CHARACTERIZATION OF MUNICIPAL WASTEWATERS

by

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DECLARATION BY CANDIDATE

I, ALFRED MBEWE, hereby declare that this thesis is my own work and has not been submitted at another University.

Signed by candidate

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SYNOPSIS

BACKGROUND AND OBJECTIVES

Over the past 20 years there have been extensive developments in the activated sludge method of treating wastewater. The functions of the single sludge system have expanded from carbonaceous energy removal to include progressively nitrification, denitrification and phosphorus removal, all mediated biologically. Not only has the system configuration and its operation increased in complexity, but concomitantly the number of biological processes influencing the system performance and the number of compounds involved in these processes have increased. With such complexity, designs based on experience or semi-empirical methods no longer will give optimal performance; design procedures based on more fundamental behavioural patterns are required. Also, it is no longer possible to make a reliable quantitative, or sometimes even qualitative prediction as to the effluent quality to be expected from a design, or to assess the effect of a system or operational modification, without some model that simulates the system behaviour accurately. To address these problems, over a number of years design procedures and kinetic models of increasing complexity have been developed, to progressively include aerobic COD removal and nitrification (Marais and Ekama, 1976; Dold *et al.*, 1980), anoxic denitrification (van Haandel *et al.*, 1981; WRC, 1984; Henze *et al.*, 1987; Dold *et al.*, 1991) and anaerobic, anoxic, aerobic biological excess phosphorus removal (Wentzel *et al.*, 1990; Wentzel *et al.*, 1992; Henze *et al.*, 1995).

In terms of the framework of these design procedures and kinetic models, the influent carbonaceous (C) material (measured in terms of the COD parameter) is subdivided into a number of fractions – this subdivision is specific to the structure of this group of models. The influent COD is subdivided into three main fractions, biodegradable, unbiodegradable and heterotrophic active biomass. The unbiodegradable COD is subdivided into particulate and soluble fractions based on whether the material will settle out in the settling tank (unbiodegradable particulate) or not (unbiodegradable soluble). The biodegradable material also has two subdivisions, slowly biodegradable (SBCOD) and readily biodegradable (RBCOD); this subdivision is based wholly on the dynamic response observed in aerobic (Dold *et al.*, 1980) and anoxic/aerobic (van Haandel *et al.*, 1981) activated sludge systems, that is, the division is biokinetically based. Thus, as input to the design procedures and kinetic models, it is necessary to quantify five influent COD fractions, that is, to characterize the wastewater COD. From a review of the

literature on existing tests to quantify the COD fractions, it was evident that the existing procedures are either too elaborate or approximate or sometimes not even available. This research project addresses these deficiencies.

In this research project, the principal objective was to develop simple accurate procedures to quantify the influent wastewater COD fractions. A batch test method has been developed to quantify the five influent COD fractions; namely heterotrophic active biomass, readily biodegradable COD, slowly biodegradable COD, unbiodegradable particulate COD and unbiodegradable soluble COD. Also, the physical flocculation–filtration method of Mamais *et al.* (1993) to quantify RBCOD has been evaluated and refined.

BATCH TEST

In the batch test, the influent wastewater to be tested is placed in a stirred batch reactor, aerated and the oxygen utilization rate (OUR) monitored automatically with time (Randall *et al.*, 1991). Also, samples are drawn from the start and end of the test and total COD and nitrate concentrations determined. From these data the following can be calculated:

- COD recovery (%)
- Wastewater heterotrophic active biomass, $Z_{BH(o)}$ (mgCOD/ℓ)
- Wastewater RBCOD, S_{bsi} (mgCOD/ℓ)
- Wastewater heterotrophic maximum specific growth rate on RBCOD, $\hat{\mu}_H$ (/d)
- Wastewater heterotrophic maximum specific growth rate on SBCOD, K_{MP} (/d)

Using raw (unsettled) municipal wastewater from two sources (Borcherds Quarry and Mitchell's Plain, Cape Town, South Africa) the batch test procedure was comprehensively evaluated. Results for RBCOD from the batch test were compared to those from the conventional square-wave flow through activated sludge system method (Ekama and Marais, 1979; WRC, 1984; Ekama *et al.*, 1986). The results indicated that:

- COD recoveries in the batch test are generally good, the majority falling in the range 95–105% indicating the reliability of the method.

- For wastewaters from both Borcherds Quarry and Mitchell's Plain autotrophic active biomass could not be detected in the batch test, indicated by an absence

of nitrification (no increase in nitrate concentration).

- For Mitchell's Plain wastewater, usually heterotrophic active biomass was present in low concentrations, ranging from 3% to 10% of total COD. However, on occasion concentrations > 10% of total COD were measured. These high values could be traced to operational procedures at the Mitchell's Plain Wastewater Treatment Plant – sludge handling facilities were shut down for maintenance and repairs and waste sludge recycled to the head of the works upstream of the point where the wastewater was collected for the batch tests.

- For Borcherds Quarry wastewater, heterotrophic active biomass concentration was very variable, ranging from 7% to 16% of total COD. From an investigation of operational procedures at the Borcherds Quarry Wastewater Treatment Plant, it was found that intermittently waste activated sludge was recycled to the head of the works and mixed with the incoming wastewater upstream of the point where wastewater was drawn for the batch test.

- Although the heterotrophic active biomass concentration obtained from the batch test could not be compared to a conventional test (no such test was available), the values measured in the batch test could correctly reflect changes arising from Wastewater Treatment Plant operation.

- The values for the kinetic constants derived from the batch test (K_{MP} and $\hat{\mu}_H$) differ from those in literature for activated sludge. Most probably a population develops in the activated sludge system (low COD, high active mass) that differs appreciably from that in the wastewater (high COD, low active mass). Accordingly it is unlikely that the values for the constants derived from the batch test (which reflect the wastewater population) will be of much value in modelling and design of activated sludge systems – their use is restricted to the batch test to derive estimates for RBCOD.

The batch test was extended to quantify soluble unbiodegradable COD. This extension was achieved by drawing a sample from the batch reactor at the end of the test, flocculating with aluminium sulphate and filtering through 0,45μm filter paper; the COD of the filtrate gives the unbiodegradable soluble COD (USCOD). To evaluate this extension, results from the batch test were compared to those from the effluent of a long sludge age activated sludge system (Ekama *et al.*, 1986).

Results indicated that:

- The batch test method gives values for USCOD that tend to be slightly higher than those from the activated sludge system methods; this may be due to the inability of the organisms within the batch test to degrade some of the soluble biodegradable material. However, the differences in USCOD between the two methods are relatively small (< 10%) – the estimates provided by the batch tests are acceptable for design and modelling purposes. Furthermore, values for USCOD as a fraction of the total COD from the batch test (f_{us} = 0,07 to 0,10) fall within the range of values to be expected for a South African raw municipal wastewater (f_{us} = 0,04 to 0,10; WRC, 1984).

- Glass fibre filters can replace the 0,45μm filters without any loss in accuracy.

Having developed the batch test method to quantify three of the five influent COD fractions, namely RBCOD, heterotrophic active biomass and USCOD, various extensions to the batch test to provide estimates for unbiodegradable particulate COD and slowly biodegradable COD were proposed and evaluated:

- Division of OUR.
- Pasteurization of influent.
- Extended aeration.
- OUR at the end of batch test.
- Addition of acetate.
- Addition of flocculated–filtered raw sewage.

Of all the proposals above, only the last (namely addition of flocculated–filtered raw sewage) appeared to hold promise for development. In this proposed method, raw wastewater is flocculated with aluminium sulphate and filtered through 0,45μm filter papers. The filtrate is added to the batch test after about 2days. From the exponential increase in OUR after sewage filtrate addition, the heterotrophic active biomass concentration in the batch test at the time of adding the sewage filtrate can be determined from which the remaining two COD fractions can be quantified (i.e. slowly biodegradable and unbiodegradable particulate COD). This method was evaluated by comparing estimates for unbiodegradable particulate COD and slowly biodegradable COD with those from the conventional activated sludge method (Ekama *et al.*, 1986).

Although the proposed extension to the batch test method to determine influent slowly biodegradable (S_{bpi}) and unbiodegradable particulate (S_{upi}) COD provides estimates for S_{bpi} and S_{upi} that fall in the same range as estimates from the conventional completely aerobic activated sludge system method (Ekama *et al.*, 1986), the direct correlation between the estimates from the two methods is poor. The batch test method provides estimates for S_{upi} that tend to be higher than those derived from the conventional activated sludge method and correspondingly provides estimates for S_{bpi} that tend to be lower than those derived from the conventional activated sludge method. A more extensive experimental evaluation is required to discern if these trends are consistent.

FLOCCULATION–FILTRATION METHOD

A flocculation–filtration method has been developed by Mamais *et al.* (1993) to quantify the influent RBCOD concentration. In this method, the inclusion of the flocculation step prior to filtration appears to overcome the problem of correct selection of filter pore size inherent in other physical methods. In the Mamais *et al.* method, raw wastewater is flocculated using zinc sulphate with the pH adjusted to 10,5. The flocculated wastewater is then filtered through 0,45μm filter paper. Likewise effluent from an activated sludge system is also flocculated and then filtered through 0,45μm filter papers. The difference between the COD of the filtrates of the raw wastewater and the effluent gives the RBCOD concentration.

In preliminary tests it was found that the zinc sulphate flocculant recommended by Mamais *et al.* could be replaced with aluminium sulphate – this has the advantage that no pH adjustment is necessary. The physical flocculation–filtration method was evaluated by comparing the RBCOD concentration measured with this method with those from the batch test and "standard" flow–through square wave methods. Also, the experimental protocol was examined to determine whether this could be improved by using glass fibre filter papers in place of the expensive 0,45μm filter papers. Results showed that the flocculation–filtration method provided estimates that correlated closely with those from both the batch test and the flow–through square wave methods and that the 0,45μm filter paper can be replaced with glass fibre filter paper to reduce the cost of this method without any loss in accuracy.

CONCLUSIONS

The batch test method developed in this investigation has advantages over previous methods in that,

- The experimental procedure is relatively simple.

- No mixed liquor acclimatized to the wastewater is required.

- The only independent constants required for calculation are the heterotrophic yield (Y_{ZH}), endogenous residue fraction for heterotrophic active biomass (f), and specific death rate (b_H): Dosing the batch test with known concentrations of acetate showed that the standard value for Y_{ZH} in the literature (Y_{ZH} = 0,666 mgCOD/mgCOD; Dold and Marais, 1986) can be accepted; the batch test procedure is relatively insensitive to the value for b_H. All other constants required for calculations are obtained from the experimental data. However, it is unlikely that these constants (i.e. maximum specific growth rate of heterotrophs on RBCOD, $\hat{\mu}_H$, and maximum specific growth rate of heterotrophs on SBCOD, K_{MP}) will be of much value in modelling and design of activated sludge systems – most probably a population will develop in the activated sludge system that differs appreciably from that in the wastewater since the conditions in the wastewater (high COD, low active mass) differ significantly from those in the activated sludge system (low COD, high active mass).

The batch test method was evaluated by comparing its results with those from conventional flow through activated sludge system methods accepted as the standard in the literature. Results from a number of batch tests on municipal wastewater from Mitchell's Plain and Borcherds Quarry (Cape Town, South Africa) indicate that:

- Autotrophic biomass is not present in either wastewater.

- Measured RBCOD concentrations correlate closely with those from the conventional square-wave flow through method (WRC, 1984; Ekama *et al.*, 1986).

- Although the values for wastewater heterotrophic active biomass could not be compared to conventional methods (none are available), the batch test was able to detect correctly variations in heterotrophic active biomass caused by changes in plant operational procedures, as described above.

- Values for unbiodegradable soluble COD derived from the batch test compared reasonably well with those derived from the effluent of a long sludge age activated sludge system (Ekama *et al.*, 1986).

- Values for unbiodegradable particulate COD derived from the batch test fall in the same range as estimates from the conventional completely aerobic activated sludge system method (Ekama *et al.*, 1986). However, the direct correlation between the values from the two tests is poor. For the present, the batch test does not provide estimates for unbiodegradable particulate COD that are sufficiently accurate and precise for use in design and simulation of activated sludge systems. For design and simulation, unbiodegradable particulate COD as a fraction of total COD should at least be able to be quantified into the ranges 0–0,05; 0,05–0,10; 0,10–0,15; etc. As yet, there is not sufficient surety that the estimate for f_{up} from the batch test will meet this requirement; more data are required.

- The errors in unbiodegradable particulate COD are reflected in the estimate from the batch test for slowly biodegradable COD. However, because the absolute value for the slowly biodegradable COD concentration is very much larger than that for the unbiodegradable particulate COD concentration, the relative error in the estimate for slowly biodegradable COD is very much less. The estimate for slowly biodegradable COD can be accepted for design and simulation.

For the flocculation–filtration method proposed by Mamais *et al.* (1993) to determine RBCOD:

- The zinc sulphate flocculant recommended by Mamais *et al.* (1993) can be replaced with aluminium sulphate. This has the advantage that pH adjustment after flocculation is now required.

- Measured RBCOD correlate closely with those from the conventional flow–through square wave method (WRC, 1984; Ekama *et al.*, 1986) and the batch test method.

- The method is relatively simple and easy to apply but requires independent determination of unbiodegradable soluble COD, from effluent samples which may not always be available.

- The 0,45μm filters recommended by Mamais *et al.* (1993) can be replaced with glass fibre filters (Whatman's GF/C) to reduce costs, without any loss in accuracy.

RECOMMENDATIONS

From this investigation, the following recommendations can be made:

- The batch test can be used successfully to determine the heterotrophic active biomass, RBCOD and the soluble unbiodegradable COD concentrations in the influent wastewater. In this investigation, the estimates for RBCOD and unbiodegradable soluble COD concentrations from the batch test could be compared to results from conventional test methods. However, the heterotrophic active biomass concentration could not be evaluated against other tests because no such tests are available. To evaluate estimates for heterotrophic active biomass, it is recommended that an inoculum of activated sludge mixed liquor from a defined continuous flow steady state system is introduced into the batch test. From the steady state model (WRC, 1984) the concentration of the heterotrophic active biomass in the continuous flow system and therefore added into the batch test can be calculated, and compared to the concentration obtained from the batch test. However, due account must be taken of nitrification, since the mixed liquor dosed to the batch test may nitrify. If similar results are obtained then a powerful verification of the basis of present activated sludge models (see Background and Objectives above) will have been provided.

- For the batch test method, a technique has been developed to quantify the unbiodegradable particulate COD and slowly biodegradable COD fractions. However, direct correlation of estimates for these parameters from the batch test and conventional tests were poor. Also, no discernible trends could be identified

in the relationship between values from the two tests. To identify clear trends, a more extensive experimental investigation is required, so that more data are available.

- This investigation has been restricted to quantifying the influent carbonaceous material fractions. Similar studies should be undertaken on the influent nitrogenous and phosphorous materials.

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Symbol	Description
ATU	Allyl thiourea
AVSS	Active volatile suspended solids concentration (mgVSS/ℓ)
b_H	Specific death rate for heterotrophs (/d)
b_H^*	Net specific endogenous mass loss rate for heterotrophs (/d)
COD	Chemical oxygen demand
DO	Dissolved oxygen concentration (mgO/ℓ)
DNA	Deoxyribonucleic acid
f	Endogenous residue fraction for heterotroph active biomass (mgVSS/mgVSS)
f_{av}	Active fraction of the volatile suspended solids (mgAVSS/mgVSS)
f_{Zbh}	Fraction of influent total COD which is heterotroph active biomass (mgCOD/mgCOD)
f_{bs}	Fraction of influent biodegradable COD that is readily biodegradable (mgCOD/mgCOD)
f_{bp}	Fraction of influent total COD that is biodegradable particulate (mgCOD/mgCOD)
$f_{Sbs,a}$	Fraction of readily biodegradable COD that is short chain fatty acids (mgCOD/mgCOD)
$f_{Sbs,f}$	Fraction of readily biodegradable COD that is fermentable (mgCOD/mgCOD)
f_{cv}	COD to VSS ratio of the mixed liquor (mgCOD/mgVSS)
f_{up}	Unbiodegradable particulate fraction of the influent COD (mgCOD/mgCOD)
f_{us}	Unbiodegradable soluble fraction of the influent COD (mgCOD/mgCOD)
f_{ts}	Fraction of influent total COD that is readily biodegradable (mgCOD/mgCOD)
IAWQ	International Association on Water Quality
K_H	Maximum specific SBCOD hydrolysis rate (/d)
K_{SH}	Half saturation constant for RBCOD (mgCOD/ℓ)
K_{SP}	Half saturation constant for SBCOD (mgCOD/mgCOD)
K_{MP}	Maximum specific growth rate of heterotrophs on SBCOD (/d)
K_{SA}	Half saturation constant of autotrophs (mgN/ℓ)
LR	Loading rate (mgCOD/mgVSS)

MWD	Molecular weight distribution
MLSS	Mixed liquor total suspended solids concentration (mgTSS/ℓ)
MLVSS	Mixed liquor volatile suspended solids concentration (mgVSS/ℓ)
MO_C	Carbonaceous oxygen demand (mgO/ℓ)
O_{ee}	Endogenous respiration OUR at end of the batch test (mgO/ℓ/h)
OUR	Oxygen utilization rate (mgO/ℓ/h)
OUR_C	OUR due to carbonaceous material utilization (mgO/ℓ/h)
OUR_N	OUR due to nitrification (mgO/ℓ/h)
PolyP	Polyphosphate
RBCOD; S_{bsi}	Readily biodegradable COD concentration in the influent (mgCOD/ℓ)
R_s	System sludge age (d)
S_{ads}	Adsorbed SBCOD concentration (mgCOD/ℓ)
SBCOD; S_{bpi}	Slowly biodegradable COD concentration in the influent (mgCOD/ℓ)
S_{bpe}	Biodegradable particulate COD concentration at the end of the batch test (mgCOD/ℓ)
S_{bi}	Biodegradable COD in the influent (mgCOD/ℓ)
S_{bse}	Readily biodegradable COD concentration at the end of the batch test (mgCOD/ℓ)
SCFA; S_{bsai}	Short chain fatty acids (mgCOD/ℓ)
S_{te}	Total COD concentration of the wastewater at the end of the batch test (mgCOD/ℓ)
S_{ti}	Total influent COD concentration of the wastewater (mgCOD/ℓ)
S_{ui}	Unbiodegradable COD in the influent (mgCOD/ℓ)
S_{use}	Unbiodegradable soluble COD concentration at the end of the batch test (mgCOD/ℓ)
S_{usi}	Unbiodegradable soluble COD concentration of the influent wastewater (mgCOD/ℓ)
TKN	Total Kjeldahl Nitrogen (mgN/ℓ)
$\hat{\mu}_H$	Maximum specific growth rate of heterotrophs on RBCOD, UCT model (/d)
$\hat{\mu}_H{}^*$	Maximum specific growth rate of heterotrophs on RBCOD, IAWQ model (/d)
UCT	University of Cape Town
V_p	Volume of the reactor (ℓ)
V_{ww}	Volume of the wastewater (ℓ)
$Y_H{}^*$	Heterotroph active biomass yield (VSS units) (mgVSS/mgCOD)
Y_{ZH}	Heterotroph active biomass yield (COD units) (mgCOD/mgCOD)

$Z_{BH(o)}$	Heterotrophic active biomass concentration in the influent (mgCOD/ℓ)
X_v	Volatile suspended solids concentration of mixed liquor (mgVSS/ℓ)
X_{Ii}	Unbiodegradable particulate organics concentration in the influent expressed as VSS (mgVSS/ℓ)
Z_{Ee}	Endogenous residue at the end of the batch test (mgCOD/ℓ)
Z_{BHe}	Heterotrophic active biomass concentration at the end of the batch test (mgCOD/ℓ)

CHAPTER 1

INTRODUCTION

Worldwide, increasing awareness of the adverse impact of eutrophication on aquatic environments has led to the introduction of more stringent legislation controlling discharges of the nutrients nitrogen (N) and phosphorus (P) with municipal wastewater effluents (e.g. South Africa, 1984 amendment to Section 21 of the 1956 Water Act, Government Gazette, 1984). To comply with the new legislations, over the past 20 years there have been extensive developments in the activated sludge method of treating wastewater. The functions of the single sludge system have expanded from carbonaceous energy removal to include progressively nitrification, denitrification and phosphorus removal, all mediated biologically. These extensions have been accommodated through manipulation of the system configuration – incorporation of multiple in–series reactors, some aerated and others not, with various inter–reactor recycles. Not only has the system configuration and its operation increased in complexity, but concomitantly the number of biological processes influencing the system performance and the number of compounds involved in these processes have increased. With such complexity, designs based on experience or semi–empirical methods no longer will give optimal performance; design procedures based on more fundamental behavioural patterns are required. Also, it is no longer possible to make a reliable quantitative, or sometimes even qualitative prediction as to the effluent quality to be expected from a design, or to assess the effect of a system or operational modification, without some model that simulates the system behaviour accurately. To address these problems, over a number of years design procedures and kinetic models of increasing complexity have been developed, to progressively include aerobic COD removal and nitrification (Marais and Ekama, 1976; Dold *et al.*, 1980), anoxic denitrification (van Haandel *et al.*, 1981; WRC, 1984; Henze *et al.*, 1987; Dold *et al.*, 1991) and anaerobic, anoxic, aerobic biological excess phosphorus removal (Wentzel *et al.*, 1990; Wentzel *et al.*, 1992; Henze *et al.*, 1995; Gujer *et al.*, 1995).

In a large measure these design procedures and kinetic models are based on a conceptual understanding of the mechanisms operating in the activated sludge system, in particular of the processes acting on the different organics that make up the influent carbonaceous material. In terms of the framework of the design procedures and kinetic models, the influent carbonaceous (C) material (measured in

terms of the COD parameter) is subdivided into a number of fractions – this subdivision is specific to the structure of this group of models. The influent COD is subdivided into three main fractions, biodegradable, unbiodegradable and heterotrophic active biomass. The unbiodegradable COD is subdivided into particulate and soluble fractions based on whether the material will settle out in the settling tank (unbiodegradable particulate) or not (unbiodegradable soluble). The biodegradable material also has two subdivisions, slowly biodegradable (SBCOD) and readily biodegradable (RBCOD); this subdivision is based wholly on the dynamic response observed in aerobic (Dold *et al.*, 1980) and anoxic/aerobic (van Haandel *et al.*, 1981) activated sludge systems, that is, the division is biokinetically based.

Thus, as input to the design procedures and kinetic models, it is necessary to quantify five influent COD fractions, that is, to characterize the wastewater COD. The design or simulation will be only as reliable as the wastewater COD characteristics that serve as input. Existing procedures for quantifying the COD fractions are either biologically (bioassay tests) or physically based, or a combination of both. Since the division of the influent COD is based principally on a biological response, tests in which the response of activated sludge to wastewater is monitored, bioassay tests, have found wider application than the physically based tests. A variety of bioassay test techniques have been developed which can be categorized as either continuous flow–through systems or batch type experiments. The continuous flow–through systems (Ekama and Marais, 1979; WRC, 1984; Ekama *et al.*, 1986), while providing good estimates for COD fractions, have been criticized for their cost and difficulty of operation. For procedures using batch experiments, sludge acclimatized to the wastewater has to be obtained, either generated in special laboratory–scale continuous flow–through reactors (Ekama *et al.*, 1986; Solfrank and Gujer, 1989; Kappelar and Gujer, 1992) or from a full–scale plant (Nicholls *et al.*, 1985).

The requirement of a laboratory–scale reactor for sludge generation for the batch methods does not resolve criticisms levelled at the flow–through methods, while the option of obtaining sludge from a full–scale plant may not be available if a new plant is to be built. Furthermore, in batch type experiments the use of sludge from biological excess phosphorus removal systems will produce erroneous results for RBCOD due to the phenomenon of RBCOD uptake and storage by polyP organisms under aerobic and anoxic conditions without the utilization of oxygen and nitrate

(Still *et al.*, 1986; Wentzel *et al.*, 1989a,1989b). In any event, the batch type experiments do not provide an accurate estimate for all the COD fractions, in particular it is very difficult to obtain an acceptable estimate for SBCOD and unbiodegradable particulate COD.

In an attempt to overcome the problems associated with the biologically based tests, a number of physically based tests have been developed. It has been hypothesized that the difference in biokinetic response of activated sludge to RBCOD and SBCOD is due to differences in molecule size – RBCOD consists of relatively small molecules that are readily transported into microbial cells whereas SBCOD comprises larger and more complex molecules that require extracellular breakdown (hydrolysis) to smaller units before uptake and utilization (Dold *et al.*, 1980; Dold *et al.*, 1986). Accordingly, physical separation of the two biodegradable COD fractions on the basis of molecular size has been proposed as an approximation of the biokinetic division. For physical separation, filtration methods with various filter pore sizes have been used (e.g. Dold *et al.*, 1986; Lesouef *et al.*, 1992; Mamais *et al.*, 1993; Torrijos *et al.*, 1994). Success with the filtration methods has been closely linked to the filter pore size used – the larger the pore size, the more "particulate" material passes through the filter and the less accurate the estimates for RBCOD. To overcome this problem, Mamais *et al.* (1993) successfully investigated flocculation of colloidal material (SBCOD) before filtration through 0,45μm filters.

In all filtration methods, irrespective of whether flocculation is used or not, since both biodegradable and unbiodegradable COD pass through the filter, the unbiodegradable fraction has to be quantified independently and subtracted from the COD of the filtrate to give the RBCOD. This requires effluent from a continuous flow–through activated sludge system (Dold *et al.*, 1986; Mamais *et al.*, 1993; Bortone *et al.*, 1994) or sequencing batch reactor (Torrijos *et al.*, 1994) which may not be available, or measurements of filtered COD over at least 10 days in batch tests (Lesouef *et al.*, 1992), a time consuming task. Furthermore, the particulate COD retained by the filter consists of three fractions, unbiodegradable particulate, SBCOD, and heterotrophic active biomass, which have to be quantified in independent tests.

From the above it is evident that quantification of the influent wastewater COD fractions is crucial for optimal design and operation of activated sludge systems.

Existing procedures to quantify these fractions are either too elaborate or approximate or are sometimes not even available. This research project addresses these deficiencies - the objective is to develop simple accurate procedures to quantify the influent wastewater COD fractions. In terms of this objective, the following specific aims have been identified:

- Review and evaluate existing methods for quantifying influent COD fractions.
- Identify the more promising methods for further development and modification.
- Experimentally assess the proposed modifications/methods by comparing the results against those from "standard" methods.

This report documents progress achieved in addressing these aims.

CHAPTER 2

CHARACTERIZATION OF MUNICIPAL WASTEWATER

2.1 INTRODUCTION

In the wastewater treatment plant, removal of organic (C), nitrogenous (N) and/or phosphorous (P) compounds from wastewaters is effected physically (screening, grit removal, primary and secondary settling, flocculation, precipitation, filtration, etc), and biologically (oxidation, nitrification, denitrification, biological excess phosphorus removal) by the various unit operations that make up the treatment plant. For the design of the different unit operations to achieve physical and biological removal, it is necessary to characterize the wastewater, that is, to assess in some fashion the character and quantity of the various C, N and P constituents of the wastewater.

The parameters required for characterization of the wastewater are strongly linked to the type of unit operation to be designed. This research project focusses on the activated sludge system because this system has the capacity to obtain biological C, N and P removal. For the activated sludge system, the degree of wastewater characterization required is determined by the level of sophistication of the design procedures and simulation models that are to be applied, which in turn is determined largely by the effluent quality required in terms of C, N and P. Generally, the more stringent the effluent quality requirements in terms of C, N and P, the more complex the activated sludge system has to be to achieve the required removals, and the more advanced and realistic the design procedures and simulation models need to be – the more sophisticated the design procedures and models are, the more detailed and refined the wastewater characterization needs to be.

For organic material (C) removal only, with the wastewater strength measured in terms of BOD_5 and suspended solids (SS), little more than a knowledge of the organic load in terms of BOD_5 and SS is adequate; knowledge of the kind of organics that make up the BOD_5 and SS generally are not required because various empirical relationships have been developed linking the BOD_5 load and SS to the expected response and performance of the activated sludge system. Where the organics are assessed in terms of COD, because the COD parameter includes both unbiodegradable and biodegradable organic material, an elementary characterization of the organic material is required, i.e. biodegradable and unbiodegradable and soluble and particulate. Without nitrification, N removal or P removal, no

wastewater N and P characteristics are required. If nitrification is included in the system, knowledge of the components making up the N material is required. With biological nitrogen removal (denitrification), much more information is required: Now not only the global organic load in terms of COD (not BOD_5, see WRC, 1984) needs to be specified, but also the quality and quantity of some of the organic compounds that make up the total organic (COD) load. Also, the nitrogenous (N) materials need to be characterized and quantified in the same way. With biological P removal, still further specific information characterizing the carbonaceous material is required and additionally characterization of the phosphorous (P) materials is required.

This research project investigates characterization of the carbonaceous (C) materials only, for activated sludge systems with biological C, N and/or P removal. In this Chapter, the basis for division of the C material into various fractions (characterization) is described.

2.2 WASTEWATER CHARACTERIZATION FOR THE ACTIVATED SLUDGE SYSTEM

The activated sludge system comprises a biological reactor and a secondary settling tank. Irrespective of whether or not biological N and/or P removal are included, many different biological and physical processes take place in the biological reactor, and the physical process sedimentation takes place in the secondary settling tank. These processes form the basis for subdividing the influent wastewater C, N and P materials into subfractions (see Fig 2.1). On entry of the influent into the biological reactor, the particulate materials, which include both settleable and suspended (non–settleable or colloidal), organic and inorganic materials, are enmeshed (a biologically mediated flocculation) and become part of the activated sludge mixed liquor. The soluble materials, both organic and inorganic, remain in solution. In the biological reactor, the bacteria present will act on the biologically utilizable material, termed *biodegradable*, whether organic or inorganic, soluble or particulate, and transform these to other compounds or products, either gaseous, soluble or particulate: The gaseous products escape to the atmosphere, the particulate products become (or remain) part of the mixed liquor solids and the soluble products become (or remain) dissolved in solution. The non-biologically utilizable material, termed *unbiodegradable*, will not be transformed and will remain in either the soluble or particulate form. Therefore, the first major division of the influent is based on whether the material is *biodegradable* or *unbiodegradable*, see Fig 2.1.

After biological treatment the flow passes from the biological reactor to the secondary settling tank. In the secondary settling tank, the particulate materials making up the mixed liquor (whether organic or inorganic, biodegradable or unbiodegradable) settle out and are returned to the biological reactor. The particulate components of the mixed liquor entering the settling tank are thus retained in the system. All the soluble components of the mixed liquor (whether organic or inorganic, biodegradable or unbiodegradable) cannot settle out and escape with the effluent, see Fig 2.1.

The settling behaviour in the secondary settling tank therefore forms the basis for subdividing the influent *unbiodegradable* material into subfractions: The influent unbiodegradable material passes unmodified through the biological reactor to the secondary settling tank; ideally all the particulate (and colloidal) material settles out in the secondary settling tank and these constituents are therefore termed *unbiodegradable particulate*, the soluble constituents cannot settle out so that these constituents are termed *unbiodegradable soluble,* see Fig 2.1. With regard to the influent *biodegradable* material, because a substantial amount of this material has been biologically transformed in the biological reactor preceding the secondary settling tank, it cannot be subdivided into subfractions based on its behaviour in the secondary settling tank; subdivision of the biodegradable material is based on the rates of transformation/utilization by the bacteria in the biological reactor.

