

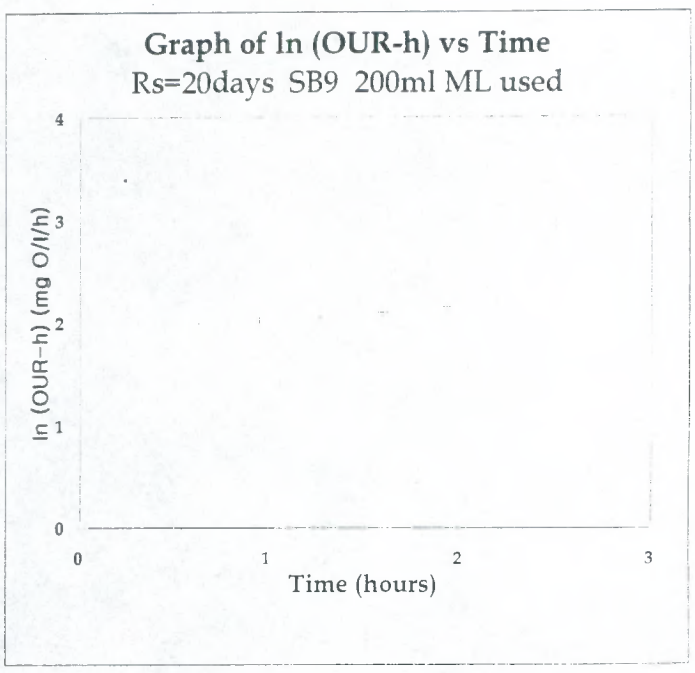
Parent System		fcv=	1.347	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.263	3359.0	300	119.08306	81.00	4.72578437961	1.77	2.99	2.66

0.251	3472.0	300	128.81556
0.246	3450.0	300	125.58141
0.291	3324.0	300	143.21113
0.267	3376.0	300	133.52436
0.238	3296.0	300	115.86166
0.287	3236.0	300	137.61988

Regression Output:		
Constant		2.112215347
Std Err of Y Est		0.010009104
R Squared		0.995675079
No. of Observations		8
Degrees of Freedom		6
X Coefficient(s)	0.172273477	
Std Err of Coef.	0.004635249	





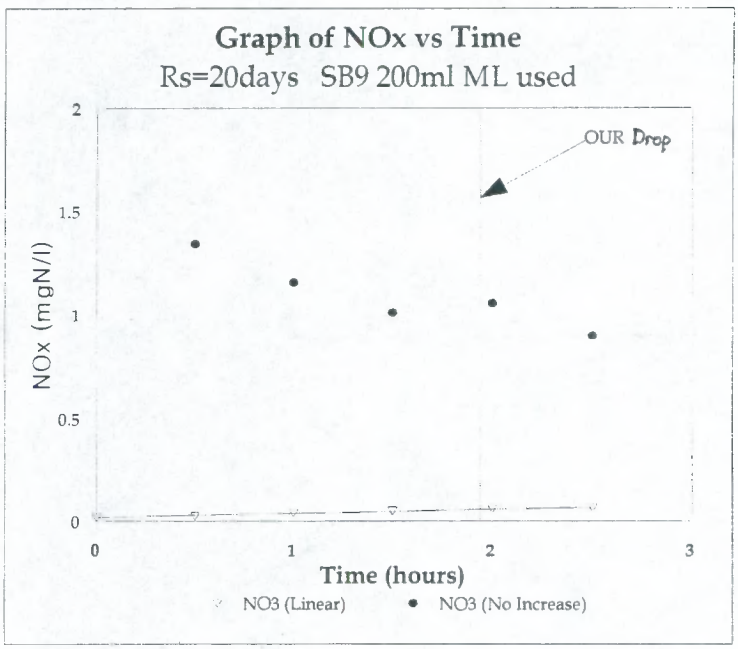


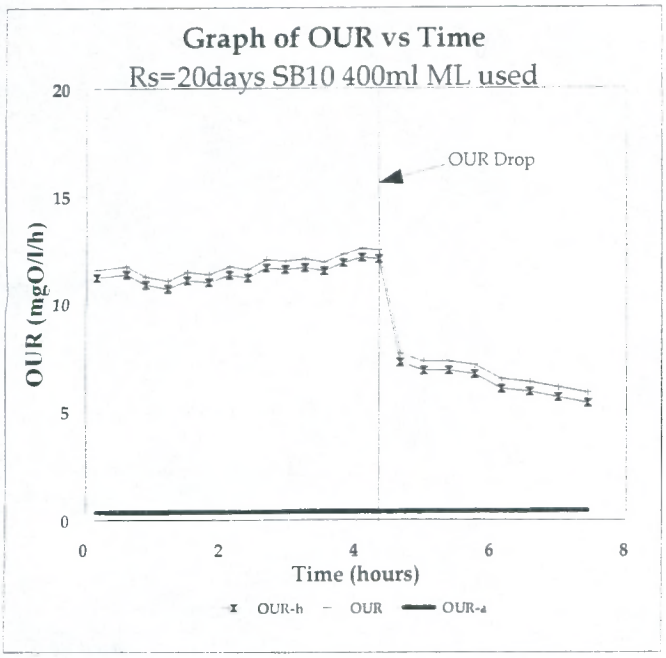
% COD Recovery		End Point=	3.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
441.50	415.30	14.30	0.20	0.00	0.20	14.10	97.26

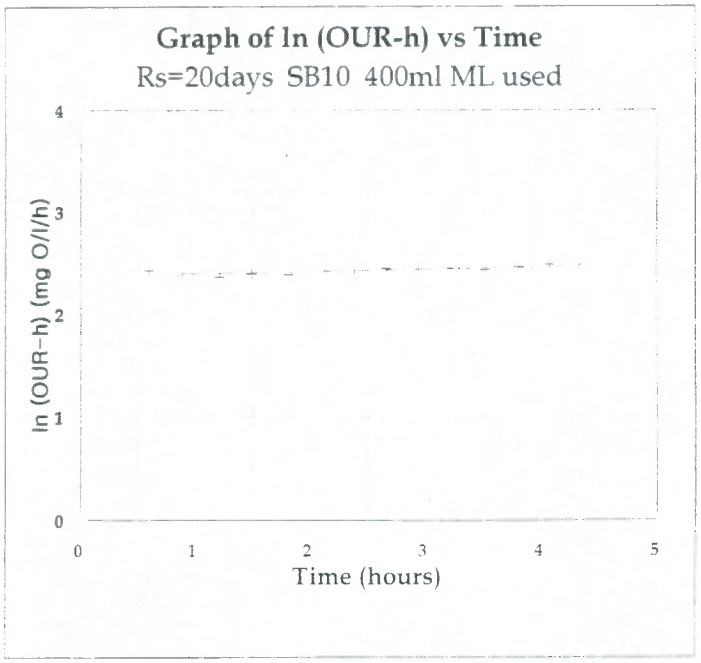
Parent System		fcv=	1.347	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),3T}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.263	3359.0	200	79.388708	132.74	3.0124562673	0.93	1.59	1.94

0.251	3472.0	200	85.877037
0.246	3450.0	200	83.720939
0.291	3324.0	200	95.474089
0.267	3376.0	200	89.016241
0.238	3296.0	200	77.241108
0.287	3236.0	200	91.746588

Regression Output:		
Constant		1.970035034
Std Err of Y Est		0.03986229
R Squared		0.653588453
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	0.079036845	
Std Err of Coef.	0.028770247	





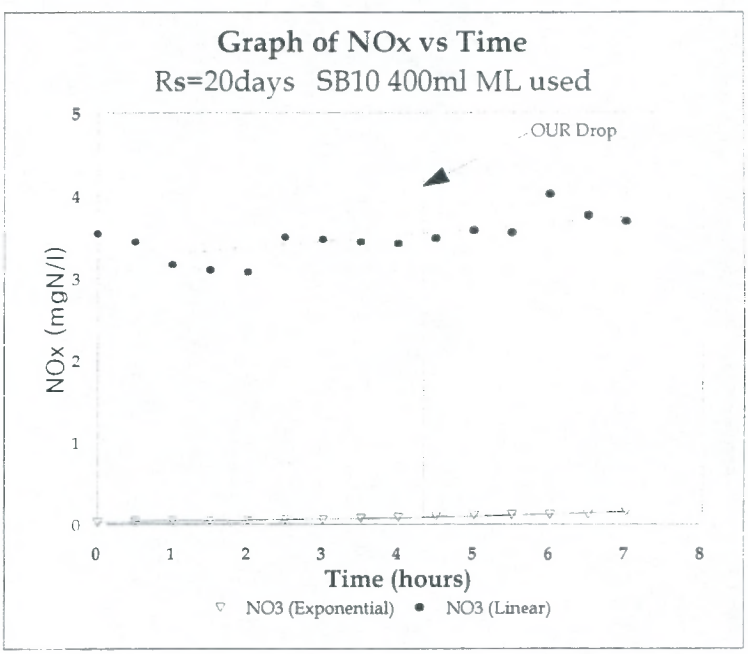


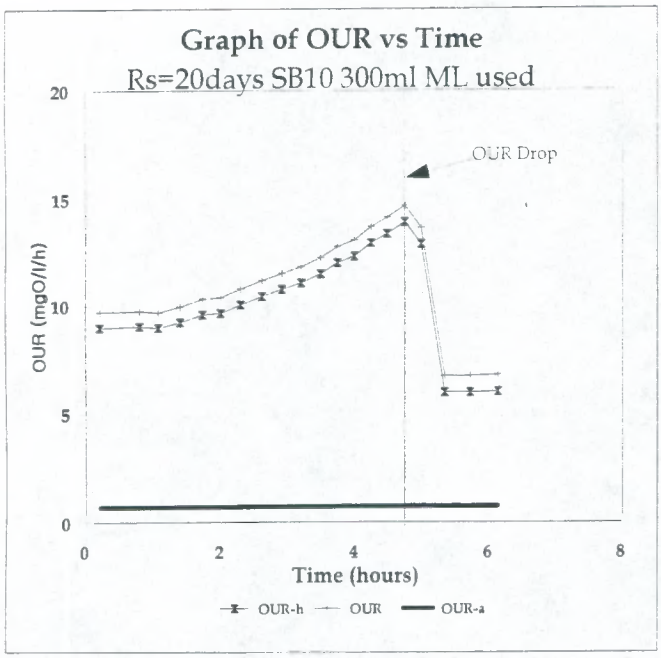
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
792.00	728.00	68.50	0.44	2.37	2.81	65.69	100.21

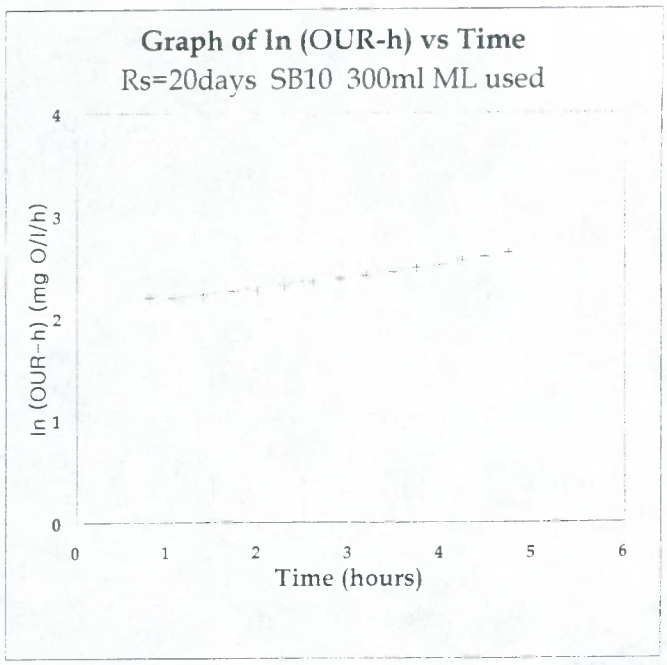
Parent System		fcv=	1.365	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.24733661	3718	400	167.40401	424.48	7.27767107547	0.74	0.44	4.33

0.274777427	3544	400	192.1654106
0.279685024	3634	400	200.5647414
0.26320723	3680	400	191.1375808
0.278466035	3736	400	205.2955574
0.255901641	3744	400	189.064227
0.227909346	3750	400	168.6529164
0.198636617	3866	400	151.538021
0.205332631	3790	400	153.5669061

Regression Output:	
Constant	2.37917801
Std Err of Y Est	0.022221258
R Squared	0.674439408
No. of Observations	15
Degrees of Freedom	13
X Coefficient(s)	0.023537617
Std Err of Coef.	0.004535605





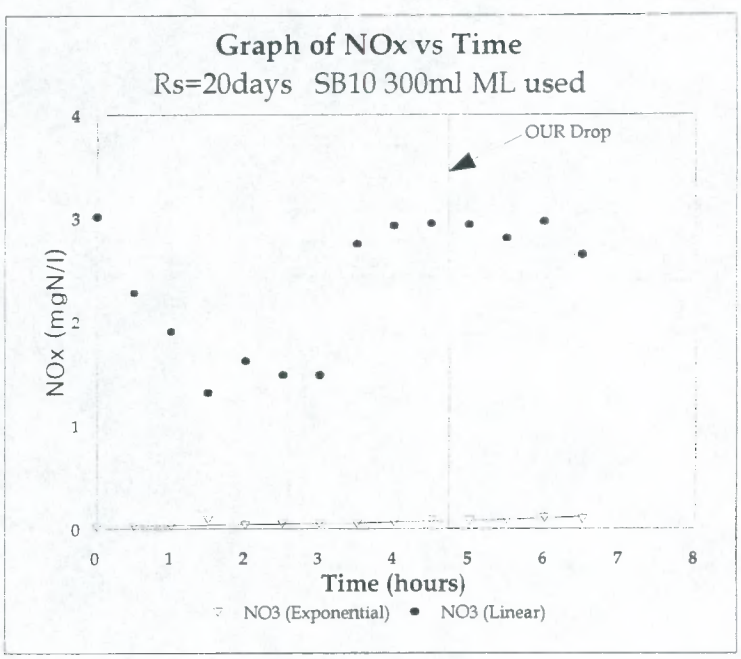


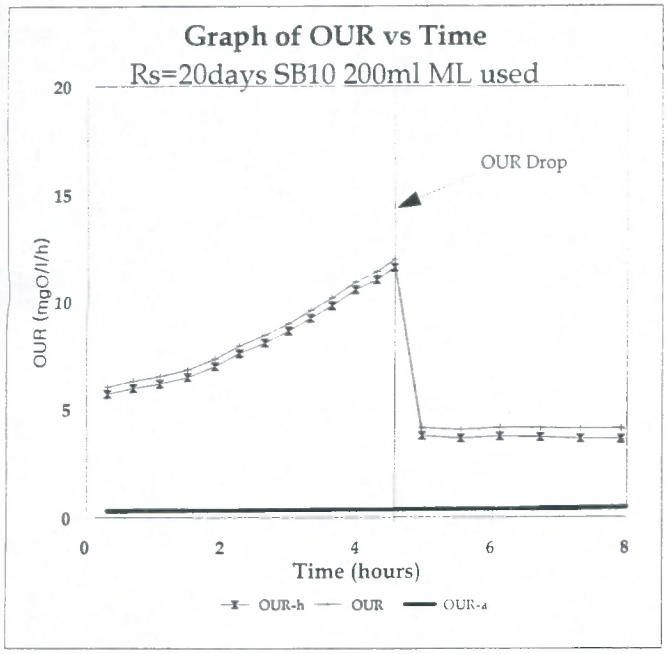
% COD Recovery		End Time=	6.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
692.00	668.00	63.90	0.30	4.52	4.82	59.08	105.07

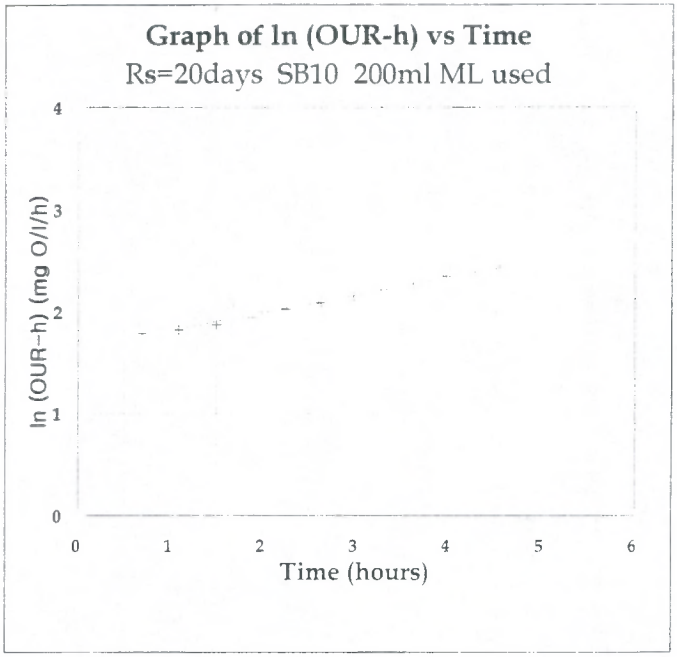
Parent System		fcv=	1.365	Batch Result				
fav	Xv	V_{M1}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.24733661	3718	300	125.55301	121.62	6.00688729981	1.44	1.68	4.73

0.274777427	3544	300	144.1240579
0.279685024	3634	300	150.423556
0.26320723	3680	300	143.3531856
0.278466035	3736	300	153.9716681
0.255901641	3744	300	141.7981702
0.227909346	3750	300	126.4896873
0.198636617	3866	300	113.6535158
0.205332631	3790	300	115.1751796

Regression Output:		
Constant		2.098990542
Std Err of Y Est		0.031261532
R Squared		0.958391775
No. of Observations		16
Degrees of Freedom		14
X Coefficient(s)	0.104378661	
Std Err of Coef.	0.005812537	





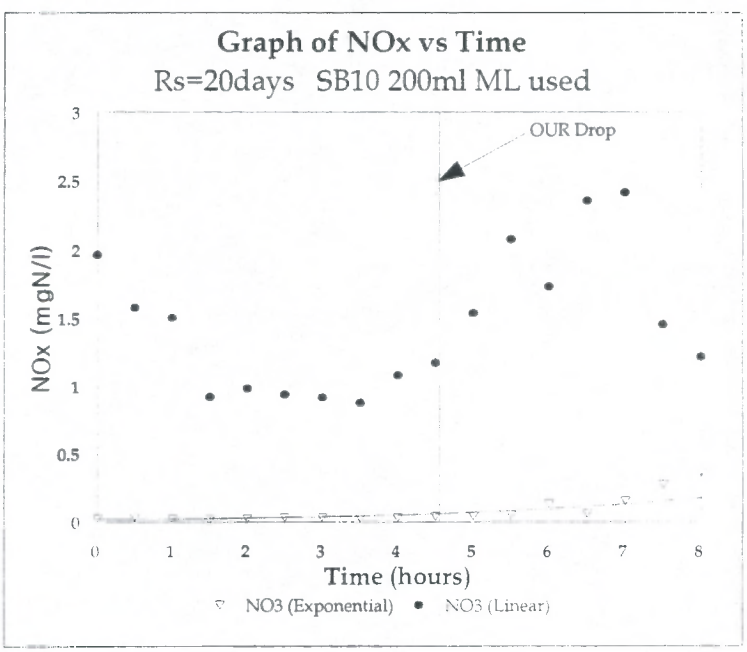


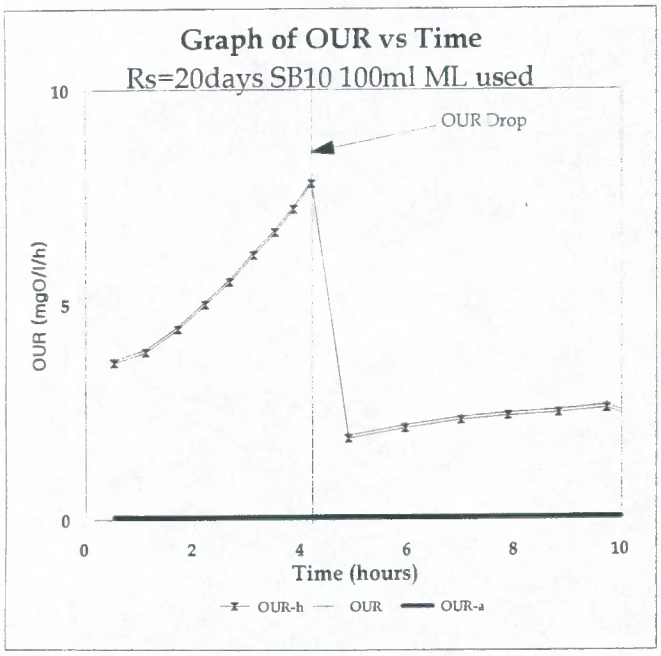
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
548.00	480.00	46.30	0.40	2.15	2.55	43.75	95.57

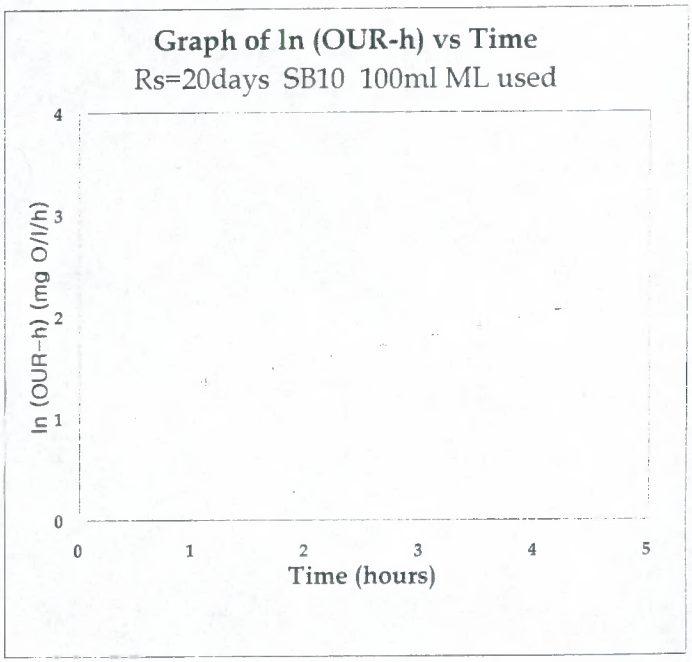
Parent System		fcv=	1.365	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.24733661	3718	200	83.702007	50.33	3.7782484953	1.62	3.18	4.55

0.274777427	3544	200	96.08270529
0.279685024	3634	200	100.2823707
0.26320723	3680	200	95.56879041
0.278466035	3736	200	102.6477787
0.255901641	3744	200	94.53211349
0.227909346	3750	200	84.3264582
0.198636617	3866	200	75.7690105
0.205332631	3790	200	76.78345305

Regression Output:	
Constant	1.64705657
Std Err of Y Est	0.022924527
R Squared	0.991841475
No. of Observations	13
Degrees of Freedom	11
X Coefficient(s)	0.174398596
Std Err of Coef.	0.004769044





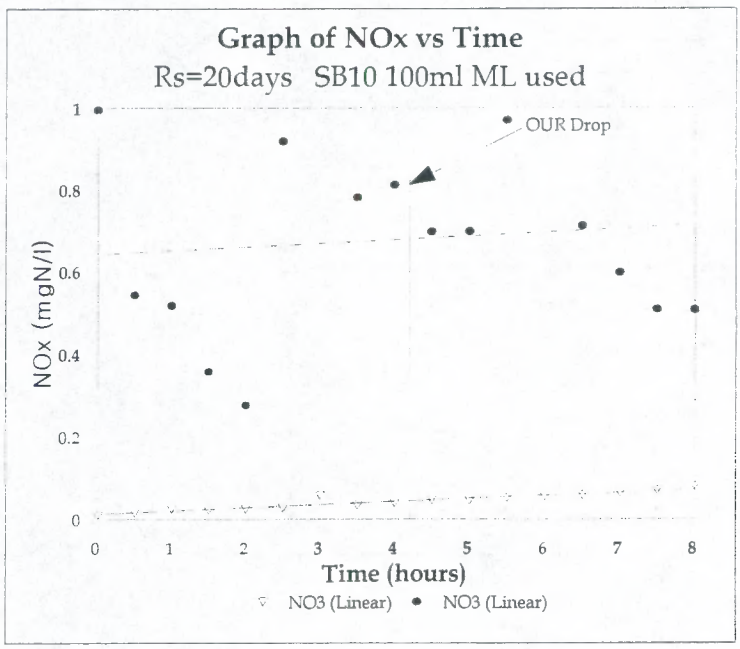


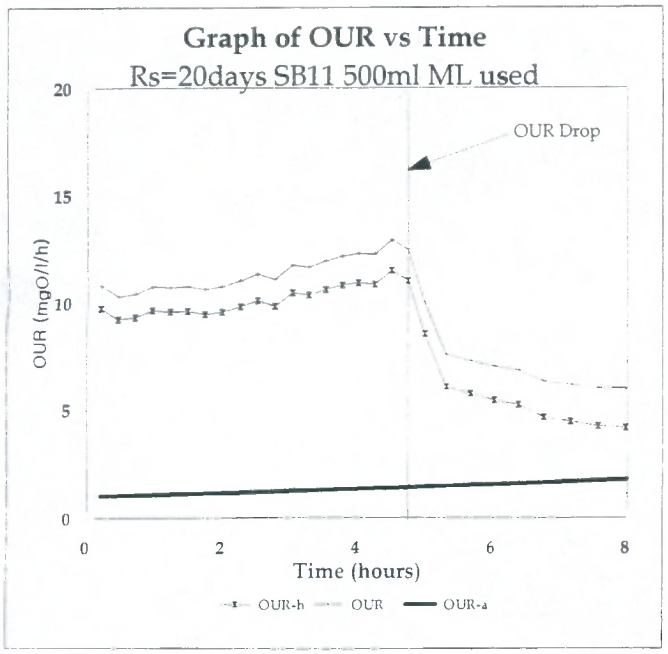
% COD Recovery		End Time=	6.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
347.00	300.00	25.30	0.17	0.27	0.44	24.86	93.62

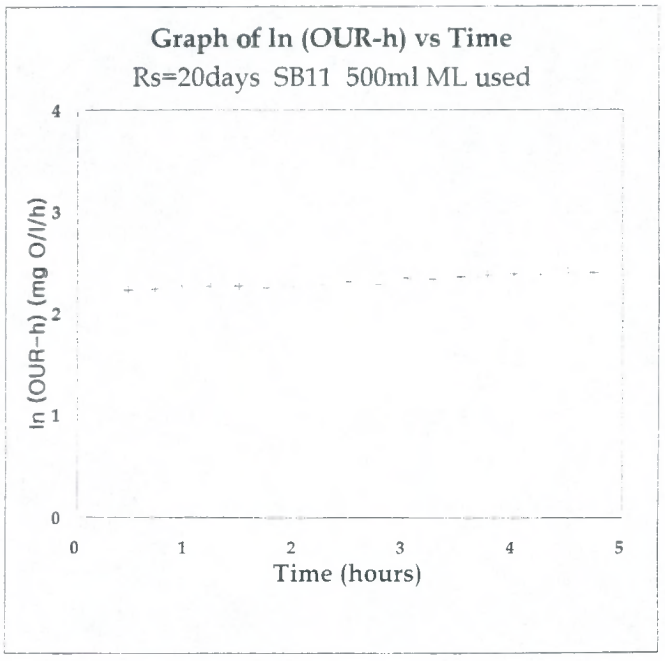
Parent System		fcv=	1.365	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.24733661	3718	100	41.851003	24.88	1.88169812334	1.45	4.38	4.2

0.274777427	3544	100	48.04135264
0.279685024	3634	100	50.14118534
0.26320723	3680	100	47.78439521
0.278466035	3736	100	51.32388936
0.255901641	3744	100	47.26605674
0.227909346	3750	100	42.1632291
0.198636617	3866	100	37.88450525
0.205332631	3790	100	38.39172653

Regression Output:	
Constant	1.135724527
Std Err of Y Est	0.019206418
R Squared	0.995671238
No. of Observations	9
Degrees of Freedom	7
X Coefficient(s)	0.217103326
Std Err of Coef.	0.005410549





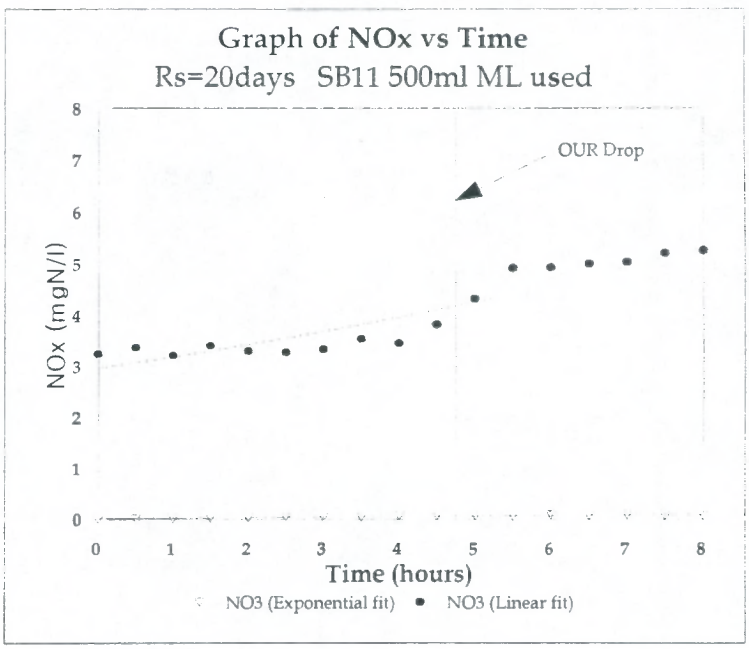


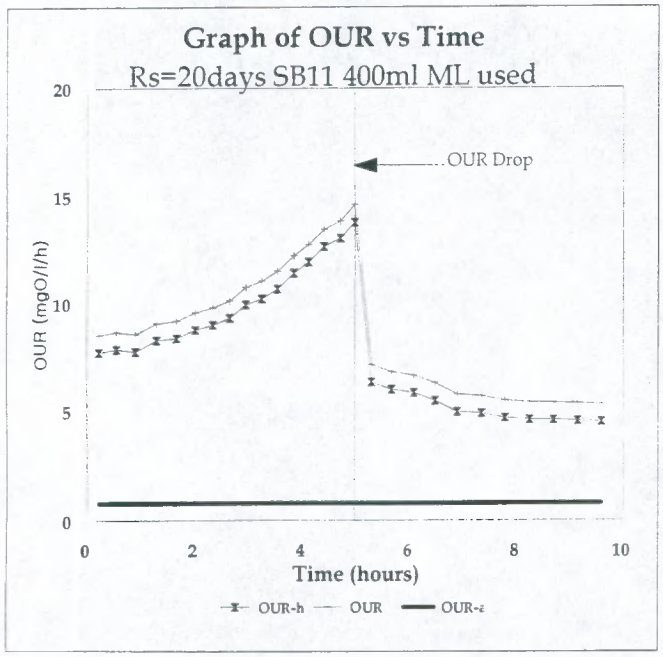
% COD Recovery		End Time=	6.00				
COD t=o	CODt=1	MOt	MOno2	MOno3	MOn	MOc	% Recovery
991.87	919.30	59.80	0.20	7.47	7.66	52.14	97.94

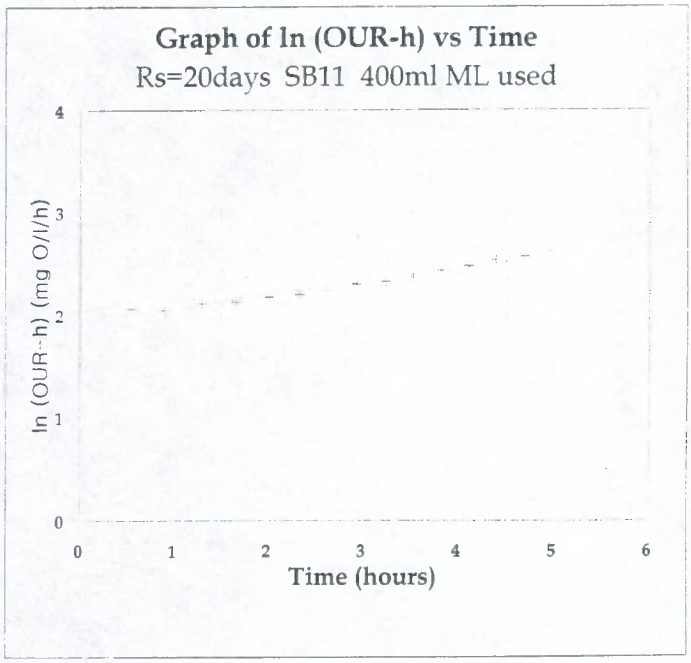
Parent System		fcv=	1.387	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.275208060280881	3396	500	216.0919	258.36	6.08441622127	0.92	0.72	4.743

0.279948764080784	3494	500	241.2747755
0.295933386299902	3394	500	247.7514852
0.277595769511744	3326	500	227.7432706
0.264029297801769	3418	500	222.6048612
0.262458313381084	3502	500	226.71849
0.276504403966408	3418	500	233.1227063
0.270077281663952	3292	500	219.3099548
0.279294813989878	3382	500	232.9951817
0.271223629067278	3338	500	223.3183035

Regression Output:		
Constant		2.209018469
Std Err of Y Est		0.025162475
R Squared		0.859936719
No. of Observations		19
Degrees of Freedom		17
X Coefficient(s)	0.042589806	
Std Err of Coef.	0.004168791	







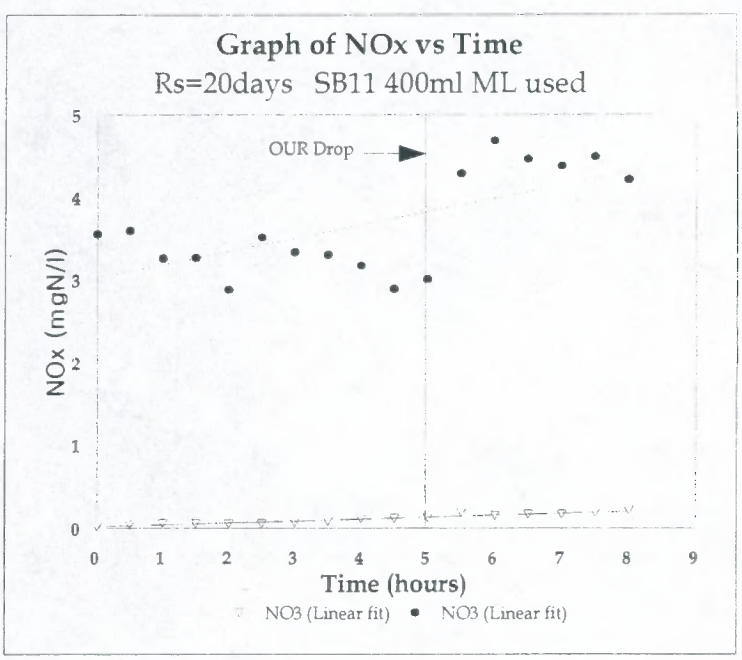
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
826.56	741.89	64.70	0.56	5.11	5.66	59.04	96.90

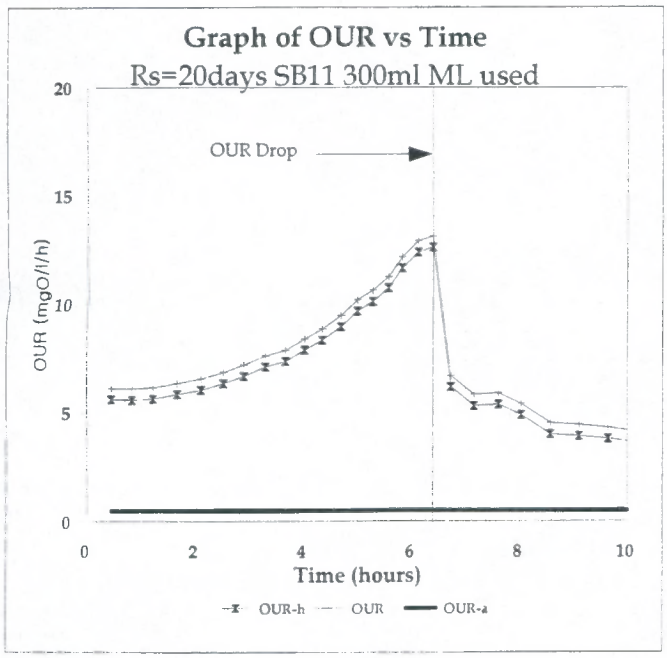
Parent System		fcv=	1.387	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_{H}	t=s
0.275208060280881	3396	400	172.87352	88.65	6.40076319198	1.83	1.85	4.96

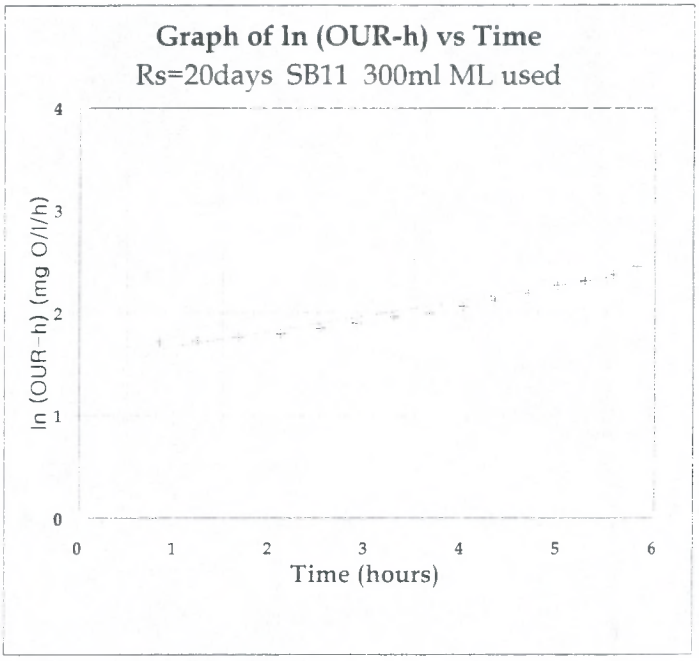
0.279948764080784	3494	400	193.0198204
0.295933386299902	3394	400	198.2011882
0.277595769511744	3326	400	182.1946165
0.264029297801769	3418	400	178.0838889
0.262458313381084	3502	400	181.374792
0.276504403966408	3418	400	186.4981651
0.270077281663952	3292	400	175.4479638
0.279294813989878	3382	400	186.3961454
0.271223629067278	3338	400	178.6546428

Regression Output:

Constant		1.947950236
Std Err of Y Est		0.036080914
R Squared		0.967990237
No. of Observations		16
Degrees of Freedom		14
X Coefficient(s)	0.127754329	
Std Err of Coef.	0.006208938	







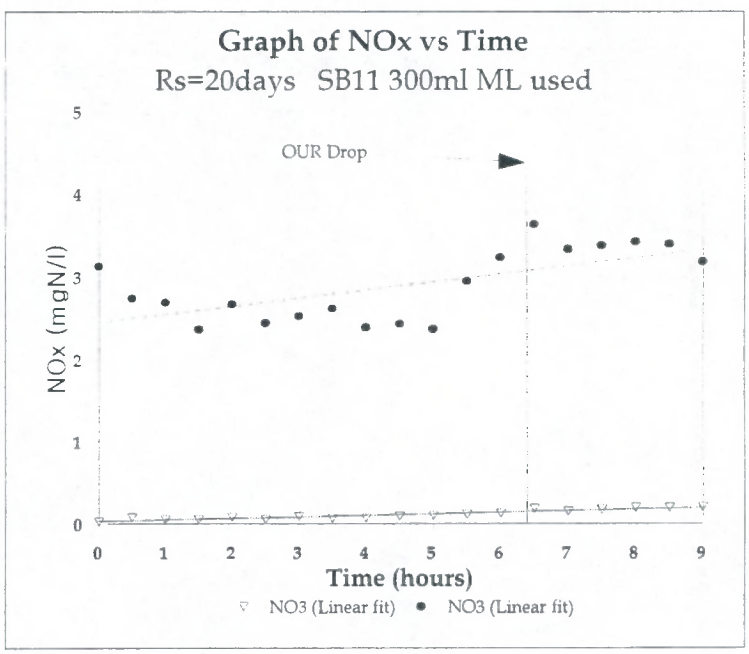
% COD Recovery		End Time=	8.00				
COD t=0	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
649.15	548.35	60.90	0.52	3.56	4.08	56.82	93.23

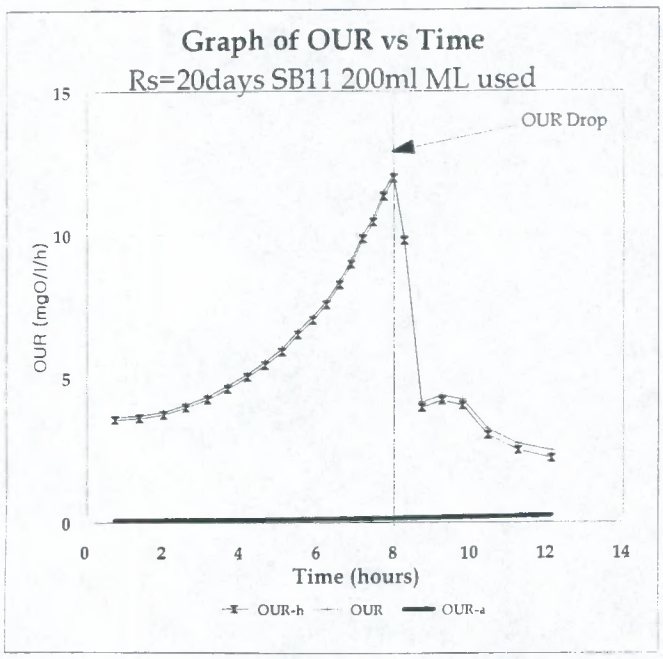
Parent System		fcv=	1.387	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.275208060280881	3396	300	129.65514	51.45	5.33025308662	1.92	2.26	6.39

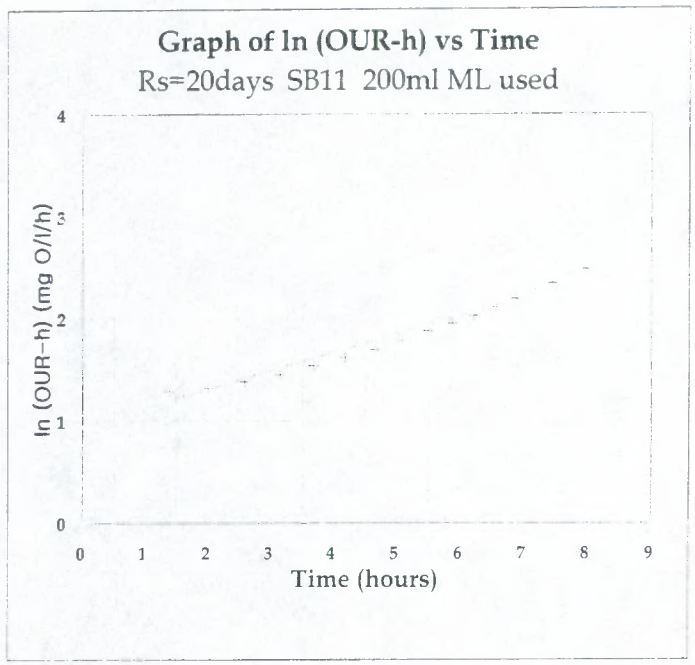
0.279948764080784	3494	300	144.7648653
0.295933386299902	3394	300	148.6508911
0.277595769511744	3326	300	136.6459624
0.264029297801769	3418	300	133.5629167
0.262458313381084	3502	300	136.031094
0.276504403966408	3418	300	139.8736238
0.270077281663952	3292	300	131.5859729
0.279294813989878	3382	300	139.797109
0.271223629067278	3338	300	133.9909821

Regression Output:

Constant		1.529813112
Std Err of Y Est		0.060815615
R Squared		0.957248571
No. of Observations		18
Degrees of Freedom		16
X Coefficient(s)	0.148379357	
Std Err of Coef.	0.007839285	







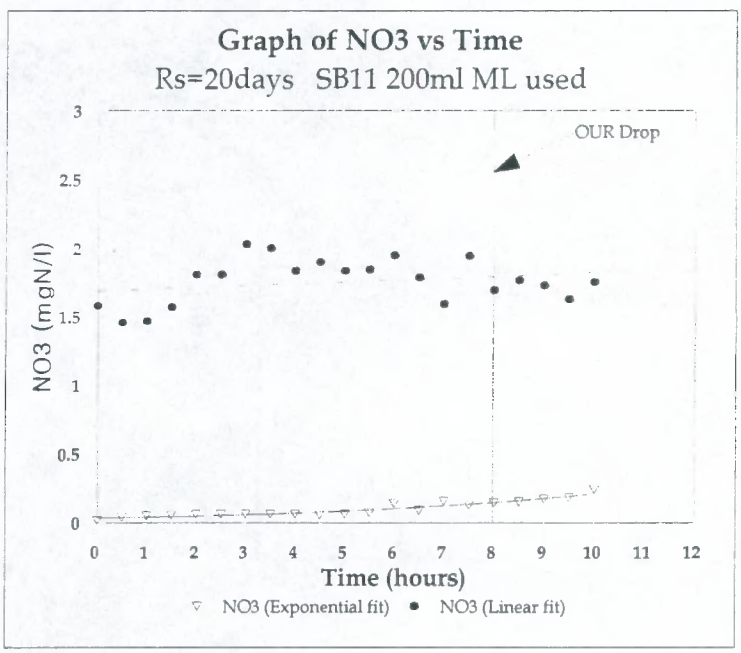
% COD Recovery		End Time=	9.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
453.60	411.26	52.90	0.55	0.58	1.13	51.77	102.08

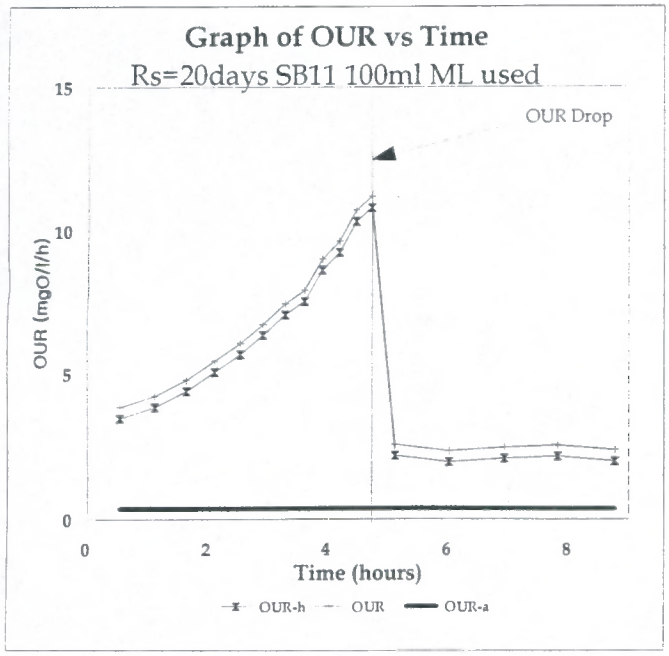
Parent System		fcv=	1.387	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.27520806028088	3396	200	86.43676	24.97	4.01163591547	1.86	3.02	7.98

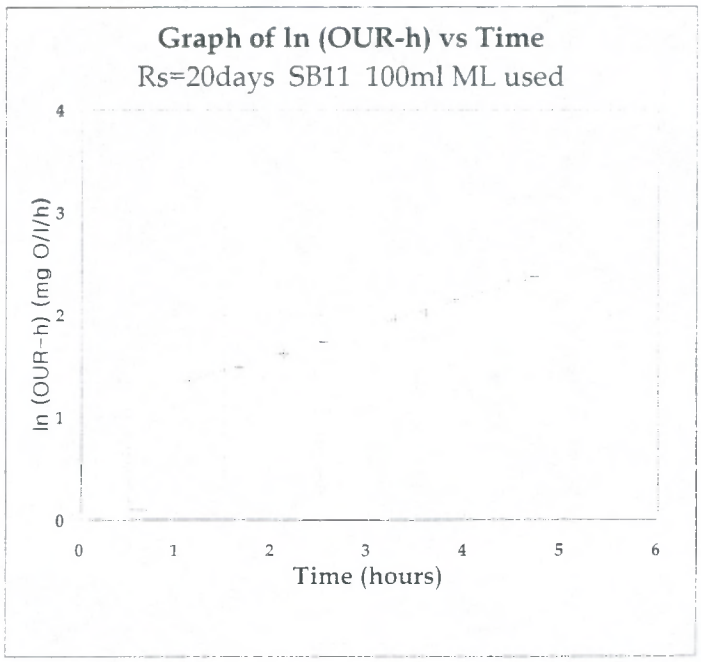
0.27994876408078	3494	200	96.50991019
0.2959333862999	3394	200	99.10059409
0.27759576951174	3326	200	91.09730823
0.26402929780177	3418	200	89.04194447
0.26245831338108	3502	200	90.68739599
0.27650440396641	3418	200	93.24903254
0.27007728166395	3292	200	87.72398191
0.27929481398988	3382	200	93.19807268
0.27122362906728	3338	200	89.32732142

Regression Output:

Constant	0.961763318
Std Err of Y Est	0.08253256
R Squared	0.96194822
No. of Observations	18
Degrees of Freedom	16
X Coefficient(s)	0.177585406
Std Err of Coef.	0.008833991





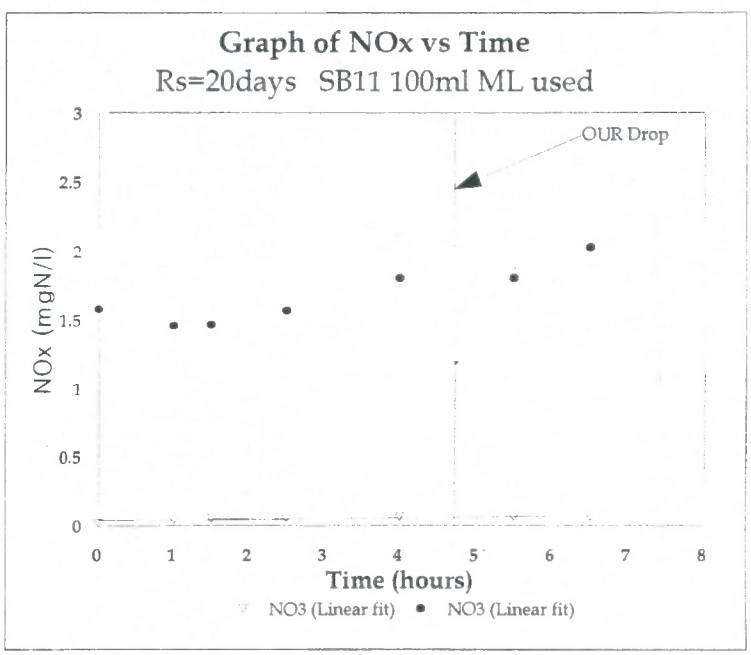


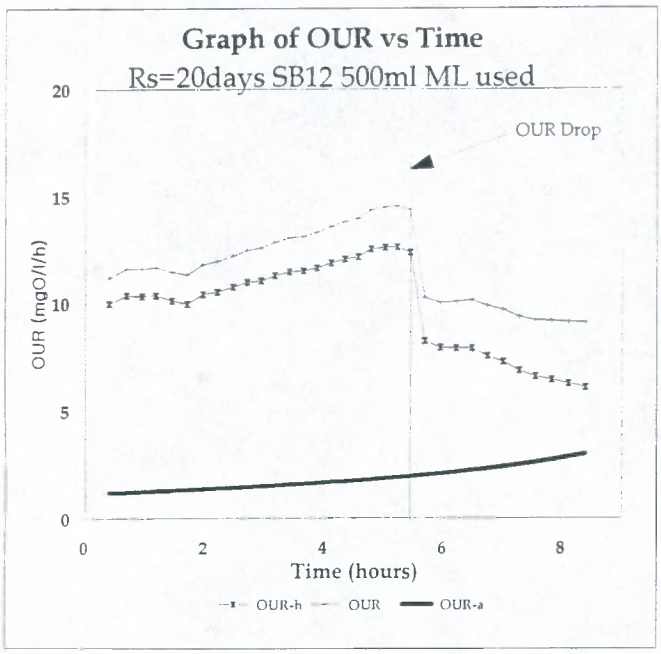
% COD Recovery		End Time=	6.50				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
298.37	239.90	32.80	0.13	2.36	2.49	30.31	90.57

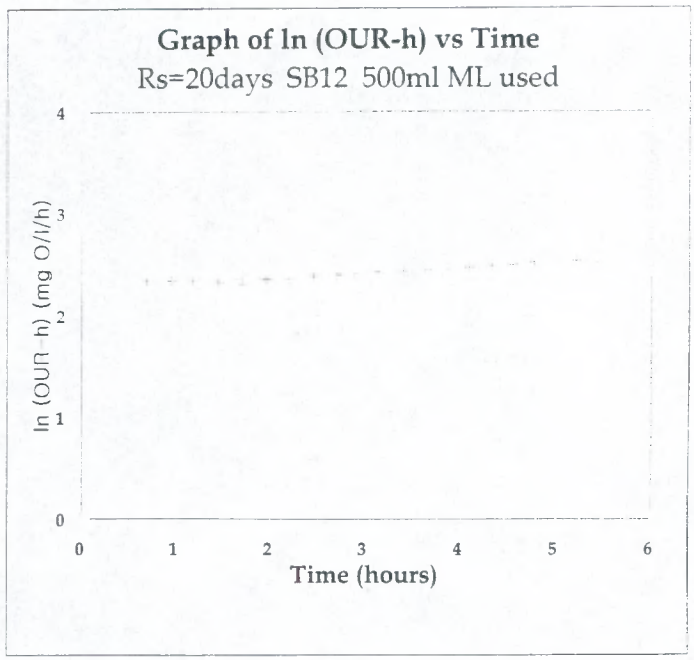
Parent System		fcv=	1.387	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.27520806028088	3396	100	43.21838	17.92	2.19750085429	1.55	5.82	4.72

0.27994876408078	3494	100	48.2549551
0.2959333862999	3394	100	49.55029705
0.27759576951174	3326	100	45.54865412
0.26402929780177	3418	100	44.52097223
0.26245831338108	3502	100	45.343698
0.27650440396641	3418	100	46.62454127
0.27007728166395	3292	100	43.86199095
0.27929481398988	3382	100	46.59903634
0.27122362906728	3338	100	44.66366071

Regression Output:	
Constant	1.042617906
Std Err of Y Est	0.027025237
R Squared	0.995412207
No. of Observations	12
Degrees of Freedom	10
X Coefficient(s)	0.281513261
Std Err of Coef.	0.006043649





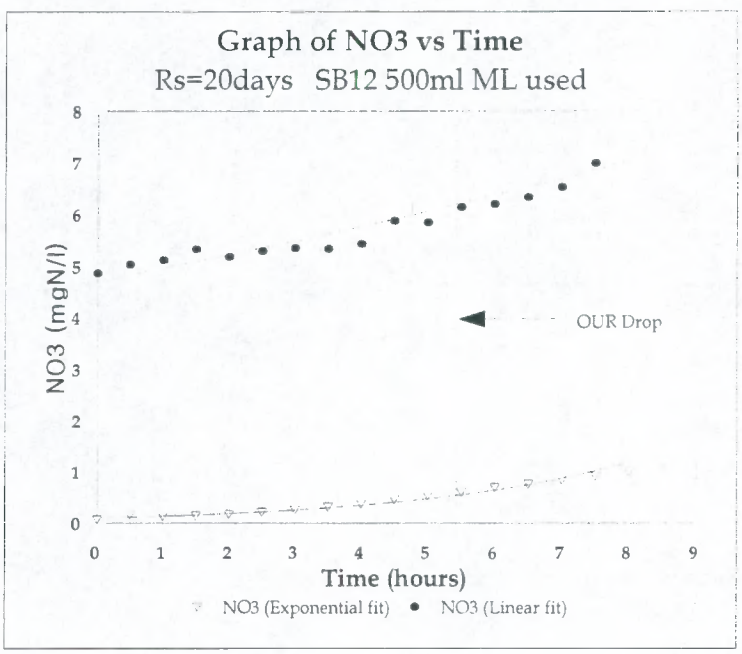


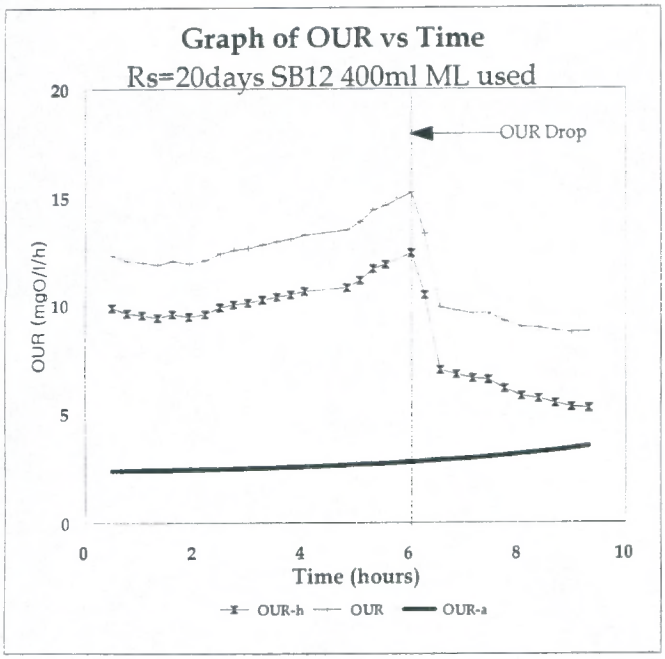
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
956.29	797.57	80.40	2.66	8.99	11.65	68.75	90.59

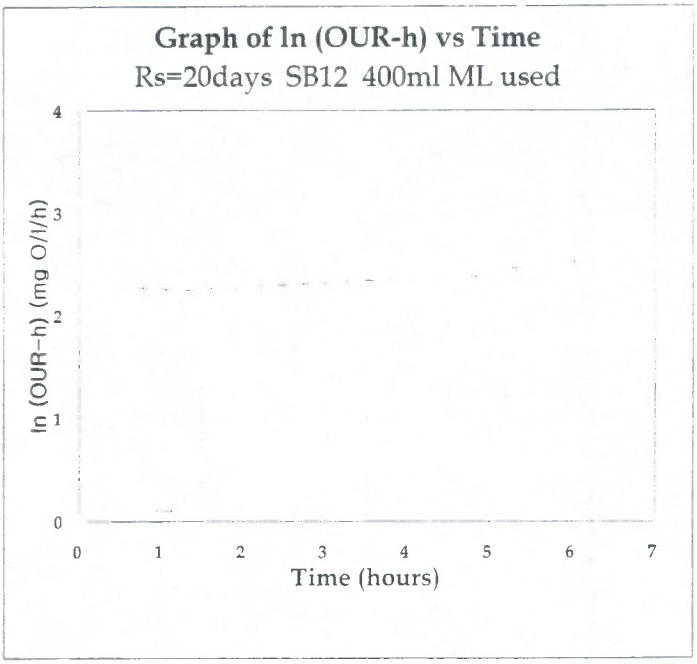
Parent System		fcv=	1.377305676	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.279419002398836	3471	500	222.63305	247.67	8.26411246257	1.22	0.60	5.43

0.262576530153903	3460	500	224.1003159
0.278839930140127	3462	500	238.1181467
0.26354457939007	3438	500	223.4963451
0.282508041727126	3472	500	241.9474205
0.31241967515306	3448	500	265.7150165
0.305198666464373	3466	500	260.9285826
0.263615506083788	3500	500	227.5880536
0.268541916198189	3522	500	233.2984751

Regression Output:		
Constant		2.268242397
Std Err of Y Est		0.019900847
R Squared		0.94065462
No. of Observations		22
Degrees of Freedom		20
X Coefficient(s)	0.049899447	
Std Err of Coef.	0.002802587	







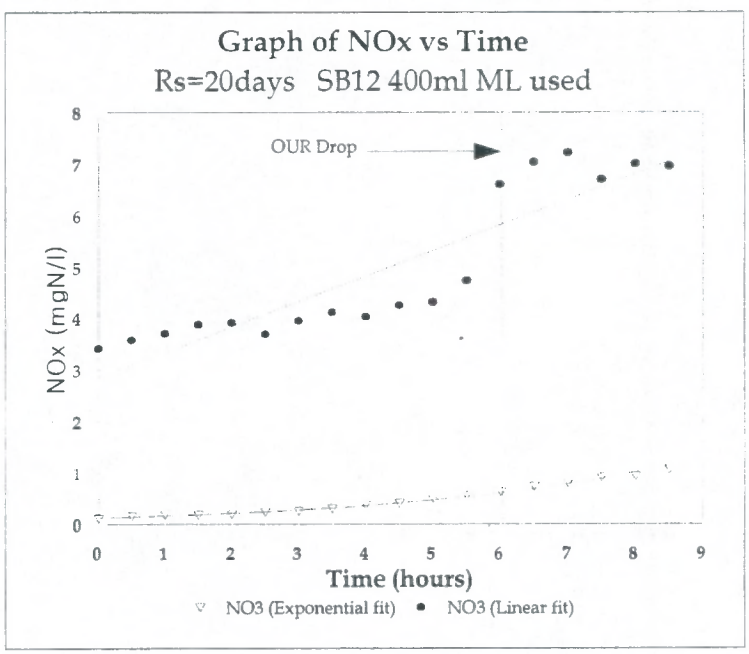
% COD Recovery		End Time=	7.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
872.96	726.14	84.30	2.25	15.88	18.13	66.17	90.76

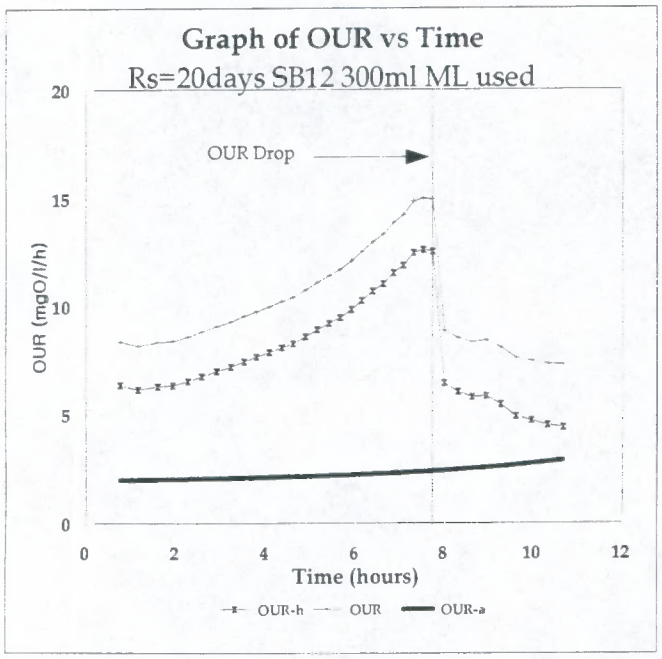
Parent System		fcv=	1.377305676	Batch Result				
fav	Xv	VML	ZBH(Theo),BT	ZBH(O)	OURSBCOD	KMP	UH	t=s
0.279419002398836	3471	400	178.10644	247.54	7.01628098711	1.04	0.66	6.03

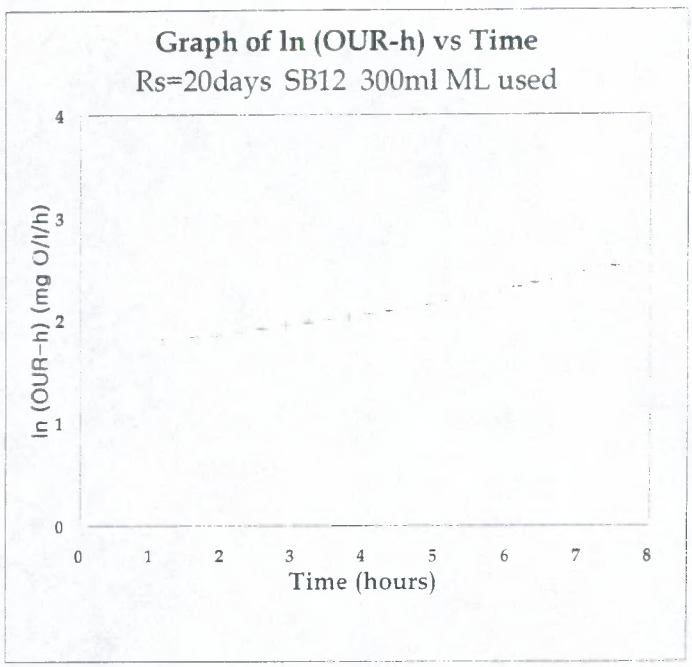
0.262576530153903	3460	400	179.2802527
0.278839930140127	3462	400	190.4945174
0.26354457939007	3438	400	178.7970761
0.282508041727126	3472	400	193.5579364
0.31241967515306	3448	400	212.5720132
0.305198666464373	3466	400	208.7428661
0.263615506083788	3500	400	182.0704429
0.268541916198189	3522	400	186.6387801

Regression Output:

Constant	2.195970181
Std Err of Y Est	0.030695896
R Squared	0.86653015
No. of Observations	19
Degrees of Freedom	17
X Coefficient(s)	0.044654852
Std Err of Coef.	0.004250538







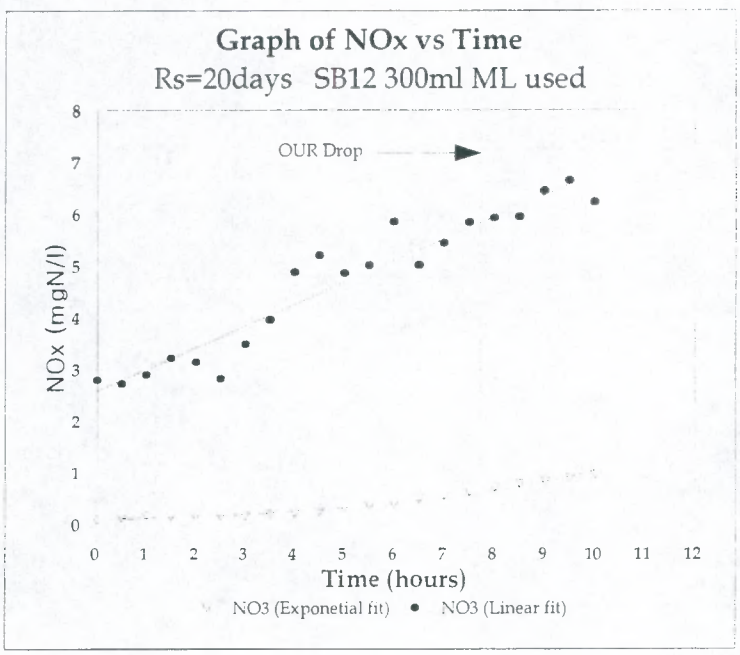
% COD Recovery		End Time=	8.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
666.62	579.33	77.50	1.89	15.37	17.26	60.24	95.94

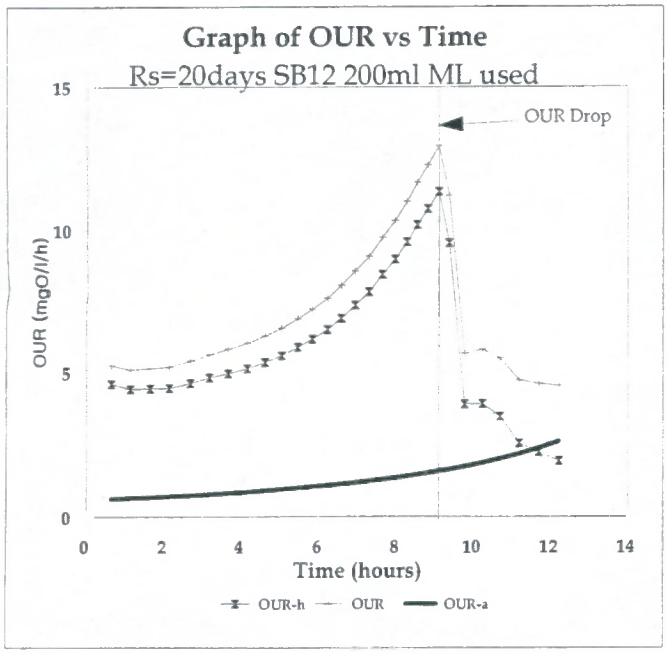
Parent System		fcv=	1.377305676	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.279419002398836	3471	300	133.57983	71.77	6.45555283103	1.80	1.54	7.72

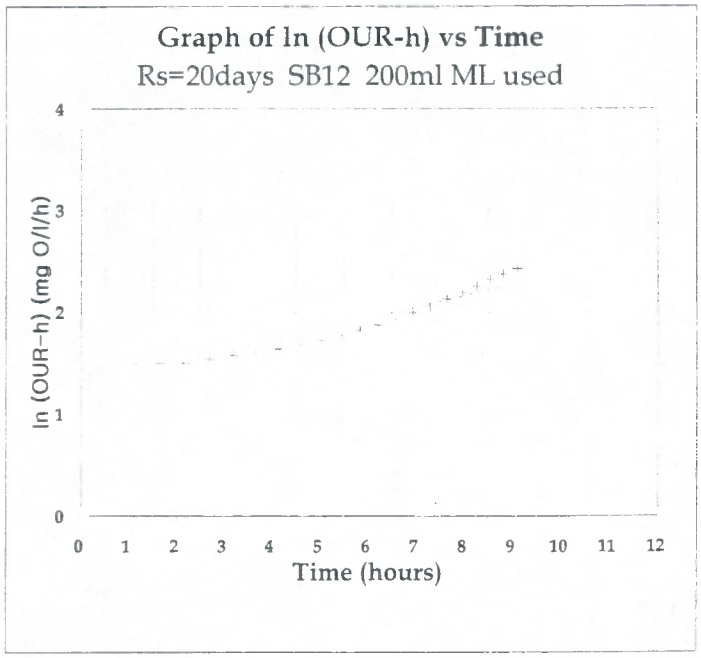
0.262576530153903	3460	300	134.4601896
0.278839930140127	3462	300	142.870888
0.26354457939007	3438	300	134.0978071
0.282508041727126	3472	300	145.1684523
0.31241967515306	3448	300	159.4290099
0.305198666464373	3466	300	156.5571495
0.263615506083788	3500	300	136.5528322
0.268541916198189	3522	300	139.9790851

Regression Output:

Constant		1.637341065
Std Err of Y Est		0.041587066
R Squared		0.971198378
No. of Observations		26
Degrees of Freedom		24
X Coefficient(s)	0.113236135	
Std Err of Coef.	0.003980466	





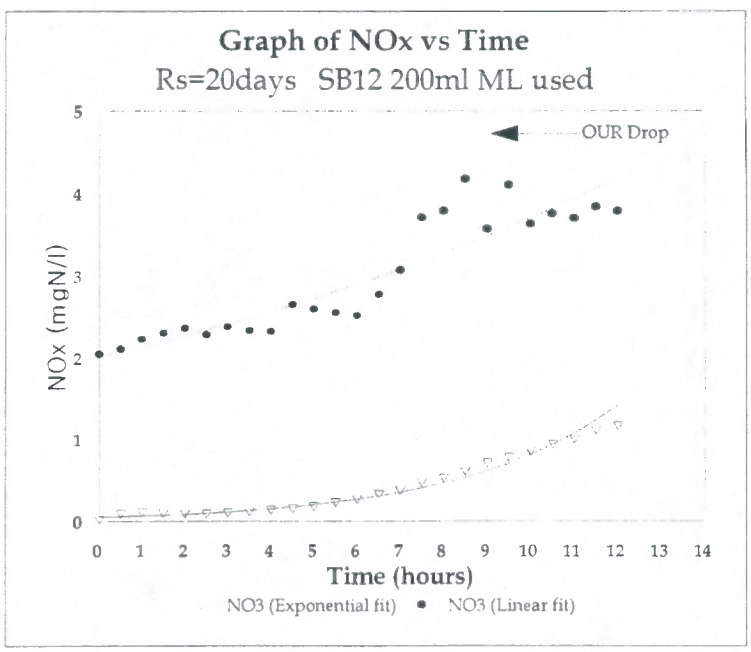


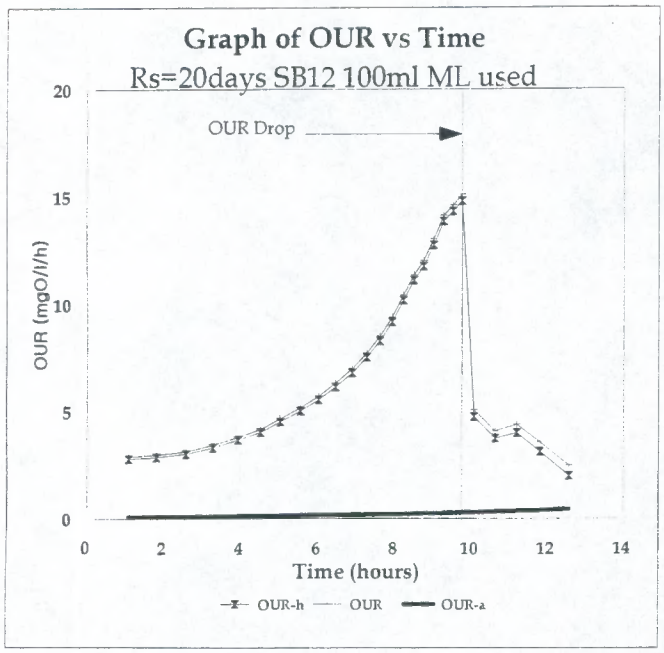
% COD Recovery		End Time=	11.00				
COD t=o	CODt=f	MOt	MOno2	MOno3	MOn	MOc	% Recovery
516.00	428.00	73.50	3.53	8.80	12.33	61.17	94.80

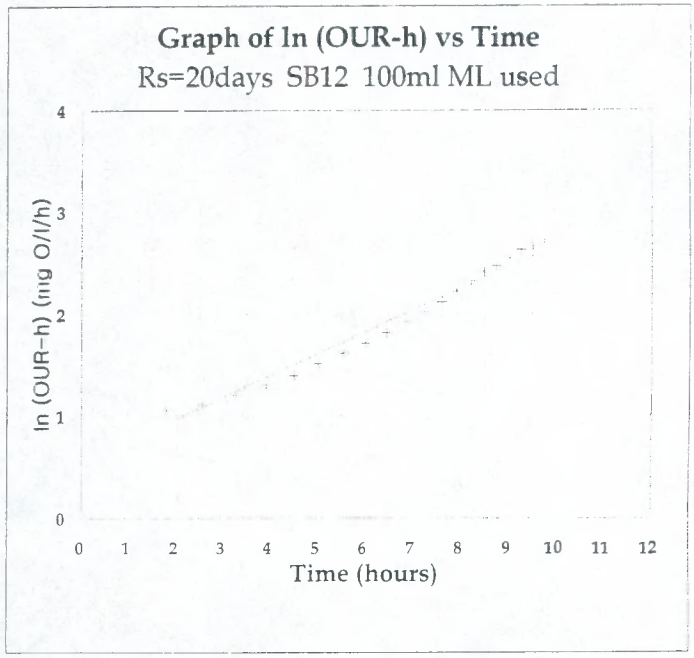
Parent System		fcv=	1.377305676	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.27941900239884	3471	200	89.05322	48.46	3.93104728479	1.37	1.99	9.1

0.2625765301539	3460	200	89.64012637
0.27883993014013	3462	200	95.2472587
0.26354457939007	3438	200	89.39853804
0.28250804172713	3472	200	96.77896819
0.31241967515306	3448	200	106.2860066
0.30519866646437	3466	200	104.371433
0.26361550608379	3500	200	91.03522143
0.26854191619819	3522	200	93.31939005

Regression Output:		
Constant		1.25163359
Std Err of Y Est		0.093398719
R Squared		0.915949395
No. of Observations		22
Degrees of Freedom		20
X Coefficient(s)	0.114198101	
Std Err of Coef.	0.007735325	







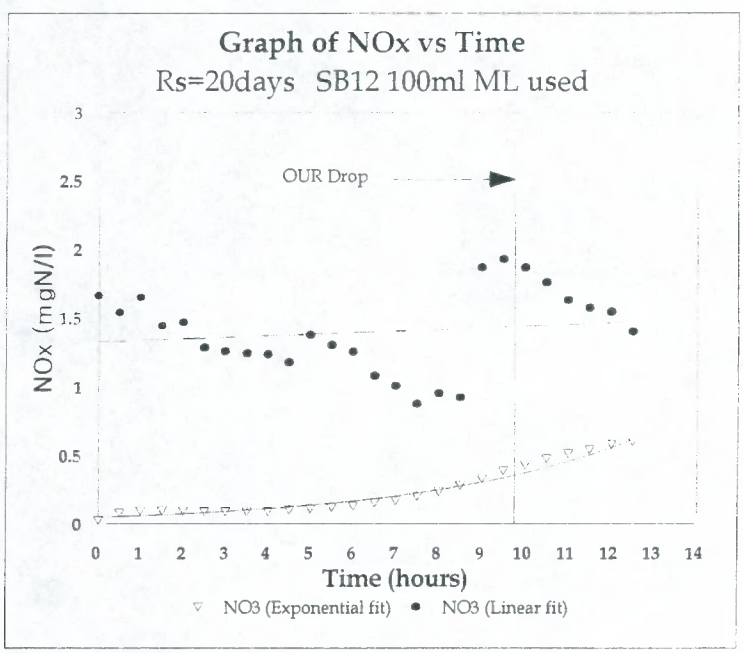
% COD Recovery		End Time=	12.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
390.00	274.00	66.10	1.74	0.63	2.38	63.72	86.60