From the above, to assess the performance of the activated sludge system, the wastewater C, N and P constituents need to be characterized (1) biologically, i.e. as biodegradable (biologically utilizable) or unbiodegradable (non–biologically utilizable) material, and (2) physically, i.e. as soluble or particulate material. Therefore, for the more detailed design procedures based on fundamentals of behaviour, it is necessary to divide the influent C, N and P constituents into at least three fractions:

- biodegradable
- unbiodegradable soluble
- unbiodegradable particulate.

This general wastewater characterization structure (see Fig 2.2) conforms to the biological degradation and physical solid/liquid separation processes that take place in the activated sludge system. When C material removal only is considered, this

structure is applied in varying degrees only to the organic or carbonaceous constituents of the wastewater; with C, N and P material removal it is applied to all three of these groups. In this research project, characterization of the C material only is considered, for activated sludge systems with C removal and with or without N and/or P removal.

2.3 CARBONACEOUS (C) MATERIALS

Assessment of the characteristics of the carbonaceous material in the influent is done via the Chemical Oxygen Demand (COD) test, which measures the electron or equivalently the energy donating capacity of the organics in the wastewater (WRC, 1984). For activated sludge system design, it is necessary to quantify, to various degrees, the constituents making up the carbonaceous (C) material (measured as COD), as these significantly affect the system response, for example, carbonaceous oxygen demand, sludge production, denitrification, and phosphorus removal. As noted earlier, the extent of characterization required for the C materials depends on the objectives for the activated sludge system. If N and/or P removal are incorporated, information additional to the general classification structure in Fig 2.1 is required. Research at the University of Cape Town has indicated that the divisions shown diagrammatically in Fig 2.3 provide a sufficiently complete description for accurate design of biological nutrient (N & P) removal systems. This division is based on the biological and physical processes acting in the activated sludge system.

2.3.1 Carbonaceous material (COD) fractions

The first division of the influent COD (S_{ti}) is based on whether the COD fraction undergoes biological degradation or not, that is, into biodegradable COD (S_{bi}) and unbiodegradable COD (S_{ui}) respectively.

Each of the unbiodegradable and biodegradable fractions is subdivided further into two subfractions.

Unbiodegradable subfractions

The influent unbiodegradable COD is subdivided into two fractions, unbiodegradable soluble COD (S_{usi}) and unbiodegradable particulate COD (S_{upi}). Both fractions are hypothesized to be unaffected by biological action in the system so that at steady state, the mass of this material that enters the system is equal the mass of this material that leaves the system. Since both fractions are

unbiodegradable, their differentiation is based on their behaviour in the secondary settling tank, see Fig 2.1: The S_{us} passes out in the secondary settling tank overflow and appears as COD in the effluent. Since S_{us} flows out with the effluent, it has a direct influence on the effluent COD concentration. By accepting that the effluent soluble COD (say <0,45μm filtered) (S_{use}) is the influent unbiodegradable soluble COD (S_{usi}) it is assumed that no soluble unbiodegradable organics are generated during biological treatment in the reactor. Over the many years of research into activated sludge systems, this has come to be accepted as a reasonable assumption. (For a detailed discussion on this aspect, see Chapter 3). The unbiodegradable particulate organics, such as paper and hair, S_{up}, are enmeshed in the sludge mass, settle out in the secondary settling tank and are retained in the system to accumulate as unbiodegradable organic (volatile) settleable solids (VSS). At steady state, the mass of S_{up} entering the system with the influent will be balanced by the mass of this material, now enmeshed with the biomass in the mixed liquor, leaving via the sludge waste stream. From a mass balance, the mass of unbiodegradable organic solids that accumulate in the reactor from the influent is equal to the daily influent mass load of this material multiplied by the sludge age. Thus, the S_{up} has a direct effect on the mixed liquor solids mass in the reactor and therefore on the system volume requirements for a selected mixed liquor solids concentration (WRC, 1984). Unlike for the S_{us} material, unbiodegradable particulate organic material (VSS) is generated by the bacteria during the biological treatment processes. Owing to its different origin, this material, called endogenous residue, is accounted for separately from the influent unbiodegradable particulate organics that accumulate in the reactor.

Biodegradable subfractions

Subdivision of the biodegradable organics, S_{bi}, into subfractions depends on the requirements for the system to be designed. *For a completely aerobic system, irrespective of whether nitrification is included or not either intentionally or unintentionally, subdivision of the S_{bi} fraction into its subfractions is not required for design purposes:* Knowing the biodegradable COD concentration and the flow per day gives the biodegradable COD load on the plant; knowing the biodegradable COD load and selecting a sludge age, the daily carbonaceous oxygen requirements and the active organism mass and unbiodegradable particulate organic fractions that make up the VSS in the reactor can be estimated from the steady state design equations (WRC, 1984). However, if denitrification and/or phosphorus removal are included in the design or the system response is simulated with a dynamic model, then subdivision of S_{bi} into subfractions is required (Dold *et al.*, 1980; WRC 1984;

Wentzel *et al.*, 1990, 1992).

The first subdivision of S_{bi} is into readily biodegradable (soluble) COD (S_{bsi}) and slowly biodegradable (particulate) COD (S_{bpi}), see Fig 2.3. This division is based on observed biological responses of activated sludge mixed liquor to domestic wastewater (Dold *et al.*, 1980; van Haandel *et al.*, 1981), that is, the division is a biokinetic one: Under dynamic loading of activated sludge (short sludge age cyclic loading, plugflow reactors, batch tests) two distinct rates of utilization of domestic wastewater biodegradable COD substrate were apparent with either oxygen (Dold *et al.*, 1980; Ekama *et al.*, 1986) or nitrate (van Haandel *et al.*, 1981; Ekama *et al.*, 1986) as electron acceptor (aerobic or anoxic conditions respectively). A fraction (called readily biodegradable COD, RBCOD) was taken up rapidly by the sludge and metabolized, giving rise to a high oxygen or nitrate utilization rate respectively. The other fraction (called slowly biodegradable COD, SBCOD) was taken up much more slowly and metabolized, giving rise to oxygen or nitrate utilization rates about 1/10 of the rate with RBCOD. To explain these observations, the RBCOD was hypothesized to consist of simple *soluble* molecules that can be absorbed readily by the organism and metabolized for energy and cell synthesis, whereas the SBCOD was assumed to be made up of *particulate/colloidal/complex* organic molecules that require extracellular adsorption and enzymatic breakdown (hydrolysis) prior to absorption and utilization. The hypothesized difference in molecule size between RBCOD and SBCOD has been used to classify the RBCOD as a biodegradable soluble COD and the SBCOD as a biodegradable particulate COD. Since the RBCOD is soluble, it is exposed to biological treatment only as long as the liquid remains in the reactor, i.e. for the hydraulic retention time which is relatively short (~ 6–24h). However, the rate of RBCOD utilization is high and for sludge ages greater than about 3 days the concentration of RBCOD in the effluent is negligible even though the retention time is relatively short. Accordingly, for design of completely aerobic systems knowledge of RBCOD concentration also is not required – it can be safely assumed that all the RBCOD will be utilized in the system. For the SBCOD, the extracellular breakdown (hydrolysis) is slow and forms the limiting rate in the utilization of SBCOD. Although the rate of SBCOD utilization is relatively slow, the SBCOD does not appear in the effluent. This is because on entry of the influent into the bioreactor, the SBCOD becomes enmeshed in the mixed liquor, settles out in the secondary settling tank and is retained in the system. Therefore, unlike the soluble biodegradable organics (RBCOD) which are exposed to biological treatment for only as long as the liquid remains in the system,

i.e. hydraulic retention time, the particulate biodegradable organics (SBCOD) are exposed to biological treatment for as long as the solid (settleable) material is retained in the system, i.e. for the sludge age. Therefore, even though the utilization of the SBCOD is around 1/10th slower that for the RBCOD, because the sludge age in most activated sludge systems is usually more than 10 times longer than the hydraulic retention time, the SBCOD is completely utilized also. From simulation studies using dynamic kinetic models (Dold *et al.*, 1991) all the SBCOD is completely utilized for sludge ages greater than about 2 to 3 days and temperatures greater than about 20° C (5 to 6 days at 14° C). Accordingly, for design using steady state based procedures, knowledge of RBCOD and SBCOD subdivision is not required – it is sufficient to assume all the biodegradable SBCOD will be utilized in the system. However, when denitrification and/or biological excess phosphorus removal are included, knowledge of RBCOD is essential (van Haandel *et al.*, 1982; Wentzel *et al.*, 1990). For denitrification, the rate of denitrification depends on, *inter alia*, whether RBCOD or SBCOD serves as electron donor (substrate), and the relative proportion of these two materials will thus influence the amount of N removal. For biological excess phosphorus removal, the magnitude of the phosphorus removal is strongly linked to the influent RBCOD concentration.

Further, with biological excess P removal, the RBCOD needs to be subdivided into two subfractions, see Fig 2.3 (Wentzel *et al.*, 1990; Wentzel *et al.*, 1992). With BEPR, the organisms mediating BEPR, variously called phosphotrophs, polyP organisms, phosphorus accumulating organisms, take up short–chain fatty acids (SCFA) in the anaerobic reactor (sequestration) with associated P release. The amount of SCFA that the phosphotrophs sequester in the anaerobic reactor determines the proportion of the biodegradable COD that these organisms obtain and therefore their active mass in the system, which in turn determines to a large extent the amount of P removal that can be achieved (Wentzel, 1990). The SCFA is derived from that present in the influent (part of the RBCOD) and is also generated in the anaerobic reactor by acid fermentation. The rate of SCFA sequestration is so rapid that it can be assumed that all SCFA in the influent will be sequestrated in the anaerobic reactor by the phosphotrophs. The RBCOD that is not in an SCFA form is called fermentable RBCOD (F–RBCOD) and will be acid fermented by the heterotrophs in the anaerobic reactor to SCFA which then can be sequestered by the phosphotrophs. The rate of this fermentation reaction is slower than the sequestration rate, and the amount of F–RBCOD fermented to SCFA

depends on the influent F–RBCOD concentration and system design. Thus, for accurate design of BEPR, the RBCOD needs to be subdivided into two subfractions, SCFA (S_{bsai}) and F–RBCOD (S_{bsfi}).

Heterotroph active biomass subfraction

The original UCT design procedures (WRC, 1984) and models (Dold *et al.*, 1980; van Haandel *et al.*, 1981) did not consider heterotroph active biomass or autotroph biomass to be present in the influent; for municipal wastewaters in South Africa, the sewers generally are short (retention <6 hours) and anaerobic, and were considered unlikely to support active biomass generation. Further, application of the design procedures and simulations with the UCT models appeared to support this supposition. However, investigations in Europe have indicated that European municipal wastewaters can contain a significant heterotroph active biomass fraction (Henze, 1989), up to 20% of the total COD (Kappelar and Gujer, 1992). Seeding of this influent biomass to the activated sludge system can have a significant influence on modelling and design. Thus, heterotroph active biomass should be included as an influent wastewater COD fraction.

2.3.2 Analytical formulation for COD

For analysis and use in steady state design procedures and simulation models, the relationships indicated in Fig 2.3 can be expressed as follows:

Biodegradable, unbiodegradable and active mass COD fractions:

$$S_{ti} = S_{ui} + S_{bi} + Z_{BHi} \qquad (2.1)$$

where

S_{ti} = total influent COD concentration (mgCOD/ℓ)
S_{ui} = unbiodegradable influent COD concentration (mgCOD/ℓ)
S_{bi} = biodegradable influent COD concentration (mgCOD/ℓ)
Z_{BHi} = influent heterotroph active biomass concentration (mgCOD/ℓ)

Each of the two biodegradable and unbiodegradable fractions on the right hand side of Eq (2.1) is again subdivided, Fig 2.3.

Unbiodegradable COD fractions

The unbiodegradable COD concentration consists of two components, soluble and

particulate, i.e.

$$S_{ui} = S_{usi} + S_{upi} \tag{2.2}$$

where

S_{usi} = unbiodegradable soluble influent COD concentration (mgCOD/ℓ)

S_{upi} = unbiodegradable particulate influent COD concentration (mgCOD/ℓ)

It is convenient to express S_{usi} and S_{upi} in terms of the total COD concentration S_{ti}, i.e.

$$S_{usi} = f_{us}\, S_{ti} \tag{2.3}$$

$$S_{upi} = f_{up}\, S_{ti} \tag{2.4}$$

where

f_{us} = fraction of total COD which is unbiodegradable soluble (mgCOD/mgCOD)

f_{up} = fraction of total COD which is unbiodegradable particulate (mgCOD/mgCOD).

Hence from Eq (2.2)

$$S_{ui} = (f_{us} + f_{up})\, S_{ti} \tag{2.5}$$

Since by convention the mixed liquor solids concentrations in the biological reactor are expressed in terms of VSS units rather than COD units, it is convenient to express the unbiodegradable particulate influent fraction in terms of its influent volatile solids concentration, (X_{Ii}). This is readily accomplished by noting that the COD and VSS are related via f_{cv}, the COD to VSS ratio:

$$X_{Ii} = S_{upi}/f_{cv} = f_{up} \cdot S_{ti}/f_{cv} \tag{2.6}$$

where

X_{Ii} = unbiodegradable particulate organics concentration in the influent expressed as VSS (mgVSS/ℓ).

f_{cv} = COD to VSS ratio of the solids
= 1,48 mgCOD/mgVSS.

It should be noted that this unbiodegradable particulate organic material cannot be directly measured as VSS in the influent. The VSS in the influent consists of both biodegradable and unbiodegradable particulate organics. This combined particulate organic VSS material can only be separated into its unbiodegradable and biodegradable constituent components by means of biodegradability tests, such as those described in Chapter 3.

Biodegradable COD fractions

The biodegradable COD concentration is found from Eq (2.1) as follows:

$$S_{bi} = S_{ti} - S_{ui} - Z_{BHi} \tag{2.7a}$$

and from Eq (2.5)

$$= S_{ti} - S_{ti} (f_{up} + f_{us}) - Z_{BHi}$$
$$= S_{ti} (1 - f_{up} - f_{us}) - Z_{BHi} \tag{2.7b}$$

From Fig 2.3 the *biodegradable* COD, S_{bi}, is divided into *readily biodegradable soluble* COD (S_{bsi}), and *slowly biodegradable particulate* COD (S_{bpi}). Each can be expressed in terms of S_{bi} as follows:

$$S_{bsi} = f_{bs} S_{bi} \tag{2.8a}$$

and

$$S_{bpi} = (1 - f_{bs}) S_{bi} \tag{2.8b}$$

where

f_{bs} = fraction of influent *biodegradable* COD which is readily biodegradable (mgCOD/mgCOD)

The readily biodegradable COD can also be expressed in terms of the *total* COD, S_{ti}, i.e. substituting for S_{bi} from Eq (2.7) in Eq (2.8) yields

$$S_{bsi} = \left\{ f_{bs} (1 - f_{up} - f_{us}) S_{ti} - Z_{BHi} \right\} \tag{2.9a}$$

$$= f_{ts}\, S_{ti} \qquad (2.9b)$$

where

f_{ts} = fraction of influent total COD which is readily biodegradable (mgCOD/mgCOD).

For BEPR systems, the readily biodegradable COD (S_{bsi}) is subdivided in fermentable readily biodegradable COD (S_{bsfi}) and SCFA (S_{bsai}), i.e.

$$S_{bsi} = S_{bsfi} + S_{bsai} \qquad (2.10)$$

Each of these can be expressed in terms of S_{bsi} as follows:

$$S_{bsai} = f_{Sbs,a}\, S_{bsi} \qquad (2.11)$$

$$S_{bsfi} = f_{Sbs,f}\, S_{bsi} \qquad (2.12a)$$

$$= (1-f_{Sbs,a})\, S_{bsi} \qquad (2.12b)$$

where

$f_{Sbs,a}$ = fraction of readily biodegradable COD which is SCFA (mgCOD/mgCOD)

$f_{Sbs,f}$ = fraction of readily biodegradable COD which is fermentable (mgCOD/mgCOD)

The SCFA can be expressed also in terms of the total COD, S_{ti}, i.e.

$$S_{bsai} = f_{S,bsa}\, S_{ti} \qquad (2.13)$$

where

$f_{S,bsa}$ = fraction of total COD which is readily biodegradable SCFA (mgCOD/mgCOD)

2.3.3 Typical wastewater COD characteristics

Values for typical South African wastewater COD characteristics are listed in Table 2.1. Table 2.1 shows that for raw (unsettled) wastewater, about 7% of the total COD is unbiodegradable soluble, 15% unbiodegradable particulate, 58% slowly

biodegradable (particulate) and 20% readily biodegradable (soluble).

2.4 FACTORS INFLUENCING WASTEWATER CHARACTERISTICS

A number of factors influence the characteristics or nature of the wastewater to be treated. Broadly these can be divided into the following categories:

- Input to the sewer
- Transformations in the sewer
- Physical/chemical treatment prior to the activated sludge system.

2.4.1 Input to the sewer

Input to the sewer depends on the community served. The relative contribution by industry and the types of industry discharging to the sewer have a major effect on wastewater characteristics (e.g. on maximum specific growth rate of nitrifiers). The wastewater characteristics presented above are valid for municipal wastewaters with a relatively minor industrial contribution, < say 30% of COD load (WRC, 1984). For the domestic portion of the wastewater, a number of factors are of importance: Availability of water resources (restricted water resources cause low water usage with resultant high strength > 1 500 mgCOD/ℓ, low flow wastes and *vice versa*), socio–economic status of the community (higher income communities use more water per capita), community diet (consumption of meat, etc), use of detergents (phosphorus based or phosphorus free), customs (use of garbage grinders, etc), use of on–site pretreatment (e.g. septic tanks), are some of the many factors of major importance. For example, caution should be exercised when selecting an unbiodegradable particulate COD fraction (f_{up}): Social organization of the community for whom the wastewater treatment system is envisaged can have a substantial influence on this parameter. Analyses of data reported by Sutton *et al.* (1979) from Canada indicate that the f_{up} fraction is 0,25 for raw wastewater. Such a high value probably arises from the use of garbage grinders. A similarly high f_{up} is used in the design procedure followed by Black and Veatch (1979) [based on McKinney's activated sludge model] which includes an unbiodegradable organic material fraction which is equivalent to an f_{up} value of 0,23. Wastewaters with high f_{up} fractions will result in greater sludge production than those with low fractions and selecting too low a value will result in under provision of reactor volume and sludge handling facilities.

The use of separate or combined sewers has a major influence on wastewater

characteristics, in particular on wastewater strengths and flows: Combined sewers have greatly reduced strengths due to dilutions, and much larger flows with increased variability due to storm flows than separate sewers. In South Africa separate sewers are mandatory by legislation; in Europe a mixture of combined and separate sewers are used. The degree of infiltration into the sewer by rainwater or sand/grit etc. will also influence the wastewater characteristics and therefore wastewater treatment plant behaviour.

2.4.2 Transformations in the sewer

In its transport through the sewer, the wastewater may undergo transformations. The nature and extent of these transformations will depend on the conditions prevailing in the sewer; residence time, temperature, aeration state and scour velocity. For anaerobic sewers with long residence times, sulphate reduction and acid fermentation may occur; for aerobic sewers, COD reduction and significant growth of heterotroph (and sometimes even autotroph) active biomass may occur. In South Africa, sewers are predominantly anaerobic so that heterotroph active biomass growth is restricted and residence times short so that very little acid fermentation occurs.

2.4.3 Physical/chemical treatment prior to the activated sludge system

For the activated sludge system in the wastewater treatment plant, the preceding unit operations for physical treatment will influence the wastewater characteristics. While unit operations such as grit removal, fats and oils removal by, for example, dissolved air flotation, will exert some influence, the unit operations that have a dominant effect are primary sedimentation and flow balancing. With primary sedimentation, the COD load on the activated sludge system is considerably reduced (± 40%), but a smaller reduction is obtained for the TKN and total phosphate, TP (± 15–20%). This has the effect that settled wastewaters have higher TKN/COD and TP/COD ratios than raw wastewaters, see Table 2.1.

In Europe chemically assisted primary sedimentation to effect chemical P removal is sometimes implemented. This significantly increases the COD removal (to around 60%) and produces a settled wastewater with very low COD, high free and saline ammonia (FSA), and low orthophosphate (OP). Primary sedimentation with or without chemical assistance, has a marked effect on the relative contribution of the COD fractions because the particulate [eg. components (eg. S_{up}, S_{bp})] are removed, the soluble components (eg. S_{us}, S_{bs}) not. This causes that the soluble COD, TKN

and TP fractions make up a larger proportion of the remaining settled wastewater COD, TKN and TP concentrations than in raw wastewater. The reduced COD loads through including primary sedimentation have a marked effect on the design; sludge production, reactor volume, oxygen demand, etc. will all be reduced, (WRC, 1984).

With the implementation of biological excess phosphorus removal, acid fermentation of primary sludge is a desirable option. This has the effect of decreasing the TP/RBCOD ratio, making the conditions for P removal more favourable (see Wentzel *et al.*, 1990; Pitman, 1991).

With flow balancing, the daily COD, TKN and TP loads to the plant are not affected with the result that the biological reactor volume is not reduced. However, flow balancing reduces the amplitudes in diurnal flow load variations which cause a marked reduction on peak oxygen demand, and secondary settling tank surface area (WRC, 1984).

2.5 CLOSURE

In this Chapter characterization of the wastewater carbonaceous (C) material fractions (measured in terms of the COD parameter), required for design and simulation models, has been described. There are numerous pitfalls in selecting wastewater characteristics uncritically and without recognition of the factors which contribute to the nature and composition of the wastewater – the importance of careful and considered wastewater characteristic selection must be emphasized as the system design and predicted response will only be as good as the selected wastewater characteristics are representative of the particular wastewater. For this reason it is imperative that for design and simulation of activated sludge systems, the wastewater fractions are accurately quantified. To achieve this, experimental measurement techniques must be available that are simple and practical to use, yet still provide estimates with acceptable accuracy. In the next Chapter the experimental techniques available in the literature to quantify wastewater C fractions will be reviewed.

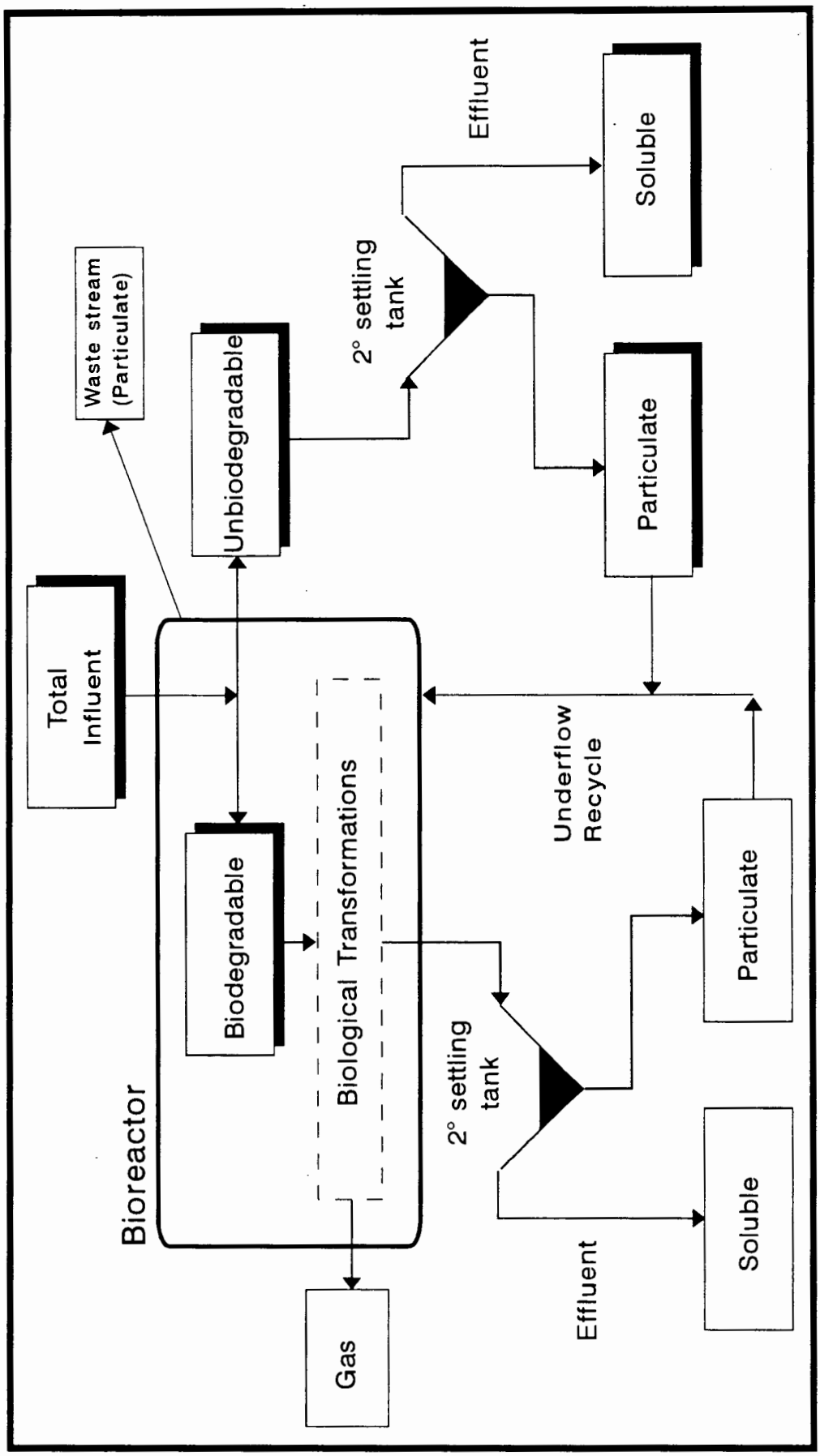

Fig 2.1: Division of influent wastewater carbon (C), nitrogen (N) and phosphorus (P) materials according to the biological and physical processes in the activated sludge system.

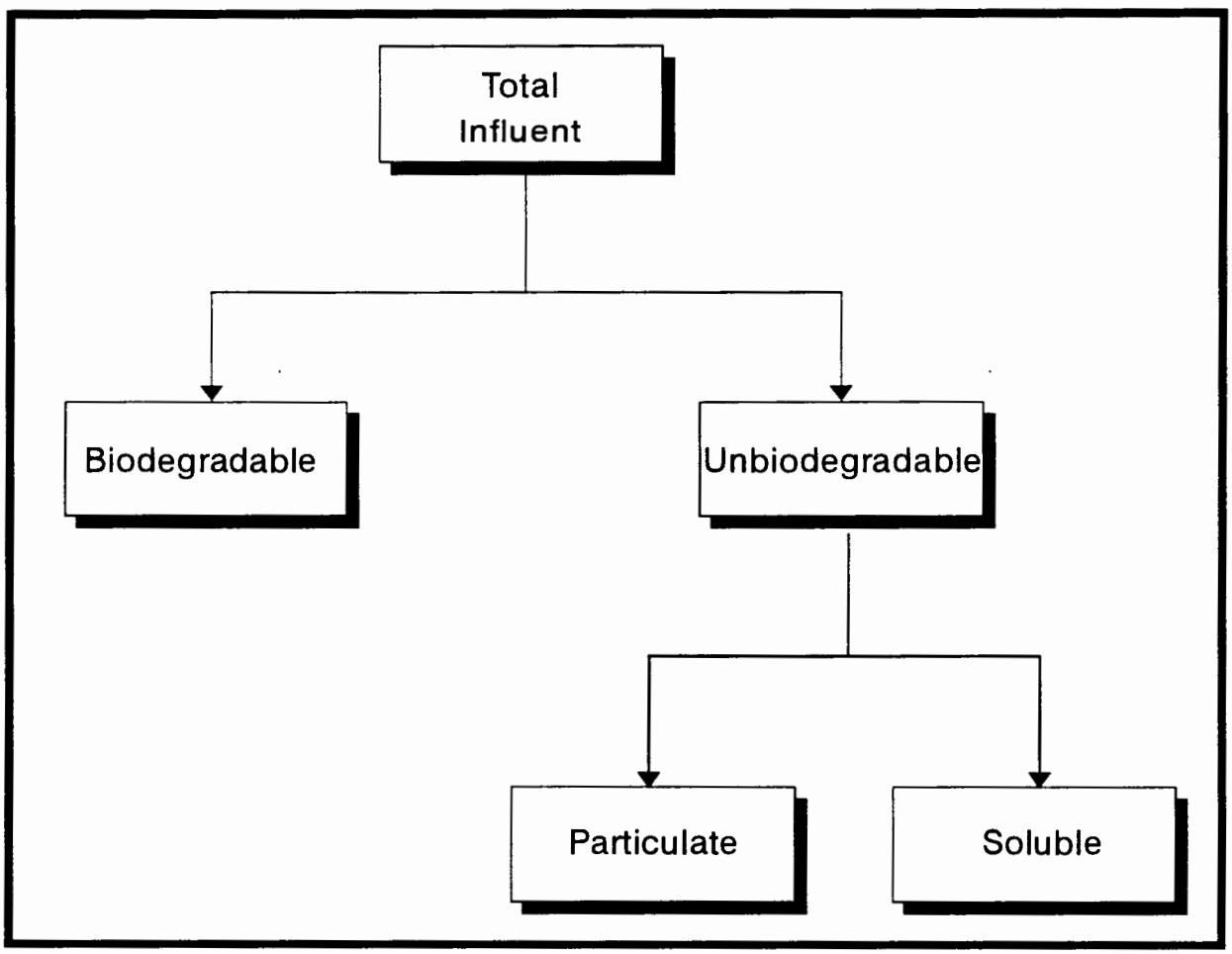

Fig 2.2: The general wastewater characterization structure for carbon (C), nitrogen (N) and phosphorus (P) material.

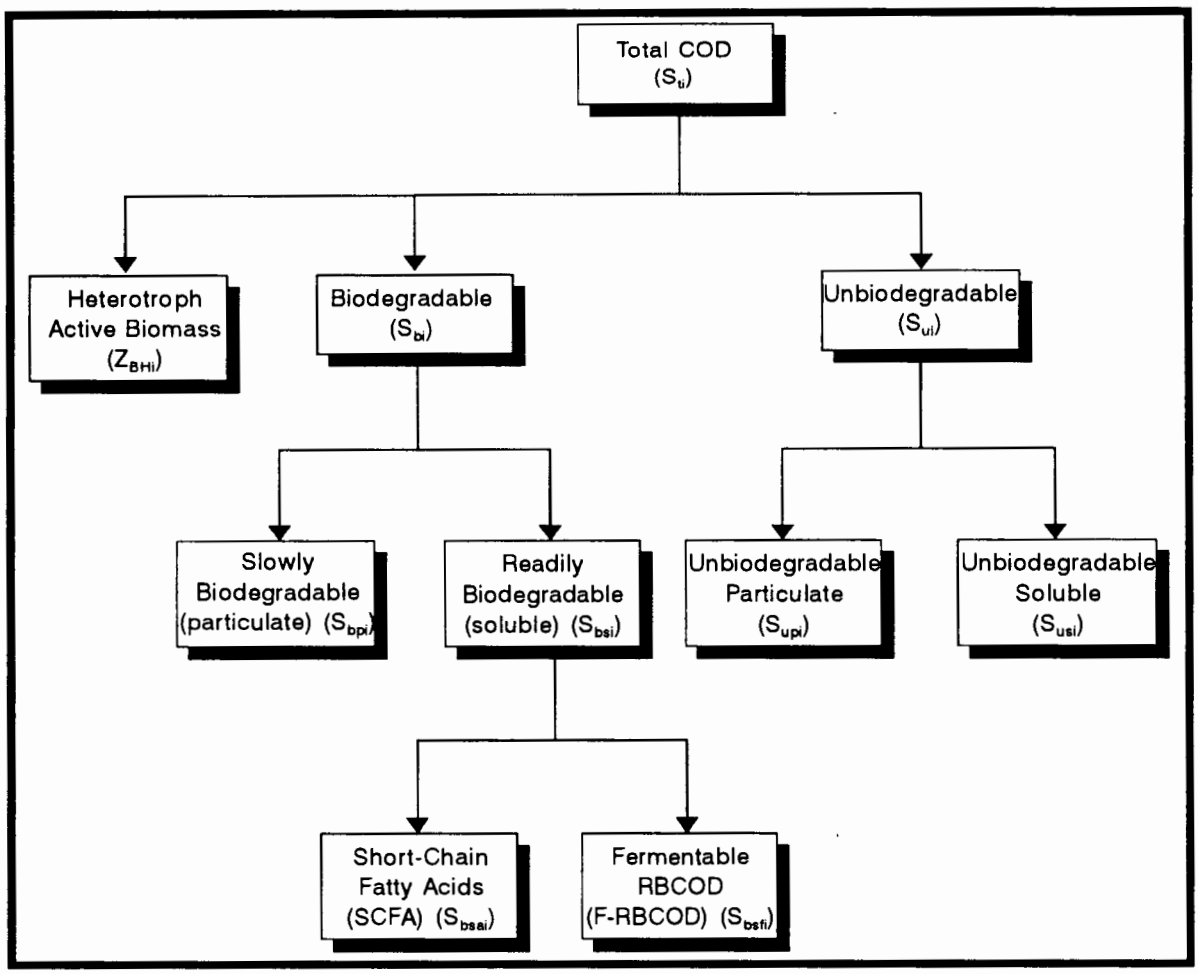

Fig 2.3: The division of COD into its different constituents.

TABLE 2.1: Representation of the magnitude of the different COD fractions in a typical South African municipal wastewater.

WASTEWATER COMPONENT		TYPICAL RANGE OF VALUES		UNITS
SYMBOL	DESCRIPTION	RAW	SETTLED	
COD				
S_{ti}	Total influent COD concentration	500 - 1 200	350 - 750	mgCOD/ℓ
f_{us}	Fraction of total COD which is unbiodegradable soluble	0,04 - 0,10	0,05 - 0,20	mgCOD/mgCOD
f_{up}	Fraction of total COD which is unbiodegradable particulate	0,07 - 0,20	0,00 - 0,10	mgCOD/mgCOD
f_{ts}	Fraction of total COD which is readily biodegradable (soluble)	0,08 - 0,25	0,10 - 0,35	mgCOD/mgCOD
f_{bs}	Fraction of biodegradable COD which is readily (soluble)	0,10 - 0,30	0,12 - 0,40	mgCOD/mgCOD
$f_{Sbs,a}$	Fraction of readily biodegradable (soluble) COD which is SCFA	0,10 - 0,40	0,10 - 0,40	mgCOD/mgCOD
$f_{Sbs,f}$	Fraction of readily biodeg. (soluble) COD which is fermentable	0,60 - 0,90	0,60 - 0,90	mgCOD/mgCOD
f_{CV}	COD/VSS ratio	1,45 - 1,50	1,45 - 1,50	mgCOD/mgVSS
$F_{SR,S}$	Fraction of total COD removed in primary settling	0,30 - 0,60	-	%
OTHERS				
μ_{nm}	Maximum specific growth rate of nitrifiers	0,20 - 0,80	0,20 - 0,80	/d
TKN/COD	Influent TKN/COD ratio	0,07 - 0,10	0,09 - 0,12	mgN/mgCOD
TP/COD	Influent TP/COD ratio	0,015 - 0,025	0,02 - 0,30	mgP/mgCOD
BOD_5	Influent BOD_5 concentration	250 - 600	150 - 375	mgBOD/ℓ
T_{min}	Minimum temperature	10 - 15	10 -15	°C
T_{max}	Maximum temperature	20 - 30	20 - 30	°C
Alk	Alkalinity	200 - 400	200 - 400	mg/ℓ as $CaCO_3$

CHAPTER 3

EXISTING METHODS FOR QUANTIFICATION OF WASTEWATER COD FRACTIONS

3.1 INTRODUCTION

In Chapter 2 the basis for subdivision of the influent wastewater carbonaceous materials (measured in terms of the COD parameter) into a number of fractions has been set out. In this Chapter existing methods to quantify these COD fractions will be reviewed, to identify their strengths and weaknesses and to select the more promising for evaluation and further development.

3.2 QUANTIFICATION METHODS

3.2.1 Readily biodegradable COD (RBCOD) measurement

The readily biodegradable COD (RBCOD) has been identified as being of fundamental importance in design and operation of N (van Haandel *et al.*, 1982) and N and P (Siebritz *et al.*, 1983; Wentzel *et al.*, 1985; Nicholls *et al.*, 1985; Wentzel *et al.*, 1990; Pitman, 1991) removal systems; the magnitude of both N and P removal has been linked to the magnitude of the influent RBCOD.

A number of methods have been proposed for measurement of RBCOD. These can be categorized as (1) physical or (2) bioassay methods.

(1) Physical methods:

The division of the biodegradable COD into the two fractions, RBCOD and slowly biodegradable COD (SBCOD) was originally based on the observed difference in response of activated sludge system biomass to the two fractions (see Chapter 2), i.e. the division was biokinetically based (Dold *et al.*, 1980; see Chapter 2). It has been hypothesized that the difference in biokinetic response of activated sludge to RBCOD and SBCOD (see Chapter 2) is due to differences in molecule size - RBCOD consists of relatively small molecules that are readily transported into the cell whereas SBCOD consists of larger more complex molecules that require breakdown (hydrolysis) to smaller units before uptake and utilization (Dold *et al.*, 1980; Dold *et al.*, 1986; see Chapter 2). Accordingly, physical separation of the two biodegradable COD fractions on the basis of molecular size has been proposed as an approximation of the biokinetic division. For the physical separation, filtration has been proposed. The basis for the filtration method is that influent wastewater

samples are filtered and the COD of the filtrate determined. Ideally, both the biodegradable and unbiodegradable soluble fractions (i.e. RBCOD and S_{usi} respectively) would be present in the filtrate. To separate out the unbiodegradable soluble COD fraction (S_{usi}), effluent from an activated sludge reactor is also filtered and the COD of the filtrate determined. Noting that all the biodegradable soluble COD (i.e. RBCOD) will be removed in the activated sludge system, provided the sludge age is in excess of about 3 days, then the effluent filtrate COD should provide a close estimate of the unbiodegradable soluble COD (S_{use}). Assuming that the unbiodegradable soluble COD in the effluent (S_{use}) equals the influent unbiodegradable soluble COD (S_{usi}), then the biodegradable soluble COD (i.e. RBCOD) can be found by difference, i.e.

RBCOD = (influent - effluent) filtrate COD.

Two problems are apparent in assessing this proposed method (Dold *et al.*, 1986):

(1) It is assumed that the effluent filtrate COD closely equals the influent unbiodegradable soluble COD (S_{usi}). This implies that there is no significant generation of unbiodegradable soluble COD within the system.

(2) The soluble/colloidal material in municipal wastewaters may span a wide range of molecular sizes and weights. The problem is to select an appropriate filter pore size that will give a separation that matches the biokinetic division of the biodegradable COD, that is, a filter pore size, which will allow the passage of RBCOD (and unbiodegradable soluble COD) through, but will retain the SBCOD (and unbiodegradable particulate COD).

These two aspects are dealt with below.

A. *Effluent Filtrate COD:*

The filterable (or "soluble") portion of the effluent COD from an activated sludge system is made up of a wide range of organic compounds. Dold *et al.* (1986) have reviewed a number of investigations that used a variety of experimental techniques to characterize and fractionate secondary effluents. Amongst these methods were, sedimentation and centrifugation (e.g. Hunter and Heukelekian, 1960), dialysis membranes (e.g. Bunch *et al.*, 1961), ultrafiltration membranes (e.g. Saunders and Dick, 1981), gel permeation chromatography (e.g. De Walle and Chian, 1974). In

comparing the results from these investigations, Dold *et al.* (1986) conclude that secondary effluents contain a wide range of organics, from low molecular weight volatile acids to high molecular weight polymeric compounds.

With regard to the origin of these compounds, there are three possible sources: (1) the influent COD, (2) intermediates and end products of metabolic pathways, and (3) products from cell lysis and death. In terms of the proposed filtration methods, all organics in the filtered effluent are assumed to originate from (1) the influent COD. It is assumed that the contribution from the other two possible sources is negligible. Information in the literature on this aspect is reviewed below:

(2) Intermediates and end products: Products of the metabolic activities of organisms in a system will be present within the organisms, and may accumulate to appreciable levels (as a result of, for example, malfunctions in the control mechanisms). Because the accumulated products will diffuse out of the cell at a rate proportional to the concentration gradient across the cell membrane, these materials, although possibly degradable, will be present in the liquid phase and therefore also in the effluent – the magnitude of the residual amount of this material will depend *inter alia* on the rate of its degradation (Chudoba *et al.*, 1969; Grady and Williams, 1975; Daigger and Grady, 1977).

Perhaps the strongest evidence demonstrating the presence of intermediates and end products in the effluent is the molecular weight fractionation work of Leidner *et al.* (1984) using low–pressure gel chromatography: In Fig 3.1, the lower line shows the molecular weight distribution (MWD) of the dissolved organic carbon (DOC) in the effluent from a laboratory unit treating a mixture of glucose and glutamic acid; the upper line represents the MWD of the influent. Component–selective tests for glucose and glutamic acid in the effluent were negative, indicating that the DOC in the effluent was derived from microbial sources only. Parallel tests were conducted on cell–free extracts of the biomass from the system, see Fig 3.2. That is, samples of sludge were centrifuged, washed and broken up to release the liquid contents (extract); the particulate matter then was removed by filtration. As is apparent in Fig 3.2, MWD fractionation of the cell–free extract showed only two peaks for compounds at the extremes of the range. These peaks appear to correspond to the two peaks at the extremes in the effluent MWD plot

(Fig 3.1). This strongly supports the proposal that products of the metabolic activities of organisms in a system are present in the effluent. These results were corroborated by Grady *et al.* (1984), who also identified two peaks in the effluent MWD using ultrafiltration fractionation and COD measurements.

(3) Cell lysis products: Researchers have also proposed that residual matter from cell lysis and death will add to the soluble COD from microbial origin (Saunders and Dick, 1981; Gloor *et al.*, 1981; Leidner *et al.*, 1984; Chudoba, 1985; Namkung and Rittman, 1986). Again confirmatory evidence for this proposal is provided by the results of Leidner *et al.* (1984). The MWD in Fig 3.2 for the cell–free extract exhibits only two peaks, whereas the effluent MWD in Fig 3.1 exhibits an indistinct distribution of compounds between the two peaks. This intermediate weight fraction would suggest that compounds present in the effluent have their origin from a source other than the influent or organism intermediate and end products, namely cell lysis products. The widespread MWD of these compounds would suggest that lysis products produced are subject to some degree of hydrolysis and degradation.

From the review above, it is evident that there exists a strong possibility for generation of unbiodegradable soluble COD in the activated sludge system, either from organism intermediate and end products or cell lysis products. However, the review provides no guidance on the relative magnitude of this generation compared to the unbiodegradable soluble COD derived from the influent. The magnitude of the contribution of the two microbial sources above to the effluent soluble COD will determine the viability of the proposed separation method. If the contribution is large then the method will fail because the assumption that the unbiodegradable soluble COD in the effluent is near equal to that in the influent will be incorrect. However, if the microbial generation within the system is small compared to the influent soluble COD fractions (RBCOD, S_{bs}, and unbiodegradable soluble COD, S_{us}), then the error introduced in the test will be small.

Some guidance on this aspect can be found in the literature. The experimental work of Chudoba (1985) on batch and continuous flow laboratory systems treating artificial *pure biodegradable* substrates has shown that the effluent COD is approximately 1 percent of the influent COD, that is, for an influent COD of 500 mgCOD/ℓ the effluent COD, which must originate from microbial activity, would be 5 mgCOD/ℓ. With the *pure substrate glucose* as influent feed, Germirli

et al. (1991) and Boero *et al.* (1991) found that microbial generation was higher than that observed by Chudoba *et al.*, approximately 2,5 to 3 percent of influent COD. This would indicate that for an influent COD of 500 mgCOD/ℓ, approximately 15 mgCOD/ℓ would be microbially generated. Assuming that similar quantities of unbiodegradable soluble COD are generated in a wastewater treatment plant, then for a municipal wastewater of 500 mgCOD/ℓ the amount generated of 5–15 mgCOD/ℓ may be significant compared to typical measured filtered effluent CODs of 25–60 mgCOD/ℓ (WRC, 1984). Comparing the highest measured microbial unbiodegradable soluble COD generated (15 mgCOD/ℓ) with the expected RBCOD (50–150 mgCOD/ℓ), the error introduced by neglecting microbial generation may be significant. However, in the literature quoted above artificial substrates were used. In the municipal wastewater treatment plant, due to the diversity of organics making up the influent it is likely that a much more diverse population would develop than in the artificial substrate fed systems. This should result in an increase in utilization of the microbially generated organics in wastewater treatment systems compared to pure cultures, or cultures grown on limited artificial substrates.

The work of Dold *et al.* (1986), Mamais *et al.* (1993) and Torrijos *et al.* (1994) using municipal wastewaters appears to confirm the above conclusion. Dold *et al.* (1986) and Mamais *et al.* (1993) compared results obtained using the proposed filtration method (i.e. assuming negligible microbial unbiodegradable soluble COD formation) with the conventional bioassay tests and found close correlation (see later). Torrijos *et al.* (1994) in an extensive investigation on quantifying wastewater COD fractions, monitored the degradation of different soluble COD molecular sizes in batch tests. They concluded that the distribution of organic compounds after degradation was closely equal to that before degradation, that is, no significant unbiodegradable soluble COD generation took place.

From the review above it would appear that generation of unbiodegradable soluble COD by microbial action in the activated sludge system does take place, but is negligible compared to that derived from the influent. However, any methods proposed that are based on the separation concept will have to be extensively evaluated by comparing the results with conventional bioassay tests.

B. ***Selection of filter pore size:***

The soluble/colloidal material in municipal wastewaters may span a wide range of

molecular sizes and weights. The problem is to select a filter pore size that will give a separation that matches the biokinetic division of the biodegradable COD, that is, a filter pore size that will allow the passage of RBCOD (and unbiodegradable soluble COD, S_{us}) through but will retain the SBCOD (and unbiodegradable particulate COD, S_{up}). Filtration methods with various filter pore sizes have been used (e.g. Dold *et al.*, 1986; Lesouef *et al.*, 1992; Mamais *et al.*, 1993; Bortone *et al.*, 1994; Torrijos *et al.*, 1994). In evaluating the effect of pore size, Dold *et al.* (1986) found that for domestic wastewater, membranes with cut–off < 10 000 molecular mass gave RBCOD that closely correlated with those determined by the conventional bioassay methods, see Fig 3.3. In contrast Bortone *et al.* (1994) found that with an industrial (textile) wastewater, membranes with cut–off < 10 000 molecular mass gave RBCOD very much lower (13% of total COD) than that measured in bioassay batch tests (20% of total COD). Recognizing that facilities for this type of ultrafiltration were not widely available, Dold *et al.* (1986) evaluated 0,45μm filters and found that with domestic wastewater a fraction of SBCOD and/or S_{up} passed through the filter causing the RBCOD to be overestimated, see Fig 3.4. Using 7–8 μm glass fibre filter papers the data of Lesouef *et al.* (1992) indicated similar results. To overcome this problem, Mamais *et al.* (1993) successfully investigated flocculation of colloidal material (SBCOD and/or S_{up}) before filtration through 0,45μm filters and obtained estimates for RBCOD that compared very favourably with those from the conventional flow–through square–wave bioassay test (see later). Torrijos *et al.* (1994) in an extensive investigation of the characteristics of a domestic wastewater, found that 0,1μm filters gave a true indication of RBCOD without the need for preflocculation.

In all the filtration methods, since both biodegradable and unbiodegradable soluble COD pass through the filter, the unbiodegradable fraction has to be quantified independently and subtracted from the COD of the filtrate to give the RBCOD. This requires effluent from a continuous flow–through activated sludge system (Dold *et al.*, 1986; Bortone *et al.*, 1994) or sequencing batch reactor (Mamais *et al.*, 1993; Torrijos *et al.*, 1993) which may not be available, or measurements of filtered COD over at least 10 days in batch tests (Lesouef *et al.*, 1992), a time–consuming task.

Of the filtration methods proposed, that of Mamais *et al.* (1993) appears to hold the most promise. By including the preflocculation step, the uncertainty regarding filter pore size appears to have been largely eliminated. Also, ultrafiltration, which is not widely available, does not have to be used – 0,45μm filters appear to be adequate for

this method. Accordingly the Mamais *et al.* method will be investigated in this research project.

(2) Bioassay methods:

Since the division between RBCOD and SBCOD is based on a biological response rather than a physical phenomenon, tests in which the response of activated sludge to wastewater is monitored, bioassay tests, have found wider application than the physical methods. A variety of bioassay tests have been developed to measure RBCOD. The basis for these tests is that environmental conditions are created which allow the difference in response of organisms to RBCOD and SBCOD to be monitored and separated.

Separation of the response of the biomass to RBCOD and SBCOD is based on the different rates of utilization of RBCOD and SBCOD (see Chapter 2). The rate of RBCOD utilization is much higher than that of SBCOD utilization, by an order of magnitude (Dold *et al.*, 1980). Because the rate of RBCOD utilization is higher, and its proportion in the wastewater much less than that of SBCOD, conditions can be created whereby the RBCOD and SBCOD are utilized simultaneously, and then SBCOD only is utilized. The difference between these two responses gives the response due to RBCOD utilization only. The bioassay tests to measure RBCOD can be categorized into three groups:

(1) Continuous flow–through activated sludge systems.
(2) Aerobic batch test methods.
(3) Anoxic batch test methods.

Each of these methods is described below.

A. *Continuous flow–through activated sludge systems*

This method involves monitoring the oxygen utilization rate (OUR) response in a single reactor aerobic activated sludge system with sludge recycle, operated at a sludge age of about 2 to 3 days under daily cyclic square wave loading conditions (12 hours with feed, 12 hours without feed). On feed termination there is a precipitous decrease in OUR after which the OUR remains near constant for a period before decreasing to a rate associated with endogenous respiration, see Fig 3.5. This behaviour was hypothesized to be due to the following (Dold *et al.*, 1980; Ekama *et al.*, 1986): During the feed period both RBCOD and SBCOD are

added to the reactor via the influent, and used simultaneously. The rate of utilization of RBCOD is system limited, that is, the RBCOD is utilized as fast as it is fed and so the feed rate limits the rate of utilization and the RBCOD concentration remains virtually zero. In contrast, the SBCOD is process limited, that is, the SBCOD is fed faster than the biomass can utilize it so that the biomass SBCOD maximum specific utilization (growth) rate limits the rate of utilization and SBCOD will accumulate in the reactor. On feed termination the supply of both RBCOD and SBCOD via the influent ceases. Since the RBCOD has been virtually completely consumed during the feed period, utilization of RBCOD also ceases and accordingly the OUR exhibits a precipitous drop. Since SBCOD has accumulated in the reactor during the feed period, utilization of SBCOD must continue. The conditions in the reactor (short sludge age, high load period) causes the utilization of SBCOD to continue at the maximum rate giving rise to the OUR plateau observed after feed termination. Also, the conditions in the system cause that nitrification, if present, continues at a maximum rate after feed termination. Thus, the precipitous drop in OUR observed after feed termination is due entirely to the RBCOD and hence the drop in OUR allows the RBCOD concentration to be determined (for details see Ekama *et al.*, 1986).

Sollfrank and Gujer *et al.* (1991) in an investigation of this method found difficulty in maintaining a constant temperature in the reactor on feed termination. They concluded that these variations in temperature will influence the nitrification rate, and so lead to an error in the RBCOD concentration determined from the precipitous drop in OUR. Accordingly, they proposed that nitrification be inhibited by addition of allyl thiourea (ATU) and that the loading rate be decreased by increasing the sludge age (to approximately 5 days). They found that these modifications improved the temperature stability in the system. However, the proposed increase in sludge age will increase the mass of organisms in the reactor which will cause SBCOD to be utilized more rapidly and so lead to situations where SBCOD does not accumulate sufficiently during the feed period to enable the SBCOD utilization to continue after feed termination for a period adequate to clearly identify the OUR plateau.

Although the continuous flow-through method has become the standard for measuring RBCOD, the method has been criticized for its cost and difficulty of operation (Sollfrank and Gujer, 1991).

B. *Aerobic batch test method.*

In this method a volume of wastewater is mixed with a volume of mixed liquor in an aerated and stirred batch reactor, and the OUR response monitored with time (e.g. Ekama *et al.*, 1986; Henze, 1991; 1992).

With the correct selection of the volumes of wastewater and mixed liquor, on mixing in the aerated, stirred batch reactor, the OUR remains constant at a plateau for a period of up to 3 hours depending on the wastewater RBCOD concentration, whereafter the OUR drops precipitously, then levels off at a second plateau, see Fig 3.6. This OUR–time profile is made up of the OURs for nitrification and for carbonaceous material utilization.

If ammonia concentration is greater than about 2 times the half saturation constant for nitrification (in the Monod formulation for the growth rate of the nitrifying autotrophs), the nitrification will take place at a maximum (and constant) rate. Consequently, if adequate ammonia is available at the start of the batch test (which is normally the case with domestic wastewater), and since the half saturation constant for the autotrophs is relatively small (K_{SA} = 1,0 mgN/ℓ, Dold *et al.*, 1980; Henze *et al.*, 1987), the nitrification rate will remain at a maximum and constant value over the test period giving rise to a constant nitrification OUR (Fig 3.6, Area 3).

Superimposed on the constant nitrification OUR is the OUR due to carbonaceous material utilization [Fig 3.6, Area 1 + Area 2(a & b)] which gives rise to the variation in the observed OUR with time. The interpretation of the carbonaceous OUR–time profile is as follows:

RBCOD and SBCOD are utilized independently but simultaneously by the heterotrophs for growth; RBCOD is directly absorbed and utilized while SBCOD is adsorbed extracellularly, hydrolyzed to smaller units which then are utilized directly. The summation of the OURs associated with RBCOD and SBCOD growth gives rise to the observed carbonaceous OUR. At the start of the batch test both RBCOD and SBCOD are present, and are utilized independently for growth, with associated OURs (Fig 3.6, Area 1 for RBCOD, Area 2a for SBCOD). The OUR is constant over the initial period because the RBCOD and SBCOD concentrations are sufficiently high to ensure that RBCOD utilization and SBCOD hydrolysis/utilization rates are close to their respective maxima. Once the influent

RBCOD is depleted, the OUR drops to the second plateau which is due to the maximum hydrolysis/utilization of SBCOD only (Fig 3.6, Area 2b). The magnitude of the drop in OUR is proportional to the heterotroph maximum specific growth rate on RBCOD, μ_H, and can be used to obtain an estimate for this constant (Fig 3.6). Also, the area under the OUR–time profile associated with RBCOD (Fig 3.6, Area 2) can be used to calculate the wastewater RBCOD concentration (see Ekama *et al.*, 1986; Dold *et al.*, 1991).

In operation of this test, the mass of COD (i.e. $V_{ww}*S_{ti}$, where S_{ti} = total COD concentration of the undiluted wastewater and V_{ww} = volume of wastewater) with respect to the mass of VSS (i.e. $V_{ml}*X_v$, where X_v = VSS concentration and V_{ml} = volume of mixed liquor) mixed in the batch test is known as the COD loading rate (LR). The LR established in the batch test should be such that the OUR response is well defined and allows (1) the initial peak OUR to be readily determined, (2) the magnitude of the precipitous drop in OUR to be clear, and (3) the area under the initial peak OUR (Fig 3.6, Area 1) to be accurately estimated (to calculate RBCOD). For the same wastewater volume changing the LR does not change the magnitude of Area 1, which is a function only of the mass of RBCOD in the wastewater sample, but it does change the shape of Area 1: If LR is too low (i.e. a higher mixed liquor volume), the shape is tall and narrow because the RBCOD is utilized very quickly, and too few measurements can be taken to give reasonable surety of initial high OUR; if LR is too high, the shape is low and wide and it is difficult to establish the magnitude of the drop in OUR (see Fig 3.7).

Selection of the optimal loading rate is not a simple task. The rate at which the organisms utilize the RBCOD (i.e. maximum specific growth rate), and hence the duration of the initial plateau, depends upon *inter alia* the conditions under which the mixed liquor has been generated (Ekama *et al.*, 1986). If the mixed liquor has been subjected to high LR (e.g. selector reactor) then it will exhibit rapid RBCOD utilization due to a high maximum specific growth rate.

The aerobic batch test method has been used successfully to derive estimates for RBCOD (e.g. Ekama *et al.*, 1986; Henze 1992; Kappelar and Gujer, 1992). However, for this method sludge acclimatized to the wastewater has to be obtained, either generated in special laboratory–scale continuous flow–through reactor (Ekama *et al.*, 1986; Sollfrank and Gujer, 1991; Kappelar and Gujer, 1992) or from a full–scale plant (Nicholls *et al.*, 1985). The requirement of a laboratory–scale

reactor for sludge generation for the batch method test does not resolve criticisms levelled at the flow-through method, while the option of obtaining a sludge from a full-scale plant may not be available if a new plant is to be designed and built. Furthermore, in batch tests the use of sludges from biological excess P removal (BEPR) systems will produce erroneous results for RBCOD due to the phenomenon of RBCOD uptake and storage with P release by polyP organisms under aerobic and anoxic conditions without the utilization of oxygen or nitrate (Still *et al.*, 1986; Wentzel *et al.*, 1989a; 1989b).

C. ***Anoxic batch test method.***

The basis of this test is identical to that for the aerobic batch test described above. The only difference is that instead of aerating the batch test contents and measuring the OUR, nitrate is added at the start of the test and the nitrate concentration is monitored over a period of approximately 4 to 5 hours (see Fig 3.8). In the absence of dissolved oxygen, nitrate serves the same function as oxygen, i.e. as electron acceptor. Therefore, in the anoxic batch test the nitrate concentration initially will decrease at a constant rapid rate reflecting the rate of utilization of RBCOD as well as SBCOD from the wastewater. The initial rapid rate of denitrification is constant, because the concentration of RBCOD is so high that the growth rate of the heterotrophs is at its maximum (μ_H) in accordance with Monod kinetics. Once the RBCOD from the influent is depleted, the denitrification rate reduces (i.e. the decrease in nitrate takes a flatter linear slope, Fig 3.7) to the rate of utilization of SBCOD; this slower denitrification rate is analogous to the second plateau in the aerobic batch test. The RBCOD concentration can be calculated from the mass of nitrate utilized during the initial rapid denitrification rate, see Ekama *et al.* (1986) and Henze (1991) for details.

With the anoxic batch test, the same restrictions and cautions identified for the aerobic batch test also apply.

Summary

The bioassay tests by their nature provide a good estimate for RBCOD – the concept of RBCOD (and SBCOD) was developed from observations made on one of the bioassay tests, the continuous flow-through system (Dold *et al.*, 1980; Ekama *et al.*, 1986). However, the bioassay tests all have a common shortcoming in that they require mixed liquor acclimatized to the wastewater being tested: In a continuous flow-through test this is generated in the same reactor in which the test

is done; in the batch test procedures it must be generated either in separate laboratory–scale reactors, or obtained from full–scale plants. The operation and maintenance of laboratory–scale systems is a difficult and costly exercise. Obtaining mixed liquor from a full–scale plant may not be possible if the plant is to be designed and built. Furthermore, as noted earlier mixed liquor from a biological excess phosphorus removal (BEPR) plant cannot be used in the batch test procedures.

From the above, it is evident that a bioassay test that does not require preacclimatized mixed liquor would be of considerable benefit; one of the intentions of this research was to develop such a test.

3.2.2 RBCOD subfractions

In Chapter 2 it was noted that if biological excess phosphorus removal (BEPR) is to be included in the activated sludge system, the RBCOD must be subdivided into two subfractions, short–chain fatty acids (S_{bsai}) and fermentable RBCOD (S_{bsfi}). A simple titration procedure has been presented in the literature to quantify S_{bsai} (Moosbrugger *et al.*, 1992;1993). With S_{bsai} and RBCOD quantified, S_{bsfi} can be determined by difference. Since a method is available in the literature, quantification of the RBCOD subfractions will not be addressed in this research project.

3.2.3 Influent heterotrophic active biomass measurement

The original UCT model (Dold *et al.*, 1980; van Haandel *et al.*, 1981) did not consider active biomass or autotroph biomass to be present in the influent; for municipal wastewaters in South Africa, the sewers generally are short (retention <6 hours) and anaerobic, and were considered unlikely to support active biomass generation. Further, simulations with the UCT model appeared to support this supposition. However, investigations in Europe have indicated that European municipal wastewaters can contain a significant heterotroph active biomass fraction (Henze, 1989), up to 20% of the total COD (Kappelar and Gujer, 1992). Seeding of this influent biomass to the activated sludge system can have a significant influence on modelling and design. For example, seeding of heterotroph active biomass with the influent can significantly influence the response of the activated sludge system at low temperatures, by ensuring that "washout" of organisms does not occur. Similarly, seeding of autotrophic biomass will cause that nitrification will be maintained at shorter sludge ages and/or lower temperatures than expected. These

findings have highlighted the need for a simple test to quantify this wastewater fraction.

In the literature there is scarcity of information on tests to quantify this wastewater fraction. Microbiological techniques have been proposed for analysis of mixed liquor from activated sludge systems which possibly could find application in wastewater characterization. For example, colony counts using a pour plate method (Gaudy and Gaudy, 1980), DNA analysis (Liebeskind and Dohmann, 1994; Blackall, 1994) and others. However, the majority of these techniques are still in their infancy, have not yet been adequately integrated with design and kinetic modelling theory and, in any event, require very sophisticated equipment and techniques that are not widely available. It is unlikely that these tests will find routine application in the design of activated sludge systems.