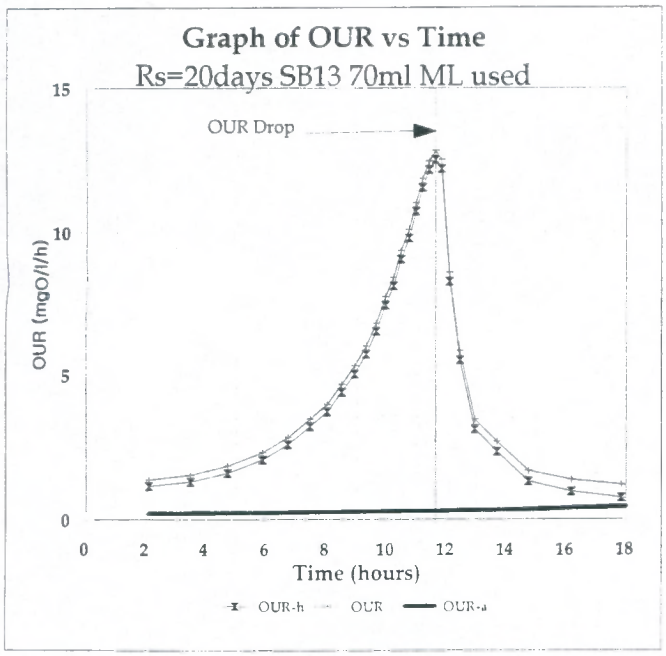
Parent System		fcv=	1.377305676	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.27941900239884	3471	100	44.52661	14.01	3.75568090612	1.61	4.13	9.752

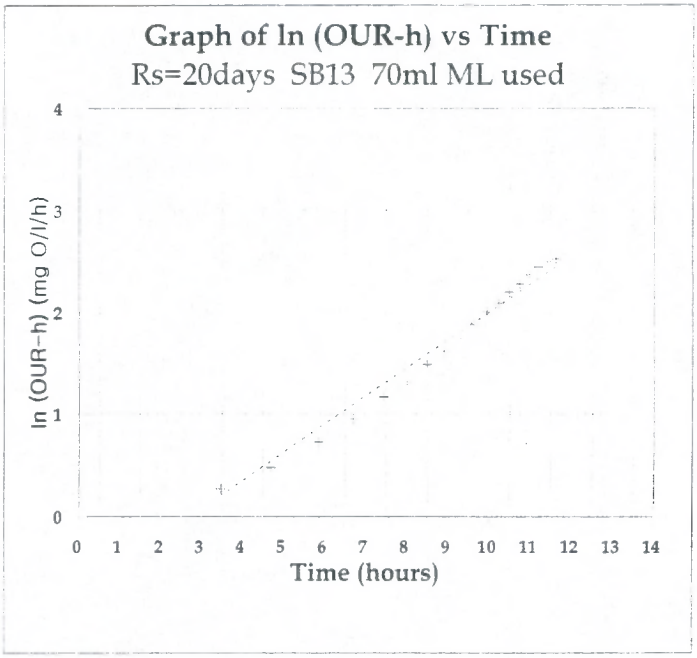
0.2625765301539	3460	100	44 82006319
0.27883993014013	3462	100	47 62362935
0.26354457939007	3438	100	44.69926902
0.28250804172713	3472	100	48.3894841
0.31241967515306	3448	100	53.1430033
0.30519866646437	3466	100	52.18571651
0.26361550608379	3500	100	45.51761072
0.26854191619819	3522	100	46.65969502

Regression Output:

Constant	0.544774985
Std Err of Y Est	0.105978792
R Squared	0 967475405
No. of Observations	21
Degrees of Freedom	19
X Coefficient(s)	0.213010968
Std Err of Coef.	0.008960065



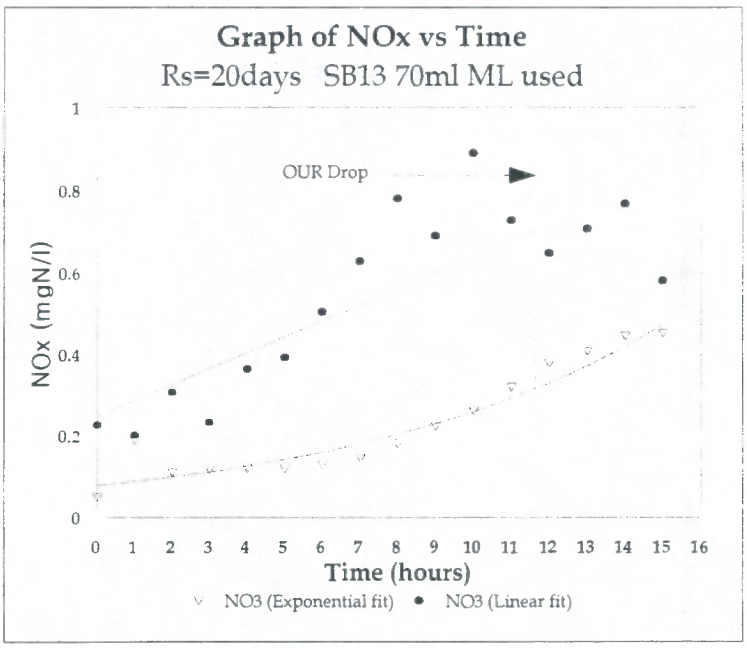


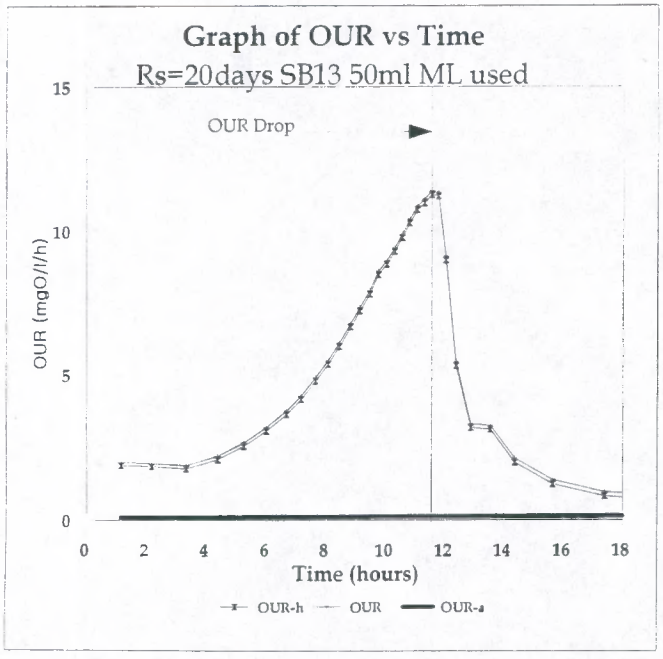


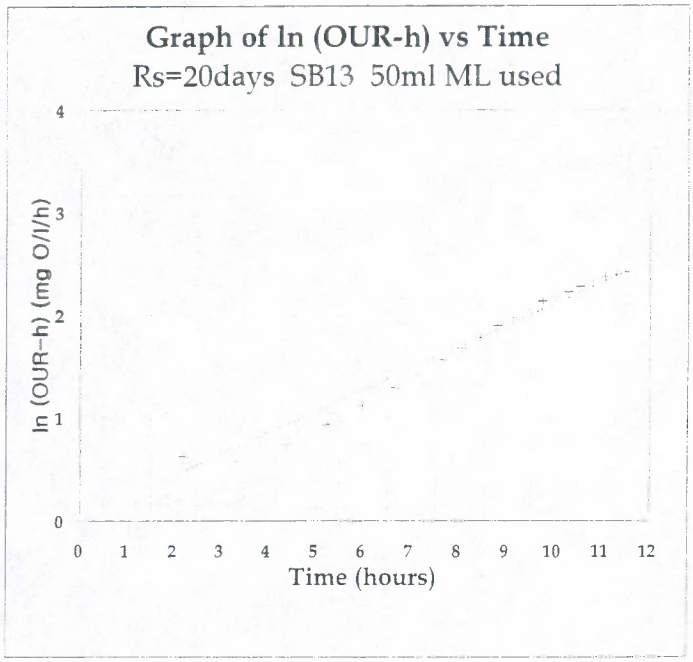
% COD Recovery		End Time=	14.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
307.38	207.58	58.50	1.17	2.50	3.67	54.83	85.37

Parent System		fcv=	1.376889252	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.31037841451517	3262.666667	70	32.534191	3.03	1.05629035862	0.67	6.57	11.623
0.3257481295905	3114	70	35.02991146					
0.30028340039593	3356	70	34.80100437					
0.30585776249758	3318	70	35.0456718					

Regression Output:		
Constant		-0.63513526
Std Err of Y Est		0.128913128
R Squared		0.972203646
No. of Observations		19
Degrees of Freedom		17
X Coefficient(s)	0.265832051	
Std Err of Coef.	0.010901799	



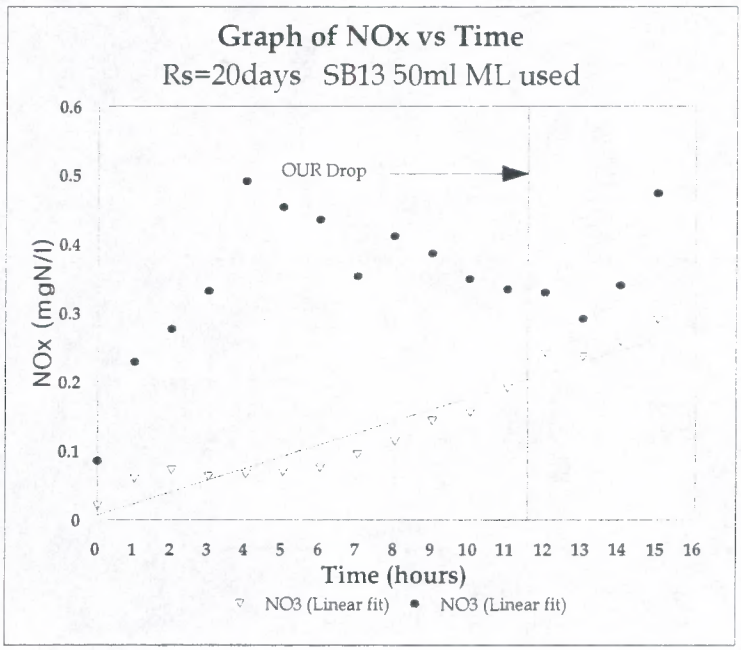




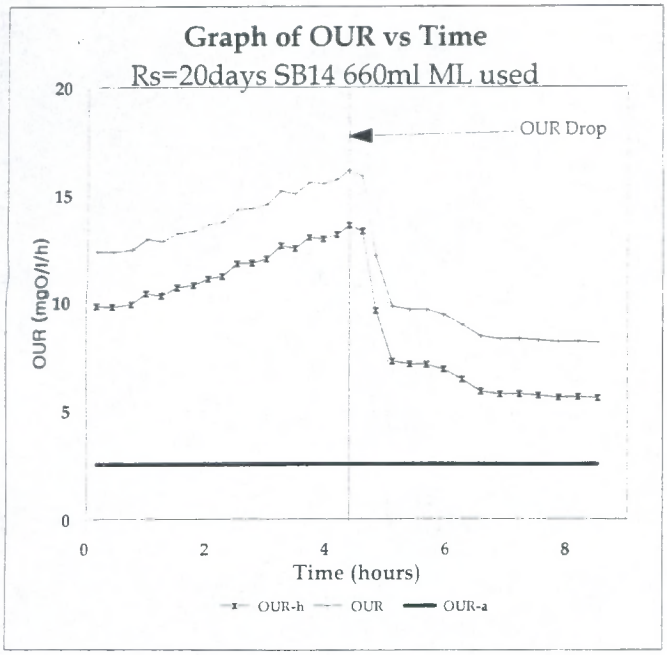
% COD Recovery		End Time=	14.00				
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recovery
293.41	175.65	61.30	0.82	0.83	1.65	59.65	80.19

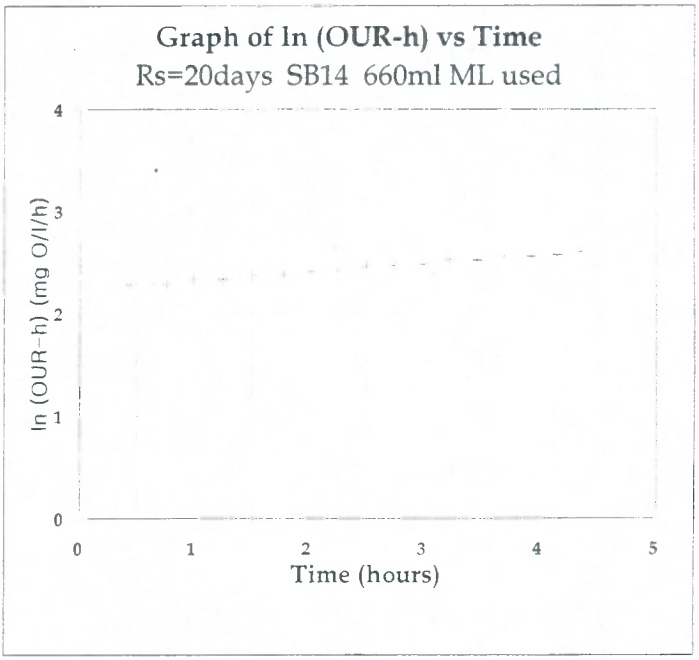
Parent System		fcv=	1.376889252	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.31037841451517	3262.666667	50	23.238708	8.50	3.12535506055	1.58	4.05	11.535

0.3257481295905	3114	50	25.02136533
0.30028340039593	3356	50	24.85786026
0.30585776249758	3318	50	25.03262271



Regression Output:			
Constant			0.026869671
Std Err of Y Est			0.128544379
R Squared			0.962152481
No. of Observations			22
Degrees of Freedom			20
X Coefficient(s)		0.208839648	
Std Err of Coef.		0.009261785	



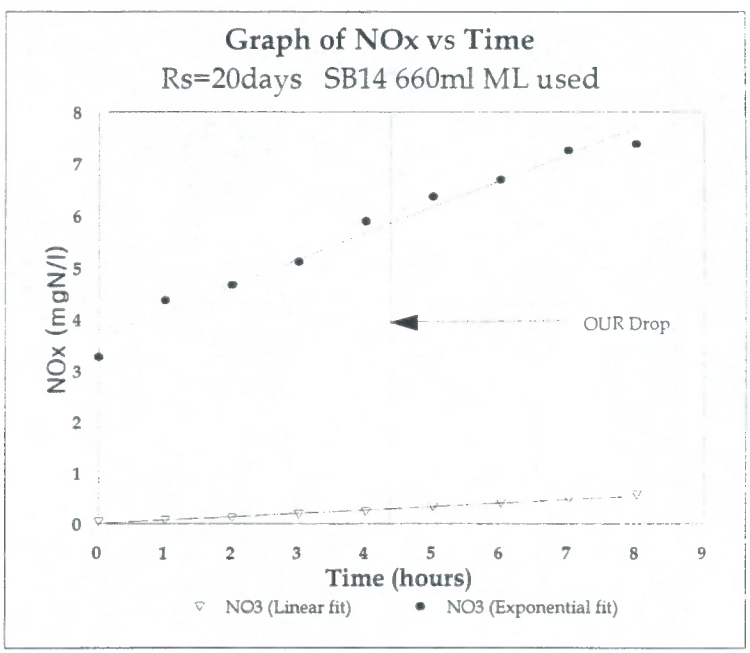


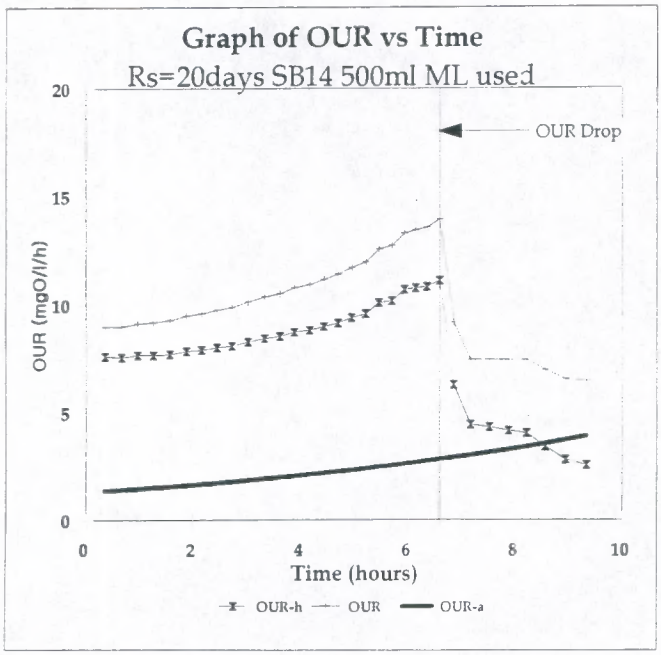
% COD Recovery		End Time=	8.00					$COD_{filt.}$	234	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/	Xo(mgMLVSS/l)	So/Xo
944.00	828.00	92.90	1.85	18.50	20.35	72.55	95.40	182.52	549.32	0.33227
								So(mgCOD/	Xo(mgMLAVSS/	So/Xo
								182.52	156.93	1.16304

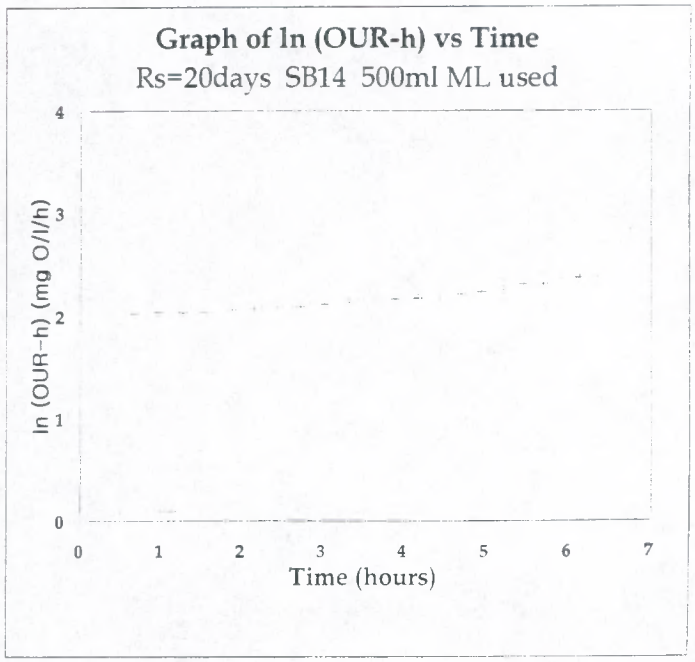
Parent System		fcv=	1.378	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.286	2496.88889	660	216.20106	169.23	7.306302408	1.44	1.16	4.36

0.288	2448	660	229.1793949
0.283	2458	660	226.6606176
0.266	2454	660	212.4310362
0.314	2450	660	250.7000834
0.288	2504	660	234.7194659
0.284	2528	660	234.1183517
0.292	2548	660	242.5256536
0.284	2498	660	231.1911407
0.272	2584	660	229.2348344

Regression Output:	
Constant	2.247091561
Std Err of Y Est	0.014269437
R Squared	0.983942664
No. of Observations	18
Degrees of Freedom	16
X Coefficient(s)	0.082683703
Std Err of Coef.	0.002640656





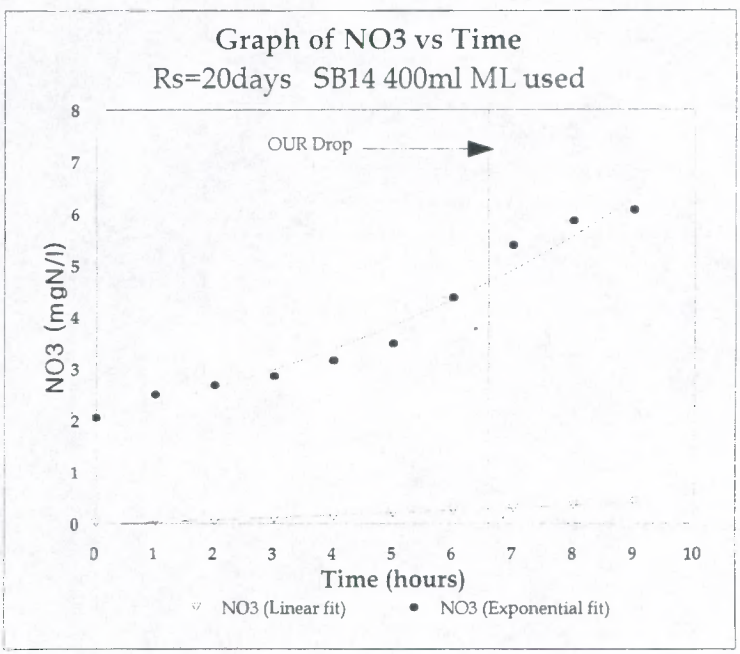


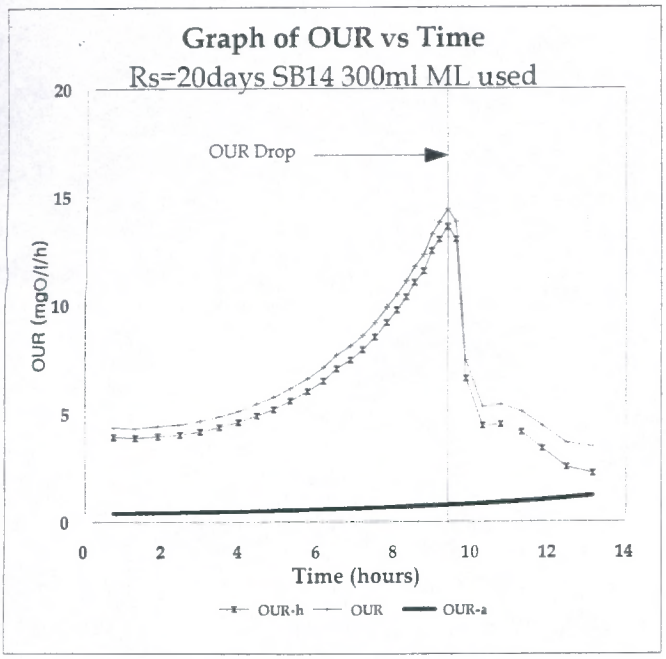
% COD Recovery		End Time=	9.00					$COD_{filt.}$	236	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/	Xo(mgMLVSS/l)	So/Xo
788.00	688.00	83.00	1.45	19.43	20.88	62.12	95.19	196.67	416.15	0.4726
								So(mgCOD/	Xo(mgMLAVSS/	So/Xo
Parent System		fcv=	1.378	Batch Result				196.67	118.89	1.6542
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s		
0.286	2496.888889	500	163.78868	150.74	4.414048368	0.92	1.24	6.58		

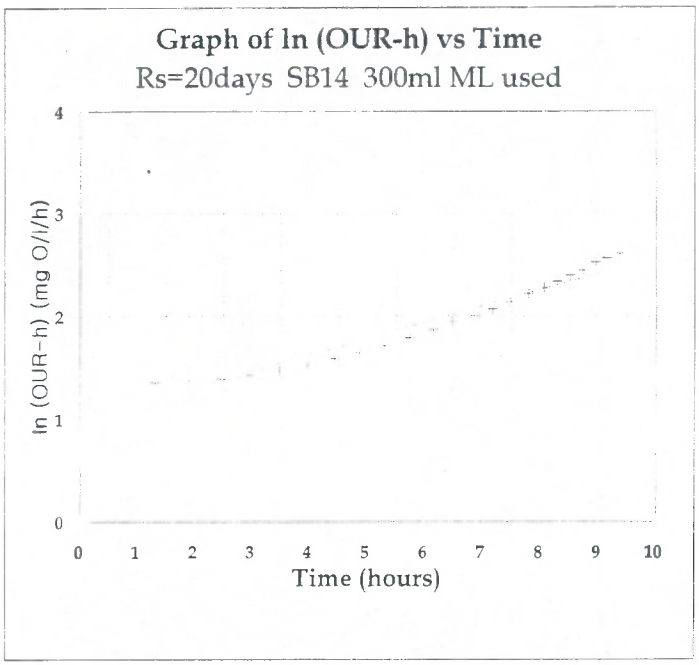
0.288	2448	500	173.6207537
0.283	2458	500	171.7125891
0.266	2454	500	160.9326032
0.314	2450	500	189.9243056
0.288	2504	500	177.8177772
0.284	2528	500	177.3623877
0.292	2548	500	183.7315558
0.284	2498	500	175.1448035
0.272	2584	500	173.6627534

Regression Output:

Constant		1.944767577
Std Err of Y Est		0.03185799
R Squared		0.940515674
No. of Observations		24
Degrees of Freedom		22
X Coefficient(s)	0.064205862	
Std Err of Coef.	0.003442561	





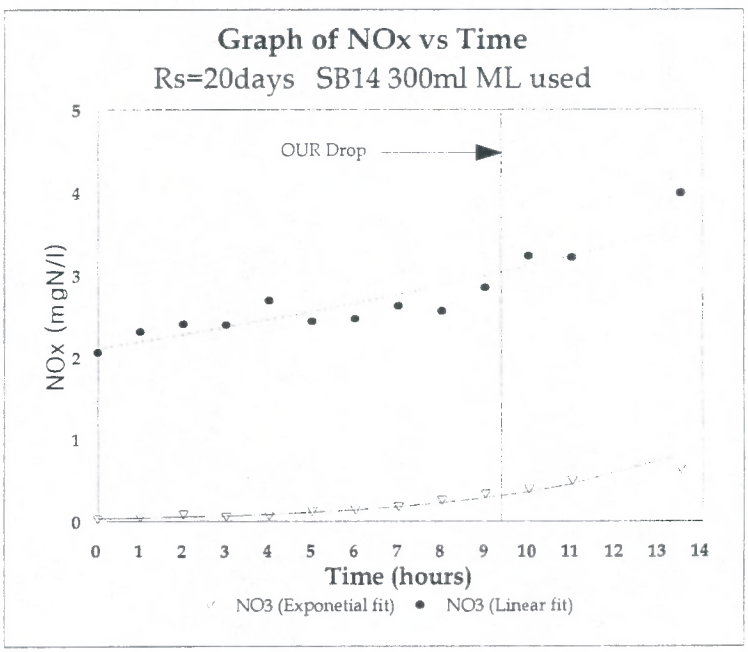


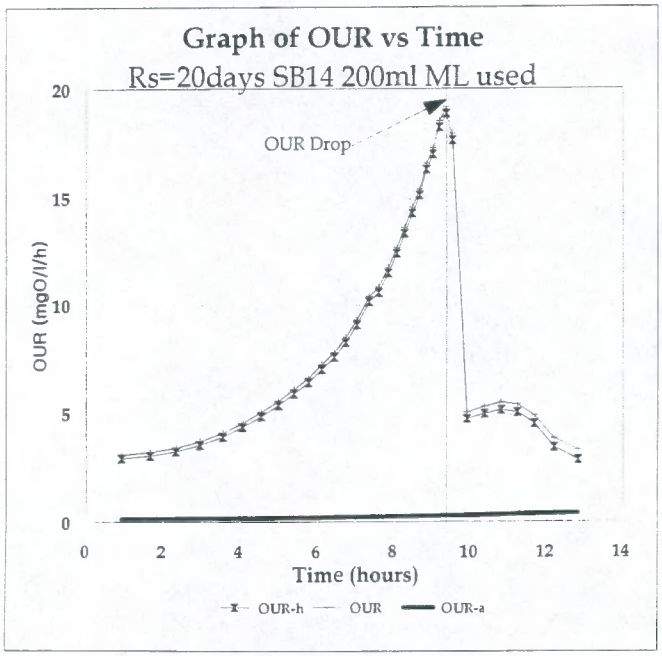
% COD Recovery		End Time=	10.50					CODfilt.	225.792	
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Recov	So(mgCOD/l	Xo(mgMLVSS/l)	So/Xo
666.62	579.33	68.90	1.28	4.89	6.17	62.73	96.32	203.2128	249.69	0.8139
								So(mgCOD/l	Xo(mgMLAVSS/l	So/Xo
Parent System		fcv=	1.378	Batch Result				203.2128	71.33	2.8488
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s		
0.286	2496.888889	300	98.27321	28.80	4.440568853	1.69	2.71	9.371		

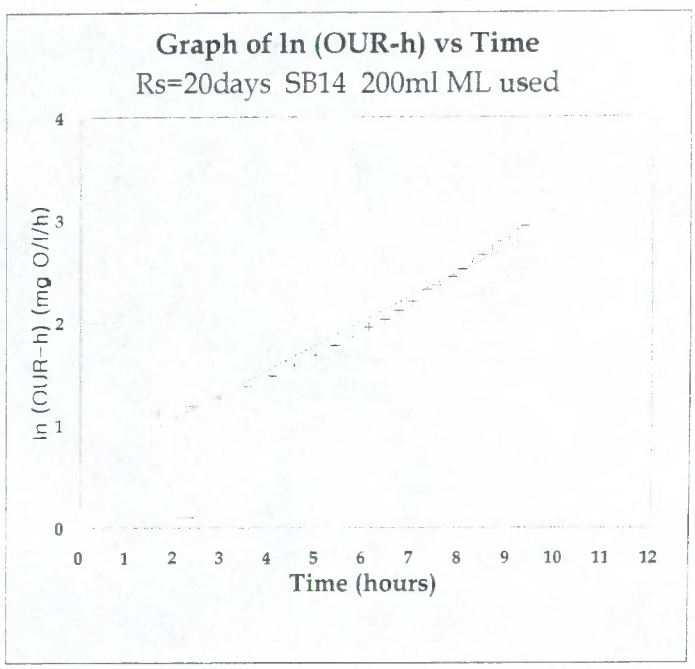
0.288	2448	300	104.1724522
0.283	2458	300	103.0275534
0.266	2454	300	96.55956193
0.314	2450	300	113.9545834
0.288	2504	300	106.6906663
0.284	2528	300	106.4174326
0.292	2548	300	110.2389335
0.284	2498	300	105.0868821
0.272	2584	300	104.197652

Regression Output:

Constant		1.000162064
Std Err of Y Est		0.103727242
R Squared		0.94475111
No. of Observations		24
Degrees of Freedom		22
X Coefficient(s)	0.157405545	
Std Err of Coef.	0.008115434	





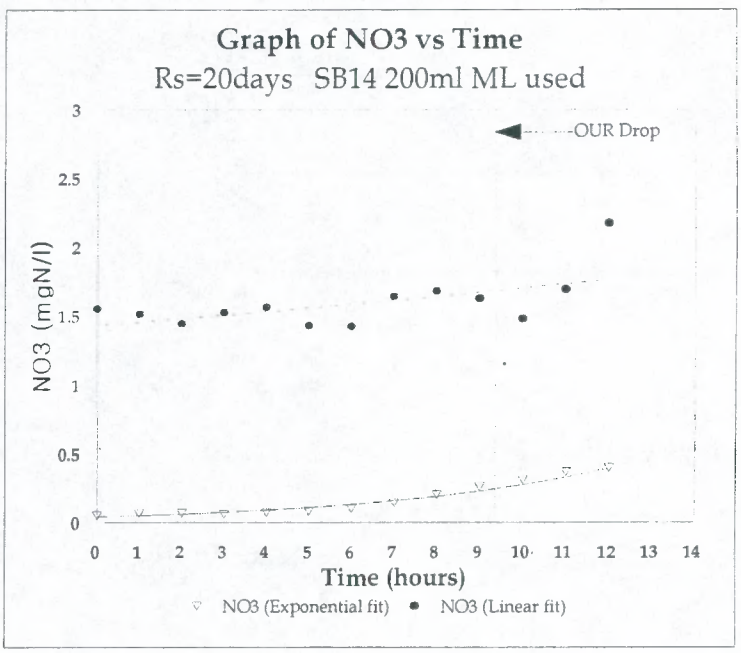


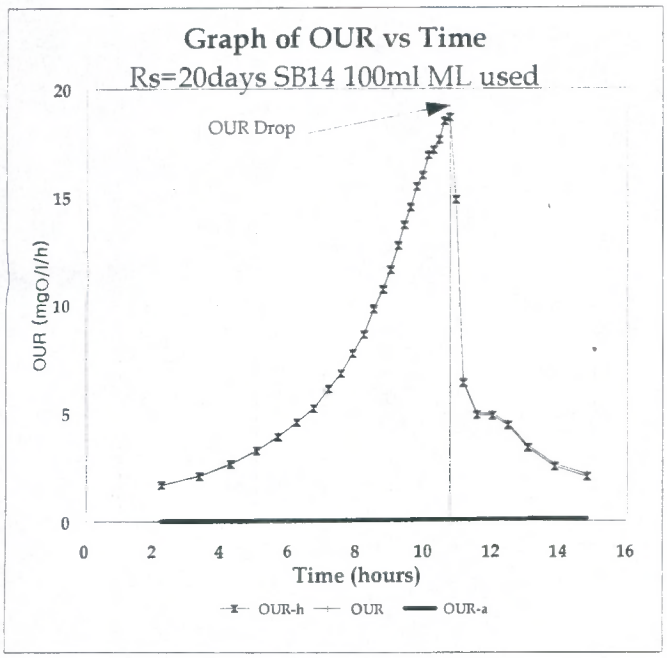
% COD Recovery		End Time=	12.00					$COD_{filt.}$	239.904	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/l	Xo(mgMLVSS/l)	So/Xo
451.58	328.61	79.30	1.22	1.52	2.75	76.55	89.72	223.91	166.46	1.34514
								So(mgCOD/l	Xo(mgMLAVSS/l)	So/Xo
								223.91	47.56	4.70837

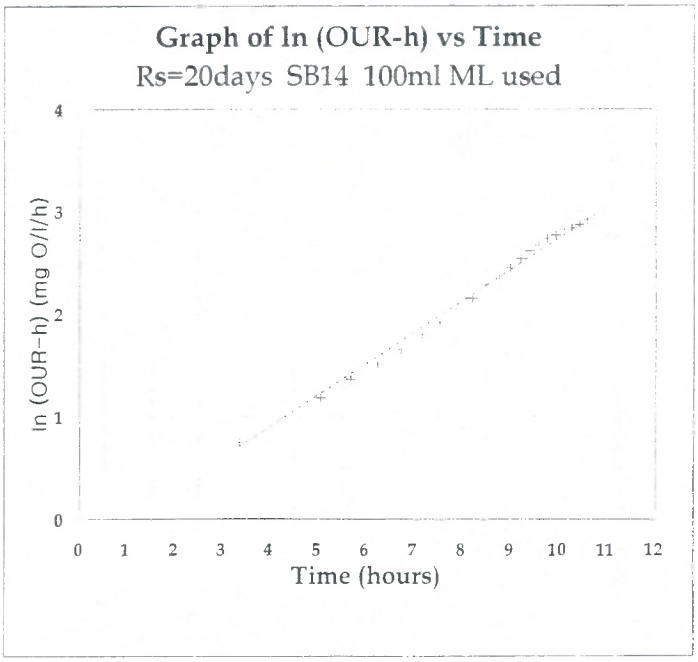
Parent System		fcv=	1.378	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.286	2496.888889	200	65.515473	13.26	4.742502669	1.84	4.51	9.36

0.288	2448	200	69.44830148
0.283	2458	200	68.68503562
0.266	2454	200	64.37304129
0.314	2450	200	75.96972225
0.288	2504	200	71.12711088
0.284	2528	200	70.94495507
0.292	2548	200	73.49262231
0.284	2498	200	70.05792141
0.272	2584	200	69.46510134

Regression Output:	
Constant	0.590793074
Std Err of Y Est	0.099524136
R Squared	0.974024597
No. of Observations	25
Degrees of Freedom	23
X Coefficient(s)	0.238426635
Std Err of Coef.	0.00811871





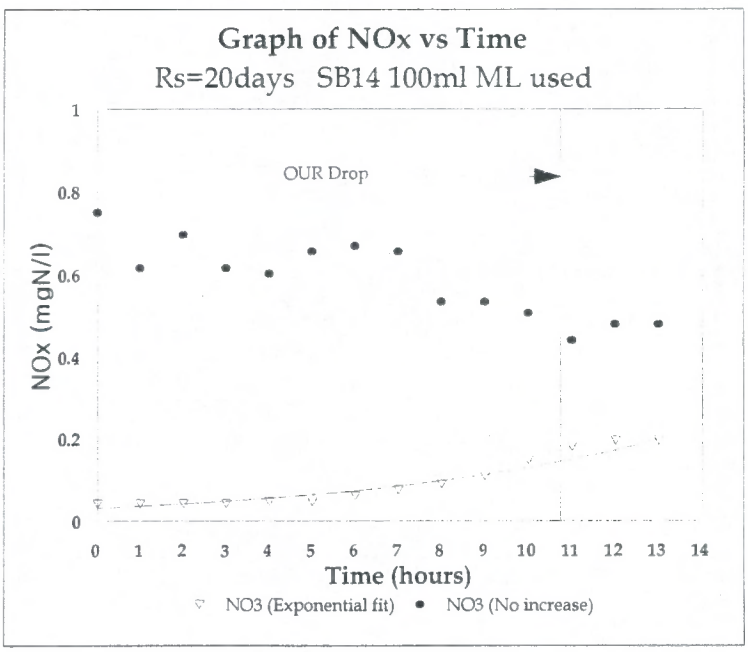


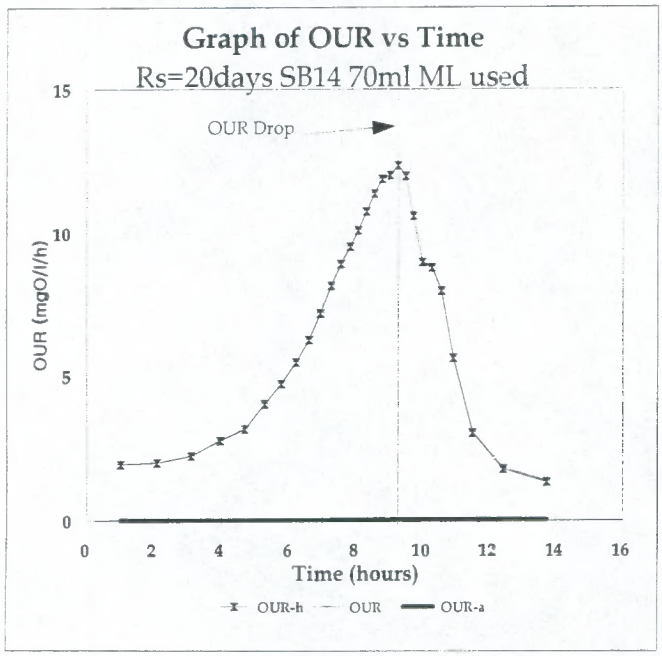
% COD Recovery		End Time=	12.00					$COD_{filt.}$	241.92	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/l	Xo(mgMLVSS/l)	So/Xo
348.77	237.89	69.10	0.48	0.00	0.48	68.62	87.88	233.86	83.23	2.8098
								So(mgCOD/l	Xo(mgMLAVSS/l	So/Xo
								233.86	23.78	9.835

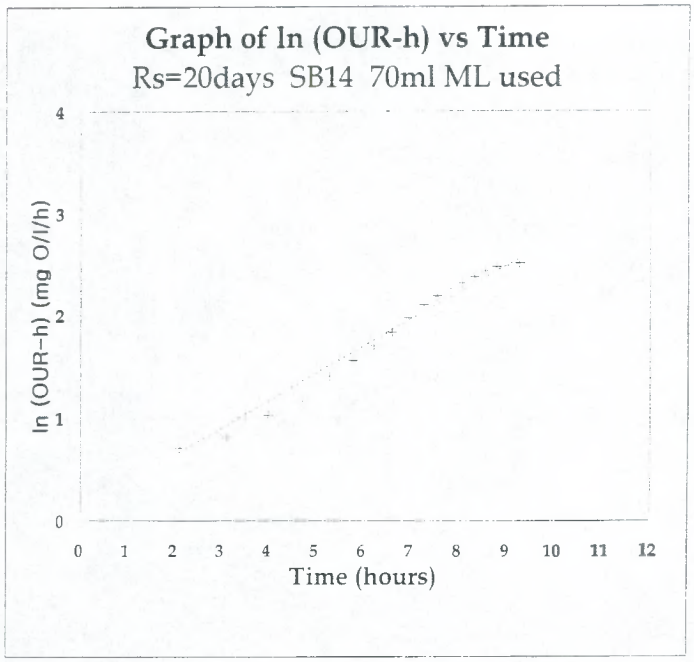
Parent System		fcv=	1.378	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.286	2496.888889	100	32.757737	4.24	4.91190580493	2.06	5.92	10.735

0.288	2448	100	34.72415074
0.283	2458	100	34.34251781
0.266	2454	100	32.18652064
0.314	2450	100	37.98486113
0.288	2504	100	35.56355544
0.284	2528	100	35.47247753
0.292	2548	100	36.74631116
0.284	2498	100	35.02896071
0.272	2584	100	34.73255067

Regression Output:		
Constant		-0.32015418
Std Err of Y Est		0.060398911
R Squared		0.993599535
No. of Observations		24
Degrees of Freedom		22
X Coefficient(s)	0.306673461	
Std Err of Coef.	0.005247651	



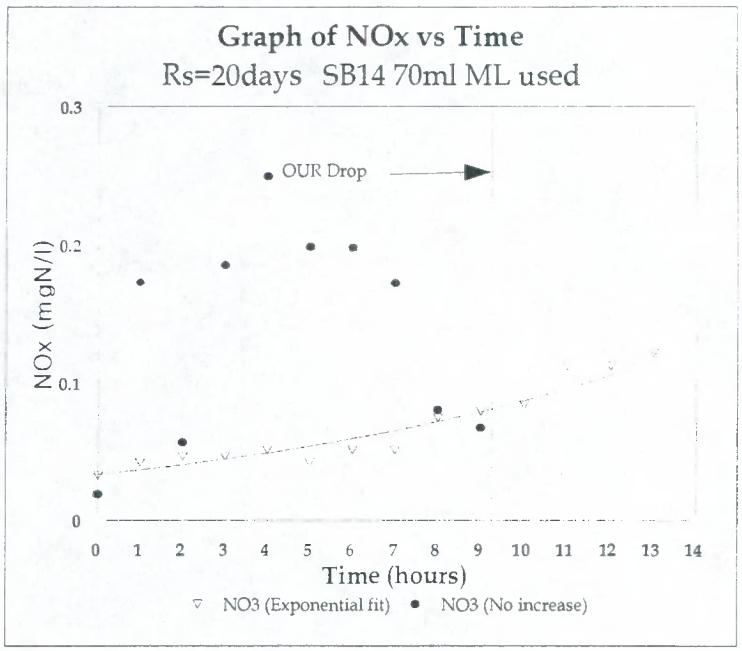


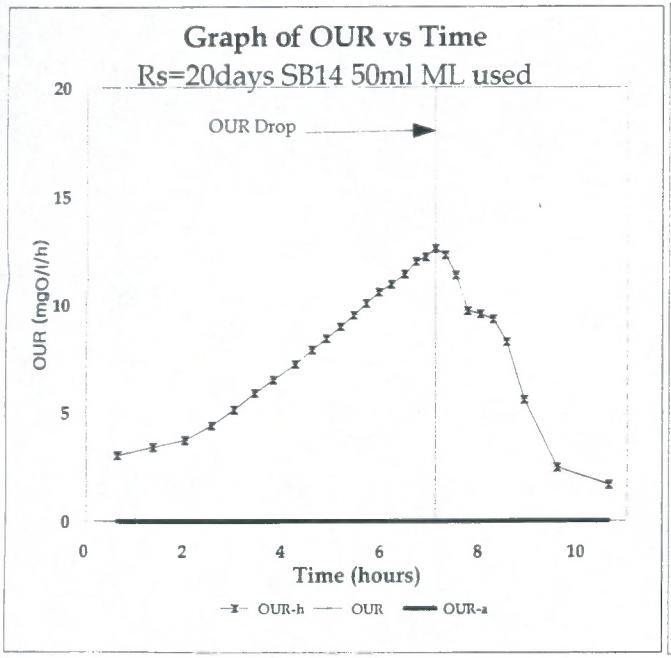


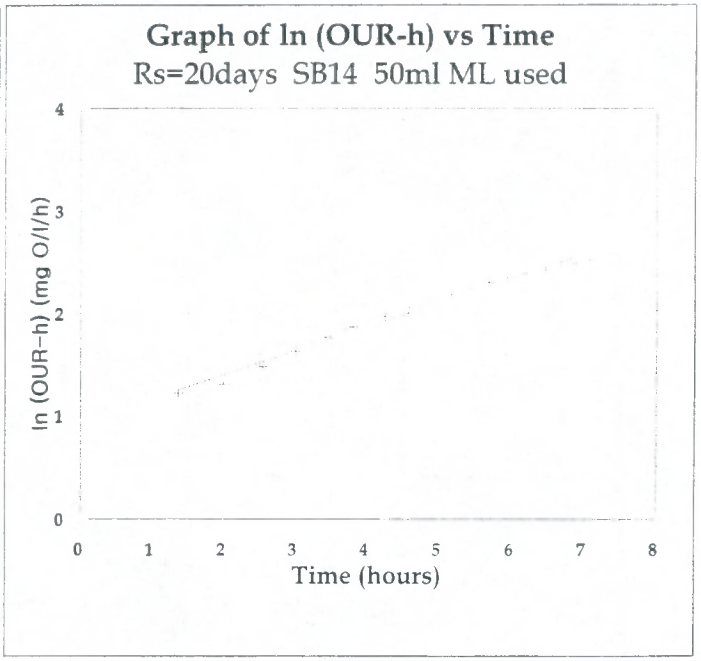
% COD Recovery		End Time=	13.00					$COD_{filt.}$	282	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/l	Xo(mgMLVSS/l)	So/Xo
362.00	212.00	63.70	0.28	0.56	0.84	62.86	75.93	275.42	58.26	4.7274
								So(mgCOD/l	Xo(mgMLAVSS/l	So/Xo
Parent System		fcv=	1.378	Batch Resul:				275.42	16.64	16.547
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s		
0.286	2496.888889	70	22.930416	7.50	1.80382388586	0.99	5.98	9.257		

0.288	2448	70	24.30690552
0.283	2458	70	24.03976247
0.266	2454	70	22.53056445
0.314	2450	70	26.58940279
0.288	2504	70	24.89448881
0.284	2528	70	24.83073427
0.292	2548	70	25.72241781
0.284	2498	70	24.52027249
0.272	2584	70	24.31278547

Regression Output:		
Constant		0.114763709
Std Err of Y Est		0.114098013
R Squared		0.970690613
No. of Observations		19
Degrees of Freedom		17
X Coefficient(s)	0.264594067	
Std Err of Coef.	0.011151123	



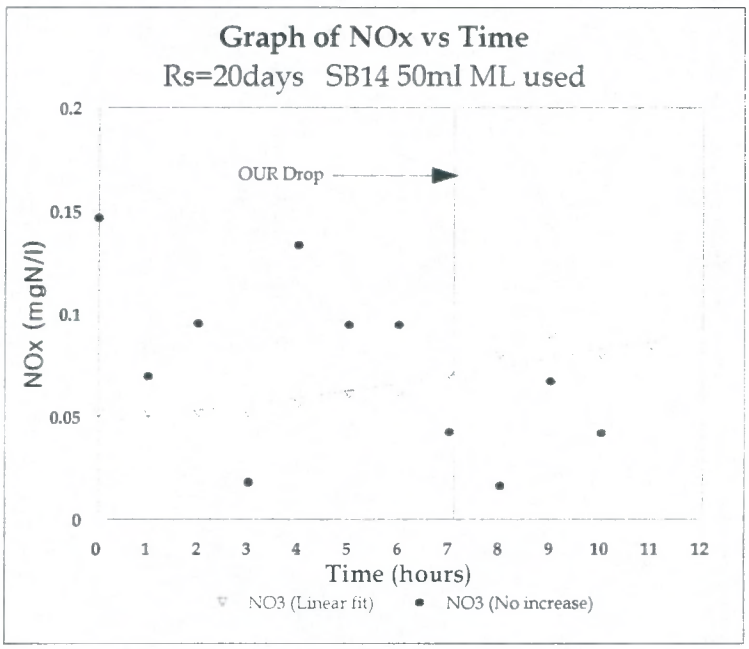


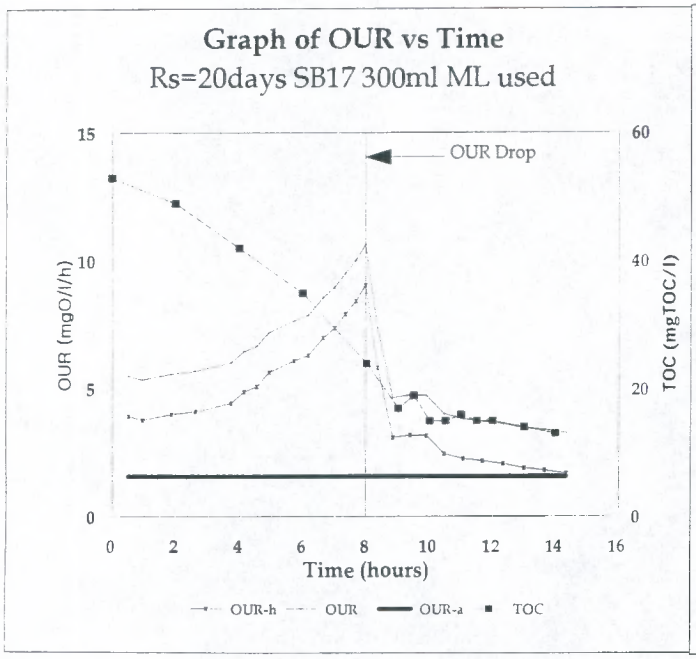


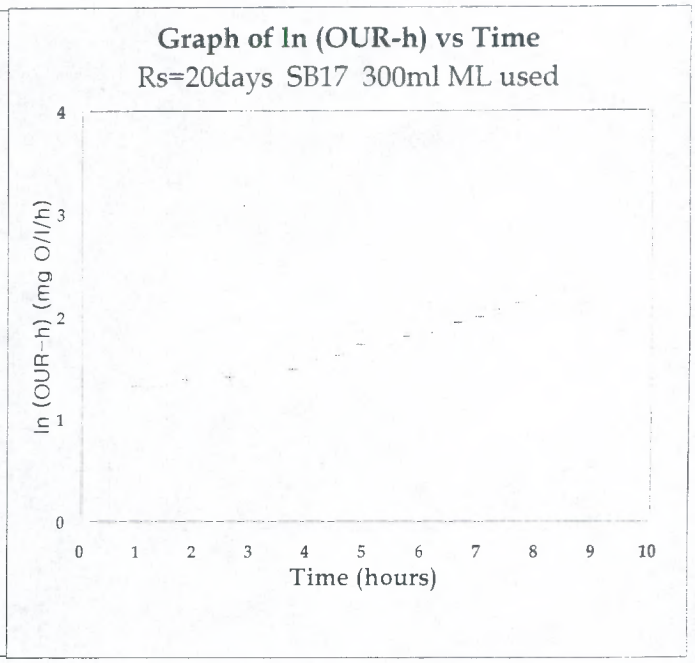
% COD Recovery		End Time=	11.00					$COD_{filt.}$	246	
COD t=o	$COD_{t=T}$	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/l	Xo(mgMLVSS/l)	So/Xo
302.00	154.00	65.20	0.14	0.00	0.14	65.06	72.54	241.90	41.61	5.81283
								So(mgCOD/l	Xo(mgMLAVSS/l	So/Xo
Parent System		fcv=	1.378	Batch Result				241.90	11.89	20.3466
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s		
0.286	2496.888889	50	16.378868	18.71	1.69361557994	0.81	5.49	7.082		

0.288	2448	50	17.36207537
0.283	2458	50	17.17125891
0.266	2454	50	16.09326032
0.314	2450	50	18.99243056
0.288	2504	50	17.78177772
0.284	2528	50	17.73623877
0.292	2548	50	18.37315558
0.284	2498	50	17.51448035
0.272	2584	50	17.36627534

Regression Output:	
Constant	0.928485381
Std Err of Y Est	0.047406275
R Squared	0.989980894
No. of Observations	19
Degrees of Freedom	17
X Coefficient(s)	0.236705534
Std Err of Coef.	0.005775439





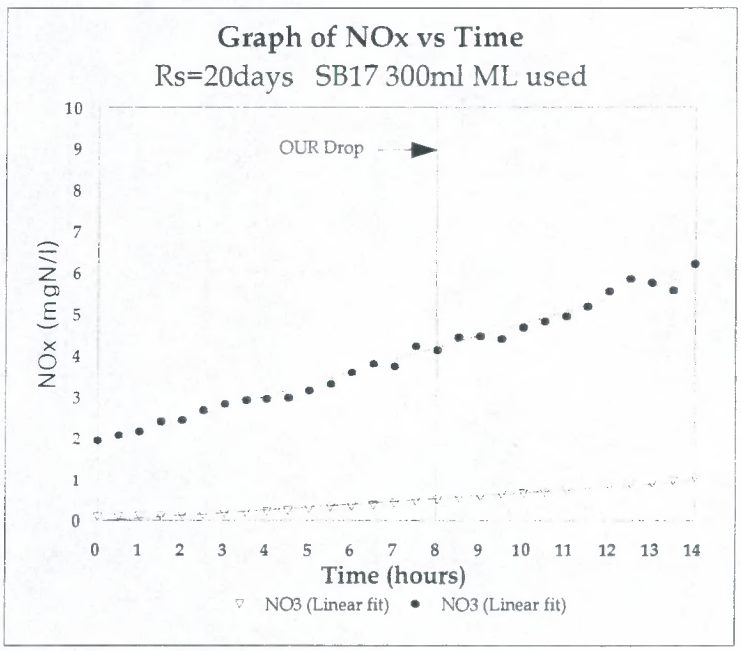


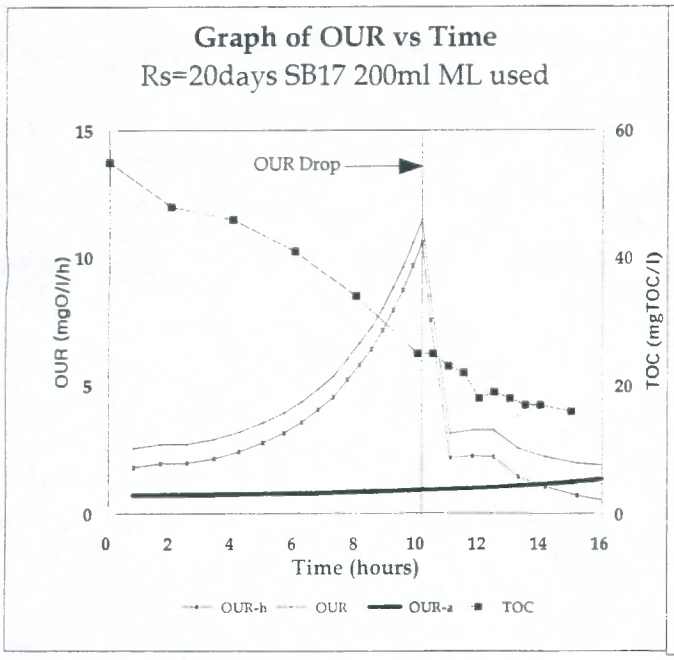
% COD Recovery		End Time=	13.50							
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/l	Xo(mgMLVSS)	So/Xo
546.34	497.95	75.40	3.20	18.11	21.30	54.10	101.05	193.50	812.18	0.64327
								So(mgCOD/l	Xo(mgMLAVSS)	So/Xo
								193.50	226.49	2.30674

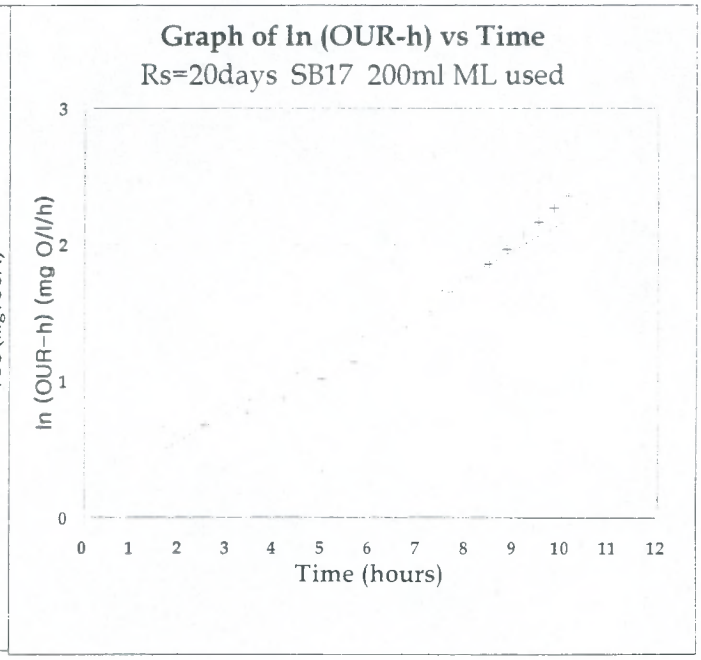
Parent System		fcv=	1.383	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.279	2707.25	300	104.43758	43.14	3.09193822887	1.34	2.13	7.967

0.277	2770	300	113.6238412
0.273	2690	300	108.7370192
0.288	2662	300	113.421185
0.291	2690	300	115.7339894
0.284	2712	300	114.0491832
0.255	2850	300	107.4799635
0.294	2632	300	114.4784829
0.272	2652	300	106.5732265

Regression Output:	
Constant	1.164661797
Std Err of Y Est	0.07257655
R Squared	0.944756529
No. of Observations	15
Degrees of Freedom	13
X Coefficient(s)	0.118389352
Std Err of Coef.	0.007940018





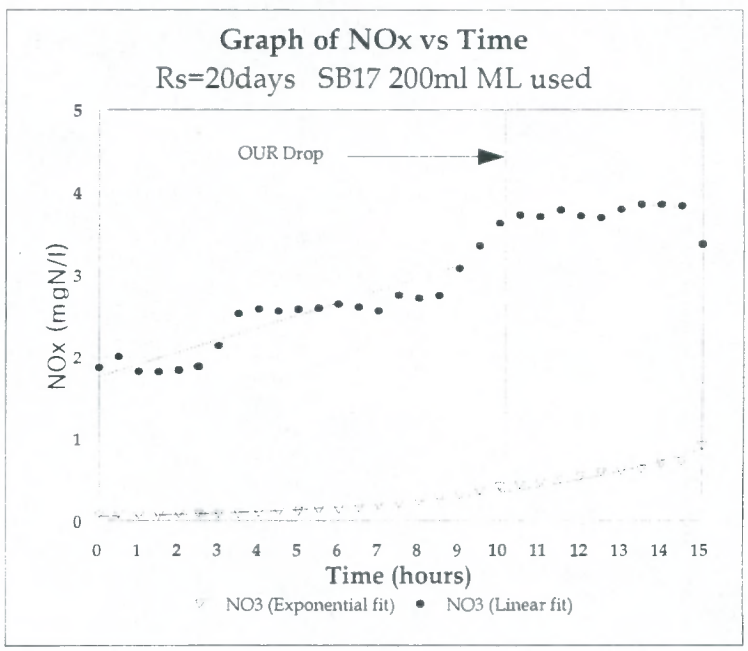


% COD Recovery		End Time=	15.00							
COD t=o	CODt=T	MOt	MOno2	MOno3	MOn	MOc	% Reco	So(mgCOD/l	Xo(mgMLVSS)	So/Xo
391.10	354.82	60.40	2.83	10.37	13.20	47.20	102.79	183.50	541.45	0.94893
								So(mgCOD/l	Xo(mgMLAVSS)	So/Xo
								183.50	150.99	3.40282

Parent System		fcv=	1.383	Batch Result				
fav	Xv	V_{ML}	$Z_{BH(Theo),BT}$	$Z_{BH(O)}$	OUR_{SBCOD}	K_{MP}	U_H	t=s
0.279	2707.25	200	69.625051	10.17	2.15992210375	1.34	4.07	10.131

0.277	2770	200	75.74922743
0.273	2690	200	72.4913461
0.288	2662	200	75.61412332
0.291	2690	200	77.15599293
0.284	2712	200	76.03278879
0.255	2850	200	71.653309
0.294	2632	200	76.31898863
0.272	2652	200	71.04881769

Regression Output:	
Constant	0.166492113
Std Err of Y Est	0.132940473
R Squared	0.952953449
No. of Observations	18
Degrees of Freedom	16
X Coefficient(s)	0.199703673
Std Err of Coef.	0.01109313



APPENDIX B

OUR vs TIME PLOTS FOR BATCH AEROBIC DIGESTION TESTS CONDUCTED WITH MIXED LIQUOR

TABLE OF CONTENTS

Table B1 Summary for batch aerobic digestion tests for **10 days sludge age activated sludge system:** Sewage (Sew.) batch number, Batch test numbers, dates of batch tests, regression data, measured specific endogenous respiration rate (b_{H20}), *measured* OHO active biomass concentration present the start of the batch test (X_{BHi}) and the *theoretical* parent system mixed liquor (ML) OHO active biomass concentration.

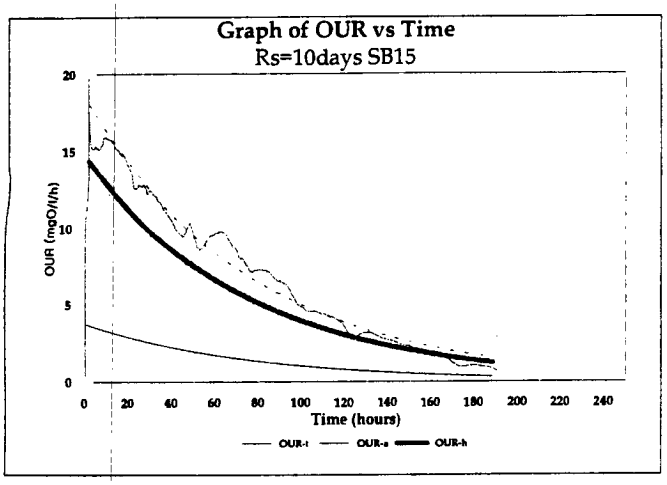
- OUR vs time and ℓn(OUR) vs time profiles for batch aerobic digestion tests No. C1 and C2. The nitrate/nitrite concentration vs time profiles recorded during each batch test are also given.

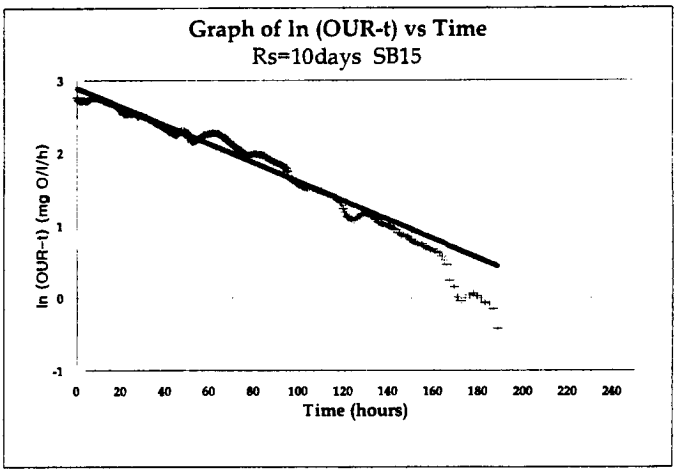
Table B2 Summary for batch aerobic digestion tests for **20 days sludge age activated sludge system:** Sewage (Sew.) batch number, Batch test numbers, dates of batch tests, regression data, measured specific endogenous respiration rate (b_{H20}), *measured* OHO active biomass concentration present the start of the batch test (X_{BHi}) and the *theoretical* parent system mixed liquor (ML) OHO active biomass concentration.

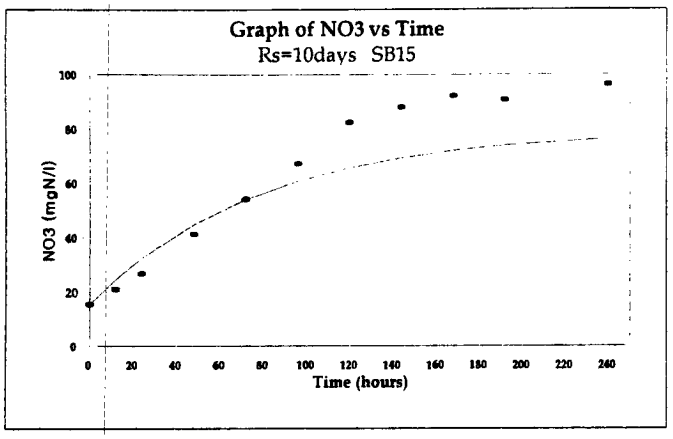
- OUR vs time and ℓn(OUR) vs time profiles for batch aerobic digestion tests No. D1 and D2. The nitrate/nitrite concentration vs time profiles recorded during each batch test are also given.

Table B1: Summary for batch aerobic digestion tests for 10 days sludge age activated sludge system: Sewage (Sew.) batch number, Batch test numbers, dates of batch tests, regression data, measured specific endogenous respiration rate (bH20), measured OHO active biomass concentration present the start of the batch test (XBHi) and the theoretical parent system mixed liquor (ML) OHO active biomass concentration.

System	Sew. Batch No.	Batch test No.	Date of Test	Regression data			bH (/d)	XBHi (mgVSS/l)	
				Y-int	Slope	R2		Meas.	Theo.
10days	15	C1	27 03	2.9029	-0.0129	0.971	0.31	996	993
	16	C2	08 04	2.9768	-0.0137	0.987	0.33	1008	983





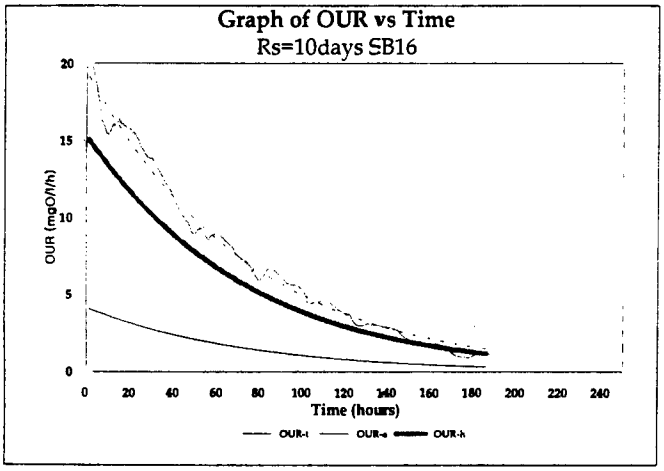


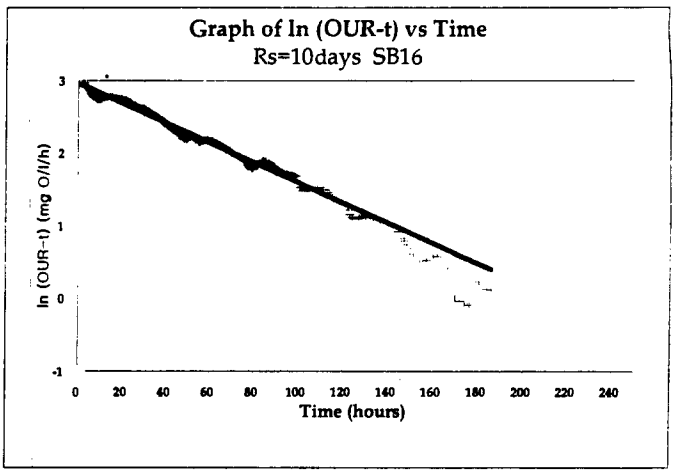
Parent System					
fav	Xv		$X_{BH(Theo),BT}$	f_{CV}	f_N
0.410	2421		992.923665	1.407	0.080

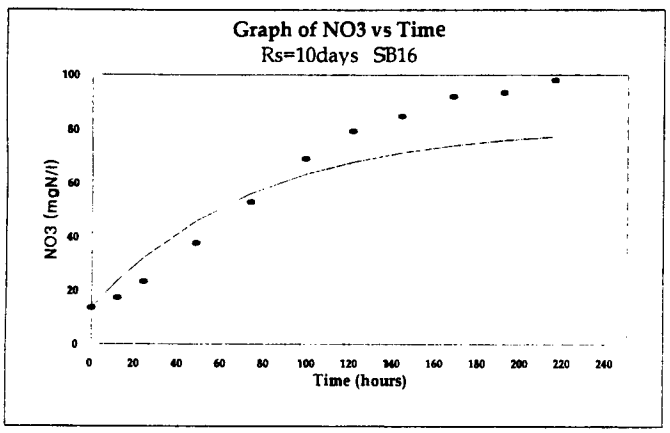
Batch Test Results	
$X_{BH,MEAS}$	b_H (/d)
995.60	0.31

0.438	2326		1019.052607	1.474	0.086
0.434	2372		1028.387236	1.444	0.083
0.390	2482		968.4512341	1.438	0.081
0.408	2474		1008.983018	1.352	0.076
0.384	2364		908.7498378	1.415	0.080
0.408	2508		1024.294768	1.326	0.076

Regression Output:		
Constant		2.902864877
Std Err of Y Est		0.092812834
R Squared		0.970730315
No. of Observations		447
Degrees of Freedom		445
X Coefficient(s)	-0.01290399	
Std Err of Coef.	0.000106219	







Parent System					
fav	Xv		$X_{BH(Theo),BT}$	f_{CV}	f_N
0.407	2416		982.8009137	1.398	0.083

Batch Test Results	
$X_{BH,MEAS}$	b_H (/d)
1008.35	0.33

0.338	2736		925.3123882	1.410	0.077
0.367	2630		964.2585558	1.382	0.080
0.433	2344		1015.805498	1.450	0.085
0.453	2306		1045.705275	1.412	0.087
0.453	2314		1049.038525	1.379	0.084
0.465	2286		1062.046752	1.375	0.085
0.488	1988		969.7190568	1.351	0.090
0.485	2046		992.621746	1.426	0.093
0.355	2610		926.335965	1.390	0.082
0.332	2672		886.6902312	1.373	0.078
0.362	2644		956.6251119	1.429	0.079

Regression Output:	
Constant	2.97681075
Std Err of Y Est	0.056120019
R Squared	0.986739465
No. of Observations	331
Degrees of Freedom	329
X Coefficient(s)	-0.01368088
Std Err of Coef.	8.7437E-05

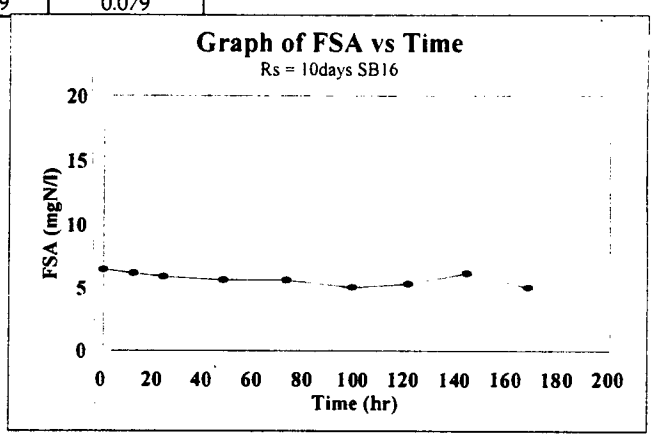
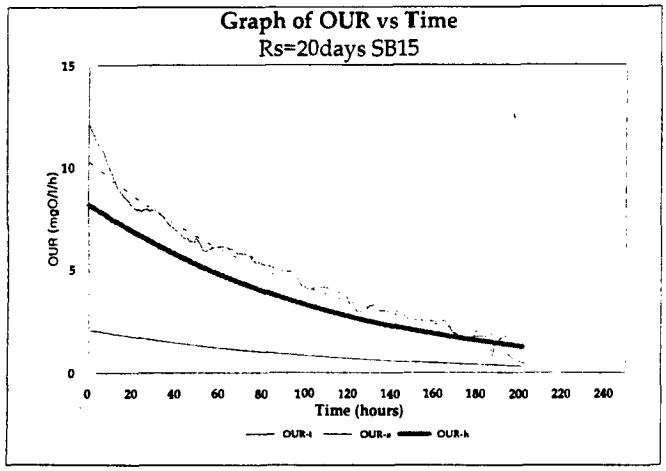
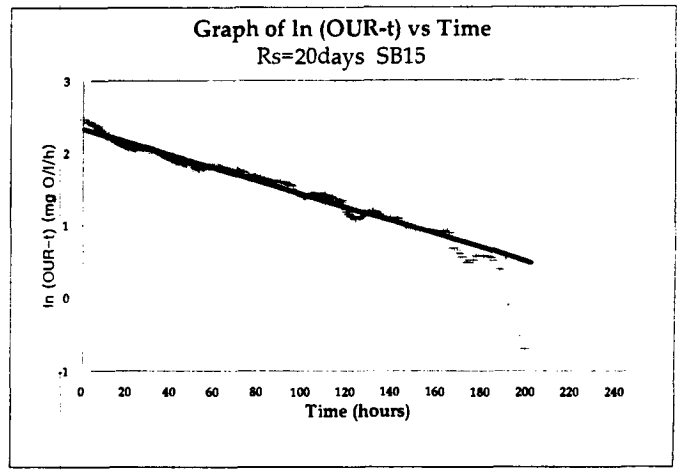
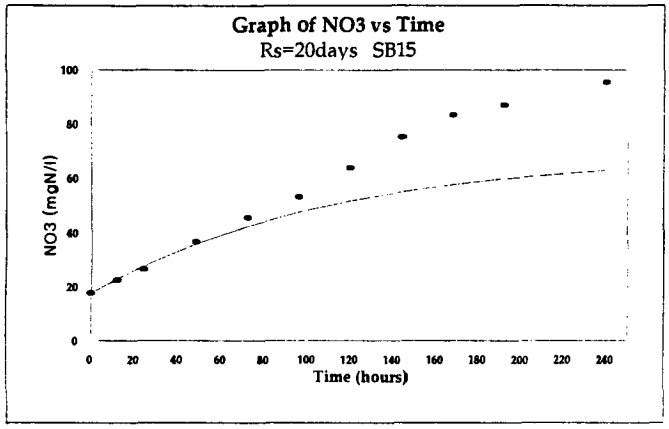


Table B2: Summary for batch aerobic digestion tests for 20 days sludge age activated sludge system: Sewage (Sew.) batch number, Batch test numbers, dates of batch tests, regression data, measured specific endogenous respiration rate (bH20), measured OHO active biomass concentration present the start of the batch test (XBHi) and the theoretical parent system mixed liquor (ML) OHO active biomass concentration.