In contrast, Kappelar and Gujer (1992) describe a simple batch test to quantify heterotrophic active biomass in the activated sludge; a small quantity of activated sludge is mixed with centrifuged wastewater and oxygen utilization rate (OUR) response monitored with time. From the observed exponential increase in the OUR, the initial OUR in the batch test can be quantified which can be used to derive an estimate for the heterotroph active biomass concentration (see Chapter 4). Kappelar and Gujer note that the test can be adapted to quantify the heterotroph active biomass in wastewater by excluding the activated sludge, but details of this modification are sparse. However, the proposals of Kappelar and Gujer appear to hold promise for further development and will be investigated in this research.

3.2.4 Unbiodegradable soluble COD measurement

Measurement of the influent unbiodegradable soluble COD (S_{usi}) is relatively simple: For sludge ages greater than 3 days, all the RBCOD is consumed in the biological reactor and the SBCOD and particulate unbiodegradable COD are enmeshed in the mixed liquor and will settle out in the secondary settling tank (see Chapter 2). Thus, the only soluble COD from the influent that will be present in the effluent is the S_{us}. Furthermore, it can be assumed that the generation of unbiodegradable soluble COD by microbial action in the activated sludge system is negligible compared to that derived from the influent (for a detailed discussion on this aspect see Section 3.2.1 above). Accordingly, the effluent soluble COD in a long sludge age activated sludge system will equal S_{usi}: By running a steady state laboratory–scale unit at a sludge age greater than 3 days and measuring the filtered

(0,45μm) effluent COD, S_{use} can be determined; at steady state $S_{usi} = S_{use}$ (Ekama *et al.*, 1986). The difficulty with this method to determine S_{usi} is that running laboratory–scale activated sludge systems can be a time consuming and costly task. Lesouef *et al.* (1992) have shown that S_{usi} can be determined from an aerated batch test as the filtered COD after 10 days. With the method of Lesouef *et al.*, there is considerable delay in obtaining an estimate for S_{usi} (10 days). This research will investigate whether it may be possible to reduce the length of time required for the batch test without detrimentally affecting the estimate for S_{usi}.

3.2.5 Unbiodegradable particulate and slowly biodegradable CODs measurement

Measurement of influent unbiodegradable particulate (S_{upi}) and slowly biodegradable (S_{bpi}) COD fractions present difficulties as both contribute to the mixed liquor solids in the biological reactor (see Chapter 2): Measurement of the mixed liquor solids does not distinguish between the components making it up – active biomass, endogenous mass, S_{upi} and S_{bpi}, see Fig 3.9. S_{upi} and S_{bpi} can be estimated simultaneously by running a laboratory–scale unit at a long sludge age, say 15 days or longer, and comparing the measured mixed liquor volatile suspended solids (VSS) concentrations and carbonaceous oxygen consumptions to those calculated using theoretical design equations (WRC, 1984) with different S_{upi} values (Ekama *et al.*, 1986). The values for S_{upi} that give theoretical VSS and carbonaceous oxygen consumption equal to those measured will be the same provided the COD mass balance is 100%. If the COD mass balance is not 100%, using the VSS comparison will provide the more accurate estimate for S_{upi}. A long sludge age is selected because the mixed liquor VSS concentration becomes more sensitive to S_{upi} as the sludge age increases. Having found S_{upi}, S_{usi} and S_{bsi}, S_{bpi} then can be found by difference. Overall, the S_{upi}, S_{usi} and S_{bpi} must provide consistency between theoretical and measured responses at different sludge ages (Ekama *et al.*, 1986). It is evident that determining S_{upi} and S_{bpi} by running laboratory–scale activated sludge systems is a time consuming and costly exercise. Furthermore, S_{upi} (and thus S_{bpi}) can be estimated only via the hypothesized design equations (WRC, 1984) and in this regard it has meaning only in terms of the model structure.

Sollfrank and Gujer (1991) have proposed a method to determine S_{bpi} that provides an estimate in a relatively short time. The wastewater is centrifuged and the pellet is spiked into an activated sludge system in which the feed has been stopped. By monitoring the OUR response, an estimate of S_{bpi} could be obtained. However, not

all the S_{bpi} present in the wastewater will be centrifuged into the pellet; some will remain suspended in the supernatant so that the method will underestimate S_{bpi}. The S_{bpi} in the supernatant will have to be determined independently. Sollfrank and Gujer (1991) proposed that this be done in separate batch tests in which the supernatant is added to mixed liquor and the OUR response monitored. Due to the low concentration of particulate material in these batch tests compared to the high concentrations of soluble biodegradable material, it is unlikely that accurate estimates for S_{bpi} can be derived.

Kappelar and Gujer (1992) proposed that S_{bpi} be determined from the aerobic batch test described above for RBCOD determination, see Fig 3.6. After the precipitous drop in OUR, the OUR is due to nitrification and particulate carbonaceous material utilization. Kappelar and Gujer (1992) eliminated nitrification from the batch test by adding the inhibitor ATU. Thus, the OUR following the precipitous drop is due to SBCOD utilization only. However, this SBCOD is that derived from the influent and that formed from the death/lysis of heterotroph active biomass added to the batch test with the mixed liquor. Separation in a batch test of the OUR due to each of these two sources of SBCOD is not easy and introduces fairly large errors in the estimate of S_{bpi}, a problem that will become evident in the research presented here (see Chapter 8).

3.3 CONCLUSION

Quantification of the influent wastewater COD fractions is of crucial importance for modelling and design of wastewater treatment systems. Existing procedures to quantify wastewater COD fractions are either too elaborate or approximate; the need exists for simple, reliable methods for accurate estimation of these parameters.

From the review above, it would appear that two tests in particular hold promise for further evaluation and development:

- The flocculation/filtration method of Mamais *et al.* (1993).
- The batch test method of Kappelar and Gujer (1992).

In this research project these two methods will be investigated.

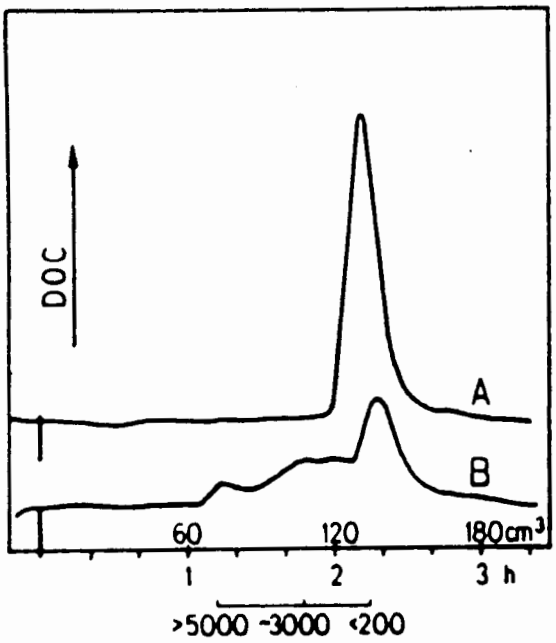

Fig 3.1: Molecular weight distribution of dissolved organic carbon (DOC) in the influent and effluent of laboratory activated sludge system treating a mixture of glucose and glutamic acid. (After Leidner *et al.*, 1984).

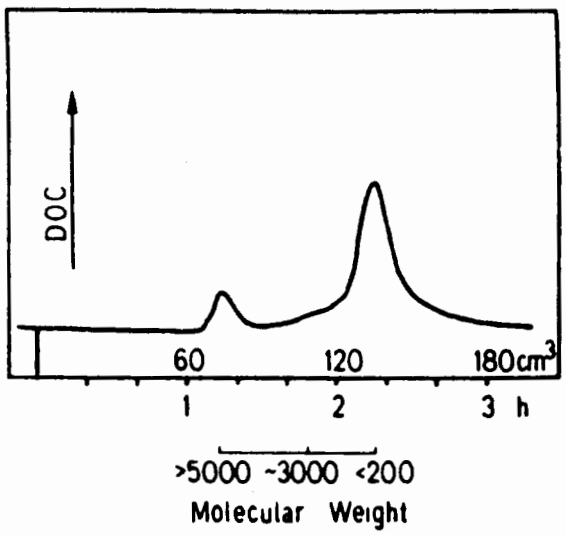

Fig 3.2: Molecular weight distribution of dissolved organic carbon (DOC) in the cell–free extract of sludge in a laboratory activated sludge system treating a mixture of glucose and glutamic acid. (After Leidner *et al.*, 1984).

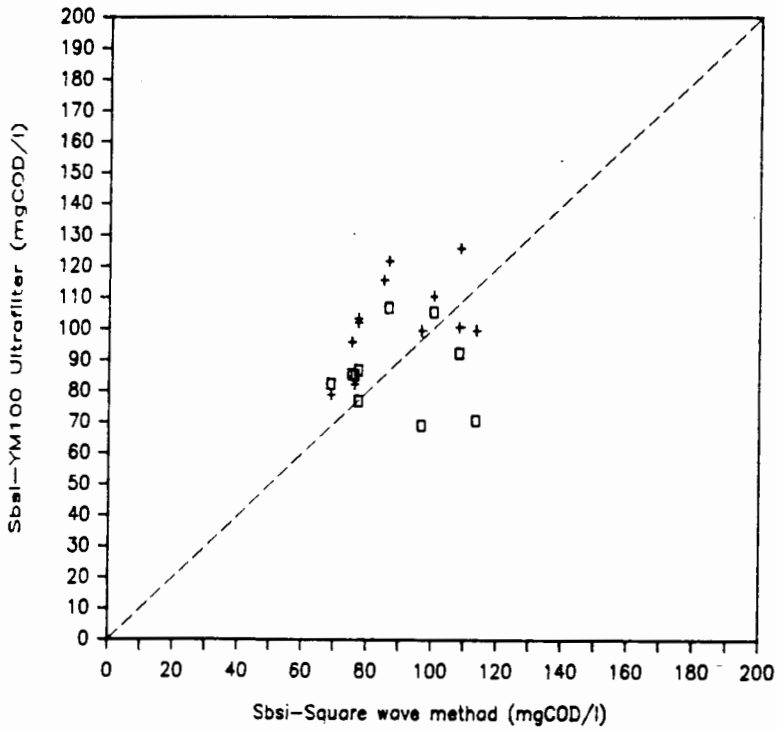

Fig 3.3: Examples of daily data pairs for a number of sewage batches, values of readily biodegradable COD (S_{bs}) determined by ultra-filtration plotted versus values obtained by the flow-through square wave method. (After Dold *et al.*, 1986).

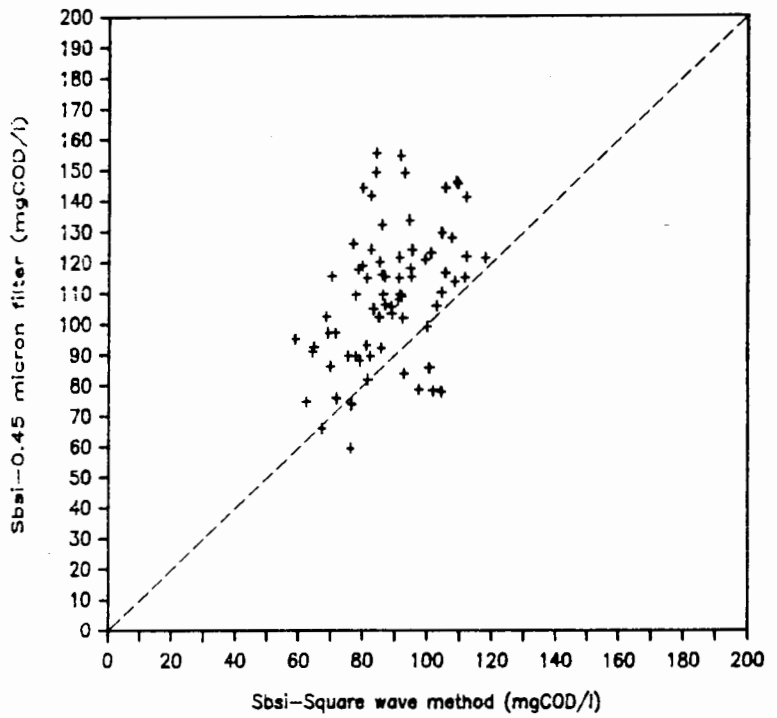

Fig 3.4: COD of raw wastewater 0,45μm filtrate plotted versus corresponding values of the readily biodegradable COD (S_{bs}) obtained by the flow-through square wave method. (After Dold *et al.*, 1986).

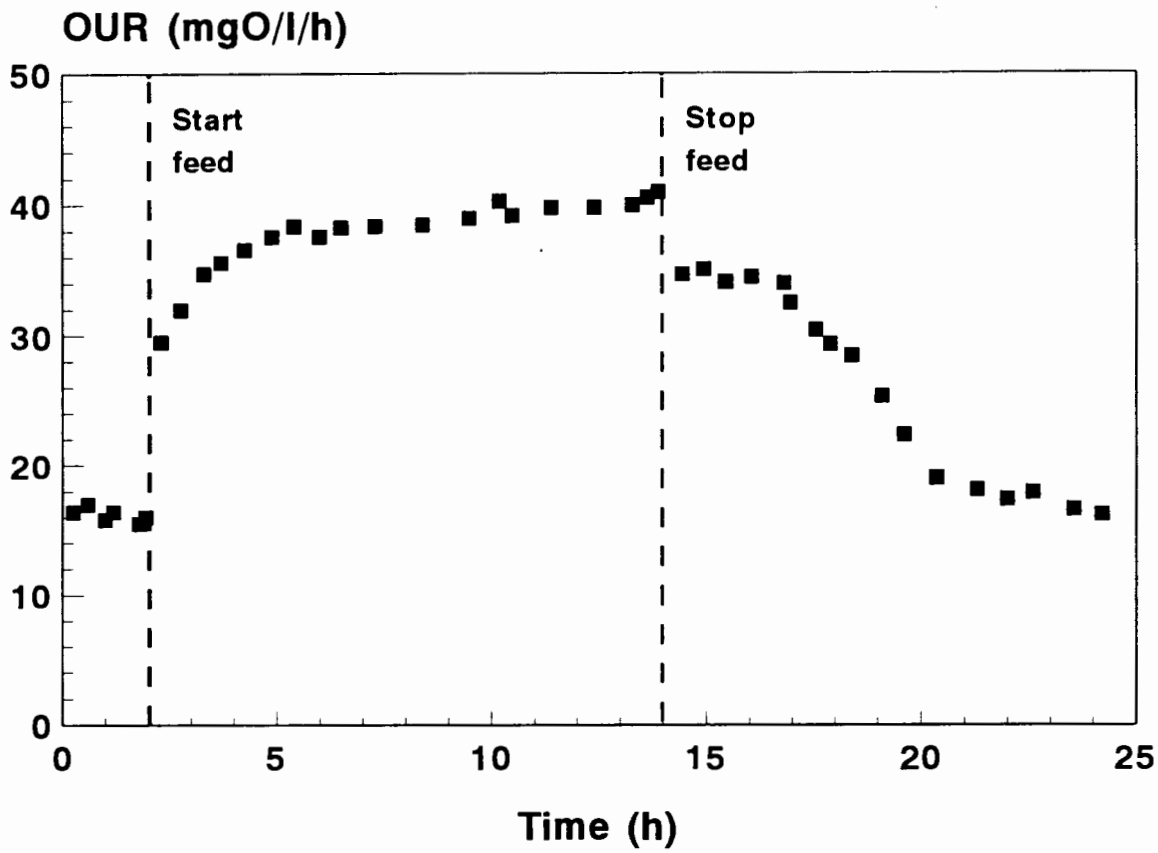

Fig 3.5: OUR response over one cycle in an aerobic activated sludge unit subjected to daily cyclic square wave feed (12h feed on, 12h feed off) with municipal wastewater as influent. (After Ekama *et al.*, 1986).

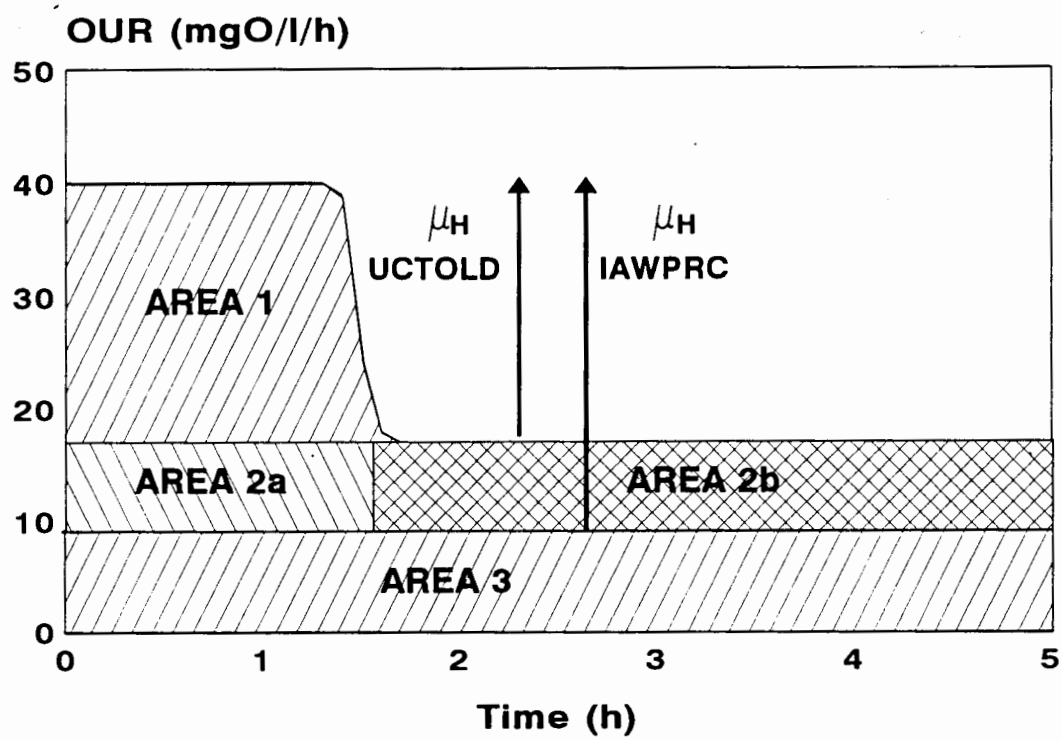

Fig 3.6: OUR–time profile for aerobic batch test with activated sludge addition, with nitrification. (After Dold *et al.*, 1991).

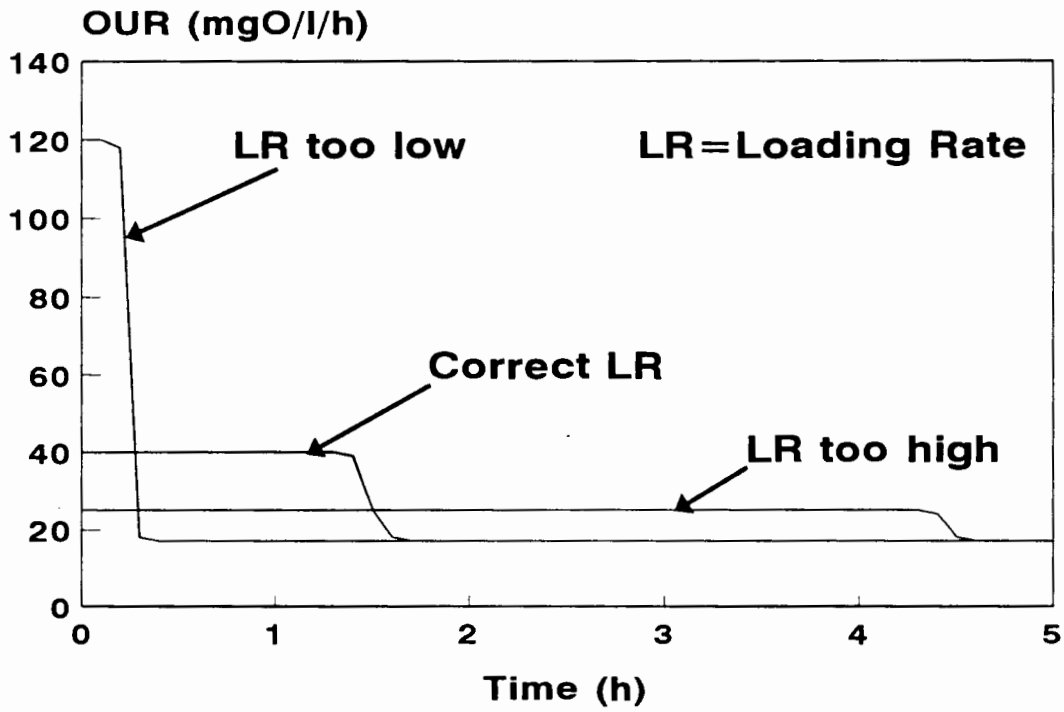

Fig 3.7: OUR–time profile for aerobic batch test to show the effect of loading rate on the shape of the OUR–time plot. (After Dold *et al.*, 1991).

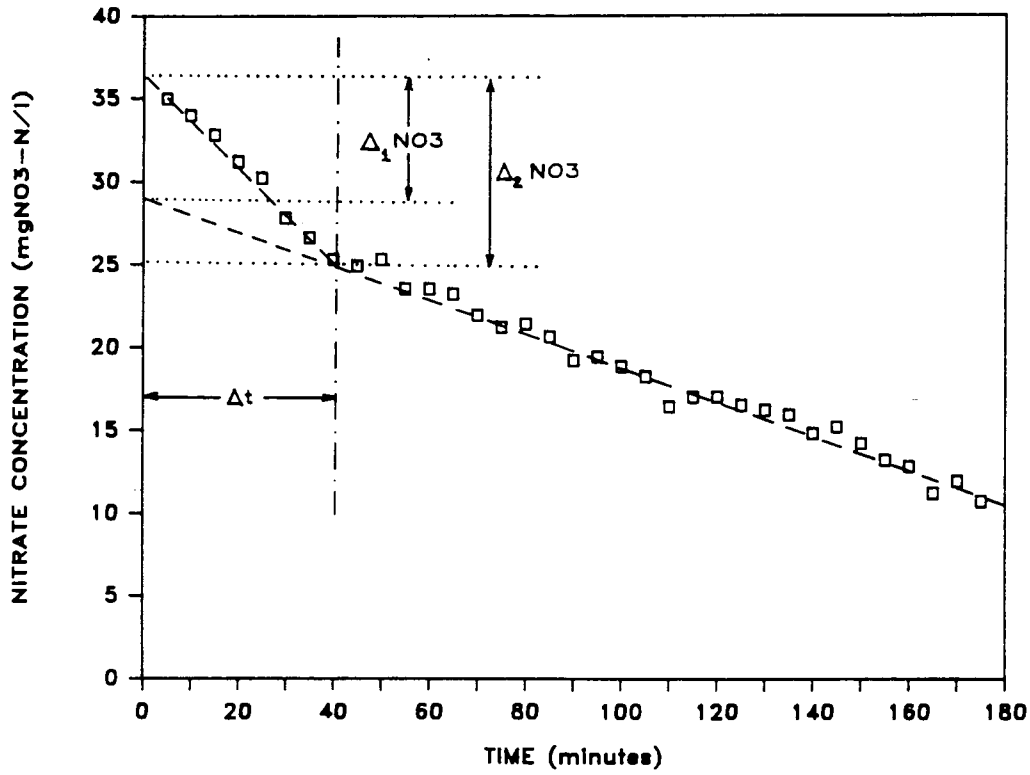

Fig 3.8: Example of nitrate concentration–time plot in an anoxic batch test for measuring the influent readily biodegradable COD concentration. (After Ekama *et al.*, 1986).

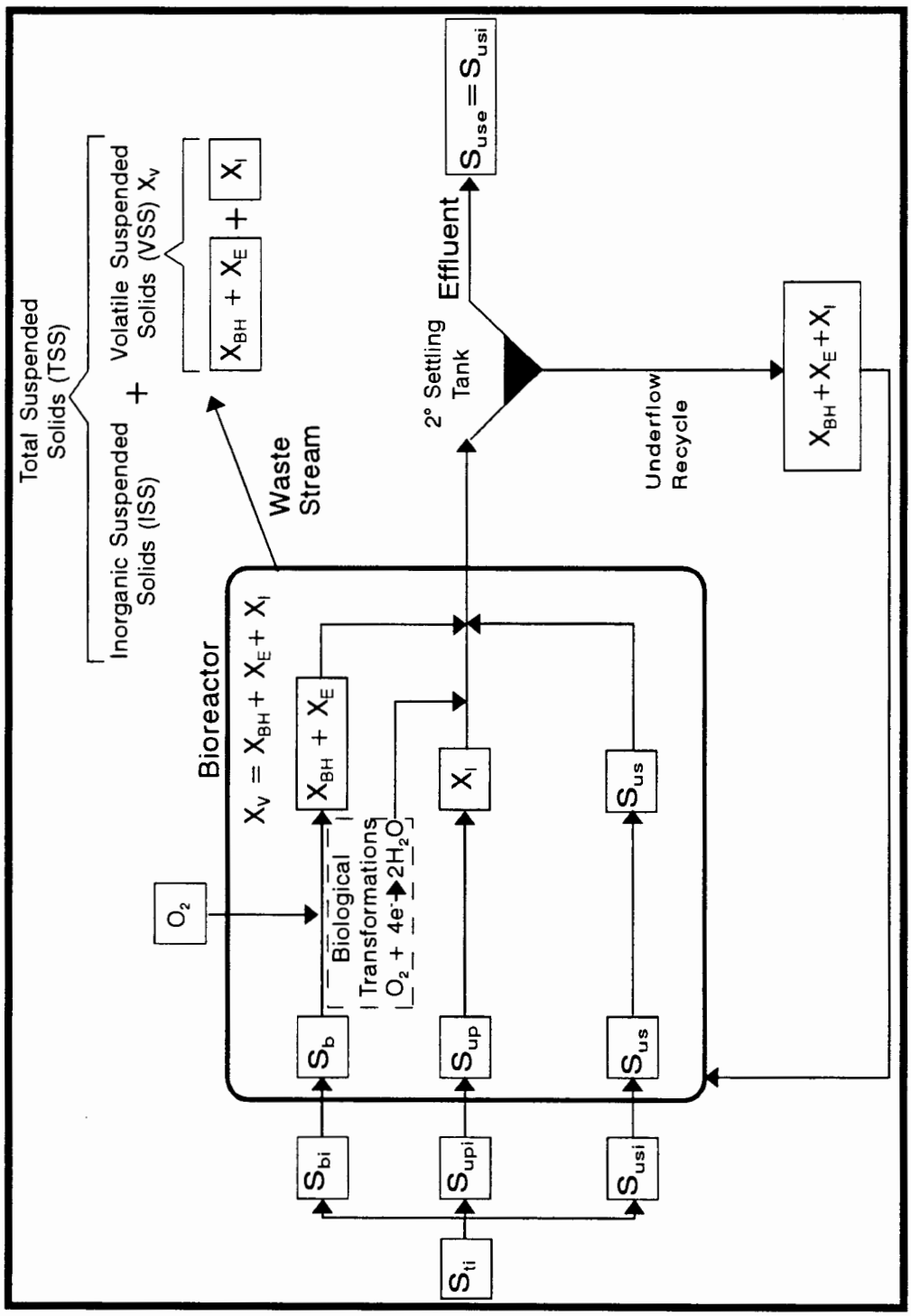

Fig 3.9: Schematic representation of the transformations of the influent COD fractions within the activated sludge system.

CHAPTER 4

BATCH TEST FOR MEASUREMENT OF READILY BIODEGRADABLE COD AND ACTIVE ORGANISM CONCENTRATIONS IN MUNICIPAL WASTEWATERS

4.1 INTRODUCTION

Quantification of influent wastewater RBCOD and heterotroph active biomass is of crucial importance for modelling and design of wastewater treatment systems. Further, from the review in Chapter 3 the need exists for simple, reliable methods for accurate estimation of these parameters. To this end, in this Chapter the batch test proposal of Kappelar and Gujer (1992) in which the OUR response of wastewater is monitored with time, will be refined and developed, to measure simultaneously the influent heterotroph active biomass and RBCOD concentrations.

4.2 TEST PROCEDURE

The batch test was done on wastewater samples *without* activated sludge seed. The wastewater samples were unsettled because the active organisms, being particulate, would largely settle out in the primary settling tank. The procedure for the batch test was as follows: A defined volume (3ℓ) of unsettled municipal wastewater, obtained from either Mitchell's Plain or Borcherds Quarry Treatment Plants, Cape Town was placed in a continually stirred batch reactor maintained at a constant temperature of 20° C. A sample was drawn to obtain the initial total COD concentration (Standard Methods, 1985). In operating the batch test, the surface of the wastewater was covered by small plastic balls to limit surface exchange of oxygen. The OUR was monitored continually using an automated technique (Randall *et al.*, 1991) - the DO was raised to 6 mgO/ℓ, the air switched off and the decrease in DO monitored, the rate of decrease giving the OUR; when the DO reached 4 mgO/ℓ, the air was switched on again and the cycle repeated. The pH of the reactor was monitored continually and controlled to pH 7,5 (± 0,2). Because of the low OUR values, regularly during an aeration cycle the walls of the reactor were thoroughly brushed to prevent particulate matter sticking to them. At intervals samples were drawn from the reactor, filtered (0,45μm) and analyzed for nitrate and nitrite. The tests were run for approximately 20 hours. At the end of the test the contents of the batch reactor were homogenized in a liquidizer, a sample drawn and total COD concentration measured.

4.3 RESULTS

Using the results of one batch test on Mitchell's Plain wastewater as an example, the OUR (mgO/ℓ/h) versus time (h) response is shown plotted in Fig 4.1. The initial and final COD concentrations were 821 and 481 mgCOD/ℓ respectively. No nitrate or nitrite was detected in the test indicating the absence of nitrification, that is, no autotrophic biomass was present in the wastewater. Should the presence of nitrifiers in the wastewater be a possibility, allyl thiourea probably can be used as a nitrification inhibitor (due to the absence of nitrification, addition of allyl thiourea was not tested).

Referring to the OUR–time plot (Fig 4.1), during the first period of the batch test (< 7¼ h) the OUR exhibits an exponential increase due to heterotroph active biomass growth. After ± 7¼ h, the OUR drops precipitously due to depletion of the RBCOD. For the remainder of the batch test, the OUR exhibits an inverted S pattern typical of saturation kinetics, due to SBCOD utilization.

4.4 DATA INTERPRETATION

The data from the batch test can be interpreted in terms of either the UCT (Dold *et al.*, 1980; 1991) or IAWQ (Henze *et al.*, 1987) models. For this investigation, the UCT model was selected, using the data from Fig 4.1 as a worked example; interpretation in terms of IAWQ model does not present undue difficulty and is also briefly presented.

For application of the UCT model to the batch test, the model can be greatly simplified by recognizing that specific conditions prevail:

- Aerobic conditions – denitrification processes need not be included.
- No nitrification – nitrification processes need not be included.
- Excess ammonia present – nitrate as a N–source for growth need not be considered.
  – transformations from organic to ammonia nitrogen need not be included.

Accepting these conditions, the UCT model can be simplified to that presented in Table 4.1. In terms of this model the following information can be obtained from the batch test:

- COD recovery (%).

- Wastewater heterotroph active biomass, $Z_{BH(0)}$ (mgCOD/ℓ).
- Wastewater RBCOD, S_{bsi} (mgCOD/ℓ).
- Wastewater heterotroph maximum specific growth rate on RBCOD, $\hat{\mu}_H$ (/d).
- Wastewater heterotroph maximum specific growth rate on SBCOD, K_{MP} (/d).

In the calculations, values have to be assumed for:

- Specific death rate, $b_H = 0{,}62$/d.
- Heterotroph yield, $Y_{ZH} = 0{,}666$ mgCOD/mgCOD.

4.4.1 COD recovery

The acceptability of the data from the batch test can be evaluated by doing a COD mass balance, as follows:

$$\% \text{ COD recovery} = \frac{COD_{t=T} + \int_{t=0}^{t=T} OUR \, dt}{COD_{t=0}} \cdot 100 \qquad (4.1)$$

where

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

Using the data in Fig 4.1 as an example, $COD_{t=0} = 821$ mgCOD/ℓ; $COD_{t=T} = 481$ mgCOD/ℓ and $\int_{t=0}^{t=T} OUR \cdot dt = 332$ mgO/ℓ, then:

$$\% \text{ COD recovery} = \frac{481 + 332}{821} \cdot 100 = 99\%.$$

Mass balances between 95–105% indicate that the test results are acceptable, and these were generally obtained in most batch tests without undue difficulty (see Chapter 5).

4.4.2 Wastewater heterotroph active biomass, $Z_{BH(0)}$

From the simplified UCT model (Table 4.1), the rate of growth of heterotroph biomass (dZ_{BH}/dt) is given by:

$$\frac{dZ_{BH}}{dt} = \text{growth on RBCOD} + \text{growth on SBCOD} - \text{death}$$

$$\frac{dZ_{BH}}{dt} = \hat{\mu}_H \frac{S_{bs}}{K_{SH}+S_{bs}} \cdot Z_{BH} + K_{MP} \frac{S_{ads}/Z_{BH}}{K_{SP}+S_{ads}/Z_{BH}} \cdot Z_{BH} - b_H \cdot Z_{BH} \qquad (4.2)$$

where

Z_{BH} = heterotroph active biomass concentration (mgCOD/ℓ)
S_{bs} = RBCOD concentration (mgCOD/ℓ)
K_{SH} = half saturation constant for RBCOD
= 5 mgCOD/ℓ
S_{ads} = adsorbed SBCOD concentration (mgCOD/ℓ)
K_{SP} = half saturation constant for SBCOD
= 0,027 mgCOD/mgCOD

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

$$\frac{dZ_{BH}}{dt} = (\hat{\mu}_H + K_{MP} - b_H) Z_{BH} \qquad (4.3)$$

Integrating Eq (4.3) and solving yields the active organism concentration at time t [$Z_{BH(t)}$, mgCOD/ℓ] in terms of the initial active organism concentration [$Z_{BH(0)}$, mgCOD/ℓ], time (t, in h) and the net specific growth rate ($\hat{\mu}_H + K_{MP} - b_h$) viz;

$$Z_{BH(t)} = Z_{BH(0)} e^{(\hat{\mu}_H + K_{MP} - b_H)t/24} \qquad (4.4)$$

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

$$OUR_{(t)} = \frac{1-Y_{ZH}}{Y_{ZH}} (\hat{\mu}_H + K_{MP})\, Z_{BH(t)}/24 \qquad (4.5)$$

Substituting Eq (4.4) for $Z_{BH(t)}$ in Eq (4.5) and taking natural logs yields

$$\ell n\ OUR_{(t)} = \ell n \left[\frac{1-Y_{ZH}}{Y_{ZH}} (\hat{\mu}_H + K_{MP})\, Z_{BH(0)}/24 \right] + (\hat{\mu}_H + K_{MP} - b_H)t/24 \qquad (4.6)$$

which is a straight line with,

$$\text{slope} = (\hat{\mu}_H + K_{MP} - b_H)/24 \qquad (4.7)$$

$$\text{y-intercept} = \ell n\,(OUR_{(t=0)}) = \ell n \left[\frac{1-Y_{ZH}}{Y_{ZH}} (\hat{\mu}_H + K_{MP})\, Z_{BH(0)}/24 \right] \qquad (4.8)$$

From a plot of $\ell n\ OUR_{(t)}$ versus time (h), $Z_{BH(0)}$ can be obtained:

$$Z_{BH(0)} = \frac{(e^{\text{y-intercept}}) \cdot 24}{\frac{1-Y_{ZH}}{Y_{ZH}} \cdot (\text{slope} \cdot 24 + b_H)} \qquad (\text{mgCOD}/\ell) \qquad (4.9)$$

The OUR values for the data in Fig 4.1 up to the precipitous drop in OUR, are shown plotted ℓn OUR versus time (h) in Fig 4.2. Linear regression yields,

$$\ell n\ OUR = 1{,}2814 + 0{,}297\ t \qquad (R^2 = 0{,}998).$$

Accepting Y_{ZH} = 0,666 mgCOD/mgCOD and b_H = 0,62/d (the value for b_H is probably less for the raw sewage in the batch test than the 0,62/d for normal activated sludge systems because predators probably will not be present in significant concentrations; however, a reduced value for b_H has relatively little influence since $\hat{\mu}_H + K_{MP} \gg b_H$), and inserting into Eq (4.9) yields:

$$Z_{BH(0)} = \frac{e^{1,2814} \cdot 24}{\frac{1-0,666}{0,666} \cdot (0,297 \cdot 24 + 0,62)} = 22 \text{ mgCOD}/\ell.$$

This represents $22/821 \cdot 100 = 2,7\%$ of the wastewater COD, a very minor fraction.

In terms of the IAWQ model, growth and OUR are due to utilization of RBCOD only, either directly from RBCOD in the influent or from RBCOD generated by SBCOD hydrolysis. However, this does not influence determination of $Z_{BH(0)}$ except that $(\hat{\mu}_H + K_{MP})$ in the equations above is equivalent to the maximum specific growth rate, $\hat{\mu}_H^*$, in the IAWQ model. Accordingly, Eq (4.9) above can be used directly to determine $Z_{BH(0)}$ in terms of the IAWQ model.

4.4.3 Heterotroph maximum specific growth rate on SBCOD, K_{MP}

The RBCOD concentration is calculated from the concentration of oxygen utilized in its degradation. This requires the OUR before the precipitous drop to be separated into its RBCOD and SBCOD contributions, which is equivalent to separating the overall growth rate $(\hat{\mu}_H + K_{MP})$ into its $\hat{\mu}_H$ and K_{MP} components. These calculated values for $\hat{\mu}_H$ and K_{MP} from the batch test are unlikely to be of value in modelling activated sludge system. The organism population that develops in the activated sludge system is likely to differ appreciably from that which develops in the batch reactor since the conditions present in the batch test (high COD, low active biomass) differ significantly from those in the activated sludge system (low COD, high active biomass). Consequently, the two populations probably will have different kinetic constants.

In terms of the UCT model, growth of heterotrophs on RBCOD and SBCOD is independent. The OUR's (mgO/ℓ/h) associated with these two growth processes are given by Eq (4.5) which can be separated to give:

$$(1) \quad OUR_{RBCOD(t)} \cdot 24 = \frac{1-Y_{ZH}}{Y_{ZH}} \cdot \hat{\mu}_H \cdot Z_{BH(0)} \cdot e^{(\hat{\mu}_H + K_{MP} - b_H)t/24} \tag{4.10}$$

$$(2) \quad OUR_{SBCOD(t)} \cdot 24 = \frac{1-Y_{ZH}}{Y_{ZH}} \cdot K_{MP} \cdot Z_{BH(0)} e^{(\hat{\mu}_H + K_{MP} - b_H)t/24} \tag{4.11}$$

Up to the precipitous decrease, the OUR is the sum of both the RBCOD and

SBCOD utilization [Eq (4.10) + Eq (4.11)]. Once the RBCOD is depleted, which causes the precipitous OUR decrease, the OUR is that for SBCOD only [Eq (4.11)]. If the precipitous decrease occurs at t=s hours at which time the OUR is $OUR_{SBCOD(t=s)}$, then from Eq (4.11) K_{MP} is given by

$$K_{MP} = \frac{OUR_{SBCOD(t=s)} \cdot 24}{\frac{1-Y_{ZH}}{Y_{ZH}} \cdot Z_{BH(0)} e^{(\hat{\mu}_H + K_{MP} - b_H)\cdot(t=s)/24}} \qquad (4.12)$$

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)

$(\hat{\mu}_H + K_{MP} - b_H)/24$ = slope of ℓn $OUR_{(t)}$ versus time (h) plot.

Using the data in Figs 4.1 and 4.2 as an example, time s = 7,8h; $OUR_{SBCOD(t=7,8h)}$ = 11,2 mgO/ℓ/h; slope of ℓn $OUR_{(t)}$ vs time plot = 0,297 (Fig 4.2); $Z_{BH(0)}$ = 22 mgCOD/ℓ:

$$K_{MP} = \frac{11,2 \cdot 24}{\frac{1-0,666}{0,666} \cdot 22 \cdot e^{0,297 \cdot 7,8}} = 2,4/d$$

In the IAWQ model, utilization of RBCOD and SBCOD is not independent; only RBCOD is utilized, either from that present in the wastewater or from SBCOD hydrolysis. However, to interpret the data in the batch test to calculate the RBCOD present in the wastewater, distinction has to be made between the RBCOD in the wastewater and the RBCOD generated from hydrolysis of SBCOD. To do this, the approach developed here for the UCT model can be followed. Conceptually, in the IAWQ model this amounts to independent utilization of the two "types" of RBCOD, but does not influence the value calculated for influent wastewater RBCOD. To determine the contribution of SBCOD hydrolysis to the RBCOD, the maximum specific hydrolysis rate, K_H, in the IAWQ model needs to be calculated, as follows:

$$K_H = K_{MP}/Y_{ZH} \qquad (mgCOD/mgCOD/d) \tag{4.13}$$

For the example presented here,

$K_H = 2,4/0,666 = 3,6$ mgCOD/mgCOD/d.

4.4.4 Heterotroph maximum specific growth rate on RBCOD, $\hat{\mu}_H$

For the UCT model, the value for $\hat{\mu}_H$ can be calculated from the value for K_{MP} derived above and the slope of the ℓn OUR versus time plot, as follows

$$\hat{\mu}_H = SLOPE \cdot 24 - K_{MP} + b_H \tag{4.14}$$

For the example,

$\hat{\mu}_H = 0,297 \cdot 24 - 2,4 + 0,62 = 5,4/d.$

For interpretation in terms of the IAWQ model,

$$\hat{\mu}_H^* = (\hat{\mu}_H + K_{MP}) = slope \cdot 24 + b_H \tag{4.15}$$

For the example,

$\hat{\mu}_H^* = 5,4 + 2,4 = 7,8/d.$

4.4.5 Determination of the influent RBCOD concentration

Knowing K_{MP} and $\hat{\mu}_H$ individually, the OUR_{SBCOD} can now be subtracted from OUR_{total} to give the OUR_{RBCOD}. The RBCOD then is given by $1/(1-Y_{ZH})$ times the area between the observed OUR and the theoretical OUR_{SBCOD} from the start of the batch test (t=0) to the precipitous drop (t=d):

$$RBCOD = \frac{1}{1-Y_{ZH}} \int_{t=0}^{t=d} (OUR_{total} - OUR_{SBCOD})\, dt \qquad (mgCOD/\ell) \tag{4.16}$$

$$= \frac{1}{1-Y_{ZH}} \int_{t=0}^{t=d} OUR_{RBCOD}\, dt \tag{4.17}$$

The RBCOD concentration can be found by doing the integration in Eq (4.16) graphically or that in Eq (4.17) analytically. For the former, the OUR_{SBCOD} from Eq (4.11) with K_{MP} = 2,4/d is shown plotted in Fig 4.1. The area between the observed OUR and the theoretical OUR_{SBCOD} was determined to be 68,9 mgO/ℓ. Therefore, RBCOD = [1/(1–0,666)]·68,9 = 206 mgCOD/ℓ.

For the latter, Eq (4.17) is integrated analytically by substituting Eq (4.10) for OUR_{RBCOD} and solving the definite integral between t=0 and t=d, viz.:

$$RBCOD = \frac{\hat{\mu}_H \cdot Z_{BH(0)}}{Y_{ZH} \cdot slope \cdot 24} \left\{ e^{slope \cdot t_d} - 1 \right\} \qquad (mgCOD/\ell) \qquad (4.18)$$

where

t_d = time of precipitous drop in OUR (h)
slope = slope of ℓn OUR versus time (h) plot

For the example, $\hat{\mu}_H$ = 5,4/d; $Z_{BH(0)}$ = 22 mgCOD/ℓ; Y_{ZH} = 0,666 mgCOD/-mgCOD; slope = 0,297; t_d = 7,4 h:

$$RBCOD = \frac{5,4 \cdot 22}{0,666 \cdot 0,297 \cdot 24} \left\{ e^{0,297 \cdot 7,4} - 1 \right\} = 200 \text{ mgCOD}/\ell$$

In a comparative test, the results for the conventional flow–through test (Ekama and Marais, 1979) for the same batch of wastewater gave RBCOD = 207 mgCOD/ℓ.

In terms of the IAWQ model, to determine the influent RBCOD an artificial division of the observed OUR has to be made, between OUR_{RBCOD} for influent RBCOD utilization and OUR_{SBCOD} for utilization of RBCOD generated from SBCOD hydrolysis. Equations for these OURs can be derived from the IAWQ model. These are identical to Eqs (4.10) and (4.11) except that

$\hat{\mu}_H + K_{MP}$ in UCT = $\hat{\mu}_H{}^*$ in IAWQ.
$\hat{\mu}_H$ in UCT = $\hat{\mu}_H{}^* - K_H/Y_{ZH}$ in IAWQ.
K_{MP} in UCT = K_H/Y_{ZH} in IAWQ.

Equation (4.18) for the RBCOD concentration also applies except that $\hat{\mu}_H$ is replaced by $\hat{\mu}_H^*-K_H/Y_{ZH}$ as indicated above.

4.5 CLOSURE

A batch test method has been presented to determine two influent wastewater COD fractions, heterotroph active biomass and readily biodegradable COD (RBCOD). The method has advantages over previous methods in that:

- The experimental procedure is relatively simple.
- No mixed liquor acclimatized to the wastewater is required.
- Independent determination of unbiodegradable COD is not necessary.
- The only independent constants required for calculation are the heterotroph yield (Y_{ZH}) and specific death rate (b_H); the procedure is relatively insensitive to the value for b_H. All other constants required for calculations are obtained from the experimental data. However, it is unlikely that these constants (UCT model, $\hat{\mu}_H$ and K_{MP}; IAWQ model, $\hat{\mu}_H^*$ and K_H) will be of much value in modelling and design of activated sludge systems – most probably a population will develop in the activated sludge system that differs appreciably from that in the wastewater since the conditions in the wastewater (high COD, low active mass) differ significantly from those in the activated sludge system (low COD, high active mass).

The batch test method presented in this Chapter provides a simple means to quantify two of the five influent wastewater COD fractions, namely readily biodegradable COD and heterotroph active biomass. The accuracy of these estimates will be evaluated in Chapter 5. Attempts to extend the batch test to quantify also the remaining three COD fractions, unbiodegradable soluble COD, unbiodegradable particulate COD and slowly biodegradable particulate COD are set out later in this report.

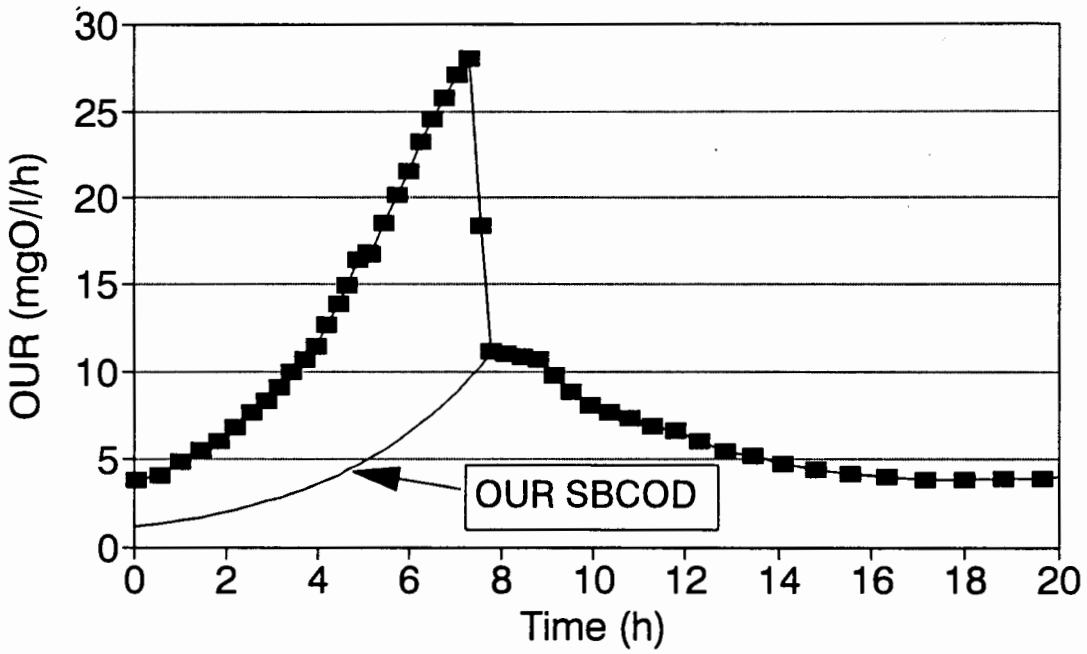

Fig 4.1: OUR–time plot for aerobic batch test on raw municipal wastewater from Mitchell's Plain Treatment Plant.

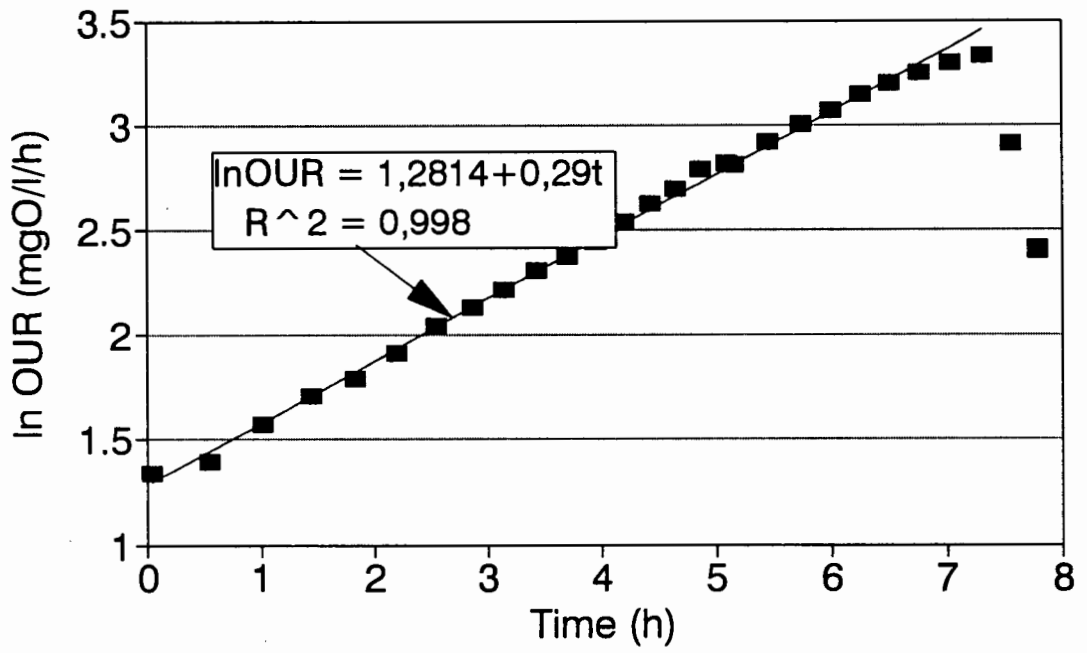

Fig 4.2: ℓn–OUR versus time for the measured OUR data in Fig 4.1 up to the precipitous drop in OUR.

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					$-1/Y_{ZH}$		$-\frac{1-Y_{ZH}}{Y_{ZH}}$	$\hat{\mu}_H \left[\frac{S_{bs}}{K_{SH}+S_{bs}}\right] Z_{BH}$
2 Aerobic 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** $\hat{\mu}_H$ = 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

CHAPTER 5

EVALUATION OF BATCH TEST FOR MEASUREMENT OF READILY BIODEGRADABLE COD AND ACTIVE ORGANISM CONCENTRATIONS

5.1 INTRODUCTION

In Chapter 4 a batch test method was developed to quantify two wastewater COD fractions, readily biodegradable COD (RBCOD) and heterotroph active biomass concentrations. Results from one batch test were used as an example to illustrate the method for calculation of the results. In this Chapter the intention is to evaluate the results from a number of such batch tests. This is to be done by comparing the RBCOD results derived from the batch test with those from the conventional flow-through square wave method (Ekama *et al.*, 1986; see Chapter 3). For heterotroph active biomass concentration, no conventional test is available.

5.2 METHOD

Wastewater from two sources was used for the batch tests, Borcherds Quarry and Mitchell's Plain Treatment Plants (Cape Town, South Africa). For both Treatment Plants, sewer retention times are short (3 to 4 hours) and the conditions are anaerobic; therefore it is expected that heterotroph active biomass concentrations in both wastewaters should be low. Batches of raw (unsettled) wastewater were obtained from the inlet works to the treatment plants and stored in stainless steel tanks at 4° C for a period of approximately two weeks. (Experience has indicated that storage for a period longer than about three weeks leads to significant changes in the sewage characteristics; storage for two weeks was selected to eliminate this possibility). Regularly, the contents of the stainless steel tanks were thoroughly mixed and wastewater samples drawn off into a plastic container. The wastewater was brought to a temperature of 20° C by placing the container in a warm water bath (±50° C) and stirring gently. For some batch tests the wastewater was diluted to approximately 500 mgCOD/ℓ by addition of tap water so that the measured OURs would not be excessively high. Using the wastewater, the batch test procedure detailed in Chapter 4 was followed. A number of batch tests were conducted on each batch of wastewater collected, see Table 5.1. From the batch tests the following information was derived using the equations set out in Chapter 4:

- COD recovery (%).
- Wastewater autotrophic active biomass.

- Wastewater heterotrophic active biomass.
- Wastewater heterotrophic maximum specific growth rate on RBCOD.
- Wastewater heterotrophic maximum specific growth rate on SBCOD.
- Wastewater RBCOD.

For the RBCOD measurements, the values were evaluated by comparing the results from the batch test with results from the conventional flow–through square wave bioassay test, see Chapter 3 (WRC, 1984; Ekama *et al.*, 1986). This unit was operated as specified by Ekama *et al.* (1986) and received the same wastewater used in the batch tests, at a concentration of 500±50 mgCOD/ℓ. For wastewater heterotroph active biomass, no conventional tests are available.

5.3 RESULTS

Comprehensive data for all the batch tests are listed in Tables B.1a to B.5b in Appendix B. Plots of OUR–time profiles for each batch test are also given in Appendix A. Typical OUR–time profiles for Borcherds Quarry and Mitchell's Plain wastewaters are shown plotted in Figs 5.1a and 5.2a respectively. The OUR–time profiles for both wastewaters conform to that shown plotted in Fig 4.1 (Chapter 4).

5.3.1 COD recovery

For every batch test, total unfiltered COD concentrations at the start and end of the test, and area under the OUR–time curves are listed in Tables B.1a and B.1b in Appendix B for wastewaters from Borcherds Quarry and Mitchell's Plain respectively. For every batch test, % COD recoveries were calculated using Eq (4.1) in Chapter 4 and are also listed in Tables B.1a and B.1b in Appendix B. The % COD recovery is a function of the batch test method and so should not be specific to each batch of wastewater tested. Accordingly, statistical plots of % COD recoveries for all the batch tests on wastewaters from Borcherds Quarry and Mitchell's Plain were constructed. From the statistical plots the means and standard deviations for the batch tests on the two wastewaters were determined. Batch tests with % COD recoveries more than, or less than two standard deviations from the mean were rejected for further analysis, that is, batch tests that did not fall within the 95% confidence interval were rejected (3 batch tests for Borcherds Quarry wastewater and 7 for Mitchell's Plain wastewater, see Appendix B, Tables B.1a and B.1b respectively). Statistical plots of the % COD recovery for the accepted batch tests for Borcherds Quarry and Mitchell's Plain wastewaters are given in Figs 5.3 and 5.4 respectively. (The method used to construct the statistical

plots and how to interpret them is given in Appendix C). From these plots, mean COD recoveries for Borcherds Quarry and Mitchell's Plain were 96% and 99% respectively, with standard deviations of the mean of 0,76% and 0,82% respectively. It is evident that COD recoveries were good lending credibility to the reliability of the measurements and the batch test itself.

5.3.2 Wastewater autotrophic biomass concentration

Nitrate concentration at the start and end of the batch tests was measured; the results are listed in Appendix B, Tables B.2a and B.2b for Borcherds Quarry and Mitchell's Plain wastewaters respectively. For wastewaters from both sources, no significant increase in nitrate concentration could be detected, indicating that autotrophic biomass was not present in significant concentrations in these wastewaters. Accordingly, for further analysis of all batch tests on raw wastewater, the effect of nitrification was ignored. Should nitrification be detected in the batch test, allyl thiourea probably can be used as a nitrification inhibitor. Due to the absence of nitrification, the effect of adding allyl thiourea could not be tested.

5.3.3 Heterotrophic active biomass

Influent wastewater concentrations

Following the procedure set out in Chapter 4, for each batch test the OUR from the start of the test until the precipitous drop in OUR was plotted as ℓn OUR versus time; typical profiles are shown in Figs 5.1b and 5.2b for Borcherds Quarry and Mitchell's Plain wastewaters respectively. Linear regression was used to analyze the data to derive the y-intercept, slope and correlation coefficient (R^2). Values for these parameters for all the different batch tests on the various wastewater batches are listed in Appendix B, Tables B.3a and B.3b for Borcherds Quarry and Mitchell's Plain wastewaters respectively. From the y-intercept and slope, the heterotroph active biomass could be calculated using Eq (4.9) in Chapter 4. Values for heterotroph active biomass as percentage of the total starting COD concentration for every batch test are also listed in Appendix B, Tables B.3a and B.3b. Statistical plots of heterotroph active biomass (% of wastewater total COD concentration) were constructed for each wastewater batch; for example see Figs 5.5 and 5.6 for Borcherds Quarry and Mitchell's Plain wastewaters respectively. Batch tests with heterotroph active biomass more than, or less than two standard deviations from the mean were rejected for analysis, that is, batch tests that did not fall within the 95% confidence interval were rejected (these are shown marked in Tables B.3a and b). Statistical plots excluding the rejected data were constructed for each wastewater

batch. From these statistical plots the mean and standard deviation of the mean were determined for each batch of wastewater; these values are listed in Table 5.2 for both Borcherds Quarry and Mitchell's Plain wastewaters (see Table 5.1 for wastewater source).

For Borcherds Quarry wastewater a statistical plot of the means of heterotroph active biomass (%) for the different wastewater batches is shown in Fig 5.7. From Fig 5.7, the mean heterotroph active biomass as a % of wastewater total COD was 10,3% with standard deviation of the mean of 1,0%. The relatively high heterotroph active biomass was unexpected; the retention time of the sewers at Borcherds Quarry is short (± 3 hours) so that low influent heterotroph active biomass was expected. From an investigation of the operational procedures at the Borcherds Quarry Wastewater Treatment Plant it was found that regularly waste activated sludge was recycled to the head of the works, and mixed with the incoming influent wastewater upstream of the point from where wastewater was drawn for the batch test. The recycled waste activated sludge was correctly detected in the batch test, indicated by the high heterotroph active biomass values.

For Mitchell's Plain wastewater, from Table 5.2 the first two batches of wastewater (batches 10 and 11) had low heterotroph active biomass with means of 4,0% and 3,0% of the total COD respectively; variability also was low with standard deviations of the means of 0,6% and 0,2% respectively, the low heterotroph active biomass was expected as the retention times for the Mitchell's Plain sewers also are short (± 4 hours). However, for the subsequent two wastewater batches (batches 12 and 13) and a further batch (batch 21), heterotroph active biomass concentrations were considerably higher see Table 5.1; for example batch 13 mean is 10% with standard deviation of the mean of 1,4%. From an investigation of the plant operation at Mitchell's Plain Wastewater Treatment Plant it was discovered that when wastewater batches 12, 13 and 21 were collected, waste sludge from the activated sludge system was being recycled to the head of the works, because of repairs to the sludge treatment facilities. Again, the recycled waste activated sludge was correctly detected in the batch test. For the remaining wastewater batches, recycling of waste activated sludge was not practised which is reflected in the lower measured heterotroph active biomass. For the wastewater batches in which no activated sludge was recycled, a statistical plot of the measured mean heterotroph active biomass for the different wastewater batches is given in Fig 5.8; from the plot the mean heterotroph active biomass is 6,1% and the standard deviation of the

mean is 0,65%.

Results obtained from the batch test for heterotroph active biomass could not be evaluated against results from any conventional test since no conventional tests are available. However, the batch test consistently reflected changes in heterotroph active biomass concentration that could be traced to plant operation.

5.3.4 Heterotroph maximum specific growth rates on RBCOD and SBCOD

These constants are required to determine the RBCOD concentration, see Chapter 4. For every batch test the maximum specific growth rate of the heterotrophs on SBCOD (K_{MP}) was determined using Eq (4.12) in Chapter 4 and the values are listed in Appendix B, Tables B.4a and B.4b for Borcherds Quarry and Mitchell's Plain wastewaters respectively. Statistical plots of K_{MP} for each wastewater batch were constructed; for example see Figs 5.9 and 5.10 for Borcherds Quarry and Mitchell's Plain respectively. Batch tests with K_{MP} more than, or less than two standard deviations from the mean were rejected for analysis, that is, batch tests that did not fall within the 95% confidence interval were rejected (these are shown marked in Tables B.4a and b). From the statistical plots the means and standard deviations of the means for each wastewater batch, were determined, see Table 5.3 (see Table 5.1 for wastewater source). Statistical plots of K_{MP} means for the different wastewaters are shown in Figs 5.11 and 5.12 for Borcherds Quarry and Mitchell's Plain respectively. Mean K_{MP} values were 1,91/d and 2,47/d for Borcherds Quarry and Mitchell's Plain respectively, with standard deviation of the mean of 0,10 and 0,20 respectively.

The maximum specific growth rates of the heterotrophs on RBCOD ($\hat{\mu}_H$) were calculated using Eq (4.14) in Chapter 4 and are listed in Table B.4a and B.4b for Borcherds Quarry and Mitchell's Plain wastewaters respectively. The $\hat{\mu}_H$ data were evaluated in exactly the same fashion as described above for K_{MP} data. Examples of statistical plots for $\hat{\mu}_H$ for one wastewater batch from Borcherds Quarry and Mitchell's Plain are shown in Figs 5.13 and 5.14 respectively; mean $\hat{\mu}_H$ and standard deviation of the means are listed in Table 5.3 for the different wastewater batches (see Table 5.1 for wastewater sources). Statistical plots of the $\hat{\mu}_H$ means for the different wastewater batches are shown in Figs 5.15 and 5.16 respectively. Mean values were 3,85/d and 4,38/d for Borcherds Quarry and Mitchell's Plain respectively, with standard deviations of the mean of 0,30 and 0,12 respectively.