System	Sew. Batch No.	Batch test No.	Date of Test	Regression data			bH (/d)	XBHi (mgVSS/l)	
				Y-int	Slope	R2		Meas.	Theo.
20days	15	D1	27 03	2.3453	-0.0091	0.979	0.22	834	758
	16	D2	08 04	2.4741	-0.0110	0.987	0.26	774	718





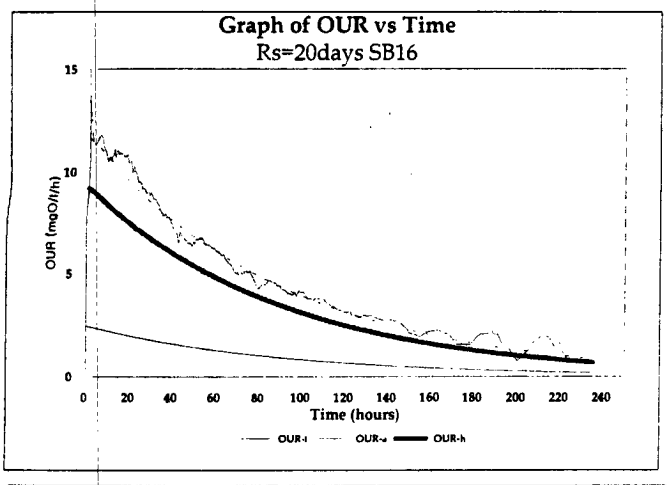


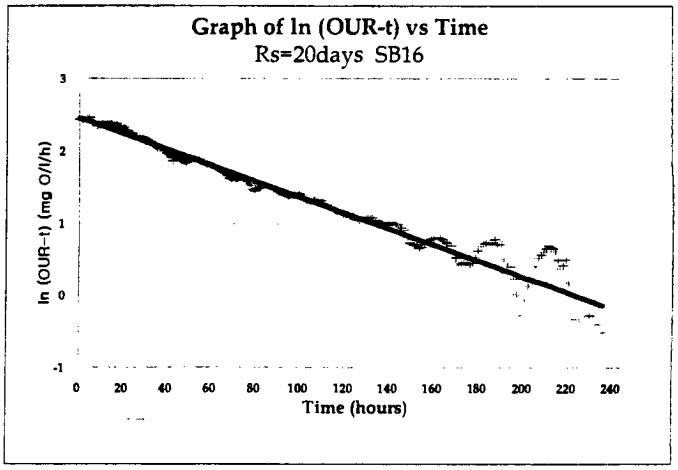
Parent System					
fav	Xv		$X_{BH(Theo),BT}$	f_{CV}	f_N
0.300	2524		757.76119	1.364	0.076

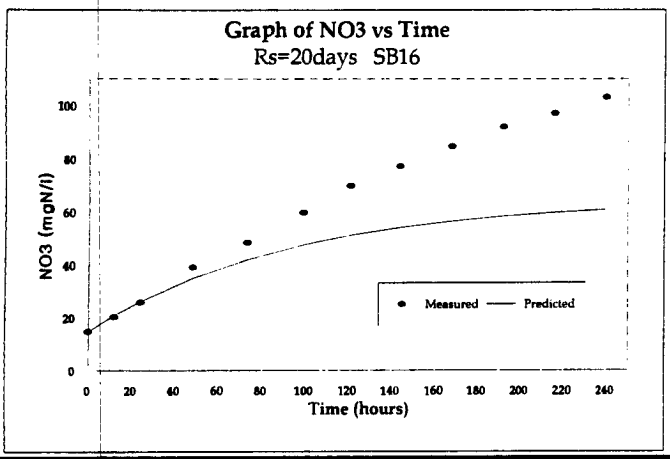
Batch Test Results	
$X_{BH,MEAS}$	b_H (/d)
833.73	0.22

0.311	2510		779.52397	1.308	0.078
0.312	2456		765.48365	1.394	0.082
0.306	2510		768.1435	1.368	0.077
0.293	2592		759.44433	1.333	0.070
0.277	2536		701.25631	1.378	0.074
0.305	2540		773.92872	1.402	0.077

Regression Output:		
Constant		2.902864877
Std Err of Y Est		0.092812834
R Squared		0.970730315
No. of Observations		447
Degrees of Freedom		445
X Coefficient(s)	-0.01290399	
Std Err of Coef.	0.000106219	





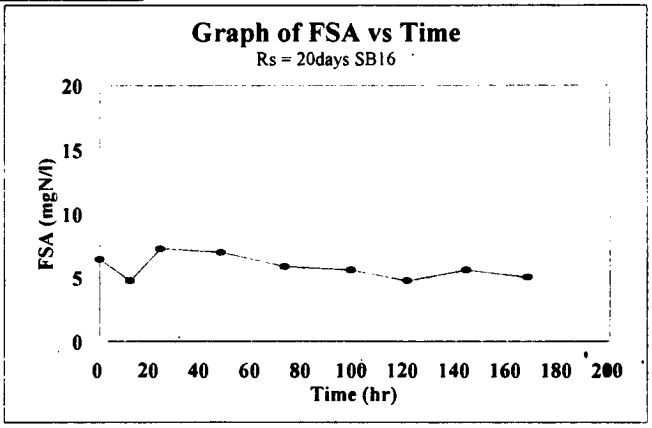


Parent System					
fav	Xv		$X_{BH(Theo),BT}$	f_{CV}	f_N
0.275	2610		718	1.379	0.080

Batch Test Results	
$X_{BH,MEAS}$	b_H (/d)
774.20	0.26

0.273	2640		719	1.373	0.076
0.271	2618		710	1.403	0.076
0.284	2606		740	1.397	0.083
0.291	2586		752	1.386	0.081
0.275	2702		743	1.318	0.076
0.281	2628		739	1.377	0.079
0.263	2572		677	1.330	0.085
0.276	2518		694	1.429	0.085
0.278	2570		714	1.390	0.081
0.250	2656		663	1.356	0.079
0.285	2618		747	1.417	0.079

Regression Output:	
Constant	2.474075071
Std Err of Y Est	0.050578813
R Squared	0.986850148
No. of Observations	241
Degrees of Freedom	239
X Coefficient(s)	-0.01099016
Std Err of Coef.	8.2062E-05



APPENDIX C

OUR vs TIME PLOTS WITH COMPETITION MODEL

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Table C1 Summary for the parameter estimation with the aid of AQUASIM 2.0 computer program for the modified batch test data of the **10 day sludge age activated sludge system.**. Also shown are the total OHO active biomass concentrations at the start of the batch test, ($Z_{BH(0)}$) predicted by competition models both of kinetic selection and process selection, from analysis using the procedure in chapter 4 (UCT model), and predicted by application of the steady state model to the parent system (taking due account of dilution)

- Measured Oxygen Uptake Rate of Heterotrophic organisms ($OUR_{H\text{-}M}$), OUR calculated by the analytical procedure of Wentzel *et al.* (1995) ($OUR_{H\text{-}S}$), OUR simulated by (a) **competition model of kinetic selection** or (b) **competition model of process selection** ($OUR_{H\text{-}C}$), OUR of the fast grower (OUR_{H1}) and OUR of the slow grower (OUR_{H2}) OUR.

Table C2 Summary for the parameter estimation with the aid of AQUASIM 2.0 computer program for the modified batch test data of the **20 day sludge age activated sludge system.**. Also shown are the total OHO active biomass concentrations at the start of the batch test, ($Z_{BH(0)}$) predicted by competition model models both of kinetic selection and process selection, from analysis using the procedure in chapter 4 (UCT model), and predicted by application of the steady state model to the parent system (taking due account of dilution)

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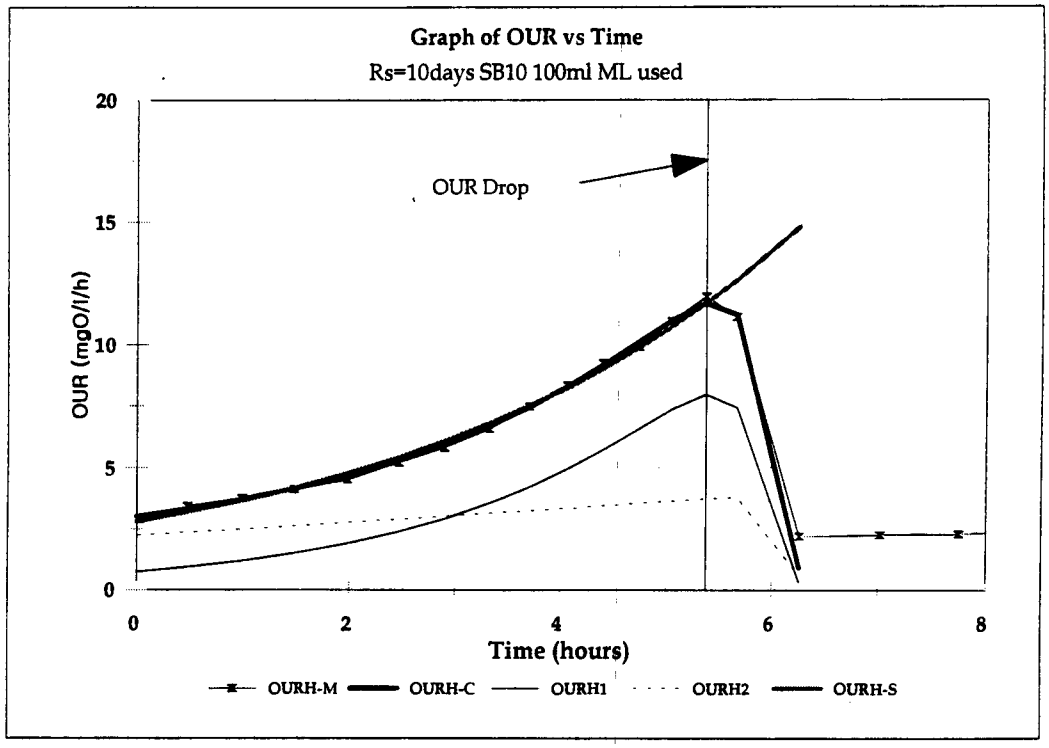


Fig. (a): Measured OUR of Heterotrophic organisms (OURH-M),
OUR calculated by the analytical procedure of Wentzel et al. (1995) (OURH-S),
OUR simulated by the **competition model of kinetic selection** (OURH-C),
OUR of the fast grower (OURH1) and OUR of the slow grower (OURH2)
For Sewage Batch No.10, Batch Test No.A12

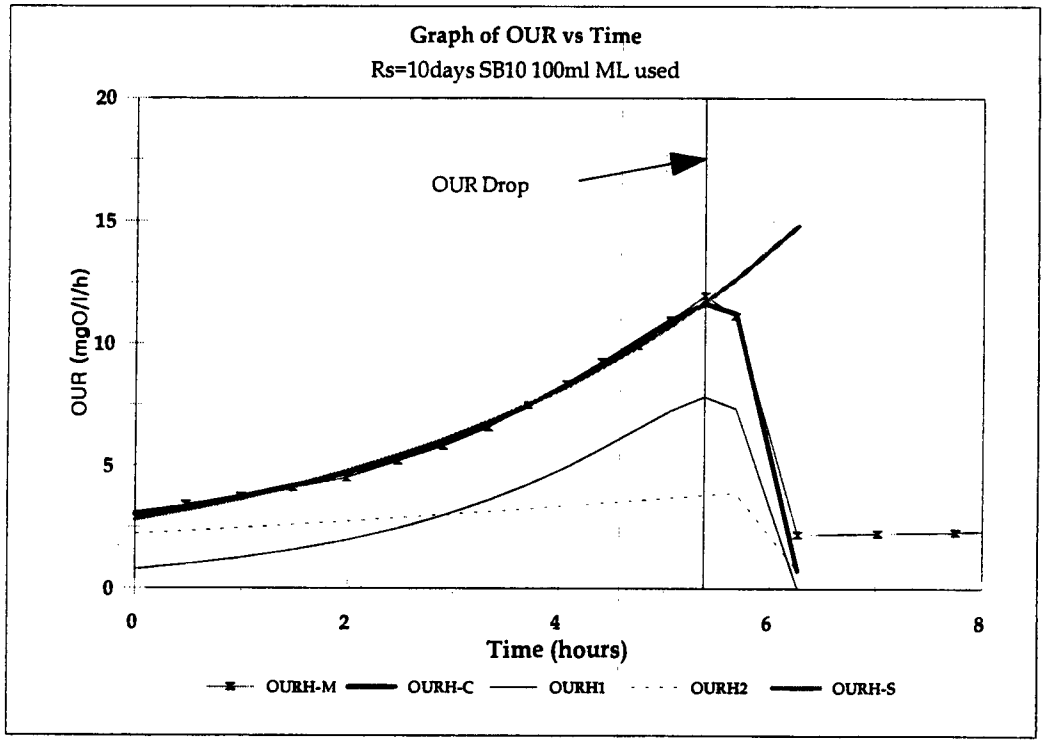


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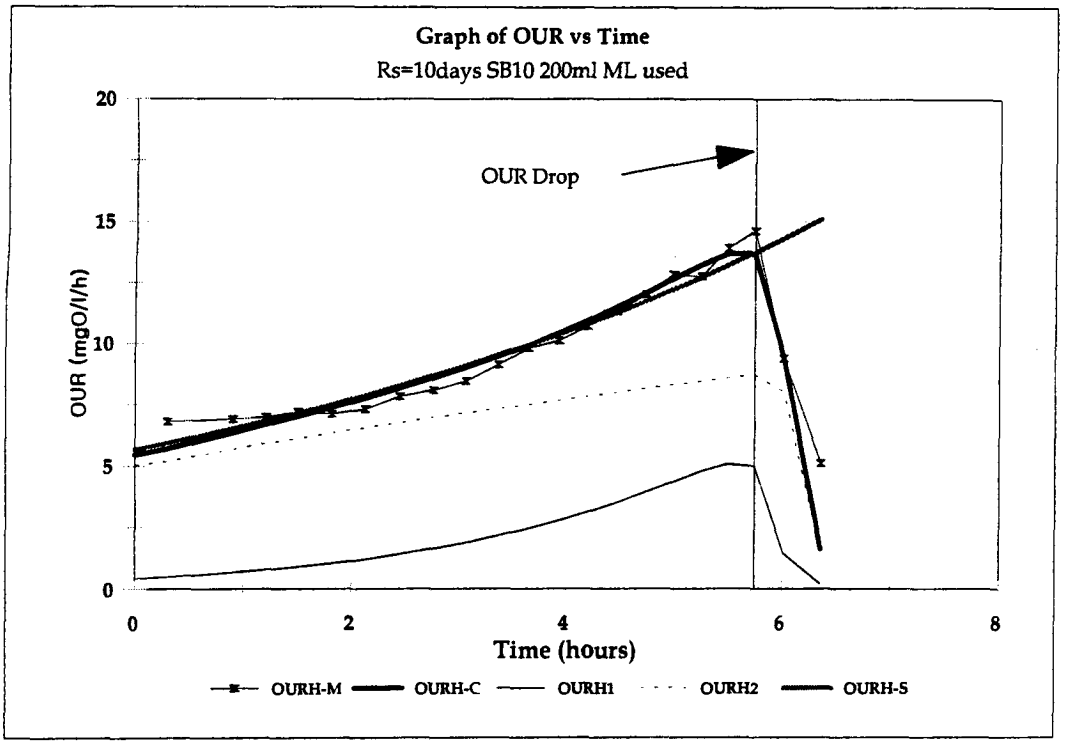


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OUR of the fast grower (OURH1) and OUR of the slow grower (OURH2)
For Sewage Batch No.10, Batch Test No.A13

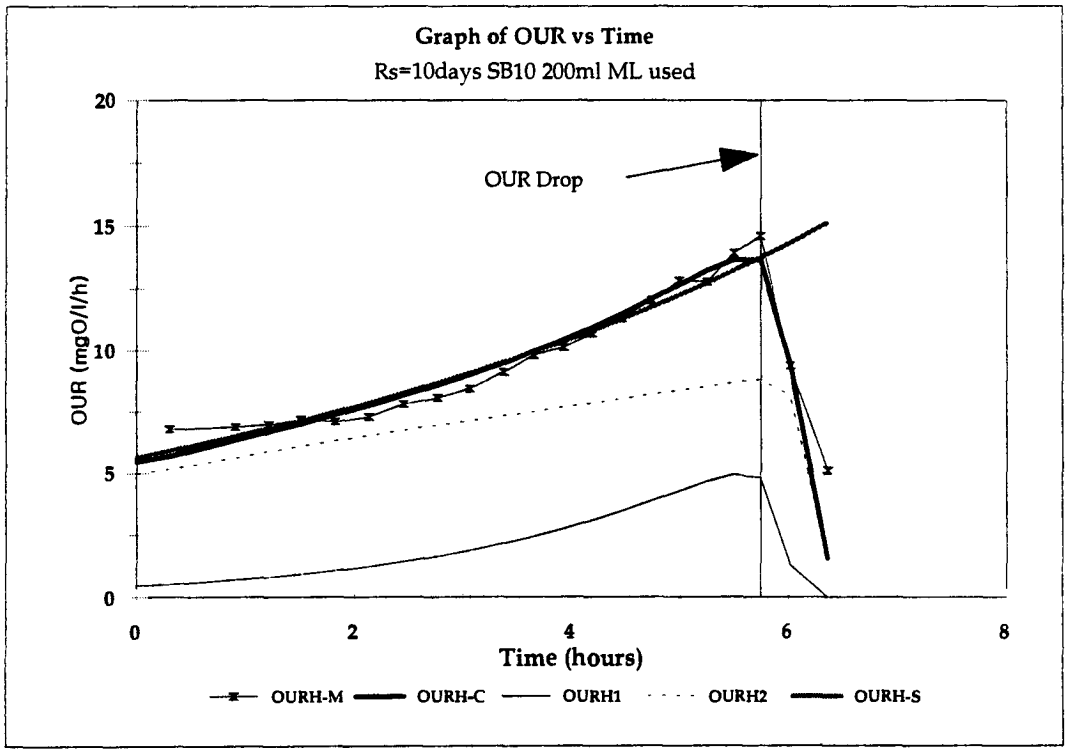


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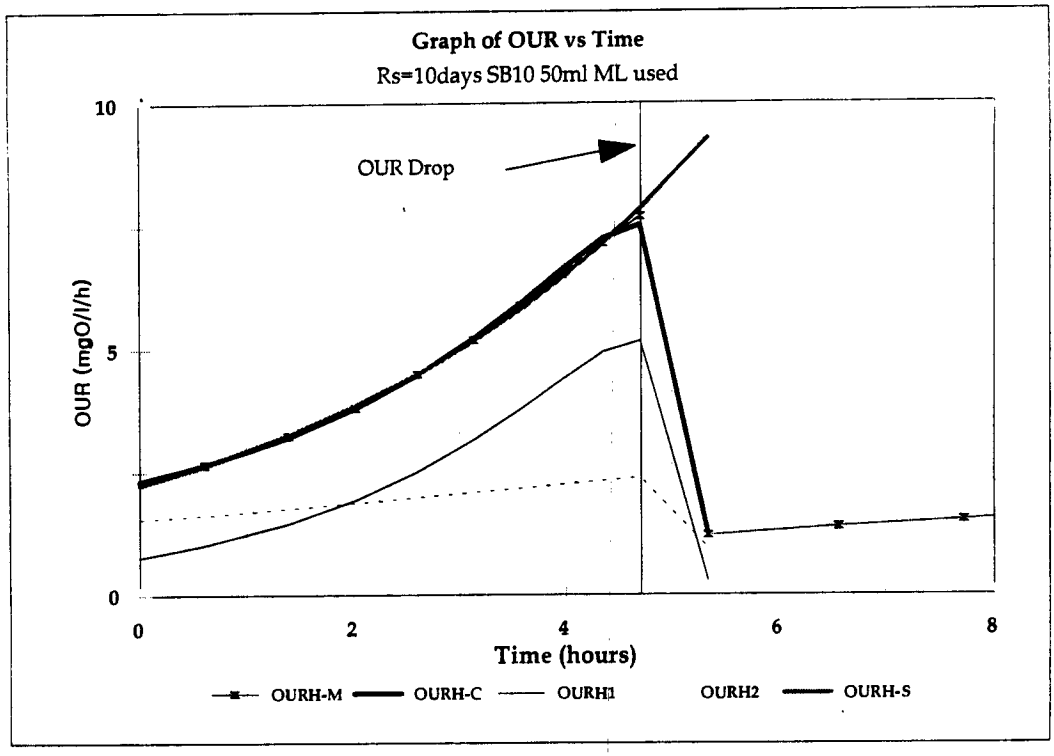


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For Sewage Batch No.10, Batch Test No.A14

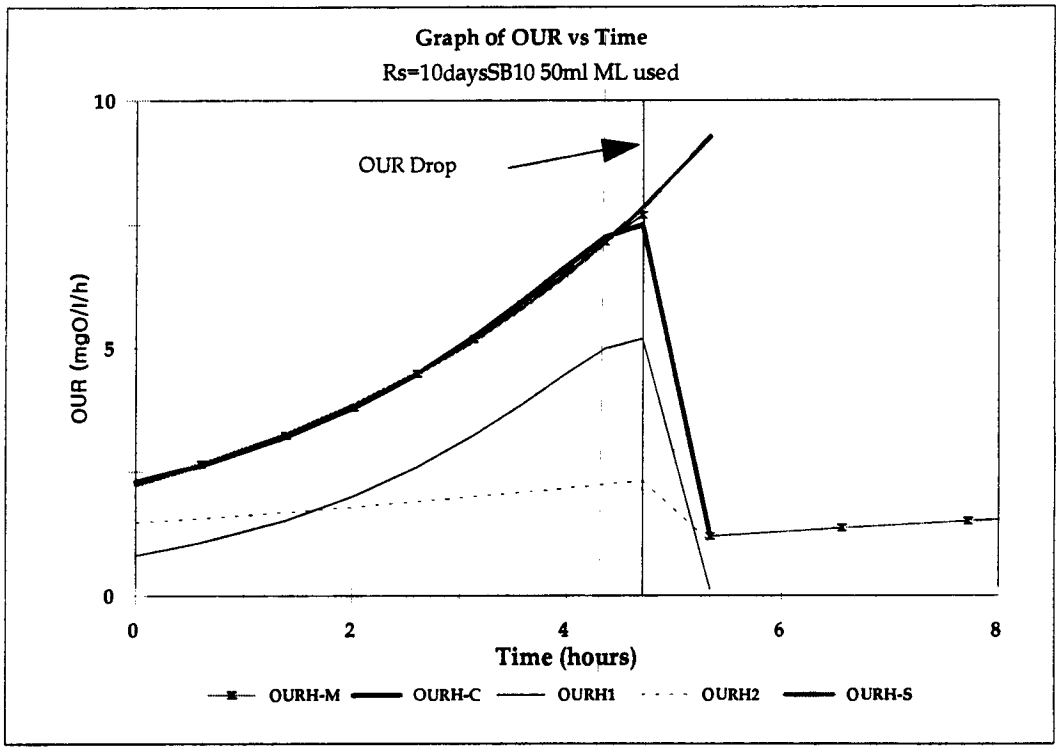


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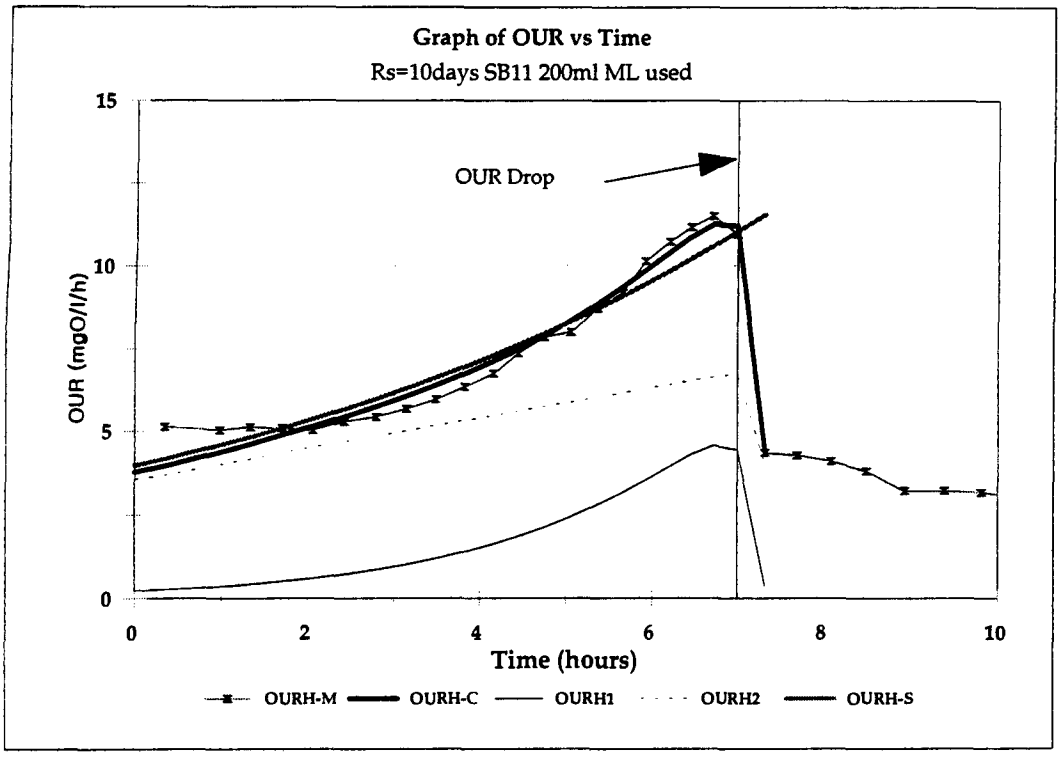


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For Sewage Batch No.11, Batch Test No.A17

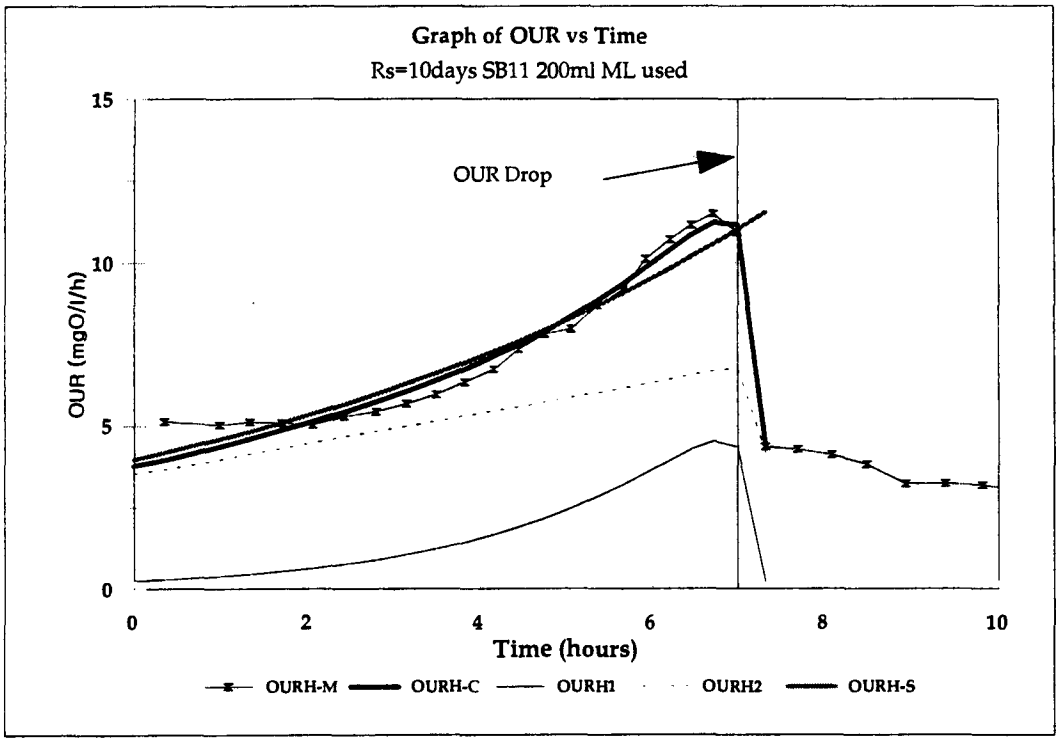


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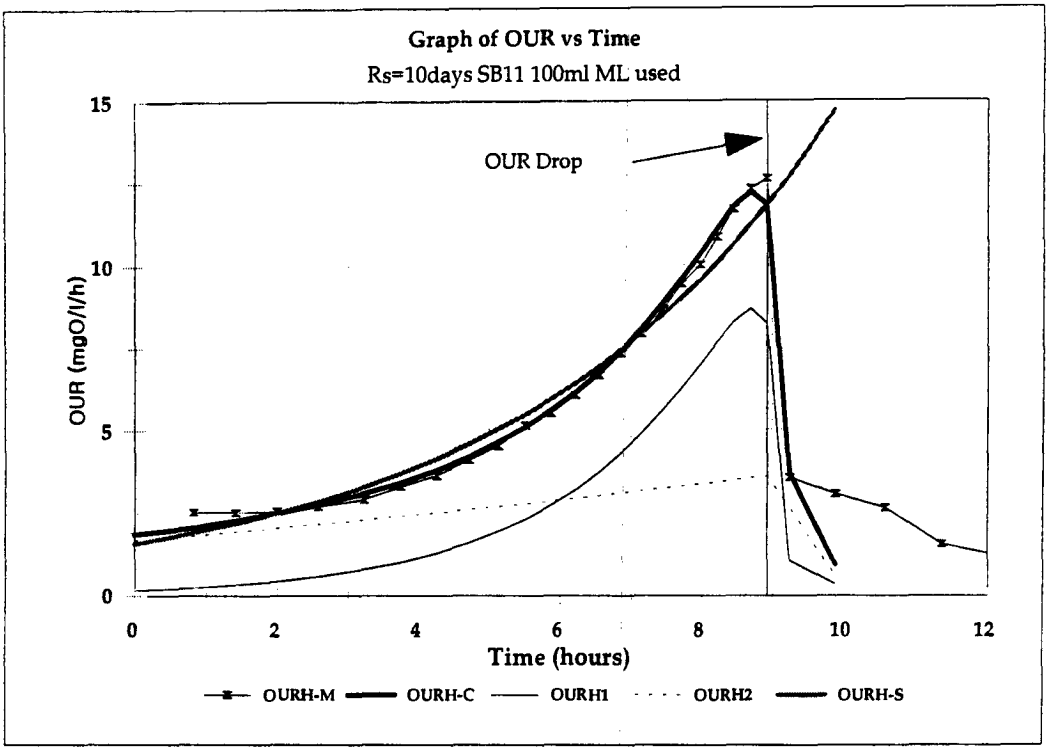


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For Sewage Batch No.11, Batch Test No.A18

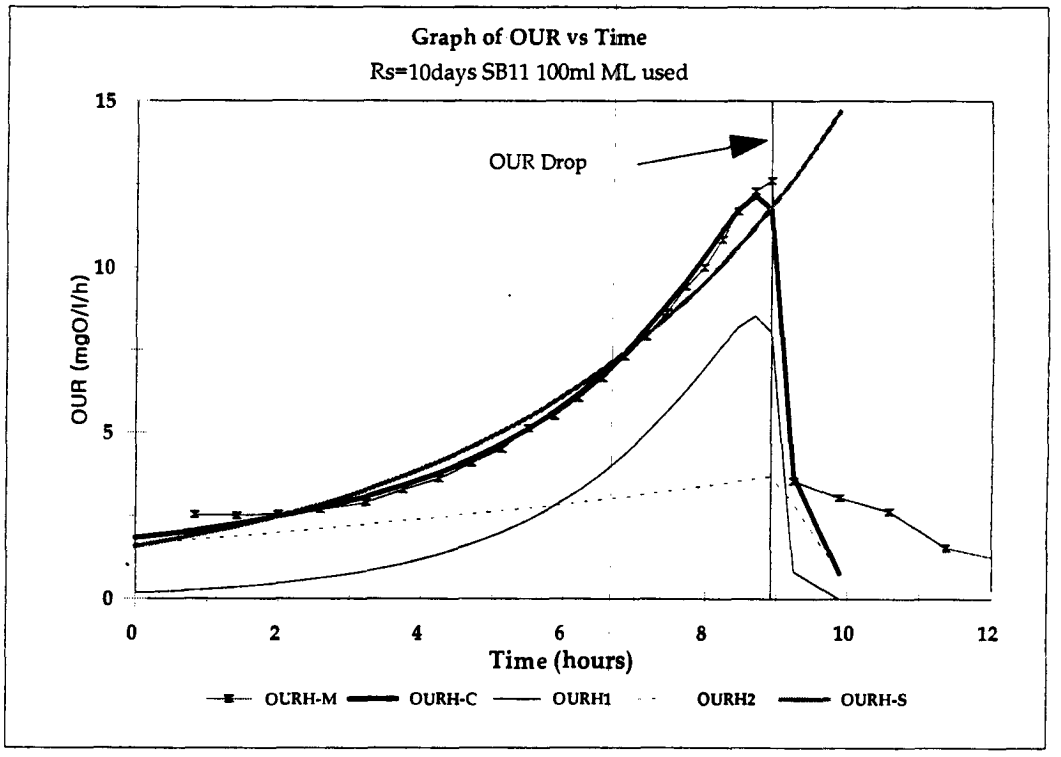


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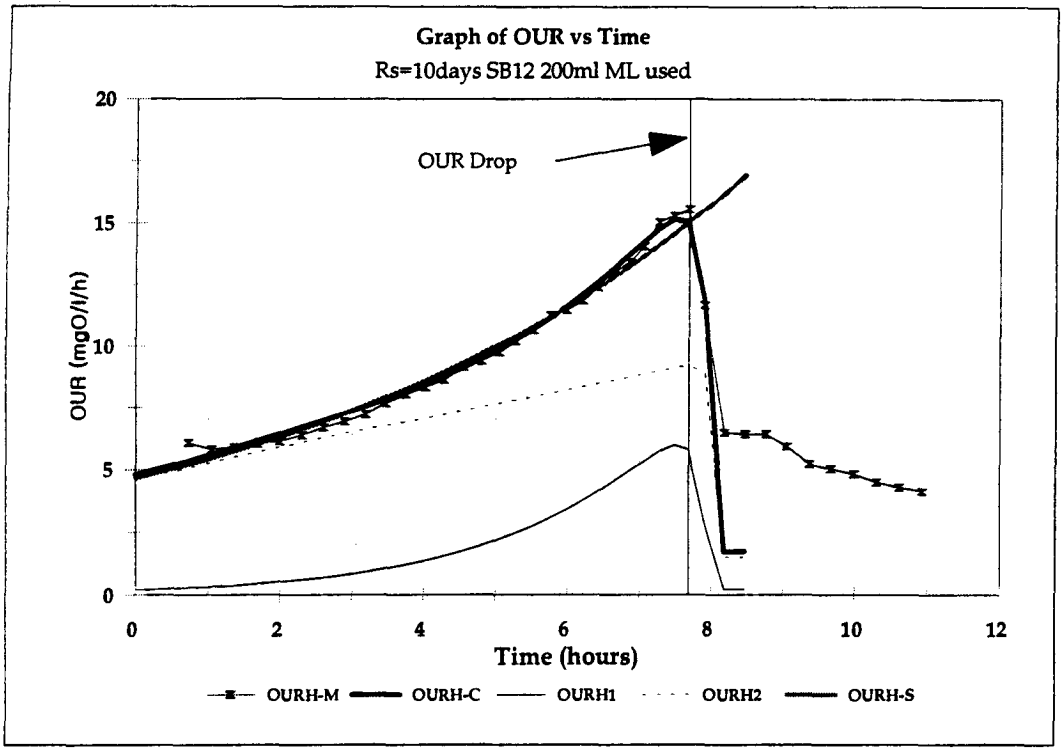


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For Sewage Batch No.12, Batch Test No.A22

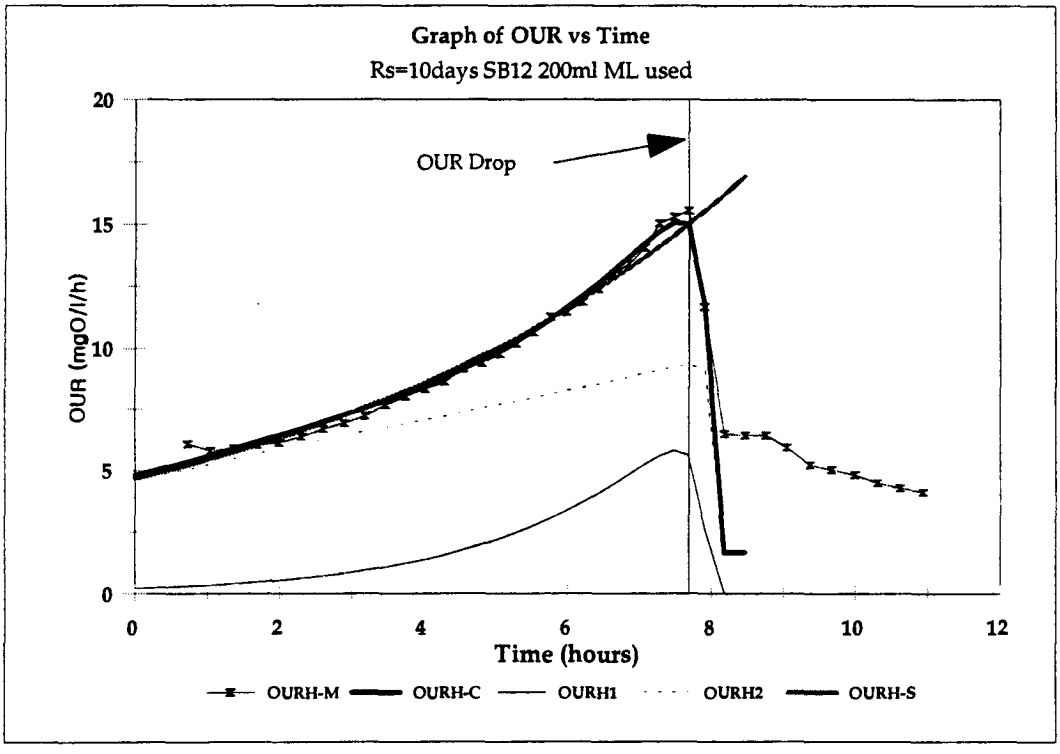


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For Sewage Batch No.12, Batch Test No.A22

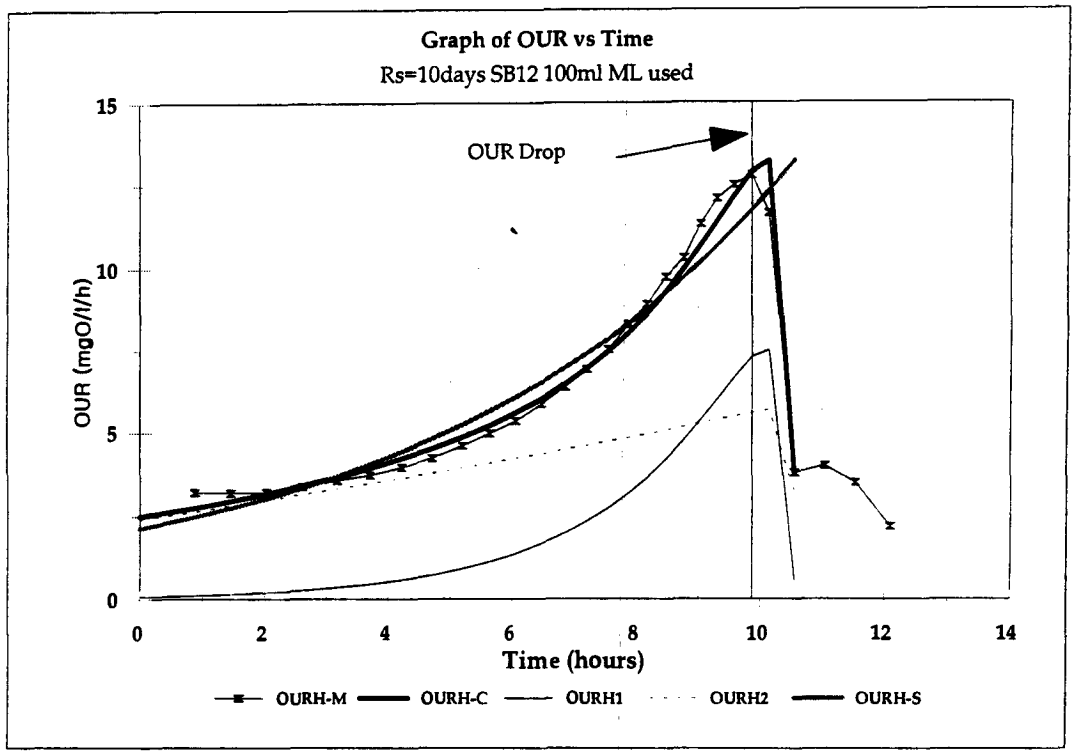


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For Sewage Batch No.11, Batch Test No.A23

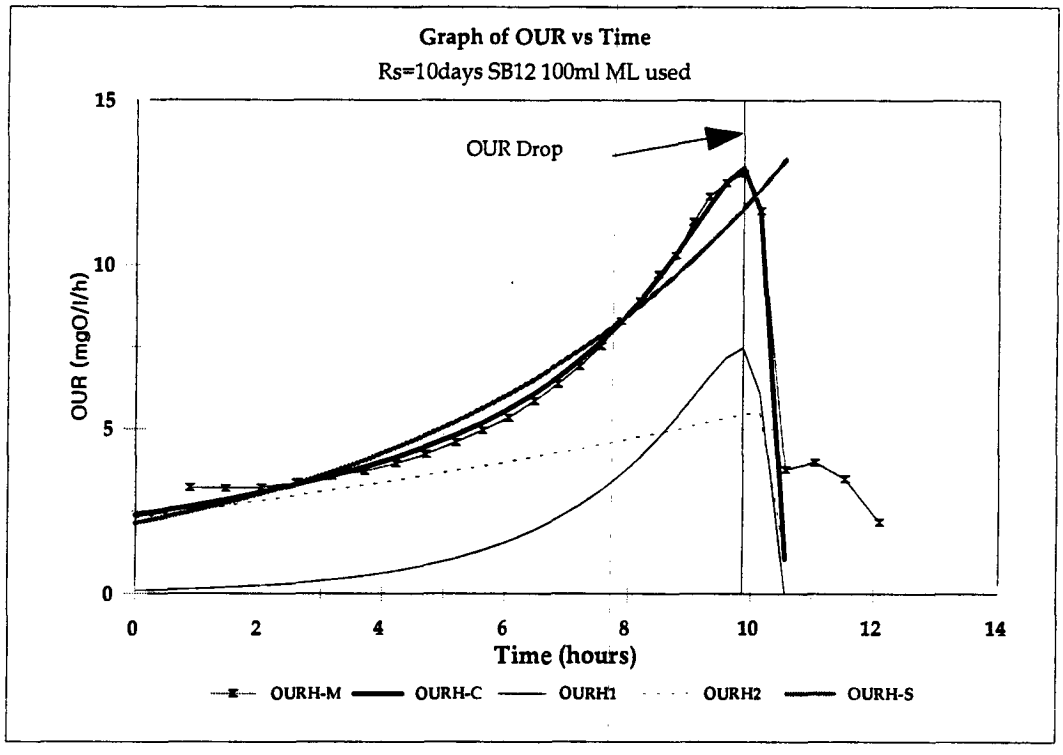


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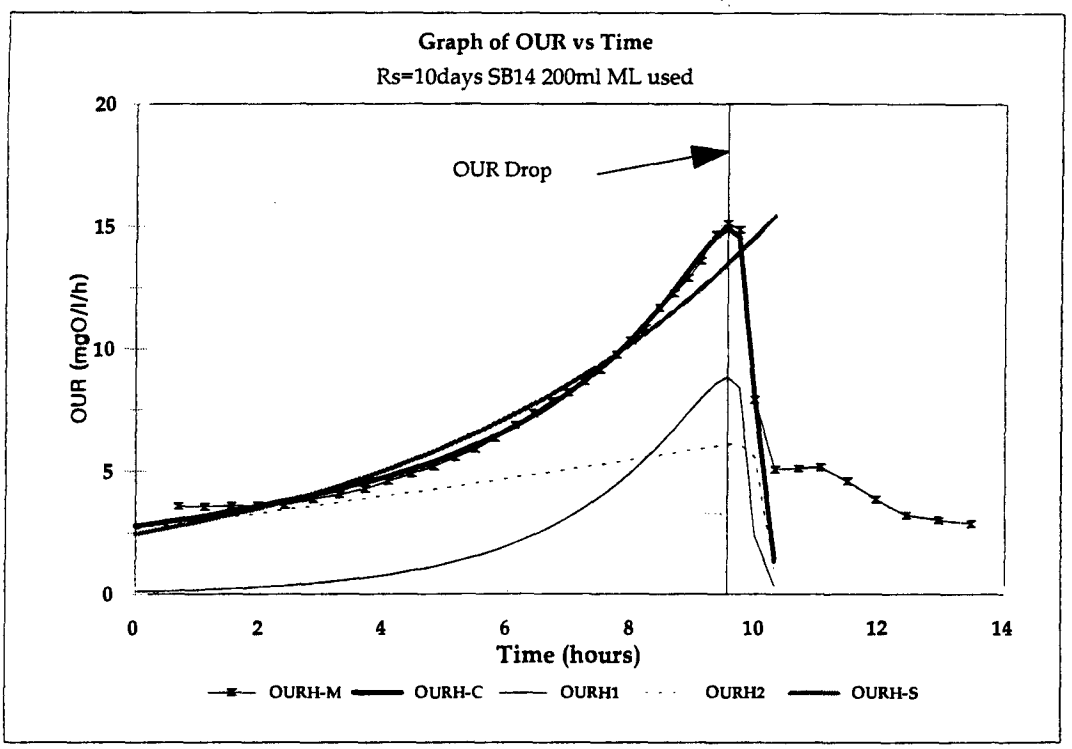


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For Sewage Batch No.14, Batch Test No.A29

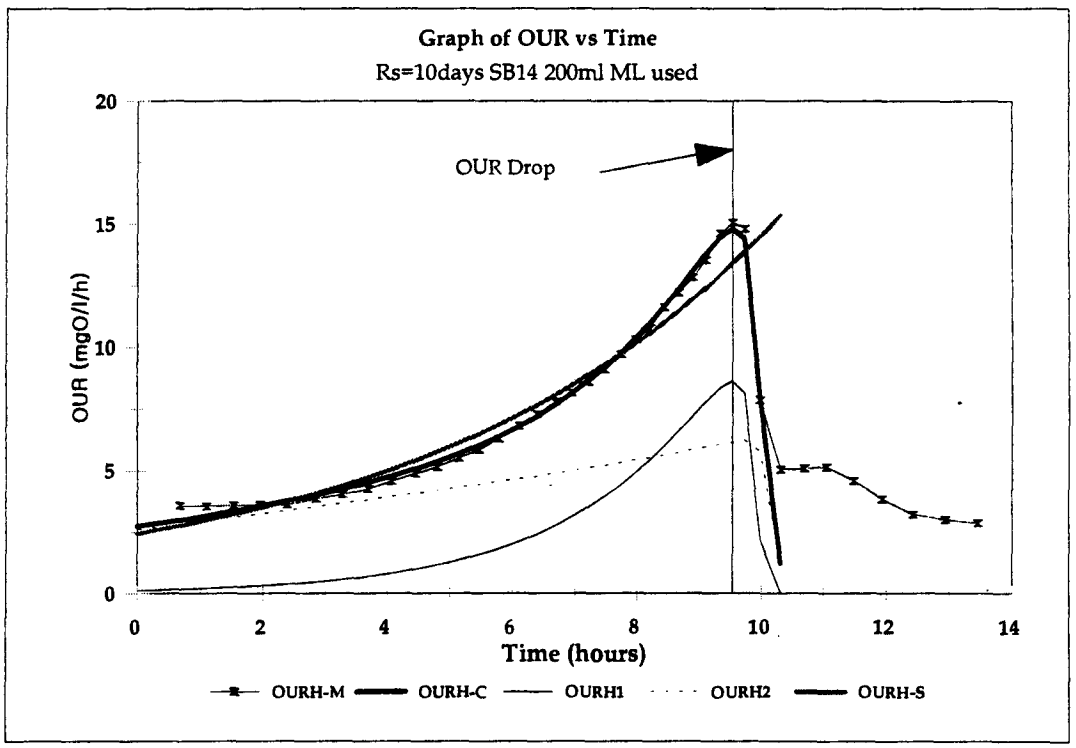


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For Sewage Batch No.14, Batch Test No.A29

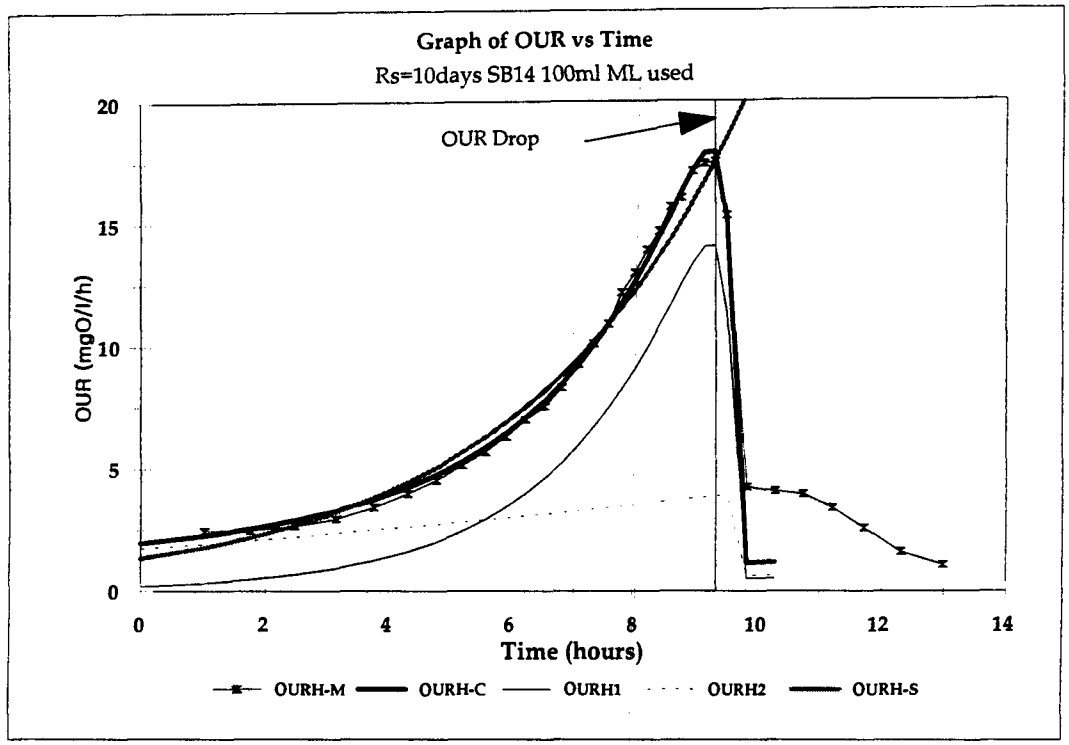


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For Sewage Batch No.14, Batch Test No.A30

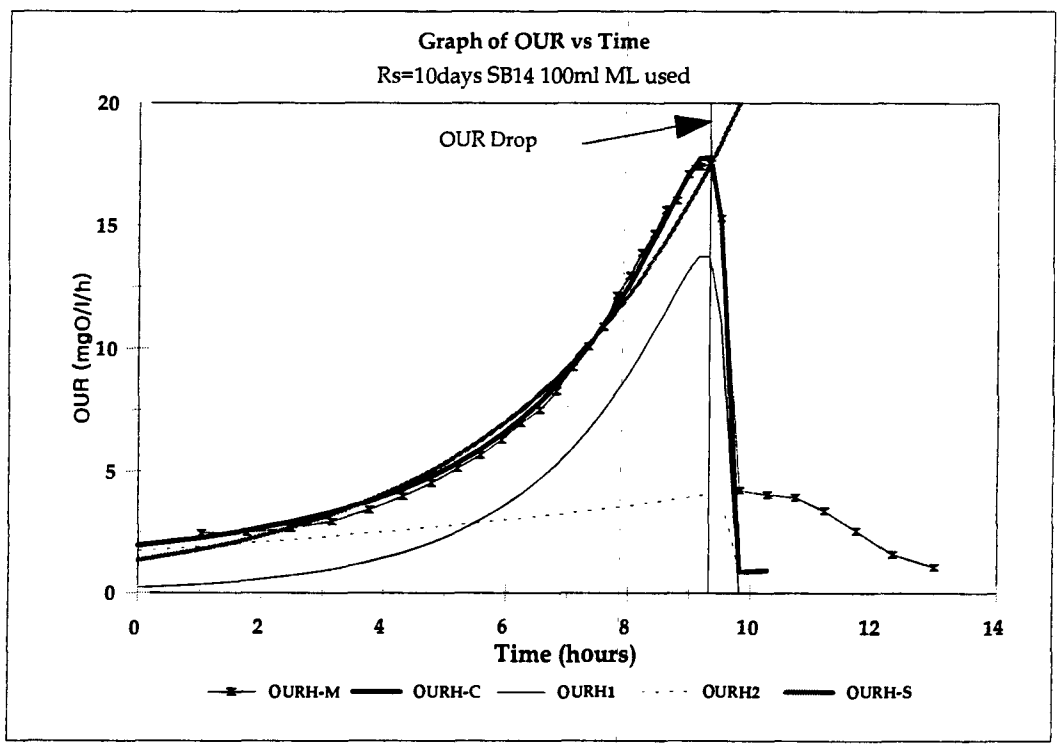


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For Sewage Batch No.14, Batch Test No.A30

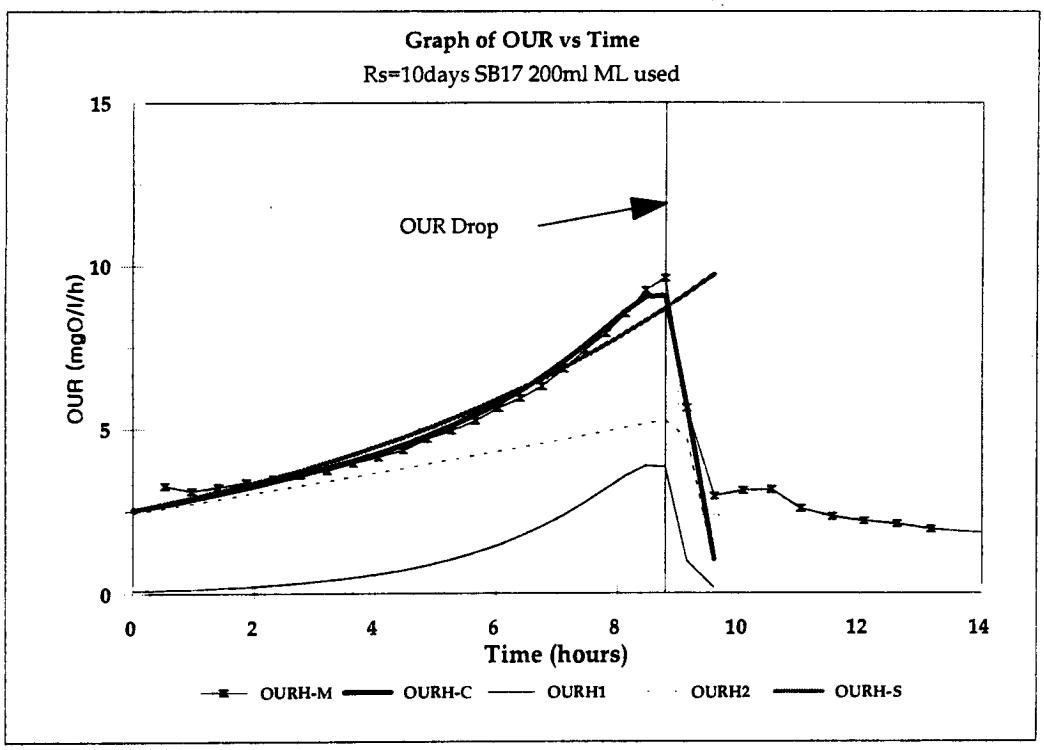


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For Sewage Batch No.17, Batch Test No.A34

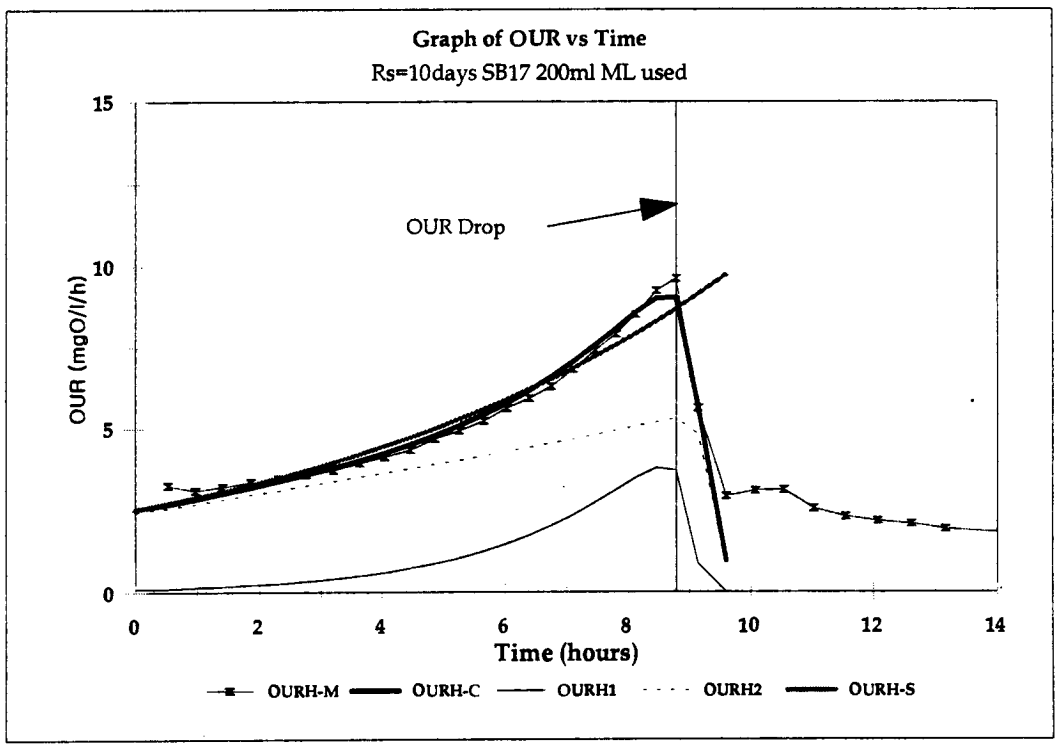


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For Sewage Batch No.17, Batch Test No.A34

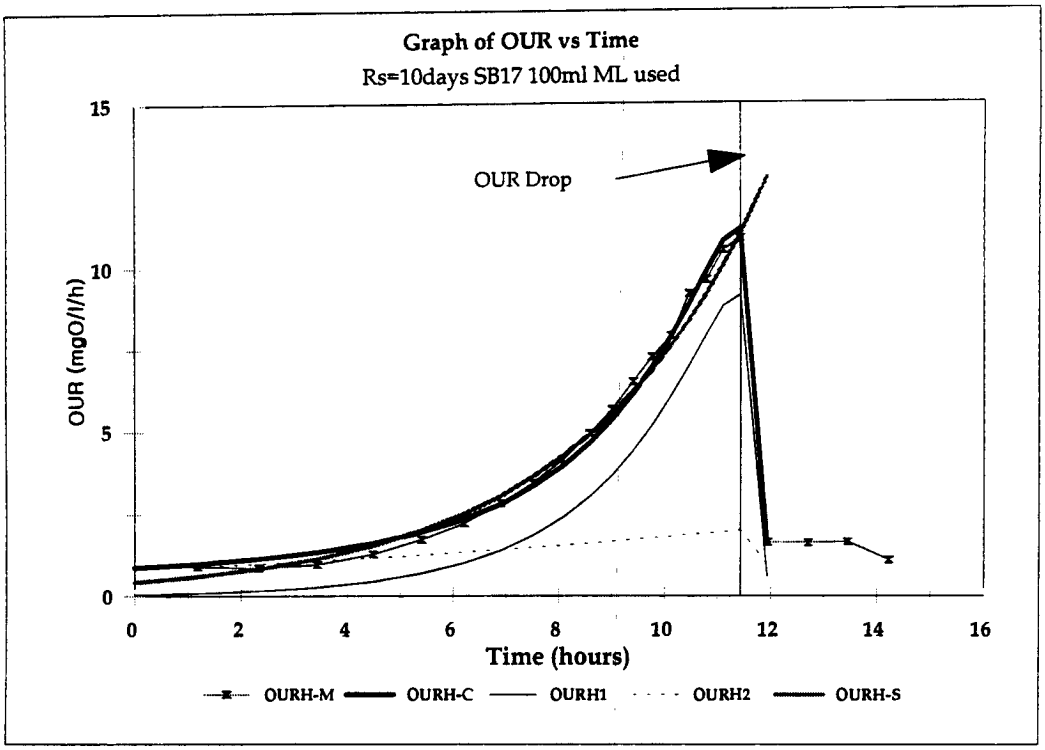


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For Sewage Batch No.17, Batch Test No.A35

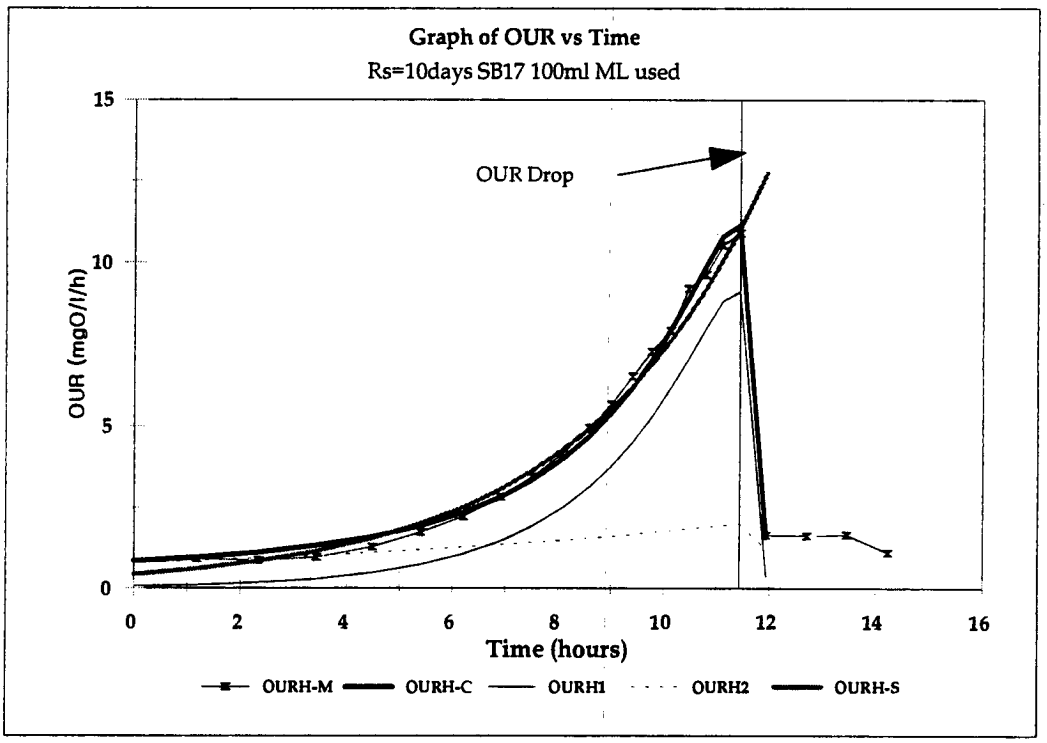


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OUR of the fast grower (OURH1) and OUR of the slow grower (OURH2)
For Sewage Batch No.17, Batch Test No.A35

Table C2: Summary for the parameter estimation with the aid of AQUASIM 2.0 computer program for the modified batch test data of the **20 day sludge age activated sludge system.**. Also shown are the total OHO active biomass concentrations at the start of the batch test, ($Z_{BH(0)}$) predicted by competition model models both of kinetic selection and process selection, from analysis using the procedure in chapter 4 (UCT model), and predicted by application of the steady state model to the parent system (taking due account of dilution)

Sew. Batch No.	Batch test No.	Batch test date	Volume (l)		Parameter Estimation				ZBH(0) (mgCOD/l)		
			WW	ML	Sti	$Z_{BH1(0)}$	$Z_{BH2(0)}$	χ^2	Competition Model	UCT Model	Steady-state Model
COMPETITION MODEL OF KINETIC SELECTION											
10	B13	12 12	2.80	0.20	109.96	2.43	110.06	5.86	112.49	50.3	83.7
	B14	13 12	2.90	0.10	72.28	2.95	58.30	0.09	61.25	24.9	41.9
11	B17	30 12	2.70	0.30	141.44	1.23	98.25	2.67	99.48	51.4	129.7
	B18	31 12	2.80	0.20	137.33	0.74	61.50	9.97	62.24	25.0	86.4
	B19	05 01	2.90	0.10	89.29	4.55	42.79	3.26	47.34	17.9	43.2
12	B22	11 01	2.70	0.30	175.02	0.41	114.31	21.20	114.72	71.8	133.6
	B23	14 01	2.80	0.20	162.99	0.22	77.55	6.28	77.77	48.5	89.1
	B24	15 01	2.90	0.10	166.27	0.52	47.30	7.66	47.82	14.0	44.5
14	B29	18 02	2.70	0.30	171.32	0.40	65.50	12.07	65.9	28.8	98.3
	B30	20 02	2.80	0.20	198.91	0.71	51.79	1.87	52.5	13.3	65.5
17	B34	22 04	2.70	0.30	121.04	0.33	71.39	5.59	71.72	43.1	104.4
	B35	24 04	2.80	0.20	117.18	0.32	30.71	3.22	31.03	10.2	69.6
COMPETITION MODEL OF PROCESS SELECTION											
10	B13	12 12	2.80	0.20	110.38	2.54	109.68	6.11	112.22	50.3	83.7
	B14	13 12	2.90	0.10	72.76	3.14	56.96	0.10	60.1	24.9	41.9
11	B17	30 12	2.70	0.30	141.93	1.33	97.39	2.82	98.72	51.4	129.7
	B18	31 12	2.80	0.20	138.44	0.80	61.16	10.67	61.96	25.0	86.4
	B19	05 01	2.90	0.10	90.44	4.74	42.17	3.85	46.91	17.9	43.2
12	B22	11 01	2.70	0.30	175.32	0.44	114.11	21.54	114.55	71.8	133.6
	B23	14 01	2.80	0.20	163.57	0.25	77.18	5.12	77.43	48.5	89.1
	B24	15 01	2.90	0.10	167.80	0.58	46.44	8.72	47.02	14.0	44.5
14	B29	18 02	2.70	0.30	172.26	0.45	64.89	12.90	65.34	28.8	98.3
	B30	20 02	2.80	0.20	200.42	0.79	50.01	1.87	50.8	13.3	65.5
17	B34	22 04	2.70	0.30	121.48	0.36	71.35	5.78	71.71	43.1	104.4
	B35	24 04	2.80	0.20	118.57	0.35	30.30	3.79	30.65	10.2	69.6

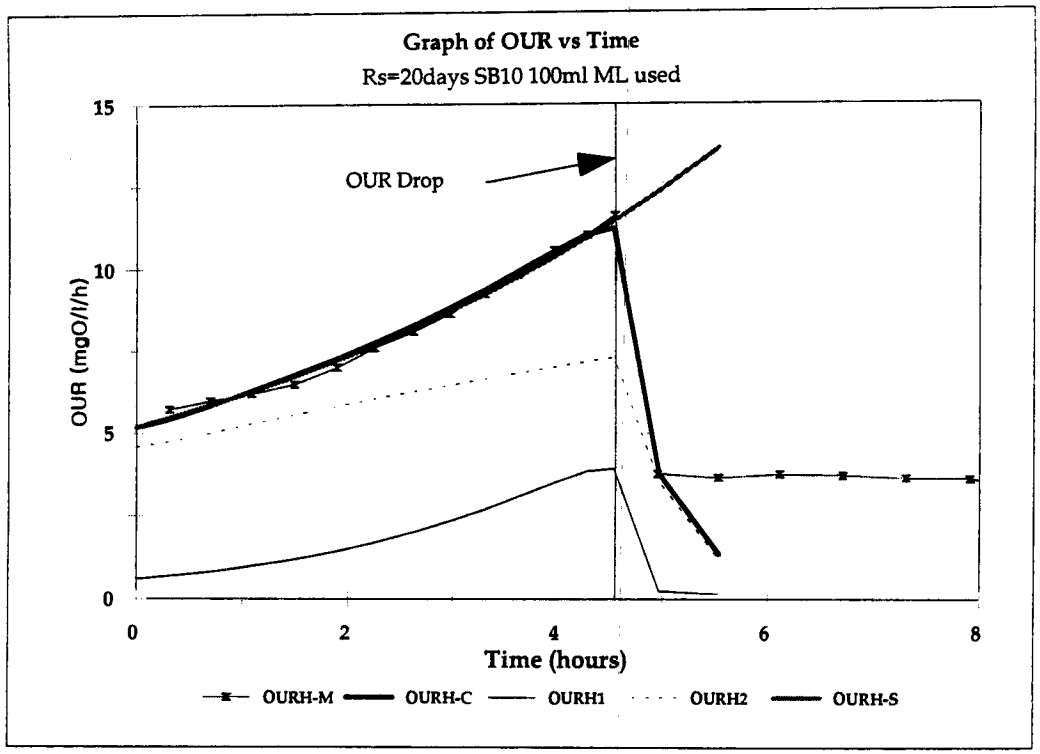


Fig. (a): Measured OUR of Heterotrophic organisms (OURH-M),
OUR calculated by the analytical procedure of Wentzel et al. (1995) (OURH-S),
OUR simulated by the **competition model of kinetic selection** (OURH-C),
OUR of the fast grower (OURH1) and OUR of the slow grower (OURH2)
For Sewage Batch No.10, Batch Test No.B13

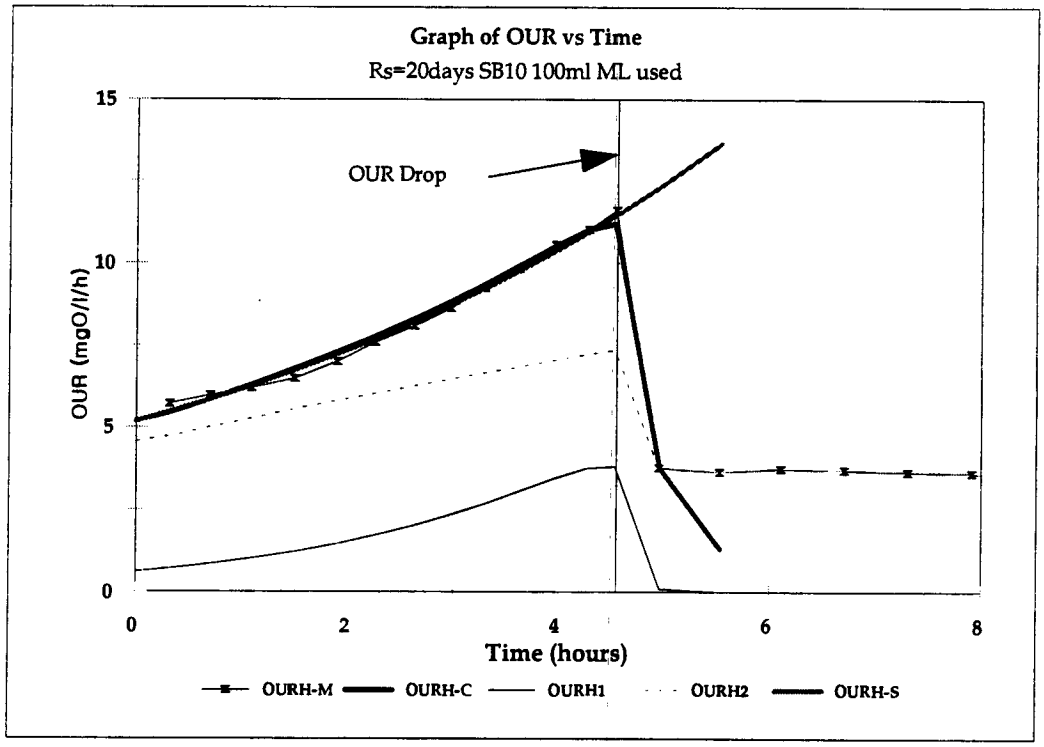


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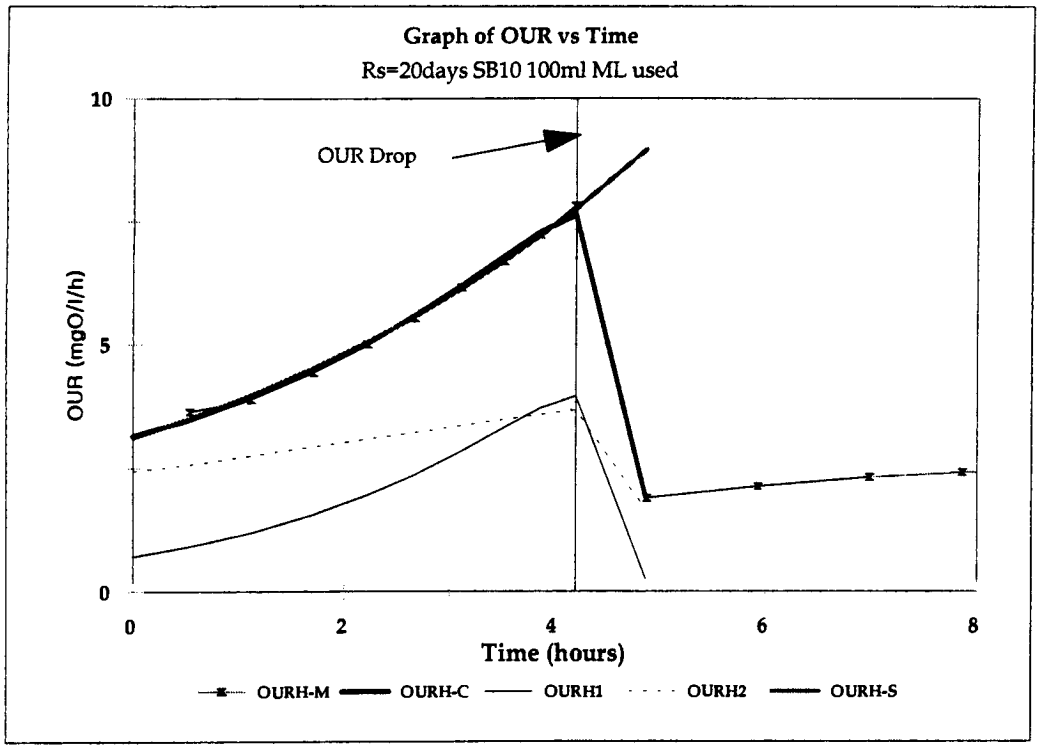


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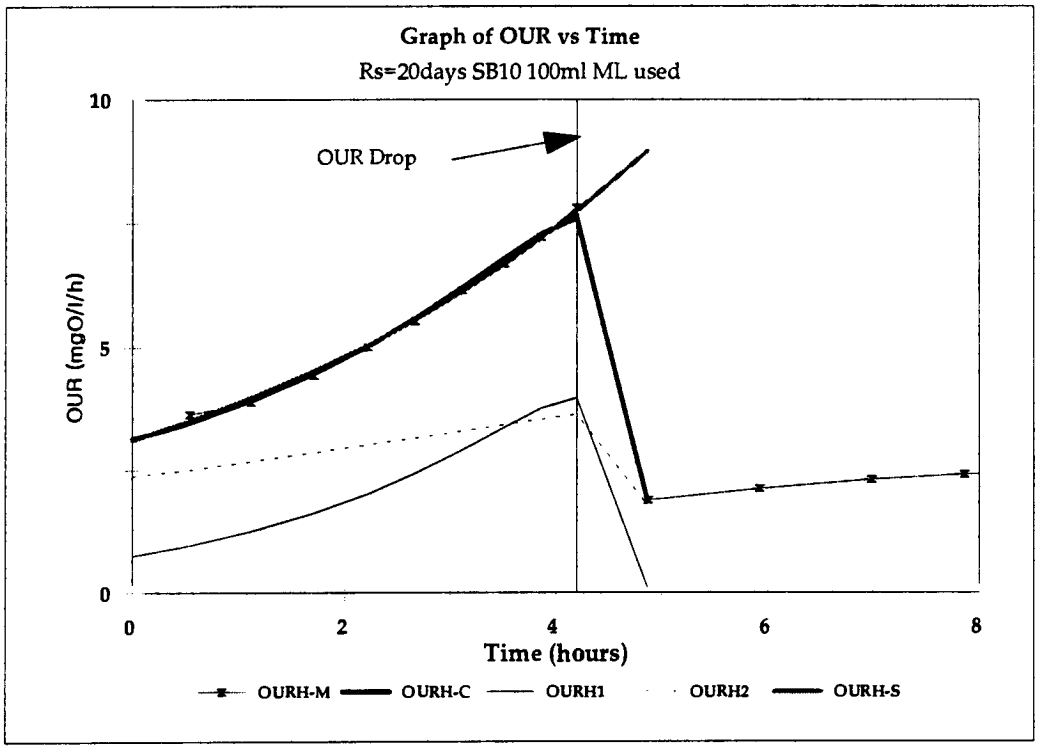


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For Sewage Batch No.10, Batch Test No.B14