Comparing the values for K_{MP} and $\hat{\mu}_H$ obtained from the batch test with those available in literature for activated sludge, K_{MP} = 1,35 (/d) and $\hat{\mu}_H$ = 1,5–3,5 (/d) (Dold *et al.*, 1991), the values obtained in the batch tests are considerably higher. Most probably a population develops in the activated sludge system that differs appreciably from that in the wastewater (measured in the batch tests), since conditions in the wastewater (high COD, low active mass) differ significantly from those in the activated sludge system (low COD, high active mass). Accordingly, it is unlikely that the values for the constants derived from the batch test, which reflect the wastewater population, will be of much value in modelling and design of activated sludge systems – their use is restricted to the batch test to derive estimates for RBCOD.

Comparing the mean K_{MP} and $\hat{\mu}_H$ values for Borcherds Quarry and Mitchell's Plain wastewaters, both values were higher for Mitchell's Plain wastewater. This can be explained by noting the origin of the heterotroph active biomass in the two wastewaters: For the Mitchell's Plain wastewater, the heterotroph active biomass originates principally from growth in the sewer, whereas a significant portion of the heterotroph active biomass in the Borcherds Quarry wastewater originates from mixed liquor from the activated sludge plant being recycled to the head of the works (see Section 5.3.3 above). It has been noted above that the K_{MP} and $\hat{\mu}_H$ are lower for heterotroph active biomass that develops in an activated sludge system compared to that which develops in the sewer, because of the different conditions that prevail.

5.3.5 Wastewater RBCOD concentration

In Chapter 4 graphical and analytical procedures are given to determine wastewater RBCOD, see Eqs (4.16) and (4.18) respectively. In determining RBCOD from the batch test, both procedures gave values that did not differ significantly. Accordingly, RBCOD concentrations determined from the batch test in this section were calculated using the analytical procedure, Eq (4.18) Chapter 4. Calculated RBCOD as a percentage of total COD for all the batch tests is listed in Appendix B, Tables B.5a and B.5b for Borcherds Quarry and Mitchell's Plain respectively. For each batch of wastewater, statistical plots of the % RBCOD were constructed, and the mean and standard deviation of the mean determined; an example of one plot is given in Figs 5.17a and 5.18a for Borcherds Quarry and Mitchell's Plain respectively. Batch tests with % RBCOD more than, or less than two standard deviations from the mean were rejected for analysis, that is, batch

tests that did not fall within the 95% confidence interval were rejected (these are shown marked in Tables B.5a and b). The means and standard deviation of the means (excluding rejected data) for the different batches of wastewater are listed in Table 5.4 for both wastewater sources (see Table 5.1 for wastewater source).

To evaluate the values for RBCOD obtained from the batch tests, daily the RBCOD for the batch of wastewater was determined also using the flow-through square wave method (see Chapter 3; WRC, 1984). Daily data for the flow-through square wave RBCOD as a percentage of total COD are listed in Appendix F, Tables F.1a and F.1b for Borcherds Quarry and Mitchell's Plain wastewater respectively. For each batch of wastewater, statistical plots for these values were constructed and the mean and standard deviation of the mean determined, for example, see Figs 5.17b and 5.18b; values are listed in Table 5.4. To test the statistical significance of the differences in RBCOD from the two methods, the technique of Velz (1950) was applied (see Appendix C for details on the method); for all the mean values listed in Table 5.4 with the exception of three wastewater batches (sewage batches No. 13, 17 and 18) there was no significant difference at the 95% confidence interval between the RBCOD determined by the two test method (see Table 5.5).

In Fig 5.19 the mean values for the different wastewater batches for RBCOD as a percentage of total COD from the batch test are plotted against the corresponding values obtained from the conventional flow-through square wave test. From the plot it is evident that the two methods give results that compare very closely.

5.4 CONCLUSIONS

Results from a number of tests on municipal wastewater from Borcherds Quarry and Mitchell's Plain indicate that:

- COD recoveries in the batch test are generally good, the majority falling in the range 90–110% indicating the reliability of the method.

- For wastewaters from both Borcherds Quarry and Mitchell's Plain autotrophic active biomass could not be detected in the batch test, indicated by an absence in nitrification (no increase in nitrate concentration).

- The RBCOD concentrations measured in the batch test correlate closely with

those measured in the flow-through square wave method of Ekama and Marais (1979).

- Although heterotroph active biomass concentration obtained from the batch test could not be compared to conventional tests (no such test available), the values measured in the batch test could correctly reflect changes arising from Wastewater Treatment Plant operation.

- The values for the kinetic constants derived from the batch test (K_{MP} and $\hat{\mu}_H$) differ from those in literature for activated sludge. Most probably a population develops in the activated sludge system that differs appreciably from that in the wastewater (high COD, low active mass). Accordingly it is unlikely that the values for the constants derived from the batch test (which reflect the wastewater population) will be of much value in modelling and design of activated sludge systems – their use is restricted to the batch test to derive estimates for RBCOD.

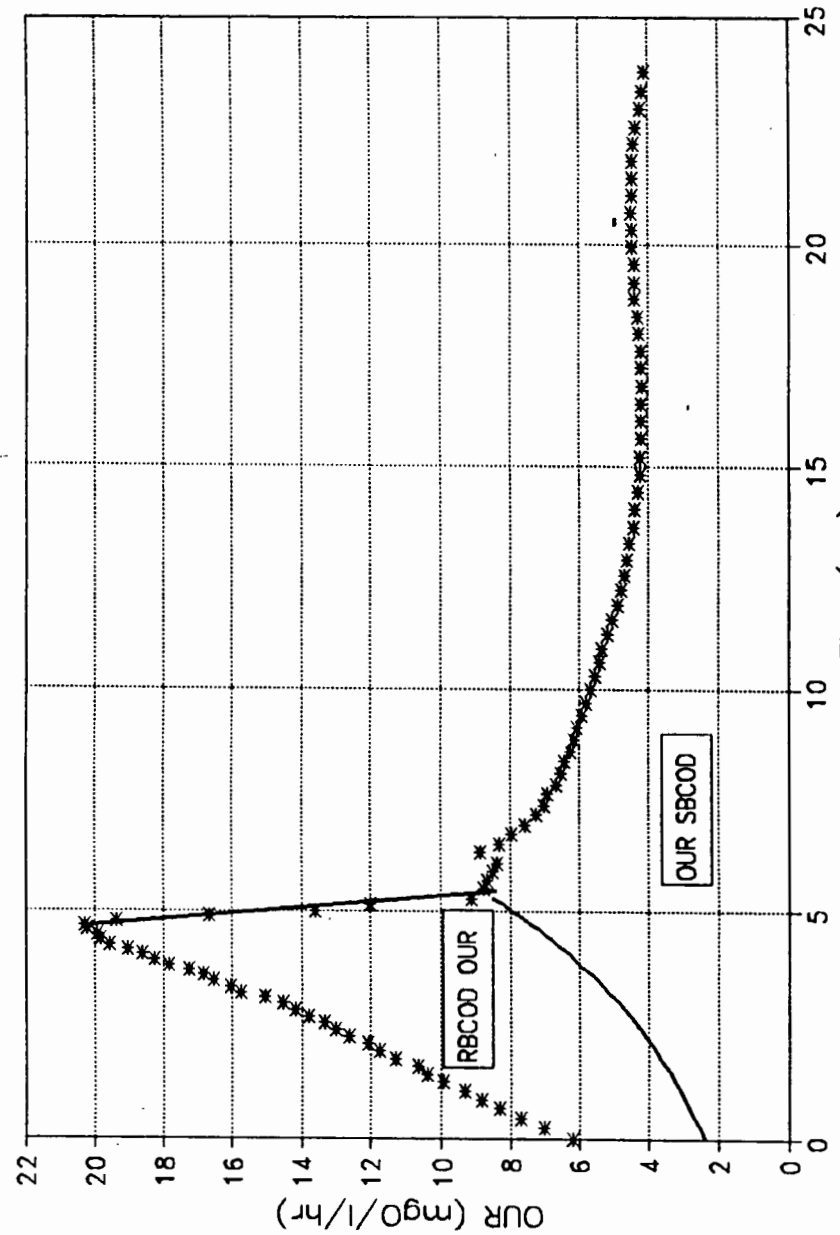

Fig 5.1a: OUR–time plot for aerobic batch test on raw municipal wastewater from Borcherds Quarry Treatment Plant.

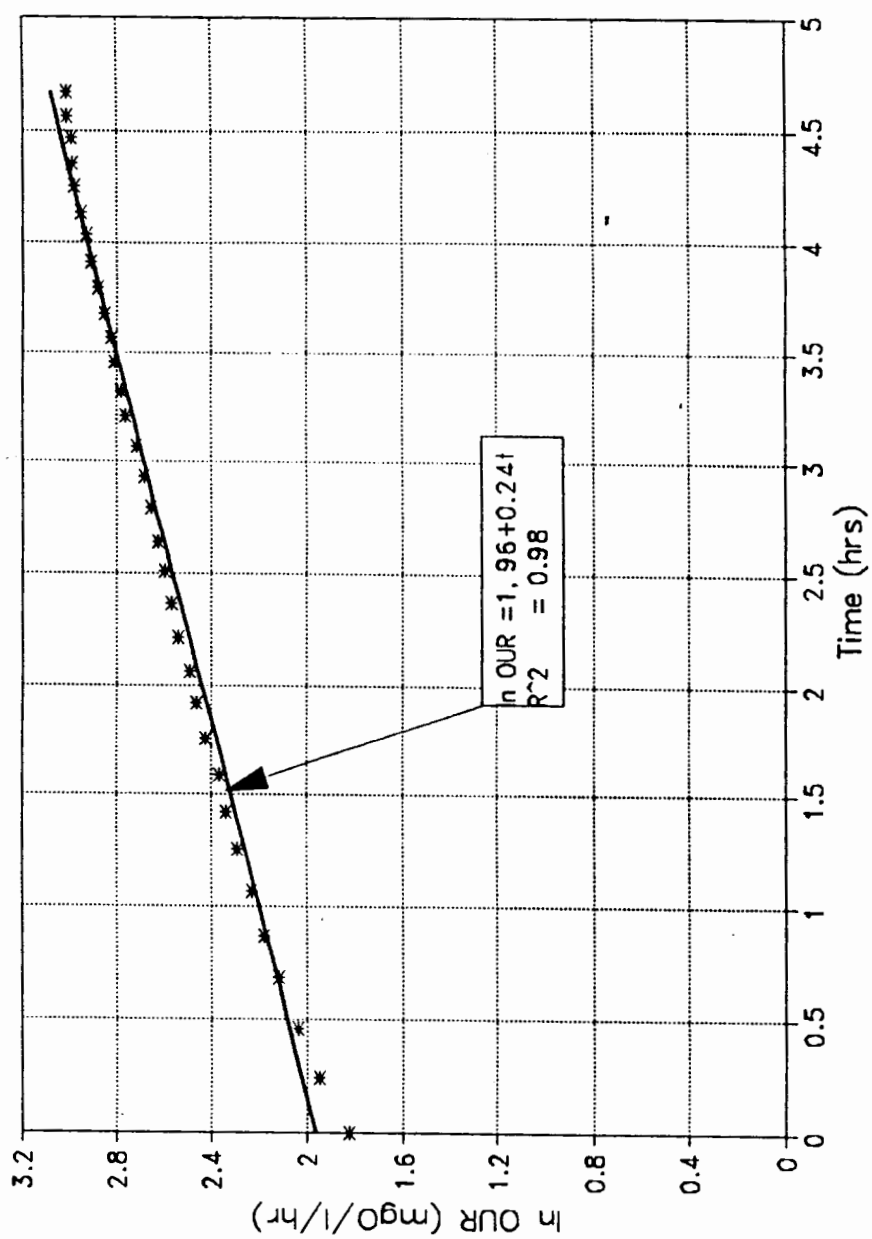

Fig 5.1b: ℓn–OUR versus time for the measured OUR data in Fig 5.1a up to the precipitous drop in OUR.

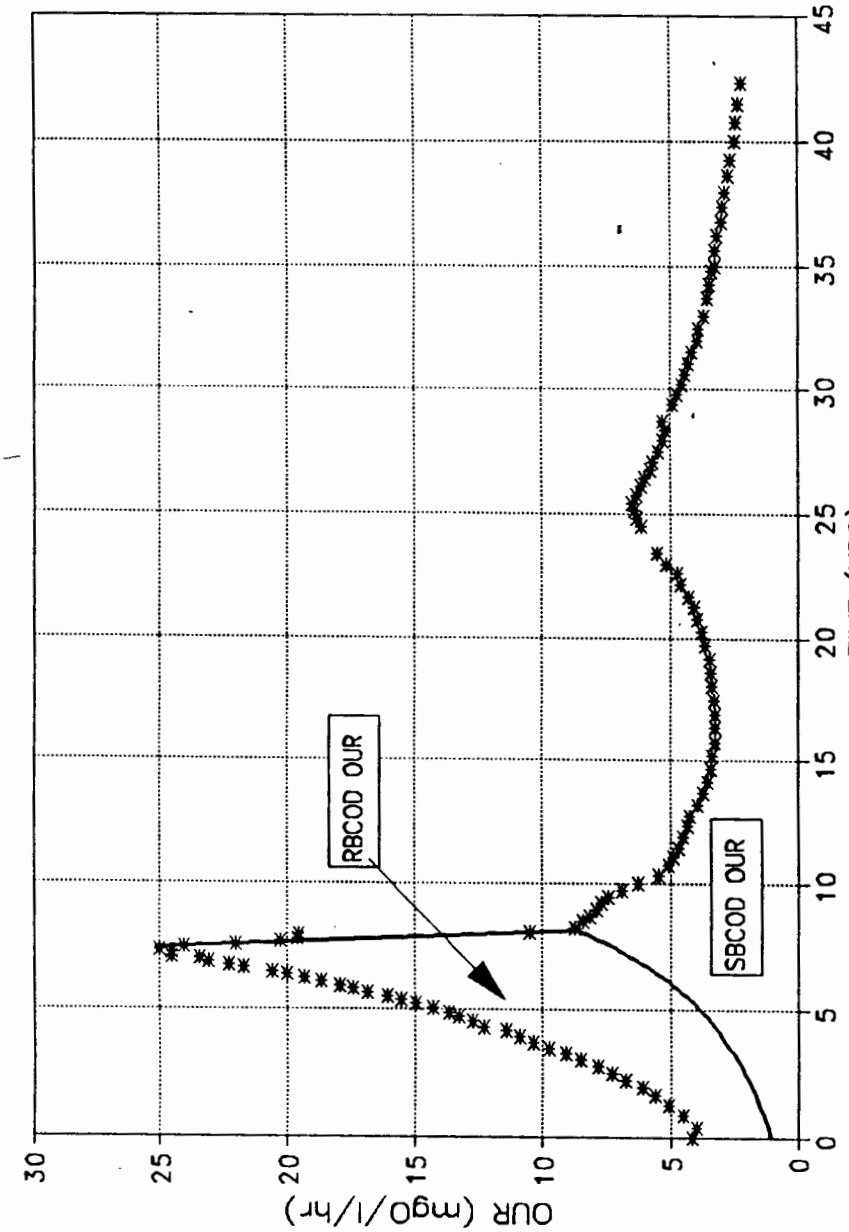

Fig 5.2a: OUR-time plot for aerobic batch test on raw municipal wastewater from Mitchell's Plain Treatment Plant.

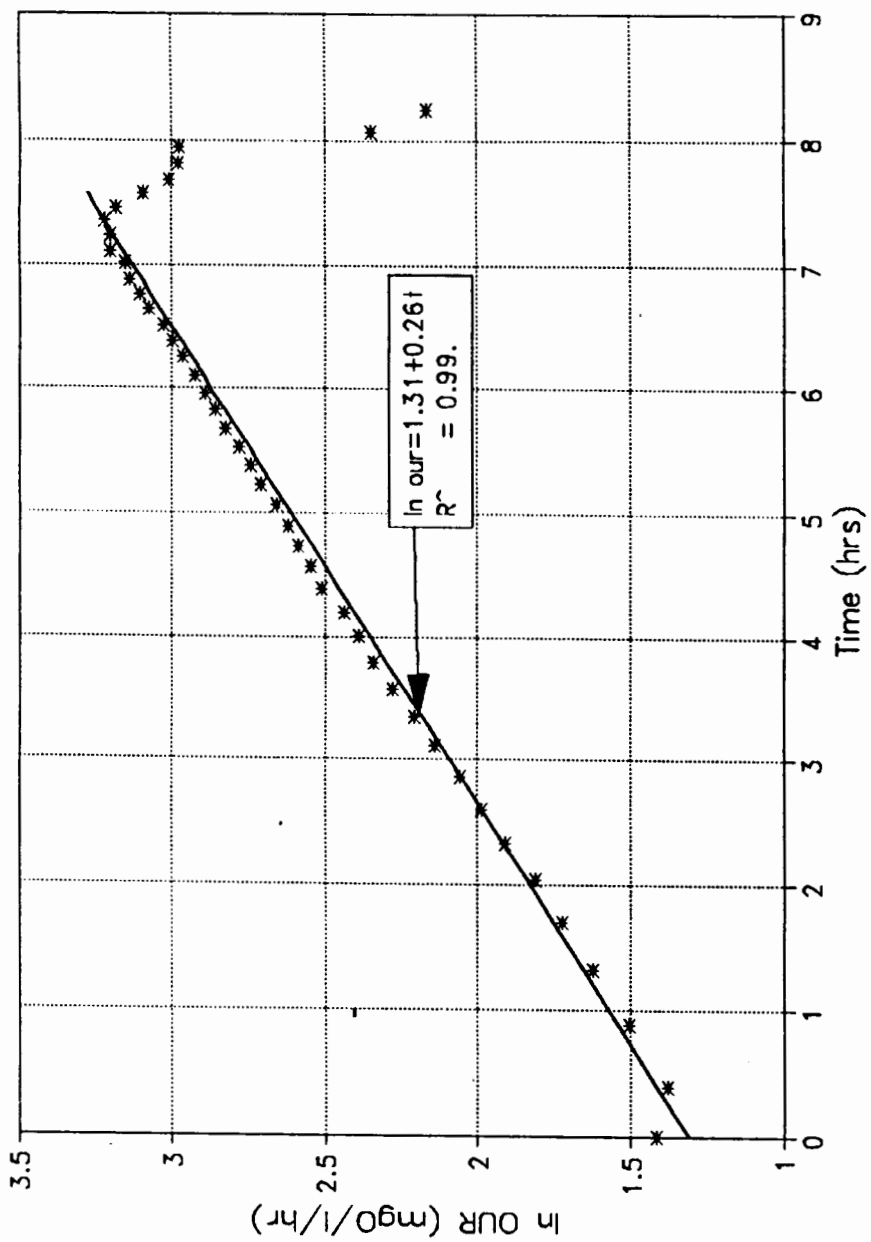

Fig 5.2b: *ln*-OUR versus time for the measured OUR data in Fig 5.2a up to the precipitous drop in OUR.

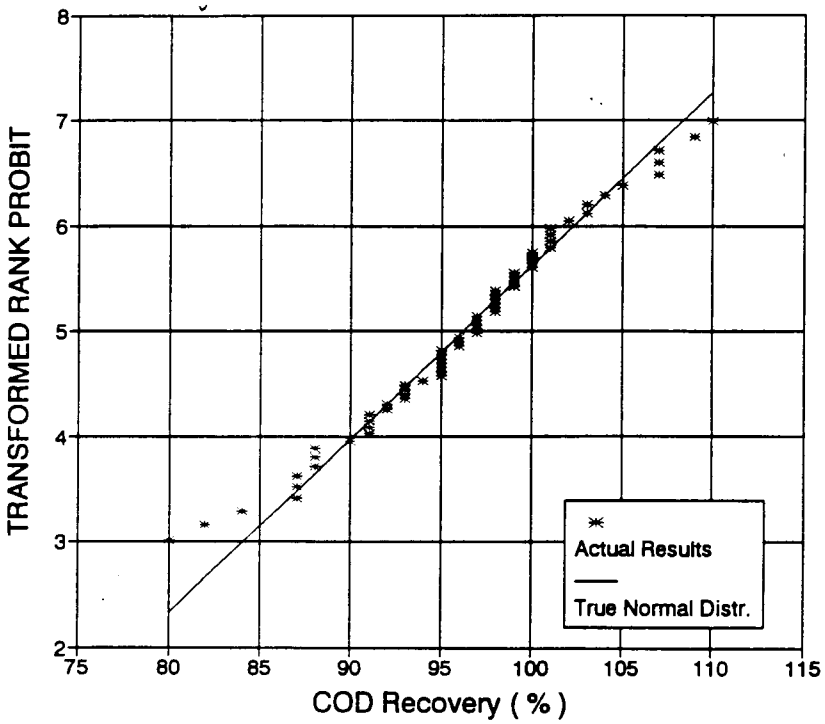

Fig 5.3: Probability plot of % COD recovery from the batch test results for wastewater from Borcherds Quarry Treatment Plant.

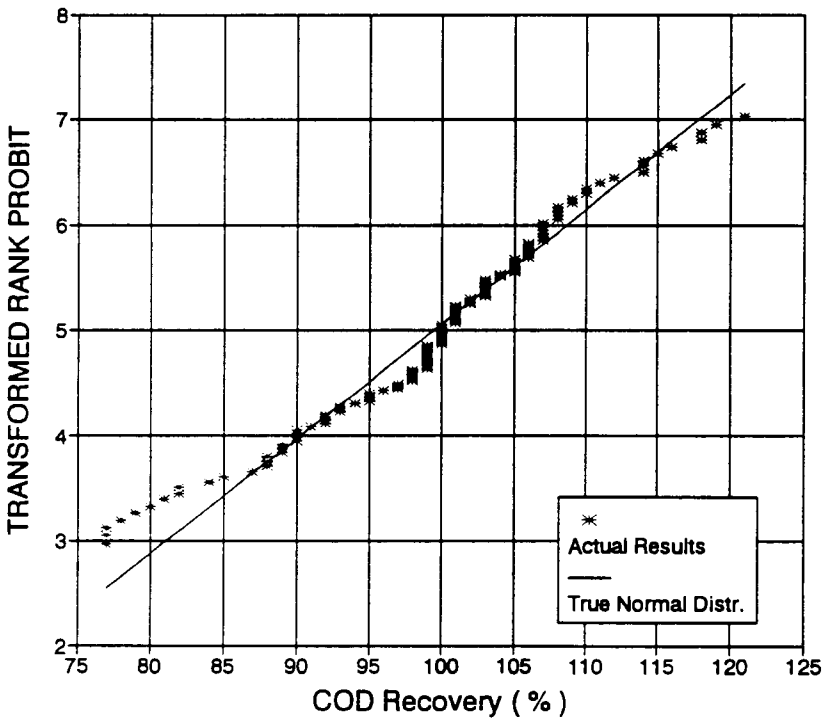

Fig 5.4: Probability plot of % COD from the batch test results for wastewater from Mitchell's Plain Treatment Plant.

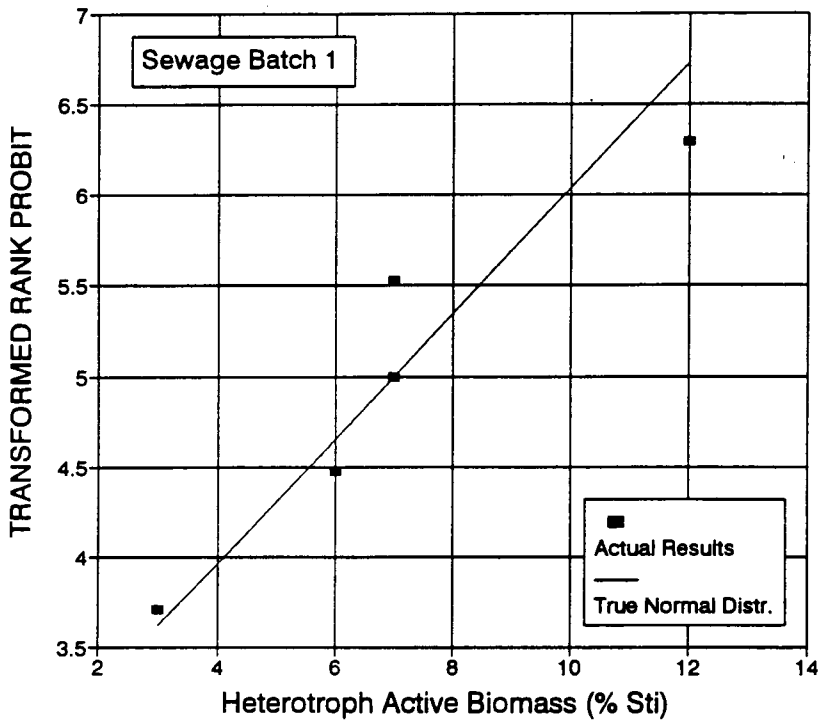

Fig 5.5: Probability plot of heterotroph active biomass COD (as a % of total wastewater COD concentration) from the batch test results on a batch of wastewater from Borcherds Quarry Treatment Plant. (Sewage batch No. 1).

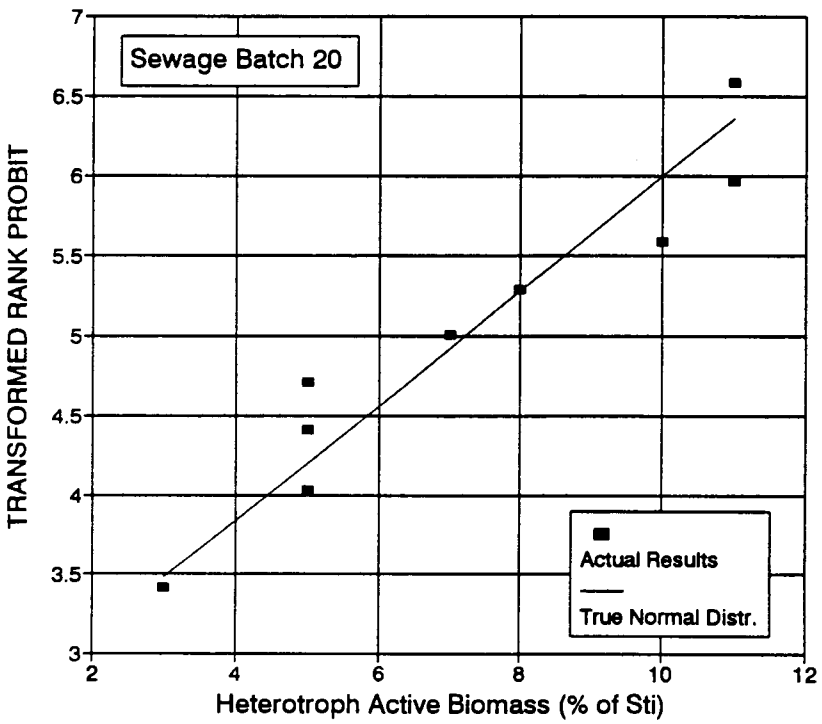

Fig 5.6: Probability plot of heterotroph active biomass COD (as a % of total wastewater COD concentration) from the batch test results on a batch of wastewater from Mitchell's Plain Treatment Plant. (Sewage batch No. 20).

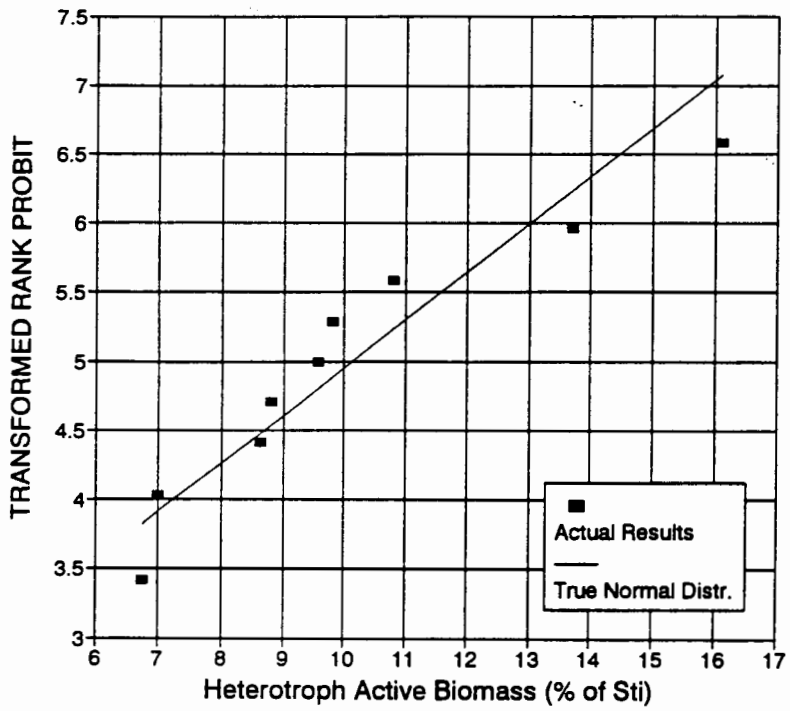

Fig 5.7: Probability plot of the means of heterotroph active biomass (%) for the different wastewater batches from Borcherds Quarry Treatment Plant.

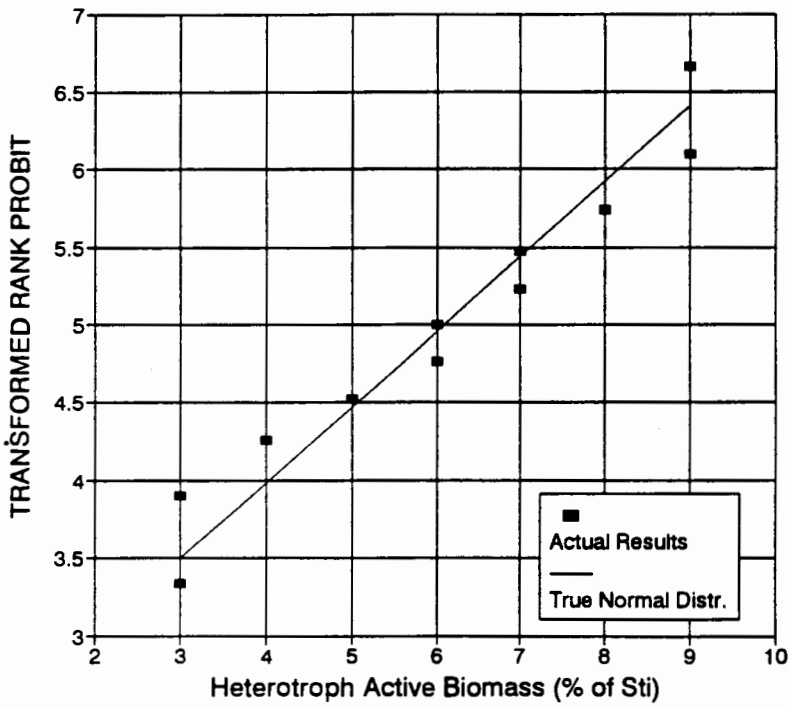

Fig 5.8: Probability plot of the means of heterotroph active biomass (%) for the different wastewater batches from Mitchell's Plain Treatment Plant.