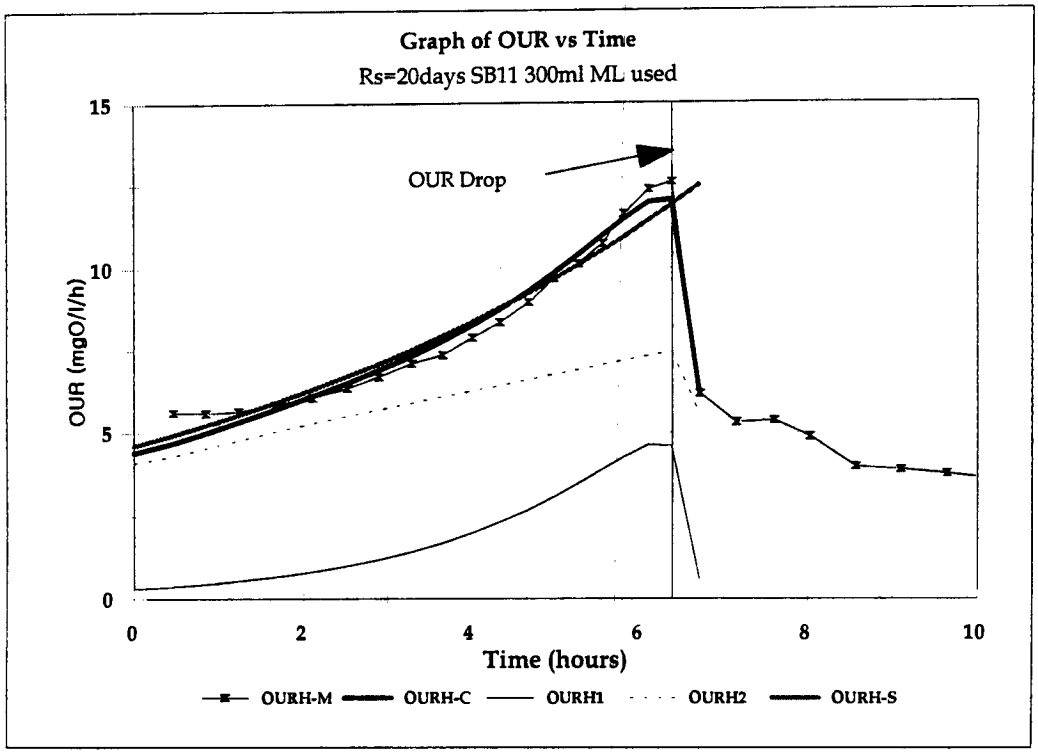


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OUR of the fast grower (OURH1) and OUR of the slow grower (OURH2)
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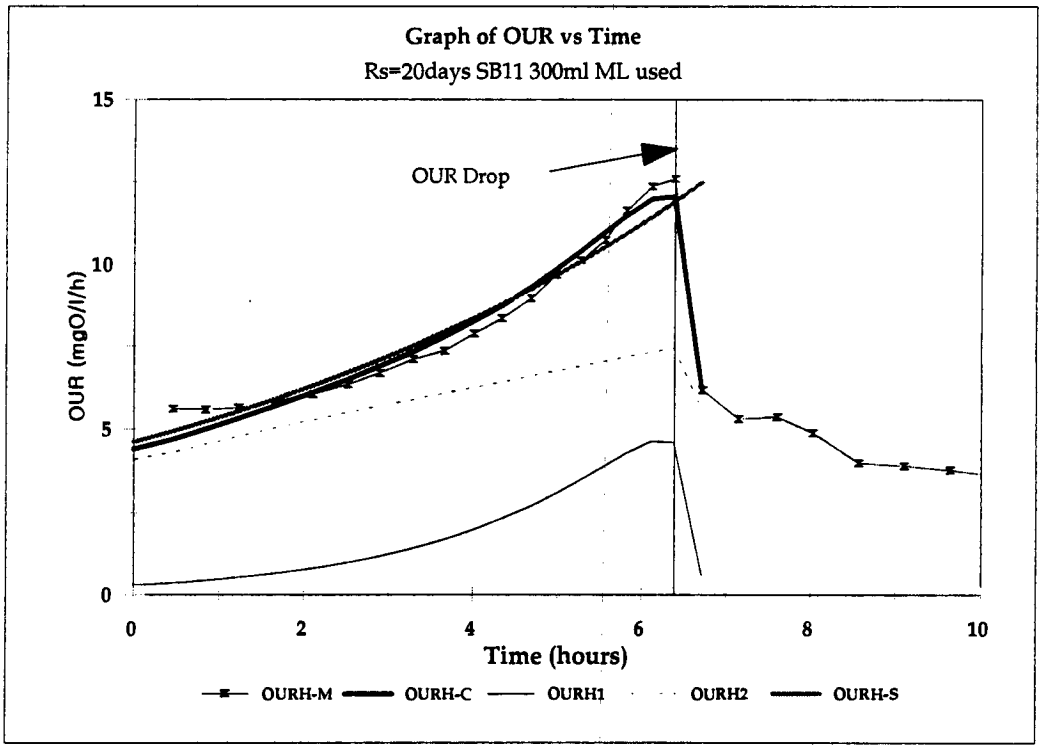


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For Sewage Batch No.11, Batch Test No.B17

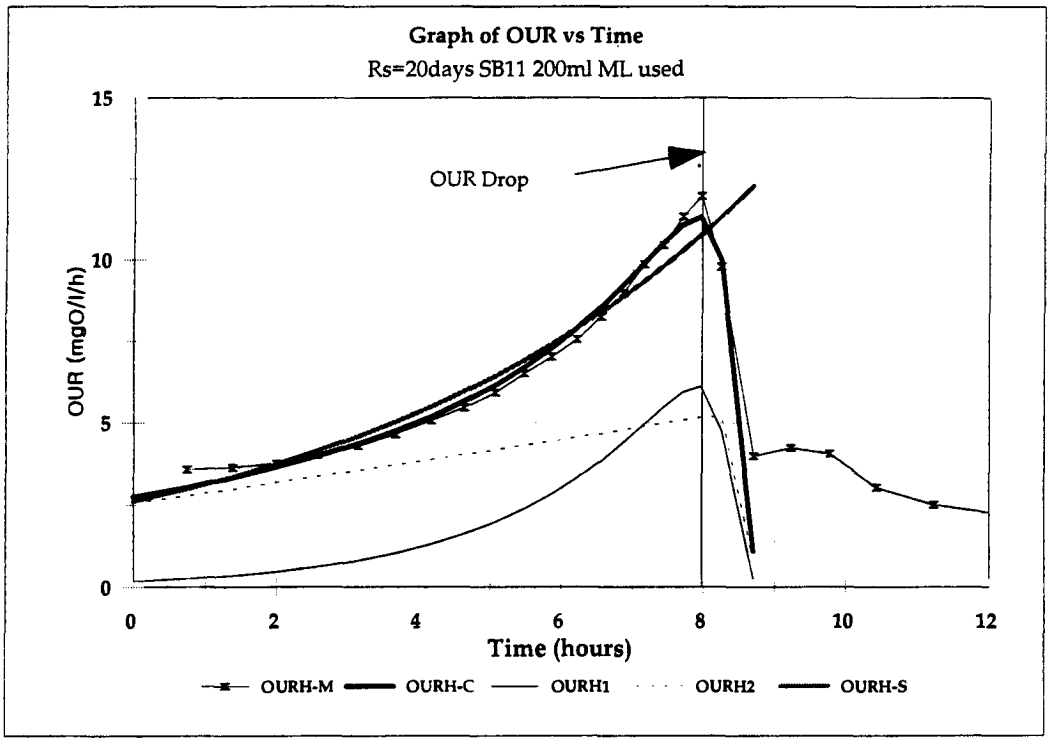


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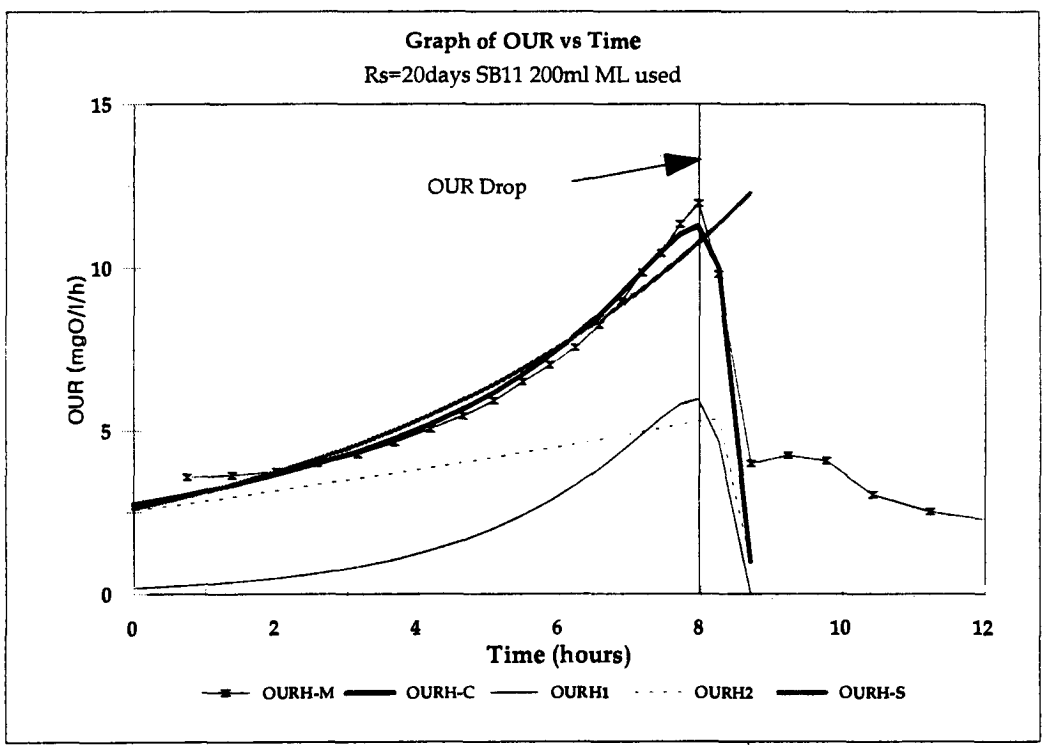


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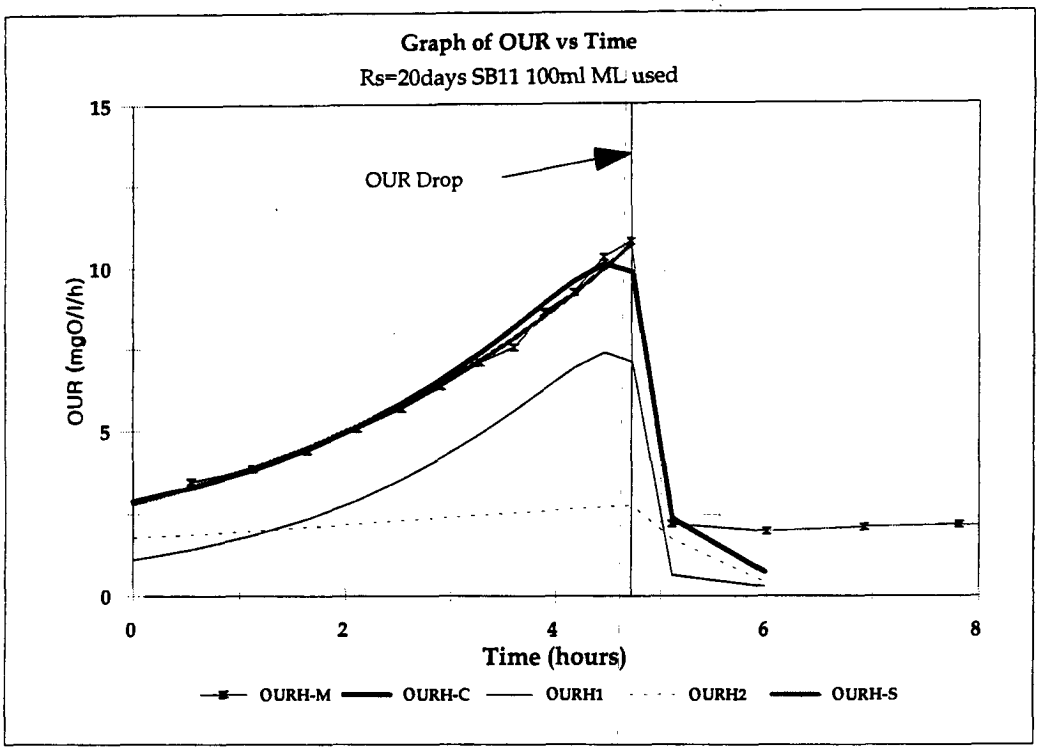


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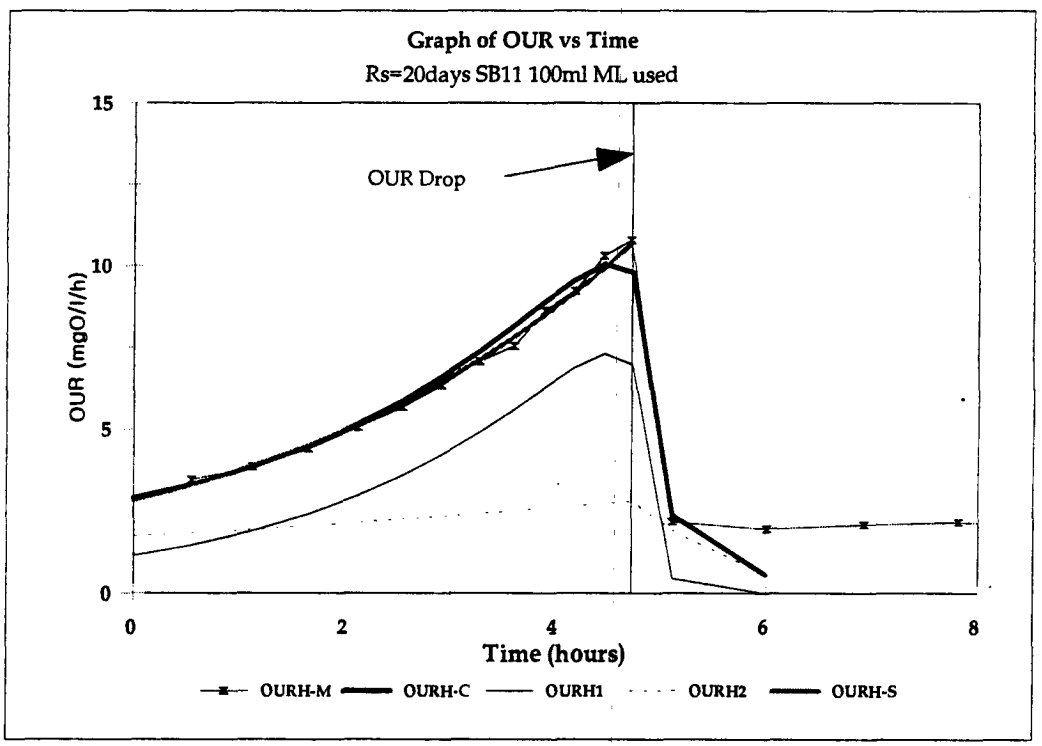


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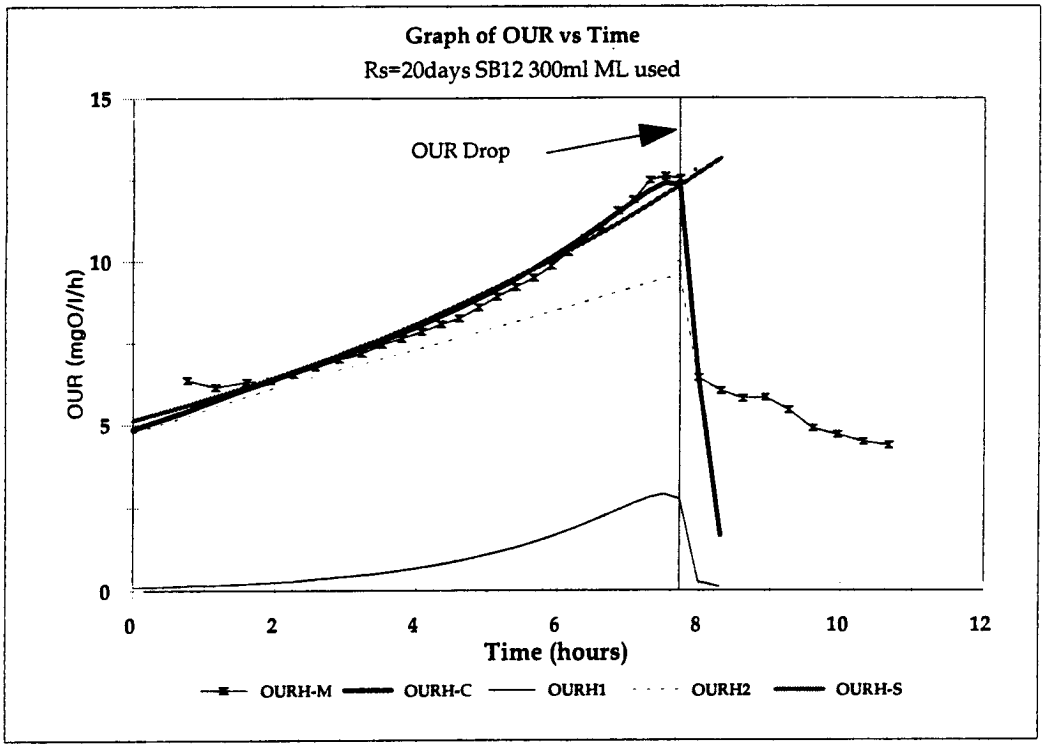


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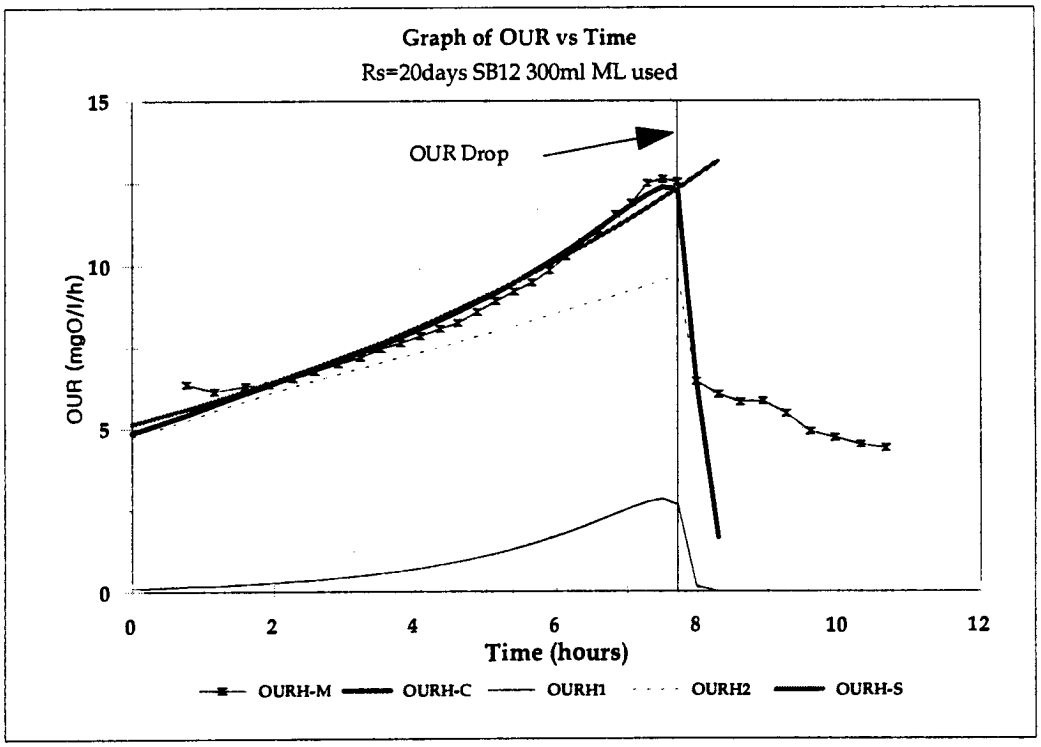


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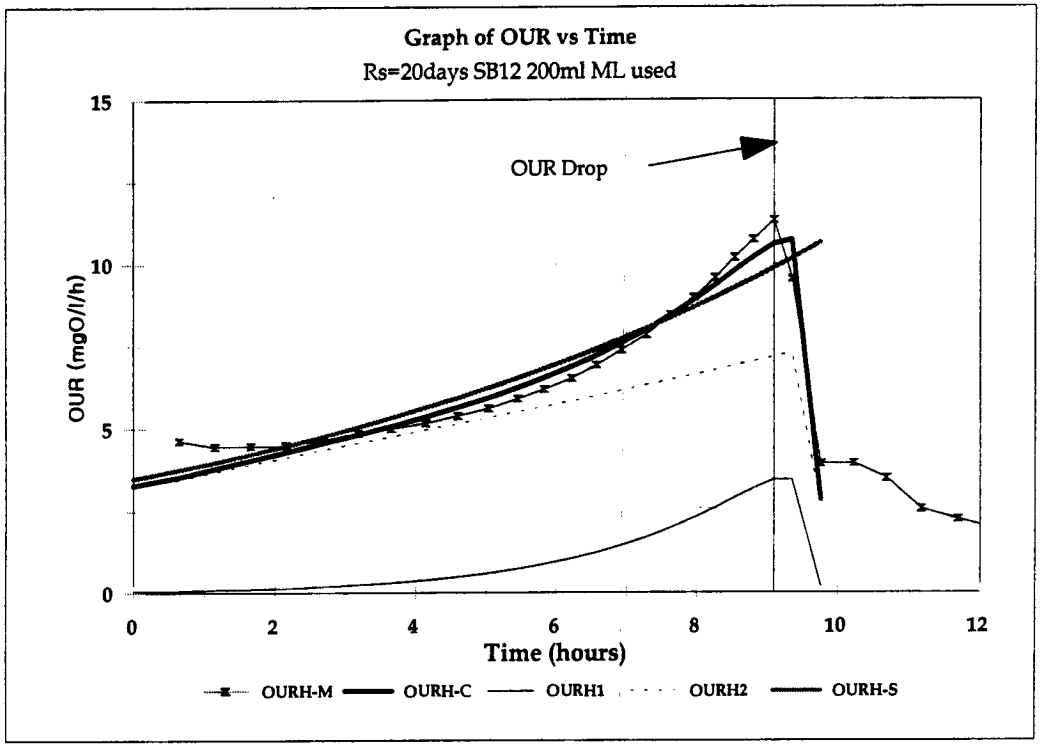


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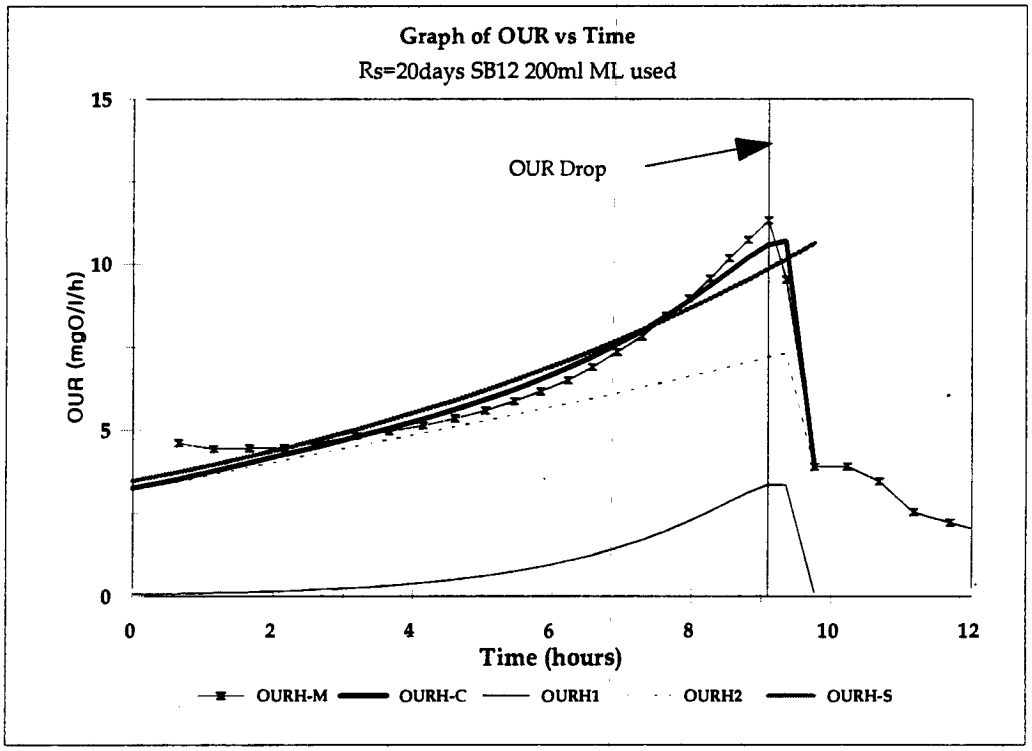


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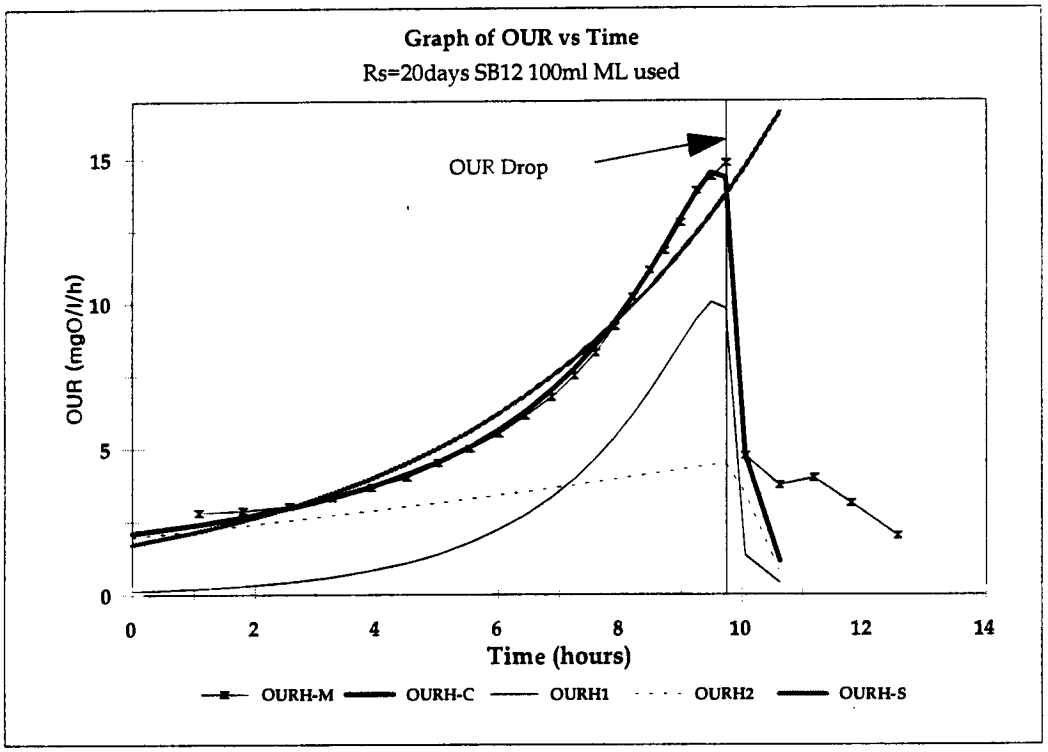


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For Sewage Batch No.12, Batch Test No.B24

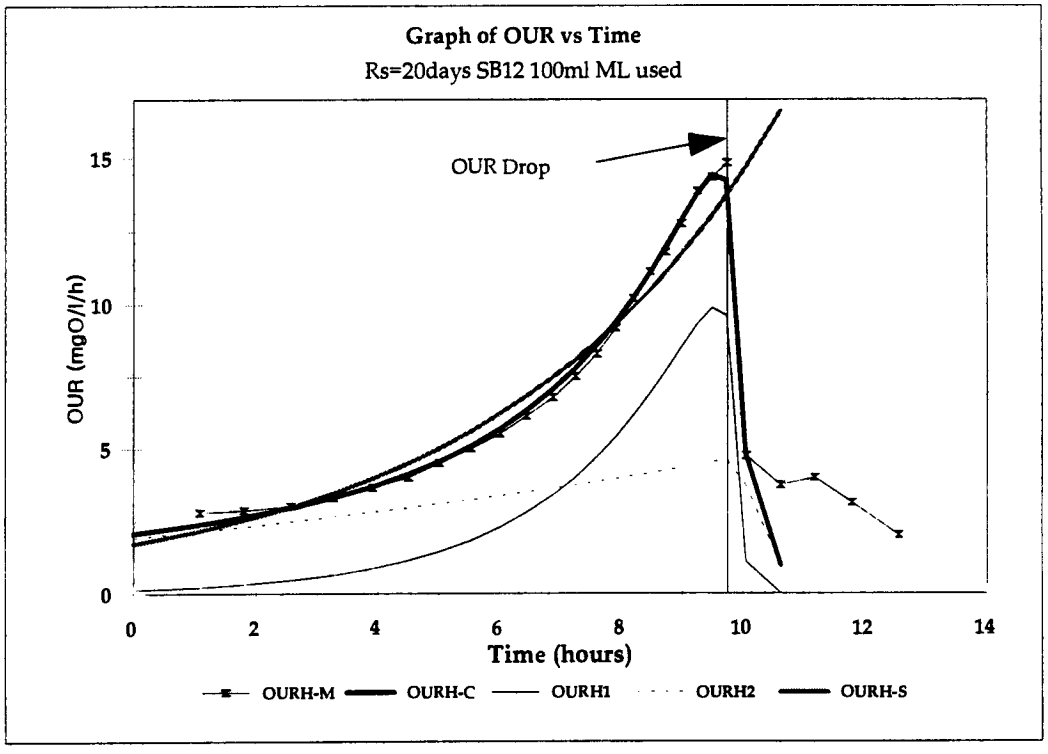


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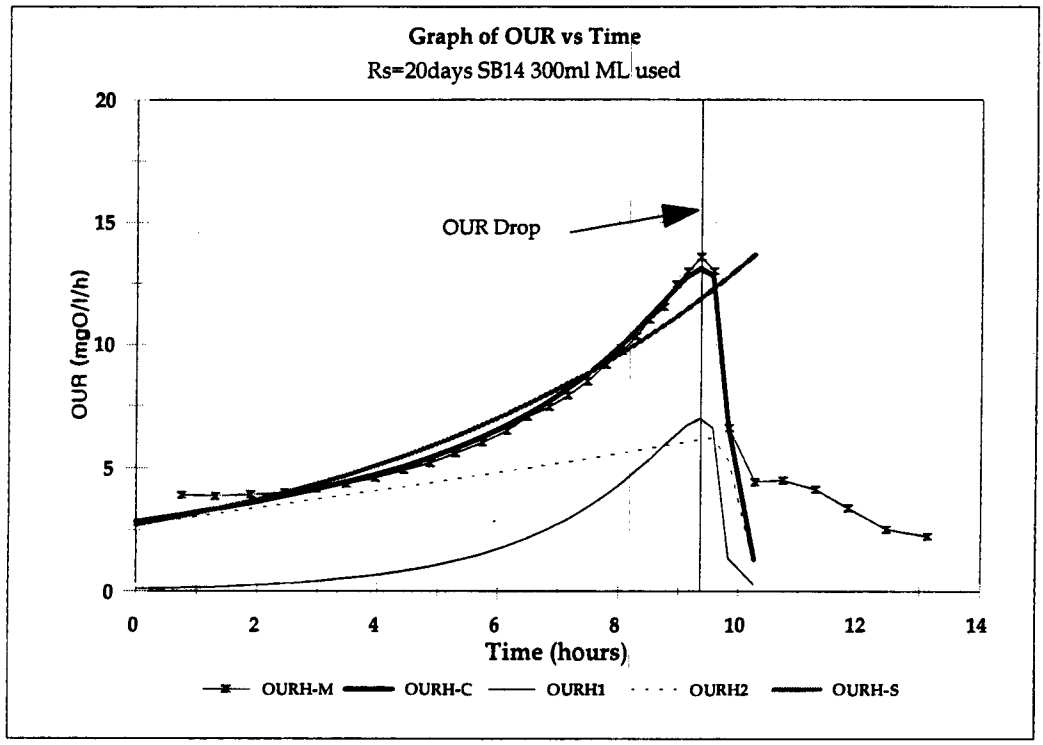


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For Sewage Batch No.14, Batch Test No.B29

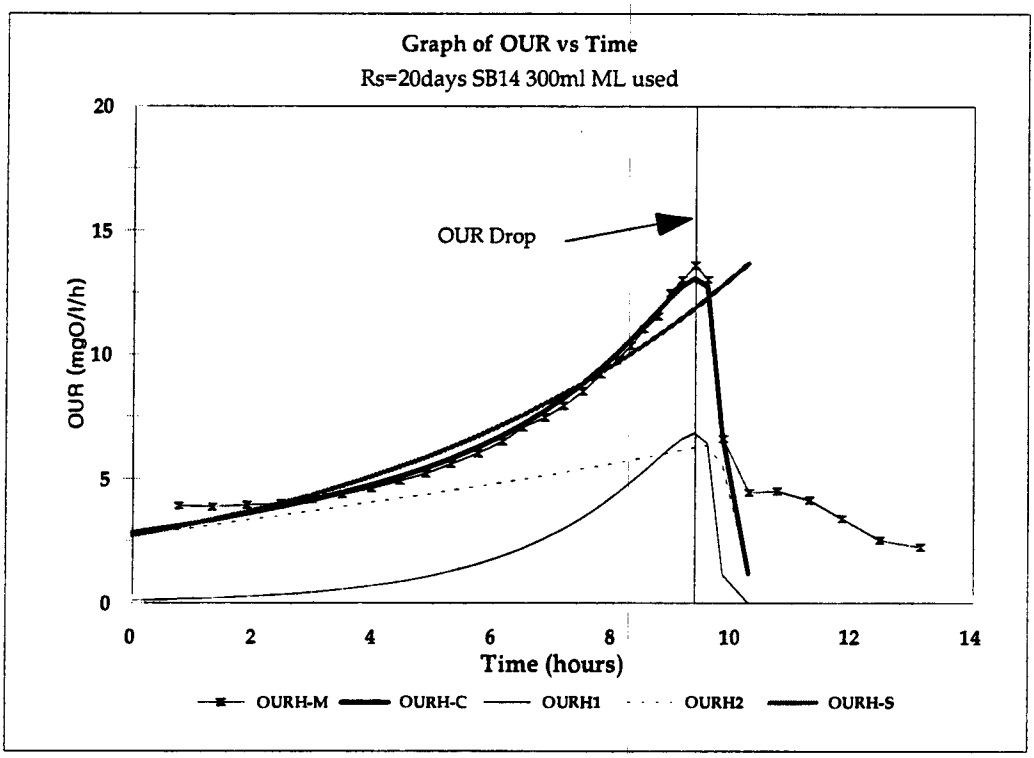


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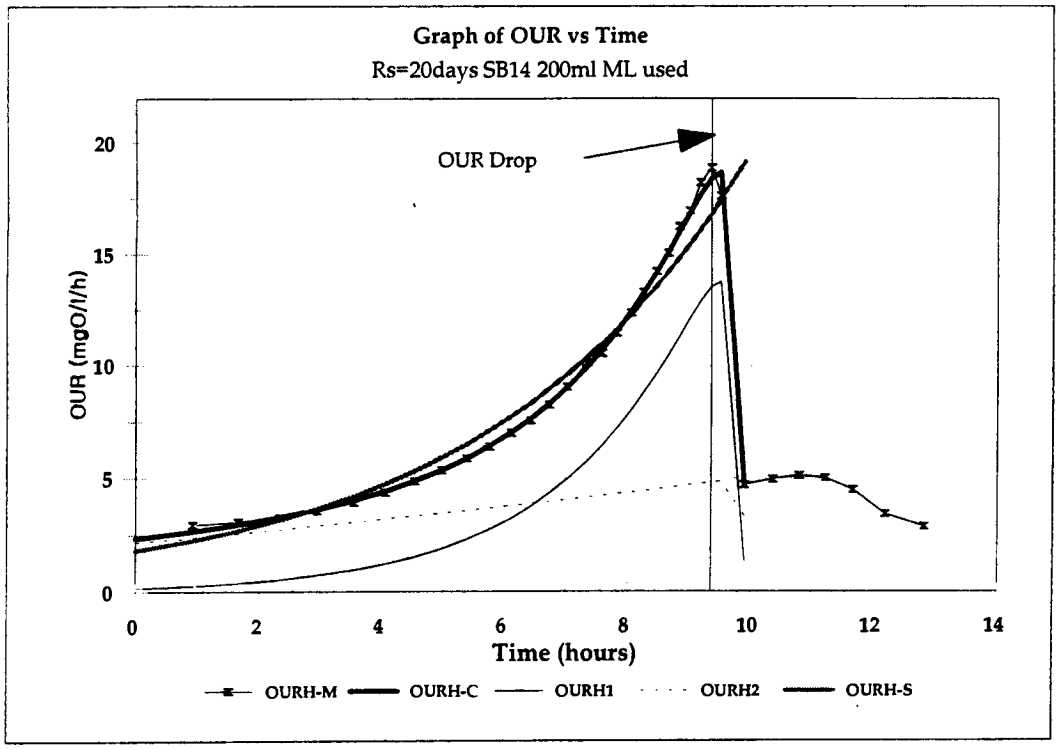


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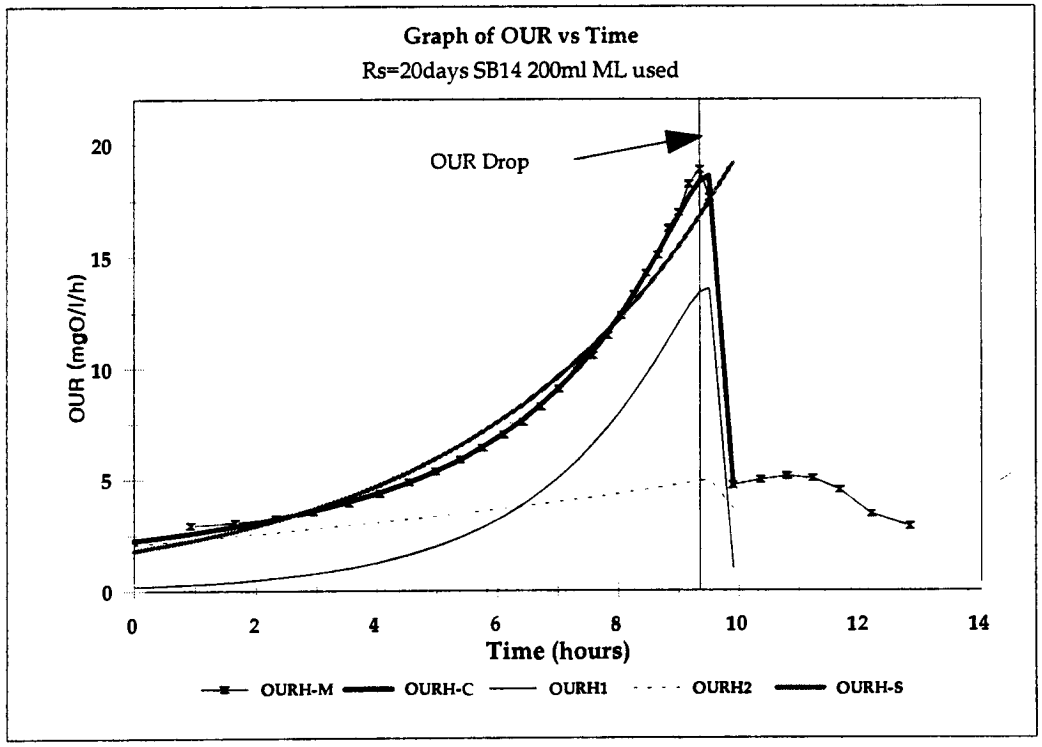


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For Sewage Batch No.14, Batch Test No.B30

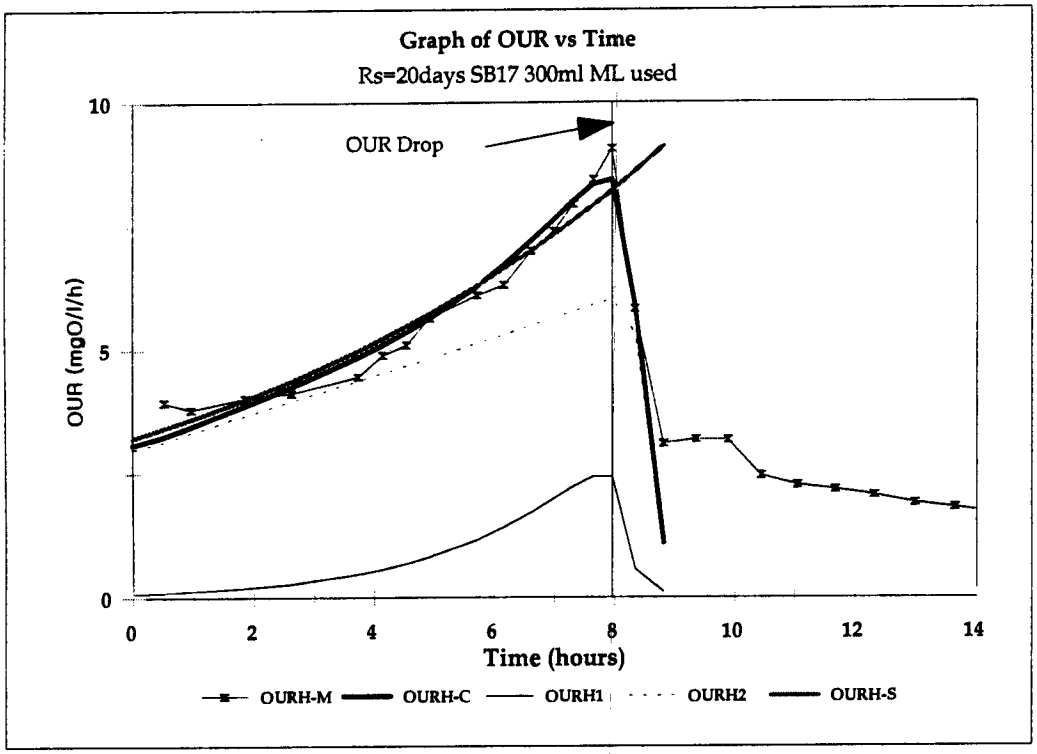


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For Sewage Batch No.17, Batch Test No.B34

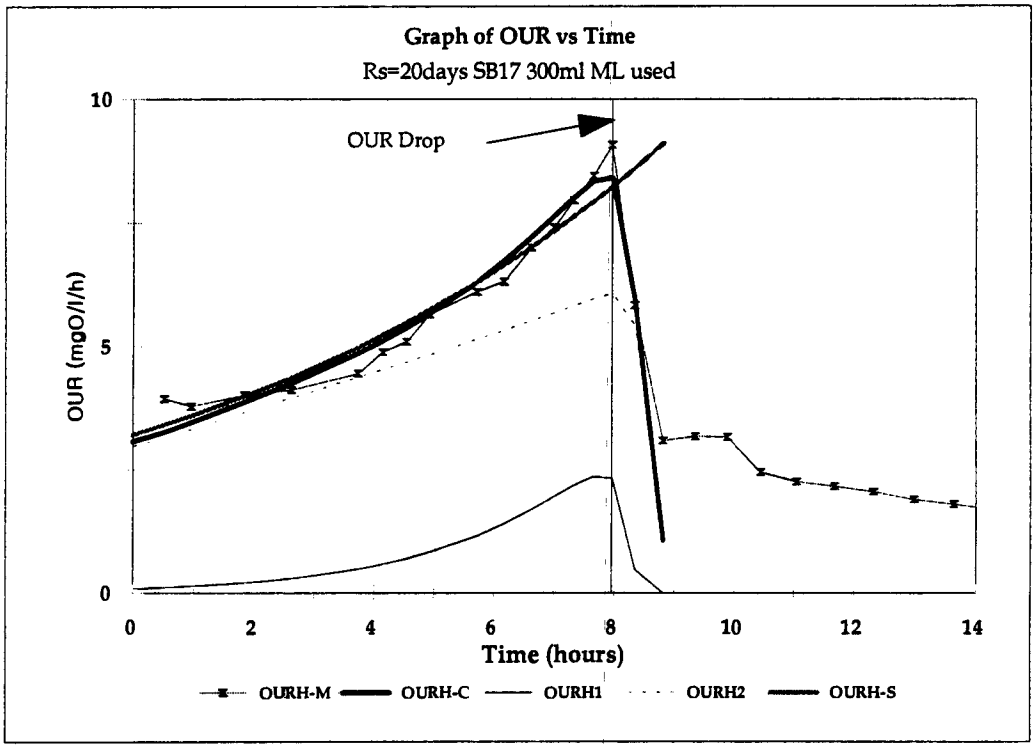


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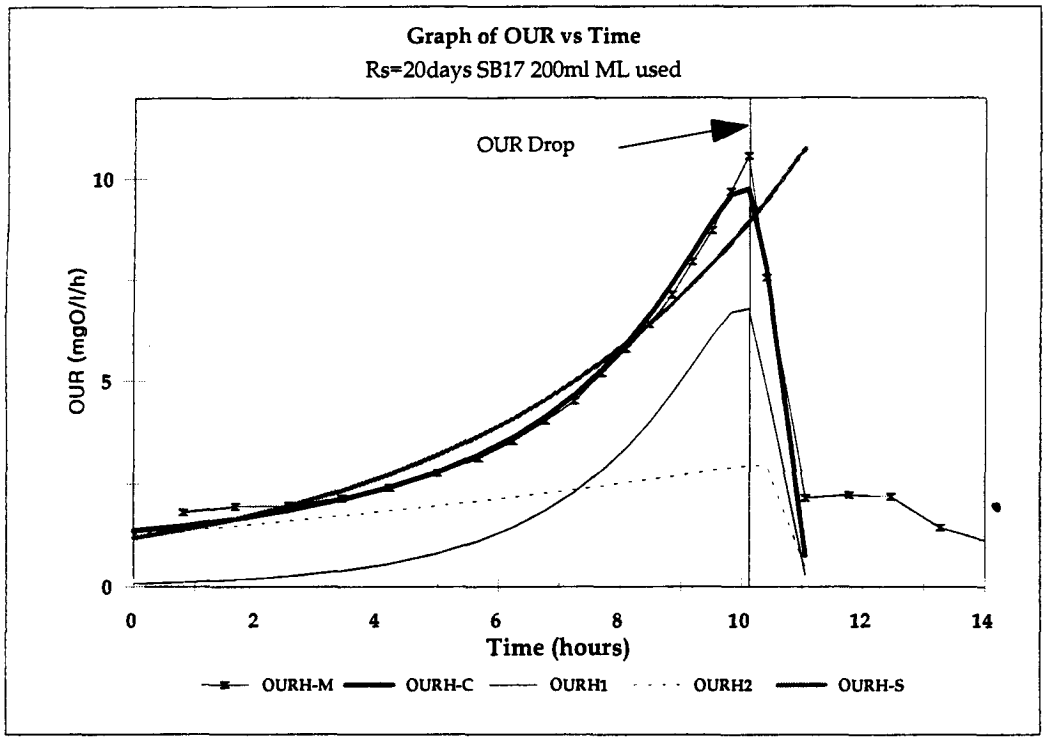


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For Sewage Batch No.17, Batch Test No.B35

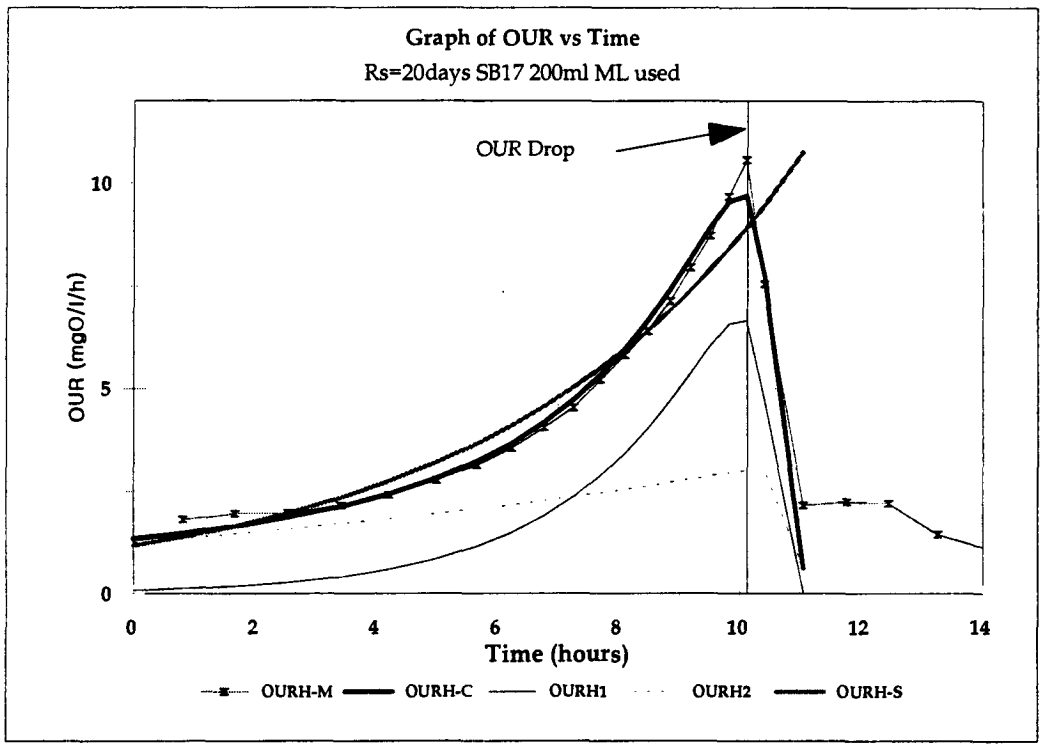


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For Sewage Batch No.17, Batch Test No.B35

APPENDIX D

COMPREHENSIVE DATA FOR THE 10 DAYS SLUDGE AGE PARENT LABORATORY-SCALE NITRIFICATION / DENITRIFICATION SYSTEM

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Table D1	Summary of statistical data for the various sewage batches for the 10 days system, listing the mean, standard deviation of the sample and the number of samples tested, for the influent, unfiltered effluent and mixed liquor TKN concentrations; the nitrate measured in the aerobic and anoxic reactors and effluent nitrate.
Table D2	Summary of statistical data for the various sewage batches for the 10 days system, listing the mean, standard deviation of the sample and the number of samples tested, for the influent, unfiltered effluent and mixed liquor COD concentrations; the OUR and the VSS measured in the aerobic reactor.
Table D3(a) - D19(a)	All the experimental data of each sewage batch for the 10 days system.
Table D3(b) - D19(b)	The calculation of N/COD mass balances, wastewater fractions and active fraction of mixed liquor for the 10 days system.
Fig. D1 - D5	Graphical representations of daily COD, TKN, aerobic nitrate and OUR, mixed liquor COD, VSS and TKN, anoxic nitrate and DSVI measurements for the 10 days system.

Table D1: Summary of the 10 days sludge age parent MLE system TKN and Nitratre statistical data for the various sewage batches.

Sew. Batch No.	TKN (mgN/l)									NITRATE (mgN/l)								
	INFLUENT			UNFILT. EFFLUENT			MIXED LIQUOR			ANOXIC			AEROBIC			EFFLUENT		
	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests
1	57.9	3.8	14	3.1	0.8	14	211.1	14.7	14	0.2	0.6	14	8.8	1.4	14	10.4	1.1	14
2	75.4	1.7	7	3.4	0.6	7	222.7	6.5	7	1.8	1.6	7	15.3	1.7	7	17.3	0.9	7
3	62.2	1.7	7	3.7	0.3	7	221.9	7.8	7	2.4	2.4	7	14.5	3.6	7	14.6	3.1	7
4	90.2	1.7	7	3.0	1.1	7	289.3	12.0	7	14.9	2.1	7	35.2	2.6	7	34.3	1.2	7
5	85.1	1.3	3	3.6	0.7	3	292.6	15.9	3	5.8	1.0	3	30.0	2.8	3	27.0	1.6	3
6	66.7	1.9	3	3.2	0.3	3	290.3	9.7	3	0.1	0.0	3	15.8	0.3	3	12.0	0.3	3
7	83.2	3.2	7	4.8	1.1	6	271.9	6.0	7	0.1	0.1	7	19.9	2.9	7	13.4	0.4	7
8	59.7	2.0	3	4.2	0.7	3	289.3	10.9	3	0.1	0.0	3	15.4	0.5	3	4.2	0.8	3
9	66.5	1.6	6	5.4	1.1	5	264.6	20.4	6	0.0	0.0	6	11.5	1.1	6	13.3	0.7	6
10	60.8	2.3	8	4.5	0.8	7	235.3	19.2	8	0.0	0.0	8	13.6	1.1	8	6.3	0.9	8
11	61.8	1.3	9	4.5	0.6	9	258.9	9.0	9	0.0	0.0	9	12.5	0.7	9	13.7	0.9	9
12	83.4	2.2	8	4.8	0.5	8	270.3	7.7	8	0.1	0.3	8	18.8	1.3	8	20.3	3.4	8
13	65.1	0.6	3	4.2	0.3	3	270.2	6.6	3	0.0	0.0	3	14.4	0.2	3	8.4	1.7	3
14	59.2	1.7	9	4.0	0.5	9	203.8	7.2	9	0.0	0.0	9	11.5	0.8	9	12.6	0.4	9
15	66.1	0.5	6	3.0	0.7	6	191.6	4.7	6	0.0	0.0	6	19.3	0.3	6	19.5	0.2	6
16	50.7	1.3	11	4.5	0.5	11	197.0	10.6	11	0.0	0.0	11	10.3	1.4	11	10.2	0.9	11
17	61.7	1.6	8	4.2	0.3	8	203.1	7.3	8	0.0	0.1	8	12.8	0.9	8	13.8	0.7	8

Table D2: Summary of the 10 days sludge age parent MLE system COD, OUR and VSS statistical data for the various sewage batches.

Sew. Batch No.	COD (mgN/l)									OUR (mgO/l/h)			VSS (mgVSS/l)		
	INFLUENT			UNFILT. EFFLUENT			MIXED LIQUOR								
	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests
1	717.7	28.2	14	25.4	8.2	14	3791.4	167.8	14	36.3	1.9	14	2836.2	75.3	14
2	709.6	11.4	7	27.4	9.9	7	3813.1	113.2	7	38.6	1.2	6	2760.1	94.3	7
3	757.1	14.7	7	32.8	13.7	7	3923.4	95.6	7	32.1	1.5	7	2765.0	107.3	7
4	712.0	33.1	7	32.9	6.7	7	5105.7	140.5	7	47.5	2.9	7	3510.2	129.1	7
5	706.7	28.5	3	30.7	5.7	3	4626.7	66.0	3	55.7	0.0	3	3360.1	68.3	3
6	734.5	12.8	3	26.1	3.2	3	4892.2	90.7	3	44.6	1.3	3	3457.7	112.7	3
7	760.2	63.2	7	34.7	18.3	7	4632.8	129.5	7	60.2	3.8	7	3325.0	75.5	7
8	677.3	27.8	3	17.6	8.5	3	4897.1	315.2	3	51.2	2.8	3	3468.7	142.9	3
9	686.7	22.8	6	49.2	15.9	6	4330.6	252.0	6	60.6	6.6	4	3291.0	127.1	6
10	749.4	40.1	8	42.8	11.2	8	4251.6	225.0	8	52.0	3.9	8	3131.7	205.1	8
11	733.8	22.3	9	44.8	7.3	9	4733.1	160.1	9	57.2	4.2	9	3461.6	121.9	9
12	749.4	26.1	8	51.4	5.6	8	4711.6	188.6	8	67.8	6.1	8	3520.6	173.0	8
13	762.5	11.8	3	36.6	1.9	3	4364.6	216.4	3	48.6	7.6	3	3195.1	165.9	3
14	727.2	23.2	9	37.5	4.3	9	3482.0	72.5	9	44.8	3.2	9	2532.2	62.2	9
15	764.9	15.2	6	43.2	8.6	6	3443.0	80.6	6	51.8	2.9	6	2557.4	39.8	6
16	743.4	18.1	11	42.8	6.6	11	3416.5	354.3	11	45.1	3.9	11	2489.4	226.6	11
17	772.6	13.0	8	38.1	4.7	8	3615.5	96.7	8	43.9	1.0	8	2632.3	100.6	8

Table D3(a): All the expeperimental results of sewage batch No.1 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10	10	13.3	20	2	1	0.45	0.2	0.24	1.48	1	0.751879699

< Sewage Batch 1 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)
09 07	20.5	21.5	58.8	15.3	14.7	210	3	4.2	1.7	2.38	15.2	42.56	0.3	0.42	0.14	0	0	0.44	8.19	10.75
10 07	21.3	22.7	61.6	15	14.9	209.3	2.3	3.22	1.8	2.52	16.1	45.08	1.7	2.38	0	0	0	0	7.89	9.94
11 07	21.1	21.1	59.08	15	15.5	213.5	1.4	1.96	0.3	0.42	15.6	43.68	0.5	0.7	0	0	0	0	8.39	9.54
12 07	21.2	20.5	58.38	14.9	15.1	210	1.8	2.52	1.3	1.82	15.7	43.96	0.9	1.26	0	0	0	0	8.39	9.74
13 07	17.7	15.4	46.34	15	15	210	1.9	2.66	1.7	2.38	16.2	45.36	0.6	0.84	0	0	0	0	8.79	9.64
14 07	19.4	18.6	53.2	12.9	12.3	176.4	2.1	2.94	0.2	0.28	15.5	43.4	2.1	2.94	0	0	0	0	9.8	9.54
16 07	21.2	21.2	59.36	13.5	16.5	210	2.3	3.22	0.3	0.42	16.3	45.64	0.8	1.12	0	0	0	0	8.39	9.09
17 07	19.9	19.9	55.72	15.9	14.4	212.1	1.7	2.38			16.4	45.92	0.8	1.12	0	0	0	0	8.19	9.9
18 07	20.7	20.7	57.96	13	13.1	182.7	2.1	2.94	1.6	2.24	17.2	48.16	0.8	1.12	0	0	0	0	9.2	10.4
19 07	21.4	21.4	59.92	16.3	15.3	221.2	3.3	4.62	2.7	3.78	13.6	38.08	2.8	3.92	0	0	0	0	5.93	11.2
20 07	21.2	21.2	59.36	16.5	16.5	231	1.6	2.24	0.3	0.42	16.8	47.04	1.1	1.54	0	0	0	0	8.32	10.48
21 07	21.5	21.5	60.2	15.5	15.5	217	2.4	3.36	1.9	2.66	16.7	46.76	1.2	1.68	0	0	0	0	8.8	10.6
23 07	21.1	21.7	59.92	16	15.7	221.9	3.1	4.34	1.9	2.66	17.2	48.16	0.4	0.56	1.09	0.8	0	0.72	10.24	11.08
24 07	21.7	21.7	60.76	16.8	16.1	230.3	1.5	2.1			17.2	48.16	1.3	1.82	1.48	0	0	2.32	12.45	13.49
Mean			57.9			211.1		3.05		1.831666667		45.14		1.53	0.193571429	0.057142857	0	0.248571429	8.783571429	10.385
SSD			3.803156584			14.7444905		0.813203542		1.11041909		2.639772717		0.942814934	0.453046941	0.206031501	0	0.611168169	1.391205064	1.0517451483
No.			14			14		14		12		14		14	14	14	14	14	14	14

Normality	COD													OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.05	23.8	23.8	14.7	14.7	728	14.4	14.7	3700	22.9	23.3	28	23.2	23.3	22	33.69	0.79	131
0.05	25.1	24.7	15.5	15.5	752	16.1	15.6	3620	24.3	23.8	34	24.4	24.4	20	33.93	1.14	145
0.05	24.3	24.7	14.7	15.4	756	15	14.9	3820	23.6	23.4	40	24	24	20	35.2	0.8	133
0.05	24.7	24.9	15.3	15.3	760	14.8	14.5	4060	23.8	23.9	38	23.9	23.8	38	35.38	1.19	148
0.05	24.8	23.9	15.3	15.3	724	15.3	15	3680	23.7	23.8	24	23.4	23.9	28	38	1.07	142
0.05	24.2	24	15.2	15.1	716	15.1	15	3620	23.3	23.5	28	23.5	23.4	26	38.86	0.98	149
0.05	24.2	23.9	15.5	15.2	696	14.5	14.3	3860	23.5	23.6	20	23.5	23.3	26	39.74	1.56	142
0.05	23.8	24.2	15.2	15	712	14.5	14.3	3840	23.3	23.3	28	23.3	23.3	28	38.06	1.14	136
0.05	25.1	24.9	16.1	16.1	712	15.5	15.7	3760	24.3	24.5	24	24.4	24.6	20	38.15	0.76	148
0.05	24.9	24.5	15.8	14.9	748	15.5	15.1	3760	24	24.2	24	24.2	24.4	16	37.23	1.41	143
0.05	24.3	23.8	15.4	15.4	692	15.3	15.1	3540	23.6	24	10	24.1	24	0	35.37	0.78	148
0.05	24.3	24.2	15.3	15.6	704	15	15.1	3680	23.9	24	12	23.7	23.9	18	34.34	0.72	149
0.05	23.7	23.3	15	14.8	688	13.3	13.2	4100	22.8	22.9	26	23	22.9	22	34.54	1.4	138
0.05	24.1	23.6	15.7	15.5	660	13.6	13.9	4040	23.2	23.5	20	23.1	23.6	20	35.69	1.26	135
					717.7142857			3791.428571			25.42857143			21.71428571	36.29857143		
					28.15119528			167.7948213			8.226388599			8.066053836	1.914675866		
					14			14			14			14	14		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
59.2147	59.3764	59.2374	3234	2780	43.4092	43.5675	43.4325	3166	2700	7.32	7.3	165	104.23247
59.2127	59.3803	59.239	3352	2826	56.3837	56.5464	56.4095	3254	2738	7.79	7.74	165	101.4136447
59.2167	59.3785	59.2383	3236	2804	56.3869	56.5505	56.4103	3272	2804	7.77	7.67	160	97.799511
59.2142	59.3814	59.2398	3344	2832	56.3869	56.5489	56.4125	3240	2728	7.77	7.71	160	98.7654321
59.2166	59.3893	59.2424	3454	2938	56.3912	56.5569	56.4159	3314	2820	7.72	7.71	165	99.57754979
59.219	59.379	59.2406	3200	2768	56.3925	56.5568	56.4155	3286	2826	7.7	7.72	160	97.38283628
59.2208	59.3874	59.243	3332	2888	56.3946	56.5706	56.4192	3520	3028	7.79	7.76	180	102.2727273
59.2194	59.388	59.2412	3372	2936	56.3943	56.5632	56.418	3378	2904	7.77	7.74	175	103.6116045
59.2191	59.3782	59.241	3182	2744	42.4499	42.6136	42.4736	3274	2800	7.74	7.7	190	116.0659743
59.221	59.3795	59.2447	3170	2696	56.398	56.5657	56.4233	3354	2848	7.8	7.7	180	107.3345259
59.226	59.3905	59.2493	3290	2824	56.4009	56.5617	56.4244	3216	2746	7.71	7.7	180	111.9402985
59.226	59.393	59.2475	3340	2910	56.4026	56.569	56.425	3328	2880	7.7	7.7	180	108.1730769
59.2263	59.3979	59.2526	3432	2906	56.403	56.5743	56.4296	3426	2894	7.61	7.55	180	105.0788091
59.2301	59.4083	59.2568	3564	3030	56.4054	56.5777	56.4325	3446	2904	7.6	7.6	180	104.4689495
			3321.571429	2848.714286				3319.571429	2830	7.69285714	7.664285714		104.1512436
			108.9381963	86.99953085				93.57709906	85.18551185	0.121153049	0.114312497		5.191356099
			14	14				14	14	14	14		14

Table D3(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.1 for 10 days sludge age pilot system.

< Sewage Batch 1 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
09 07	58.8	210	4.2	2.38	0.14	0	0	0.44	8.19	10.75	-7.4	337.4	0.0	330.0	42.2	51.7	6.6	132.2	16.9	220.8	28.2	782.0	93.9
10 07	61.6	209.3	3.22	2.52	0	0	0	0	7.89	9.94	0.0	342.1	0.0	342.1	41.8	39.6	4.8	122.3	14.9	219.2	26.8	819.3	88.3
11 07	59.08	213.5	1.96	0.42	0	0	0	0	8.39	9.54	0.0	350.1	0.0	350.1	44.5	24.1	3.1	117.3	14.9	223.0	28.4	785.8	90.9
12 07	58.38	210	2.52	1.82	0	0	0	0	8.39	9.74	0.0	352.7	0.0	352.7	45.4	31.0	4.0	119.8	15.4	219.7	28.3	776.5	93.1
13 07	46.34	210	2.66	2.38	0	0	0	0	8.79	9.64	0.0	362.0	0.0	362.0	58.7	32.7	5.3	118.6	19.2	219.6	35.6	616.3	118.9
14 07	53.2	176.4	2.94	0.28	0	0	0	0	9.8	9.54	0.0	387.6	3.5	387.6	55.3	36.2	5.1	117.3	16.6	185.9	26.3	707.6	103.2
16 07	59.36	210	3.22	0.42	0	0	0	0	8.39	9.09	0.0	344.1	0.0	344.1	43.6	39.6	5.0	111.8	14.2	219.1	27.8	789.5	90.5
17 07	55.72	212.1	2.38	0	0	0	0	0	8.19	9.9	0.0	349.5	0.0	349.5	47.2	29.3	4.0	121.8	16.4	222.0	30.0	741.1	97.5
18 07	57.96	182.7	2.94	2.24	0	0	0	0	9.2	10.4	0.0	383.0	0.0	383.0	49.7	36.2	4.7	127.9	16.6	193.1	25.0	770.9	96.0
19 07	59.92	221.2	4.62	3.78	0	0	0	0	5.93	11.2	0.0	306.7	0.0	306.7	38.5	56.8	7.1	137.8	17.3	232.4	29.2	796.9	92.1
20 07	59.36	231	2.24	0.42	0	0	0	0	8.32	10.48	0.0	360.7	0.0	360.7	45.7	27.6	3.5	128.9	16.3	241.5	30.6	789.5	96.1
21 07	60.2	217	3.36	2.66	0	0	0	0	8.8	10.6	0.0	375.1	0.0	375.1	46.8	41.3	5.2	130.4	16.3	227.6	28.4	800.7	96.7
23 07	59.92	221.9	4.34	2.66	1.09	0.8	0	0.72	10.24	11.08	-36.7	381.4	0.0	344.7	43.3	53.4	6.7	136.3	17.1	233.0	29.2	796.9	96.3
24 07	60.76	230.3	2.1		1.48	0	0	2.32	12.45	13.49	-78.7	387.2	0.0	308.4	38.2	25.8	3.2	165.9	20.5	243.8	30.2	808.1	92.1
Mean	57.9	211.1	3.05	1.83166667	0.19357143	0.05714286	0	0.24857143	8.78357143	10.385	-8.8	358.5	0.0	349.8	45.4	37.5	4.9	127.7	16.6	221.5	28.8	770.1	95.6

< Sewage Batch 1 - COD Mass Balance >

Date	Conc. (mg/l)				OUR	Mass (mg/d)											COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
09 07	728	3700	28	22	808.6	344.4	3.6	-7.4	412.3	1858.7	3558.7	36.8	952.3	9.8	3700.0	38.2	9682.4	88.4
10 07	752	3620	34	20	814.3	418.2	4.2	0.0	419.7	1918.2	3537.7	35.4	978.3	9.8	3620.0	36.2	10001.6	85.5
11 07	756	3820	40	20	844.8	492.0	4.9	0.0	446.3	2039.8	3620.3	36.0	1001.2	10.0	3820.0	38.0	10054.8	88.8
12 07	760	4060	38	38	849.1	467.4	4.6	0.0	446.3	2039.8	3649.3	36.1	1008.8	10.0	4060.0	40.2	10108.0	90.9
13 07	724	3680	24	28	912.0	295.2	3.1	0.0	467.6	2137.1	3973.3	41.3	1035.4	10.8	3680.0	38.2	9629.2	93.3
14 07	716	3620	28	26	932.6	344.4	3.6	0.0	521.4	2382.6	3866.1	40.6	1118.3	11.7	3620.0	38.0	9522.8	94.0
16 07	696	3860	20	26	953.8	246.0	2.7	0.0	446.3	2039.8	4350.4	47.0	984.0	10.6	3860.0	41.7	9256.8	102.0
17 07	712	3840	28	28	913.4	344.4	3.6	0.0	435.7	1991.2	4128.9	43.6	999.6	10.6	3840.0	40.6	9469.6	98.3
18 07	712	3760	24	20	915.6	295.2	3.1	0.0	489.4	2236.7	3897.8	41.2	1095.5	11.6	3760.0	39.7	9469.6	95.6
19 07	748	3760	24	16	893.5	295.2	3.0	0.0	315.5	1441.7	4544.9	45.7	877.2	8.8	3760.0	37.8	9948.4	95.3
20 07	692	3540	10	0	848.9	123.0	1.3	0.0	442.6	2022.8	3664.7	39.8	1031.6	11.2	3540.0	38.5	9203.6	90.8
21 07	704	3680	12	18	824.2	147.6	1.6	0.0	468.2	2139.5	3382.4	36.1	1072.7	11.5	3680.0	39.3	9363.2	88.5
23 07	688	4100	26	22	829.0	319.8	3.5	-15.4	506.5	2261.6	3292.4	36.0	1028.2	11.2	4100.0	44.8	9150.4	95.5
24 07	660	4040	20	20	856.6	246.0	2.8	-78.7	538.9	2192.8	3546.2	40.4	972.6	11.1	4040.0	46.0	8778.0	100.3
Mean	717.714286	3791.42857	25.4285714	21.7142857	871.2	312.8	3.3	-7.3	454.1	2050.2	3786.6	39.7	1010.4	10.6	3791.4	39.7	9545.6	93.2

< Sewage Batch 1 - Charateristics of Wastewater and Mixed Liqour >

Date	Fractions		Mixed Liqour		
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
09 07	0.030	0.170	1.362	0.079	0.376
10 07	0.027	0.152	1.315	0.077	0.393
11 07	0.026	0.163	1.355	0.076	0.385
12 07	0.050	0.181	1.474	0.078	0.373
13 07	0.039	0.188	1.295	0.075	0.345
14 07	0.036	0.180	1.272	0.063	0.352
16 07	0.037	0.225	1.266	0.069	0.303
17 07	0.039	0.211	1.313	0.073	0.322
18 07	0.028	0.187	1.336	0.066	0.354
19 07	0.021	0.159	1.315	0.079	0.386
20 07	0.000	0.182	1.289	0.084	0.360
21 07	0.026	0.199	1.272	0.076	0.332
23 07	0.032	0.247	1.409	0.078	0.301
24 07	0.030	0.277	1.384	0.079	0.273
Mean	0.030	0.193	1.332	0.075	0.346

Table D4(a): All the expeperimental results of sewage batch No.2 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10	10	13.3	20	2	1	0.45	0.2	0.24	1.48	1	0.7518797

< Sewage Batch 2 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
27 07	25.9	25.8	72.38	16.3	15.4	221.9	2.6	3.64	1.7	2.38	21	58.8	0.4	0.56	1.31	0.41	0	2.51	14.41	17.75
28 07	28	25.9	75.46	15.6	16.9	227.5	2.8	3.92	2.4	3.36	21.3	59.64	1	1.4	1.36	0	0.61	3.43	16.3	18.35
30 07	27.5	26.8	76.02	16.3	16.1	226.8	3.2	4.48	2.2	3.08	21.7	60.76	0.5	0.7	0.62	0	0	0.35	14.82	18.35
31 07	25.9	27.3	74.48	15.6	16.3	223.3	1.9	2.66	1.4	1.96	21	58.8	1.4	1.96	0	0	0	0	15.85	16.3
01 08	29.3	26.9	78.68	16.7	16	228.9	2.2	3.08	1.9	2.66	21.4	59.92	1	1.4	0.74	0.7	0	0.75	15.71	16.08
02 08	26.9	27	75.46	17.1	14.7	222.6	1.9	2.66	2.6	3.64	21.3	59.64	0.9	1.26	0.83	0	0	1.05	17.9	16.42
03 08	26.4	27.2	75.04	14.6	15.1	207.9	2.2	3.08	2.1	2.94	21.2	59.36	0.7	0.98	1.4	0	0	4.59	12.07	17.84
Mean			75.36			222.7		3.36		2.86		59.56		1.18	0.89428571	0.15857143	0.08714286	1.81142857	15.2942857	17.2985714
SSD			1.74172328			6.5283995		0.63055531		0.53366656		0.62992063		0.44181444	0.4703147	0.26242978	0.21345553	1.60141392	1.67697736	0.9228748
No.			7			7		7		7		7		7	7	7	7	7	7	7

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0504	24.1	23.6	15.1	14.9	713.664	14.5	14.4	3790.08	23.2	23.3	24.192	23.9	23.3	10.08	38.34	0.94	187
0.0504	24.1	23.8	15.4	14.9	709.632	14.6	14.4	3810.24	23.6	23.5	16.128	23.8	23.6	10.08	37.64	1.34	196
0.0504	24.1	24.2	15.5	15.4	701.568	14.3	14.3	3971.52	23.3	23.2	36.288	23.5	23.4	28.224	37.96	2.4	132
0.0504	23.7	23.7	14.9	14.9	709.632	14.1	14.8	3729.6	23.4	23.3	14.112	23.3	23.2	18.144	41.25	1.5	145
0.0504	24.1	24.1	15.2	14.9	729.792	14.1	14.6	3931.2	23.4	23.3	30.24	22.9	23.1	44.352			
0.0504	24.6	24.6	16.1	16	689.472	15.7	15.6	3608.64	24.2	23.7	26.208	24.4	23.9	18.144	38.41	2.42	135
0.0504	24.5	24.9	16	15.7	713.664	15.1	15.2	3850.56	23.7	23.5	44.352	23.8	23.5	42.336	38.09	1.35	141
					709.632			3813.12			27.36			24.48	38.615		
					11.4042182			113.239315			9.92660425			13.2166586	1.20527659		
					7			7			7			7	6		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
59.2315	59.3898	59.2515	3166	2766	56.4088	56.5741	56.4306	3306	2870	7.74	7.7	180	108.892922
59.23	59.3972	59.2558	3344	2828	56.4095	56.5764	56.4352	3338	2824	7.74	7.72	180	107.849011
59.2331	59.4173	59.2562	3684	3222	43.4458	43.6115	43.4688	3314	2854	7.78	7.72	190	114.665057
59.2347	59.4143	59.2605	3592	3076	56.4138	56.5825	56.4381	3374	2888	7.76	7.68	185	109.662122
59.239	59.3991	59.2601	3202	2780	56.4183	56.5901	56.4412	3436	2978	7.71	7.58	195	113.504075
59.2411	59.4011	59.2643	3200	2736	56.4211	56.5791	56.4445	3160	2692	7.74	7.64	195	123.417722
59.2422	59.4068	59.2658	3292	2820	56.4246	56.5812	56.4475	3132	2674	7.73	7.71	190	121.328225
			3354.28571	2889.71429				3294.28571	2825.71429	7.74285714	7.67857143		114.188448
			189.60539	171.028581				102.290503	100.521091	0.02050386	0.04793703		5.67664519
			7	7				7	7	7	7		7

Table D4(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.2 for 10 days sludge age parent system.

< Sewage Batch 2 - N Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
27 07	72.38	221.9	3.64	2.38	1.31	0.41	0	2.51	14.41	17.75	-58.8	485.8	0.0	427.1	44.4	44.8	4.7	218.3	22.7	239.7	24.9	962.7	96.6
28 07	75.46	227.5	3.92	3.36	1.36	0	0.61	3.43	16.3	18.35	-64.2	495.2	0.0	430.9	42.9	48.2	4.8	233.2	23.2	246.5	24.6	1003.6	95.5
30 07	76.02	226.8	4.48	3.08	0.62	0	0	0.35	14.82	18.35	-33.0	619.6	0.0	586.7	58.0	55.1	5.5	225.7	22.3	245.2	24.2	1011.1	110.(
31 07	74.48	223.3	2.66	1.96	0	0	0	0	15.85	16.3	0.0	638.4	0.0	638.4	64.4	32.7	3.3	200.5	20.2	239.6	24.2	990.6	112.2
01 08	78.68	228.9	3.08	2.66	0.74	0.7	0	0.75	15.71	16.08	-20.7	591.9	0.0	571.1	54.6	37.9	3.6	197.8	18.9	245.0	23.4	1046.4	100.5
02 08	75.46	222.6	2.66	3.64	0.83	0	0	1.05	17.9	16.42	-44.2	638.7	19.7	594.5	61.2	32.7	3.3	202.0	20.1	239.0	23.8	1003.6	108.4
03 08	75.04	207.9	3.08	2.94	1.4	0	0	4.59	12.07	17.84	-74.5	314.1	0.0	239.7	24.0	37.9	3.8	219.4	22.0	225.7	22.6	998.0	72.4
Mean	**75.36**	**222.7**	**3.36**	**2.86**	**0.894286**	**0.158571**	**0.087143**	**1.811429**	**15.29429**	**17.29857**	**-42.2**	**540.5**	**0.0**	**498.3**	49.7	**41.3**	**4.1**	**213.8**	**21.3**	**240.1**	**24.0**	**1002.3**	99.1

< Sewage Batch 2 - COD Mass Balance >

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
27 07	713.664	3790.08	24.192	10.08	920.2	297.6	3.1	-47.9	633.1	2728.9	3436.1	36.2	1289.0	13.6	3790.1	39.9	9491.7	92.8
28 07	709.632	3810.24	16.128	10.08	903.4	198.4	2.1	-72.4	684.7	2880.8	3171.7	33.6	1306.3	13.8	3810.2	40.4	9438.1	89.9
30 07	701.568	3971.52	36.288	28.224	911.0	446.3	4.8	-33.0	769.8	3404.9	2699.1	28.9	1715.8	18.4	3971.5	42.6	9330.9	94.7
31 07	709.632	3729.6	14.112	18.144	990.0	173.6	1.8	0.0	843.2	3853.5	2779.5	29.4	1825.8	19.3	3729.6	39.5	9438.1	90.2
01 08	729.792	3931.2	30.24	44.352														
02 08	689.472	3608.64	26.208	18.144	921.8	322.4	3.5	-44.2	896.4	3945.2	2231.1	24.3	1807.4	19.7	3608.6	39.4	9170.0	86.9
03 08	713.664	3850.56	44.352	42.336	914.2	545.5	5.7	-74.5	397.9	1563.1	4561.8	48.1	771.1	8.1	3850.6	40.6	9491.7	102.5
Mean	**709.632**	**3813.12**	**27.36**	**24.48**	**926.8**	**336.5**	**3.6**	**-39.1**	**717.3**	**3143.8**	**3065.5**	**32.5**	1473.8	**15.6**	**3813.1**	**40.4**	**9438.1**	**92.1**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
27 07	0.014	0.188	1.317	0.078	0.354
28 07	0.014	0.194	1.346	0.082	0.350
30 07	0.040	0.248	1.382	0.081	0.295
31 07	0.026	0.209	1.285	0.078	0.324
01 08	0.061	0.204	1.305	0.078	0.324
02 08	0.026	0.189	1.334	0.084	0.352
03 08	0.059	0.203	1.424	0.079	0.341
Mean	**0.034**	**0.205**	**1.341**	**0.080**	**0.334**

Table D5(a): All the expeperimental results of sewage batch No.3 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10	10	13.3	20	2	1	0.45	0.2	0.24	1.48	1	0.7518797

< Sewage Batch 3 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
06 08	21.5	21.8	60.62	16.9	15.6	227.5	2.7	3.78	2.6	3.64	16.5	46.2	0.8	1.12	0	0	0	0	11	12.18
07 08	21.6	22.2	61.32	15.9	15.2	217.7	2.7	3.78	2.3	3.22	15.5	43.4	0.9	1.26	0	0	0	0	11.32	11.32
08 08	22.5	21.8	62.02	16.8	16.8	235.2	2.9	4.06	2.7	3.78	15.3	42.84	0.7	0.98	0	0	0	0	10.89	12.28
09 08	20.8	22.2	60.2	16	15.6	221.2	2.4	3.36	2.3	3.22	17	47.6	1.1	1.54	1.93	0	0	2.66	14.63	14
13 08	21.8	22.3	61.74	16.1	16.3	226.8	2.9	4.06	2.5	3.5	17.7	49.56	1	1.4	2.02	0	0	2.19	14.21	14.1
15 08	23.4	22.9	64.82	15.1	15.4	213.5	2.7	3.78	2.1	2.94	17.6	49.28	1.9	2.66	1.78	0	0	6.06	20.06	19.68
16 08	23.2	22.9	64.54	14.8	15.4	211.4	2.4	3.36	2.4	3.36			1.3	1.82	1.52	0	0	5.56	19.68	18.92
Mean			62.18			221.9		3.74		3.38		46.48		1.54	1.03571429	0	0	2.35285714	14.5414286	14.64
SSD			1.68404275			7.84856675		0.26683328		0.26381812		2.62663283		0.52383203	0.90830859	0	0	2.41298105	3.64945173	3.0952682
No.			7			7		7		7		6		7	7	7	7	7	7	7

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0503	23.3	23.4	13.9	14.1	752.488	13.5	13.9	3883.16	22.9	23.3	10.06	23.3	22.7	14.084	33.85	1.12	142
0.0503	23.5	23.5	13.5	14.5	764.56	13.6	13.7	3963.64	23.2	23.1	14.084	23.1	22.9	20.12	33.45	1.29	149
0.0503	23.3	23.4	13.9	13.9	760.536	13.1	13.2	4104.48	22.1	22.5	42.252	22.5	22.5	34.204	33.76	1.17	140
0.0503	23.3	23.4	14.3	14.3	728.344	13.6	13.8	3883.16	22.6	22.5	32.192	22.8	22.6	26.156	29.58	0.82	147
0.0503	23.6	23.4	14	13.7	776.632	13.6	13.8	3943.52	22.5	22.4	42.252	22.7	22.7	32.192	31.17	1.12	147
0.0503	23.6	23.6	14.3	14.3	748.464	14.2	14.3	3762.44	22.4	22.7	42.252	22.8	22.8	32.192	32.16	0.78	115
0.0503	24	24	14.5	14.4	768.584	14.2	14.3	3923.4	22.9	22.8	46.276	23.4	23	32.192	30.8	2.4	122
					757.086857			3923.4			32.7668571			27.3057143	32.11		
					14.6560389			95.5889079			13.7185053			7.04053337	1.53756765		
					7			7			7			7	7		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
59.2445	59.4106	59.2676	3322	2860	56.4266	56.6012	56.4512	3492	3000	7.76	7.74	200	114.547537
59.2476	59.4068	59.2707	3184	2722	56.4301	56.5958	56.4542	3314	2832	7.78	7.77	200	120.70006
43.7111	43.8825	43.737	3428	2910	51.3388	51.5066	51.364	3356	2852	7.78	7.74	205	122.169249
59.2494	59.4054	59.2716	3120	2676	56.4325	56.5942	56.4553	3234	2778	7.7	7.78	190	117.501546
43.7162	43.8803	43.74	3282	2806	51.3438	51.4981	51.3664	3086	2634	7.66	7.69	185	119.896306
59.2508	59.402	59.2731	3024	2578	56.4317	56.5887	56.4551	3140	2672	7.68	7.69	180	114.649682
43.7133	43.8623	43.7359	2980	2528	51.3424	51.5031	51.367	3214	2722	7.77	7.74	180	112.009956
			3191.42857	2725.71429				3262.28571	2784.28571	7.73285714	7.73571429		117.353477
			150.764582	131.928243				127.272165	114.958023	0.04742341	0.0324509		3.47678432
			7	7				7	7	7	7		7

Table D5(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.3 for 10 days sludge age parent system.

< Sewage Batch 3 - N Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)											Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
06 08	60.6	227.5	3.8	3.6	0.0	0.0	0.0	0.0	11.0	12.2	0.0	454.6	0.0	454.6	56.4	46.5	5.8	149.8	18.6	239.7	29.7	806.2	110.5
07 08	61.3	217.7	3.8	3.2	0.0	0.0	0.0	0.0	11.3	11.3	0.0	451.7	0.0	451.7	55.4	46.5	5.7	139.2	17.1	229.0	28.1	815.6	106.2
08 08	62.0	235.2	4.1	3.8	0.0	0.0	0.0	0.0	10.9	12.3	0.0	453.0	0.0	453.0	54.9	49.9	6.1	151.0	18.3	247.5	30.0	824.9	109.3
09 08	60.2	221.2	3.4	3.2	1.9	0.0	0.0	2.7	14.6	14.0	-102.7	433.8	8.4	331.2	42.4	41.3	5.2	172.2	21.5	235.2	29.4	800.7	98.5
13 08	61.7	226.8	4.1	3.5	2.0	0.0	0.0	2.2	14.2	14.1	-107.5	449.0	1.5	341.5	41.8	49.9	6.1	173.4	21.1	240.9	29.3	821.1	98.3
15 08	64.8	213.5	3.8	2.9	1.8	0.0	0.0	6.1	20.1	19.7	-94.7	472.9	5.1	378.3	44.5	46.5	5.4	242.1	28.1	233.2	27.0	862.1	105.0
16 08	64.5	211.4	3.4	3.4	1.5	0.0	0.0	5.6	19.7	18.9	-80.9	479.3	10.1	398.5	47.6	41.3	4.8	232.7	27.1	230.3	26.8	858.4	106.4
Mean	62.2	221.9	3.7	3.4	1.0	0.0	0.0	2.4	14.5	14.6	-55.1	456.3	0.0	401.2	48.5	46.0	5.6	180.1	21.8	236.5	28.6	827.0	104.5

< Sewage Batch 3 - COD Mass Balance >

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
06 08	752.5	3883.2	10.1	14.1	812.4	123.7	1.2	0.0	585.2	2674.4	2768.7	27.7	1300.1	13.0	3883.2	38.8	10008.1	80.7
07 08	764.6	3963.6	14.1	20.1	802.8	173.2	1.7	0.0	602.2	2752.2	2626.6	25.8	1291.8	12.7	3963.6	39.0	10168.6	79.2
08 08	760.5	4104.5	42.3	34.2	810.2	519.7	5.1	0.0	579.3	2647.6	2781.0	27.5	1295.6	12.8	4104.5	40.6	10115.1	86.0
09 08	728.3	3883.2	32.2	26.2	709.9	396.0	4.1	-102.7	636.8	2558.0	2198.4	22.7	1089.2	11.2	3883.2	40.1	9687.0	78.1
13 08	776.6	3943.5	42.3	32.2	748.1	519.7	5.0	-107.5	639.5	2553.7	2458.4	23.8	1104.6	10.7	3943.5	38.2	10329.2	77.7
15 08	748.5	3762.4	42.3	32.2	771.8	519.7	5.2	-94.7	744.8	3078.9	2092.4	21.0	1205.2	12.1	3762.4	37.8	9954.6	76.1
16 08	768.6	3923.4	46.3	32.2	739.2	569.2	5.6	-80.9	751.2	3155.5	1797.1	17.6	1261.5	12.3	3923.4	38.4	10222.2	73.9
Mean	757.1	3923.4	32.8	27.3	770.6	403.0	4.0	-55.1	648.4	2774.3	2388.9	23.7	1210.9	12.0	3923.4	39.0	10069.3	78.7

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
06 08	0.019	0.178	1.290	0.077	0.360
07 08	0.026	0.161	1.392	0.078	0.391
08 08	0.045	0.192	1.427	0.084	0.356
09 08	0.036	0.180	1.388	0.081	0.366
13 08	0.041	0.152	1.485	0.087	0.410
15 08	0.043	0.150	1.396	0.081	0.403
16 08	0.042	0.144	1.430	0.079	0.415
Mean	**0.036**	**0.165**	**1.399**	**0.081**	**0.385**

Table D6(a): All the expeperimental results of sewage batch No.4 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.0	7.8	13.3	20.0	2.0	1.0	0.5	0.2	0.2	1.5	0.8	0.6

< Sewage Batch 4 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
23 08	31.5	32.2	89.2	19.4	19.5	272.3	3.8	5.3	1.3	1.8	25.4	71.1	0.9	1.3	1.9	0.0	0.0	15.3	37.0	33.2
24 08	32.2	32.7	90.9	19.9	19.8	277.9	2.0	2.8	1.9	2.7	24.7	69.2	1.6	2.2	2.4	0.0	0.0	15.5	38.6	34.9
27 08	32.7	32.7	91.6	22.9	20.3	302.4	2.7	3.8			26.4	73.9	1.3	1.8	2.0	0.0	0.0	12.0	31.7	33.4
28 08	30.0	31.8	86.5	21.3	21.6	300.3	1.7	2.4	0.4	0.6	23.2	65.0	1.1	1.5	1.7	0.0	0.0	12.4	33.4	33.0
29 08	32.1	32.1	89.9	18.8	21.1	279.3	1.8	2.5	1.2	1.7	26.1	73.1	0.7	1.0	1.8	0.0	0.0	14.3	32.0	34.0
30 08	33.0	32.4	91.6	22.2	21.1	303.1	1.3	1.8	1.0	1.4	27.8	77.8	0.8	1.1	2.6	0.0	0.0	15.7	36.0	34.5
31 08	31.8	33.6	91.6	21.8	19.6	289.8	1.8	2.5	1.7	2.4	27.2	76.2	0.7	1.0	2.1	0.0	0.0	18.8	37.4	36.7
Mean			90.2			289.3		3.0		1.8		72.3		1.4	2.1	0.0	0.0	14.9	35.2	34.3
SSD			1.7			12.0		1.1		0.7		4.0		0.4	0.3	0.0	0.0	2.1	2.6	1.2
No.			7.0			7.0		7.0		6.0		7.0		7.0	7.0	7.0	7.0	7.0	7.0	7.0

Normality	COD													OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.1	23.0	22.8	13.3	13.7	752.0	10.5	11.0	4860.0	21.9	21.9	40.0	22.2	22.2	28.0	44.1	2.3	118.0
0.1	23.1	23.2	13.6	13.7	760.0	10.5	10.8	5000.0	22.3	22.2	36.0	22.2	22.3	36.0	49.5	3.3	173.0
0.1	23.8	24.1	14.9	14.8	728.0	11.1	10.7	5220.0	23.0	22.9	40.0	23.2	22.9	36.0	46.2	3.2	168.0
0.1	23.6	23.8	15.3	15.2	676.0	10.4	10.4	5320.0	23.2	23.0	24.0	23.3	22.9	24.0	50.6	2.6	188.0
0.1	23.5	23.3	14.9	15.1	672.0	10.5	10.8	5100.0	23.1	22.6	22.0	22.9	22.7	24.0	51.1	3.3	191.0
0.1	23.2	22.9	14.3	14.1	708.0	10.6	10.2	5060.0	22.2	22.3	32.0	22.3	22.2	32.0	43.3	6.1	149.0
0.1	23.1	23.1	14.5	14.5	688.0	10.2	10.1	5180.0	22.2	22.2	36.0	22.3	22.4	30.0	48.1	3.0	99.0
					712.0			5105.7			32.9			30.0	47.5		
					33.1			140.5			6.7			4.7	2.9		
					7.0			7.0			7.0			7.0	7.0		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.7	43.9	43.7	3520.0	3040.0	51.3	51.5	51.4	3980.0	3436.0	8.0	7.9	230.0	115.6
59.3	59.4	59.3	3850.0	3354.0	56.4	56.6	56.5	3824.0	3322.0	8.0	8.0	230.0	120.3
43.7	43.9	43.7	4168.0	3580.0	51.3	51.6	51.4	4110.0	3516.0	7.9	7.8	240.0	116.8
59.3	59.5	59.3	4044.0	3504.0	56.4	56.6	56.5	4148.0	3576.0	7.9	7.8	200.0	96.4
43.7	43.9	43.7	4158.0	3616.0	51.4	51.6	51.4	4138.0	3588.0	7.8	7.7	250.0	120.8
59.3	59.5	59.3	4240.0	3622.0	56.4	56.7	56.5	4306.0	3534.0	7.9	7.8	250.0	116.1
43.7	43.9	43.8	4254.0	3664.0	51.4	51.6	51.4	4292.0	3694.0	7.8	7.8	260.0	121.2
			4033.4	3482.9				4114.0	3523.7	7.9	7.8		115.3
			245.6	204.4				156.9	109.8	0.1	0.1		8.0
			7.0	7.0				7.0	7.0	7.0	7.0		7.0

Table D6(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.4 for 10 days sludge age parent system.

< Sewage Batch 4 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)											Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
23 08	89.2	272.3	5.3	1.8	1.9	0.0	0.0	15.3	37.0	33.2	-100.5	613.4	50.7	512.8	47.5	66.6	5.6	415.9	35.1	238.3	20.1	1186.1	108.3
24 08	90.9	277.9	2.8	2.7	2.4	0.0	0.0	15.5	38.6	34.9	-128.7	664.1	48.3	535.3	48.3	35.1	2.9	437.3	36.2	244.0	20.2	1208.4	107.6
27 08	91.6	302.4	3.8	0.0	2.0	0.0	0.0	12.0	31.7	33.4	-105.9	651.6	0.0	545.7	44.8	47.3	3.9	418.3	34.3	261.9	21.5	1217.7	104.6
28 08	86.5	300.3	2.4	0.6	1.7	0.0	0.0	12.4	33.4	33.0	-92.0	668.3	5.1	576.3	50.5	29.8	2.6	413.5	35.9	260.0	22.6	1150.7	111.6
29 08	89.9	279.3	2.5	1.7	1.8	0.0	0.0	14.3	32.0	34.0	-95.8	541.8	0.0	446.1	37.3	31.6	2.6	425.7	35.6	244.4	20.4	1195.4	96.0
30 08	91.6	303.1	1.8	1.4	2.6	0.0	0.0	15.7	36.0	34.5	-139.9	578.6	20.5	438.6	37.7	22.8	1.9	431.4	35.4	263.3	21.6	1217.7	96.6
31 08	91.6	289.8	2.5	2.4	2.1	0.0	0.0	18.8	37.4	36.7	-109.1	482.0	9.2	372.9	31.4	31.6	2.6	460.0	37.8	254.7	20.9	1217.7	92.7
Mean	**90.2**	**289.3**	**3.0**	**1.8**	**2.1**	**0.0**	**0.0**	**14.9**	**35.2**	**34.3**	**-110.3**	**600.0**	**11.9**	**489.7**	**41.8**	**37.8**	**3.2**	**428.9**	**35.8**	**252.4**	**21.0**	**1199.1**	**101.8**

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2fi}	MNO_{3fi}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
23 08	752.0	4860.0	40.0	28.0	1058.4	500.8	5.0	-100.5	1156.6	4940.6	590.6	5.9	1727.3	17.3	3790.8	37.9	10001.6	66.1
24 08	760.0	5000.0	36.0	36.0	1187.3	450.7	4.5	-128.7	1225.2	5157.6	1047.2	10.4	1817.2	18.0	3900.0	38.6	10108.0	71.4
27 08	728.0	5220.0	40.0	36.0	1107.8	500.8	5.2	-105.9	1050.2	4436.1	1353.4	14.0	1682.4	17.4	4071.6	42.1	9682.4	78.6
28 08	676.0	5320.0	24.0	24.0	1214.6	300.5	3.3	-92.0	1117.7	4792.4	1555.4	17.3	1768.5	19.7	4149.6	46.2	8990.8	86.5
29 08	672.0	5100.0	22.0	24.0	1225.2	275.4	3.1	-95.8	939.5	3965.1	2437.8	27.3	1385.9	15.5	3978.0	44.5	8937.6	90.4
30 08	708.0	5060.0	32.0	32.0	1038.5	400.6	4.3	-139.9	1077.8	4445.8	981.3	10.4	1474.0	15.7	3946.8	41.9	9416.4	72.2
31 08	688.0	5180.0	36.0	30.0	1155.1	450.7	4.9	-109.1	989.0	4145.6	1891.1	20.7	1218.3	13.3	4040.4	44.2	9150.4	83.1
Mean	**712.0**	**5105.7**	**32.9**	**30.0**	**1141.0**	**411.4**	**4.3**	**-110.3**	**1079.4**	**4554.7**	**1408.1**	**14.9**	1561.4	**16.5**	**3982.5**	**42.1**	**9469.6**	77.8

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
23 08	0.037	0.134	1.406	0.080	0.425
24 08	0.047	0.149	1.494	0.084	0.414
27 08	0.049	0.205	1.474	0.086	0.346
28 08	0.036	0.249	1.481	0.084	0.307
29 08	0.036	0.245	1.415	0.078	0.303
30 08	0.045	0.213	1.423	0.086	0.333
31 08	0.044	0.243	1.394	0.079	0.301
Mean	**0.042**	**0.204**	**1.440**	**0.083**	**0.345**

Table D7(a): All the expeperimental results of sewage batch No.5 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.0	7.8	13.3	20.0	2.0	1.0	0.5	0.2	0.2	1.5	0.8	0.6

< Sewage Batch 5 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA Unfiltered Influent		FSA Unfiltered Effluent		NITRITE Anoxic	NITRITE Aerobic	NITRITE Effluent	NITRATE Anoxic	NITRATE Aerobic	NITRATE Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
05 09	30.0	30.0	84.0	20.3	20.1	282.8	2.8	3.9	1.8	2.5	23.9	66.9	1.4	2.0	2.1	0.0	0.0	5.4	27.2	25.8
06 09	30.1	30.1	84.3	21.4	23.6	315.0	1.9	2.7	1.7	2.4	25.3	70.8	1.3	1.8	2.1	0.0	0.0	7.1	29.0	26.0
08 09	31.5	30.6	86.9	19.1	20.9	280.0	3.1	4.3	2.3	3.2			2.1	2.9	2.8	0.0	0.0	4.7	33.8	29.2
Mean			85.1			292.6		3.6		2.7		68.9		2.2	2.3	0.0	0.0	5.8	30.0	27.0
SSD			1.3			15.9		0.7		0.4		2.0		0.5	0.3	0.0	0.0	1.0	2.8	1.6
No.			3.0			3.0		3.0		3.0		2.0		3.0	3.0	3.0	3.0	3.0	3.0	3.0

Normality	COD Blank		COD Influent			COD Mixed Liqour			COD Unfiltered Effluent			COD Filtered Effluent			OUR Mean	OUR SSD	OUR No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.1	24.7	24.7	16.4	16.3	668.0	13.3	12.9	4640.0	24.1	23.8	30.0	24.1	24.1	24.0	55.7		
0.1	23.2	23.3	14.5	14.1	716.0	11.4	11.6	4700.0	22.4	22.2	38.0	22.5	22.6	28.0	55.7		
0.1	23.3	23.3	14.0	14.2	736.0	12.0	11.9	4540.0	22.6	22.8	24.0	22.7	22.4	30.0	55.7	2.7	67.0
					706.7			4626.7			30.7			27.3	55.7		
					28.5			66.0			5.7			2.5	0.0		
					3.0			3.0			3.0			3.0	3.0		

TSS/VSS (Anoxic) Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	TSS/VSS (Aerobic) Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	pH Anoxic	pH Aerobic	DSVI 500SET	DSVI (l/g)
59.3	59.5	59.3	3998.0	3458.0	56.4	56.6	56.5	3904.0	3376.0	7.9	7.7	320.0	163.9
43.7	43.9	43.8	3970.0	3388.0	51.4	51.6	51.4	4008.0	3426.0	7.8	7.6	300.0	149.7
59.3	59.5	59.3	3908.0	3316.0	56.4	56.6	56.5	3812.0	3238.0	7.9	7.8	320.0	167.9
			3958.7	3387.3				3908.0	3346.7	7.8	7.7		160.5
			37.6	58.0				80.1	79.5	0.1	0.1		7.8
			3.0	3.0				3.0	3.0	3.0	3.0		3.0

Table D7(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.5 for 10 days sludge age parent system.

< Sewage Batch 5 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
05 09	84.0	282.8	3.9	2.5	2.1	0.0	0.0	5.4	27.2	25.8	-84.2	488.0	18.2	403.8	37.8	49.1	4.4	322.9	28.9	240.7	21.5	1117.2	92.6
06 09	84.3	315.0	2.7	2.4	2.1	0.0	0.0	7.1	29.0	26.0	-84.2	446.9	39.5	362.7	35.9	33.3	3.0	325.6	29.1	266.0	23.7	1120.9	91.6
08 09	86.9	280.0	4.3	3.2	2.8	0.0	0.0	4.7	33.8	29.2	-111.3	649.0	60.8	537.7	51.8	54.3	4.7	365.7	31.6	241.2	20.9	1156.3	108.9
Mean	85.1	292.6	3.6	2.7	2.3	0.0	0.0	5.8	30.0	27.0	-93.2	528.0	39.5	434.7	41.9	45.6	4.0	338.1	29.9	249.3	22.0	1131.5	97.9

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
05 09	668.0	4640.0	30.0	24.0	1337.5	375.6	4.2	-84.2	867.4	3675.4	3314.5	37.3	1303.8	14.7	3619.2	40.7	8884.4	96.9
06 09	716.0	4700.0	38.0	28.0	1337.5	475.8	5.0	-84.2	871.8	3695.4	3294.5	34.6	1247.1	13.1	3666.0	38.5	9522.8	91.2
08 09	736.0	4540.0	24.0	30.0	1337.5	300.5	3.1	-111.3	1159.1	4915.2	2074.6	21.2	1839.7	18.8	3541.2	36.2	9788.8	79.2
Mean	706.7	4626.7	30.7	27.3	1337.5	383.9	4.1	-93.2	966.1	4095.3	2894.5	30.8	1463.5	15.6	3608.8	38.4	9398.7	88.9

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
05 09	0.036	0.205	1.367	0.085	0.336
06 09	0.039	0.170	1.364	0.093	0.374
08 09	0.041	0.138	1.393	0.087	0.418
Mean	0.039	0.170	1.374	0.088	0.375

Table D8(a): All the expeperimental results of sewage batch No.6 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.0	7.8	13.3	20.0	2.0	1.0	0.5	0.2	0.2	1.5	0.8	0.6

< Sewage Batch 6 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
05 09	30.0	30.0	84.0	20.3	20.1	282.8	2.8	3.9	1.8	2.5	23.9	66.9	1.4	2.0	2.1	0.0	0.0	5.4	27.2	25.8
06 09	30.1	30.1	84.3	21.4	23.6	315.0	1.9	2.7	1.7	2.4	25.3	70.8	1.3	1.8	2.1	0.0	0.0	7.1	29.0	26.0
08 09	31.5	30.6	86.9	19.1	20.9	280.0	3.1	4.3	2.3	3.2			2.1	2.9	2.8	0.0	0.0	4.7	33.8	29.2
Mean			85.1			292.6		3.6		2.7		68.9		2.2	2.3	0.0	0.0	5.8	30.0	27.0
SSD			1.3			15.9		0.7		0.4		2.0		0.5	0.3	0.0	0.0	1.0	2.8	1.6
No.			3.0			3.0		3.0		3.0		2.0		3.0	3.0	3.0	3.0	3.0	3.0	3.0

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.1	24.7	24.7	16.4	16.3	668.0	13.3	12.9	4640.0	24.1	23.8	30.0	24.1	24.1	24.0	55.7		
0.1	23.2	23.3	14.5	14.1	716.0	11.4	11.6	4700.0	22.4	22.2	38.0	22.5	22.6	28.0	55.7		
0.1	23.3	23.3	14.0	14.2	736.0	12.0	11.9	4540.0	22.6	22.8	24.0	22.7	22.4	30.0	55.7	2.7	67.0
					706.7			4626.7			30.7			27.3	55.7		
					28.5			66.0			5.7			2.5	0.0		
					3.0			3.0			3.0			3.0	3.0		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
59.3	59.5	59.3	3998.0	3458.0	56.4	56.6	56.5	3904.0	3376.0	7.9	7.7	320.0	163.9
43.7	43.9	43.8	3970.0	3388.0	51.4	51.6	51.4	4008.0	3426.0	7.8	7.6	300.0	149.7
59.3	59.5	59.3	3908.0	3316.0	56.4	56.6	56.5	3812.0	3238.0	7.9	7.8	320.0	167.9
			3958.7	3387.3				3908.0	3346.7	7.8	7.7		160.5
			37.6	58.0				80.1	79.5	0.1	0.1		7.8
			3.0	3.0				3.0	3.0	3.0	3.0		3.0

Table D8(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.6 for 10 days sludge age parent system.

< Sewage Batch 6 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
17 09	68.3	297.5	3.6	1.7	0.0	0.0	1.0	0.0	15.5	12.3	13.0	411.5	42.7	424.5	51.4	45.6	5.0	166.9	18.4	242.4	26.7	908.7	101.5
18 09	64.1	276.5	2.9	1.7	0.0	0.0	1.0	0.1	16.2	12.2	12.6	426.4	52.4	439.0	57.6	36.8	4.3	165.5	19.4	226.0	26.5	852.8	107.8
19 09	67.8	296.8	3.1	2.2	0.0	0.0	1.2	0.1	15.6	11.6	14.8	410.4	53.6	425.2	53.1	38.6	4.3	160.0	17.8	241.5	26.8	901.2	102.0
Mean	66.7	290.3	3.2	1.9	0.0	0.0	1.1	0.1	15.8	12.0	13.5	416.1	49.6	429.6	54.0	40.3	4.5	164.1	18.5	236.6	26.7	887.6	103.7

	Conc. (mg/l)				OUR	Mass (mg/d)											COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
17 09	752.0	5020.0	30.0	36.0	1025.8	375.6	3.8	-0.8	617.7	2819.9	2540.7	25.4	1321.3	13.2	3915.6	39.1	10001.6	81.5
18 09	729.8	4838.4	22.2	18.1	1093.0	277.6	2.9	-0.8	641.2	2927.5	2784.3	28.7	1391.0	14.3	3774.0	38.9	9706.2	84.8
19 09	721.7	4818.2	26.2	22.2	1093.0	328.1	3.4	-1.2	618.1	2820.4	2891.4	30.1	1352.4	14.1	3758.2	39.2	9599.0	86.8
Mean	734.5	4892.2	26.1	25.4	1070.6	327.1	3.3	-0.9	625.6	2855.9	2738.8	28.0	1354.9	13.9	3815.9	39.1	9768.9	84.3

Date					
	$f_{s,us}$	$f_{s,up}$	f_{vv}	f_N	fav
05 09	0.036	0.205	1.367	0.085	0.336
06 09	0.039	0.170	1.364	0.093	0.374
08 09	0.041	0.138	1.393	0.087	0.418
Mean	0.039	0.170	1.374	0.088	0.375

Table D9(a): All the expeperimental results of sewage batch No.7 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.0	7.8	13.3	20.0	1.0	1.0	0.5	0.2	0.2	1.5	0.8	0.6

< Sewage Batch 7 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
22 09	27.6	28.1	78.0	19.6	19.6	274.4	1.9	2.7	1.7	2.4	22.5	63.0	1.7	2.4	0.4	0.0	0.7	0.0	17.1	14.2
25 09	31.2	30.9	86.9	20.1	19.3	275.8	3.0	4.2	2.7	3.8	24.5	68.6	1.2	1.7	0.1	0.0	1.5	0.1	19.2	13.1
26 09	31.7	30.4	86.9	19.0	19.0	266.0	3.6	5.0	3.2	4.5	26.8	75.0	1.7	2.4	0.1	0.0	1.5	0.2	17.3	13.6
27 09	29.6	28.8	81.8	19.2	19.0	267.4	3.4	4.8	3.1	4.3	24.0	67.2	1.1	1.5	0.1	0.0	1.2	0.0	16.4	13.1
02 10	30.3	30.8	85.5	18.9	21.5	282.8	4.5	6.3	3.5	4.9	24.9	69.7	2.1	2.9	0.0	0.0	1.4	0.1	23.0	12.9
03 10	29.4	29.3	82.2	19.6	19.3	272.3	4.0	5.6	3.7	5.2	22.1	61.9	1.4	2.0	0.0	0.0	1.3	0.0	23.8	13.2
04 10	27.4	30.3	80.8	18.4	19.4	264.6			2.7	3.8	19.2	53.8	1.9	2.7	0.0	0.0	1.2	0.2	22.8	13.9
Mean			**83.2**			**271.9**		**4.8**		**4.1**		**65.6**		**2.2**	**0.1**	**0.0**	**1.3**	**0.1**	**19.9**	**13.4**
SSD			**3.2**			**6.0**		**1.1**		**0.9**		**6.3**		**0.5**	**0.1**	**0.0**	**0.3**	**0.1**	**2.9**	**0.4**
No.			**7.0**			**7.0**		**6.0**		**7.0**		**7.0**		**7.0**	**7.0**	**7.0**	**7.0**	**7.0**	**7.0**	**7.0**

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.050	23.5	23.3	14.8	14.4	709.6	11.9	12.1	4596.5	22.9	23.1	16.1	22.7	22.6	30.2	54.5	2.5	168.0
0.050	23.0	23.0	12.4	12.9	834.6	10.9	10.9	4878.7	22.0	22.1	38.3	22.2	22.0	36.3	63.9	2.5	285.0
0.050	22.8	23.1	12.5	12.6	838.7	11.2	11.3	4717.4	21.7	21.6	52.4	21.8	21.8	46.4	65.9	3.0	210.0
0.050	23.7	23.5	13.8	13.7	794.3	12.2	12.1	4616.6	22.9	22.7	32.3	23.0	23.0	24.2	62.2	2.2	192.0
0.050	23.0	23.0	13.2	13.5	772.0	11.6	11.3	4620.0	21.4	21.2	68.0	22.1	22.0	38.0	56.3	3.1	148.0
0.050	23.6	24.0	14.8	15.0	712.0	12.6	12.1	4580.0	23.8	23.0	16.0	23.8	23.3	10.0	58.3	2.7	131.0
0.050	23.4	23.2	15.1	15.0	660.0	12.2	12.3	4420.0	22.6	23.0	20.0	23.0	22.7	18.0	60.1	3.1	108.0
					760.2			**4632.8**			**34.7**			**29.0**	**60.2**		
					63.2			**129.5**			**18.3**			**11.6**	**3.8**		
					7.0			**7.0**			**7.0**			**7.0**	**7.0**		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TS5 (mg/l)	VS5 (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.7	43.9	43.8	3996.0	3448.0	51.4	51.6	51.4	3772.0	3222.0	7.5	7.4	650.0	344.6
59.3	59.5	59.3	4068.0	3542.0	56.5	56.6	56.5	3786.0	3302.0	7.6	7.4	430.0	227.2
43.7	43.9	43.8	3966.0	3412.0	51.4	51.6	51.4	3672.0	3164.0	7.5	7.6	400.0	217.9
59.3	59.5	59.3	4162.0	3592.0	56.5	56.6	56.5	3766.0	3252.0	7.9	7.9	610.0	324.0
43.7	43.9	43.8	4194.0	3582.0	51.4	51.6	51.4	3612.0	3074.0	7.8	7.8	490.0	271.3
59.3	59.5	59.3	4238.0	3630.0	56.5	56.7	56.5	3994.0	3382.0	7.9	7.8	430.0	215.3
43.7	43.9	43.8	4064.0	3386.0	51.4	51.6	51.4	3886.0	3230.0	7.8	7.8	550.0	283.1
			4098.3	**3513.1**				**3784.0**	**3232.3**	**7.7**	**7.7**		**269.0**
			94.7	**89.5**				**117.8**	**90.6**	**0.2**	**0.2**		**48.1**

Table D9(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.7 for 10 days sludge age parent system.

< Sewage Batch 7 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
22 09	78.0	274.4	2.7	2.4	0.4	0.0	0.7	0.0	17.1	14.2	-6.1	454.6	38.3	448.5	46.9	33.3	3.2	186.8	18.0	225.7	21.8	1037.1	89.9
25 09	86.9	275.8	4.2	3.8	0.1	0.0	1.5	0.1	19.2	13.1	18.1	506.2	81.0	524.3	52.3	52.6	4.5	183.2	15.8	226.5	19.6	1156.3	92.3
26 09	86.9	266.0	5.0	4.5	0.1	0.0	1.5	0.2	17.3	13.6	16.9	453.7	48.4	470.6	44.9	63.1	5.5	189.3	16.4	219.3	19.0	1156.3	85.7
27 09	81.8	267.4	4.8	4.3	0.1	0.0	1.2	0.0	16.4	13.1	12.9	435.8	44.3	448.7	45.3	59.6	5.5	178.8	16.4	219.7	20.2	1087.4	87.5
02 10	85.5	282.8	6.3	4.9	0.0	0.0	1.4	0.1	23.0	12.9	17.3	609.3	133.9	626.6	66.8	78.9	6.9	179.4	15.8	231.8	20.4	1137.7	109.9
03 10	82.2	272.3	5.6	5.2	0.0	0.0	1.3	0.0	23.8	13.2	15.8	632.8	140.7	648.6	72.2	70.1	6.4	182.2	16.7	223.7	20.5	1093.0	115.8
04 10	80.8	264.6	0.0	3.8	0.0	0.0	1.2	0.2	22.8	13.9	15.3	599.0	118.5	614.3	68.2	0.0	0.0	189.3	17.6	218.2	20.3	1074.4	106.1
Mean	83.2	271.9	4.8	4.1	0.1	0.0	1.3	0.1	19.9	13.4	**12.9**	527.3	86.5	**540.2**	56.7	**59.6**	**5.4**	**184.1**	**16.6**	**223.6**	**20.2**	**1106.0**	**98.9**

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
22 09	709.6	4596.5	16.1	30.2	1308.2	201.9	2.1	-15.6	681.9	3062.9	3774.0	40.0	1399.2	14.8	3585.3	38.0	9438.1	94.9
25 09	834.6	4878.7	38.3	36.3	1532.4	479.6	4.3	-2.0	761.7	3474.1	4534.2	40.8	1710.3	15.4	3805.4	34.3	11100.5	94.9
26 09	838.7	4717.4	52.4	46.4	1582.3	656.2	5.9	-2.8	683.5	3114.0	5155.2	46.2	1464.8	13.1	3679.6	33.0	11154.1	98.2
27 09	794.3	4616.6	32.3	24.2	1491.6	403.8	3.8	-3.2	654.0	2977.7	4817.4	45.6	1395.2	13.2	3601.0	34.1	10564.2	96.7
02 10	772.0	4620.0	68.0	38.0	1351.2	851.4	8.3	-1.6	914.9	4175.7	2885.7	28.1	2155.1	21.0	3603.6	35.1	10267.6	92.5
03 10	712.0	4580.0	16.0	10.0	1399.4	200.3	2.1	-1.6	949.6	4334.3	2979.2	31.5	2239.4	23.6	3572.4	37.7	9469.6	94.9
04 10	660.0	4420.0	20.0	18.0	1442.6	250.4	2.9	-0.8	902.5	4121.9	3417.4	38.9	2078.3	23.7	3447.6	39.3	8778.0	104.7
Mean	760.2	4632.8	34.7	29.0	1444.0	**434.8**	**4.3**	-3.9	**792.6**	**3608.6**	**3937.6**	**38.9**	1777.5	**17.6**	**3613.5**	**35.7**	**10110.3**	96.6

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
22 09	0.043	0.167	1.417	0.086	0.384
25 09	0.043	0.103	1.467	0.085	0.475
26 09	0.055	0.087	1.476	0.085	0.500
27 09	0.030	0.114	1.412	0.084	0.456
02 10	0.049	0.126	1.491	0.094	0.443
03 10	0.014	0.169	1.351	0.082	0.379
04 10	0.027	0.188	1.363	0.083	0.356
Mean	**0.038**	**0.135**	**1.424**	**0.085**	**0.427**

Table D10(a): All the expeperimental results of sewage batch No.8 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.0	7.8	13.3	20.0	1.0	1.0	0.5	0.2	0.2	1.5	0.8	0.6

< Sewage Batch 8 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l
11 10	21.2	20.7	58.7	19.4	19.9	275.1	2.7	3.8	2.7	3.8	15.9	44.5	2.0	2.8	0.0	0.0	0.7	0.1	15.9	3.5
15 10	20.6	20.8	58.0	20.0	21.6	291.2	3.7	5.2	1.7	2.4	16.1	45.1	1.7	2.4	0.0	0.0	0.6	0.1	14.8	3.8
16 10	23.0	21.6	62.4	21.4	21.7	301.7	2.5	3.5			16.5	46.2	2.4	3.4	0.0	0.0	1.0	0.1	15.5	5.3
Mean			**59.7**			**289.3**		**4.2**		**3.1**		**45.3**		**2.8**	**0.0**	**0.0**	**0.8**	**0.1**	**15.4**	**4.2**
SSD			**2.0**			**10.9**		**0.7**		**0.7**		**0.7**		**0.4**	**0.0**	**0.0**	**0.1**	**0.0**	**0.5**	**0.8**
No.			**3.0**			**3.0**		**3.0**		**2.0**		**3.0**		**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0508	22.7	22.7	14.0	14.3	694.9	11.5	11.4	4572.0	22.0	22.1	26.4	22.5	22.1	16.3	54.5	2.1	156.0
0.0508	22.6	22.9	14.8	15.0	638.0	11.2	10.7	4795.5	22.6	22.6	6.1	23.2	23.2	-18.3	47.7	1.8	179.0
0.0508	23.1	22.9	14.2	14.6	699.0	9.7	10.1	5323.8	22.7	22.3	20.3	22.7	22.6	14.2	51.6	1.7	190.0
					677.3			**4897.1**			**17.6**			**4.1**	**51.2**		
					27.8			**315.2**			**8.5**			**15.8**	**2.8**		
					3.0			**3.0**			**3.0**			**3.0**	**3.0**		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
59.3	59.5	59.3	4524.0	3524.0	56.5	56.7	56.5	4050.0	3140.0	7.7	7.7	400.0	197.5
43.7	44.0	43.8	5088.0	3782.0	51.4	51.6	51.4	4678.0	3472.0	7.8	7.8	350.0	149.6
59.3	59.5	59.3	4806.0	3730.0	56.5	56.7	56.5	4512.0	3484.0	7.7	7.6	290.0	128.5
			4806.0	**3678.7**				**4413.3**	**3365.3**	**7.7**	**7.7**		**158.6**
			230.3	**111.4**				**265.7**	**159.4**	**0.0**	**0.1**		**28.9**

Table E1: Summary of the 20 days sludge age parent MLE system TKN and Nitratre statistical data for the various sewage batches.

Sew. Batch No.	TKN (mgN/l)									NITRATE (mgN/l)								
	INFLUENT			UNFILT. EFFLUENT			MIXED LIQUOR			ANOXIC			AEROBIC			EFFLUENT		
	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests
1	57.9	3.8	14	2.7	0.8	14	293.2	21.1	14	1.7	2.1	14	13.2	3.5	14	12.2	3.0	14
2	75.4	1.7	7	3.3	0.5	7	327.5	5.6	7	2.8	1.4	7	20.0	1.5	7	15.1	1.5	7
3	62.2	1.7	7	3.7	0.8	7	313.8	9.1	7	0.8	0.9	7	12.7	2.0	7	4.9	1.5	7
4	90.2	1.7	7	3.2	0.7	7	290.4	6.5	7	11.4	3.0	7	33.2	4.3	7	30.3	2.3	7
5	85.1	1.3	3	3.6	0.5	3	275.6	5.5	3	4.9	1.1	3	31.4	1.8	3	31.6	2.3	3
6	66.7	1.9	3	4.0	0.1	3	300.1	6.3	3	0.0	0.1	3	18.3	0.6	3	11.7	0.5	3
7	83.2	3.1	7	3.9	0.6	6	302.3	10.0	7	0.3	0.3	7	20.2	2.6	7	18.3	2.6	7
8	59.7	2.0	3	3.7	0.2	2	283.0	6.7	3	0.1	0.1	3	16.8	0.3	3	12.9	1.0	3
9	66.5	1.6	6	4.2	0.7	6	257.7	13.0	6	0.0	0.0	6	14.6	1.0	6	12.4	2.2	6
10	60.4	2.0	8	4.3	0.9	6	291.0	16.5	8	0.0	0.0	8	14.6	1.1	8	11.6	2.3	8
11	61.8	1.3	9	5.0	0.4	9	265.8	14.0	9	0.0	0.0	9	15.0	1.0	9	15.4	0.5	9
12	83.4	2.2	8	4.3	0.8	7	269.9	9.9	8	0.7	0.6	8	21.1	0.9	8	21.6	0.8	8
13	65.1	0.6	3	4.7	0.5	3	269.3	19.2	3	0.0	0.0	3	15.1	0.3	3	12.4	1.4	3
14	59.2	1.7	9	3.8	0.4	9	200.8	3.9	9	0.0	0.0	9	12.9	1.0	9	13.4	1.3	9
15	66.1	0.5	6	2.9	0.4	6	190.6	5.7	6	0.1	0.0	6	20.7	0.3	6	20.7	0.5	6
16	50.7	1.3	11	4.5	0.5	11	204.6	5.2	11	0.0	0.0	11	11.3	1.1	11	12.3	0.8	11
17	61.7	1.6	8	4.1	0.5	8	207.3	4.8	8	0.0	0.0	8	15.3	0.4	8	15.0	0.7	8

APPENDIX E

COMPREHENSIVE DATA FOR THE 20 DAYS SLUDGE AGE PARENT LABORATORY-SCALE NITRIFICATION / DENITRIFICATION SYSTEM

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Table E2	Summary of statistical data for the various sewage batches for the 20 days system, listing the mean, standard deviation of the sample and the number of samples tested, for the influent, unfiltered effluent and mixed liquor COD concentrations; the OUR and the VSS measured in the aerobic reactor.
Table E3(a) - E19(a)	All the experimental data of each sewage batch for the 20 days system.
Table E3(b) - E19(b)	The calculation of N/COD mass balances, wastewater fractions and active fraction of mixed liquor for the 20 days system.
Fig. E1 - E5	Graphical representations of daily COD, TKN, aerobic nitrate and OUR, mixed liquor COD, VSS and TKN, anoxic nitrate and DSVI measurements for the 20 days system.

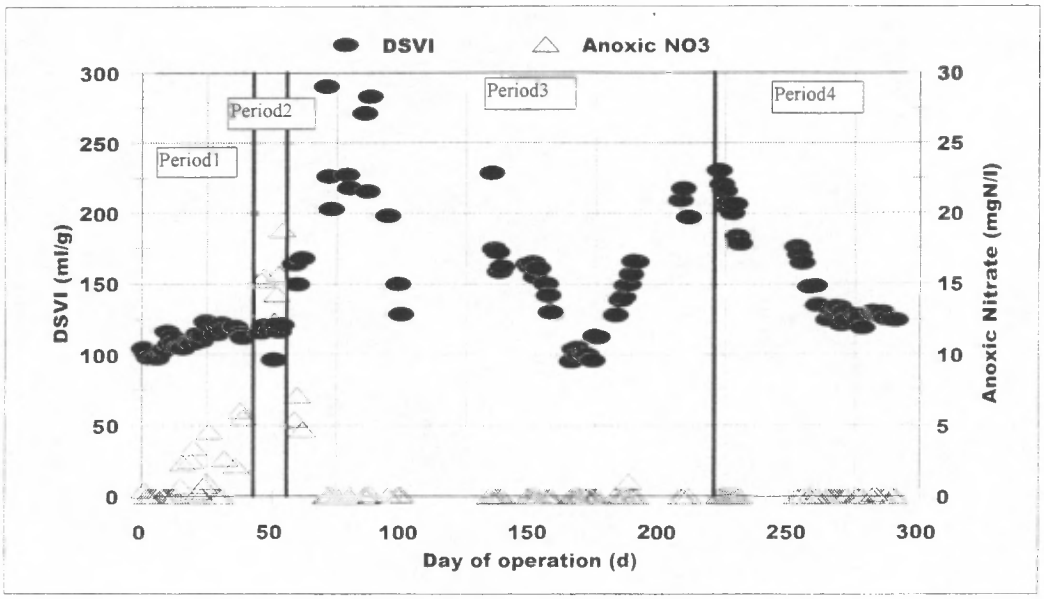


Fig. D5: Graphical representation of the daily Diluted Sludge Volume Index (DSVI) and anoxic nitrate (NO_3) concentration for the 10 days parent MLE system

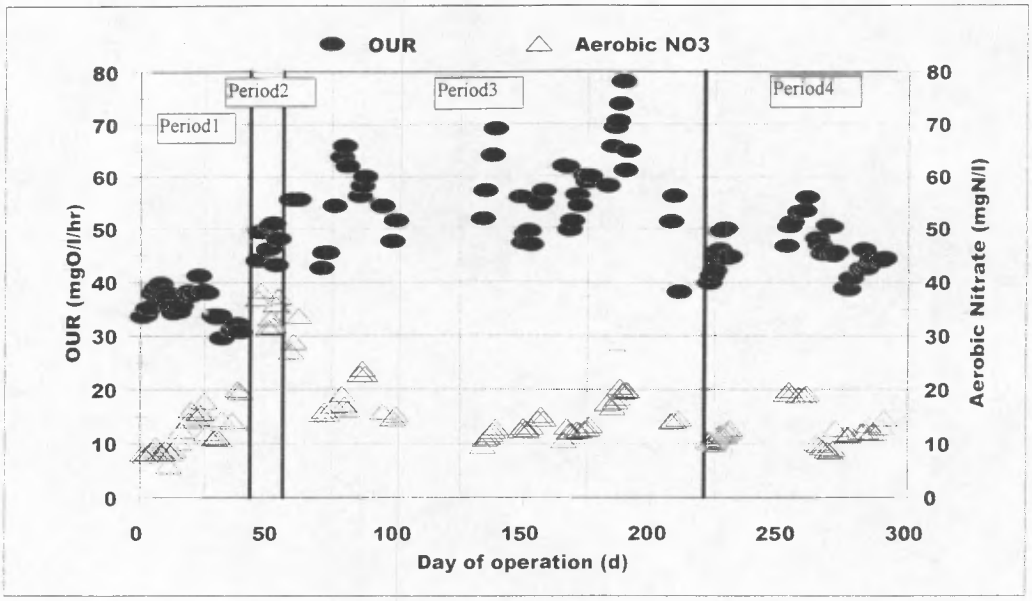


Fig. D3: Graphical representation of the daily Oxygen Utilization Rate (OUR) and nitrate (NO_3) concentrations for the aerobic reactor for the 10 days parent MLE system

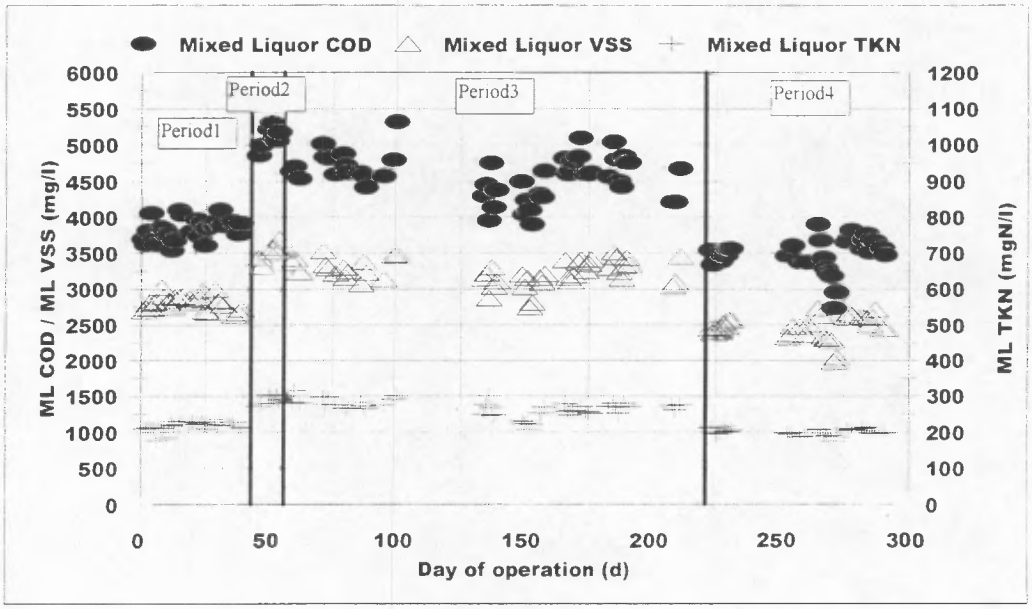


Fig. D4: Graphical representation of the daily mixed liquor COD, VSS and TKN concentrations for the 10 days sludge age parent MLE system

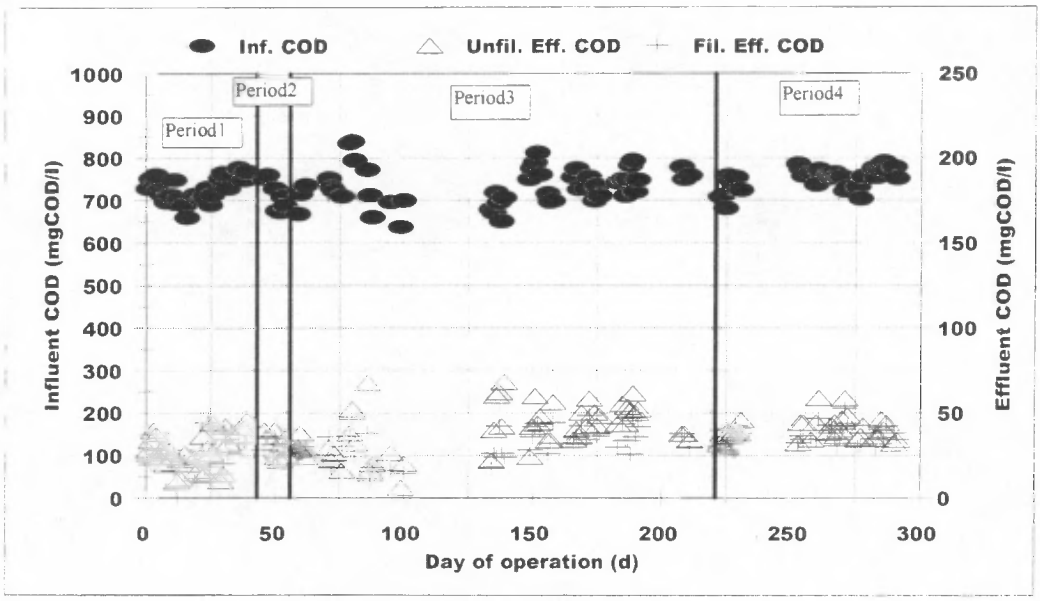


Fig. D1: Graphical representation of the daily influent, unfiltered effluent and filtered effluent COD concentrations for the 10 days sludge age parent MLE system

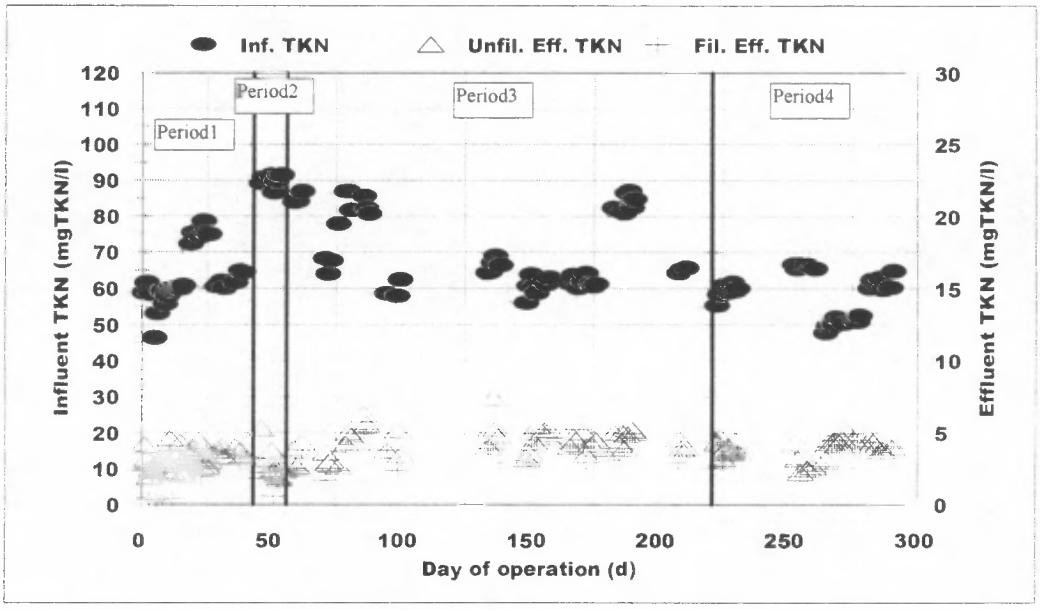


Fig. D2: Graphical representation of the daily influent, unfiltered effluent and filtered effluent TKN concentrations for the 10 days sludge age parent MLE system

Table D19(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.17 for 10 days sludge age parent system.

< Sewage Batch 17 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
16 04	60.2	209.3	4.6	4.3	0.0	0.0	0.0	0.0	12.2	13.3	0.0	255.6	0.0	255.6	42.5	42.6	7.1	123.0	20.4	173.7	28.8	602.0	98.8
17 04	62.4	214.2	4.3	4.1	0.0	0.0	0.0	0.2	12.2	13.3	0.0	248.7	0.0	248.7	39.8	40.0	6.4	122.2	19.6	177.4	28.4	624.4	94.2
18 04	61.9	212.1	4.6	3.9	0.0	0.0	0.0	0.0	12.3	13.1	0.0	253.7	0.0	253.7	41.0	42.6	6.9	120.4	19.5	175.6	28.4	618.8	95.7
19 04	61.3	203.7	4.2	3.9	0.0	0.0	0.0	0.0	13.5	13.5	0.0	270.6	0.0	270.6	44.1	38.7	6.3	124.7	20.3	169.4	27.6	613.2	98.4
20 04	63.0	196.7	3.8	3.5	0.0	0.0	0.0	0.0	12.0	14.1	0.0	261.2	0.0	261.2	41.5	34.9	5.5	129.9	20.6	164.4	26.1	630.0	93.7
21 04	59.8	195.3	3.8	3.6	0.0	0.0	0.0	0.0	12.1	13.3	0.0	253.8	0.0	253.8	42.5	34.9	5.8	122.2	20.4	162.7	27.2	597.8	95.9
24 04	60.3	196.0	4.1	4.1	0.0	0.0	0.0	0.0	13.1	14.8	0.0	278.1	0.0	278.1	46.1	37.4	6.2	136.0	22.5	164.4	27.2	603.4	102.
25 04	64.8	197.4	4.1	3.9	0.0	0.0	0.0	0.0	14.8	15.0	0.0	297.8	0.0	297.8	45.9	37.4	5.8	138.6	21.4	165.7	25.6	648.2	98.7
Mean	61.7	203.1	4.2	3.9	0.0	0.0	0.0	0.0	12.8	13.8	0.0	264.9	0.0	264.9	42.9	38.6	6.2	127.1	20.6	169.2	27.4	617.2	97.2

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
16 04	776.2	3556.0	34.5	34.5	1021.0	318.5	4.1	0.0	366.6	1675.4	3660.2	47.2	731.0	9.4	2773.7	35.7	7762.2	96.4
17 04	754.0	3689.3	36.3	30.2	1103.3	334.6	4.4	0.0	360.6	1647.9	4117.8	54.6	711.3	9.4	2877.6	38.2	7539.8	106.7
18 04	774.1	3769.9	36.3	38.3	1023.6	334.6	4.3	0.0	369.3	1687.7	3661.6	47.3	725.6	9.4	2940.5	38.0	7741.4	99.0
19 04	786.2	3507.8	46.4	40.3	1037.0	427.5	5.4	0.0	405.9	1855.0	3564.6	45.3	773.9	9.8	2736.1	34.8	7862.4	95.4
20 04	790.3	3689.3	40.3	34.3	1058.9	371.8	4.7	0.0	360.9	1649.3	3884.4	49.2	747.0	9.5	2877.6	36.4	7902.7	99.7
21 04	770.1	3669.1	44.4	42.3	1063.4	408.9	5.3	0.0	363.9	1663.0	3894.5	50.6	725.9	9.4	2861.9	37.2	7701.1	102.5
24 04	778.2	3568.3	32.3	38.3	1057.2	297.4	3.8	0.0	391.8	1790.5	3734.4	48.0	795.4	10.2	2783.3	35.8	7781.8	97.8
25 04	751.4	3474.4	34.3	34.3	1065.1	316.6	4.2	0.0	442.5	2022.2	3544.1	47.2	851.7	11.3	2710.0	36.1	7514.4	98.8
Mean	772.6	3615.5	38.1	36.6	1053.7	351.2	4.5	0.0	382.7	1748.9	3757.7	48.6	757.7	9.8	2820.1	36.5	7725.7	99.5

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
16 04	0.045	0.149	1.343	0.081	0.397
17 04	0.040	0.164	1.400	0.083	0.385
18 04	0.049	0.171	1.434	0.083	0.380
19 04	0.051	0.116	1.387	0.083	0.447
20 04	0.043	0.154	1.401	0.077	0.397
21 04	0.055	0.177	1.334	0.073	0.359
24 04	0.049	0.133	1.440	0.082	0.428
25 04	0.046	0.148	1.404	0.082	0.406
Mean	0.047	0.152	1.392	0.081	0.399

Table D19(a): All the expeperimental results of sewage batch No.17 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	10.00	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.78

< Sewage Batch 17 - Experimental Data >

Date											FSA				NITRITE			NITRATE		
	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
16 04	21.3	21.7	60.2	14.8	15.1	209.3	3.3	4.62	3.1	4.34	16.5	46.2	2.1	2.94	0	0	0	0	12.22	13.34
17 04	22.3	22.3	62.44	15.3	15.3	214.2	3.1	4.34	2.9	4.06	17.5	49	2.1	2.94	0	0	0	0.2	12.22	13.25
18 04	21.8	22.4	61.88	14.9	15.4	212.1	3.3	4.62	2.8	3.92	16.4	45.92	1.9	2.66	0	0	0	0	12.31	13.06
19 04	21.6	22.2	61.32	14.1	15	203.7	3	4.2	2.8	3.92	17.2	48.16	2.1	2.94	0	0	0	0	13.53	13.53
20 04	22.5	22.5	63	13.8	14.3	196.7	2.7	3.78	2.5	3.5	16.9	47.32	1.8	2.52	0	0	0	0	12.03	14.09
21 04	21.4	21.3	59.78	13.9	14	195.3	2.7	3.78	2.6	3.64	16.5	46.2	1.8	2.52	0	0	0	0	12.13	13.25
24 04	21.4	21.7	60.34	13.7	14.3	196	2.9	4.06	2.9	4.06	17.4	48.72	1.5	2.1	0	0	0	0	13.06	14.75
25 04	23.2	23.1	64.82	14.2	14	197.4	2.9	4.06	2.8	3.92	17.4	48.72	1.9	2.66	0	0	0	0	14.75	15.03
Mean			61.7225			203.0875		4.1825		3.92		47.53		2.66	0	0	0	0.025	12.78125	13.7875
SSD			1.57839911			7.31188032		0.30861586		0.24248711		1.20228948		0.27110883	0	0	0	0.06614378	0.89126928	0.7013691
No.			8			8		8		8		8		8	8	8	8	8	8	8

Normality	COD													OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0508	23.1	23.1	13.4	13.7	776.224	14.4	14.3	3556	22.4	22.1	34.544	22.3	22.2	34.544	42.54	1.82	151
0.0504	23	22.8	13.2	13.9	753.984	13.9	13.6	3689.28	22	22	36.288	22.2	22.1	30.24	45.97	2.35	167
0.0504	22.8	23.1	13.7	13	774.144	13.5	13.7	3769.92	22	22.1	36.288	21.9	22.1	38.304	42.65	1.97	215
0.0504	23.3	23.6	13.8	13.6	786.24	14.9	14.6	3507.84	22.3	22.3	46.368	22.6	22.3	40.32	43.21	2.2	181
0.0504	23.2	23.3	13.4	13.5	790.272	14.1	14.1	3689.28	22.3	22.2	40.32	22.4	22.4	34.272	44.12	1.05	190
0.0504	23.2	23.5	13.9	13.7	770.112	14.3	14.2	3669.12	22.3	22.2	44.352	22.4	22.2	42.336	44.31	1.18	196
0.0504	23.2	23.3	13.6	13.6	778.176	14.4	14.4	3568.32	22.5	22.4	32.256	22.3	22.3	38.304	44.05	1.02	189
0.0505	22.8	22.6	13.4	13.4	751.44	14.1	14.1	3474.4	22	21.7	34.34	21.9	21.8	34.34	44.38	1.03	172
					772.574			3615.52			38.0945			36.5825	43.90375		
					12.9684428			96.7430246			4.74179879			3.66995909	1.03937406		
					8			8			8			8	8		

	TSS / VSS (Anoxic)				TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.7867	43.9495	43.8101	3256	2788	43.3444	43.4981	43.367	3074	2622	7.9	7.96	100	130.123617
59.2802	59.4401	59.3053	3198	2696	56.5028	56.6588	56.5281	3120	2614	7.9	7.95	100	128.205128
43.7877	43.9579	43.8134	3404	2890	51.4307	51.5854	51.4553	3094	2602	7.85	7.84	100	129.282482
59.2805	59.4263	59.3034	2916	2458	56.5032	56.6526	56.5276	2988	2500	7.93	7.87	95	127.175368
43.7891	43.9602	43.8147	3422	2910	51.432	51.5861	51.4557	3082	2608	8.05	8.03	100	129.785853
59.282	59.4522	59.3049	3404	2946	56.5053	56.6647	56.5288	3188	2718	7.95	7.95	100	125.470514
59.2829	59.4374	59.3043	3090	2662	56.5069	56.6517	56.5291	2896	2452	7.86	7.83	90	124.309392
43.7918	43.9499	43.8145	3162	2708	51.4343	51.5789	51.4564	2892	2450	7.81	7.78	90	124.481328
			3231.5	2757.25				3041.75	2570.75	7.90625	7.90125		127.35421
			166.552544	150.966677				99.661615	88.1982851	0.06872727	0.07849164		2.21160188
			8	8				8	8	8	8		8

Table D18(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.16 for 10 days sludge age parent system.

< Sewage Batch 16 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
30 03	47.9	207.9	3.2	2.5	0.0	0.0	0.0	0.0	10.2	11.4	0.0	216.2	0.0	216.2	45.2	29.7	6.2	105.4	22.0	171.1	35.7	478.8	109.1
31 03	49.8	205.1	4.3	4.1	0.0	0.0	0.0	0.0	9.8	11.3	0.0	211.5	0.0	211.5	42.4	40.0	8.0	104.6	21.0	168.8	33.9	498.4	105.3
01 04	49.4	196.0	4.3	4.1	0.0	0.0	0.0	0.0	9.3	10.9	0.0	201.9	0.0	201.9	40.9	40.0	8.1	100.1	20.3	161.4	32.6	494.2	101.9
02 04	50.3	196.0	4.5	4.5	0.0	0.0	0.0	0.0	9.3	10.8	0.0	200.9	0.0	200.9	40.0	41.3	8.2	99.2	19.7	161.3	32.1	502.6	100.0
03 04	52.1	191.1	4.5	3.6	0.0	0.0	0.0	0.0	8.8	10.4	0.0	191.4	0.0	191.4	36.8	41.3	7.9	95.7	18.4	157.2	30.2	520.8	93.2
04 04	51.9	189.7	4.3	4.1	0.0	0.0	0.0	0.0	8.5	9.1	0.0	176.1	0.0	176.1	33.9	40.0	7.7	84.3	16.2	155.1	29.9	519.4	87.7
05 04	51.7	174.3	4.6	4.2	0.0	0.0	0.0	0.0	9.1	8.9	0.0	179.0	2.0	179.0	35.0	42.6	8.2	81.6	15.8	142.9	27.7	516.6	86.7
06 04	50.4	185.5	5.3	4.9	0.0	0.0	0.0	0.0	12.8	8.4	0.0	211.5	43.9	211.5	50.7	49.1	9.7	77.3	15.3	151.2	30.0	504.0	105.3
10 04	51.2	210.0	4.5	3.9	0.0	0.0	0.0	0.0	11.8	10.3	0.0	221.0	15.2	221.0	46.1	41.3	8.1	94.9	18.5	171.8	33.5	512.4	106.2
11 04	50.8	204.4	4.9	4.5	0.0	0.0	0.0	0.0	11.6	10.3	0.0	219.1	13.3	219.1	45.7	45.2	8.9	94.9	18.7	167.5	33.0	508.2	106.3
12 04	52.5	206.5	4.5	3.6	0.0	0.0	0.0	0.0	11.9	10.4	0.0	222.9	15.3	222.9	45.4	41.3	7.9	95.7	18.2	169.2	32.2	525.0	103.7
Mean	50.7	197.0	4.5	4.0	0.0	0.0	0.0	0.0	10.3	10.2	0.0	204.7	0.9	204.7	40.5	41.1	8.1	94.0	18.5	161.6	31.8	507.3	99.0

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
30 03	760.0	3901.4	38.6	42.7	1155.4	356.0	4.7	0.0	305.7	1397.0	4640.9	61.1	618.3	8.1	3043.1	40.0	7599.7	113.9
31 03	751.8	3677.9	42.7	42.7	1127.3	393.4	5.2	0.0	294.3	1345.0	4546.2	60.5	604.9	8.0	2868.8	38.2	7518.4	111.9
01 04	764.0	3434.1	44.7	34.5	1086.7	412.2	5.4	0.0	279.9	1279.1	4400.1	57.6	577.4	7.6	2678.6	35.1	7640.3	105.6
02 04	754.4	3285.4	36.5	30.4	1103.0	336.6	4.5	0.0	279.9	1279.1	4485.3	59.5	574.6	7.6	2562.6	34.0	7544.2	105.5
03 04	750.4	3224.5	40.6	34.5	1214.2	374.0	5.0	0.0	262.8	1201.0	5144.2	68.6	547.4	7.3	2515.1	33.5	7503.6	114.4
04 04	754.4	3184.0	46.6	40.6	1207.9	430.1	5.7	0.0	254.1	1161.2	5151.4	68.3	503.6	6.7	2483.5	32.9	7544.2	113.6
05 04	722.0	2737.8	58.8	52.7	1081.2	542.2	7.5	0.0	271.5	1240.8	4409.6	61.1	517.7	7.2	2135.5	29.6	7219.7	105.3
06 04	730.1	2960.9	48.7	42.6	1093.9	448.8	6.1	0.0	383.1	1750.8	3966.1	54.3	730.4	10.0	2309.5	31.6	7300.8	102.1
10 04	731.5	3657.6	34.5	30.5	933.8	318.5	4.4	0.0	354.3	1619.2	3261.1	44.6	675.5	9.2	2852.9	39.0	7315.2	97.2
11 04	703.1	3698.2	36.6	30.5	930.7	337.2	4.8	0.0	348.6	1593.1	3270.8	46.5	664.7	9.5	2884.6	41.0	7030.7	101.8
12 04	755.9	3820.2	42.7	42.7	978.2	393.4	5.2	0.0	357.3	1632.9	3479.4	46.0	681.3	9.0	2979.7	39.4	7559.0	99.7
Mean	743.4	3416.5	42.8	38.6	1082.9	394.8	5.3	0.0	308.3	1409.0	4250.5	57.2	587.9	7.9	2664.9	35.8	7434.2	106.2

Date					
	$f_{s,us}$	$f_{s,up}$	$f_{i,v}$	f_N	f_{av}
30 03	0.05614973	0.20396799	1.41036842	0.07690789	0.33819897
31 03	0.05675676	0.17526522	1.38222357	0.07952852	0.36663823
01 04	0.04521277	0.13087572	1.45031399	0.08534983	0.43336412
02 04	0.04032258	0.11450548	1.41150911	0.08693842	0.4534715
03 04	0.04594595	0.11157357	1.37858427	0.0841573	0.45334422
04 04	0.05376344	0.10317506	1.37506562	0.08475941	0.46458738
05 04	0.07303371	0.08572872	1.35063984	0.08978873	0.48778625
06 04	0.05833333	0.09310477	1.42634018	0.09305963	0.48515237
10 04	0.04166667	0.18921618	1.38970115	0.08196169	0.35491799
11 04	0.0433526	0.20844363	1.37266467	0.07817365	0.33184515
12 04	0.05645161	0.18432024	1.42870197	0.07947806	0.3618098
Mean	0.05188481	0.14532993	1.39816632	0.08317505	0.40678846

Table D18(a): All the expeperimental results of sewage batch No.16 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	10.00	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.78

< Sewage Batch 16 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)
30 03	17.2	17	47.88	14.9	14.8	207.9	2.3	3.22	1.8	2.52	12.7	35.56	1.5	2.1	0	0	0	0	10.19	11.43
31 03	17.5	18.1	49.84	14.7	14.6	205.1	3.1	4.34	2.9	4.06	13.9	38.92	1.8	2.52	0	0	0	0	9.81	11.34
01 04	17.1	18.2	49.42	13.9	14.1	196	3.1	4.34	2.9	4.06	14.2	39.76	1.9	2.66	0	0	0	0	9.33	10.86
02 04	17.8	18.1	50.26	14.4	13.6	196	3.2	4.48	3.2	4.48	13.6	38.08	2.1	2.94	0	0	0	0	9.33	10.76
03 04	18.1	19.1	52.08	13	14.3	191.1	3.2	4.48	2.6	3.64	14.3	40.04	2.1	2.94	0	0	0	0	8.76	10.38
04 04	17.6	19.5	51.94	13.4	13.7	189.7	3.1	4.34	2.9	4.06	13.6	38.08	1.1	1.54	0	0	0	0	8.47	9.14
05 04	18.5	18.4	51.66	12.5	12.4	174.3	3.3	4.62	3	4.2	14.1	39.48	2.3	3.22	0	0	0	0	9.05	8.85
06 04	18.2	17.8	50.4	12.9	13.6	185.5	3.8	5.32	3.5	4.9	14.3	40.04	2	2.8	0	0	0	0	12.77	8.38
10 04	18.4	18.2	51.24	14.8	15.2	210	3.2	4.48	2.8	3.92	14.2	39.76	1.7	2.38	0	0	0	0	11.81	10.29
11 04	18.1	18.2	50.82	14.8	14.4	204.4	3.5	4.9	3.2	4.48	15.1	42.28	2	2.8	0	0	0	0	11.62	10.29
12 04	18.6	18.9	52.5	14.5	15	206.5	3.2	4.48	2.6	3.64	14.6	40.88	1.6	2.24	0	0	0	0	11.91	10.38
Mean			50.73090909			196.9545455		4.454545455		3.996363636		39.35272727		2.558181818	0	0	0	0	10.27727273	10.19090909
SSD			1.297308084			10.60037423		0.480612557		0.586007644		1.65160578		0.451055695	0	0	0	0	1.418283796	0.948697236
No.			11			11		11		11		11		11	11	11	11	11	11	11

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0508	22.7	22.8	13.4	13.4	759.968	13.2	13.1	3901.44	21.9	21.7	38.608	21.6	21.8	42.672	48.14	1.42	202
0.0508	23.3	23.2	14	14	751.84	14.2	14.2	3677.92	22.2	22.2	42.672	22.2	22.2	42.672	46.97	0.77	199
0.0508	23.2	23.5	14	13.9	764.032	14.9	14.9	3434.08	22.3	22.2	44.704	22.6	22.4	34.544	45.28	0.9	199
0.0507	22.7	23	13.5	13.6	754.416	14.8	14.7	3285.36	22.1	21.8	36.504	22.3	21.9	30.42	45.96	1.88	240
0.0507	22.8	22.8	13.5	13.6	750.36	14.8	14.9	3224.52	21.9	21.7	40.56	22	21.9	34.476	50.59	1.38	219
0.0507	23	23	13.7	13.7	754.416	15.2	15.1	3183.96	21.9	21.8	46.644	22	22	40.56	50.33	1.07	259
0.0507	23	23.2	14.1	14.3	721.968	16.3	16.4	2737.8	21.7	21.6	58.812	21.8	21.8	52.728	45.05	2.78	221
0.0507	23	23.1	14.1	14	730.08	15.7	15.8	2960.88	21.7	22	48.672	21.9	22.1	42.588	45.58	1.79	188
0.0508	22.6	22.9	13.8	13.7	731.52	13.8	13.7	3657.6	22	21.8	34.544	22	22	30.48	38.91	1.57	175
0.0508	22.8	22.8	14.2	14.1	703.072	13.8	13.6	3698.24	22	21.8	36.576	22.2	21.9	30.48	38.78	0.56	157
0.0508	22.8	23	13.3	13.9	755.904	13.4	13.6	3820.16	21.8	21.9	42.672	22	21.7	42.672	40.76	0.95	153
					743.416			3416.541818			42.81527273			38.572	45.12272727		
					18.1487289			354.2747311			6.594943477			6.750897368	3.911809837		
					11			11			11			11	11		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
59.2763	59.45	59.3003	3474	2994	56.4956	56.6558	56.519	3204	2736	8.03	7.94	100	124.8439451
43.7785	43.9377	43.7998	3184	2758	51.423	51.5746	51.4431	3032	2630	7.99	7.93	100	131.9261214
59.2778	59.436	59.3005	3164	2710	56.4978	56.6351	56.5179	2746	2344	7.9	7.94	90	131.0997815
43.7809	43.929	43.8016	2962	2548	51.4256	51.5599	51.4446	2686	2306	7.86	7.9	90	134.0282949
59.279	59.4215	59.2979	2850	2472	56.4995	56.6344	56.5187	2698	2314	7.97	7.89	90	133.432172
43.7821	43.9199	43.8	2756	2398	51.4273	51.5596	51.4453	2646	2286	7.99	7.97	80	120.9372638
59.2784	59.415	59.2967	2732	2366	56.5005	56.6159	56.5165	2308	1988	7.91	7.92	75	129.982669
43.7823	43.9234	43.8028	2822	2412	51.4275	51.548	51.4457	2410	2046	7.91	7.9	75	124.4813278
43.7838	43.9538	43.8112	3400	2852	51.429	51.5857	51.4552	3134	2610	7.93	8	100	127.6324186
59.2788	59.4415	59.3052	3254	2726	56.5012	56.661	56.5274	3196	2672	7.95	7.96	100	125.1564456
43.7853	43.9528	43.8134	3350	2788	51.4306	51.5907	51.4585	3202	2644	7.88	7.93	95	118.6758276
			3086.181818	2638.545455				2842	2416	7.938181818	7.934545455		127.4723879
			258.9720301	200.1528342				312.1491485	246.4334688	0.050057818	0.031439303		4.853544634
			11	11				11	11	11	11		11

Table D17(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.15 for 10 days sludge age parent system.