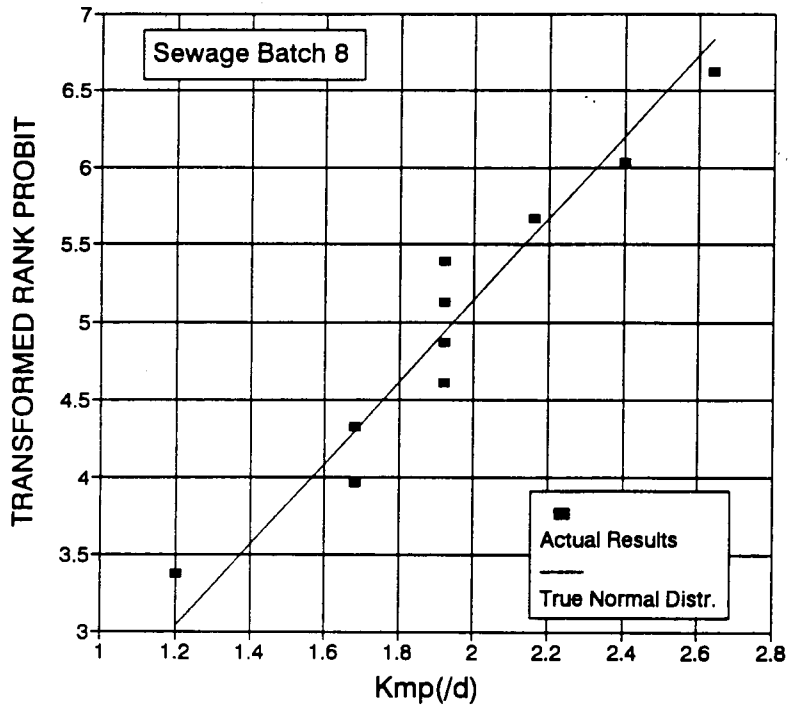

Fig 5.9: Probability plot of heterotroph maximum specific growth rate on SBCOD (K_{MP}) for batch tests on one wastewater batch from Borcherds Quarry Treatment Plant. (Sewage batch No.8).

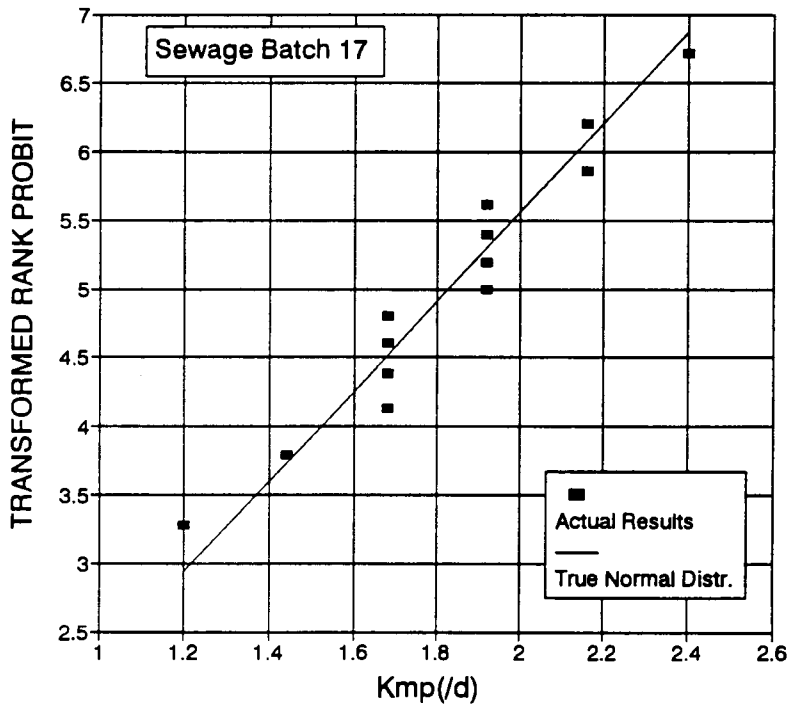

Fig 5.10: Probability plot of heterotroph maximum specific growth rate on SBCOD (K_{MP}) for batch tests on one wastewater batch from Mitchell's Plain Treatment Plant. (Sewage batch No.17).

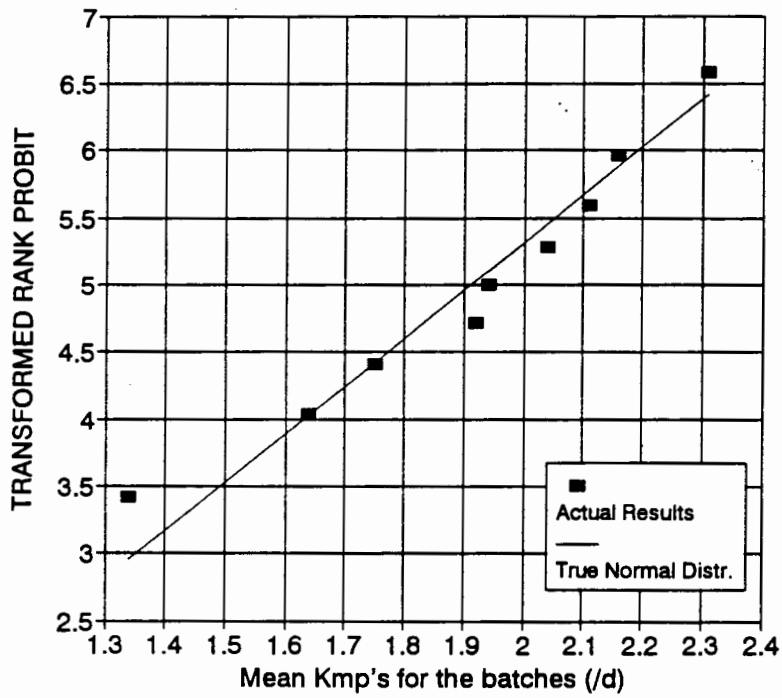

Fig 5.11: Probability plot of the means of heterotroph maximum specific growth rate on SBCOD (K_{MP}) for the different wastewater batches from Borcherds Quarry Treatment Plant.

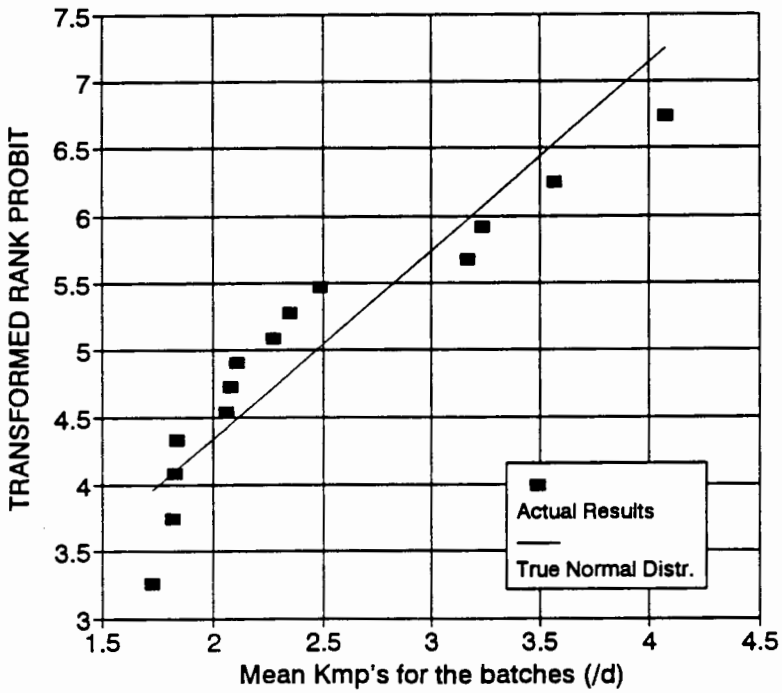

Fig 5.12: Probability plot of the means of heterotroph maximum specific growth rate on SBCOD (K_{MP}) for the different wastewater batches from Mitchell's Plain Treatment Plant.

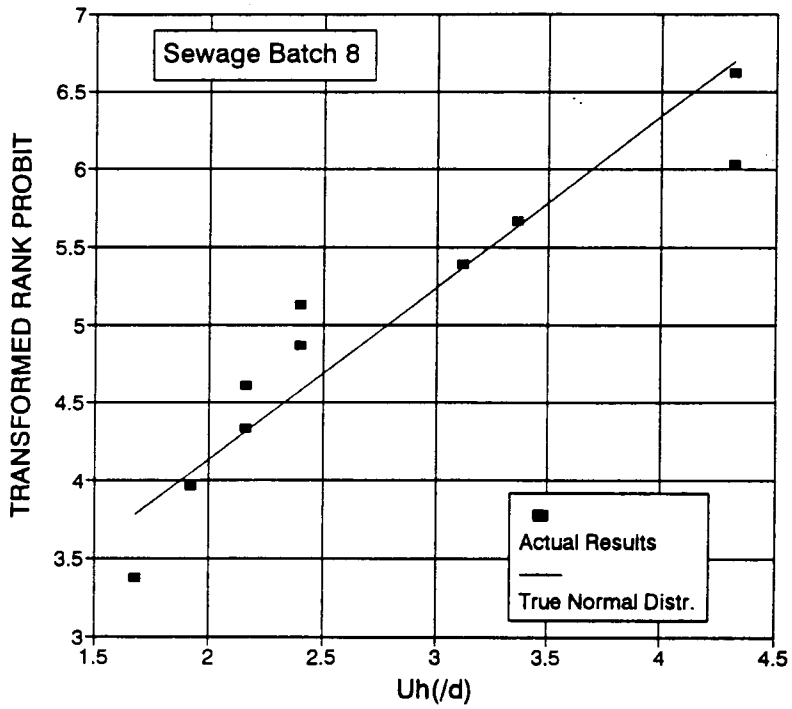

Fig 5.13: Probability plot of heterotrophic maximum specific growth rate on RBCOD (μ_H) for batch tests on one wastewater batch from Borcherds Quarry Treatment Plant. (Sewage batch No.8).

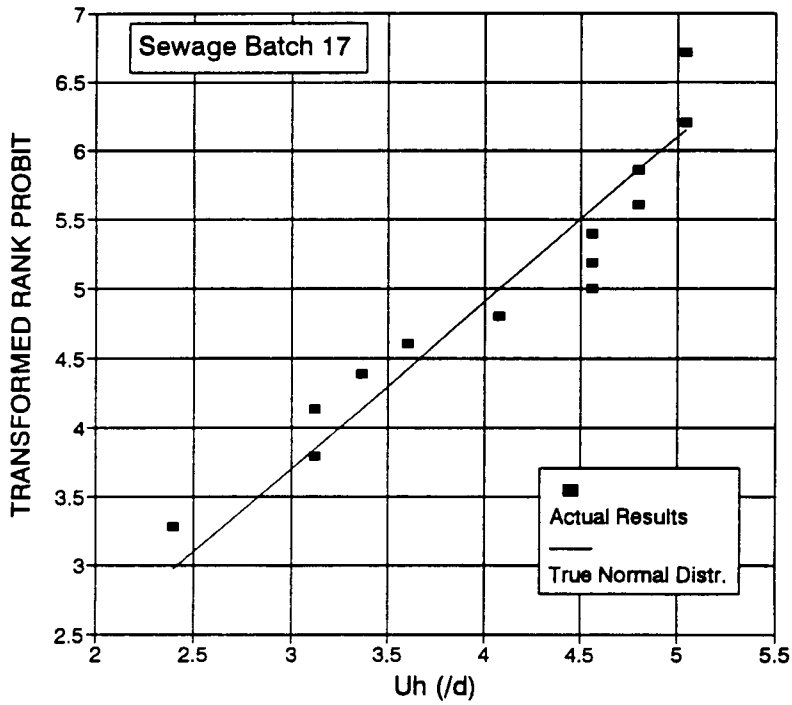

Fig 5.14: Probability plot of heterotroph maximum specific growth rate on RBCOD (μ_H) for batch tests on one batch of wastewater from Mitchell's Plain Treatment Plant. (Sewage batch No.17).

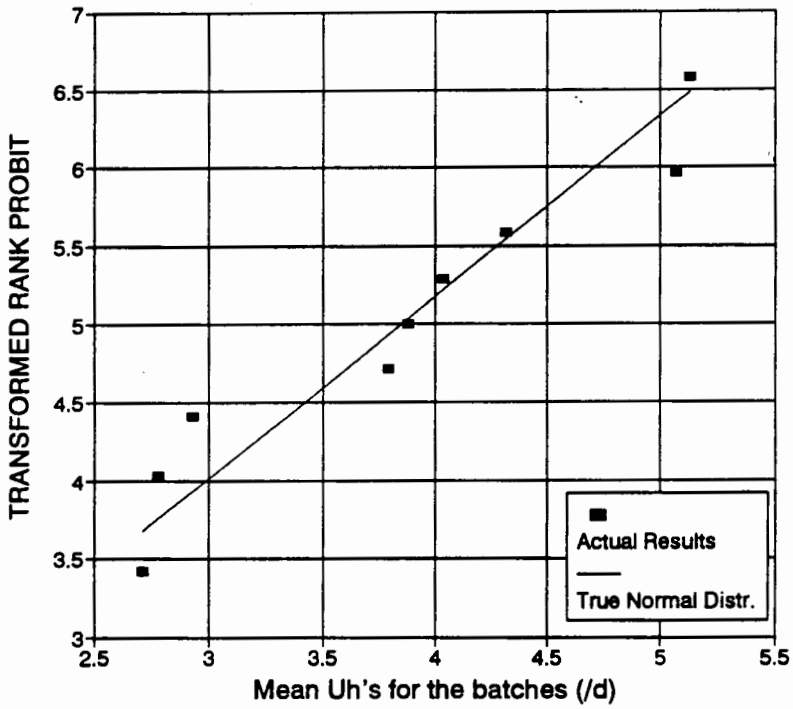

Fig 5.15: Probability plot of the means of heterotrophic maximum specific growth rate on RBCOD (μ_H) for the different wastewater batches from Borcherds Quarry Treatment Plant.

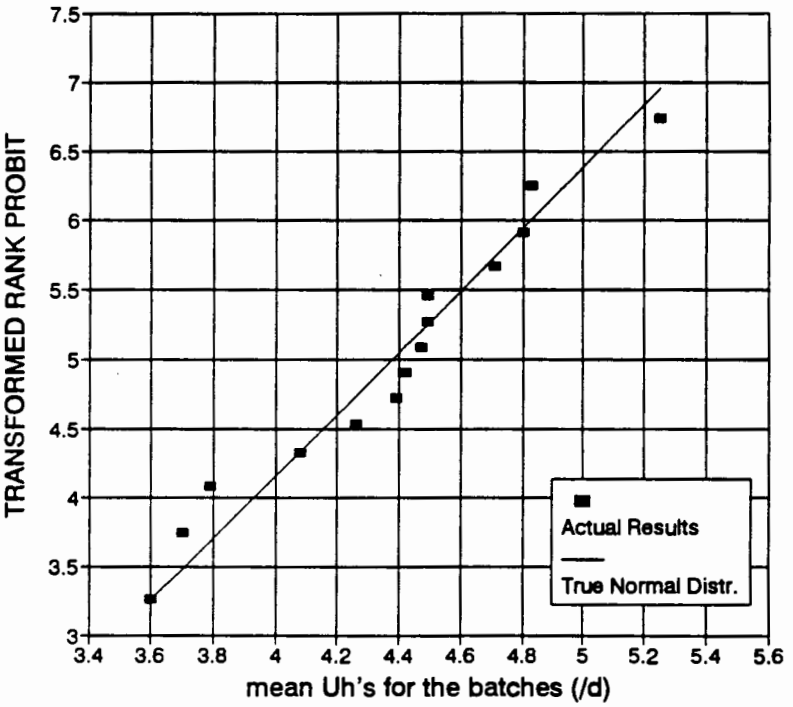

Fig 5.16: Probability plot of the means of heterotrophic maximum specific growth rate on RBCOD (μ_H) for the different wastewater batches from Mitchell's Plain Treatment Plant.

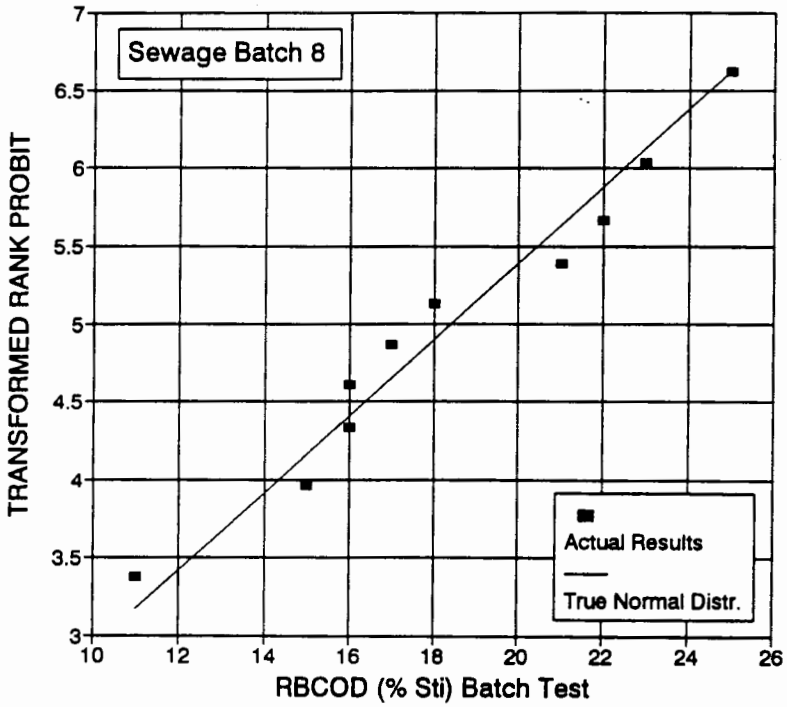

Fig 5.17a: Probability plot of RBCOD (% of total COD, S_{ti}) derived from the batch test for one batch of wastewater from Borcherds Quarry Treatment Plant. (Sewage batch No.8).

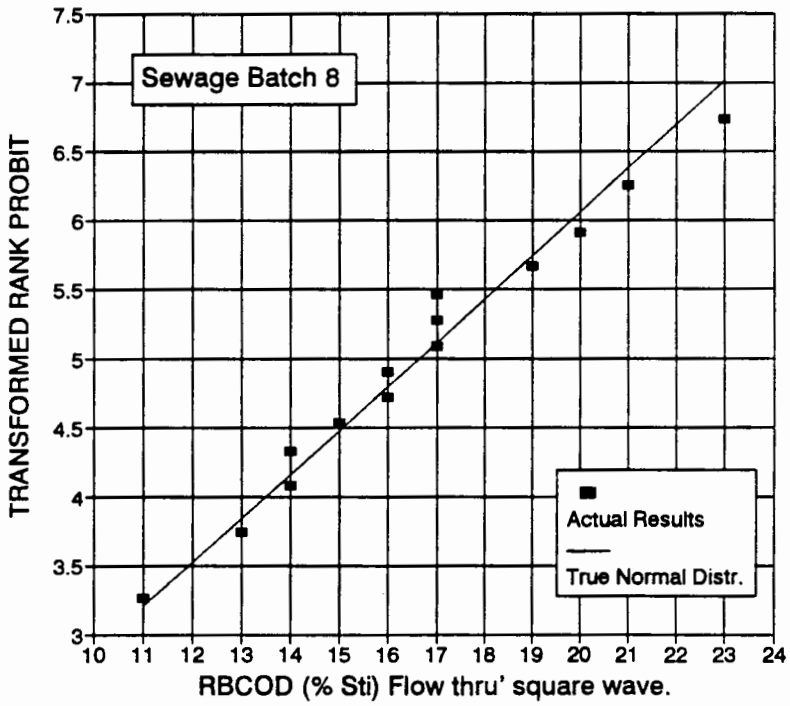

Fig 5.17b: Probability plot of RBCOD (% of total COD, S_{ti}) derived from the flow-through square wave test for one batch of wastewater from Borcherds Quarry Treatment Plant (Sewage batch No.8).

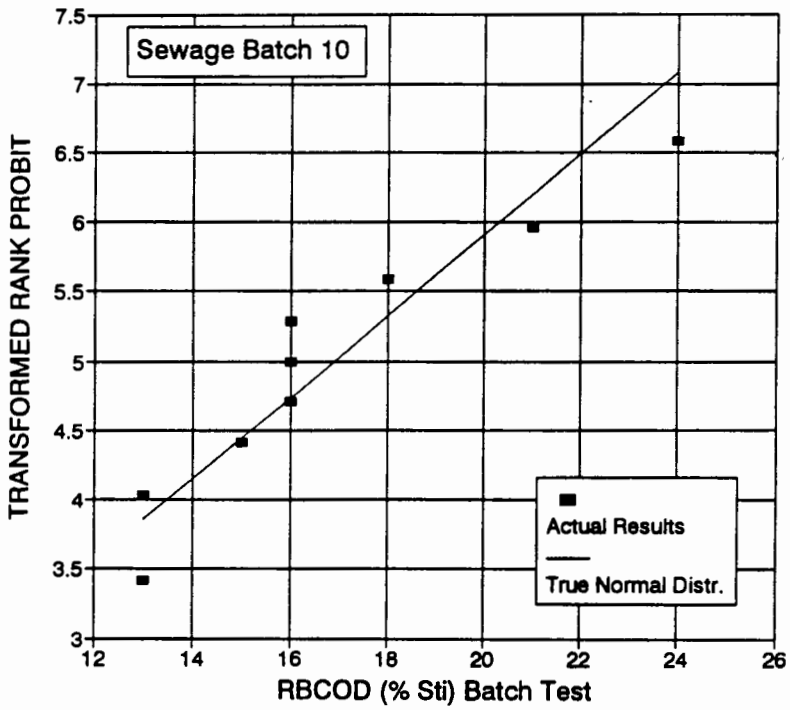

Fig 5.18a: Probability plot of RBCOD (% of total COD, S_{ti}) derived from the batch test for one batch of wastewater from Mitchell's Plain Treatment Plant. (Sewage batch No.10).

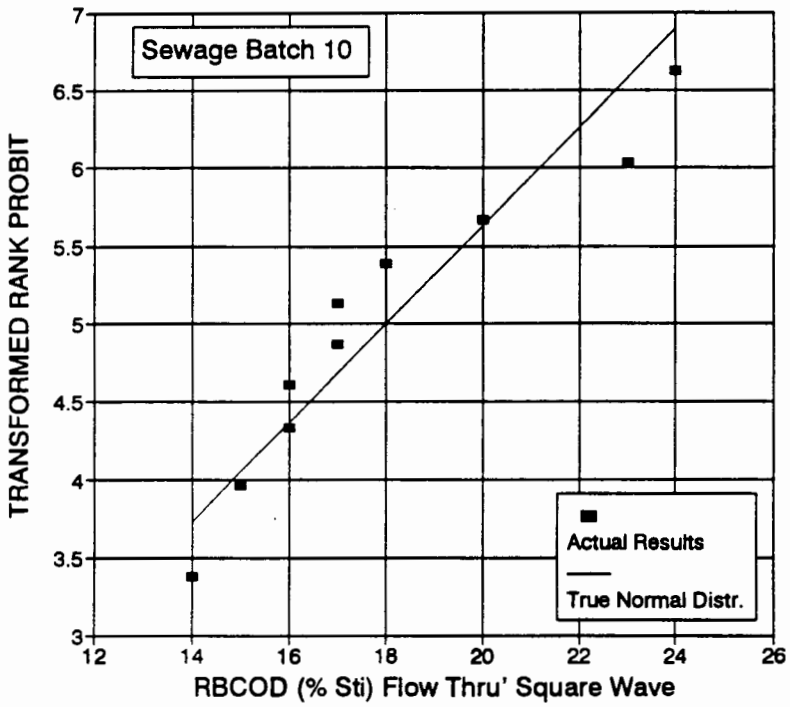

Fig 5.18b: Probability plot of RBCOD (% of total COD, S_{ti}) derived from the flow-through square wave test for one batch of wastewater from Mitchell's Plain Treatment Plant. (Sewage batch No.10).

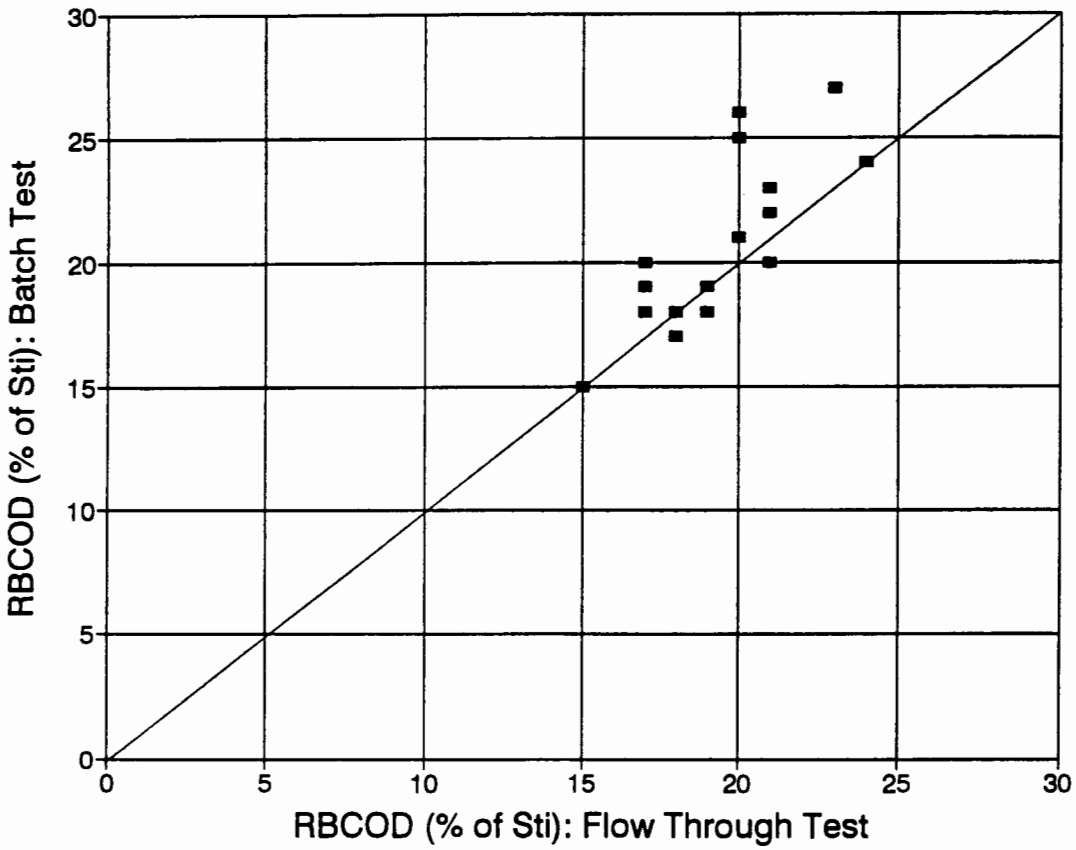

Fig 5.19: Readily biodegradable COD (RBCOD, as % of total COD) derived from the batch test versus those from the flow-through square wave method. Each data point is the mean of a number of tests on one batch of sewage.

Table 5.1: Wastewater batch number, dates of testing, source of wastewater batches and number of batch tests on each wastewater batch.

Sewage Batch	Dates of Tests	Sewage Source	No. of tests
1	12 - 28 July	Boucherds Quarry	6
2	26 - 17 Aug.	"	5
3	25 Aug - 2 Sep	"	9
4	8 - 13 Sep	"	8
5	16 - 23 Sep	"	6
6	26 Sep - 2 Oct	"	6
7	5 - 14 Oct	"	9
8	16 - 30 Oct.	"	10
9	31 Oct-8 Nov	"	8
10a	Jan 21-2 Feb	Mitchell's Plain	7
10	4 - 13 Feb	"	9
11	17 Feb - 1 Mar	"	9
12	18 - 28 Mar	"	8
13	1 -13 April	"	12
14	19 Apr-15 May	"	11
15	19 - 31 May	"	8
15a	1 - 9 June	"	9
16	12 Jun-1 Jul	"	7
17	2 - 21 Jul	"	13
18	25 Jul-9 Aug	"	11
19	12 - 30 Aug	"	11
20	1 - 15 Sept	"	10
21	16 Sep- 2 Oct	"	9
22	12 - 20 Oct	"	4
23	21 Oct - 3 Nov	"	9

Table 5.2: Mean heterotrophic active biomass (as % of total COD, S_{ti}), number of tests and standard deviation for the batch tests on the different sewage batches.

Sewage Batch	Dates of Test	Mean Heterotroph Active Mass		
		mean Zbho(%)	No. of tests	Std.dev (of mean)
1	12-28 July	7	5	1.5
2	6-17 Aug.	10	5	1.0
3	25 Aug-2 Sep	9	8	0.7
4	8-13 Sep	7	8	1.0
5	16-23 Sep	9	5	0.5
6	26 Sep-2 Oct	11	5	1.4
7	5-14 Oct	16	9	1.7
8	16-30 Oct.	14	10	1.8
9	31 Oct-8 Nov	10	7	1.7
10	4-13 Feb	4	9	0.6
11	17 Feb-2 Mar	3	8	0.2
12	18-28 Mar	11	5	1.2
13	1-13 April	10	12	1.4
14	19 Apr-15 May	6	8	0.8
15	19-31 May	9	7	1.5
16	12 Jun-1 Jul	5	6	0.9
17	2-21 Jul	8	12	1.1
18	25 Jul-9 Aug	6	10	0.8
19	12-30 Aug	9	9	1.4
20	1-15 Sept	7	9	1.0
21	16 Sep-2 Oct	12	9	1.4
22	12-20 Oct	3	4	0.5
23	21 Oct-3 Nov	7	9	1.0

Table 5.3: Mean heterotroph maximum specific growth rates on SBCOD (K_{MP}) and RBCOD ($\hat{\mu}_H$), number of tests and standard deviation of the means for the batch tests on the different sewage batches.