< Sewage Batch 15 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
18 03	66.6	196.7	4.3	3.6	0.0	0.0	0.0	0.0	19.2	19.4	0.0	386.2	0.0	386.2	58.0	40.0	6.0	178.7	26.8	168.5	25.3	666.4	116.1
19 03	65.5	193.2	3.2	2.8	0.0	0.0	0.0	0.0	19.9	19.8	0.0	397.0	1.4	397.0	60.8	29.7	4.5	182.4	27.8	166.1	25.4	655.2	118.5
20 03	66.6	198.1	2.2	2.0	0.0	0.0	0.0	0.0	19.2	19.8	0.0	390.2	0.0	390.2	58.6	20.7	3.1	182.4	27.4	169.9	25.5	666.4	114.5
23 03	66.5	185.5	2.5	2.0	0.0	0.0	0.0	0.0	19.0	19.4	0.0	383.5	0.0	383.5	57.7	23.2	3.5	178.7	26.9	159.8	24.0	665.0	112.1
25 03	65.8	187.6	2.7	2.4	0.0	0.0	0.0	0.0	19.0	19.5	0.0	384.8	0.0	384.8	58.5	24.5	3.7	179.9	27.3	161.5	24.6	658.0	114.1
26 03	65.5	188.3	3.2	2.1	0.0	0.0	0.0	0.0	19.2	19.2	0.0	383.6	0.0	383.6	58.5	29.7	4.5	177.4	27.1	161.9	24.7	655.2	114.9
Mean	66.1	191.6	3.0	2.5	0.0	0.0	0.0	0.0	19.3	19.5	0.0	387.6	0.0	**387.6**	58.6	**28.0**	**4.2**	**179.9**	**27.2**	**164.6**	**24.9**	**661.0**	115.6

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
18 03	785.3	3461.0	32.4	32.4	1122.5	298.6	3.8	0.0	577.2	2637.8	3228.3	41.1	1104.5	14.1	2699.6	34.4	7853.1	93.4
19 03	773.2	3461.0	44.5	36.4	1208.2	410.5	5.3	0.0	597.6	2731.0	3582.8	46.3	1139.4	14.7	2699.6	34.9	7731.7	101.3
20 03	757.0	3602.7	44.5	34.4	1230.0	410.5	5.4	0.0	577.2	2637.8	3790.2	50.1	1116.0	14.7	2810.1	37.1	7569.8	107.4
23 03	765.1	3380.1	34.4	34.4	1277.8	317.2	4.1	0.0	569.1	2600.8	4076.8	53.3	1096.8	14.3	2636.5	34.5	7650.7	106.2
25 03	736.7	3380.1	44.5	34.4	1281.6	410.5	5.6	0.0	569.1	2600.8	4096.9	55.6	1100.5	14.9	2636.5	35.8	7367.4	111.9
26 03	772.2	3373.1	58.9	46.7	1343.5	543.3	7.0	0.0	576.0	2632.3	4388.9	56.8	1097.1	14.2	2631.0	34.1	7721.6	112.2
Mean	764.9	3443.0	43.2	36.5	1243.9	**398.5**	**5.2**	**0.0**	**577.7**	**2640.1**	**3860.6**	**50.5**	1108.4	**14.5**	**2685.6**	**35.1**	**7649.0**	105.3

Date	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
18 03	0.041	0.130	1.474	0.086	0.438
19 03	0.047	0.130	1.444	0.083	0.434
20 03	0.045	0.163	1.438	0.081	0.390
23 03	0.045	0.142	1.352	0.076	0.408
25 03	0.047	0.165	1.415	0.080	0.384
26 03	0.061	0.137	1.326	0.076	0.408
Mean	0.048	0.144	1.407	0.080	0.410

Table D17(a): All the expeperimental results of sewage batch No.10 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	10.00	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.78

< Sewage Batch 15 - Experimental Data >

Date											FSA				NITRITE			NITRATE		
	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
18 03	23.5	24.1	66.64	14.4	13.7	196.7	3.1	4.34	2.6	3.64	19.5	54.6	2	2.8	0	0	0	0	19.24	19.38
19 03	23.3	23.5	65.52	13.8	13.8	193.2	2.3	3.22	2	2.8	16.8	47.04	0.7	0.98	0	0	0	0	19.92	19.78
20 03	23.6	24	66.64	14	14.3	198.1	1.6	2.24	1.4	1.96	18.9	52.92	0.6	0.84	0	0	0	0	19.24	19.78
23 03	23.6	23.9	66.5	13.6	12.9	185.5	1.8	2.52	1.4	1.96	19.1	53.48	1	1.4	0	0	0	0	18.97	19.38
25 03	23	24	65.8	13.7	13.1	187.6	1.9	2.66	1.7	2.38	18.5	51.8	0.8	1.12	0	0	0	0	18.97	19.51
26 03	22.3	24.5	65.52	13.2	13.7	188.3	2.3	3.22	1.5	2.1	18.2	50.96	0.8	1.12	0	0	0	0.04	19.24	22.22
Mean			66.10333			191.5667		3.033333		2.473333		51.8		1.376667	0	0	0	0.006667	19.26333	20.00833
SSD			0.500988			4.741894		0.684268		0.597625		2.424871		0.658728	0	0	0	0.014907	0.317525	1.002803
No.			6			6		6		6		6		6	6	6	6	6	6	6

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0506	22.7	22.9	13.2	13	785.312	14.3	14.2	3461.04	22.1	21.9	32.384	22.2	21.8	32.384	46.77	1.75	234
0.0506	23	23.1	13.5	13.5	773.168	14.7	14.3	3461.04	22.1	21.8	44.528	22.1	22.2	36.432	50.34	1.66	219
0.0506	23.1	23.2	13.8	13.8	756.976	14.2	14.3	3602.72	22.1	22	44.528	22.4	22.2	34.408	51.25	1.74	226
0.0506	23	22.8	13.7	13.2	765.072	14.4	14.7	3380.08	22	22.1	34.408	22	22.1	34.408	53.24	1.59	232
0.0506	22.8	22.9	13.7	13.8	736.736	14.4	14.6	3380.08	21.5	22	44.528	21.9	22.1	34.408	53.4	1.75	308
0.0508	23	22.9	13.4	13.5	772.16	14.6	14.7	3373.12	21.8	21.2	58.928	22	21.6	46.736	55.98	1.35	233
					764.904			3443.013			43.21733			36.46267	51.83		
					15.2411			80.58373			8.630798			4.740654	2.882002		
					6			6			6			6	6		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI		
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)	
43.7722	43.9421	43.7962	3398	2918	51.4155	51.5515	51.4352	2720	2326	7.77	7.79	120	176.4706	2521.4
59.2721	59.4325	59.296	3208	2730	56.4912	56.6317	56.5131	2810	2372	7.78	7.8	120	170.8185	2490.1
43.7749	43.9408	43.798	3318	2856	51.4182	51.5637	51.4396	2910	2482	7.81	7.78	120	164.9485	2605.4
59.2747	59.4352	59.294	3210	2824	56.4931	56.6349	56.5112	2836	2474	7.78	7.87	105	148.0959	2589.5
43.7776	43.9466	43.7984	3380	2964	51.4207	51.5555	51.4373	2696	2364	8.03	8.03	100	148.368	2562.0
59.2763	59.4325	59.2968	3124	2714	56.4946	56.6425	56.5171	2958	2508	8.01	8.02	100	135.2265	2576.0
			3273	2834.333				2821.667	2421	7.863333	7.881667		157.3213	2557.4
			99.57744	91.06347				93.86101	69.25075	0.111604	0.105422		14.49421	39.84448
			6	6				6	6	6	6		6	

Table D16(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.14 for 10 days sludge age parent system.

< Sewage Batch 14 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
16 02	55.4	211.4	4.3	4.3	0.0	0.0	0.0	0.0	10.5	12.7	0.0	232.1	0.0	232.1	41.9	40.0	7.2	117.1	21.1	174.8	31.5	554.4	101.7
17 02	58.4	213.5	4.8	4.2	0.0	0.0	0.0	0.0	10.2	12.5	0.0	226.8	0.0	226.8	38.8	43.9	7.5	115.4	19.8	176.3	30.2	583.8	96.3
18 02	58.5	194.6	3.2	3.1	0.0	0.0	0.0	0.0	10.9	12.0	0.0	228.6	0.0	228.6	39.1	29.7	5.1	110.6	18.9	161.1	27.5	585.2	90.6
19 02	61.0	196.7	3.9	3.1	0.0	0.0	0.0	0.0	11.4	13.5	0.0	248.7	0.0	248.7	40.7	36.1	5.9	124.3	20.4	163.9	26.9	610.4	93.9
20 02	59.1	196.7	4.1	4.1	0.0	0.0	0.0	0.0	11.8	12.7	0.0	245.2	0.0	245.2	41.5	37.4	6.3	117.1	19.8	163.3	27.6	590.8	95.3
21 02	59.1	214.2	3.6	3.5	0.0	0.0	0.0	0.0	12.0	12.4	0.0	244.8	0.0	244.8	41.4	33.6	5.7	114.7	19.4	176.8	29.9	590.8	96.5
22 02	61.6	201.6	3.8	3.4	0.0	0.0	0.0	0.0	11.6	12.1	0.0	236.5	0.0	236.5	38.4	34.9	5.7	111.5	18.1	166.7	27.1	616.0	89.2
23 02	59.5	200.2	4.5	3.9	0.0	0.0	0.0	0.0	12.4	12.7	0.0	250.5	0.0	250.5	42.1	41.3	6.9	117.1	19.7	166.1	27.9	595.0	96.6
24 02	60.1	205.1	3.6	3.6	0.0	0.0	0.0	0.0	12.9	12.9	0.0	257.4	0.0	257.4	42.9	33.6	5.6	118.7	19.8	170.0	28.3	600.6	96.5
Mean	59.2	203.8	4.0	3.7	0.0	0.0	0.0	0.0	11.5	12.6	0.0	241.2	0.0	**241.2**	40.7	**36.7**	**6.2**	**116.3**	**19.6**	**168.8**	**28.5**	**591.9**	95.1

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
16 02	708.0	3540.0	32.0	30.0	957.4	295.0	4.2	0.0	315.3	1440.9	3562.2	50.3	663.8	9.4	2761.2	39.0	7080.0	102.9
17 02	712.0	3340.0	38.0	40.0	991.0	350.4	4.9	0.0	304.8	1392.9	3785.8	53.2	648.6	9.1	2605.2	36.6	7120.0	103.8
18 02	681.4	3528.0	30.2	28.2	1013.0	278.8	4.1	0.0	325.8	1488.9	3805.2	55.8	653.8	9.6	2751.8	40.4	6814.1	109.9
19 02	758.0	3487.7	38.3	32.3	1073.3	353.2	4.7	0.0	341.7	1561.6	4047.4	53.4	711.3	9.4	2720.4	35.9	7580.2	103.3
20 02	745.9	3386.9	36.3	32.3	1103.5	334.6	4.5	0.0	354.6	1620.5	4146.5	55.6	701.3	9.4	2641.8	35.4	7459.2	104.9
21 02	737.9	3467.5	38.3	34.3	1191.1	353.2	4.8	0.0	361.2	1650.7	4574.1	62.0	700.1	9.5	2704.7	36.7	7378.6	112.9
22 02	754.0	3467.5	40.3	42.3	1198.8	371.8	4.9	0.0	346.8	1584.9	4680.1	62.1	676.4	9.0	2704.7	35.9	7539.8	111.8
23 02	724.0	3560.0	38.0	38.0	1068.7	350.4	4.8	0.0	370.5	1693.2	3891.9	53.8	716.4	9.9	2776.8	38.4	7240.0	106.8
24 02	724.0	3560.0	46.0	38.0	1071.6	424.1	5.9	0.0	386.1	1764.5	3835.7	53.0	736.2	10.2	2776.8	38.4	7240.0	107.4
Mean	727.2	3482.0	37.5	35.0	1074.3	345.7	4.8	0.0	345.2	1577.6	4036.6	55.5	689.8	9.5	**2715.9**	**37.3**	**7272.4**	107.1

Date	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
16 02	0.042	0.174	1.433	0.088	0.378
17 02	0.056	0.155	1.376	0.091	0.390
18 02	0.041	0.189	1.425	0.080	0.359
19 02	0.043	0.131	1.430	0.083	0.431
20 02	0.043	0.147	1.361	0.081	0.402
21 02	0.046	0.160	1.359	0.086	0.384
22 02	0.056	0.150	1.383	0.083	0.398
23 02	0.052	0.179	1.367	0.079	0.361
24 02	0.052	0.180	1.370	0.081	0.360
Mean	**0.048**	**0.162**	**1.389**	**0.084**	**0.385**

Table D16(a): All the expeperimental results of sewage batch No.14 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	10.00	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.78

< Sewage Batch 14 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
16 02	19.6	20	55.44	14.9	15.3	211.4	3.1	4.34	3.1	4.34	16.7	46.76	2.2	3.08	0	0	0	0	10.51	12.7
17 02	20.6	21.1	58.38	14.9	15.6	213.5	3.4	4.76	3	4.2	15.6	43.68	1.5	2.1	0	0	0	0	10.16	12.52
18 02	20.8	21	58.52	13.7	14.1	194.6	2.3	3.22	2.2	3.08	15.9	44.52	2	2.8	0	0	0	0	10.86	12
19 02	21.6	22	61.04	13.7	14.4	196.7	2.8	3.92	2.2	3.08	17.1	47.88	1.6	2.24	0	0	0	0	11.39	13.48
20 02	20.9	21.3	59.08	14.6	13.5	196.7	2.9	4.06	2.9	4.06	17.1	47.88	1.2	1.68	0	0	0	0	11.82	12.7
21 02	20.7	21.5	59.08	15.3	15.3	214.2	2.6	3.64	2.5	3.5	17.1	47.88	1.9	2.66	0	0	0	0	12.04	12.44
22 02	21.9	22.1	61.6	13.9	14.9	201.6	2.7	3.78	2.4	3.36	17.4	48.72	1.8	2.52	0	0	0	0	11.56	12.09
23 02	21.7	20.8	59.5	13.5	15.1	200.2	3.2	4.48	2.8	3.92	18.2	50.96	2.2	3.08	0	0	0	0	12.35	12.7
24 02	21.8	21.1	60.06	15.3	14	205.1	2.6	3.64	2.6	3.64	17.3	48.44	1.6	2.24	0	0	0	0	12.87	12.87
Mean			59.18889			203.7778		3.982222		3.686667		47.41333		2.488889	0	0	0	0	11.50667	12.61111
SSD			1.675818			7.187609		0.452985		0.442719		2.074437		0.441624	0	0	0	0	0.829592	0.412079
No.			9			9		9		9		9		9	9	9	9	9	9	9

Normality	COD													OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.05	23.3	23.4	14.6	14.4	708	14.5	14.5	3540	22.5	22.6	32	22.6	22.6	30	39.89	1.2	167
0.05	23.7	23.7	15.1	14.5	712	15.4	15.3	3340	22.7	22.8	38	22.7	22.7	40	41.29	1.07	152
0.0504	23	23	14.5	14.6	681.408	14.2	14.3	3528	22.2	22.3	30.24	22.3	22.3	28.224	42.21	1.49	153
0.0504	23.3	23.1	13.8	13.8	758.016	14.5	14.6	3487.68	22.2	22.3	38.304	22.3	22.5	32.256	44.72	0.93	163
0.0504	23.4	23.1	13.5	14.5	745.92	14.6	15.1	3386.88	22.2	22.5	36.288	22.1	22.8	32.256	45.98	1.64	205
0.0504	23.3	23.3	14	14.3	737.856	14.6	14.8	3467.52	22.3	22.4	38.304	22.6	22.3	34.272	49.63	2.57	192
0.0504	23.3	23.4	14	14	753.984	14.8	14.7	3467.52	22.4	22.3	40.32	22.3	22.3	42.336	49.95	1.84	213
0.05	23.3	23.1	14.1	14.2	724	14.3	14.3	3560	22.3	22.2	38	22.3	22.2	38	44.53	0.71	169
0.05	23.2	23.4	14.3	14.2	724	14.4	14.4	3560	22.1	22.2	46	22.3	22.4	38	44.65	1.36	183
					727.2427			3481.956			37.49511			35.03822	44.76111		
					23.20931			72.50395			4.300149			4.51303	3.239827		
					9			9			9			9	9		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.7646	43.9203	43.7912	3114	2582	51.4081	51.5555	51.433	2948	2450	7.89	7.88	170	230.6649
59.2714	59.4226	59.2963	3024	2526	56.4851	56.63	56.5101	2898	2398	7.78	7.76	160	220.842
43.7652	43.9163	43.7902	3022	2522	51.4089	51.557	51.4342	2962	2456	7.87	7.85	160	216.0702
59.2682	59.4215	59.2935	3066	2560	56.4853	56.6304	56.5096	2902	2416	7.74	7.71	150	206.754
43.7659	43.9277	43.7916	3236	2722	51.4101	51.5579	51.4347	2956	2464	7.81	7.76	150	202.977
59.268	59.4283	59.2932	3206	2702	56.4868	56.6366	56.5103	2996	2526	7.74	7.71	150	200.267
43.7674	43.9274	43.7924	3200	2700	51.4114	51.5566	51.4328	2904	2476	7.82	7.76	150	206.6116
59.2708	59.4298	59.2951	3180	2694	56.4894	56.6416	56.5128	3044	2576	7.82	7.79	140	183.9685
43.7697	43.929	43.7935	3186	2710	51.4135	51.5646	51.4361	3022	2570	7.78	7.74	135	178.6896
			3137.111	2635.333				2959.111	2481.333	7.805556	7.773333		205.205
			77.70663	80.60328				50.21829	59.61357	0.049015	0.054975		15.62958
			9	9				9	9	9	9		9

Table D15(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.13 for 10 days sludge age parent system.

< Sewage Batch 13 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
01 02	64.4	273.0	4.6	2.9	0.0	0.0	1.7	0.0	14.2	6.9	0.0	376.4	96.2	376.4	55.2	57.8	6.8	108.2	12.6	219.7	25.6	856.5	100.2
02 02	65.2	261.1	3.9	4.1	0.0	0.0	1.8	0.0	14.3	7.5	0.0	381.4	91.1	381.4	54.5	49.1	5.7	116.4	13.4	210.9	24.3	867.7	97.8
04 02	65.8	276.5	3.9	3.5	0.0	0.0	1.1	0.0	14.6	10.7	0.0	389.2	52.1	389.2	50.4	49.1	5.6	147.5	16.9	224.9	25.7	875.1	98.6
Mean	65.1	270.2	4.2	3.5	0.0	0.0	1.5	0.0	14.4	8.4	0.0	382.3	79.8	**382.3**	53.3	**52.0**	**6.0**	**124.0**	**14.3**	**218.5**	**25.2**	**866.5**	98.9

Date	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
01 02	778.4	4211.6	37.9	37.9	1231.9	474.8	4.6	0.0	564.6	2580.2	3857.9	37.3	1351.5	13.1	3285.0	31.7	10353.3	86.6
02 02	750.5	4211.6	37.9	35.9	1350.2	474.8	4.8	0.0	572.2	2614.8	4441.6	44.5	1351.5	13.5	3285.0	32.9	9981.6	95.7
04 02	758.5	4670.6	33.9	29.9	919.0	424.8	4.2	0.0	583.7	2667.7	2134.8	21.2	1262.1	12.5	3643.1	36.1	10087.8	74.0
Mean	762.5	4364.6	36.6	34.6	1167.0	**458.1**	**4.5**	**0.0**	**573.5**	**2620.9**	**3478.1**	**34.3**	1321.7	**13.0**	**3404.4**	**33.6**	**10140.9**	85.4

Date	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
01 02	0.04872	0.07865	1.37381	0.09083	0.50615
02 02	0.04787	0.10699	1.34698	0.08554	0.45659
04 02	0.03947	0.13945	1.34435	0.08111	0.41076
Mean	0.04538	0.10834	1.35453	0.08562	0.45576

Table D15(a): All the expeperimental results of sewage batch No.13 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.59

< Sewage Batch 13 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
01 02	23	23	64.4	19.2	19.8	273	3.3	4.62	2.1	2.94	19.5	54.6	1.6	2.24	0	0	1.72	0	14.15	6.92
02 02	22.7	23.9	65.24	18.8	18.5	261.1	2.8	3.92	2.9	4.06	19.3	54.04	2.4	3.36	0	0	1.81	0	14.34	7.49
04 02	23.5	23.5	65.8	19.4	20.1	276.5	2.8	3.92	2.5	3.5	18.9	52.92	1.9	2.66	0	0	1.07	0	14.63	10.71
Mean			65.14667			270.2		4.153333		3.5		53.85333		2.753333	0	0	1.533333	0	14.37333	8.373333
SSD			0.575345			6.591409		0.329983		0.457238		0.698443		0.461976	0	0	0.32968	0	0.197372	1.66857
No.			3			3		3		3		3		3	3	3	3	3	3	3

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0499	23.5	23.6	13.9	13.7	778.44	13.1	12.9	4211.56	22.5	22.7	37.924	22.5	22.7	37.924	51.33	0.53	70
0.0499	23.4	23.4	14	14	750.496	12.8	12.9	4211.56	22.4	22.5	37.924	22.4	22.6	35.928	56.26	1	172
0.0499	23.5	23.4	13.9	14	758.48	11.8	11.7	4670.64	22.7	22.5	33.932	22.8	22.6	29.94	38.29	2.13	200

					762.472			4364.587			36.59333			34.59733	48.62667		
					11.75213			216.4124			1.881847			3.392548	7.581171		
					3			3			3			3	3		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.7565	43.9339	43.7834	3548	3010	51.4017	51.5832	51.4313	3630	3038	7.77	7.73	190	209.3664
59.269	59.4578	59.2975	3776	3206	56.4824	56.6661	56.5111	3674	3100	7.79	7.7	200	217.7463
43.7599	43.957	43.789	3942	3360	51.4054	51.6083	51.4357	4058	3452	7.75	7.78	200	197.1414

			3755.333	3192				3787.333	3196.667	7.77	7.736667		208.0847
			161.5123	143.2294				192.2313	182.3135	0.01633	0.032998		8.460585
			3	3				3	3	3	3		3

Table D14(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.12 for 10 days sludge age pilot system.

< Sewage Batch 12 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
07 01	82.3	269.5	5.0	3.1	1.2	0.0	0.5	0.0	17.5	26.6	-49.1	586.9	0.0	537.9	49.1	63.1	5.8	338.9	31.0	231.3	21.1	1094.9	107.0
09 01	82.2	279.3	4.2	3.4	0.1	0.0	0.2	0.0	16.7	21.8	-3.6	511.9	0.0	508.3	46.5	52.6	4.8	275.9	25.2	235.0	21.5	1093.0	98.1
10 01	81.2	271.6	5.0	3.9	0.2	0.0	0.4	0.0	17.9	20.8	-6.8	514.2	0.0	507.4	47.0	63.1	5.8	265.4	24.6	228.4	21.1	1080.0	98.6
11 01	80.9	252.7	3.9	3.9	0.1	0.0	1.2	0.0	18.5	15.3	-5.2	450.2	42.7	445.0	45.3	49.1	4.6	206.8	19.2	210.0	19.5	1076.2	88.6
12 01	86.5	268.8	4.9	4.8	1.5	0.0	1.3	1.0	20.5	15.8	-60.2	441.8	63.4	381.6	38.7	61.3	5.3	213.2	18.5	222.9	19.4	1150.7	81.9
13 01	87.1	279.3	5.5	4.9	0.1	0.0	0.4	0.0	19.7	20.8	-3.6	538.8	0.0	535.2	46.2	68.4	5.9	265.5	22.9	234.4	20.2	1158.2	95.3
14 01	82.5	270.2	5.2	4.6	0.8	0.0	0.4	0.0	20.0	19.6	-33.1	527.6	5.5	494.5	45.6	64.9	5.9	250.8	22.9	226.4	20.6	1096.7	95.0
15 01	84.8	270.9	5.0	4.8	0.1	0.0	0.2	0.0	19.9	21.8	-4.0	554.2	0.0	550.2	48.8	63.1	5.6	275.9	24.5	228.5	20.2	1128.4	99.1
Mean	83.4	270.3	4.8	4.2	0.5	0.0	0.6	0.1	18.8	20.3	-20.7	515.7	0.0	495.0	44.6	60.7	5.5	261.6	23.6	227.1	20.5	1109.8	94.1

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
07 01	742.0	4563.2	43.6	29.8	1398.7	546.5	5.5	-49.1	699.0	3026.3	4283.4	43.4	1594.7	16.2	3559.3	36.1	9868.8	101.2
09 01	750.0	5039.4	55.6	43.6	1578.0	695.5	7.0	-3.6	665.9	3031.0	5215.6	52.3	1457.9	14.6	3930.7	39.4	9974.4	113.3
10 01	710.3	4801.3	43.6	33.7	1666.6	546.5	5.8	-6.8	712.6	3233.4	5476.1	58.0	1459.0	15.4	3745.0	39.6	9446.6	118.8
11 01	750.0	4503.7	53.6	33.7	1694.9	670.7	6.7	-5.2	739.3	3361.0	5496.4	55.1	1400.8	14.0	3512.9	35.2	9974.4	111.1
12 01	781.7	4424.3	51.6	25.8	1773.1	645.8	6.2	-60.2	778.4	3350.9	5915.5	56.9	1342.0	12.9	3451.0	33.2	10396.6	109.2
13 01	793.6	4841.0	61.5	47.6	1875.6	770.0	7.3	-3.6	786.0	3579.8	6222.0	58.9	1534.8	14.5	3775.9	35.8	10554.9	116.6
14 01	720.0	4760.0	50.0	36.0	1472.4	626.0	6.5	-33.1	799.6	3540.6	4154.2	43.4	1467.9	15.3	3712.8	38.8	9576.0	104.0
15 01	748.0	4760.0	52.0	42.0	1559.0	651.0	6.5	-4.0	792.8	3609.5	4538.1	45.6	1578.2	15.9	3712.8	37.3	9948.4	105.3
Mean	749.4	4711.6	51.4	36.5	1627.3	644.0	6.5	-20.7	746.7	3341.6	5162.7	51.8	1439.5	14.4	3675.0	36.9	9967.5	109.6

Date	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
07 01	0.04011	0.21534	1.3746	0.08265	0.32577
09 01	0.0582	0.18984	1.42328	0.08053	0.35459
10 01	0.04749	0.19701	1.38431	0.08	0.34444
11 01	0.04497	0.13692	1.37791	0.07911	0.41707
12 01	0.03299	0.10253	1.39725	0.0869	0.4714
13 01	0.06	0.15819	1.44117	0.08545	0.39357
14 01	0.05	0.20843	1.37485	0.07998	0.33062
15 01	0.05615	0.17093	1.41173	0.08248	0.37543
Mean	0.04875	0.17172	1.39826	0.08209	0.37449

Table D14(a): All the expeperimental results of sewage batch No.12 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.59

< Sewage Batch 12 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
07 01	29.2	29.6	82.32	19.3	19.2	269.5	3.6	5.04	2.2	3.08	24.1	67.48	1.6	2.24	1.23	0	0.46	0	17.52	26.61
09 01	29.5	29.2	82.18	20.5	19.4	279.3	3	4.2	2.4	3.36	23.7	66.36	2.2	3.08	0.09	0	0.24	0	16.69	21.8
10 01	29.3	28.7	81.2	19.6	19.2	271.6	3.6	5.04	2.8	3.92	23.4	65.52	1.8	2.52	0.17	0	0.4	0	17.86	20.8
11 01	29.4	28.4	80.92	18.5	17.6	252.7	2.8	3.92	2.8	3.92	23.6	66.08	1.4	1.96	0.13	0	1.2	0	18.53	15.32
12 01	30.9	30.9	86.52	19.3	19.1	268.8	3.5	4.9	3.4	4.76	25.4	71.12	2.9	4.06	1.51	0	1.26	1.03	20.54	15.77
13 01	31.1	31.1	87.08	20	19.9	279.3	3.9	5.46	3.5	4.9	26.1	73.08	2.4	3.36	0.09	0	0.4	0	19.7	20.81
14 01	29.7	29.2	82.46	19.1	19.5	270.2	3.7	5.18	3.3	4.62	24.7	69.16	2.1	2.94	0.83	0	0.4	0	20.04	19.63
15 01	29.8	30.8	84.84	18.9	19.8	270.9	3.6	5.04	3.4	4.76	25.4	71.12	2.3	3.22	0.1	0	0.24	0	19.87	21.8
Mean			83.44			270.2875		4.8475		4.165		68.74		2.9225	0.51875	0	0.575	0.12875	18.84375	20.3175
SSD			2.232331			7.719365		0.484658		0.651978		2.622899		0.627809	0.547847	0	0.385584	0.34064	1.301527	3.365151
No.			8			8		8		8		8		8	8	8	8	8	8	8

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0496	23.9	23.8	14.7	14.3	742.016	12.4	12.3	4563.2	22.9	22.6	43.648	23.4	22.8	29.76	58.28	1.5	136
0.0496	23.7	23.5	14.3	14	749.952	10.8	11	5039.36	22.3	22.1	55.552	22.5	22.5	43.648	65.75	1.53	207
0.0496	23.6	23.6	14.5	14.8	710.272	11.6	11.4	4801.28	22.5	22.5	43.648	22.8	22.7	33.728	69.44	2.19	229
0.0496	23.5	23.3	13.9	14	749.952	11.9	12.2	4503.68	22.1	22	53.568	22.5	22.6	33.728	70.62	1.44	261
0.0496	23.9	23.7	13.9	14	781.696	12.6	12.7	4424.32	22.4	22.6	51.584	23.1	23.2	25.792	73.88	1.01	258
0.0496	23.2	23.2	13	13.4	793.6	10.9	11.1	4840.96	21.6	21.7	61.504	22.1	21.9	47.616	78.15	2.92	174
0.05	23.4	23.4	14.5	14.3	720	11.4	11.6	4760	22.2	22.1	50	22.5	22.5	36	61.35	2.18	177
0.05	23.3	23.4	13.7	14.3	748	11.5	11.4	4760	21.9	22.2	52	22.2	22.4	42	64.96	2.17	195
					749.436			4711.6			51.438			36.534	67.80375		
					26.09865			188.637			5.55157			6.897526	6.115879		
					8			8			8			8	8		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
59.2617	59.5648	59.3197	6062	4902	56.4721	56.6746	56.5097	4050	3298	7.79	7.7	130	128.3951
43.7452	43.9755	43.788	4606	3750	51.392	51.608	51.4325	4320	3510	7.81	7.73	150	138.8889
59.2648	59.4897	59.3066	4498	3662	56.476	56.6889	56.5167	4258	3444	7.81	7.76	150	140.9112
43.7498	43.958	43.7843	4164	3474	51.3944	51.589	51.4268	3892	3244	7.76	7.65	145	149.0236
59.2639	59.4734	59.3028	4190	3412	43.4882	43.6817	43.5243	3870	3148	7.74	7.66	145	149.8708
43.7506	43.9982	43.7968	4952	4028	51.3959	51.5998	51.4335	4078	3326	7.73	7.61	160	156.9397
59.2671	59.5154	59.312	4966	4068	56.479	56.6897	56.5179	4214	3436	7.69	7.67	175	166.113
43.755	43.9839	43.7966	4578	3746	51.4001	51.6053	51.4382	4104	3342	7.75	7.67	170	165.692
			4752	3880.25				4098.25	3343.5	7.76	7.68125		149.4793
			567.8459	442.7148				152.2742	110.0443	0.039051	0.044282		12.37771
			8	8				8	8	8	8		8

Table D13(b): The calculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.11 for 10 days sludge age plant system.

< Sewage Batch 11 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AF)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
21 12	61.5	277.9	4.1	3.9	0.0	0.0	0.0	0.0	10.7	13.4	0.0	320.4	0.0	320.4	39.2	50.8	6.2	168.1	20.6	227.2	27.8	817.4	93.8
22 12	63.7	257.6	4.8	4.1	0.0	0.0	0.0	0.0	13.1	13.0	0.0	347.7	1.1	347.7	41.2	59.6	7.0	163.1	19.3	211.1	24.9	847.2	92.4
23 12	60.9	246.4	4.5	3.6	0.0	0.0	0.0	0.0	12.2	13.0	0.0	336.1	0.0	336.1	41.5	56.1	6.9	163.1	20.1	202.4	25.0	810.0	93.5
24 12	60.2	259.0	5.7	3.9	0.0	0.0	0.0	0.0	12.3	13.0	0.0	336.1	0.0	336.1	42.0	71.9	9.0	162.1	20.3	212.1	26.5	800.7	97.7
26 12	62.0	256.2	5.0	4.1	0.0	0.0	0.0	0.0	12.6	15.2	0.0	369.7	0.0	369.7	44.8	63.1	7.6	190.8	23.1	211.7	25.7	824.9	101.3
27 12	64.3	270.2	3.5	2.9	0.0	0.0	0.0	0.0	12.4	13.3	0.0	341.4	0.0	341.4	39.9	43.8	5.1	166.1	19.4	221.1	25.9	854.7	90.4
29 12	61.5	256.2	4.2	4.1	0.0	0.0	0.0	0.0	12.7	13.4	0.0	347.8	0.0	347.8	42.5	52.6	6.4	168.1	20.6	210.3	25.7	817.4	95.3
30 12	60.6	255.5	4.6	4.3	0.0	0.0	0.0	0.0	12.9	13.4	0.0	349.8	0.0	349.8	43.4	57.8	7.2	168.1	20.9	209.8	26.0	806.2	97.4
31 12	61.3	251.3	4.5	3.4	0.0	0.0	0.0	0.0	13.4	15.6	0.0	385.6	0.0	385.6	47.3	56.1	6.9	194.8	23.9	208.2	25.5	815.6	103.0
Mean	61.8	258.9	4.5	3.8	0.0	0.0	0.0	0.0	12.5	13.7	0.0	348.3	0.0	**348.3**	42.4	**56.9**	**6.9**	**171.6**	**20.9**	**212.7**	**25.9**	**821.6**	**96.1**

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
21 12	754.0	4818.2	34.3	32.3	1487.8	429.1	4.3	0.0	425.3	1943.8	5831.3	58.1	916.3	9.1	3758.2	37.5	10028.0	109.0
22 12	774.1	4596.5	40.3	36.3	1483.7	504.8	4.9	0.0	523.1	2390.5	5363.2	52.1	997.4	9.7	3585.3	34.8	10296.1	101.5
23 12	725.8	4657.0	36.3	32.3	1195.7	454.3	4.7	0.0	488.4	2231.9	4016.7	41.6	961.2	10.0	3632.4	37.6	9652.6	93.9
24 12	729.8	4777.9	50.4	42.3	1234.8	631.0	6.5	0.0	491.6	2246.5	4206.6	43.3	961.2	9.9	3726.8	38.4	9706.2	98.1
26 12	725.8	4838.4	42.3	34.3	1355.3	530.0	5.5	0.0	501.1	2290.2	4792.5	49.6	1057.5	11.0	3774.0	39.1	9652.6	105.2
27 12	754.0	5100.5	58.5	48.4	1306.6	732.0	7.3	0.0	494.8	2261.1	4567.0	45.5	976.4	9.7	3978.4	39.7	10028.0	102.3
29 12	697.5	4596.5	50.4	38.3	1442.9	631.0	6.8	0.0	507.5	2319.4	5221.1	56.3	994.7	10.7	3585.3	38.6	9277.2	112.4
30 12	733.8	4596.5	42.3	36.3	1413.8	530.0	5.4	0.0	513.5	2346.8	5042.0	51.7	1000.4	10.3	3585.3	36.7	9759.9	104.1
31 12	709.6	4616.6	48.4	38.3	1442.2	605.8	6.4	0.0	535.9	2448.9	5087.9	53.9	1102.7	11.7	3601.0	38.2	9438.1	110.2
Mean	733.8	4733.1	44.8	37.6	1373.6	**560.9**	**5.7**	**0.0**	**497.9**	**2275.4**	**4903.1**	**50.2**	996.1	10.2	3691.8	37.8	9759.9	104.0

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
21 12	0.04278	0.16019	1.40599	0.08279	0.39062
22 12	0.04687	0.12763	1.4431	0.0828	0.43678
23 12	0.04444	0.15807	1.48704	0.0804	0.40208
24 12	0.05801	0.17951	1.48358	0.08237	0.37327
26 12	0.04722	0.20226	1.42218	0.07705	0.34343
27 12	0.06417	0.19277	1.47982	0.08001	0.35657
29 12	0.05491	0.20672	1.40165	0.08003	0.33454
30 12	0.04945	0.18111	1.36125	0.07756	0.35888
31 12	0.05398	0.20685	1.34183	0.07464	0.32726
Mean	**0.05128**	**0.17938**	**1.42422**	**0.07969**	**0.36807**

Table D13(a): All the expeperimental results of sewage batch No.11 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.59

< Sewage Batch 11 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
21 12	21.8	22.1	61.46	19.2	20.5	277.9	2.9	4.06	2.8	3.92	17.1	47.88	1.9	2.66	0	0	0	0	10.66	13.43
22 12	22.9	22.6	63.7	17.8	19	257.6	3.4	4.76	2.9	4.06	18	50.4	2	2.8	0	0	0	0	13.11	13.03
23 12	21.7	21.8	60.9	17.6	17.6	246.4	3.2	4.48	2.6	3.64	17	47.6	2.6	3.64	0	0	0	0	12.24	13.03
24 12	22	21	60.2	18.3	18.7	259	4.1	5.74	2.8	3.92	17.6	49.28	2.1	2.94	0	0	0	0	12.32	12.95
26 12	21.7	22.6	62.02	18	18.6	256.2	3.6	5.04	2.9	4.06	17.4	48.72	1.7	2.38	0	0	0	0	12.56	15.24
27 12	23.3	22.6	64.26	20.3	18.3	270.2	2.5	3.5	2.1	2.94	18.4	51.52	1.8	2.52	0	0	0	0	12.4	13.27
29 12	21.5	22.4	61.46	17.9	18.7	256.2	3	4.2	2.9	4.06	17.5	49	2.2	3.08	0	0	0	0	12.72	13.43
30 12	21.9	21.4	60.62	18.2	18.3	255.5	3.3	4.62	3.1	4.34	17	47.6	2.2	3.08	0	0	0	0	12.87	13.43
31 12	22.4	21.4	61.32	18.4	17.5	251.3	3.2	4.48	2.4	3.36	17.6	49.28	1.6	2.24	0	0	0	0	13.43	15.56
Mean			61.77111			258.9222		4.542222		3.811111		49.03111		2.815556	0	0	0	0	12.47889	13.70777
SSD			1.287827			9.009474		0.594377		0.405639		1.234292		0.403846	0	0	0	0	0.73918	0.92463
No.			9			9		9		9		9		9	9	9	9	9	9	9

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0504	23.9	23.8	14.5	14.5	753.984	11.8	12	4818.24	23	23	34.272	23.1	23	32.256	61.99	2.57	159
0.0504	23.9	23.9	14.3	14.3	774.144	12.5	12.5	4596.48	22.9	22.9	40.32	23	23	36.288	61.82	3.6	161
0.0504	23.7	23.7	14.7	14.7	725.76	12.2	12.1	4656.96	22.8	22.8	36.288	23	22.8	32.256	49.82	1.12	105
0.0504	23.9	23.7	14.5	15	729.792	11.8	12.1	4777.92	22.4	22.7	50.4	22.7	22.8	42.336	51.45	1.2	124
0.0504	23.4	23.4	14.4	14.4	725.76	11.4	11.4	4838.4	22.4	22.3	42.336	22.6	22.5	34.272	56.47	2.51	140
0.0504	23.2	23.2	13.9	13.8	753.984	10.4	10.7	5100.48	21.7	21.8	58.464	22	22	48.384	54.44	1.8	119
0.0504	23.8	23.7	15.1	15.1	697.536	12.7	12	4596.48	22.5	22.5	50.4	22.8	22.8	38.304	60.12	2.55	159
0.0504	23.8	23.5	14.7	14.4	733.824	12.4	12.1	4596.48	22.6	22.6	42.336	22.8	22.7	36.288	58.91	3.38	116
0.0504	23.6	23.6	15	14.6	709.632	12.3	12	4616.64	22.4	22.4	48.384	22.7	22.6	38.304	60.09	1.55	189
					733.824			4733.12			44.8			37.632	57.23444		
					22.3282			160.0934			7.286028			4.845861	4.213178		
					9			9			9			9	9		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
59.26	59.5038	59.3233	4876	3610	56.4649	56.6953	56.5251	4608	3404	7.81	7.76	110	95.48611
43.7408	43.9807	43.8012	4798	3590	51.3843	51.5962	51.4382	4238	3160	7.63	7.75	110	103.8226
59.2603	59.4967	59.3202	4728	3530	56.4663	56.6763	56.5208	4200	3110	7.74	7.85	110	104.7619
43.7408	43.9834	43.7977	4852	3714	51.3848	51.5947	51.4351	4198	3192	7.64	7.76	105	100.0476
59.2586	59.5172	59.3178	5172	3988	56.4678	56.6855	56.5166	4354	3378	7.7	7.67	110	101.0565
43.7407	43.9858	43.7951	4902	3814	51.3868	51.6074	51.4367	4412	3414	7.64	7.69	110	99.72801
59.2607	59.5119	59.3156	5024	3926	56.4678	56.6762	56.5136	4168	3252	7.71	7.67	100	95.96929
43.744	43.9934	43.7955	4988	3958	51.3896	51.6015	51.434	4238	3350	7.62	7.63	120	113.261
59.2613	59.5129	59.3112	5032	4034	56.4707	56.6837	56.5131	4260	3412	7.76	7.8	120	112.6761
			4930.222	3796				4297.333	3296.889	7.694444	7.731111		102.9788
			128.7459	179.9654				132.2355	112.8031	0.062913	0.066907		6.071604

Table D12(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.10 for 10 days sludge age parent system.

< Sewage Batch 10 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
04 12	56.1	231.0	3.2	3.1	0.0	0.0	0.0	0.0	12.5	6.9	0.0	331.4	73.9	331.4	54.3	40.3	5.4	86.4	11.6	185.6	24.9	746.7	96.1
05 12	60.8	223.3	3.6	2.9	0.0	0.0	0.0	0.0	13.1	6.0	0.0	349.5	95.0	349.5	55.0	45.6	5.6	75.1	9.3	178.9	22.1	808.1	92.1
06 12	63.8	228.2	0.0	4.5	0.0	0.0	0.0	0.0	12.8	5.9	0.0	339.2	91.8	339.2	50.8	0.0	0.0	73.2	8.6	182.6	21.5	849.1	80.9
07 12	60.5	205.8	4.3	4.2	0.0	0.0	0.0	0.0	12.5	5.2	0.0	331.4	97.0	331.4	53.3	54.3	6.8	64.7	8.0	164.6	20.5	804.4	88.5
08 12	58.8	221.2	5.5	4.1	0.0	0.0	0.0	0.0	13.1	4.9	0.0	349.5	110.0	349.5	58.8	68.4	8.7	61.0	7.8	176.3	22.5	782.0	97.8
11 12	62.0	252.7	5.2	5.2	0.0	0.0	0.8	0.0	14.6	6.4	0.0	389.2	109.5	389.2	60.4	64.9	7.9	89.9	10.9	202.7	24.6	824.9	103.8
12 12	61.3	252.0	4.8	4.3	0.0	0.0	1.1	0.0	15.4	7.4	0.0	409.9	106.9	409.9	63.4	59.6	7.3	106.0	13.0	203.2	24.9	815.6	108.6
13 12	63.0	268.1	5.2	4.6	0.0	0.0	1.0	0.0	14.6	7.6	0.0	388.4	93.2	388.4	57.5	64.9	7.7	108.0	12.9	215.8	25.8	837.9	103.9
Mean	60.8	235.3	4.5	4.1	0.0	0.0	0.4	0.0	13.6	6.3	0.0	361.1	97.2	361.1	56.7	56.8	7.0	83.1	10.3	188.7	23.3	808.6	97.3

Date	Conc. (mg/l)				(mgO/l/	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
04 12	750.0	4495.7	24.2	28.2	1344.7	302.9	3.0	0.0	497.2	2272.0	4755.5	47.7	1159.4	11.6	3506.6	35.2	9974.4	97.5
05 12	776.0	4040.0	42.0	36.0	1134.2	525.8	5.1	0.0	524.3	2396.0	3531.6	34.2	1271.2	12.3	3151.2	30.5	10320.8	82.2
06 12	788.0	4240.0	60.0	42.0	1175.0	751.2	7.2	0.0	508.7	2324.9	3815.9	36.4	1232.4	11.8	3307.2	31.6	10480.4	86.9
07 12	812.0	4100.0	44.0	44.0	1188.0	550.9	5.1	0.0	497.2	2272.0	3936.5	36.5	1225.2	11.3	3198.0	29.6	10799.6	82.5
08 12	760.0	3900.0	48.0	40.0	1127.8	601.0	5.9	0.0	524.3	2396.0	3497.7	34.6	1314.2	13.0	3042.0	30.1	10108.0	83.6
11 12	716.0	4320.0	34.0	26.0	1313.8	425.7	4.5	0.0	583.7	2667.7	4198.0	44.1	1426.0	15.0	3369.6	35.4	9522.8	98.9
12 12	696.0	4280.0	34.0	32.0	1322.6	425.7	4.6	0.0	614.9	2809.9	4102.2	44.3	1478.2	16.0	3338.4	36.1	9256.8	100.9
13 12	697.5	4636.8	56.4	44.4	1373.0	706.7	7.6	0.0	582.5	2662.2	4513.3	48.6	1377.4	14.8	3616.7	39.0	9277.2	110.1
Mean	749.4	4251.6	42.8	36.6	1247.4	536.2	5.4	0.0	541.6	2475.1	4043.8	40.6	1310.5	13.1	3316.2	33.3	9967.5	92.4

Date	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
04 12	0.038	0.127	1.394	0.073	0.434
05 12	0.046	0.084	1.321	0.075	0.491
06 12	0.053	0.111	1.330	0.074	0.448
07 12	0.054	0.031	1.478	0.077	0.604
08 12	0.053	0.063	1.373	0.080	0.535
11 12	0.036	0.148	1.360	0.082	0.402
12 12	0.046	0.146	1.375	0.083	0.404
13 12	0.064	0.195	1.429	0.085	0.348
Mean	0.049	0.111	1.381	0.078	0.454

Table D12(a): All the expeperimental results of sewage batch No.10 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.59

<·Sewage Batch 10 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
04 12	19.7	20.4	56.14	16.1	16.9	231	2.3	3.22	2.2	3.08	16	44.8	1.6	2.24	0	0	0	0	12.46	6.9
05 12	21.7	21.7	60.76	16.3	15.6	223.3	2.6	3.64	2.1	2.94	17.1	47.88	1.8	2.52	0	0	0	0	13.14	6
06 12	22.8	22.8	63.84	16.3	16.3	228.2			3.2	4.48	17.5	49	2.6	3.64	0	0	0	0	12.75	5.85
07 12	21.5	21.7	60.48	14.7	14.7	205.8	3.1	4.34	3	4.2	18.2	50.96	1.8	2.52	0	0	0	0	12.46	5.17
08 12	21.2	20.8	58.8	16.2	15.4	221.2	3.9	5.46	2.9	4.06	17.1	47.88	1.8	2.52	0	0	0	0	13.14	4.87
11 12	22.2	22.1	62.02	18.1	18	252.7	3.7	5.18	3.7	5.18	17.4	48.72	1.7	2.38	0	0	0.78	0	14.63	6.4
12 12	21.7	22.1	61.32	18	18	252	3.4	4.76	3.1	4.34	17.4	48.72	1.9	2.66	0	0	1.1	0	15.41	7.37
13 12	22.4	22.6	63	19.3	19	268.1	3.7	5.18	3.3	4.62	17.4	48.72	2.6	3.64	0	0	1.04	0	14.6	7.59
Mean			60.795			235.2875		4.54		4.1125		48.335		2.765	0	0	0.365	0	13.57375	6.26875
SSD			2.281989			19.16849		0.784347		0.710207		1.608097		0.517953	0	0	0.478827	0	1.065152	0.920970
No.			8			8		7		8		8		8	8	8	8	8	8	8

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0504	23.9	23.8	14.2	14.9	749.952	12.5	12.9	4495.68	23.4	23.1	24.192	23.1	23.2	28.224	56.03	1.53	204
0.05	23.9	23.8	14.3	14	776	13.6	13.9	4040	23	22.6	42	22.8	23.1	36	47.26	1.06	123
0.05	23.8	23.8	14.1	13.8	788	13.2	13.2	4240	22.3	22.3	60	23	22.5	42	48.96	1.81	165
0.05	23.3	23.4	13.5	12.9	812	13	13.2	4100	22.3	22.2	44	22	22.5	44	49.5	1.23	133
0.05	23.3	23.1	13.9	13.5	760	13.6	13.3	3900	22.1	21.9	48	22.2	22.2	40	46.99	0.93	106
0.05	23.3	23.6	14.5	14.5	716	12.8	12.5	4320	22.8	22.4	34	23	22.6	26	54.74	1.07	160
0.05	23.2	23.3	14.6	14.5	696	12.6	12.5	4280	22.6	22.2	34	22.6	22.3	32	55.11	2.11	207
0.0504	23	22.8	14.4	14.1	697.536	11.4	11.4	4636.8	21.6	21.4	56.448	21.9	21.7	44.352	57.21	1.25	168
					749.436			4251.56			42.83			36.572	51.975		
					40.13404			224.9871			11.24921			6.704519	3.930951		
					8			8			8			8	8		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.747	43.963	43.795	4320	3360	51.3849	51.5922	51.432	4146	3204	7.82	7.81	170	164.0135
59.2684	59.4782	59.3166	4196	3232	56.4616	56.6592	56.5076	3952	3032	7.85	7.88	160	161.9433
43.7437	43.9817	43.799	4760	3654	51.3848	51.5908	51.433	4120	3156	7.8	7.81	170	165.0485
59.2655	59.4512	59.3094	3714	2836	56.4656	56.6462	56.509	3612	2744	7.84	7.91	140	155.0388
43.7458	43.9363	43.792	3810	2886	51.3867	51.573	51.4324	3726	2812	7.7	7.7	150	161.0306
43.7454	43.981	43.8047	4712	3526	51.3853	51.5983	51.4404	4260	3158	7.8	7.67	160	150.2347
59.262	59.4818	59.3198	4396	3240	56.4659	56.6769	56.5224	4220	3090	7.75	7.62	150	142.1801
43.7419	43.9863	43.805	4888	3626	51.3853	51.6007	51.44	4308	3214	7.7	7.62	140	129.9907
			4349.5	3295				4043	3051.25	7.7825	7.7525		153.685
			404.8787	291.7585				239.7165	167.9671	0.055396	0.107442		11.54061
			8	8				8	8	8	8		8

Table D11(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.9 for 10 days sludge age parent system

< Sewage Batch 9 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
19 11	64.4	266.7	4.2	2.1	0.1	0.0	0.3	0.0	13.5	12.9	-4.0	358.7	8.9	354.7	42.5	53.1	6.2	166.8	19.5	184.7	21.6	856.5	89.7
20 11	64.7	270.2	3.6	0.0	0.1	0.0	1.1	0.0	13.4	10.5	-4.8	354.2	38.0	349.4	45.0	46.0	5.3	146.6	17.0	186.0	21.6	860.2	89.1
21 11	67.2	264.6	4.9	2.9	0.1	0.0	1.6	0.1	13.9	9.2	-4.4	366.9	62.8	362.6	47.6	61.9	6.9	135.9	15.2	181.7	20.3	893.8	90.1
22 11	69.0	259.0	5.2	3.8	0.1	0.0	0.5	0.0	15.1	13.3	-4.8	399.1	23.1	394.3	45.5	65.5	7.1	174.3	19.0	180.0	19.6	918.0	91.2
23 11	67.2	254.8	3.5	3.2	0.0	0.0	0.8	0.0	15.5	12.5	0.0	410.7	39.9	410.7	50.4	44.2	4.9	168.0	18.8	176.9	19.8	893.8	94.0
24 11	66.5	231.0	3.6	3.1	0.0	0.0	0.0	0.1	16.1	16.2	0.0	424.4	0.0	424.4	48.0	46.0	5.2	205.1	23.2	163.2	18.4	884.5	94.8
Mean	**66.5**	**257.7**	**4.2**	**3.0**	**0.1**	**0.0**	**0.7**	**0.0**	**14.6**	**12.4**	-3.0	385.7	28.4	382.7	46.5	52.8	6.0	166.1	18.8	178.8	20.2	884.5	91.4

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
19 11	678.7	4297.1	22.1	18.1	1243.9	276.5	3.1	0.0	381.4	1743.2	4757.5	52.7	866.1	9.6	3351.8	37.1	9026.8	102.5
20 11	670.7	4457.8	40.2	26.1	1375.7	502.8	5.6	0.0	435.7	1991.2	5198.1	58.3	960.5	10.8	3477.1	39.0	8919.9	113.7
21 11																		
22 11																		
23 11	650.6	4136.5	42.2	26.1	1538.2	527.9	6.1	-6.4	490.0	2217.3	5821.1	67.3	956.4	11.1	3226.5	37.3	8652.9	121.7
24 11	706.8	4377.4	68.3	24.1	1660.6	854.8	9.1	0.0	518.3	2368.6	6309.5	67.1	986.7	10.5	3414.4	36.3	9400.7	123.0
Mean	686.7	4330.6	49.2	26.8	1454.6	615.9	6.7	-1.1	456.0	2080.2	5521.4	**60.5**	771.7	8.4	3377.9	37.0	9133.6	112.6

Date	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
19 11	0.027	0.159	1.358	0.080	0.390
20 11	0.039	0.214	1.375	0.087	0.327
21 11	0.034	0.121	1.368	0.107	0.440
22 11	0.061	0.213	1.427	0.082	0.329
23 11	0.040	0.189	1.354	0.082	0.351
24 11	0.034	0.162	1.398	0.081	0.390
Mean	0.039	0.176	1.381	0.086	0.370

Table D11(a): All the expeperimental results of sewage batch No.9 for 10 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	10.00	7.80	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.78	0.59

< Sewage Batch 9 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA Unfiltered Influent		FSA Unfiltered Effluent		NITRITE Anoxic	NITRITE Aerobic	NITRITE Effluent	NITRATE Anoxic	NITRATE Aerobic	NITRATE Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
19 11	23.0	23.0	64.4	17.3	18.1	247.8	2.9	4.1	2.8	3.9	19.3	54.0	1.6	2.2	0.0	0.0	0.5	0.0	9.6	13.3
20 11	23.1	23.1	64.7	19.9	19.6	276.5	3.8	5.3	2.8	3.9	21.1	59.1	1.8	2.5	0.0	0.0	0.1	0.0	10.9	14.4
21 11	24.0	24.0	67.2	21.6	21.6	302.4	5.3	7.4	2.7	3.8			1.7	2.4	0.0	0.0	0.3	0.1	11.2	13.0
22 11	24.7	24.6	69.0	19.0	19.2	267.4	3.8	5.3	3.1	4.3	19.8	55.4	2.0	2.8	0.0	0.0	0.3	0.1	11.8	13.9
23 11	23.3	24.7	67.2	17.5	17.5	245.0	3.4	4.8	2.8	3.9	22.9	64.1	1.6	2.2	0.2	0.0	0.5	0.1	12.4	13.3
24 11	23.9	23.6	66.5	17.9	17.6	248.5			2.1	2.9	19.9	55.7	1.7	2.4	0.0	0.0	0.7	0.0	13.0	12.1
Mean			66.5			264.6		5.4		3.8		57.7		2.4	0.0	0.0	0.4	0.0	11.5	13.3
SSD			1.6			20.4		1.1		0.4		3.6		0.2	0.1	0.0	0.2	0.0	1.1	0.7
No.			6.0			6.0		5.0		6.0		5.0		6.0	6.0	6.0	6.0	6.0	6.0	6.0

Normality	COD Blank		COD Influent			COD Mixed Liqour			COD Unfiltered Effluent			COD Filtered Effluent			OUR		
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Mean	SSD	No.
0.0502	23.9	23.8	15.7	15.1	678.7	13.2	13.1	4297.1	23.6	23.0	22.1	23.6	23.2	18.1	51.8	2.5	124.0
0.0502	23.9	23.9	15.6	15.5	670.7	12.9	12.7	4457.8	22.9	22.9	40.2	23.1	23.4	26.1	57.3	2.6	223.0
0.0502	23.7	23.6	14.6	14.8	718.9	13.6	14.0	3955.8	22.4	21.9	60.2	23.3	22.8	24.1			
0.0502	23.4	23.7	14.9	14.9	694.8	11.7	11.7	4759.0	21.8	22.2	62.2	22.6	22.4	42.2			
0.0502	24.1	24.6	16.0	16.5	650.6	13.6	14.5	4136.5	23.6	23.0	42.2	23.9	23.5	26.1	64.1	2.6	277.0
0.0502	24.3	24.5	15.7	15.5	706.8	13.5	13.5	4377.4	22.6	22.8	68.3	23.8	23.8	24.1	69.2	2.6	273.0
					686.7			4330.6			49.2			26.8	60.6		
					22.8			252.0			15.9			7.4	6.6		
					6.0			6.0			6.0			6.0	4.0		

TSS / VSS (Anoxic) Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	TSS / VSS (Aerobic) Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	pH Anoxic	pH Aerobic	DSVI 500SET	DSVI (l/g)
59.3	59.5	59.3	3968.0	3306.0	56.5	56.6	56.5	3788.0	3150.0	7.8	7.7	650.0	343.2
43.7	44.0	43.8	4706.0	3926.0	51.4	51.6	51.4	3854.0	3222.0	7.8	7.8	440.0	228.3
59.3	59.5	59.3	4324.0	3604.0	56.5	56.6	56.5	3436.0	2874.0	7.5	7.7	150.0	174.6
43.7	44.0	43.8	4462.0	3760.0	51.4	51.6	51.4	3944.0	3306.0	7.8	7.7	170.0	172.4
59.3	59.5	59.3	4330.0	3614.0	56.5	56.6	56.5	3652.0	3036.0	7.9	7.8	145.0	158.8
43.7	44.0	43.8	4342.0	3656.0	51.4	51.6	51.4	3700.0	3114.0	7.6	7.7	150.0	162.2
			4355.3	3644.3				3729.0	3117.0	7.7	7.7		206.6
			218.4	187.0				162.2	137.5	0.1	0.0		65.3

Table D10(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.8 for 10 days sludge age parent system.

< Sewage Batch 8 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
11 10	58.7	275.1	3.8	3.8	0.0	0.0	0.7	0.1	15.9	3.5	0.0	419.3	164.9	419.3	74.9	47.3	6.1	52.5	6.7	217.8	27.9	780.2	115.(
15 10	58.0	291.2	5.2	2.4	0.0	0.0	0.6	0.1	14.8	3.8	0.0	387.6	146.3	387.6	69.3	64.9	8.4	54.7	7.1	230.5	29.9	770.9	114.1
16 10	62.4	301.7	3.5	0.0	0.0	0.0	1.0	0.1	15.5	5.3	0.0	405.7	135.7	405.7	65.2	43.8	5.3	77.7	9.4	240.2	28.9	830.5	108.1
Mean	59.7	289.3	4.2	3.1	0.0	0.0	0.8	0.1	15.4	4.2	0.0	404.2	149.0	404.2	69.7	52.0	6.6	61.6	7.8	229.5	28.9	793.8	112.1

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
11 10	694.9	4572.0	26.4	16.3	1307.5	330.7	3.6	0.0	630.8	2882.8	3950.3	42.7	1671.0	18.1	3566.2	38.6	9242.8	103.0
15 10	638.0	4795.5	6.1	-18.3	1144.1	76.3	0.9	0.0	583.7	2667.7	3311.3	39.0	1526.8	18.0	3740.5	44.1	8486.0	102.0
16 10	699.0	5323.8	20.3	14.2	1237.2	254.4	2.7	0.0	611.3	2793.5	3672.1	39.5	1548.1	16.7	4152.6	44.7	9296.8	103.6
Mean	677.3	4897.1	17.6	4.1	1229.6	220.5	2.4	0.0	608.6	2781.3	3644.6	40.5	1582.0	17.6	3819.8	42.4	9008.5	102.9

Date	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
11 10	0.023	0.171	1.451	0.089	0.387
15 10	-0.029	0.242	1.386	0.085	0.317
16 10	0.020	0.233	1.524	0.087	0.330
Mean	0.006	0.215	1.454	0.087	0.343

Table E2: Summary of the 20 days sludge age parent MLE system COD, OUR and VSS statistical data for the various sewage batches.

Sew. Batch No.	COD (mgN/l)									OUR (mgO/l/h)			VSS (mgVSS/l)		
	INFLUENT			UNFILT. EFFLUENT			MIXED LIQUOR								
	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests	Mean	SSD	No. of tests
1	717.7	28.2	14	21.4	8.1	14	5558.6	253.8	14	38.4	1.7	14	4073.8	229.4	14
2	709.6	11.4	7	24.5	10.4	7	5737.0	137.9	7	44.5	1.6	6	4207.6	106.7	7
3	756.5	15.1	7	31.9	14.4	7	5702.6	235.3	7	38.0	1.5	7	4201.3	162.8	7
4	712.0	33.1	7	30.0	8.9	7	5071.4	159.6	7	34.9	1.9	7	3646.5	66.2	7
5	706.7	28.5	3	23.3	4.1	3	4813.3	120.4	3	34.0	1.8	3	3487.0	39.2	3
6	734.5	12.8	3	32.8	8.2	3	5086.6	175.7	3	33.4	1.6	3	3598.5	64.1	3
7	760.2	63.2	7	23.0	10.9	7	5287.9	353.0	7	43.1	3.6	7	3718.2	141.4	7
8	677.3	27.8	3	-4.7	18.9	3	4876.8	141.8	3	34.2	0.4	3	3715.2	122.6	3
9	686.7	22.8	6	23.1	10.2	6	4548.1	69.3	6	35.0	0.5	6	3308.6	68.1	6
10	747.4	41.1	8	40.8	10.5	8	5115.3	182.7	8	40.7	2.5	8	3668.3	102.5	8
11	733.8	22.3	9	42.8	5.8	9	4748.8	144.2	9	36.7	1.4	9	3351.4	62.0	9
12	749.4	26.1	8	37.3	6.0	8	4815.9	93.9	8	38.2	0.8	8	3406.6	52.6	8
13	762.5	11.8	3	26.6	2.5	3	4517.6	89.8	3	32.8	0.8	3	3272.3	48.6	3
14	727.2	23.2	9	31.5	4.9	9	3470.9	27.3	9	27.8	2.6	9	2459.8	47.5	9
15	764.9	15.2	6	34.1	4.3	6	3473.5	83.3	6	31.4	2.3	6	2507.2	49.8	6
16	743.4	18.1	11	39.9	9.2	11	3634.1	69.1	11	30.7	3.5	11	2571.8	41.2	11
17	772.6	13.0	8	35.8	4.5	8	3774.6	52.9	8	26.1	1.3	8	2666.9	70.2	8

Table E3(a): All the expeperimental results of sewage batch No.1 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20	10	13.3	20	2	1	0.45	0.2	0.24	1.48	0.5	0.7518797

< Sewage Batch 1 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l
09 07	20.5	21.5	58.8	19.1	20.3	275.8	2.1	2.94	1	1.4	15.2	42.56	0.5	0.7	0.78	0	0	7.49	20.95	20.84
10 07	21.3	22.7	61.6	21.5	21.5	301	2.5	3.5	1.9	2.66	16.1	45.08			0.69	0	0	2.5	15.09	16.91
11 07	21.1	21.1	59.08	21.4	19.5	286.3	2.1	2.94	1.2	1.68	15.6	43.68	0.7	0.98	0.3	0	0	0.17	11.96	11.16
12 07	21.1	20.5	58.24	21.2	20.7	293.3	1.5	2.1	1.2	1.68	15.9	44.52	0.5	0.7	0.1	0	0	0.07	11.45	10.95
13 07	17.7	15.4	46.34	19.4	21.7	287.7	1.7	2.38	1.4	1.96	16.2	45.36	0.8	1.12	0.08	0	0	0.05	11.05	10.35
14 07	19.4	18.6	53.2	21.6	21.6	302.4	3.2	4.48	1.5	2.1	15.5	43.4	0.6	0.84	0.13	0	0	0.04	12.27	10.85
16 07	21.2	21.2	59.36	21.5	22.7	309.4	2.5	3.5			16.3	45.64	0.9	1.26	0	0	0	1.08	8.39	11.01
17 07	19.9	19.9	55.72	21.2	21.2	296.8	1.9	2.66	1	1.4	16.4	45.92	0.7	0.98	0	0	0	0.18	9.3	11.51
18 07	20.7	20.7	57.96	16.4	17.4	236.6	1.5	2.1	0.3	0.42	17.2	48.16	0.6	0.84	0	0	0	0	8.19	11.41
19 07	21.4	21.4	59.92	18.9	19.7	270.2	1.7	2.38	0	0	13.6	38.08	1.2	1.68	1.2	0	0.86	1.75	13.61	8.78
20 07	21.2	21.2	59.36	23.3	22.5	320.6	0.7	0.98	0	0	16.8	47.04	0.5	0.7	1.02	0	0.43	1.1	14.21	9.74
21 07	21.5	21.5	60.2	21.7	20.7	296.8	2.2	3.08	1.4	1.96	16.7	46.76	0.4	0.56	1.25	0	0	2.01	15.29	11.86
23 07	21.1	21.7	59.92	22.6	21.1	305.9	1.7	2.38	1.2	1.68	17.2	48.16	0.3	0.42	1.35	0	0	2.91	15.29	12.41
24 07	21.7	21.7	60.76	23.7	22.2	321.3	2.1	2.94			17.2	48.16	0.6	0.84	1.54	0	0	4.61	18.42	13.61
Mean			57.89			293.15		2.74		1.4116667		45.18		0.8938462	0.6028571	0	0.0921429	1.7114286	13.247857	12.242142
SSD			3.8020652			21.126583		0.7896835		0.8071951		2.6257951		0.3132347	0.5578457	0	0.2398862	2.0807583	3.5285472	3.0131857
No.			14			14		14		12		14		13	14	14	14	14	14	14

Normality	Blank		Influent		COD	Mixed Liqour			Unfiltered Effluent			Filtered Effluent			OUR		
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Mean	SSD	No.
0.05	23.8	23.8	14.7	14.7	728	10.4	10.8	5280	23.4	22.9	26	23.3	23.3	20	35.92	2.15	149
0.05	25.1	24.7	15.5	15.5	752	11.7	12.6	5100	24.7	24.3	16	24.4	24.3	22	36.49	2.32	147
0.05	24.3	24.7	14.7	15.4	756	10.9	11.2	5380	24.2	23.8	20	24.2	24	16	37.66	2.22	149
0.05	24.7	24.9	15.3	15.3	760	10.7	10.7	5640	24.2	23.8	32	24	24.1	30	38.59	2.29	149
0.05	24.8	23.9	15.3	15.3	724	10.8	10.5	5480	23.8	23.7	24	24	24	14	39.24	2.28	144
0.05	24.2	24	15.2	15.1	716	10.3	10	5580	23.3	23.7	24	23.9	23.4	18	40.74	2.12	149
0.05	24.2	23.9	15.5	15.2	696	9.6	9.6	5780	23.3	23.3	30	23.4	23.2	30	42.05	2.21	129
0.05	23.8	24.2	15.2	15	712	9.5	9.4	5820	23.2	23.2	32	23.4	23.2	28	40.04	2.26	149
0.05	25.1	24.9	16.1	16.1	712	11	11.8	5440	24.5	24.2	26	24.8	24.1	22	39.06	2.2	147
0.05	24.9	24.5	15.8	14.9	748	11.8	11.7	5180	24.4	24.2	16	24.3	24.2	18	36.81	2.37	147
0.05	24.3	23.8	15.4	15.4	692	9.9	10.2	5600	24	24.1	0	24.1	24	0	37.29	2.35	131
0.05	24.3	24.2	15.3	15.6	704	10.2	9.9	5680	23.9	23.7	18	23.9	23.7	18	37.5	2.46	145
0.05	23.7	23.3	15	14.8	688	8.6	8.9	5900	23	23.1	18	22.9	23	22	37.35	2.65	146
0.05	24.1	23.6	15.7	15.5	660	8.9	9	5960	23.5	23.3	18	23.5	23.1	22	38.37	2.44	142
					717.71429			5558.5714			21.428571			20	38.365		
					28.151195			253.82382			8.0508587			7.2899148	1.6619169		
					14			14			14			14	14		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
56.383	56.6174	56.4249	4688	3850	42.4532	42.6891	42.4958	4718	3866	7.25	7.24	160	101.738025
43.41	43.6425	43.4519	4650	3812	42.4549	42.6953	42.4988	4808	3930	7.74	7.68	155	96.7138103
43.4124	43.6482	43.4535	4716	3894	42.4564	42.7019	42.5002	4910	4034	7.74	7.72	160	97.7596741
43.412	43.656	43.4556	4880	4008	42.4546	42.7017	42.4998	4942	4038	7.69	7.67	160	97.1266694
43.4145	43.6623	43.4581	4956	4084	42.4268	42.706	42.5003	5584	4114	7.69	7.72	160	85.9598854
43.4172	43.673	43.4599	5116	4262	42.4552	42.7034	42.4969	4964	4130	7.67	7.68	165	99.7179694
43.429	43.6755	43.4616	4930	4278	42.454	42.713	42.4974	5180	4312	7.73	7.78	170	98.4555985
43.4186	43.6726	43.4601	5080	4250	42.4519	42.7029	42.4934	5020	4190	7.69	7.66	180	107.569721
43.4209	43.6459	43.4591	4500	3736	56.3959	56.6329	56.4357	4740	3944	7.68	7.67	180	113.924051
43.4224	43.6498	43.4611	4548	3774	42.4477	42.6739	42.5058	4524	3362	7.7	7.77	160	106.100796
43.425	43.6771	43.4713	5042	4116	42.4481	42.7017	42.4944	5072	4146	7.64	7.6	180	106.466877
43.4286	43.6905	43.4723	5238	4364	42.4425	42.7053	42.4873	5256	4360	7.64	7.67	180	102.739726
43.4301	43.6882	43.4766	5162	4232	42.4424	42.7028	42.4895	5208	4266	7.58	7.58	185	106.56682
43.4353	43.6995	43.4822	5284	4346	42.4438	42.7076	42.4899	5276	4354	7.58	7.6	200	113.722517
			4913.5714	4071.8571				5014.4286	4074.7143	7.6442857	7.6457143		102.46872
			247.36113	215.90403				265.17183	248.97115	0.1197446	0.1259089		7.1239875
			14	14				14	14	14	14		14

Table E3(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.1 for 20 days sludge age parent system.

< Sewage Batch 1 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
09 07	58.8	275.8	2.94	1.4	0.78	0	0	7.49	20.95	20.84	-41.496	435.974	1.463	395.941	50.816327	37.632	4.8120301	266.752	34.109764	148.32	18.965782	782.04	108.7
10 07	61.6	301	3.5	2.66	0.69	0	0	2.5	15.09	16.91	-36.708	493.297	0	456.589	55.730519	44.8	5.468216	216.448	26.419295	158.955	19.401792	819.28	107.6
11 07	59.08	286.3	2.94	1.68	0.3	0	0	0.17	11.96	11.16	-15.96	457.52	10.64	452.2	58.903182	37.632	4.7892242	142.848	18.179504	148.73	18.928075	785.764	100.8
12 07	58.24	293.3	2.1	1.68	0.1	0	0	0.07	11.45	10.95	-5.32	446.481	6.65	447.811	58.671016	26.88	3.470214	140.16	18.094687	152.125	19.639371	774.592	99.9
13 07	46.34	287.7	2.38	1.96	0.08	0	0	0.05	11.05	10.35	-4.256	428.925	9.31	433.979	71.924903	30.464	4.9428708	132.48	21.495257	149.025	24.179731	616.322	122.5
14 07	53.2	302.4	4.48	2.1	0.13	0	0	0.04	12.27	10.85	-6.916	468.559	18.886	480.529	70.582707	57.344	8.1044717	138.88	19.628017	156.625	22.135932	707.56	120.5
16 07	59.36	309.4	3.5	0	0	0	0	1.08	8.39	11.01	0	312.151	0	312.151	39.53841	44.8	5.6745638	140.928	17.850556	160.205	20.292265	789.488	83.4
17 07	55.72	296.8	2.66	1.4	0	0	0	0.18	9.3	11.51	0	390.887	0	390.887	52.745872	34.048	4.5944006	147.328	19.880282	154.155	20.80151	741.076	98.0
18 07	57.96	236.6	2.1	0.42	0	0	0	0	8.19	11.41	0	369.607	0	369.607	47.94686	26.88	3.4869783	146.048	18.945916	124.005	16.086412	770.868	86.5
19 07	59.92	270.2	2.38	0	1.2	0	0.86	1.75	13.61	8.78	-52.402	385.7	64.239	397.537	57.943925	30.464	3.8226407	123.392	15.483301	139.92	17.557244	796.936	94.8
20 07	59.36	320.6	0.98	0	1.02	0	0.43	1.1	14.21	9.74	-48.545	449.008	59.451	459.914	65.78504	12.544	1.5888779	130.176	16.488661	165.385	20.948387	789.488	104.8
21 07	60.2	296.8	3.08	1.96	1.25	0	0	2.01	15.29	11.86	-66.5	457.52	45.619	436.639	60.232558	39.424	4.9239378	151.808	18.960358	154.33	19.275348	800.66	103.4
23 07	59.92	305.9	2.38	1.68	1.35	0	0	2.91	15.29	12.41	-71.82	416.955	38.304	383.439	52.920561	30.464	3.8226407	158.848	19.932341	159.155	19.970863	796.936	96.6
24 07	60.76	321.3	2.94	0	1.54	0	0	4.61	18.42	13.61	-81.928	425.733	63.973	407.778	58.377222	37.632	4.6568033	174.208	21.557515	167.455	20.721859	808.108	105.3
Mean	**57.89**	**293.15**	**2.74**	**1.4116667**	**0.6028571**	**0**	**0.0921429**	**1.7114286**	**13.247857**	**12.242143**	**-30.8465**	**424.1655**	**13.376**	**406.695**	**54.559139**	**35.072**	**4.5551779**	**157.87886**	**20.505425**	**152.74214**	**19.838265**	**769.937**	**99.5**

< Sewage Batch 1 - COD Mass Balance >

Date	Conc. (mg/l)				OUR	Mass (mg/d)											COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
09 07	728	5280	26	20	862.08	332.8	3.4371643	-41.496	716.072	3130.1178	2645.8182	27.326058	1180.1117	12.188214	2640	27.265967	9682.4	70.217404
10 07	752	5100	16	22	875.76	204.8	2.0476724	-36.708	669.788	2935.0227	2932.5693	29.321001	1348.0587	13.478431	2550	25.495921	10001.6	70.343025
11 07	756	5380	20	16	903.84	256	2.5460477	-15.96	627.228	2811.6892	3244.0388	32.263584	1311.646	13.044974	2690	26.753391	10054.8	74.607997
12 07	760	5640	32	30	926.16	409.6	4.0522359	-5.32	605.416	2748.5035	3456.7685	34.198343	1286.8575	12.731079	2820	27.898694	10108	78.880352
13 07	724	5480	24	14	941.76	307.2	3.1902962	-4.256	585.2	2659.7659	3650.0261	37.905808	1246.0743	12.94058	2740	28.455116	9629.2	82.4918
14 07	716	5580	24	18	977.76	307.2	3.2259419	-6.916	650.636	2949.6846	3601.3074	37.817736	1382.2663	14.515335	2790	29.298106	9522.8	84.857119
16 07	696	5780	30	30	1009.2	384	4.1483018	0	388.892	1777.2364	4984.4036	53.84586	892.75186	9.6442816	2890	31.220292	9256.8	98.858735
17 07	712	5820	32	28	960.96	409.6	4.3254203	0	485.184	2217.2909	4221.1411	44.575707	1117.9368	11.805534	2910	30.729915	9469.6	91.436575
18 07	712	5440	26	22	937.44	332.8	3.514404	0	435.708	1991.1856	4289.6624	45.299299	1057.076	11.162837	2720	28.723494	9469.6	88.700034
19 07	748	5180	16	18	883.44	204.8	2.0586225	-63.84	630.952	2664.4794	3254.5686	32.714492	1197.2181	12.034278	2590	26.034337	9948.4	72.84173
20 07	692	5600	0	0	894.96	0	0	-54.264	697.452	3001.2301	2995.0019	32.541635	1371.1808	14.898309	2800	30.422878	9203.6	77.862822
21 07	704	5680	18	18	900	230.4	2.4606972	-66.5	706.496	3000.5917	3029.4083	32.354412	1325.2625	14.153949	2840	30.331511	9363.2	79.300568
23 07	688	5900	18	22	896.4	230.4	2.5179227	-71.82	658.616	2763.5325	3242.3475	35.433943	1179.2285	12.88718	2950	32.239028	9150.4	83.078073
24 07	660	5960	18	22	920.88	230.4	2.6247437	-81.928	734.692	3076.5294	3093.3666	35.239993	1260.4623	14.359333	2980	33.948508	8778	86.172578
Mean	**717.71429**	**5558.5714**	**21.428571**	**20**	**920.76**	**274.28571**	**2.8734256**	**-32.072**	**613.738**	**2694.7757**	**3474.3163**	**36.397045**	**1198.6212**	**12.556792**	**2779.2857**	**29.115883**	**9545.6**	**80.943146**

< Sewage Batch 1 - Charateristics of Wastewater and Mixed Liqour >

Date	Fractions		Mixed Liqour		
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
09 07	0.027	0.088	1.361	0.072	0.344
10 07	0.029	0.075	1.292	0.077	0.357
11 07	0.021	0.082	1.330	0.071	0.351
12 07	0.039	0.094	1.389	0.073	0.338
13 07	0.019	0.107	1.329	0.070	0.318
14 07	0.025	0.120	1.347	0.074	0.303
16 07	0.043	0.145	1.333	0.072	0.271
17 07	0.039	0.133	1.382	0.071	0.289
18 07	0.031	0.099	1.374	0.060	0.330
19 07	0.024	0.055	1.535	0.080	0.406
20 07	0.000	0.123	1.351	0.077	0.303
21 07	0.020	0.137	1.299	0.069	0.279
23 07	0.032	0.149	1.378	0.072	0.273
24 07	0.033	0.174	1.364	0.074	0.248
Mean	0.028	0.112	1.359	0.072	0.313

Table E4(a): All the expeperimental results of sewage batch No.2 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20	10	13.3	20	2	1	0.45	0.2	0.24	1.48	0.5	0.7518797

< Sewage Batch 2 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
27 07	25.9	25.8	72.38	23.7	23.3	329	1.8	2.52	1.6	2.24	21	58.8	0.6	0.84	1.36	0	0	3.66	22.46	18.35
28 07	28	25.9	75.46	22.6	23.4	322	2.4	3.36	2	2.8	21.3	59.64	1.2	1.68	1.23	0	0.67	4.93	21.66	14.61
30 07	27.5	26.8	76.02	23.1	24.7	334.6	2.4	3.36	2	2.8	21.7	60.76	0.7	0.98	0.96	0	0.54	2.69	19.49	13.71
31 07	25.9	27.3	74.48	24.1	23.6	333.9	3	4.2	2.1	2.94	21	58.8	1.4	1.96	0.18	0	0.57	0.17	18.01	14.36
01 08	29.3	26.9	78.68	23	23.8	327.6	2.8	3.92	2.2	3.08	21.4	59.92	0.9	1.26	0.5	0	0.51	1.96	19.61	14.08
02 08	26.9	27	75.46	23.1	23.7	327.6	2.3	3.22	2.3	3.22	21.3	59.64	0.7	0.98	0.61	0	0.48	2.65	20.63	16.28
03 08	26.4	27.2	75.04	22.7	22.7	317.8	2	2.8	1.9	2.66	21.1	59.08	1.2	1.68	0.69	0	0.32	3.74	18.38	14.42
Mean			75.36			327.5		3.34		2.82		59.52		1.34	0.79	0	0.441429	2.828571	20.03429	15.11571
SSD			1.741723			5.580323		0.541849		0.293939		0.649923		0.401995	0.38656	0	0.205039	1.40466	1.520929	1.520139
No.			7			7		7		7		7		7	7	7	7	7	7	7

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0504	24.1	23.6	15.1	14.9	713.664	9.6	9.6	5745.6	23.4	23.5	16.128	23.4	23.6	14.112	44.59	3.45	148
0.0504	24.1	23.8	15.4	14.9	709.632	10.4	10.3	5483.52	23.6	23.3	20.16	23.7	23.7	10.08	44.15	3.47	149
0.0504	24.1	24.2	15.5	15.4	701.568	9.9	9.7	5785.92	23.4	23.4	30.24	23.8	23.4	22.176	42.34	1.99	198
0.0504	23.7	23.7	14.9	14.9	709.632	9.6	9.4	5725.44	23.7	23.2	10.08	23.7	23.3	8.064	47.71	3.88	137
0.0504	24.1	24.1	15.2	14.9	729.792	8.7	9.9	5967.36	23.2	23	40.32	23.2	23	40.32			
0.0504	24.6	24.6	16.1	16	689.472	10.9	10.3	5644.8	24.4	23.9	18.144	24.6	23.9	14.112	44.04	2.61	189
0.0504	24.5	24.9	16	15.7	713.664	10.5	10.1	5806.08	24	23.6	36.288	24	23.6	36.288	44	2.61	187
					709.632			5736.96			24.48			20.736	44.47167		
					11.40422			137.9397			10.41589			11.88851	1.610232		
					7			7			7			7	6		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.44	43.696	43.4818	5120	4284	42.442	42.6994	42.484	5148	4308	7.71	7.7	195	113.63636
43.441	43.6916	43.4847	5012	4138	42.4376	42.6893	42.4815	5034	4156	7.71	7.7	195	116.20977
56.4123	56.664	56.4565	5034	4150	42.4384	42.6976	42.485	5184	4252	7.7	7.65	185	107.06019
43.4499	43.7142	43.5002	5286	4280	42.4339	42.7025	42.4855	5372	4340	7.65	7.65	180	100.52122
43.4526	43.7162	43.5039	5272	4246	42.432	42.7006	42.485	5372	4312	7.65	7.6	180	100.52122
43.4549	43.7125	43.5064	5152	4122	42.43	42.6934	42.4826	5268	4216	7.69	7.66	180	102.50569
43.4572	43.7032	43.5077	4920	3910	42.4303	42.6844	42.483	5082	4028	7.72	7.71	180	106.25738
			5113.714	4161.429				5208.571	4230.286	7.69	7.667143		106.6731
			125.6227	120.5261				124.0494	101.3251	0.026726	0.03614		5.767103
			7	7				7	7	7	7		7

Table E4(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.2 for 20 days sludge age parent system.

< Sewage Batch 2 - N Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nba
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
27 07	72.38	329	2.52	2.24	1.36	0	0	3.66	22.46	18.35	-72.4	646.8	54.7	574.4	65.3	32.3	3.4	234.9	24.4	173.7	18.0	962.7	111.
28 07	75.46	322	3.36	2.8	1.23	0	0.67	4.93	21.66	14.61	-56.5	508.2	93.8	451.7	54.3	43.0	4.3	195.6	19.5	168.6	16.8	1003.6	94.9
30 07	76.02	334.6	3.36	2.8	0.96	0	0.54	2.69	19.49	13.71	-43.9	557.7	76.9	513.8	58.4	43.0	4.3	182.4	18.0	174.4	17.3	1011.1	98.(
31 07	74.48	333.9	4.2	2.94	0.18	0	0.57	0.17	18.01	14.36	-2.0	661.0	48.5	659.0	71.4	53.8	5.4	191.1	19.3	174.4	17.6	990.6	113.
01 08	78.68	327.6	3.92	3.08	0.5	0	0.51	1.96	19.61	14.08	-19.8	604.6	73.5	584.8	62.9	50.2	4.8	186.8	17.8	171.1	16.4	1046.4	101.
02 08	75.46	327.6	3.22	3.22	0.61	0	0.48	2.65	20.63	16.28	-26.1	624.3	57.9	598.2	65.4	41.2	4.1	214.5	21.4	172.2	17.2	1003.6	108.
03 08	75.04	317.8	2.8	2.66	0.69	0	0.32	3.74	18.38	14.42	-32.5	481.7	52.7	449.3	50.3	35.8	3.6	188.7	18.9	166.3	16.7	998.0	89.4
Mean	75.36	327.5	3.34	2.82	0.79	0	0.44143	2.82857	20.0343	15.1157	-36.2	583.5	65.4	547.3	61.1	42.8	4.3	199.1	19.9	171.5	17.1	1002.3	102.

< Sewage Batch 2 - COD Mass Balance >

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
27 07	713.664	5745.6	16.128	14.112	1070.2	206.4	2.2	-72.4	1000.2	4322.6	2847.5	30.0	1882.4	19.8	2872.8	30.3	9491.7	82.3
28 07	709.632	5483.52	20.16	10.08	1059.6	258.0	2.7	-65.4	890.0	3843.0	3256.3	34.5	1624.9	17.2	2741.8	29.0	9438.1	83.5
30 07	701.568	5785.92	30.24	22.176	1016.2	387.1	4.1	-51.1	893.8	3909.3	2899.0	31.1	1739.7	18.6	2893.0	31.0	9330.9	84.9
31 07	709.632	5725.44	10.08	8.064	1145.0	129.0	1.4	-9.6	949.1	4304.5	3367.3	35.7	2025.9	21.5	2862.7	30.3	9438.1	88.8
01 08	729.792	5967.36	40.32	40.32														
02 08	689.472	5644.8	18.144	14.112	1057.0	232.2	2.5	-32.5	956.5	4260.1	2821.6	30.8	1906.4	20.8	2822.4	30.8	9170.0	84.9
03 08	713.664	5806.08	36.288	36.288	1056.0	464.5	4.9	-36.7	778.8	3433.4	3641.8	38.4	1472.9	15.5	2903.0	30.6	9491.7	89.4
Mean	709.632	5736.96	24.48	20.736	1067.3	313.3	3.3	-42.0	915.3	4039.0	3112.1	33.0	1794.0	19.0	2868.5	30.4	9438.1	85.7

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
27 07	0.020	0.129	1.330	0.077	0.291
28 07	0.014	0.115	1.317	0.078	0.307
30 07	0.032	0.135	1.356	0.079	0.286
31 07	0.011	0.129	1.317	0.078	0.291
01 08	0.055	0.134	1.375	0.077	0.284
02 08	0.020	0.133	1.336	0.078	0.288
03 08	0.051	0.120	1.432	0.080	0.306
Mean	0.029	0.128	1.351	0.078	0.293

Table E5(a): All the expeperimental results of sewage batch No.3 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20	10	13.3	20	2	1	0.45	0.2	0.24	1.48	0.5	0.7518797

< Sewage Batch 3 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg
06 08	21.5	21.8	60.62	23.3	22.9	323.4	2	2.8	1.6	2.24	16.5	46.2	1.1	1.54	0	0	0.51	0	11.32	5.25
07 08	21.6	22.2	61.32	21.7	21.5	302.4	2.7	3.78	1.9	2.66	15.5	43.4	0.9	1.26	0	0	0.45	0	11.21	3.27
08 08	22.5	21.8	62.02	23	22.7	319.9	2	2.8	1.9	2.66	15.3	42.84	1.1	1.54	0	0	0.37	0	10.25	1.94
12 08	20.8	22.2	60.2	22.9	23.4	324.1	3.7	5.18	2.2	3.08	17	47.6	1	1.4	0.97	0	0.63	2.45	12.93	6.73
13 08	21.8	22.3	61.74	22.5	23	318.5	2.9	4.06	2.5	3.5	17.7	49.56			0.91	9	0.7	0.85	12.39	5.27
15 08	23.4	22.9	64.82	22	21.5	304.5	2.5	3.5	2.9	4.06	17.6	49.28	0.9	1.26	1.01	0	0	0.53	14.73	5.96
16 08	23.2	22.9	64.54	21.6	21.8	303.8	2.7	3.78					1.6	2.24	1.36	0	0	1.43	16.25	5.57
Mean			62.18			313.8		3.7		3.03333333		46.48		1.54	0.60714286	1.28571429	0.38	0.75142857	12.7257143	4.8557142
SSD			1.68404275			9.05538514		0.7552483		0.60306624		2.62663283		0.33326666	0.54226283	3.14934396	0.26065851	0.85342049	1.96377084	1.5392749
No.			7			7		7		6		6		6	7	7	7	7	7	7

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0503	23.3	23.4	13.9	14.1	752.488	8.6	8.6	5935.4	22.7	22.7	26.156	22.9	22.9	18.108	39.85	1.88	186
0.0503	23.5	23.5	13.5	14.5	764.56	9.9	10.3	5392.16	23.4	23.2	8.048	23.6	23.7		38.86	1.92	172
0.0503	23.3	23.4	13.9	13.9	760.536	8.9	9.1	5774.44	22.6	22.6	30.18	23	22.7	20.12	38.37	2.04	90
0.0503	23.3	23.4	14.3	14.3	728.344	8.5	8.9	5895.16	22.4	22.6	34.204	22.8	22.8	22.132	35.11	1.26	123
0.0503	23.6	23.4	14	13.7	776.632	8.7	8.7	5955.52	22.1	22.4	50.3	22.4	22.4	44.264	36.77	1.59	134
0.0503	23.6	23.6	14.3	14.4	744.44	10.3	10.3	5351.92	23.1	23	22.132	23.1	23	22.132	38.79	2.1	96
0.0503	24	24	14.5	14.4	768.584	10.1	10	5613.48	22.7	22.7	52.312	22.8	23.3	38.228	38.28	3.79	73
					756.512			5702.58286			31.9045714			27.4973333	38.0042857		
					15.0564293			235.340645			14.4459667			9.97017677	1.45731512		
					7			7			7			6	7		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.459	43.7363	43.5156	5546	4414	42.4306	42.7133	42.489	5654	4486	7.75	7.78	190	100.813583
43.462	43.7151	43.5147	5062	4008	42.4285	42.681	42.481	5050	4000	7.76	7.76	180	106.930693
43.2801	43.5459	43.3364	5316	4190	25.6408	25.9116	25.6986	5416	4260	7.74	7.79	180	99.704579
43.4638	43.7287	43.5153	5298	4268	42.427	42.7058	42.4817	5576	4482	7.78	7.73	190	102.223816
43.282	43.5374	43.3338	5108	4072	25.6414	25.8987	25.6949	5146	4076	7.68	7.7	180	104.935873
43.4646	43.7155	43.5132	5018	4046	42.4262	42.682	42.4756	5116	4128	7.69	7.74	180	105.551212
43.2801	43.5463	43.3311	5324	4304	25.6351	25.8843	25.6828	4984	4030	7.78	7.78	185	111.35634
			5238.85714	4186				5277.42857	4208.85714	7.74	7.75428571		104.502299
			172.467329	139.861156				248.225046	190.42466	0.03741657	0.03016959		3.70288319
			7	7				7	7	7	7		7

Table E5(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.3 for 20 days sludge age parent system.

< Sewage Batch 3 - N Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nba
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
06 08	60.62	323.4	2.8	2.24	0	0	0.51	0	11.32	5.25	6.8	451.7	80.7	458.5	66.9	35.8	4.4	73.7	9.1	164.6	20.4	806.2	100.
07 08	61.32	302.4	3.78	2.66	0	0	0.45	0	11.21	3.27	6.0	447.3	105.6	453.3	68.5	48.4	5.9	47.6	5.8	153.1	18.8	815.6	99.1
08 08	62.02	319.9	2.8	2.66	0	0	0.37	0	10.25	1.94	4.9	409.0	110.5	413.9	63.6	35.8	4.3	29.6	3.6	161.1	19.5	824.9	91.0
12 08	60.2	324.1	5.18	3.08	0.97	0	0.63	2.45	12.93	6.73	-43.2	385.6	82.5	342.3	53.1	66.3	8.3	94.2	11.8	165.7	20.7	800.7	93.8
13 08	61.74	318.5	4.06	3.5	0.91	0	0.7	0.85	12.39	5.27	-39.1	449.1	94.7	410.0	61.5	52.0	6.3	76.4	9.3	162.2	19.8	821.1	96.9
15 08	64.82	304.5	3.5	4.06	1.01	0	0	0.53	14.73	5.96	-53.7	559.5	116.6	505.8	72.2	44.8	5.2	76.3	8.8	155.2	18.0	862.1	104.
16 08	64.54	303.8	3.78	0	1.36	0	0	1.43	16.25	5.57	-72.4	572.3	142.0	499.9	74.8	48.4	5.6	71.3	8.3	154.7	18.0	858.4	106.
Mean	**62.18**	**313.8**	**3.7**	**3.03333**	**0.60714**	**1.28571**	**0.38**	**0.75143**	**12.7257**	**4.85571**	**7.0**	467.8	104.7	**474.7**	70.1	**47.4**	**5.7**	**67.0**	**8.1**	**159.5**	**19.3**	**827.0**	**103.**

< Sewage Batch 3 - COD Mass Balance >

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
06 08	752.5	5935.4	26.2	18.1	956.4	334.8	3.3	0.0	602.2	2752.2	3655.7	36.5	1534.3	15.3	2967.7	29.7	10008.1	84.9
07 08	764.6	5392.2	8.0	0.0	932.6	103.0	1.0	0.0	596.4	2725.4	3523.3	34.6	1591.5	15.7	2696.1	26.5	10168.6	77.8
08 08	760.5	5774.4	30.2	20.1	920.9	386.3	3.8	0.0	545.3	2492.0	3677.9	36.4	1494.2	14.8	2887.2	28.5	10115.1	83.5
12 08	728.3	5895.2	34.2	22.1	842.6	437.8	4.5	-51.6	557.5	2370.9	3274.8	33.8	1264.6	13.1	2947.6	30.4	9687.0	81.8
13 08	776.6	5955.5	50.3	44.3	882.5	643.8	6.2	430.4	613.9	4281.9	1630.7	15.8	1897.9	18.4	2977.8	28.8	10329.2	69.2
15 08	744.4	5351.9	22.1	22.1	931.0	283.3	2.9	-53.7	755.4	3268.1	2969.4	30.0	1842.0	18.6	2676.0	27.0	9901.1	78.5
16 08	768.6	5613.5	52.3	38.2	918.7	669.6	6.6	-72.4	788.4	3354.9	2800.5	27.4	1919.3	18.8	2806.7	27.5	10222.2	80.2
Mean	**756.5**	**5702.6**	**31.9**	**27.5**	**912.1**	**408.4**	**4.1**	**36.1**	**637.0**	**3035.1**	**3076.0**	**30.6**	1649.1	**16.4**	**2851.3**	**28.3**	**10061.6**	**79.4**

Date					
	$f_{s,us}$	$f_{s,up}$	f_v	f_N	fav
06 08	0.024	0.123	1.319	0.073	0.297
07 08		0.076	1.348	0.076	0.364
08 08	0.026	0.104	1.351	0.076	0.322
12 08	0.030	0.131	1.310	0.073	0.286
13 08	0.057	0.100	1.450	0.079	0.332
15 08	0.030	0.096	1.291	0.075	0.328
16 08	0.050	0.100	1.383	0.075	0.327
Mean	0.036	**0.100**	1.340	0.075	**0.310**

Table E6(a): All the expeperimental results of sewage batch No.4 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.0	13.2	13.3	20.0	2.0	1.0	0.5	0.2	0.2	1.5	0.7	1.0

< Sewage Batch 4 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)
23 08	31.5	32.2	89.2	21.1	21.2	296.1	2.9	4.1	1.9	2.7	25.4	71.1	1.4	2.0	1.4	0.0	0.0	8.2	28.5	26.7
24 08	32.2	32.7	90.9	21.7	21.0	298.9	2.2	3.1	2.0	2.8	24.7	69.2	1.5	2.1	2.0	0.0	0.0	8.2	27.9	30.2
27 08	32.7	32.7	91.6	19.5	21.1	284.2	1.6	2.2	1.4	2.0	26.4	73.9	1.6	2.2	1.4	0.0	0.0	9.5	31.7	31.9
28 08	30.0	31.8	86.5	21.6	20.8	296.8	1.6	2.2	0.8	1.1	23.2	65.0	1.0	1.4	1.2	0.0	0.0	10.3	30.6	29.6
29 08	32.1	32.1	89.9	20.6	20.7	289.1	2.4	3.4	1.5	2.1	26.1	73.1	1.1	1.5	1.1	0.0	0.0	12.7	37.0	28.3
30 08	33.0	32.4	91.6	19.9	20.2	280.7	2.7	3.8	1.3	1.8	27.8	77.8			1.4	0.0	0.0	14.2	39.0	31.5
31 08	31.8	33.6	91.6	19.9	21.1	287.0	2.7	3.8	0.8	1.1	27.2	76.2	0.7	1.0	1.9	0.0	0.0	16.7	37.9	34.2
Mean			**90.2**			**290.4**		**3.2**		**1.9**		**72.3**		**1.7**	1.5	**0.0**	0.0	**11.4**	**33.2**	**30.3**
SSD			**1.7**			**6.5**		**0.7**		**0.6**		**4.0**		**0.4**	0.3	**0.0**	0.0	**3.0**	**4.3**	**2.3**
No.			**7.0**			**7.0**		**7.0**		**7.0**		**7.0**		**6.0**	7.0	**7.0**	7.0	**7.0**	**7.0**	**7.0**

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.1	23.0	22.8	13.3	13.7	752.0	10.0	10.0	5160.0	22.2	21.1	50.0	22.2	22.2	28.0	34.3	3.5	161.0
0.1	23.1	23.2	13.6	13.7	760.0	10.1	10.2	5200.0	22.5	22.6	24.0	22.3	22.4	32.0	37.4	5.9	148.0
0.1	23.8	24.1	14.9	14.8	728.0	11.1	10.8	5200.0	23.1	23.2	32.0	23.1	23.1	34.0	35.5	4.7	177.0
0.1	23.6	23.8	15.3	15.2	676.0	10.6	10.5	5260.0	23.1	22.8	30.0	23.1	22.9	28.0	35.6	7.8	223.0
0.1	23.5	23.3	14.9	15.1	672.0	10.9	11.1	4960.0	23.0	22.5	26.0	22.8	22.6	28.0	36.2	3.2	191.0
0.1	23.2	22.9	14.3	14.1	708.0	11.0	10.8	4860.0	22.2	22.5	28.0	22.4	22.4	26.0	31.1	3.0	151.0
0.1	23.1	23.1	14.5	14.5	688.0	10.8	11.1	4860.0	22.7	22.5	20.0	22.5	22.5	24.0	34.3	3.1	164.0
					712.0			5071.4			30.0			28.6	34.9		
					33.1			**159.6**			8.9			**3.2**	**1.9**		
					7.0			7.0			7.0			7.0	7.0		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.3	43.5	43.3	4340.0	3542.0	42.4	42.7	42.5	4644.0	3788.0	8.0	8.0	310.0	200.3
43.5	43.7	43.5	4642.0	3816.0	58.1	58.4	58.2	4392.0	3612.0	8.0	8.0	310.0	211.7
43.3	43.5	43.3	4332.0	3542.0	42.4	42.6	42.5	4448.0	3634.0	7.9	7.8	310.0	209.1
43.5	43.7	43.5	4274.0	3522.0	58.1	58.4	58.2	4486.0	3816.0	7.9	7.7	330.0	220.7
43.3	43.5	43.3	4286.0	3572.0	42.4	42.6	42.5	4502.0	3748.0	7.9	7.7	320.0	213.2
43.5	43.7	43.5	4328.0	3556.0	58.1	58.4	58.2	4230.0	3626.0	7.8	7.8	320.0	227.0
43.3	43.5	43.3	4162.0	3434.0	42.4	42.6	42.5	4332.0	3568.0	7.8	8.0	320.0	221.6
			4337.7	3569.1				4433.4	3684.6	7.9	7.8		214.8
			136.5	**108.9**				122.7	90.1	0.1	0.1		8.3
			7.0	7.0				7.0	7.0	7.0	7.0		7.0

Table E6(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.4 for 20 days sludge age parent system.

< Sewage Batch 4 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
23 08	89.2	296.1	4.1	2.7	1.4	0.0	0.0	8.2	28.5	26.7	-76.6	675.6	22.7	599.0	52.4	51.3	4.3	338.0	28.5	213.1	18.0	1186.1	103.2
24 08	90.9	298.9	3.1	2.8	2.0	0.0	0.0	8.2	27.9	30.2	-104.8	708.8	0.0	604.0	50.0	38.9	3.2	381.3	31.6	217.2	18.0	1208.4	102.7
27 08	91.6	284.2	2.2	2.0	1.4	0.0	0.0	9.5	31.7	31.9	-73.9	761.6	0.0	687.6	56.5	28.3	2.3	403.0	33.1	208.6	17.1	1217.7	109.0
28 08	86.5	296.8	2.2	1.1	1.2	0.0	0.0	10.3	30.6	29.6	-63.8	660.5	12.6	596.6	52.9	28.3	2.5	374.1	32.5	215.4	18.7	1150.7	106.0
29 08	89.9	289.1	3.4	2.1	1.1	0.0	0.0	12.7	37.0	28.3	-59.1	684.7	115.3	625.6	62.0	42.5	3.6	357.7	29.9	209.5	17.5	1195.4	113.0
30 08	91.6	280.7	3.8	1.8	1.4	0.0	0.0	14.2	39.0	31.5	-76.6	702.1	100.3	625.5	59.6	47.8	3.9	398.0	32.7	206.0	16.9	1217.7	113.1
31 08	91.6	287.0	3.8	1.1	1.9	0.0	0.0	16.7	37.9	34.2	-103.2	573.6	48.7	470.4	42.6	47.8	3.9	432.7	35.5	212.0	17.4	1217.7	99.5
Mean	**90.2**	**290.4**	**3.2**	**1.9**	**1.5**	**0.0**	**0.0**	**11.4**	**33.2**	**30.3**	**-79.7**	**681.0**	38.1	**601.3**	53.3	**40.7**	**3.4**	**383.6**	**32.0**	**211.7**	**17.7**	**1199.1**	**106.4**

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2j}	MNO_{3j}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
23 08	752.0	5160.0	50.0	28.0	823.7	632.0	6.3	-76.6	1076.8	4658.1	2626.6	26.3	1866.4	18.7	3405.6	34.1	10001.6	85.3
24 08	760.0	5200.0	24.0	32.0	896.4	303.4	3.0	-104.8	1049.1	4434.9	3492.8	34.6	1847.8	18.3	3432.0	34.0	10108.0	89.8
27 08	728.0	5200.0	32.0	34.0	850.8	404.5	4.2	-73.9	1180.5	5141.3	2383.2	24.6	2051.6	21.2	3432.0	35.4	9682.4	85.4
28 08	676.0	5260.0	30.0	28.0	854.4	379.2	4.2	-63.8	1079.4	4714.0	2842.3	31.6	1815.9	20.2	3471.6	38.6	8990.8	94.6
29 08	672.0	4960.0	26.0	28.0	869.5	328.6	3.7	-59.1	1291.7	5700.5	1989.5	22.3	2187.0	24.5	3273.6	36.6	8937.6	87.0
30 08	708.0	4860.0	28.0	26.0	745.4	353.9	3.8	-76.6	1321.5	5776.4	816.2	8.7	2163.8	23.0	3207.6	34.1	9416.4	69.5
31 08	688.0	4860.0	20.0	24.0	823.2	252.8	2.8	-103.2	1126.2	4792.9	2487.4	27.2	1603.3	17.5	3207.6	35.1	9150.4	82.5
Mean	**712.0**	**5071.4**	**30.0**	**28.6**	**837.6**	**379.2**	**4.0**	**-79.7**	**1160.7**	**5031.2**	2376.9	**25.1**	1920.2	**20.3**	**3347.1**	**35.3**	**9469.6**	**84.7**

Date					
	$f_{s,us}$	$f_{s,up}$	$f_{i,v}$	f_N	fav
23 08	0.037	0.168	1.355	0.079	0.252
24 08	0.042	0.173	1.431	0.084	0.254
27 08	0.047	0.183	1.422	0.079	0.243
28 08	0.041	0.220	1.371	0.078	0.210
29 08	0.042	0.209	1.316	0.078	0.214
30 08	0.037	0.177	1.333	0.078	0.241
31 08	0.035	0.183	1.355	0.081	0.239
Mean	0.040	0.187	1.369	0.079	**0.236**

Table E7(a): All the expeperimental results of sewage batch No.5 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.0	13.2	13.3	20.0	2.0	1.0	0.5	0.2	0.2	1.5	0.7	1.0

< Sewage Batch 5 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
05 09	30.0	30.0	84.0	19.6	18.9	269.5	2.3	3.2	1.3	1.8	23.9	66.9	0.8	1.1	1.7	0.0	0.0	5.6	32.0	31.5
06 09	30.1	30.1	84.3	20.0	19.2	274.4	3.1	4.3	3.0	4.2	25.3	70.8	1.4	2.0	1.0	0.0	0.0	5.8	33.3	34.5
08 09	31.5	30.6	86.9	20.1	20.3	282.8	2.3	3.2	2.1	2.9			1.9	2.7	1.0	0.0	0.0	3.3	29.0	28.8
Mean			85.1			275.6		3.6		3.0		68.9		1.9	1.2	0.0	0.0	4.9	31.4	31.6
SSD			1.3			5.5		0.5		1.0		2.0		0.6	0.3	0.0	0.0	1.1	1.8	2.3
No.			3.0			3.0		3.0		3.0		2.0		3.0	3.0	3.0	3.0	3.0	3.0	3.0

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.1	24.7	24.7	16.4	16.3	668.0	13.0	12.9	4700.0	24.1	23.9	28.0	24.1	23.7	32.0	33.6	2.7	177.0
0.1	23.2	23.3	14.5	14.1	716.0	10.8	10.8	4980.0	23.0	22.6	18.0	22.5	22.5	30.0	32.0	3.0	162.0
0.1	23.3	23.3	14.0	14.2	736.0	11.4	11.4	4760.0	22.8	22.6	24.0	22.5	22.7	28.0	36.3	2.8	104.0
					706.7			4813.3			23.3			30.0	34.0		
					28.5			120.4			4.1			1.6	1.8		
					3.0			3.0			3.0			3.0	3.0		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.5	43.7	43.5	4174.0	3476.0	58.2	58.4	58.2	4184.0	3482.0	7.9	7.7	320.0	153.0
43.3	43.5	43.3	4270.0	3534.0	42.4	42.6	42.5	4306.0	3540.0	7.8	7.6	310.0	144.0
43.5	43.7	43.5	4152.0	3408.0	58.2	58.4	58.2	4232.0	3460.0	7.9	7.8	330.0	156.0
			4198.7	3472.7				4240.7	3494.0	7.9	7.7		151.0
			51.2	51.5				50.2	33.7	0.1	0.1		5.1
			3.0	3.0				3.0	3.0	3.0	3.0		3.0

Table E7(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.5 for 20 days sludge age parent system.

< Sewage Batch 5 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
05 09	84.0	269.5	3.2	1.8	1.7	0.0	0.0	5.6	32.0	31.5	-66.6	621.9	6.1	555.3	50.3	40.7	3.6	398.0	35.6	198.7	17.8	1117.2	107.3
-06 09	84.3	274.4	4.3	4.2	1.0	0.0	0.0	5.8	33.3	34.5	-37.9	670.9	0.0	632.9	56.5	54.9	4.9	435.6	38.9	203.8	18.2	1120.9	118.4
08 09	86.9	282.8	3.2	2.9	1.0	0.0	0.0	3.3	29.0	28.8	-41.1	636.1	3.1	595.0	51.7	40.7	3.5	363.4	31.4	205.6	17.8	1156.3	104.5
Mean	**85.1**	**275.6**	**3.6**	**3.0**	**1.2**	**0.0**	**0.0**	**4.9**	**31.4**	**31.6**	**-48.5**	**643.0**	0.0	**594.4**	52.5	**45.4**	**4.0**	**399.0**	**35.3**	**202.7**	**17.9**	**1131.5**	**109.7**

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
05 09	668.0	4700.0	28.0	32.0	805.7	353.9	4.0	-66.6	1053.0	4583.5	2542.0	28.6	1682.2	18.9	3102.0	34.9	8884.4	86.4
06 09	716.0	4980.0	18.0	30.0	768.5	227.5	2.4	-37.9	1098.8	4891.7	1904.7	20.0	1853.8	19.5	3286.8	34.5	9522.8	76.4
08 09	736.0	4760.0	24.0	28.0	870.7	303.4	3.1	-41.1	1024.6	4541.6	3159.0	32.3	1757.8	18.0	3141.6	32.1	9788.8	85.4
Mean	**706.7**	**4813.3**	**23.3**	**30.0**	**815.0**	**294.9**	**3.1**	**-48.5**	**1058.8**	**4672.3**	2535.2	**27.0**	1755.9	**18.7**	**3176.8**	**33.8**	**9398.7**	**82.6**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
05 09	0.048	0.192	1.341	0.078	0.228
06 09	0.042	0.177	1.398	0.079	0.247
08 09	0.038	0.148	1.368	0.083	0.272
Mean	**0.042**	0.172	**1.369**	**0.080**	**0.249**

Table E8(a): All the expeperimental results of sewage batch No.6 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.0	13.2	13.3	20.0	2.0	1.0	0.5	0.2	0.2	1.5	0.7	1.0

<.Sewage Batch 6 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
05 09	30.0	30.0	84.0	19.6	18.9	269.5	2.3	3.2	1.3	1.8	23.9	66.9	0.8	1.1	1.7	0.0	0.0	5.6	32.0	31.5
06 09	30.1	30.1	84.3	20.0	19.2	274.4	3.1	4.3	3.0	4.2	25.3	70.8	1.4	2.0	1.0	0.0	0.0	5.8	33.3	34.5
08 09	31.5	30.6	86.9	20.1	20.3	282.8	2.3	3.2	2.1	2.9			1.9	2.7	1.0	0.0	0.0	3.3	29.0	28.8
Mean			85.1			275.6		3.6		3.0		68.9		1.9	1.2	0.0	0.0	4.9	31.4	31.6
SSD			1.3			5.5		0.5		1.0		2.0		0.6	0.3	0.0	0.0	1.1	1.8	2.3
No.			3.0			3.0		3.0		3.0		2.0		3.0	3.0	3.0	3.0	3.0	3.0	3.0

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.1	24.7	24.7	16.4	16.3	668.0	13.0	12.9	4700.0	24.1	23.9	28.0	24.1	23.7	32.0	33.6	2.7	177.0
0.1	23.2	23.3	14.5	14.1	716.0	10.8	10.8	4980.0	23.0	22.6	18.0	22.5	22.5	30.0	32.0	3.0	162.0
0.1	23.3	23.3	14.0	14.2	736.0	11.4	11.4	4760.0	22.8	22.6	24.0	22.5	22.7	28.0	36.3	2.8	104.0
					706.7			4813.3			23.3			30.0	34.0		
					28.5			120.4			4.1			1.6	1.8		
					3.0			3.0			3.0			3.0	3.0		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.5	43.7	43.5	4174.0	3476.0	58.2	58.4	58.2	4184.0	3482.0	7.9	7.7	320.0	153.0
43.3	43.5	43.3	4270.0	3534.0	42.4	42.6	42.5	4306.0	3540.0	7.8	7.6	310.0	144.0
43.5	43.7	43.5	4152.0	3408.0	58.2	58.4	58.2	4232.0	3460.0	7.9	7.8	330.0	156.0
			4198.7	3472.7				4240.7	3494.0	7.9	7.7		151.0
			51.2	51.5				50.2	33.7	0.1	0.1		5.1
			3.0	3.0				3.0	3.0	3.0	3.0		3.0

Table E8(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.6 for 20 days sludge age parent system.

< Sewage Batch 6 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	NO_{2d}	MNO_{3e}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
17 09	68.3	291.2	3.8	3.8	0.0	0.0	0.9	0.1	17.8	12.0	9.7	467.8	76.3	477.5	60.9	47.8	5.3	162.9	17.9	200.7	22.1	908.7	106.2
18 09	64.1	305.2	4.1	1.4	0.0	0.0	1.3	0.0	19.1	12.1	15.8	507.5	93.5	523.4	72.3	51.3	6.0	168.5	19.8	210.2	24.7	852.8	122.8
19 09	67.8	303.8	4.1	1.4	0.0	0.0	1.0	0.0	18.1	10.9	12.6	481.5	96.0	494.1	65.5	51.3	5.7	150.7	16.7	208.4	23.1	901.2	111.0
Mean	**66.7**	**300.1**	**4.0**	**2.2**	**0.0**	**0.0**	**1.1**	**0.0**	**18.3**	**11.7**	**12.7**	485.6	**88.6**	**498.3**	**66.1**	**50.1**	**5.6**	**160.7**	**18.1**	**206.4**	**23.3**	**887.6**	**113.1**

	Conc. (mg/l)				OUR	Mass (mg/d)											COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
17 09	752.0	5200.0	42.0	34.0	749.0	530.9	5.3	-1.6	704.2	3212.9	3411.6	34.1	1572.7	15.7	3432.0	34.3	10001.6	89.5
18 09	729.8	4838.4	22.2	18.1	827.8	280.3	2.9	-1.2	761.3	3475.0	3845.7	39.6	1746.0	18.0	3193.3	32.9	9706.2	93.4
19 09	721.7	5221.4	34.3	34.3	828.2	433.2	4.5	-1.2	722.2	3296.3	4028.7	42.0	1673.2	17.4	3446.2	35.9	9599.0	99.8
Mean	**734.5**	**5086.6**	**32.8**	**28.8**	**801.7**	**414.8**	**4.2**	**-1.3**	**729.2**	**3328.1**	3762.0	**38.5**	1664.0	17.0	**3357.2**	**34.4**	**9768.9**	**94.2**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
05 09	0.048	0.192	1.341	0.078	0.228
06 09	0.042	0.177	1.398	0.079	0.247
08 09	0.038	0.148	1.368	0.083	0.272
Mean	**0.042**	0.172	**1.369**	**0.080**	**0.249**

Table E9(a): All the expeperimental results of sewage batch No.7 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.0	13.2	13.3	20.0	1.0	1.0	0.5	0.2	0.2	1.5	0.7	1.0

< Sewage Batch 7 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
22 09	27.6	28.1	78.0	22.3	21.9	309.4	3.2	4.5	2.1	2.9	22.5	63.0	1.8	2.5	0.1	0.0	1.9	0.1	17.7	12.4
25 09	31.2	30.9	86.9	22.6	22.4	315.0	3.2	4.5	2.5	3.5	24.5	68.6			0.1	0.0	0.5	0.0	17.2	19.2
26 09	31.7	30.4	86.9	21.9	22.8	312.9			2.1	2.9	26.8	75.0	1.6	2.2	0.1	0.0	0.3	0.0	17.5	19.0
27 09	29.6	28.8	81.8	21.2	21.0	295.4	2.1	2.9	2.0	2.8	24.0	67.2	0.8	1.1	0.4	0.0	0.3	0.5	20.1	19.8
02 10	30.3	30.8	85.5	21.9	21.5	303.8	2.3	3.2	2.3	3.2	24.9	69.7	1.6	2.2	0.0	0.0	1.0	0.5	22.3	20.3
03 10	29.4	29.5	82.5	21.1	20.7	292.6	3.1	4.3	1.5	2.1	22.1	61.9	1.6	2.2	0.2	0.0	1.3	0.1	23.7	20.0
04 10	27.4	30.3	80.8	20.5	20.5	287.0	2.8	3.9	2.3	3.2	19.2	53.8	2.2	3.1	0.7	0.0	1.7	0.8	23.3	17.4
Mean			83.2			302.3		3.9		3.0		65.6		2.2	0.2	0.0	1.0	0.3	20.2	18.3
SSD			3.1			10.0		0.6		0.4		6.3		0.6	0.2	0.0	0.6	0.3	2.6	2.6
No.			7.0			7.0		6.0		7.0		7.0		6.0	7.0	7.0	7.0	7.0	7.0	7.0

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.050	23.5	23.3	14.8	14.4	709.6	9.6	9.7	5544.0	23.0	23.0	16.1	22.1	22.3	48.4	41.4	2.3	141.0
0.050	23.0	23.0	12.4	12.9	834.6	8.9	9.0	5665.0	22.5	22.3	24.2	22.1	22.4	30.2	47.5	3.4	218.0
0.050	22.8	23.1	12.5	12.6	838.7	8.9	8.7	5705.3	22.0	21.9	40.3	22.0	22.1	36.3	48.5	3.0	167.0
0.050	23.7	23.5	13.8	13.7	794.3	11.0	10.6	5161.0	23.2	22.9	22.2	22.7	23.1	28.2	45.1	2.2	197.0
0.050	23.0	23.0	13.2	13.5	772.0	9.7	9.7	5320.0	22.1	22.1	36.0	22.1	22.3	32.0	38.7	2.3	138.0
0.050	23.6	24.0	14.8	15.0	712.0	11.5	11.6	4900.0	23.5	23.7	8.0	23.6	23.2	16.0	40.1	2.0	146.0
0.050	23.4	23.2	15.1	15.0	660.0	11.2	11.8	4720.0	23.0	22.9	14.0	23.0	22.9	14.0	40.7	2.8	146.0
					760.2			5287.9			23.0			29.3	43.1		
					63.2			353.0			10.9			10.9	3.6		
					7.0			7.0			7.0			7.0	7.0		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.3	43.5	43.3	4342.0	3636.0	42.4	42.7	42.5	4688.0	3928.0	7.5	7.4	360.0	153.6
43.5	43.7	43.5	4352.0	3696.0	58.2	58.4	58.2	4686.0	3976.0	7.5	7.4	360.0	153.6
43.3	43.5	43.3	4608.0	3878.0	42.4	42.7	42.5	4582.0	3856.0	7.6	7.5	350.0	152.8
43.5	43.7	43.5	4214.0	3552.0	58.2	58.4	58.2	4414.0	3732.0	7.9	7.9	385.0	174.4
43.3	43.5	43.3	4290.0	3594.0	42.4	42.6	42.5	4396.0	3680.0	7.8	7.7	360.0	163.8
43.5	43.7	43.5	4154.0	3510.0	58.2	58.4	58.2	4440.0	3750.0	7.9	7.8	360.0	162.2
43.3	43.5	43.3	4102.0	3392.0	42.4	42.6	42.5	4200.0	3484.0	7.9	7.8	320.0	152.4
			4294.6	3608.3				4486.6	3772.3	7.7	7.6		159.0
			154.5	141.9				163.5	154.2	0.2	0.2		7.7
			7.0	7.0				7.0	7.0	7.0	7.0		7.0

Table E9(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.7 for 20 days sludge age parent system.

< Sewage Batch 7 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
22 09	78.0	309.4	4.5	2.9	0.1	0.0	1.9	0.1	17.7	12.4	20.2	465.9	70.8	486.1	53.7	56.6	5.5	180.0	17.4	213.6	20.6	1037.1	97.1
25 09	86.9	315.0	4.5	3.5	0.1	0.0	0.5	0.0	17.2	19.2	1.1	457.0	0.0	458.1	39.6	56.6	4.9	248.2	21.5	220.9	19.1	1156.3	85.1
26 09	86.9	312.9	0.0	2.9	0.1	0.0	0.3	0.0	17.5	19.0	-0.5	465.0	0.0	464.4	40.2	0.0	0.0	244.6	21.2	219.3	19.0	1156.3	80.3
27 09	81.8	295.4	2.9	2.8	0.4	0.0	0.3	0.5	20.1	19.8	-12.0	513.5	3.6	501.5	46.5	37.2	3.4	254.1	23.4	208.2	19.1	1087.4	92.4
02 10	85.5	303.8	3.2	3.2	0.0	0.0	1.0	0.5	22.3	20.3	10.8	572.2	26.9	583.0	53.6	40.7	3.6	268.7	23.6	214.5	18.9	1137.7	99.7
03 10	82.5	292.6	4.3	2.1	0.2	0.0	1.3	0.1	23.7	20.0	10.8	623.8	49.2	634.5	62.3	54.9	5.0	268.2	24.5	207.1	18.9	1096.7	110.7
04 10	80.8	287.0	3.9	3.2	0.7	0.0	1.7	0.8	23.3	17.4	-5.1	588.4	78.2	583.3	61.6	49.5	4.6	242.2	22.5	202.1	18.8	1074.4	107.5
Mean	**83.2**	**302.3**	**3.9**	**3.0**	**0.2**	**0.0**	**1.0**	**0.3**	**20.2**	**18.3**	**3.6**	526.5	25.9	**530.1**	50.3	**49.3**	**4.5**	**243.7**	**22.0**	**212.2**	**19.2**	**1106.6**	**95.9**

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
22 09	709.6	5544.0	16.1	48.4	992.4	203.9	2.2	-4.8	701.0	3187.3	5589.4	59.2	1569.4	16.6	3659.0	38.8	9438.1	116.8
25 09	834.6	5665.0	24.2	30.2	1140.5	305.8	2.8	-5.2	685.5	3114.9	6971.5	62.8	1308.8	11.8	3738.9	33.7	11100.5	111.0
26 09	838.7	5705.3	40.3	36.3	1163.8	509.6	4.6	-4.8	697.5	3170.9	7121.4	63.8	1328.9	11.9	3765.5	33.8	11154.1	114.1
27 09	794.3	5161.0	22.2	28.2	1082.6	280.3	2.7	-15.6	780.8	3515.1	6059.8	57.4	1458.4	13.8	3406.2	32.2	10564.2	106.1
02 10	772.0	5320.0	36.0	32.0	929.3	455.0	4.4	-2.0	869.0	3964.7	4253.8	41.4	1731.7	16.9	3511.2	34.2	10267.6	96.9
03 10	712.0	4900.0	8.0	16.0	961.9	101.1	1.1	-6.0	938.4	4268.2	4239.0	44.8	1943.1	20.5	3234.0	34.2	9469.6	100.5
04 10	660.0	4720.0	14.0	14.0	975.8	177.0	2.0	-27.9	898.5	4010.6	4619.8	52.6	1897.8	21.6	3115.2	35.5	8778.0	111.8
Mean	**760.2**	**5287.9**	**23.0**	**29.3**	**1035.2**	**290.4**	**2.9**	**-9.5**	**795.8**	**3604.5**	5550.7	**54.9**	1586.2	**15.7**	**3490.0**	**34.5**	**10110.3**	**108.0**

Date					
	$f_{s,us}$	$f_{s,up}$	$f_{i,v}$	f_N	fav
22 09	0.068	0.224	1.399	0.080	0.205
25 09	0.036	0.152	1.417	0.080	0.273
26 09	0.043	0.157	1.470	0.082	0.271
27 09	0.036	0.144	1.375	0.080	0.277
02 10	0.041	0.164	1.437	0.083	0.263
03 10	0.022	0.174	1.302	0.079	0.244
04 10	0.021	0.188	1.351	0.083	0.236
Mean	**0.039**	**0.171**	**1.394**	**0.081**	0.253

Table E10(a): All the expeperimental results of sewage batch No.8 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.0	13.2	13.3	20.0	1.0	1.0	0.5	0.2	0.2	1.5	0.7	1.0

< Sewage Batch 8 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg
11 10	21.2	20.7	58.7	21.7	19.6	289.1	2.5	3.5	2.1	2.9	15.9	44.5	1.1	1.5	0.0	0.0	0.6	0.2	17.2	11.5
15 10	20.6	20.8	58.0	20.7	20.2	286.3			2.4	3.4	16.1	45.1	2.0	2.8	0.0	0.0	0.5	0.0	16.5	13.2
16 10	23.0	21.6	62.4	19.2	19.9	273.7	2.8	3.9	1.8	2.5	16.5	46.2			0.0	0.0	0.2	0.0	16.8	13.9
Mean			59.7			283.0		3.7		2.9		45.3		2.2	0.0	0.0	0.5	0.1	16.8	12.9
SSD			2.0			6.7		0.2		0.3		0.7		0.6	0.0	0.0	0.2	0.1	0.3	1.0
No.			3.0			3.0		2.0		3.0		3.0		2.0	3.0	3.0	3.0	3.0	3.0	3.0

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0508	22.7	22.7	14.0	14.3	694.9	10.4	10.1	5059.7	22.4	22.3	14.2	22.6	22.3	10.2	34.7	1.7	110.0
0.0508	22.6	22.9	14.8	15.0	638.0	11.1	10.5	4856.5	23.6	23.4	-30.5	23.9	23.4	-36.6	33.7	1.9	141.0
0.0508	23.1	22.9	14.2	14.6	699.0	11.4	11.4	4714.2	23.0	22.9	2.0	23.4	23.2	-12.2	34.3	1.5	151.0
					677.3			4876.8			-4.7			-12.9	34.2		
					27.8			141.8			18.9			19.1	0.4		
					3.0			3.0			3.0			3.0	3.0		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.5	43.7	43.5	4496.0	3534.0	58.2	58.4	58.2	4602.0	3614.0	7.8	7.7	370.0	160.8
43.3	43.5	43.4	4700.0	3554.0	42.4	42.7	42.5	4962.0	3738.0	7.8	7.7	310.0	124.9
43.5	43.7	43.5	4824.0	3744.0	58.2	58.4	58.2	5064.0	3948.0	7.7	7.7	310.0	122.4
			4673.3	3610.7				4876.0	3766.7	7.7	7.7		136.1
			135.2	94.6				198.2	137.9	0.0	0.0		17.5
			3.0	3.0				3.0	3.0	3.0	3.0		3.0

Table E10(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.8 for 20 days sludge age parent system.

< Sewage Batch 8 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	$MNO3_i$	$MNO3_e$	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
11 10	58.7	289.1	3.5	2.9	0.0	0.0	0.6	0.2	17.2	11.5	8.5	452.1	76.5	460.6	68.8	44.2	5.7	153.1	19.6	198.8	25.5	780.2	119.6
15 10	58.0	286.3	0.0	3.4	0.0	0.0	0.5	0.0	16.5	13.2	6.5	439.2	43.9	445.7	63.5	0.0	0.0	173.2	22.5	198.0	25.7	770.9	111.7
16 10	62.4	273.7	3.9	2.5	0.0	0.0	0.2	0.0	16.8	13.9	3.1	446.3	38.2	449.4	58.7	49.5	6.0	178.7	21.5	190.0	22.9	830.5	109.1
Mean	**59.7**	**283.0**	**3.7**	**2.9**	**0.0**	**0.0**	**0.5**	**0.1**	**16.8**	**12.9**	**6.0**	445.9	52.8	**451.9**	63.6	**46.9**	**5.9**	**168.3**	**21.2**	**195.6**	**24.6**	**793.8**	**115.3**

	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
11 10	694.9	5059.7	14.2	10.2	832.1	179.8	1.9	0.0	681.1	3112.6	4246.3	45.9	1526.2	16.5	3339.4	36.1	9242.8	100.5
15 10	638.0	4856.5	-30.5	-36.6	808.1	-385.3	-4.5	0.0	658.7	3010.5	4136.2	48.7	1392.7	16.4	3205.3	37.8	8486.0	98.4
16 10	699.0	4714.2	2.0	-12.2	822.5	25.7	0.3	0.0	669.5	3059.7	4214.3	45.3	1391.0	15.0	3111.4	33.5	9296.8	94.0
Mean	**677.3**	**4876.8**	**-4.7**	**-12.9**	**820.9**	**-59.9**	**-0.7**	**0.0**	**669.8**	**3060.9**	4198.9	**46.6**	1436.6	**15.9**	**3218.7**	**35.7**	**9008.5**	**97.6**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
11 10	0.015	0.189	1.397	0.081	0.241
15 10	-0.057	0.205	1.309	0.077	0.231
16 10	-0.017	0.177	1.197	0.070	0.237
Mean	**-0.019**	**0.190**	**1.298**	**0.076**	**0.236**

Table E11(a): All the expeperimental results of sewage batch No.9 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	0.99

< Sewage Batch 9 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluen
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg
19 11	23.0	23.0	64.4	19.0	19.1	266.7	3.0	4.2	1.5	2.1	19.3	54.0	1.5	2.1	0.1	0.0	0.3	0.0	13.5	12.9
20 11	23.1	23.1	64.7	19.3	19.3	270.2	2.6	3.6			21.1	59.1	2.1	2.9	0.1	0.0	1.1	0.0	13.4	10.5
21 11	24.0	24.0	67.2	18.9	18.9	264.6	3.5	4.9	2.1	2.9			1.7	2.4	0.1	0.0	1.6	0.1	13.9	9.2
22 11	24.7	24.6	69.0	18.2	18.8	259.0	3.7	5.2	2.7	3.8	19.8	55.4	1.8	2.5	0.1	0.0	0.5	0.0	15.1	13.3
23 11	23.3	24.7	67.2	17.7	18.7	254.8	2.5	3.5	2.3	3.2	22.9	64.1	1.6	2.2	0.0	0.0	0.8	0.0	15.5	12.5
24 11	23.9	23.6	66.5	16.7	16.3	231.0	2.6	3.6	2.2	3.1	19.9	55.7	1.6	2.2	0.0	0.0	0.0	0.1	16.1	16.2
Mean			66.5			257.7		**4.2**		**3.0**		57.7		**2.4**	**0.1**	**0.0**	**0.7**	**0.0**	14.6	12.4
SSD			1.6			13.0		**0.7**		**0.5**		3.6		**0.3**	**0.1**	**0.0**	**0.5**	**0.0**	1.0	2.2
No.			6.0			6.0		**6.0**		**5.0**		5.0		**6.0**	**6.0**	**6.0**	**6.0**	6.0	6.0	6.0

Normality	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			OUR		
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Til.2(ml)	Conc.(mg/l)	Mean	SSD	No.
0.0502	23.9	23.8	15.7	15.1	678.7	12.4	12.1	4658.6	23.5	23.3	18.1	23.5	23.3	18.1	33.9	0.9	123.0
0.0502	23.9	23.9	15.6	15.5	670.7	12.5	12.5	4578.2	23.4	23.2	24.1	23.6	23.1	22.1	34.7	0.5	128.0
0.0502	23.7	23.6	14.6	14.8	718.9	12.7	12.2	4497.9	23.5	23.3	10.0	23.5	23.1	14.1	35.4	1.0	124.0
0.0502	23.4	23.7	14.9	14.9	694.8	12.0	12.2	4598.3	22.9	22.5	34.1	23.0	22.9	24.1	35.4	1.0	124.0
0.0502	24.1	24.6	16.0	16.5	650.6	13.6	12.7	4497.9	23.2	23.6	38.2	23.2	23.2	46.2	35.0	0.9	144.0
0.0502	24.3	24.5	15.7	15.5	706.8	13.5	13.1	4457.8	24.0	24.1	14.1	24.0	24.2	12.0	35.4	0.9	161.0
					686.7			**4548.1**			**23.1**			**22.8**	**35.0**		
					22.8			**69.3**			**10.2**			**11.3**	0.5		
					6.0			**6.0**			6.0			**6.0**	6.0		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.5	43.7	43.5	4062.0	3266.0	58.2	58.4	58.2	4328.0	3472.0	7.9	7.8	320.0	147.9
43.3	43.5	43.3	4044.0	3272.0	42.4	42.6	42.5	4266.0	3450.0	7.8	7.7	340.0	159.4
43.5	43.7	43.5	3950.0	3188.0	58.2	58.4	58.2	4116.0	3324.0	7.8	7.7	145.0	140.9
43.3	43.5	43.3	3876.0	3160.0	42.4	42.6	42.5	4140.0	3376.0	7.8	7.8	150.0	144.9
43.5	43.7	43.5	3782.0	3064.0	58.2	58.4	58.2	4064.0	3296.0	7.9	7.8	150.0	147.6
43.3	43.5	43.3	4022.0	3288.0	42.4	42.6	42.5	3970.0	3236.0	7.9	7.8	150.0	151.1
			3956.0	**3206.3**				**4147.3**	**3359.0**	7.8	7.8		148.6
			100.0	**78.8**				**119.8**	**83.3**	**0.0**	**0.0**		5.7
			6.0	**6.0**				**6.0**	**6.0**	**6.0**	**6.0**		6.0

Table E11(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.9 for 20 days sludge age parent system.

< Sewage Batch 9 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nba
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
19 11	64.4	266.7	4.2	2.1	0.1	0.0	0.3	0.0	13.5	12.9	-4.0	358.7	8.9	354.7	42.5	53.1	6.2	166.8	19.5	184.7	21.6	856.5	89.7
20 11	64.7	270.2	3.6	0.0	0.1	0.0	1.1	0.0	13.4	10.5	-4.8	354.2	38.0	349.4	45.0	46.0	5.3	146.6	17.0	186.0	21.6	860.2	89.1
21 11	67.2	264.6	4.9	2.9	0.1	0.0	1.6	0.1	13.9	9.2	-4.4	366.9	62.8	362.6	47.6	61.9	6.9	135.9	15.2	181.7	20.3	893.8	90.1
22 11	69.0	259.0	5.2	3.8	0.1	0.0	0.5	0.0	15.1	13.3	-4.8	399.1	23.1	394.3	45.5	65.5	7.1	174.3	19.0	180.0	19.6	918.0	91.2
23 11	67.2	254.8	3.5	3.2	0.0	0.0	0.8	0.0	15.5	12.5	0.0	410.7	39.9	410.7	50.4	44.2	4.9	168.0	18.8	176.9	19.8	893.8	94.0
24 11	66.5	231.0	3.6	3.1	0.0	0.0	0.0	0.1	16.1	16.2	0.0	424.4	0.0	424.4	48.0	46.0	5.2	205.1	23.2	163.2	18.4	884.5	94.8
Mean	**66.5**	**257.7**	**4.2**	**3.0**	**0.1**	**0.0**	**0.7**	**0.0**	**14.6**	**12.4**	-3.0	385.7	28.4	**382.7**	46.5	**52.8**	**6.0**	**166.1**	**18.8**	**178.8**	**20.2**	**884.5**	**91.4**

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
19 11	678.7	4658.6	18.1	18.1	813.4	228.4	2.5	-4.0	538.7	2447.9	4745.4	52.6	1044.5	11.6	3074.6	34.1	9026.8	100.7
20 11	670.7	4578.2	24.1	22.1	833.5	304.6	3.4	-4.8	531.9	2414.2	4957.4	55.6	1113.6	12.5	3021.6	33.9	8919.9	105.4
21 11	718.9	4497.9	10.0	14.1	848.9	126.9	1.3	-4.4	551.4	2504.9	5002.6	52.3	1221.5	12.8	2968.6	31.0	9560.9	97.5
22 11	694.8	4598.3	34.1	24.1	848.9	431.5	4.7	-4.8	599.3	2722.4	4785.1	51.8	1199.5	13.0	3034.9	32.8	9240.4	102.3
23 11	650.6	4497.9	38.2	46.2	841.0	482.2	5.6	0.0	616.5	2817.2	4620.3	53.4	1288.7	14.9	2968.6	34.3	8652.9	108.2
24 11	706.8	4457.8	14.1	12.0	850.3	177.7	1.9	0.0	638.0	2915.7	4604.6	49.0	1213.8	12.9	2942.1	31.3	9400.7	95.1
Mean	**686.7**	**4548.1**	**23.1**	**22.8**	**839.3**	**291.9**	**3.2**	**-3.0**	**579.3**	**2637.1**	4785.9	**52.4**	1179.2	**12.9**	**3001.8**	**32.9**	**9133.6**	**101.4**

Date					
	$f_{s,us}$	$f_{s,up}$	$f_{t,v}$	f_N	fav
19 11	0.027	0.169	1.337	0.077	0.251
20 11	0.033	0.172	1.321	0.078	0.246
21 11	0.020	0.131	1.349	0.080	0.291
22 11	0.035	0.152	1.355	0.078	0.267
23 11	0.071	0.177	1.351	0.078	0.238
24 11	0.017	0.137	1.374	0.072	0.287
Mean	**0.033**	**0.156**	**1.347**	**0.078**	**0.263**

Table E12(a): All the expeperimental results of sewage batch No.10 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	℃	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	0.99

< Sewage Batch 10 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
04 12	19.7	20.4	56.14	18.9	19.2	266.7			1.9	2.66	16	44.8	1.7	2.38	0	0	0	0	13.66	8.55
05 12	21.7	21.7	60.76	19.9	20.1	280			2.9	4.06	17.1	47.88	1.4	1.96	0	0	0	0	13.51	9.6
06 12	22.8	20.7	60.9	20.4	19.1	276.5	4.5	6.3			17.5	49	2	2.8	0	0	0	0	14.11	10.13
07 12	21.5	21.7	60.48	19.3	21.5	285.6	2.5	3.5	1.8	2.52	18.2	50.96	1.8	2.52	0	0	0	0	13.66	10.13
08 12	21.2	20.8	58.8	20.2	21.8	294	3.2	4.48	2.9	4.06	17.1	47.88	1.6	2.24	0	0	0	0	14.19	11.11
11 12	22.2	22.1	62.02	21.6	20.5	294.7	2.7	3.78	2.5	3.5	17.4	48.72	1.9	2.66	0	0	0	0	15.33	13.55
12 12	21.7	22.1	61.32	22.6	22	312.2	2.9	4.06	1.9	2.66	17.4	48.72	1.9	2.66	0	0	0	0	15.74	14.44
13 12	22.4	22.6	63	23.1	22.4	318.5	2.8	3.92	2.6	3.64	17.4	48.72	2.6	3.64	0	0	0	0	16.62	14.98
Mean			60.4275			291.025		4.34		3.3		48.335		2.6075	0	0	0	0	14.6025	11.5612
SSD			1.978584			16.50483		0.925131		0.62546		1.608097		0.463998	0	0	0	0	1.076821	2.267842
No.			8			8		6		7		8		8	8	8	8	8	8	8

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0504	23.9	23.8	14.4	14.9	741.888	11.9	11.2	4959.36	22.4	22.6	54.432	23.1	23.8	16.128	36.44	0.73	150
0.05	23.9	23.8	14.3	14	776	11.6	11.9	4840	23	23.3	28	22.6	23.4	34	38.26	0.75	132
0.05	23.8	23.8	14.1	13.8	788	11.4	11.2	5000	22.2	22.5	58	22.1	22.5	60	39.64	1.06	158
0.05	23.3	23.4	13.5	12.9	812	10.6	10.4	5140	22.3	22.5	38	21.8	22.7	44	40.35	0.73	134
0.05	23.3	23.1	13.9	13.5	760	10.4	10.5	5100	22.3	22	42	22.3	22.3	36	41.45	1.1	141
0.05	23.3	23.6	14.7	14.5	708	10.7	10.7	5100	22.8	22.8	26	22.6	22.8	30	41.82	0.89	163
0.05	23.2	23.3	14.6	14.5	696	9.7	9.8	5400	22.2	22.3	40	22.3	21.8	48	42.81	1.23	175
0.0504	23	22.8	14.4	14.1	697.536	9.3	9.8	5382.72	22	21.8	40.32	21.8	21.8	44.352	44.88	0.71	165
					747.428			5115.26			40.844			39.06	40.70625		
					41.09342			182.7044			10.45638			12.31738	2.477105		
					8			8			8			8	8		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.31	43.5272	43.3575	4344	3394	42.4149	42.6438	42.4666	4578	3544	7.85	7.78	150	131.0616
43.4847	43.7037	43.5335	4380	3404	58.1685	58.4021	58.2204	4672	3634	7.86	7.76	160	136.9863
43.3083	43.5363	43.36	4560	3526	42.4097	42.6481	42.4641	4768	3680	7.8	7.77	150	125.8389
43.4857	43.7179	43.54	4644	3558	58.1688	58.4122	58.2254	4868	3736	7.76	7.74	140	115.037
43.3076	43.539	43.3626	4628	3528	42.4077	42.6534	42.4662	4914	3744	7.72	7.65	150	122.1001
43.3085	43.5487	43.3677	4804	3620	42.4028	42.6532	42.4657	5008	3750	7.7	7.62	150	119.8083
43.4863	43.7389	43.5504	5052	3770	58.1665	58.4258	58.2325	5186	3866	7.69	7.57	150	115.6961
43.3074	43.5569	43.3699	4990	3740	42.4006	42.6573	42.4678	5134	3790	7.66	7.57	140	109.0767
			4675.25	3567.5				4891	3718	7.755	7.6825		121.9506
			242.6354	129.2894				200.5866	92.11949	0.070356	0.084224		8.525451
			8	8				8	8	8	8		8

Table E12(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.10 for 20 days sludge age parent system.

< Sewage Batch 10 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
04 12	56.1	266.7	0.0	2.7	0.0	0.0	0.0	0.0	13.7	8.6	0.0	295.4	68.0	295.4	48.7	0.0	0.0	108.1	14.5	181.7	24.3	746.7	87.5
05 12	60.8	280.0	0.0	4.1	0.0	0.0	0.0	0.0	13.5	9.6	0.0	307.4	52.0	307.4	44.5	0.0	0.0	121.3	15.0	191.1	23.7	808.1	83.1
06 12	60.9	276.5	6.3	0.0	0.0	0.0	0.0	0.0	14.1	10.1	0.0	322.4	52.9	322.4	46.3	79.6	9.8	128.0	15.8	189.2	23.4	810.0	95.3
07 12	60.5	285.6	3.5	2.5	0.0	0.0	0.0	0.0	13.7	10.1	0.0	316.4	46.9	316.4	45.2	44.2	5.5	128.0	15.9	195.2	24.3	804.4	90.9
08 12	58.8	294.0	4.5	4.1	0.0	0.0	0.0	0.0	14.2	11.1	0.0	336.5	41.0	336.5	48.3	56.6	7.2	140.4	18.0	201.4	25.7	782.0	99.2
11 12	62.0	294.7	3.8	3.5	0.0	0.0	0.0	0.0	15.3	13.6	0.0	384.1	23.7	384.1	49.4	47.8	5.8	171.3	20.8	203.4	24.7	824.9	100.7
12 12	61.3	312.2	4.1	2.7	0.0	0.0	0.0	0.0	15.7	14.4	0.0	401.4	17.3	401.4	51.3	51.3	6.3	182.5	22.4	215.6	26.4	815.6	106.4
13 12	63.0	318.5	3.9	3.6	0.0	0.0	0.0	0.0	16.6	15.0	0.0	420.3	21.8	420.3	52.8	49.5	5.9	189.3	22.6	220.1	26.3	837.9	107.9
Mean	**60.4**	**291.0**	**4.3**	**3.3**	**0.0**	**0.0**	**0.0**	**0.0**	**14.6**	**11.6**	0.0	348.0	40.4	**348.0**	48.3	**54.9**	**6.8**	**146.1**	**18.2**	**199.7**	**24.8**	**803.7**	**98.2**

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
04 12	741.9	4959.4	54.4	16.1	874.6	688.0	7.0	0.0	545.0	2490.8	5243.8	53.1	1039.2	10.5	3273.2	33.2	9867.1	103.8
05 12	776.0	4840.0	28.0	34.0	918.2	353.9	3.4	0.0	539.0	2463.5	5657.5	54.8	1027.8	10.0	3194.4	31.0	10320.8	99.2
06 12	788.0	5000.0	58.0	60.0	951.4	733.1	7.0	0.0	563.0	2572.9	5841.0	55.7	1073.4	10.2	3300.0	31.5	10480.4	104.5
07 12	812.0	5140.0	38.0	44.0	968.4	480.3	4.4	0.0	545.0	2490.8	6073.7	56.2	1039.2	9.6	3392.4	31.4	10799.6	101.7
08 12	760.0	5100.0	42.0	36.0	994.8	530.9	5.3	0.0	566.2	2587.4	6210.6	61.4	1079.5	10.7	3366.0	33.3	10108.0	110.7
11 12	708.0	5100.0	26.0	30.0	1003.7	328.6	3.5	0.0	611.7	2795.3	6081.2	64.6	1166.2	12.4	3366.0	35.7	9416.4	116.2
12 12	696.0	5400.0	40.0	48.0	1027.4	505.6	5.5	0.0	628.0	2870.1	6216.6	67.2	1197.4	12.9	3564.0	38.5	9256.8	124.1
13 12	697.5	5382.7	40.3	44.4	1077.1	509.6	5.5	0.0	663.1	3030.5	6495.5	70.0	1264.4	13.6	3552.6	38.3	9277.2	127.4
Mean	**747.4**	**5115.3**	**40.8**	**39.1**	**977.0**	**516.3**	**5.2**	**0.0**	**582.6**	**2662.7**	5977.5	**60.1**	1110.9	**11.2**	**3376.1**	34.0	**9940.8**	**110.5**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
04 12	0.022	0.150	1.395	0.076	0.275
05 12	0.044	0.136	1.323	0.078	0.280
06 12	0.076	0.149	1.342	0.075	0.263
07 12	0.054	0.139	1.364	0.077	0.278
08 12	0.047	0.162	1.353	0.080	0.256
11 12	0.042	0.194	1.352	0.080	0.228
12 12	0.069	0.231	1.384	0.081	0.199
13 12	0.064	0.226	1.409	0.085	0.205
Mean	0.052	0.171	**1.365**	0.079	0.247

Table E13(a): All the expeperimental results of sewage batch No.11 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	0.99

< Sewage Batch 11 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
21 12	21.8	22.1	61.46	21.3	20.7	294	3.3	4.62	2.8	3.92	17.1	47.88	1.9	2.66	0	0	0	0	13.74	14.53
22 12	22.9	22.6	63.7	19.6	19.5	273.7	3.9	5.46	2.3	3.22	18	50.4	2.1	2.94	0	0	0	0	12.95	14.93
23 12	21.7	21.8	60.9	18.8	19.4	267.4	3.4	4.76	2.6	3.64	17	47.6	2.2	3.08	0	0	0	0	15	14.93
24 12	22	21	60.2	19.7	20.2	279.3	3.4	4.76	3.2	4.48	17.6	49.28	1.9	2.66	0	0	0	0	14.85	15.32
26 12	21.7	22.6	62.02	18.4	18.4	257.6	3.3	4.62	2.6	3.64	17.4	48.72	2.2	3.08	0	0	0	0	15.56	15.64
27 12	23.3	22.6	64.26	18.6	19.2	264.6	4.1	5.74			18.4	51.52	2.2	3.08	0	0	0	0	15.48	15.95
29 12	21.5	22.4	61.46	18	18.4	254.8	3.6	5.04	2.6	3.64	17.5	49	2.5	3.5	0	0	0	0	15.95	15.87
30 12	21.9	21.4	60.62	17.6	19.1	256.9	3.8	5.32	2.1	2.94	17	47.6	1.4	1.96	0	0	0	0	15.87	15.72
31 12	22.4	21.4	61.32	17.4	17.5	244.3	3.4	4.76			17.6	49.28	1.8	2.52	0	0	0	0	15.48	15.56
Mean			61.77111			265.8444		5.008889		3.64		49.03111		2.831111	0	0	0	0	14.98667	15.38333
SSD			1.287827			14.03797		0.383564		0.455192		1.234292		0.416238	0	0	0	0	0.957125	0.460868
No.			9			9		9		7		9		9	9	9	9	9	9	9

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent					
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Mean	SSD	No.
0.0504	23.9	23.8	14.5	14.5	753.984	11.8	12	4818.24	23	23	34.272	23.1	23	32.256	38.74	3.18	144
0.0504	23.9	23.9	14.3	14.3	774.144	11.9	11.5	4919.04	23.1	22.7	40.32	23.2	22.9	34.272	38.47	2.57	24
0.0504	23.7	23.7	14.7	14.7	725.76	11.7	11.9	4798.08	22.8	22.7	38.304	22.9	22.9	32.256	36.37	2.23	73
0.0504	23.9	23.7	14.5	15	729.792	11.8	11.9	4818.24	22.8	22.7	42.336	22.9	22.7	40.32	37.04	1.1	72
0.0504	23.4	23.4	14.4	14.4	725.76	11.4	11.6	4798.08	22.5	22	46.368	22.4	22.4	40.32	36		
0.0504	23.2	23.2	13.9	13.8	753.984	10.8	11.2	4919.04	21.9	21.9	52.416	21.9	21.9	52.416	33.72	0.64	101
0.0504	23.8	23.7	15.1	15.1	697.536	12.5	12.6	4515.84	23	22.7	36.288	23	22.9	32.256	36.72	1.28	148
0.0504	23.8	23.5	14.7	14.4	733.824	12.4	12.3	4556.16	22.6	22.5	44.352	22.8	22.7	36.288	36.01	0.73	150
0.0504	23.6	23.6	15	14.6	709.632	12.2	12.2	4596.48	22.4	22.3	50.4	22.6	22.7	38.304	36.82	1.05	149
					733.824			4748.8			42.784			37.632	36.65444		
					22.3282			144.1628			5.841205			6.085219	1.388909		
					9			9			9			9	9		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.4828	43.7117	43.545	4578	3334	58.1659	58.4064	58.2317	4810	3494	7.8	7.74	120	99.7921
43.3067	43.5334	43.3667	4534	3334	42.4003	42.6327	42.463	4648	3394	7.81	7.91	120	103.2702
43.4834	43.7087	43.5459	4506	3256	58.1676	58.3971	58.2308	4590	3326	7.78	7.8	120	104.5752
43.3077	43.536	43.3667	4566	3386	42.4001	42.6312	42.4603	4622	3418	7.74	7.76	115	99.52402
43.4808	43.702	43.5398	4424	3244	58.1639	58.4017	58.2266	4756	3502	7.73	7.67	110	92.51472
43.3092	43.5241	43.363	4298	3222	42.3998	42.6286	42.4577	4576	3418	7.73	7.69	105	91.78322
43.4834	43.6945	43.5359	4222	3172	58.1685	58.3882	58.2236	4394	3292	7.73	7.67	110	100.1365
43.3109	43.5269	43.3637	4320	3264	42.4011	42.6247	42.4556	4472	3382	7.74	7.74	100	89.44544
43.4841	43.6895	43.5327	4108	3136	58.1685	58.3867	58.2198	4364	3338	7.74	7.67	100	91.65903
			4395.111	3260.889				4581.333	3396	7.755556	7.738889		96.96672
			157.2489	75.77224				142.704	67.56725	0.030225	0.074602		5.308517
			9	9				9	9	9	9		9

Table E13(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.11 for 20 days sludge age parent system.

< Sewage Batch 11 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
21 12	61.5	294.0	4.6	3.9	0.0	0.0	0.0	0.0	13.7	14.5	0.0	376.0	0.0	376.0	46.0	58.4	7.1	183.7	22.5	203.6	24.9	817.4	100.5
22 12	63.7	273.7	5.5	3.2	0.0	0.0	0.0	0.0	13.0	14.9	0.0	370.8	0.0	370.8	43.8	69.0	8.1	188.7	22.3	190.5	22.5	847.2	96.7
23 12	60.9	267.4	4.8	3.6	0.0	0.0	0.0	0.0	15.0	14.9	0.0	398.1	0.9	398.1	49.3	60.2	7.4	188.7	23.3	186.3	23.0	810.0	103.0
24 12	60.2	279.3	4.8	4.5	0.0	0.0	0.0	0.0	14.9	15.3	0.0	401.3	0.0	401.3	50.1	60.2	7.5	193.6	24.2	194.4	24.3	800.7	106.1
26 12	62.0	257.6	4.6	3.6	0.0	0.0	0.0	0.0	15.6	15.6	0.0	415.0	0.0	415.0	50.3	58.4	7.1	197.7	24.0	180.3	21.9	824.9	103.2
27 12	64.3	264.6	5.7	0.0	0.0	0.0	0.0	0.0	15.5	16.0	0.0	418.0	0.0	418.0	48.9	72.6	8.5	201.6	23.6	185.2	21.7	854.7	102.7
29 12	61.5	254.8	5.0	3.6	0.0	0.0	0.0	0.0	16.0	15.9	0.0	423.2	1.1	423.2	51.9	63.7	7.8	200.6	24.5	178.6	21.9	817.4	106.1
30 12	60.6	256.9	5.3	2.9	0.0	0.0	0.0	0.0	15.9	15.7	0.0	420.1	2.0	420.1	52.4	67.2	8.3	198.7	24.6	179.9	22.3	806.2	107.7
31 12	61.3	244.3	4.8	0.0	0.0	0.0	0.0	0.0	15.5	15.6	0.0	412.8	0.0	412.8	50.6	60.2	7.4	196.7	24.1	171.5	21.0	815.6	103.1
Mean	**61.8**	**265.8**	**5.0**	**3.6**	**0.0**	**0.0**	**0.0**	**0.0**	**15.0**	**15.4**	0.0	403.9	0.0	**403.9**	49.2	**63.3**	**7.7**	**194.4**	**23.7**	**185.6**	**22.6**	**821.6**	**103.1**

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
21 12	754.0	4818.2	34.3	32.3	929.8	433.2	4.3	0.0	548.2	2505.4	5717.4	57.0	1075.3	10.7	3180.0	31.7	10028.0	103.8
22 12	774.1	4919.0	40.3	34.3	923.3	509.6	4.9	0.0	516.7	2361.3	5804.1	56.4	1060.5	10.3	3246.6	31.5	10296.1	103.2
23 12	725.8	4798.1	38.3	32.3	872.9	484.2	5.0	0.0	598.5	2735.1	4984.6	51.6	1141.1	11.8	3166.7	32.8	9652.6	101.3
24 12	729.8	4818.2	42.3	40.3	889.0	535.1	5.5	0.0	592.5	2707.8	5154.2	53.1	1147.6	11.8	3180.0	32.8	9706.2	103.2
26 12	725.8	4798.1	46.4	40.3	864.0	586.1	6.1	0.0	620.8	2837.3	4804.0	49.8	1186.8	12.3	3166.7	32.8	9652.6	100.9
27 12	754.0	4919.0	52.4	52.4	809.3	662.5	6.6	0.0	617.7	2822.7	4334.6	43.2	1195.5	11.9	3246.6	32.4	10028.0	94.1
29 12	697.5	4515.8	36.3	32.3	881.3	458.7	4.9	0.0	636.4	2908.4	4885.7	52.7	1213.4	13.1	2980.5	32.1	9277.2	102.8
30 12	733.8	4556.2	44.4	36.3	864.2	560.6	5.7	0.0	633.2	2893.8	4749.6	48.7	1207.3	12.4	3007.1	30.8	9759.9	97.6
31 12	709.6	4596.5	50.4	38.3	883.7	637.1	6.7	0.0	617.7	2822.7	4992.6	52.9	1180.7	12.5	3033.7	32.1	9438.1	104.3
Mean	**733.8**	**4748.8**	**42.8**	**37.6**	**879.7**	**540.8**	**5.5**	0.0	598.0	**2732.7**	5047.4	**51.7**	1155.2	**11.8**	**3134.2**	**32.1**	**9759.9**	**101.2**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
21 12	0.04278	0.14001	1.36977	0.08527	0.27995
22 12	0.04427	0.13074	1.43924	0.08159	0.29593
23 12	0.04444	0.14753	1.4329	0.08149	0.2776
24 12	0.05525	0.15627	1.39787	0.08303	0.26403
26 12	0.05556	0.15413	1.35858	0.0746	0.26246
27 12	0.06952	0.14394	1.42382	0.07741	0.2765
29 12	0.04624	0.14832	1.36196	0.07851	0.27008
30 12	0.04945	0.13671	1.33645	0.07603	0.27929
31 12	0.05398	0.14632	1.36554	0.07319	0.27122
Mean	**0.05128**	**0.14481**	**1.38727**	**0.07935**	**0.27521**

Table E14(a): All the expeperimental results of sewage batch No.12 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	0.99

< Sewage Batch 12 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
07 01	29.2	29.6	82.32	18.6	18.6	260.4	2.8	3.92	2.2	3.08	24.1	67.48	1.7	2.38	1.02	0	0.24	1.9	21.21	21.64
09 01	29.5	29.2	82.18	18.1	18.8	258.3	3.1	4.34	2.7	3.78	23.7	66.36	1.9	2.66	0.42	0	0.24	0.11	20.2	21.3
10 01	29.3	28.7	81.2	18.1	18.7	257.6	2.3	3.22	2.1	2.94	23.4	65.52	1.9	2.66	0.77	0	0.24	0.26	21.04	21.3
11 01	29.4	28.4	80.92	19.5	18.9	268.8	3	4.2	2.6	3.64	23.6	66.08	1.7	2.38	0.59	0	0.24	0.06	20.54	21.64
12 01	30.9	30.9	86.52	19.2	19.2	268.8	4	5.6	3.5	4.9	25.4	71.12	2.4	3.36	1.05	0	0.22	1.03	21.71	21.33
13 01	31.1	31.1	87.08	20.2	20.1	282.1	3.8	5.32	3.5	4.9	26.1	73.08	2.9	4.06	0.81	0	0.22	0.48	21.04	21.33
14 01	29.7	29.2	82.46	20	20.2	281.4			2.7	3.78	24.7	69.16	2.3	3.22	1.1	0	0.24	0.94	20.2	20.8
15 01	29.8	30.8	84.84	20.1	20.1	281.4	2.4	3.36			25.4	71.12	2.3	3.22	0.7	0	0.24	0.58	23.05	23.65
Mean			83.44			269.85		4.28		3.86		68.74		2.9925	0.8075	0	0.235	0.67	21.12375	21.6237
SSD			2.232331			9.948869		0.839524		0.724983		2.622899		0.541935	0.223593	0	0.00866	0.571555	0.874856	0.803662
No.			8			8		7		7		8		8	8	8	8	8	8	8

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0496	23.9	23.8	14.7	14.3	742.016	11.7	11.7	4821.12	23	22.8	37.696	23.1	22.8	35.712	37.39	1	136
0.0496	23.7	23.5	14.3	14	749.952	11.4	11.4	4840.96	22.4	22.4	47.616	22.5	22.5	43.648	37.1	0.87	149
0.0496	23.6	23.6	14.5	14.8	710.272	11.8	12	4642.56	22.8	22.6	35.712	22.9	22.8	29.76	37.85	1.05	144
0.0496	23.5	23.3	13.9	14	749.952	11.3	11.4	4781.44	22.7	22.6	29.76	22.7	22.5	31.744	38.04	0.77	134
0.0496	23.9	23.7	13.9	14	781.696	11.8	11.8	4761.6	23.2	23	27.776	23.2	23.1	25.792	39.24	0.95	134
0.0496	23.2	23.2	13	13.4	793.6	10.5	10.7	4999.68	22.2	22.1	41.664	22.4	22	39.68	38.31	0.42	116
0.05	23.4	23.4	14.5	14.3	720	11.4	11.3	4820	22.4	22.5	38	22.5	22.5	36	38.34	0.43	141
0.05	23.3	23.4	13.7	14.3	748	11.2	11.2	4860	22.3	22.4	40	22.4	22.3	40	39.52	1.06	128
					749.436			4815.92			37.278			35.292	38.22375		
					26.09865			93.92463			5.952701			5.538068	0.779855		
					8			8			8			8	8		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.4848	43.7187	43.5382	4678	3610	58.1694	58.3937	58.2207	4486	3460	7.74	7.7	130	115.9162
43.3128	43.5189	43.3596	4122	3186	42.4014	42.6258	42.4527	4488	3462	7.85	7.7	130	115.8645
43.4866	43.6993	43.5347	4254	3292	58.1719	58.3939	58.222	4440	3438	7.83	7.72	145	130.6306
43.3148	43.5194	43.3561	4092	3266	42.4027	42.622	42.4484	4386	3472	7.82	7.65	145	132.2389
56.4803	56.6795	56.5233	3984	3124	58.1734	58.394	58.2216	4412	3448	7.77	7.65	140	126.9266
43.3153	43.5189	43.3602	4072	3174	42.4034	42.6273	42.454	4478	3466	7.76	7.67	140	125.0558
43.4918	43.6946	43.5353	4056	3186	58.1744	58.3977	58.2227	4466	3500	7.73	7.64	150	134.3484
43.3194	43.5344	43.3659	4300	3370	42.4054	42.6309	42.4548	4510	3522	7.75	7.6	150	133.0377
			4194.75	3276				4458.25	3471	7.78125	7.66625		126.7523
			206.9733	145.9692				39.48971	25.70992	0.042555	0.036721		6.903126
			8	8				8	8	8	8		8

Table E14(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.12 for 20 days sludge age parent system.

< Sewage Batch 12 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
07 01	82.3	260.4	3.9	3.1	1.0	0.0	0.2	1.9	21.2	21.6	-40.7	494.1	0.0	453.4	41.4	49.5	4.5	276.6	25.3	186.3	17.0	1094.9	88.2
09 01	82.2	258.3	4.3	3.8	0.4	0.0	0.2	0.1	20.2	21.3	-16.8	547.6	0.0	530.8	48.6	54.9	5.0	272.3	24.9	184.7	16.9	1093.0	95.4
10 01	81.2	257.6	3.2	2.9	0.8	0.0	0.2	0.3	21.0	21.3	-30.7	552.7	0.0	522.0	48.3	40.7	3.8	272.3	25.2	184.2	17.1	1080.0	94.4
11 01	80.9	268.8	4.2	3.6	0.6	0.0	0.2	0.1	20.5	21.6	-23.5	558.6	0.0	535.1	49.7	53.1	4.9	276.6	25.7	191.8	17.8	1076.2	98.2
12 01	86.5	268.8	5.6	4.9	1.1	0.0	0.2	1.0	21.7	21.3	-41.9	531.3	5.1	489.4	43.0	70.8	6.2	272.4	23.7	191.6	16.7	1150.7	89.4
13 01	87.1	282.1	5.3	4.9	0.8	0.0	0.2	0.5	21.0	21.3	-32.3	544.4	0.0	512.1	44.2	67.2	5.8	272.4	23.5	200.4	17.3	1158.2	90.8
14 01	82.5	281.4	0.0	3.8	1.1	0.0	0.2	0.9	20.2	20.8	-43.9	507.8	0.0	463.9	42.3	0.0	0.0	265.9	24.2	199.6	18.2	1096.7	84.7
15 01	84.8	281.4	3.4	0.0	0.7	0.0	0.2	0.6	23.1	23.7	-27.9	598.0	0.0	570.0	50.5	42.5	3.8	302.0	26.8	201.5	17.9	1128.4	98.9
Mean	83.4	269.9	4.3	3.9	0.8	0.0	0.2	0.7	21.1	21.6	-32.2	541.8	0.0	509.6	45.9	54.1	4.9	276.3	24.9	192.5	17.3	1109.8	93.0

Date	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
07 01	742.0	4821.1	37.7	35.7	897.4	476.5	4.8	-40.7	770.5	3381.4	4554.8	46.2	1343.5	13.6	3181.9	32.2	9868.8	96.8
09 01	750.0	4841.0	47.6	43.6	890.4	601.9	6.0	-16.8	801.6	3605.8	4268.9	42.8	1537.4	15.4	3195.0	32.0	9974.4	96.3
10 01	710.3	4642.6	35.7	29.8	908.4	451.4	4.8	-30.7	829.1	3683.7	4350.2	46.1	1528.3	16.2	3064.1	32.4	9446.6	99.4
11 01	750.0	4781.4	29.8	31.7	913.0	376.2	3.8	-23.5	817.2	3653.6	4420.6	44.3	1557.3	15.6	3155.8	31.6	9974.4	95.3
12 01	781.7	4761.6	27.8	25.8	941.8	351.1	3.4	-41.9	825.1	3627.2	4701.8	45.2	1462.4	14.1	3142.7	30.2	10396.6	92.9
13 01	793.6	4999.7	41.7	39.7	919.4	526.6	5.0	-32.3	820.3	3638.1	4493.4	42.6	1501.6	14.2	3299.8	31.3	10554.9	93.1
14 01	720.0	4820.0	38.0	36.0	920.2	480.3	5.0	-43.9	768.5	3361.4	4776.5	49.9	1377.2	14.4	3181.2	33.2	9576.0	102.5
15 01	748.0	4860.0	40.0	40.0	948.5	505.6	5.1	-27.9	896.6	4001.4	4386.9	44.1	1662.4	16.7	3207.6	32.2	9948.4	98.1
Mean	**749.4**	**4815.9**	**37.3**	**35.3**	**917.4**	**471.2**	**4.7**	**-32.2**	**816.1**	**3619.1**	4494.1	**45.1**	1494.5	**15.0**	3178.5	31.9	9967.5	96.7

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
07 01	0.04813	0.15755	1.38307	0.07615	0.26258
09 01	0.0582	0.14016	1.38571	0.0757	0.27884
10 01	0.0419	0.15362	1.34171	0.07578	0.26354
11 01	0.04233	0.13751	1.368	0.07847	0.28251
12 01	0.03299	0.11293	1.37349	0.07938	0.31242
13 01	0.05	0.12116	1.43104	0.0828	0.3052
14 01	0.05	0.15464	1.36686	0.08148	0.26362
15 01	0.05040	0.1493	1.36834	0.0799	0.26854
Mean	**0.04709**	0.14053	**1.37731**	0.07886	0.27942

Table E15(a): All the expeperimental results of sewage batch No.13 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	13.30	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	0.99

< Sewage Batch 13 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
01 02	23	23	64.4	22	20.2	295.4	3.9	5.46	2	2.8	19.5	54.6	1.8	2.52	0	0	0.53	0	14.72	14.38
02 02	22.7	23.9	65.24	19	18.5	262.5	3.2	4.48	2.9	4.06	19.3	54.04	2.6	3.64	0	0	1	0	15.2	12.03
04 02	23.5	23.5	65.8	17.8	17.9	249.9	3	4.2	2.1	2.94	18.9	52.92	1.7	2.38	0	0	0.77	0	15.39	10.91
Mean			65.14667			269.2667		4.713333		3.266667		53.85333		2.846667	0	0	0.766667	0	15.10333	12.44
SSD			0.575345			19.18165		0.540206		0.563875		0.698443		0.563875	0	0	0.191891	0	0.281938	1.445982
No.			3			3		3		3		3		3	3	3	3	3	3	3

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0499	23.5	23.6	13.9	13.7	778.44	11.9	12	4630.72	22.9	22.9	25.948	22.9	22.9	25.948	31.76	0.76	137
0.0499	23.4	23.4	14	14	750.496	12.1	12.1	4510.96	22.8	22.5	29.94	22.8	22.7	25.948	33.65	0.67	141
0.0499	23.5	23.4	13.9	14	758.48	12.4	12.4	4411.16	22.9	22.8	23.952	22.8	22.9	23.952	33.12	0.64	144

					762.472			4517.613			26.61333			25.28267	32.84333		
					11.75213			89.75837			2.489449			0.940923	0.796004		
					3			3			3			3	3		
TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI					
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)				
43.3206	43.5266	43.3573	4120	3386	42.4054	42.5951	42.4394	3794	3114	7.73	7.62	160	168.6874				
43.4922	43.6866	43.5268	3888	3196	58.1758	58.3777	58.2099	4038	3356	7.74	7.7	160	158.4943				
43.3235	43.5216	43.3569	3962	3294	42.4077	42.6086	42.4427	4018	3318	7.77	7.7	160	159.2832				

			3990	3292				3950	3262.667	7.746667	7.673333		162.155				
			96.76087	77.58007				110.6104	106.2617	0.016997	0.037712		4.630336				
			3	3				3	3	3	3		3				

Table E15(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.13 for 20 days sludge age parent system.

< Sewage Batch 13 - N/COD Mass Balance >

Note) Change Nitrate conc. in s-recycle from NO3,eff to NO3,ae

Date	Conc. (mgN/l)										Mass (mgN/d)												Nba
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
01 02	64.4	295.4	5.5	2.8	0.0	0.0	0.5	0.0	14.7	14.4	0.0	391.6	4.5	391.6	46.2	69.0	8.1	188.5	22.0	204.8	23.9	856.5	100.
02 02	65.2	262.5	4.5	4.1	0.0	0.0	1.0	0.0	15.2	12.0	0.0	404.3	42.2	404.3	51.5	56.6	6.5	164.7	19.0	181.8	21.0	867.7	97.9
04 02	65.8	249.9	4.2	2.9	0.0	0.0	0.8	0.0	15.4	10.9	0.0	409.4	59.6	409.4	53.6	53.1	6.1	147.6	16.9	172.6	19.7	875.1	96.2
Mean	**65.1**	**269.3**	**4.7**	**3.3**	**0.0**	**0.0**	**0.8**	**0.0**	**15.1**	**12.4**	0.0	401.7	35.4	**401.7**	50.5	**59.6**	**6.9**	**166.9**	**19.3**	**186.4**	**21.5**	**866.5**	98.1

Date	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
01 02	778.4	4630.7	25.9	25.9	762.2	328.0	3.2	0.0	587.3	2684.1	4057.2	39.2	1132.8	10.9	3056.3	29.5	10353.3	82.8
02 02	750.5	4511.0	29.9	25.9	807.6	378.4	3.8	0.0	606.5	2771.6	4370.8	43.8	1276.9	12.8	2977.2	29.8	9981.6	90.2
04 02	758.5	4411.2	24.0	24.0	794.9	302.8	3.0	0.0	614.1	2806.3	4223.7	41.9	1341.2	13.3	2911.4	28.9	10087.8	87.0
Mean	**762.5**	**4517.6**	**26.6**	**25.3**	**788.2**	**336.4**	**3.3**	**0.0**	**602.6**	**2754.0**	4217.2	**41.6**	1250.3	**12.3**	**2981.6**	**29.4**	**10140.9**	**86.6**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
01 02	0.03333	0.10919	1.47873	0.09576	0.32575
02 02	0.03457	0.1201	1.33642	0.07943	0.30028
04 02	0.03158	0.11469	1.32224	0.0762	0.30586
Mean	**0.03316**	**0.11485**	**1.37689**	**0.08353**	**0.31038**

Table E16(a): All the expeperimental results of sewage batch No.14 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	10.00	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	1.32

< Sewage Batch 14 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg
16 02	19.6	20	55.44	15.1	14.6	207.9	2.7	3.78	2.6	3.64	16.7	46.76	2.1	2.94	0	0	0	0	12.09	12.52
17 02	20.6	21.1	58.38	14	14.2	197.4	2.9	4.06	2.9	4.06	15.6	43.68	2.1	2.94	0	0	0	0	12.09	12.61
18 02	20.8	21	58.52	14.3	13.8	196.7	2.4	3.36	2.2	3.08	15.9	44.52	2.1	2.94	0	0	0	0	11.91	12.26
19 02	21.6	22	61.04	14.5	14.1	200.2	3	4.2	2.3	3.22	17.1	47.88	2.3	3.22	0	0	0	0	12.44	11.39
20 02	20.9	21.3	59.08	13.9	14.4	198.1	2.3	3.22	2.1	2.94	17.1	47.88	1.7	2.38	0	0	0	0	12.17	12.87
21 02	20.7	21.5	59.08	14.5	14.4	202.3	2.4	3.36	2.4	3.36	17.1	47.88	2.1	2.94	0	0	0	0	12.7	13.92
22 02	21.9	22.1	61.6	14.3	14.5	201.6	3.2	4.48	3.2	4.48	17.4	48.72	1.8	2.52	0	0	0	0	14.09	15.23
23 02	21.7	20.8	59.5	13.7	14.4	196.7	2.9	4.06	2.6	3.64	18.2	50.96	2.3	3.22	0	0	0	0	14.88	15.67
24 02	21.8	21.1	60.06	14.6	14.9	206.5	2.9	4.06	2.9	4.06	17.3	48.44	1.6	2.24	0	0	0	0	13.31	13.92
Mean			59.18889			200.8222		3.842222		3.608889		47.41333		2.815556	0	0	0	0	12.85333	13.37666
SSD			1.675818			3.924504		0.412736		0.483975		2.074437		0.332903	0	0	0	0	0.975352	1.335697
No.			9			9		9		9		9		9	9	9	9	9	9	9

Normality	COD														OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.05	23.3	23.4	14.6	14.4	708	14.7	14.6	3480	22.6	22.9	24	22.7	22.8	24	23.71	0.54	125
0.05	23.7	23.7	15.1	14.5	712	15	15.2	3440	23.1	22.9	28	23.1	22.9	28	24.48	0.72	121
0.0504	23	23	14.5	14.6	681.408	14.5	14.5	3427.2	22.4	22.4	24.192	22.4	22.4	24.192	25.46	0.73	134
0.0504	23.3	23.1	13.8	13.8	758.016	14.5	14.6	3487.68	22.4	22.4	32.256	22.4	22.4	32.256	26.99	0.55	133
0.0504	23.4	23.1	13.5	14.5	745.92	14.6	14.7	3467.52	22.4	22.2	38.304	22.2	22.3	40.32	28.11	0.93	148
0.0504	23.3	23.3	14	14.3	737.856	14.6	14.7	3487.68	22.5	22.5	32.256	22.6	22.5	30.24	29.49	1.29	120
0.0504	23.3	23.4	14	14	753.984	14.7	14.6	3507.84	22.4	22.5	36.288	22.5	22.6	32.256	30.87	1.13	149
0.05	23.3	23.1	14.1	14.2	724	14.6	14.6	3440	22.3	22.3	36	22.4	22.3	34	31.35	1.38	146
0.05	23.2	23.4	14.3	14.2	724	14.6	14.5	3500	22.5	22.5	32	22.5	22.4	34	29.59	0.93	148
					727.2427			3470.88			31.47733			31.02933	27.78333		
					23.20931			27.26017			4.862152			4.864111	2.626011		
					9			9			9			9	9		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
43.327	43.4684	43.3536	2828	2296	42.407	42.5582	42.4358	3024	2448	7.9	7.86	110	145.5026
43.494	43.6392	43.5208	2904	2368	58.1782	58.3304	58.2075	3044	2458	7.8	7.78	115	151.117
43.329	43.4753	43.3556	2926	2394	42.4092	42.5603	42.4376	3022	2454	7.87	7.78	110	145.5989
43.4937	43.633	43.5189	2786	2282	58.179	58.329	58.2065	3000	2450	7.78	7.74	110	146.6667
43.3292	43.4775	43.3556	2966	2438	42.4097	42.5633	42.4381	3072	2504	7.8	7.76	100	130.2083
43.495	43.6443	43.5206	2986	2474	58.1799	58.3336	58.2072	3074	2528	7.74	7.75	100	130.1236
43.3299	43.4773	43.3551	2948	2444	42.4106	42.5649	42.4375	3086	2548	7.82	7.74	100	129.6176
43.4971	43.6381	43.5205	2820	2352	58.1824	58.3334	58.2085	3020	2498	7.82	7.78	100	132.4503
43.3322	43.4767	43.3561	2890	2412	42.4119	42.5675	42.4383	3112	2584	7.78	7.72	100	128.5347
			2894.889	2384.444				3050.444	2496.889	7.812222	7.767778		137.7578
			65.99065	62.2952				35.1097	46.14095	0.04565	0.038233		8.654307
			9	9				9	9	9	9		9

Table E16(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.14 for 20 days sludge age parent system.

< Sewage Batch 14 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)											Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
16 02	55.4	207.9	3.8	3.6	0.0	0.0	0.0	0.0	12.1	12.5	0.0	246.1	0.0	246.1	44.4	35.3	6.4	116.9	21.1	145.5	26.2	554.4	98.1
17 02	58.4	197.4	4.1	4.1	0.0	0.0	0.0	0.0	12.1	12.6	0.0	247.0	0.0	247.0	42.3	37.9	6.5	117.8	20.2	138.6	23.7	583.8	92.7
18 02	58.5	196.7	3.4	3.1	0.0	0.0	0.0	0.0	11.9	12.3	0.0	241.7	0.0	241.7	41.3	31.4	5.4	114.5	19.6	137.9	23.6	585.2	89.8
19 02	61.0	200.2	4.2	3.2	0.0	0.0	0.0	0.0	12.4	11.4	0.0	238.3	10.5	238.3	40.8	39.2	6.4	106.4	17.4	139.6	22.9	610.4	87.5
20 02	59.1	198.1	3.2	2.9	0.0	0.0	0.0	0.0	12.2	12.9	0.0	250.4	0.0	250.4	42.4	30.1	5.1	120.2	20.3	139.2	23.6	590.8	91.4
21 02	59.1	202.3	3.4	3.4	0.0	0.0	0.0	0.0	12.7	13.9	0.0	266.2	0.0	266.2	45.1	31.4	5.3	130.0	22.0	142.7	24.2	590.8	96.5
22 02	61.6	201.6	4.5	4.5	0.0	0.0	0.0	0.0	14.1	15.2	0.0	293.2	0.0	293.2	47.6	41.8	6.8	142.2	23.1	143.1	23.2	616.0	100.7
23 02	59.5	196.7	4.1	3.6	0.0	0.0	0.0	0.0	14.9	15.7	0.0	305.5	0.0	305.5	51.3	37.9	6.4	146.4	24.6	140.2	23.6	595.0	105.9
24 02	60.1	206.5	4.1	4.1	0.0	0.0	0.0	0.0	13.3	13.9	0.0	272.3	0.0	272.3	45.3	37.9	6.3	130.0	21.6	145.5	24.2	600.6	97.5
Mean	**59.2**	**200.8**	**3.8**	**3.6**	**0.0**	**0.0**	**0.0**	**0.0**	**12.9**	**13.4**	**0.0**	**262.3**	**0.0**	**262.3**	**44.3**	**35.9**	**6.1**	**124.9**	**21.1**	**141.4**	**23.9**	**591.9**	**95.4**

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
16 02	708.0	3480.0	24.0	24.0	569.0	224.2	3.2	0.0	362.7	1657.5	3375.1	47.7	703.8	9.9	2296.8	32.4	7080.0	93.2
17 02	712.0	3440.0	28.0	28.0	587.5	261.5	3.7	0.0	362.7	1657.5	3538.5	49.7	706.4	9.9	2270.4	31.9	7120.0	95.2
18 02	681.4	3427.2	24.2	24.2	611.0	226.0	3.3	0.0	357.3	1632.9	3771.2	55.3	691.3	10.1	2262.0	33.2	6814.1	102.0
19 02	758.0	3487.7	32.3	32.3	647.8	301.3	4.0	0.0	373.2	1705.5	4023.3	53.1	711.6	9.4	2301.9	30.4	7580.2	96.8
20 02	745.9	3467.5	38.3	40.3	674.6	357.8	4.8	0.0	365.1	1668.5	4298.0	57.6	716.1	9.6	2288.6	30.7	7459.2	102.7
21 02	737.9	3487.7	32.3	30.2	707.8	301.3	4.1	0.0	381.0	1741.2	4518.3	61.2	761.3	10.3	2301.9	31.2	7378.6	106.8
22 02	754.0	3507.8	36.3	32.3	740.9	338.9	4.5	0.0	422.7	1931.7	4620.6	61.3	838.6	11.1	2315.2	30.7	7539.8	107.6
23 02	724.0	3440.0	36.0	34.0	752.4	336.2	4.6	0.0	446.4	2040.0	4614.2	63.7	873.7	12.1	2270.4	31.4	7240.0	111.8
24 02	724.0	3500.0	32.0	34.0	710.2	298.9	4.1	0.0	399.3	1824.8	4455.9	61.5	778.8	10.8	2310.0	31.9	7240.0	108.3
Mean	**727.2**	**3470.9**	**31.5**	**31.0**	**666.8**	**294.0**	**4.0**	**0.0**	**385.6**	**1762.2**	**4135.0**	**56.9**	**750.2**	**10.3**	**2290.8**	**31.5**	**7272.4**	**102.7**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	f_{av}
16 02	0.034	0.138	1.412	0.086	0.288
17 02	0.039	0.139	1.388	0.082	0.283
18 02	0.036	0.157	1.387	0.081	0.266
19 02	0.043	0.113	1.410	0.083	0.314
20 02	0.054	0.131	1.369	0.080	0.288
21 02	0.041	0.136	1.368	0.081	0.284
22 02	0.043	0.128	1.364	0.081	0.292
23 02	0.047	0.135	1.363	0.080	0.284
24 02	0.047	0.144	1.341	0.081	0.272
Mean	**0.043**	**0.135**	**1.378**	**0.082**	**0.286**

Table E17(a): All the expeperimental results of sewage batch No.10 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	10.00	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	1.32

< Sewage Batch 15 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg
18 03	23.5	24.1	66.64	13.8	13.8	193.2	2.3	3.22	1.7	2.38	19.5	54.6	1.7	2.38	0.3	0	0	0.05	20.46	20.33
19 03	23.3	23.5	65.52	14.2	14.2	198.8	1.9	2.66	1.5	2.1	16.8	47.04	0.7	0.98	0.18	0	0	0.11	20.46	20.87
20 03	23.6	24	66.64	13.6	13.7	191.1	2	2.8	1.8	2.52	18.9	52.92	1	1.4	0.14	0	0	0.05	20.73	20.6
23 03	23.6	23.9	66.5	12.9	12.9	180.6	1.8	2.52	1.2	1.68	19.1	53.48	0.6	0.84	0.05	0	0	0.03	20.73	21.14
25 03	23	24	65.8	13.7	13	186.9	1.8	2.52	1.4	1.96	18.5	51.8	0.8	1.12	0.4	0	0	0.11	20.6	21.27
26 03	22.3	24.5	65.52	13.9	13.7	193.2	2.5	3.5	2	2.8	18.2	50.96	1.2	1.68	0.36	0	0	0.15	21.41	19.78
Mean			66.10333			190.6333		2.87		2.24		51.8		1.4	0.238333	0	0	0.083333	20.73167	20.665
SSD			0.500988			5.696393		0.368194		0.370405		2.424871		0.517558	0.124689	0	0	0.042687	0.32277	0.505527
No.			6			6		6		6		6		6	6	6	6	6	6	6

Normality	COD													OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0506	22.7	22.9	13.2	13	785.312	14.6	14.6	3319.36	22.1	22	30.36	22	21.8	36.432	27.7	0.88	138
0.0506	23	23.1	13.5	13.5	773.168	14.6	14.4	3461.04	22.1	22.2	36.432	22.1	22.2	36.432	29.91	0.95	140
0.0506	23.1	23.2	13.8	13.8	756.976	14.5	14.7	3461.04	22.5	22.3	30.36	22.4	22.5	28.336	30.39	0.56	145
0.0506	23	22.8	13.7	13.2	765.072	14.2	14.4	3481.28	22.1	22.1	32.384	22.2	22.3	26.312	32.89	0.83	132
0.0506	22.8	22.9	13.7	13.8	736.736	14.2	14.1	3521.76	22.1	22	32.384	22.2	22.2	26.312	32.94	0.79	147
0.0508	23	22.9	13.4	13.5	772.16	14.2	14	3596.64	22	21.8	42.672	22.1	22	36.576	34.45	0.67	145
					764.904			3473.52			34.09867			31.73333	31.38		
					15.2411			83.28931			4.335549			4.794614	2.266495		
					6			6			6			6	6		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI		
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)	
43.3336	43.4836	43.3576	3000	2520	42.4141	42.5642	42.4387	3002	2510	7.87	7.83	100	133.2445	2513.3
43.497	43.6433	43.5217	2926	2432	58.1831	58.3313	58.2085	2964	2456	7.87	7.78	100	134.9528	2448.1
43.3345	43.4741	43.3565	2792	2352	42.4149	42.565	42.4395	3002	2510	7.87	7.82	100	133.2445	2457.9
43.5004	43.6491	43.5218	2974	2546	58.1866	58.3387	58.2091	3042	2592	7.92	7.76	100	131.4924	2576.8
43.3369	43.4903	43,359	3068	2626	42.4175	42.567	42.4402	2990	2536	8.07	8.02	100	133.7793	2565.7
43.5018	43.6387	43.5206	2738	2362	58.1884	58.3388	58.2118	3008	2540	8.07	8	100	132.9787	2481.3
			2916.333	2473				3001.333	2524	7.945	7.868333		133.282	2507.17
			115.9622	99.65775				23.17086	40.9064	0.090139	0.103024		1.027623	49.84792
			6	6				6	6	6	6		6	

Table E17(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.15 for 20 days sludge age parent system.

< Sewage Batch 15 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
18 03	66.6	193.2	3.2	2.4	0.3	0.0	0.0	0.1	20.5	20.3	-9.0	406.4	1.3	397.4	59.8	30.1	4.5	189.9	28.5	140.9	21.1	666.4	114.0
19 03	65.5	198.8	2.7	2.1	0.2	0.0	0.0	0.1	20.5	20.9	-5.4	410.0	0.0	404.6	61.8	24.8	3.8	194.9	29.8	145.0	22.1	655.2	117.4
20 03	66.6	191.1	2.8	2.5	0.1	0.0	0.0	0.1	20.7	20.6	-4.2	411.8	1.3	407.6	61.4	26.2	3.9	192.4	28.9	139.7	21.0	666.4	115.1
23 03	66.5	180.6	2.5	1.7	0.1	0.0	0.0	0.0	20.7	21.1	-1.5	417.8	0.0	416.3	62.6	23.5	3.5	197.4	29.7	133.1	20.0	665.0	115.9
25 03	65.8	186.9	2.5	2.0	0.4	0.0	0.0	0.1	20.6	21.3	-12.0	415.4	0.0	403.4	61.3	23.5	3.6	198.7	30.2	137.4	20.9	658.0	116.0
26 03	65.5	193.2	3.5	2.8	0.4	0.0	0.0	0.2	21.4	19.8	-10.8	407.4	16.3	396.6	63.0	32.7	5.0	184.7	28.2	140.6	21.5	655.2	117.7
Mean	**66.1**	**190.6**	**2.9**	**2.2**	**0.2**	**0.0**	**0.0**	**0.1**	**20.7**	**20.7**	-7.2	411.5	0.7	**404.3**	61.3	**26.8**	**4.1**	**193.0**	**29.2**	**139.5**	**21.1**	**661.0**	**115.6**

Date	Conc. (mg/l)				OUR	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$	(mgO/l/d)	MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
18 03	785.3	3319.4	30.4	36.4	664.8	283.6	3.6	-9.0	612.3	2767.3	3112.2	39.6	1150.6	14.7	2190.8	27.9	7853.1	85.8
19 03	773.2	3461.0	36.4	36.4	717.8	340.3	4.4	-5.4	610.5	2771.5	3577.1	46.3	1163.4	15.0	2284.3	29.5	7731.7	95.3
20 03	757.0	3461.0	30.4	28.3	729.4	283.6	3.7	-4.2	620.4	2820.8	3629.6	47.9	1174.3	15.5	2284.3	30.2	7569.8	97.4
23 03	765.1	3481.3	32.4	26.3	789.4	302.5	4.0	-1.5	621.0	2832.8	4148.3	54.2	1192.3	15.6	2297.6	30.0	7650.7	103.8
25 03	736.7	3521.8	32.4	26.3	790.6	302.5	4.1	-12.0	614.7	2768.0	4223.7	57.3	1167.5	15.8	2324.4	31.5	7367.4	108.8
26 03	772.2	3596.6	42.7	36.6	826.8	398.6	5.2	-10.8	637.8	2877.7	4434.5	57.4	1193.3	15.5	2373.8	30.7	7721.6	108.8
Mean	**764.9**	**3473.5**	**34.1**	**31.7**	**753.1**	**318.5**	**4.2**	**-7.2**	**619.5**	**2806.4**	3854.2	**50.4**	1166.5	**15.2**	**2292.5**	**30.0**	**7649.0**	**99.8**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
18 03	0.046	0.108	1.308	0.078	0.311
19 03	0.047	0.113	1.394	0.082	0.312
20 03	0.037	0.117	1.368	0.077	0.306
23 03	0.034	0.126	1.333	0.070	0.293
25 03	0.036	0.145	1.378	0.074	0.277
26 03	0.047	0.120	1.402	0.077	0.305
Mean	0.041	0.121	1.364	0.076	0.300

Table E18(a): All the expeperimental results of sewage batch No.16 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	10.00	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	1.32

< Sewage Batch 16 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l
30 03	17.2	17	47.88	13.9	14.5	198.8	2.4	3.36	1.4	1.96	12.7	35.56	1.1	1.54	0	0	0	0	11.62	10.95
31 03	17.5	18.1	49.84	13.8	14	194.6	3.2	4.48	2.6	3.64	13.9	38.92	1.5	2.1	0	0	0	0	11.43	10.86
01 04	17.1	18.2	49.42	15.1	15.1	211.4	3.3	4.62	2.7	3.78	14.2	39.76	1.9	2.66	0	0	0	0	11.24	11.72
02 04	17.8	18.1	50.26	14.5	14.9	205.8	2.9	4.06	2.7	3.78	13.6	38.08	2.2	3.08	0	0	0	0	11.62	12.48
03 04	18.1	19.1	52.08	14.3	14.4	200.9	3.6	5.04	2.5	3.5	14.3	40.04	2.1	2.94	0	0	0	0	11.81	13.72
04 04	17.6	19.5	51.94	14.6	14.7	205.1	2.9	4.06	1.9	2.66	13.6	38.08	2.2	3.08	0	0	0	0	11.53	12.96
05 04	18.5	18.4	51.66	15.4	15	212.8	3.8	5.32	3.3	4.62	14.1	39.48	2.3	3.22	0	0	0	0	11.34	12.58
06 04	18.2	17.8	50.4	15.2	14.8	210	3.7	5.18	3.4	4.76	14.3	40.04	2.6	3.64	0	0	0	0	7.9	12.19
10 04	18.4	18.2	51.24	13.9	15.1	203	3.4	4.76	3.1	4.34	14.2	39.76	1.7	2.38	0	0	0	0	11.53	12.67
11 04	18.1	18.2	50.82	14.8	14.5	205.1	3.3	4.62	3	4.2	15.1	42.28	1.9	2.66	0	0	0	0	11.62	12.67
12 04	18.6	18.9	52.5	14.5	14.5	203	3.1	4.34	2.7	3.78	14.6	40.88	2.2	3.08	0	0	0	0	12.2	12.2
Mean			50.73090909			204.5909091		4.530909091		3.729090909		39.35272727		2.761818182	0	0	0	0	11.25818182	12.27272727
SSD			1.297308084			5.196406896		0.541470297		0.785799588		1.65160578		0.557099929	0	0	0	0	1.089034753	0.802440492
No.			11			11		11		11		11		11	11	11	11	11	11	11

Normality	COD													OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent					
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Mean	SSD	No.
0.0508	22.7	22.8	13.4	13.4	759.968	13.8	13.7	3657.6	21.9	21.7	38.608	21.9	22	32.512	31.52	0.5	93
0.0508	23.3	23.2	14	14	751.84	14.2	14	3718.56	22.2	22.1	44.704	22.1	22.2	44.704	32.2	1.24	129
0.0508	23.2	23.5	14	13.9	764.032	14.3	14.3	3677.92	22.5	22.4	36.576	22.4	22.4	38.608	31.48	0.84	140
0.0507	22.7	23	13.5	13.6	754.416	13.9	14	3609.84	22.2	21.8	34.476	22.4	22	26.364	32.14	1.13	147
0.0507	22.8	22.8	13.5	13.6	750.36	13.9	14	3589.56	21.9	22	34.476	22.1	22.1	28.392	34.35	0.95	147
0.0507	23	23	13.7	13.7	754.416	14	14	3650.4	22.1	22.1	36.504	22.3	22.1	32.448	33.82	1.13	148
0.0507	23	23.2	14.1	14.3	721.968	15	14.1	3467.88	21.5	21.4	66.924	21.8	22.1	46.644	33.12	0.66	142
0.0507	23	23.1	14.1	14	730.08	14	14.2	3630.12	22	22.1	40.56	22.3	22.2	32.448	33.64	0.7	149
0.0508	22.6	22.9	13.8	13.7	731.52	14	13.8	3596.64	22.2	21.7	32.512	22.3	22	24.384	24.98	0.75	119
0.0508	22.8	22.8	14.2	14.1	703.072	13.9	13.8	3637.28	22	21.9	34.544	22.2	21.7	34.544	24.57	0.54	113
0.0508	22.8	23	13.3	13.9	755.904	13.6	13.8	3738.88	22	21.9	38.608	22.2	22.1	30.48	26.14	0.63	119
					743.416			3634.061818			39.86290909			33.77527273	30.72363636		
					18.1487289			69.07249707			9.154356196			6.722201981	3.4934231		
					11			11			11			11	11		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI		
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)	
43.5038	43.6624	43.5282	3172	2684	58.1896	58.3461	58.2141	3130	2640	8.06	7.96	100	127.7955272	2654.5
43.3373	43.4837	43.3585	2928	2504	42.4189	42.5736	42.4427	3094	2618	8.02	7.93	105	135.7466063	2580.4
43.5045	43.6529	43.5282	2968	2494	58.1906	58.3457	58.2154	3102	2606	7.93	7.94	105	135.3965184	2569.0
43.3396	43.4842	43.3621	2892	2442	42.4205	42.5746	42.4453	3082	2586	7.9	7.9	100	129.7858533	2538.5
43.5053	43.6532	43.5282	2958	2500	58.1918	58.3516	58.2165	3196	2702	8.02	7.88	100	125.1564456	2635.3
43.3401	43.4863	43.3624	2924	2478	42.4213	42.5772	42.4458	3118	2628	8.02	7.93	100	128.2873637	2578.5
43.5058	43.6519	43.5291	2922	2456	58.19	58.343	58.2144	3060	2572	7.96	7.9	100	130.7189542	2533.7
43.341	43.4908	43.3659	2996	2498	42.4222	42.5732	42.4473	3020	2518	7.96	7.92	100	132.4503311	2511.4
43.3429	43.4932	43.3687	3006	2490	42.4225	42.5776	42.4491	3102	2570	7.98	7.97	100	128.9490651	2543.6
43.5082	43.6564	43.5334	2964	2460	58.1917	58.352	58.2192	3206	2656	7.99	7.95	100	124.7660636	2591.3
43.3455	43.4926	43.3714	2942	2424	42.4242	42.5833	42.4524	3182	2618	7.94	7.97	100	125.7071025	2554.0
			2970.181818	2493.636364				3117.454545	2610.363636	7.98	7.931818182		129.523621	2571.844
			71.35801947	65.17566853				55.11700552	46.7396517	0.045327094	0.028546034		3.623118092	41.24023
			11	11				11	11	11	11		11	

Table E18(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.16 for 20 days sludge age parent system.

< Sewage Batch 16 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
30 03	47.9	198.8	3.4	2.0	0.0	0.0	0.0	0.0	11.6	11.0	0.0	225.7	6.7	225.7	48.5	31.4	6.6	102.3	21.4	138.4	28.9	478.8	105.
31 03	49.8	194.6	4.5	3.6	0.0	0.0	0.0	0.0	11.4	10.9	0.0	222.9	5.7	222.9	45.9	41.8	8.4	101.4	20.4	135.6	27.2	498.4	101.
01 04	49.4	211.4	4.6	3.8	0.0	0.0	0.0	0.0	11.2	11.7	0.0	229.6	0.0	229.6	46.5	43.2	8.7	109.5	22.1	147.3	29.8	494.2	107.
02 04	50.3	205.8	4.1	3.8	0.0	0.0	0.0	0.0	11.6	12.5	0.0	241.0	0.0	241.0	48.0	37.9	7.5	116.6	23.2	144.1	28.7	502.6	107.
03 04	52.1	200.9	5.0	3.5	0.0	0.0	0.0	0.0	11.8	13.7	0.0	255.3	0.0	255.3	49.0	47.1	9.0	128.1	24.6	141.6	27.2	520.8	109.
04 04	51.9	205.1	4.1	2.7	0.0	0.0	0.0	0.0	11.5	13.0	0.0	244.9	0.0	244.9	47.2	37.9	7.3	121.0	23.3	143.9	27.7	519.4	105.
05 04	51.7	212.8	5.3	4.6	0.0	0.0	0.0	0.0	11.3	12.6	0.0	239.2	0.0	239.2	46.3	49.7	9.6	117.5	22.7	148.8	28.8	516.6	107.
06 04	50.4	210.0	5.2	4.8	0.0	0.0	0.0	0.0	7.9	12.2	0.0	200.9	0.0	200.9	39.9	48.4	9.6	113.9	22.6	146.6	29.1	504.0	101.
10 04	51.2	203.0	4.8	4.3	0.0	0.0	0.0	0.0	11.5	12.7	0.0	242.0	0.0	242.0	47.2	44.5	8.7	118.3	23.1	142.3	27.8	512.4	106.
11 04	50.8	205.1	4.6	4.2	0.0	0.0	0.0	0.0	11.6	12.7	0.0	242.9	0.0	242.9	47.8	43.2	8.5	118.3	23.3	143.7	28.3	508.2	107.
12 04	52.5	203.0	4.3	3.8	0.0	0.0	0.0	0.0	12.2	12.2	0.0	244.0	0.0	244.0	46.5	40.5	7.7	113.9	21.7	142.0	27.1	525.0	103.
Mean	50.7	204.6	4.5	3.7	0.0	0.0	0.0	0.0	11.3	12.3	0.0	235.3	0.0	235.3	46.4	42.3	8.3	114.6	22.6	143.1	28.2	507.3	105.

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
30 03	760.0	3657.6	38.6	32.5	756.5	360.6	4.7	0.0	348.6	1593.1	5097.2	67.1	664.7	8.7	2414.0	31.8	7599.7	112.3
31 03	751.8	3718.6	44.7	44.7	772.8	417.5	5.6	0.0	342.9	1567.1	5267.6	70.1	653.8	8.7	2454.2	32.6	7518.4	117.0
01 04	764.0	3677.9	36.6	38.6	755.5	341.6	4.5	0.0	337.2	1541.0	5140.8	67.3	656.7	8.6	2427.4	31.8	7640.3	112.1
02 04	754.4	3609.8	34.5	26.4	771.4	322.0	4.3	0.0	348.6	1593.1	5228.8	69.3	689.3	9.1	2382.5	31.6	7544.2	114.3
03 04	750.4	3589.6	34.5	28.4	824.4	322.0	4.3	0.0	354.3	1619.2	5671.8	75.6	730.2	9.7	2369.1	31.6	7503.6	121.2
04 04	754.4	3650.4	36.5	32.4	811.7	340.9	4.5	0.0	345.9	1580.8	5597.7	74.2	700.4	9.3	2409.3	31.9	7544.2	119.9
05 04	722.0	3467.9	66.9	46.6	794.9	625.1	8.7	0.0	340.2	1554.7	5475.2	75.8	684.1	9.5	2288.8	31.7	7219.7	125.7
06 04	730.1	3630.1	40.6	32.4	807.4	378.8	5.2	0.0	237.0	1083.1	6057.2	83.0	574.6	7.9	2395.9	32.8	7300.8	128.8
10 04	731.5	3596.6	32.5	24.4	599.5	303.7	4.2	0.0	345.9	1580.8	3721.4	50.9	692.1	9.5	2373.8	32.5	7315.2	96.9
11 04	703.1	3637.3	34.5	34.5	589.7	322.6	4.6	0.0	348.6	1593.1	3622.0	51.5	694.7	9.9	2400.6	34.1	7030.7	100.1
12 04	755.9	3738.9	38.6	30.5	627.4	360.6	4.8	0.0	366.0	1672.6	3875.8	51.3	697.8	9.2	2467.7	32.6	7559.0	97.9
Mean	743.4	3634.1	39.9	33.8	737.4	372.3	5.0	0.0	337.7	1543.5	4977.8	67.0	673.0	9.1	2398.5	32.3	7434.2	113.3

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
30 03	0.04278075	0.14746973	1.37313939	0.07604545	0.27252138
31 03	0.05945946	0.14894853	1.40330634	0.07572193	0.27113385
01 04	0.05053191	0.13748012	1.39651266	0.08257099	0.28387743
02 04	0.03494624	0.13224542	1.38572158	0.08104408	0.29095297
03 04	0.03783784	0.14090614	1.31797483	0.07564767	0.27488571
04 04	0.04301075	0.13938741	1.37669406	0.07905632	0.28120705
05 04	0.06460674	0.14904012	1.33018507	0.08453344	0.26340107
06 04	0.04444444	0.1491761	1.42878157	0.08528991	0.27557169
10 04	0.03333333	0.14539417	1.38998288	0.08067704	0.27765484
11 04	0.04913295	0.16860597	1.35645181	0.07880271	0.24950029
12 04	0.04032258	0.13911942	1.41650115	0.07898396	0.28549534
Mean	0.04543253	0.14514883	1.37922797	0.07980497	0.27504333

Table E19(a): All the expeperimental results of sewage batch No.17 for 20 days sludge age parent system.

< System Codition and Parameters >

	Rs	V	Q	T	a	s	Yh	f	bh	fcv	Qw	Rhn
Unit	day	l	l/day	°C	Recycle Ratio		mgVSS/mgCOD		day^{-1}	mgCOD/mgVSS	l	day
Value	20.00	13.20	10.00	20.00	1.00	1.00	0.45	0.20	0.24	1.48	0.66	1.32

< Sewage Batch 17 - Experimental Data >

Date	Influent			Mixed Liquor			Unfiltered Effluent		Filtered Effluent		FSA				NITRITE			NITRATE		
											Unfiltered Influent		Unfiltered Effluent		Anoxic	Aerobic	Effluent	Anoxic	Aerobic	Effluent
	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Tit.(ml)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/l)	Conc.(mg/
16 04	21.3	21.7	60.2	15.8	15.3	217.7	3	4.2	2.4	3.36	16.5	46.2	1.7	2.38	0	0	0	0	15.69	15.5
17 04	22.3	22.3	62.44	15	14.8	208.6	2.7	3.78	2.5	3.5	17.5	49	2.1	2.94	0	0	0	0	15.78	15.59
18 04	21.8	22.4	61.88	14.6	14.5	203.7	3	4.2	2.9	4.06	16.4	45.92	2.4	3.36	0	0	0	0	15.5	15.69
19 04	21.6	22.2	61.32	14.7	14.6	205.1	3.4	4.76	3.3	4.62	17.2	48.16	2.1	2.94	0	0	0	0	15.22	15.5
20 04	22.5	22.5	63	14.6	15.4	210	2.4	3.36	2.4	3.36	16.9	47.32	1.9	2.66	0	0	0	0	15.03	15.13
21 04	21.4	21.3	59.78	14.3	15.3	207.2	2.8	3.92	2.4	3.36	16.5	46.2	1.7	2.38	0	0	0	0	14.66	14.66
24 04	21.4	21.7	60.34	14.2	14.4	200.2	2.9	4.06	2.7	3.78	17.4	48.72	1.7	2.38	0.2	0	0	0.12	15.22	14.66
25 04	23.2	23.1	64.82	15.1	14.3	205.8	3.5	4.9	2.5	3.5	17.4	48.72	2.6	3.64	0.12	0	0	0.07	15.59	13.63
Mean			61.7225			207.2875		4.1475		3.6925		47.53		2.835	0.04	0	0	0.02375	15.33625	15.045
SSD			1.57839911			4.84263294		0.46924807		0.41963526		1.20228948		0.44685009	0.07211103	0	0	0.04299346	0.35202761	0.6550763
No.			8			8		8		8		8		8	8	8	8	8	8	8

Normality	COD													OUR		
	Blank		Influent			Mixed Liqour			Unfiltered Effluent			Filtered Effluent			Mean	SSD	No.
FSA	Tit.1(ml)	Tit.2(ml)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)	Tit.1(ml)	Tit.2(ml)	Conc.(mg/l)			
0.0508	23.1	23.1	13.4	13.7	776.224	13.8	13.7	3799.84	22.4	22.2	32.512	22.5	22.3	28.448	25.62	0.98	117
0.0504	23	22.8	13.2	13.9	753.984	13.7	13.7	3709.44	21.9	22.1	36.288	22.3	22.1	28.224	26.61	1.26	108
0.0504	22.8	23.1	13.7	13	774.144	13.7	13.8	3709.44	22.3	22	32.256	22.2	22.1	32.256	24.61	0.64	140
0.0504	23.3	23.6	13.8	13.6	786.24	14.3	13.9	3769.92	22.5	22.5	38.304	23	22.5	28.224	24.52	0.51	124
0.0504	23.2	23.3	13.4	13.5	790.272	13.7	13.8	3830.4	22.4	22.4	34.272	22.6	22.5	28.224	25.41	0.49	117
0.0504	23.2	23.5	13.9	13.7	770.112	13.7	13.8	3870.72	22.3	22.1	46.368	22.5	22.6	32.256	25.63	0.29	120
0.0504	23.2	23.3	13.6	13.6	778.176	14	13.9	3749.76	22.5	22.4	32.256	22.5	22.5	30.24	27.81	0.55	133
0.0505	22.8	22.6	13.4	13.4	751.44	13.4	13.4	3757.2	22	21.7	34.34	21.9	22.1	28.28	28.21	0.99	124
					772.574			3774.59			35.8245			29.519	26.0525		
					12.9684428			52.9422922			4.45229129			1.70350433	1.28754369		
					9			9			9			9	9		

TSS / VSS (Anoxic)					TSS / VSS (Aerobic)					pH		DSVI	
Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Blank	Dryer	Oven	TSS (mg/l)	VSS (mg/l)	Anoxic	Aerobic	500SET	DSVI (l/g)
51.4288	51.5793	51.4512	3010	2562	42.4235	42.5881	42.4496	3292	2770	7.96	7.96	100	121.506683
43.5102	43.6634	43.5356	3064	2556	58.1935	58.3553	58.2208	3236	2690	8	7.95	100	123.609394
43.3458	43.4947	43.37	2978	2494	42.4241	42.5841	42.451	3200	2662	7.9	7.88	100	125
43.5118	43.6639	43.5365	3042	2548	58.1958	58.3571	58.2226	3226	2690	7.89	7.84	100	123.99256
43.3473	43.5058	43.3727	3170	2662	42.4253	42.5869	42.4513	3232	2712	8.06	8.02	100	123.762376
43.5146	43.6776	43.539	3260	2772	58.1975	58.3661	58.2236	3372	2850	8	7.95	100	118.623962
43.5164	43.664	43.5398	2952	2484	58.2	58.3572	58.2256	3144	2632	7.92	7.88	95	120.86514
43.3506	43.5059	43.3758	3106	2602	42.4272	42.586	42.4534	3176	2652	7.9	7.85	90	113.350126
			3072.75	2585				3234.75	2707.25	7.95375	7.91625		121.33878
			96.2701278	88.3232699				66.2339603	66.7977357	0.05764926	0.05893588		3.58674551
			8	8				8	8	8	8		8

Table E19(b): The caculation of N and COD mass balances, wastewater fractions and active fraction of sewage batch No.17 for 20 days sludge age parent system.

< Sewage Batch 17 - N/COD Mass Balance >

Date	Conc. (mgN/l)										Mass (mgN/d)												Nbal
	$TKN_{(IN)}$	$TKN_{(AE)}$	$TKN_{(UE)}$	$TKN_{(FE)}$	$NO2_{(AN)}$	$NO2_{(AE)}$	$NO2_{(FE)}$	$NO3_{(AN)}$	$NO3_{(AE)}$	$NO3_{(FE)}$	MNO_{2d}	MNO_{3d}	MNd,sst	MNd,ax	%	MNte	%	MNne	%	MNw	%	MNti	%
16 04	60.2	217.7	4.2	3.4	0.0	0.0	0.0	0.0	15.7	15.5	0.0	311.9	1.9	311.9	52.1	39.2	6.5	144.8	24.0	153.9	25.6	602.0	108.3
17 04	62.4	208.6	3.8	3.5	0.0	0.0	0.0	0.0	15.8	15.6	0.0	313.7	1.9	313.7	50.5	35.3	5.7	145.6	23.3	148.0	23.7	624.4	103.2
18 04	61.9	203.7	4.2	4.1	0.0	0.0	0.0	0.0	15.5	15.7	0.0	311.9	0.0	311.9	50.4	39.2	6.3	146.5	23.7	144.8	23.4	618.8	103.8
19 04	61.3	205.1	4.8	4.6	0.0	0.0	0.0	0.0	15.2	15.5	0.0	307.2	0.0	307.2	50.1	44.5	7.3	144.8	23.6	145.6	23.7	613.2	104.7
20 04	63.0	210.0	3.4	3.4	0.0	0.0	0.0	0.0	15.0	15.1	0.0	301.6	0.0	301.6	47.9	31.4	5.0	141.3	22.4	148.6	23.6	630.0	98.9
21 04	59.8	207.2	3.9	3.4	0.0	0.0	0.0	0.0	14.7	14.7	0.0	293.2	0.0	293.2	49.0	36.6	6.1	136.9	22.9	146.4	24.5	597.8	102.6
24 04	60.3	200.2	4.1	3.8	0.2	0.0	0.0	0.1	15.2	14.7	-6.0	295.2	5.6	289.2	48.9	37.9	6.3	136.9	22.7	141.8	23.5	603.4	101.3
25 04	64.8	205.8	4.9	3.5	0.1	0.0	0.0	0.1	15.6	13.6	-3.6	290.1	19.6	286.5	47.2	45.8	7.1	127.3	19.6	144.8	22.3	648.2	96.3
Mean	**61.7**	**207.3**	**4.1**	**3.7**	**0.0**	**0.0**	**0.0**	**0.0**	**15.3**	**15.0**	-1.2	303.1	2.9	**301.9**	49.4	**38.7**	**6.3**	**140.5**	**22.8**	**146.7**	**23.8**	**617.2**	**102.2**

Date	Conc. (mg/l)				OUR (mgO/l/d)	Mass (mg/d)												COD bal
	$COD_{(IN)}$	$COD_{(ML)}$	$COD_{(UE)}$	$COD_{(FE)}$		MSte	%	MNO_{2g}	MNO_{3g}	MOn	MOc	%	MOd	%	MXsvw	%	MSti	%
16 04	776.2	3799.8	32.5	28.4	614.9	303.7	3.9	0.0	470.7	2151.1	3286.9	42.3	897.5	11.6	2507.9	32.3	7762.2	90.1
17 04	754.0	3709.4	36.3	28.2	638.6	338.9	4.5	0.0	473.4	2163.4	3484.7	46.2	902.6	12.0	2448.2	32.5	7539.8	95.2
18 04	774.1	3709.4	32.3	32.3	590.6	301.3	3.9	0.0	465.0	2125.1	3098.6	40.0	892.0	11.5	2448.2	31.6	7741.4	87.1
19 04	786.2	3769.9	38.3	28.2	588.5	357.8	4.6	0.0	456.6	2086.7	3117.9	39.7	878.6	11.2	2488.1	31.6	7862.4	87.0
20 04	790.3	3830.4	34.3	28.2	609.8	320.1	4.1	0.0	450.9	2060.6	3332.8	42.2	862.6	10.9	2528.1	32.0	7902.7	89.1
21 04	770.1	3870.7	46.4	32.3	615.1	433.1	5.6	0.0	439.8	2009.9	3430.2	44.5	838.6	10.9	2554.7	33.2	7701.1	94.2
24 04	778.2	3749.8	32.3	30.2	667.4	301.3	3.9	-6.0	453.0	2049.6	3853.2	49.5	850.0	10.9	2474.8	31.8	7781.8	96.1
25 04	751.4	3757.2	34.3	28.3	677.0	320.7	4.3	-3.6	465.6	2115.4	3872.3	51.5	879.6	11.7	2479.8	33.0	7514.4	100.5
Mean	**772.6**	**3774.6**	**35.8**	**29.5**	**625.3**	**334.6**	**4.3**	**-1.2**	**459.4**	**2095.2**	3434.6	**44.5**	873.1	**11.3**	**2491.2**	**32.2**	**7725.7**	**92.3**

Date					
	$f_{s,us}$	$f_{s,up}$	f_{cv}	f_N	fav
16 04	0.037	0.143	1.362	0.080	0.277
17 04	0.037	0.147	1.368	0.079	0.273
18 04	0.042	0.134	1.381	0.078	0.288
19 04	0.036	0.133	1.391	0.078	0.291
20 04	0.036	0.140	1.402	0.079	0.284
21 04	0.042	0.163	1.347	0.074	0.255
24 04	0.039	0.131	1.413	0.078	0.294
25 04	0.038	0.152	1.406	0.079	0.272
Mean	**0.038**	**0.143**	**1.383**	**0.078**	**0.279**

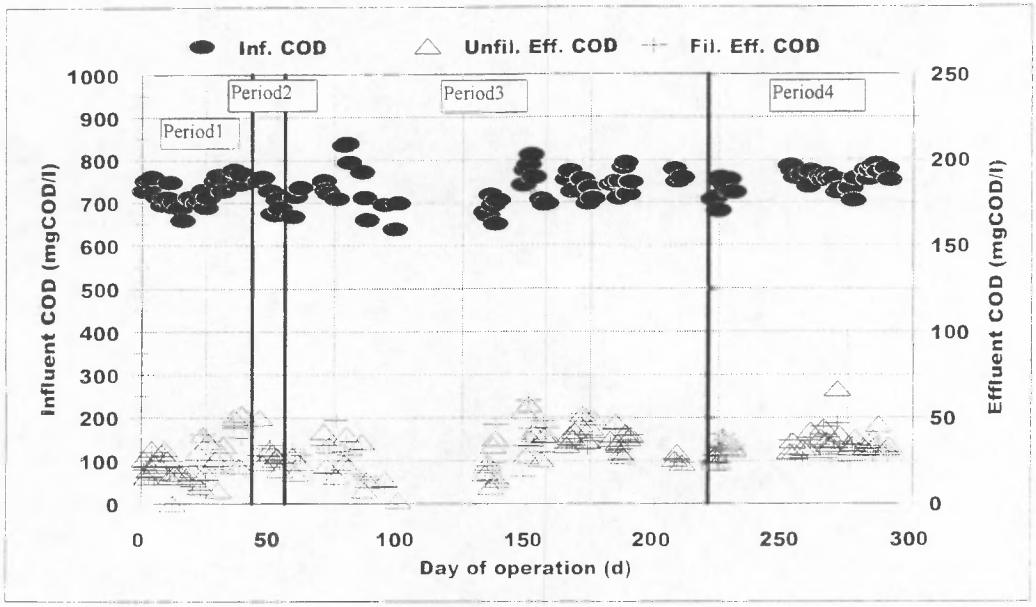


Fig. E1: Graphical representation of the daily influent, unfiltered effluent and filtered effluent COD concentrations for the 20 days sludge age parent MLE system

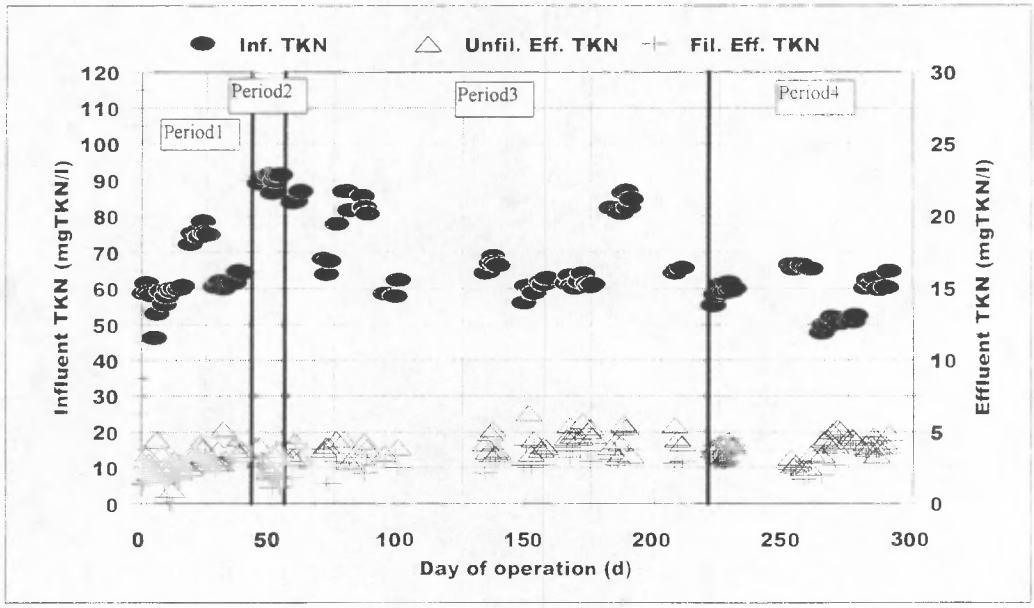


Fig. E2: Graphical representation of the daily influent, unfiltered effluent and filtered effluent TKN concentrations for the 20 days sludge age parent MLE system

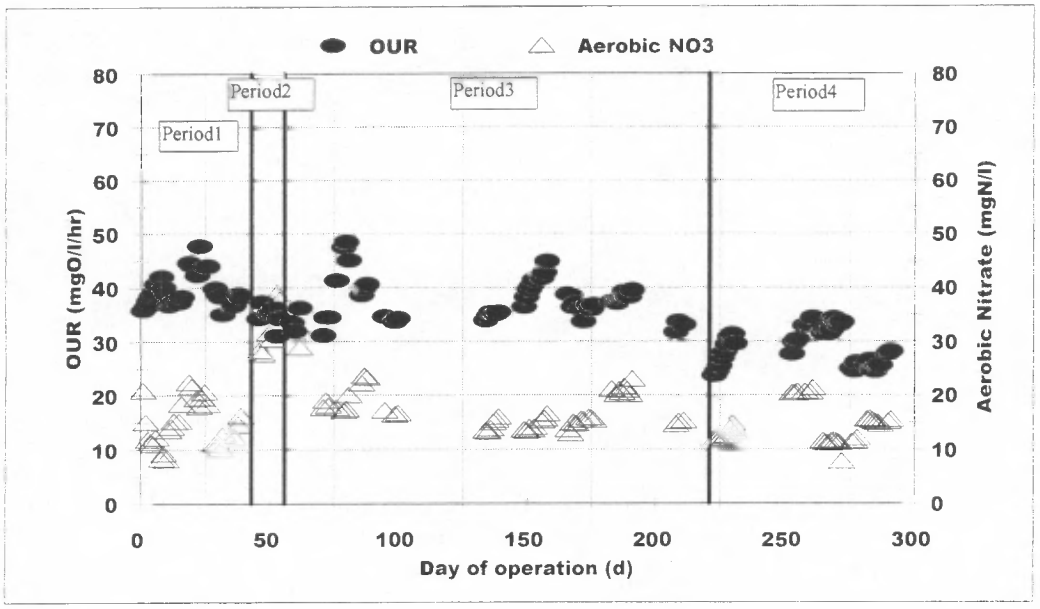


Fig. E3: Graphical representation of the daily Oxygen Utilization Rate (OUR) and nitrate (NO_3) concentrations for the aerobic reactor for the 20 days parent MLE system

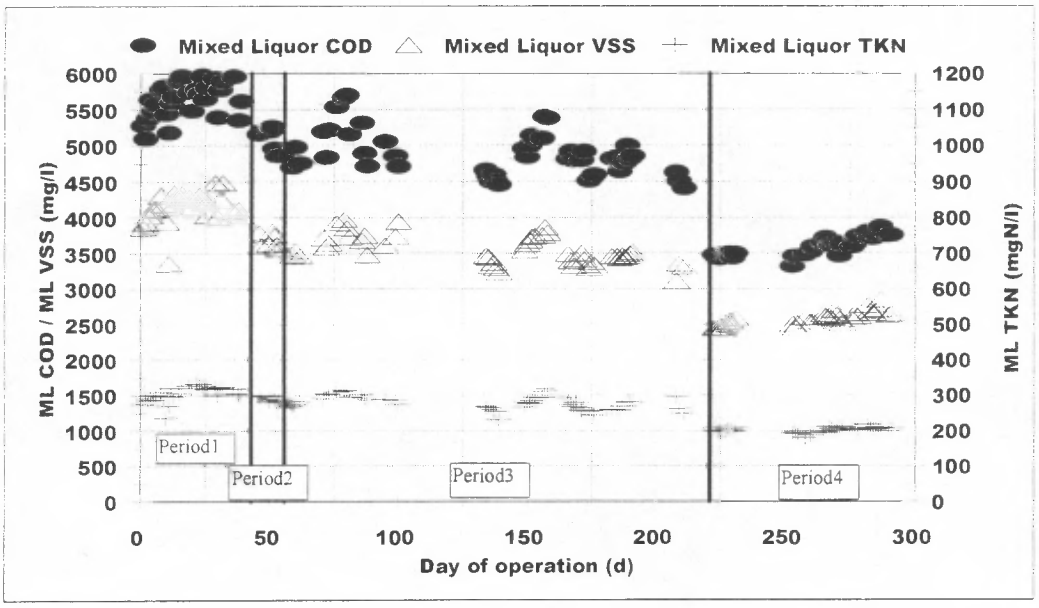


Fig. E4: Graphical representation of the daily mixed liquor COD, VSS and TKN concentrations for the 20 days sludge age parent MLE system

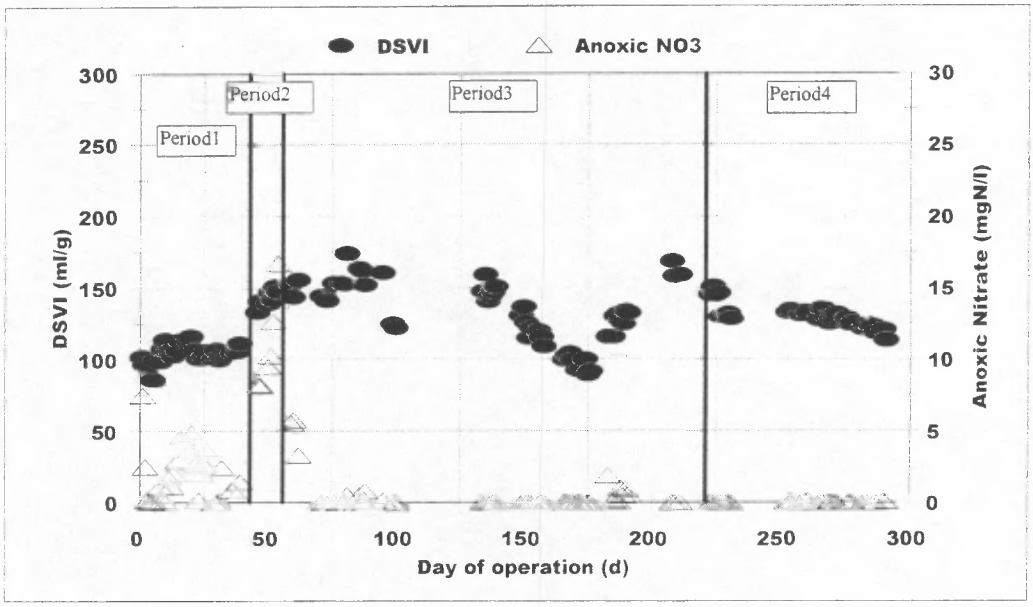


Fig. E5: Graphical representation of the daily Diluted Sludge Volume Index (DSVI) and anoxic nitrate (NO_3) concentration for the 20 days parent MLE system

APPENDIX F

CONSTRUCTION AND INTERPRETATION OF STATISTICAL PLOTS FOR DATA ANALYSIS

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F.5 ILLUSTRATION BY AN EXAMPLE

Fig. F1 Example of statistical probability plot for a number of heterotrophic active biomass (mgCOD/ℓ) derived from a batch test.

CONSTRUCTION AND INTERPRETATION OF STATISTICAL PLOT FOR DATA ANALYSIS

F.1 INTRODUCTION

Data from different tests could not be compared directly on a daily basis because of the variability in results from all the tests, due to variations in multitude of factors that influence the data. Therefore a graphical approach was used to evaluate the data (Velz, 1950), to interpret the trends and compare the results between two test methods.

For a particular batch of wastewater, the data obtained from the different test methods were statistically analysed using a graphical procedure, to determine the mean, sample standard deviation, and standard deviation of the mean for the data set. This information then could be used to evaluate whether the difference between the means from two data sets is statistically significant at a selected confidence level, or not.

F.2 CONSTRUCTION OF STATISTICAL PLOT

The experimental data is plotted using the procedure below:

- Arrange the data (n in number) in order of ascending magnitude.
- Assign a serial number "m" to each of the values (1, 2, 3, 4 .....n)
- Compute the y-axis plotting the position of each serial value, as the probability equal to or less than from the expression [m/(n + 1)]. The x-axis plotting position is the actual value for the data.
- The probability curve is linearized and plotted; for this investigation the transformed rank probability method (Scientific Tables, 1975) was used to linearize the probability curve, see Fig. F1. Alternatively, probability paper can be used on which the y-axis has been linearized.

F.3 INTERPRETATION OF THE STATISTICAL PLOT

The data plotted can give an indication of whether the data is normally distributed or not:

- If a straight line can be fitted to the plot it indicates that the data have a normal distribution.
- If a straight line can not be fitted to the plot, the data are not normally distributed.

If the data are normally distributed it indicates that a multitude of factors have each had an independent small influence on the measurements; if the data are not normally distributed it indicates that one factor has had a dominating influence.

From the above, provided a straight line can be fitted to he distribution (i.e. the data are normally distributed), it is possible to determine graphically (refer to Fig. F1):

- The mean of the data plotted - this is determined as the x-value where the straight line of the distribution intercepts a vertical line extended from y = 5.

- The standard deviation of the sample, which provides a measure of the variation of the data - this is the difference between the mean (i.e. the x-value that gives y = 5) and the x-value that gives y = 4 (or y = 6).

F.4 TEST FOR STATISTICAL SIGNIFICANCE OF THE DIFFERENCES BETWEEN TWO MEAN VALUES

Visual comparison of two data (or data sets) is a common method of appraisal, to determine whether they differ. However, observed differences or similarities may not be significant as these may arise solely by chance. Statistics defines the expected variations due to chance, to determine whether the observed differences between two data have arisen by chance alone or are significant. In the graphical method, by plotting of two or more series of data on the same probability plot, a quick visual appraisal of similarities and differences can be obtained. To test whether the visual differences in the two series of data are statistically significant, a mathematical significant test is done as follows:

- Plot the two or more distributions to test for normality as described above.

- If normal, obtain the mean (m) and the sample standard deviation (σ) of each series.

- Compute standard deviation of each mean:
  SD(mean) = $(\sigma/\sqrt{n})$
  where n = number of data points.

- Compute the standard deviation of the difference between the two means:
  SD(difference) = $\sqrt{\{(\text{SD mean1})^2 = (\text{SD mean2})^2\}}$

- Compute the absolute value (i.e. positive) of the difference between the two means.
  mean(difference) = $|\ \text{mean1} - \text{mean2}\ |$

- Decide upon a confidence level for the test for significance, 95% certainty or 99% or any other level desired.

- Apply the test for statistical significance of the difference.

For example, if 95% is selected as the confidence level, subtract from the difference between the two means [SD(difference)], i.e. [mean(difference) - 2 • SD(difference)] - if positive number is obtained it can be concluded that the difference between the two means is statistically significant at the selected level of confidence; if a negative value is obtained, then the difference between the two means was by chance alone, and it can be concluded that the apparent difference between the two means is **NOT** statistically significant.

F.5 ILLUSTRATION BY AN EXAMPLE

An example plot is given in Fig. F1.

The mean of a set of values from an experiment is read off from the statistical graph as the value of x that gives y = 5, in this case:

from the graph the mean = 18 mgCOD/ℓ

The standard deviation of a set of values is calculated from the difference between the x-value that gives y = 5 and the x-value that gives y = 6, OR, from the difference between the x-value that gives y = 5 and the x-value that gives y = 4, as shown in Fig. F1, i.e. from graph:

the x-value at y = 6 = 22,6 mgCOD/ℓ
the x-value at y = 4 = 13,4 mgCOD/ℓ
∴ the standard deviation (σ) = 22.6 - 18 **OR** 18 - 13.4 = 4.6 mgCOD/ℓ

The standard deviation of the mean is the standard deviation divided by the square root of the number of values in the data set. In this case:-

number data in set (n) = 12
∴ SD mean = $4.6/\sqrt{(12)}$ = 1.33 mgCOD/ℓ

Say a second set of 10 data is analysed as above to give:

mean = 16 mgCOD/ℓ
then standard deviation (σ) = 5.1 mgCOD/ℓ

Standard deviation of the mean is calculated:

SD mean = $5.1/\sqrt{(10)}$ = 1.61 mgCOD/ℓ

Now, comparing the data from the two sets:

SD(difference) $= \sqrt{\{1.33^2 + 1.61^2\}}$

$= 2.09$ mgCOD/ℓ

mean(difference) $= |18 - 16| = 2$ mgCOD/ℓ

Selecting a 95% confidence interval:

Test = mean(difference) – 2 • SD(difference)

= 2 – 2 • 2.09

= **-2.18**

Since the resultant value is negative, it can be concluded that the two means are not significantly different at the 95% confidence interval.

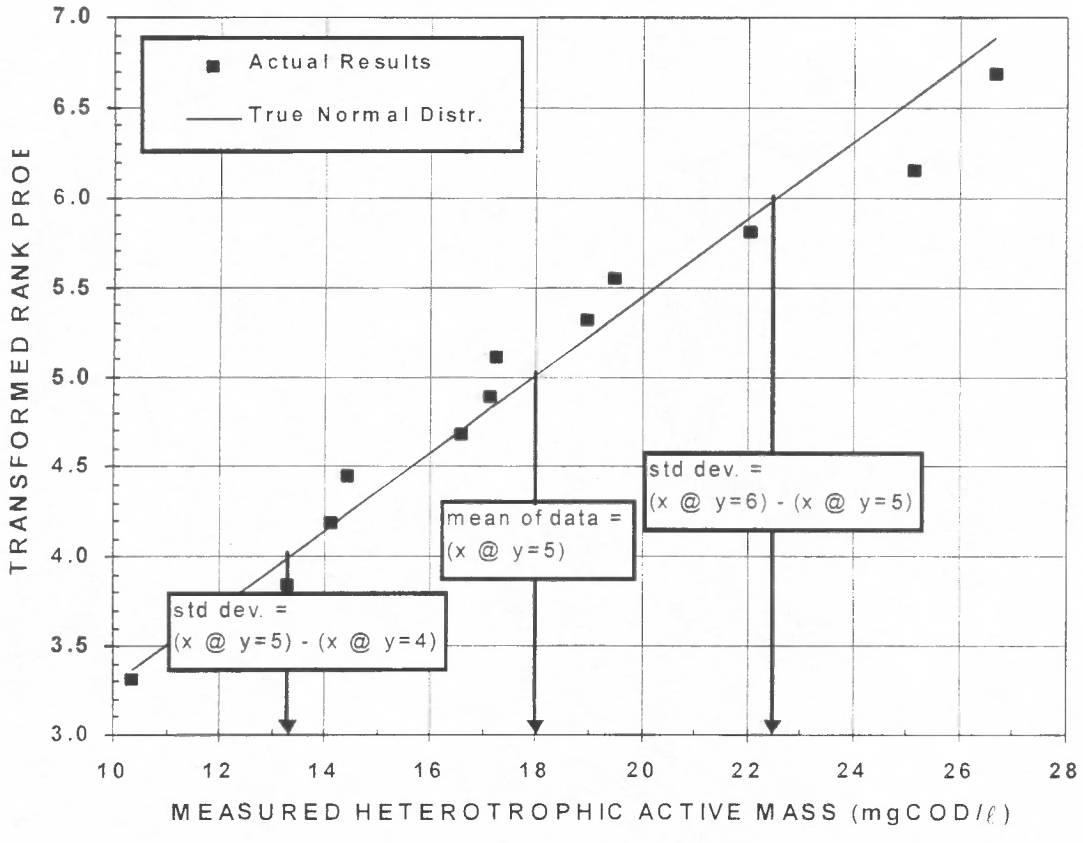


Fig. F1: Example of a statistical probability plot for a number of measured heterotrophic active biomass derived from the batch test.