Sewage Batch	Date of Test	MEAN Kmp and Uh					
		Kmp			Uh		
		mean Kmp(/d)	no.of tests	Std.dev of mean	mean Uh(/d)	no.of tests	Std.dev of mean
1	Jul 12-28	1.34	5	0.22	3.79	5	0.45
2	Aug 6-17	2.11	5	0.16	4.32	5	0.57
3	Aug 25- Sep 2	2.31	8	0.09	5.07	8	0.33
4	Sep 8-13	2.16	8	0.05	5.13	8	0.22
5	Sep 16-23	2.04	6	0.10	4.04	6	0.19
6	Sep 26-Oct 2	1.64	6	0.10	3.88	6	0.40
7	Oct 5-14	1.92	9	0.06	2.93	9	0.26
8	Oct 16 -30	1.94	10	0.13	2.78	10	0.30
9	Oct 31-Nov 8	1.75	7	0.07	2.71	7	0.19
10	Feb 4-13	3.57	9	0.16	4.83	9	0.28
11	Feb17-Mar 2	4.08	8	0.20	4.71	8	0.22
12	Mar 18-28	2.35	5	0.26	3.79	5	0.16
13	Apr 1- 13	1.84	12	0.09	3.70	12	0.33
14	Apr 19-May 15	2.11	10	0.07	4.42	10	0.45
15	May 19-31	2.49	8	0.08	4.47	8	0.32
16	Jun 13-Jul 1	2.06	7	0.10	4.39	7	0.22
17	July 2-21	1.83	13	0.09	4.08	13	0.24
18	Jul 25-Aug 9	2.27	11	0.17	4.49	11	0.16
19	Aug 12-30	1.73	9	0.07	5.25	9	0.19
20	Sept 1-15	1.82	10	0.13	4.49	10	0.23
21	Sep 16-3 Oct	2.08	9	0.14	3.60	9	0.20
22	Oct 12-20	3.24	4	0.15	4.26	4	0.11
23	oct 21-Nov 3	3.17	9	0.14	4.80	9	0.24

Table 5.4: Mean RBCOD, number of tests and standard deviation of the means for the batch tests on the different sewage batches.

Sewage Batch	Dates of Test	MEAN RBCOD (% of TOTAL COD)					
		SQUARE WAVE			BATCH TEST		
		mean RBCOD	no.of tests	Std.dev of mean	mean RBCOD	no.of tests	Std.dev of mean
1	Jul 12-28	21	11	1.2	20	5	2.0
2	6-17 August	-	-	-	11	5	0.7
3	Aug 25-Sep 3	15	5	1.6	15	8	0.9
4	Sep 8-13	17	7	1.6	20	8	0.9
5	16-23 Sept	20	6	0.9	21	6	0.9
6	Sep 26-Oct 3	21	7	1.1	23	6	0.4
7	Oct 5-14	18	7	1.4	18	9	1.0
8	Oct 16 -30	17	14	0.8	18	10	1.4
9	Oct 31-Nov 8	18	7	1.1	17	7	0.9
10a	Jan 21-Feb 2	22	6	0.5	-	-	-
10	Feb 4-13	18	10	1.1	17	9	1.2
11	feb17-mar 2	18	12	1.4	17	7	0.7
12	Mar 18-28	19	9	1.6	19	5	1.1
13	Apr 1- 13	20	12	1.1	25	10	0.8
14	Apr 19-May 15	17	10	1.8	19	9	0.9
15	May 19-31	-	-	-	19	8	1.0
16	12 June-1 July	21	17	0.6	22	7	1.9
17	july2-21	23	17	0.7	27	10	0.6
18	jul25-aug9	20	8	1.2	26	11	1.5
19	aug12-30	24	10	1.1	24	9	1.5
20	sept1-15	21	6	1.9	22	10	1.1
21	sept 16-2 oct	21	10	1.1	20	8	0.8
22	12-20 Oct	-	-	-	20	4	0.5
23	21 Oct-3 Nov.	19	9	1.9	18	8	1.3

Table 5.5: Statistical significance tests on the difference between the mean RBCOD derived from the flow-through square wave and batch test methods for the different batches of sewage.

Sewage Batch	Dates of tests	std error of diff.	diff. of means	conf. level	statistical sig.of diff.	conclusion
1	Jul 12-28	2.3	1	95	-3.6	not stat.sig.
2	6-17 August	-				-
3	Aug 25-Sep 3	1.8	0		-3.6	not stat.sig.
4	8-13 Sep	1.8	3		-0.6	not stat.sig.
5	16-23 Sep	1.3	1		-1.6	not stat.sig.
6	Sep 26-Oct 3	1.2	2		-0.4	not stat.sig.
7	Oct 5-14	1.7	0		-3.4	not stat.sig.
8	Oct 16 -30	1.6	1		-2.2	not stat.sig.
9	Oct 31-Nov 8	1.4	1		-1.8	not stat.sig.
10a	Jan 21-Feb 2	-	-	-	-	-
10	Feb 4-13	1.6	1		-2.2	not stat.sig.
11	Feb 17-Mar 2	1.6	1		-2.2	not stat.sig.
12	Mar 18-28	1.9	0		-3.8	not stat.sig.
13	Apr 1- 13	1.4	5		2.2	stat.sig
14	Apr 19-May 15	2.0	2		-2.0	not stat.sig.
15	May 19-31	-	-	-	-	-
16	12 Jun-1 Jul	2.0	1		-3.0	not stat.sig.
17	July 2-21	0.9	4		2.2	stat.sig
18	Jul 25-Aug9	1.9	6		2.2	stat.sig
19	Aug 12-30	1.9	0		-3.8	not stat.sig.
20	Sept 1-15	2.2	1		-3.4	not stat.sig.
21	sept 16-2 Oct	1.4	1		-1.8	not stat.sig.
22	12 -20 Oct	-	-		-	-
23	21 Oct-3 Nov	2.3	1		-3.6	not stat.sig.

CHAPTER 6

EVALUATION OF A PHYSICAL (FLOCCULATION–FILTRATION) METHOD TO DETERMINE READILY BIODEGRADABLE COD

6.1 INTRODUCTION

In Chapter 4 a simple bioassay batch test method was developed to determine wastewater readily biodegradable COD (RBCOD). In Chapter 5 this batch test method was evaluated by comparing the measured RBCOD with those obtained from the conventional flow–through square wave method (WRC, 1984); results from the two methods correlate closely.

In this Chapter it is intended to experimentally evaluate and refine for practical application the more promising physical methods to determine RBCOD. In reviewing the physical methods available to quantify wastewater RBCOD concentration (Chapter 3), the method of Mamais *et al.* (1993) was identified to hold the most promise. In this method, the inclusion of a flocculation step prior to filtration appears to overcome the problem of correct selection of filter pore size inherent in the other physical methods (see Chapter 3). Accordingly, in this Chapter, the physical flocculation–filtration method proposed by Mamais *et al.* (1993) to measure RBCOD will be evaluated by comparing the RBCOD concentration measured with this method with those from the batch test and flow–through square wave methods. Also, the experimental protocol of Mamais *et al.* will be examined to determine whether this can be improved.

6.2 TEST PROCEDURE

The wastewater batches collected from Borcherds Quarry and Mitchell's Plain for the batch test and flow–through square wave procedures (Chapter 5) were used also for the flocculation–filtration method (see Table 5.1 for wastewater source). A sample was drawn from the wastewater batch being tested and brought to 20° C (see Chapter 5). The wastewater was then diluted to 500±50 mgCOD/ℓ and used for all three RBCOD testing techniques, i.e. the same wastewater sample at the same COD concentration was used for the batch test, flow–through square wave and flocculation–filtration methods. For the flocculation–filtration method, Mamais *et al.* (1993) added zinc sulphate as flocculant and adjusted the pH to 10,5 with sodium hydroxide, this pH being the optimum for zinc sulphate flocculation. In this study preliminary flocculation experiments indicated that for wastewater,

aluminium sulphate [$Al(SO_4)_3 \cdot 15H_2O$] gave good flocculation. Furthermore, addition of aluminium sulphate caused the pH to decline to about 6,0 to 6,3, the near optimum pH for aluminium flocculation; consequently, with aluminium sulphate as flocculant, pH adjustment was not necessary. Accordingly, to simplify the experimental procedure aluminium sulphate was used as flocculate instead of zinc sulphate, and no pH adjustment was done.

For the flocculation–filtration, one litre of the diluted wastewater was dosed with 10 mℓ of stock aluminium sulphate [$Al(SO_4)_3 \cdot 15H_2O$, Merck] solution (stock at 50 g/ℓ). The mixture was stirred rapidly (± 200 rpm) for two minutes (rapid mix phase) and then poured slowly into a perspex cylinder with diameter 90 mm (settling column) equipped with a magnetic stirrer. The contents of the column were stirred slowly (± 1 rpm) for 30 minutes (flocculation phase) (observations indicated that the time for the flocculation phase probably could be reduced considerably to about 5–10 minutes, but this was not investigated). During the flocculation phase, the flocs coalesced and settled out to leave a "clear" liquid zone. A 50 mℓ sample was drawn from the clear liquid zone and filtered through a glass fibre filter (Whatman's GF/C) and COD of the filtrate determined. The filtrate from the glass fibre filter was then filtered through 0,45μm filter paper (Millipore HVLP) and the COD of the filtrate also determined. Both glass fibre and 0,45μm filters were used to determine if the 0,45μm filter recommended by Mamais *et al.* (1993) could be replaced with glass fibre filters, to reduce the cost of the test.

In the test procedure, the filtrate derived from the influent will contain both biodegradable and unbiodegradable soluble CODs (see Chapter 3). Thus, it is necessary to independently determine the unbiodegradable soluble COD, to derive an estimate for biodegradable soluble COD (Mamais *et al.*, 1993). Following the recommendations of Ekama *et al.* (1986), the unbiodegradable soluble COD was determined using the effluent from a laboratory–scale completely aerobic activated sludge system operated at 12 days sludge age (see Appendix D for details, configuration and operation). The effluent from this system was tested in exactly the same way as for the influent (see above).

The difference in COD between the flocculated–filtered influent and the effluent samples gives the biodegradable soluble COD, which should correspond to the readily biodegradable COD (Mamais *et al.*, 1993). The biodegradable soluble COD was determined using the glass fibre and 0,45μm filter papers. To evaluate whether

this corresponds to the readily biodegradable COD (RBCOD), the results were compared to RBCOD measured using the conventional flow–through square wave test (WRC, 1984) and the batch test (see Chapters 4 and 5) on the same sewage batches, at the same COD concentration.

6.3 RESULTS

For every test conducted, influent total COD, influent and effluent flocculation–filtration CODs, with both glass fibre and 0,45μm filter papers are listed in Appendix E, Tables E.1a, E.2a and E.1b, E.2b for Borcherds Quarry and Mitchell's Plain wastewaters. RBCOD was calculated as the difference between the influent and effluent flocculation–filtration CODs, and is expressed as a percentage of total COD for 0,45μm filtration in Appendix E, Tables E.3a and E.3b for Borcherds Quarry and Mitchell's Plain wastewaters respectively, and for glass fibre filtration in Tables E.4a and E.4b for Borcherds Quarry and Mitchell's Plain respectively. These results are summarized in Appendix F, Table F.1, together with the corresponding RBCOD percentages derived from the batch test (Chapters 4 and 5) and flow–through square wave procedures. To evaluate the results, for every batch of wastewater tested, statistical plots of RBCOD as a percentage of total COD were constructed for the glass fibre, 0,45μm, flow–through square wave and batch test methods, for example see Figs 6.1, 6.2, 6.3 and 6.4 respectively. From these plots, the mean and standard deviation of the mean for the three tests were determined (see Appendix C for interpretation of statistical plots); these values for the different batches of sewage are listed in Table 6.1 for wastewaters from both Borcherds Quarry and Mitchell's Plain (see Table 5.1 for wastewater source).

To compare the results derived from the flocculation–filtration method with those from the conventional flow–through square wave test, the mean RBCOD values for the different wastewater batches obtained from the 0,45μm filtration–flocculation were plotted against the corresponding values obtained from the flow–through square wave test, see Fig 6.5; reasonable correlation was obtained. To test whether the differences in the means between the square wave and 0,45μm flocculation–filtration tests were statistically significant, the method of Velz (1950) was used, see Table 6.2 (see Appendix C for details of the test) – six out of eighteen differences between the means from the two methods were statistically significant at the 95% confidence interval. Thus, it can be concluded that the flocculation–filtration method with 0,45μm filter paper provides a reasonable estimate of the RBCOD.

To evaluate whether the 0,45μm filter paper recommended by Mamais *et al.* (1993) could be replaced by glass fibre filter papers, the filtrate COD concentrations from the two filter papers for both influent and effluent samples were plotted against each other, see Fig 6.6: It is evident that the values from both filter papers give very similar results. Also, for the different sewage batches mean RBCOD concentrations for the glass fibre filtration were plotted against those for 0,45μm filtration, see Fig 6.7 – very close correlation was obtained. Also, the method of Velz (1950) was used to test whether the mean RBCOD values derived from the glass fibre filtration were statistically different from those derived from the flow-through square wave method, see Table 6.2. Four out of sixteen differences between the means were statistically significant at the 95% confidence interval. Clearly, the 0,45μm filter papers recommended by Mamais *et al.* can be replaced by glass fibre filters. This will reduce the cost of the test significantly.

The mean RBCODs from 0,45μm filtration were compared also to those from the batch test method (see Chapter 5), see Fig 6.8 – close correlation was obtained. The statistical significance test was applied to these data as well, see Table 6.3; only five out of nineteen differences between the means from the two methods were found to be statistically significant at the confidence interval of 95%. Evidently the two test methods give very similar results. Similarly, the mean RBCODs from the glass fibre filtration were compared with those from the batch test method, see Table 6.3; six out of seventeen differences between the means were significant at the 95% confidence interval.

6.4 CONCLUSIONS

From the results of this investigation, the following conclusions can be drawn:

- The zinc sulphate flocculant recommended by Mamais *et al.* (1993) can be replaced with aluminium sulphate. This has the advantage that pH adjustment after flocculant addition is not required.

- The flocculation–filtration method provides estimates of RBCOD that correlate reasonably with those from the conventional square wave method.

- The flocculation–filtration method provides estimates of RBCOD that also correlate reasonably with those from the batch test method.

- The flocculation–filtration method is relatively simple and easy to apply. However, the method does require effluent samples from a long sludge age activated sludge system, to independently determine unbiodegradable soluble COD; these may not always be available.

- In the flocculation–filtration method, glass fibre and 0,45μm filter papers give results that correspond closely. Accordingly, the 0,45μm filter paper recommended by Mamais *et al.* can be replaced by glass fibre filter paper to reduce the cost of the test procedure.

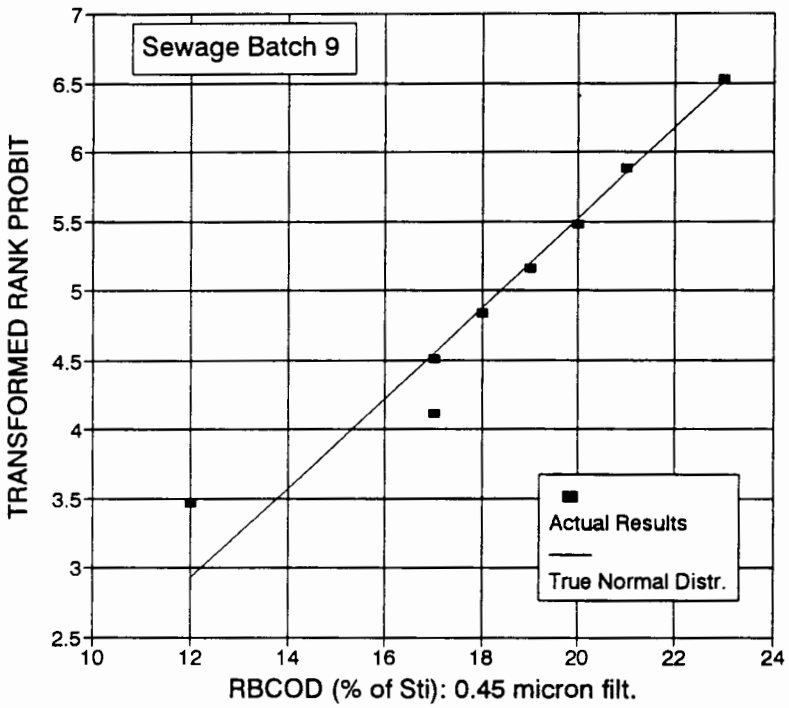

Fig 6.1: Probability plot of RBCOD (% of total COD, S_{ti}) derived from the 0,45μm flocculation–filtration test for one batch of sewage from Borcherds Quarry Treatment Plant. (Sewage batch No.9).

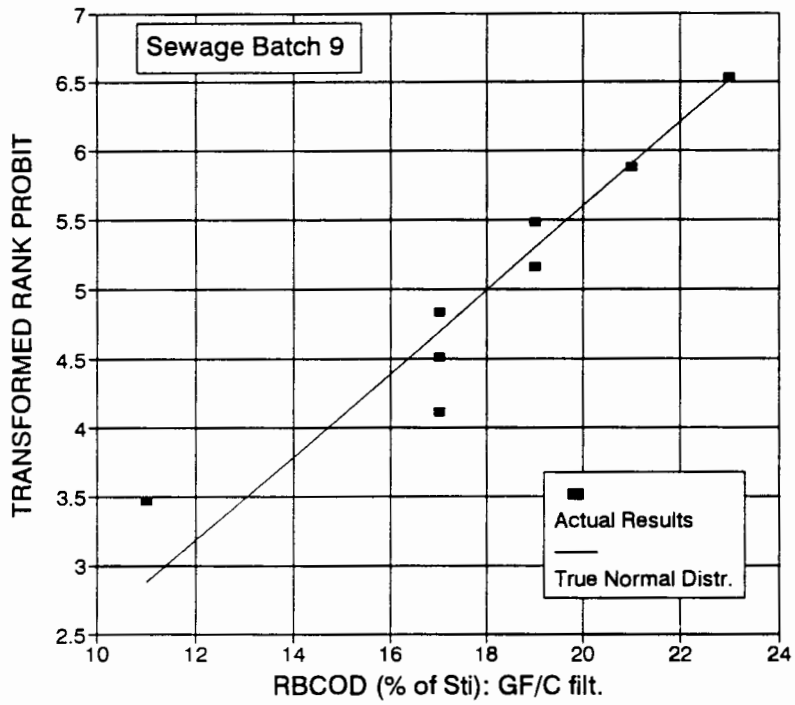

Fig 6.2: Probability plot of RBCOD (% of total COD, S_{ti}) derived from the glass fibre flocculation–filtration test for one batch of sewage from Borcherds Quarry Treatment Plant. (Sewage batch No.9).

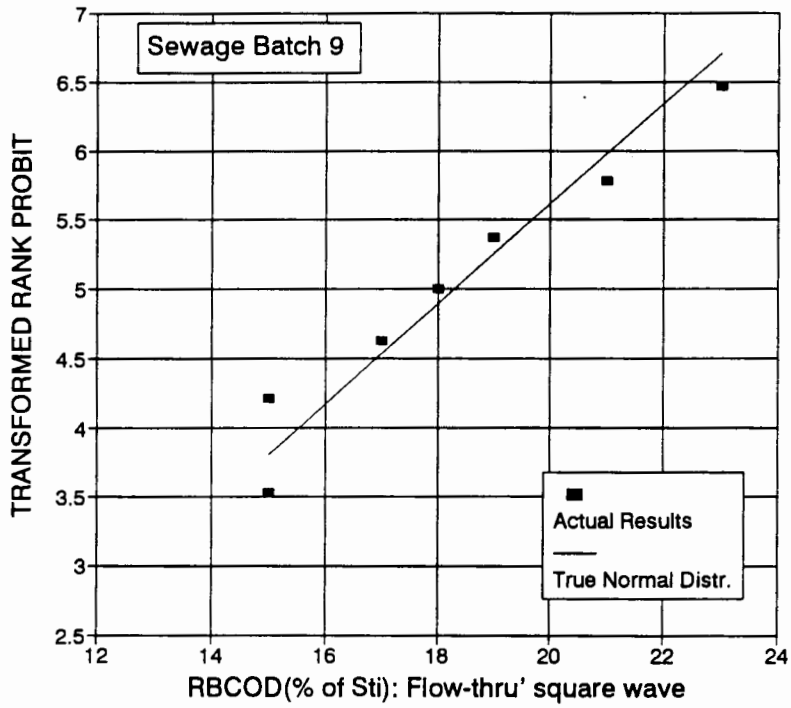

Fig 6.3: Probability plot of RBCOD (% of total COD, S_{ti}) derived from the flow-through square wave test for one batch of sewage from Borcherds Quarry Treatment Plant. (Sewage batch No.9).

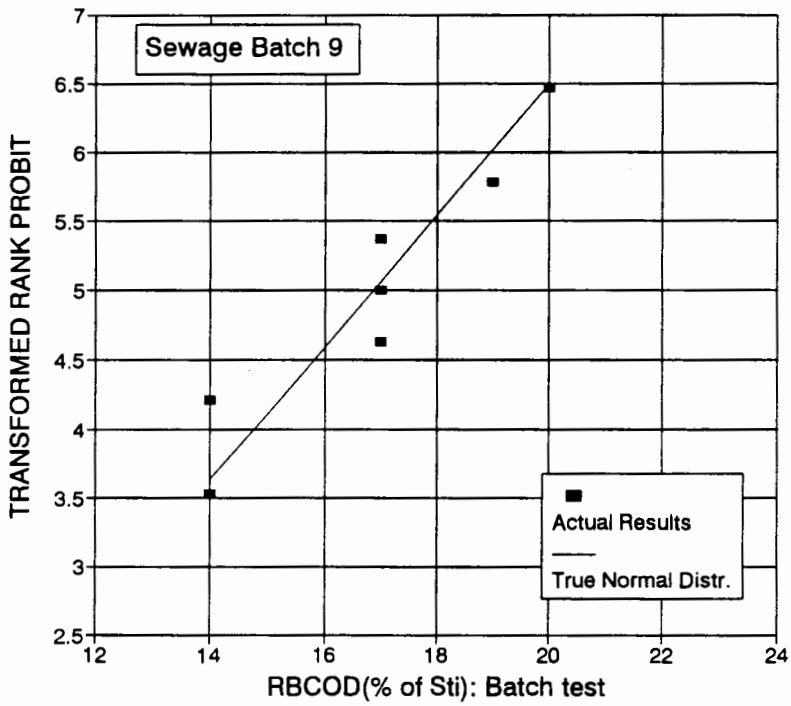

Fig 6.4: Probability plot of RBCOD (% of total COD, S_{ti}) derived from the batch wave test for one batch of sewage from Borcherds Quarry Treatment Plant. (Sewage batch No.9).

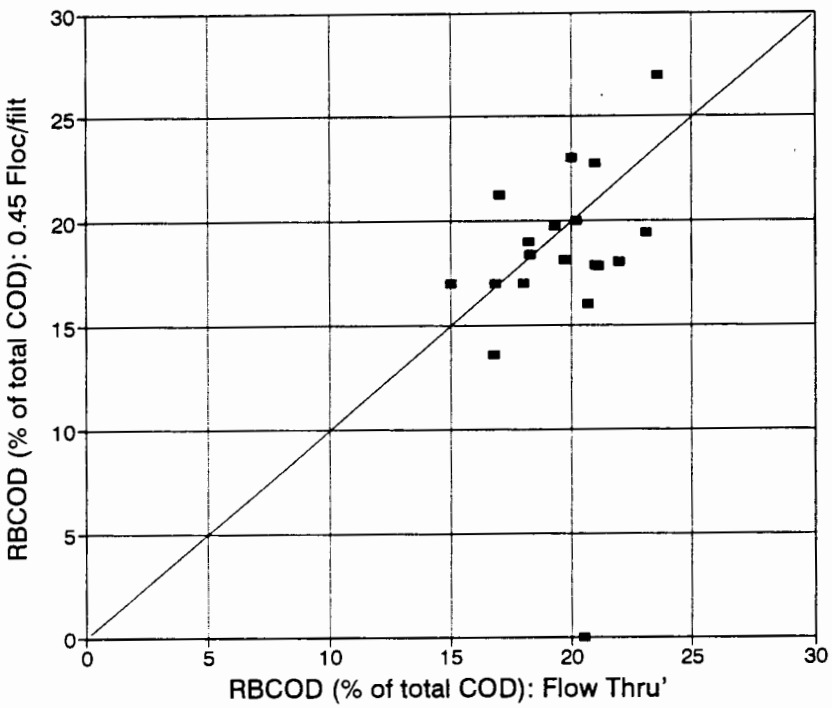

Fig 6.5: RBCOD derived from the 0,45μm flocculation–filtration test versus those from the flow–through square wave test. Each data point is the mean of a number of tests on one batch of sewage.

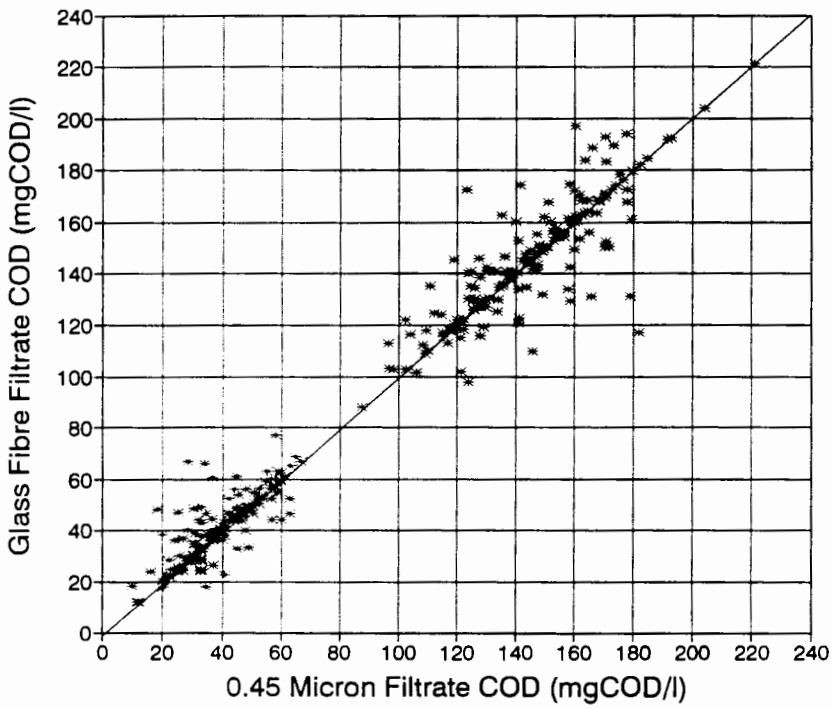

Fig 6.6: COD concentration following flocculation–filtration through glass fibre filters versus those following flocculation–filtration through 0,45μm filters. Both influent and effluent samples are plotted.

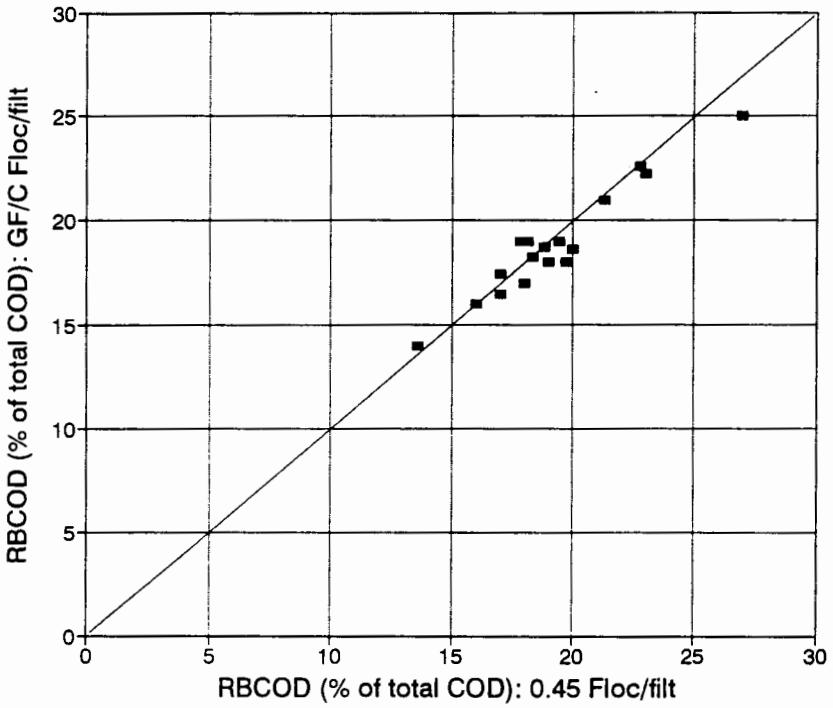

Fig 6.7: RBCOD derived from the glass fibre flocculation–filtration test versus those from 0,45μm flocculation–filtration test. Each data point is the mean of a number of tests on one batch of sewage.

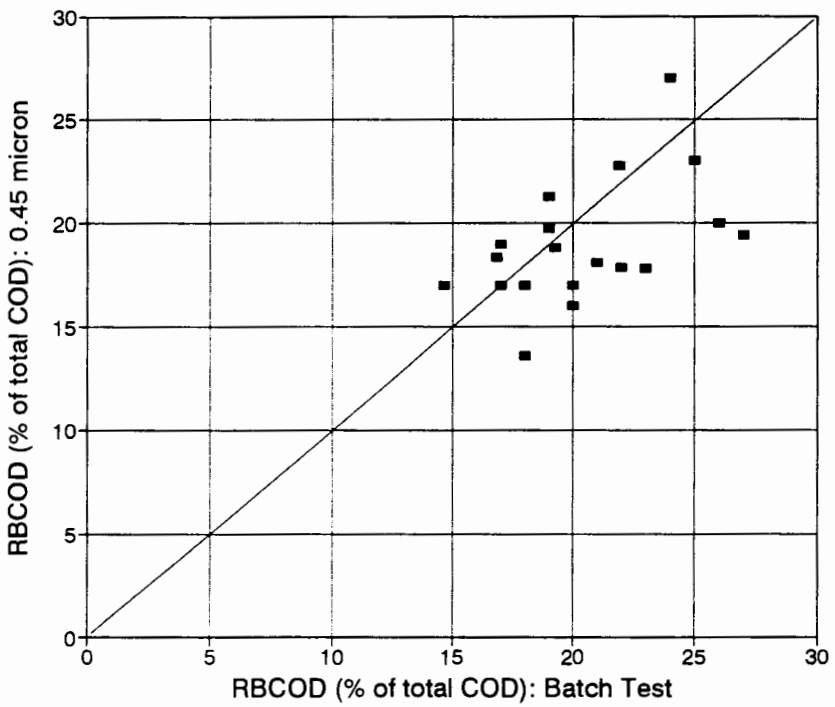

Fig 6.8: RBCOD derived from 0,45μm flocculation–filtration test versus those from the batch test. Each data point is the mean of a number of tests on one batch of sewage.

Table 6.1: Mean RBCOD, number of tests and standard deviation of the means for the flow–through square wave test, batch test and the glass fibre and 0,45μm flocculation–filtration methods for the different sewage batches.

Sewage	Dates of	MEAN RBCOD (as % of TOTAL COD)											
		SQUARE WAVE			BATCH TEST			GLASS FIBRE FILTRATION			0.45 FILTRATION		
Batch	Tests	mean of RBCOD	No. of tests	Std. dev. of mean	mean of RBCOD	No. of tests	Std. dev. of mean	mean of RBCOD	No. of tests	Std. dev. of mean	mean of RBCOD	No. of tests	Std. dev. of mean
1	Jul 12-28	21	11	1.2	20	5	2.0	-	-	-	-	-	-
2	6-17 August	-	-	-	11	5	0.7	-	-	-	-	-	-
3	Aug 25-Sep 3	15	5	1.6	15	8	0.9	-	-	-	17	7	1.9
4	Sep 8-13	17	7	1.6	20	8	0.9	-	-	-	17	6	1.7
5	16-23 Sept	20	6	0.9	21	5	0.9	19	7	1.1	18	7	1.4
6	Sep 26-Oct 3	21	7	1.1	23	5	0.4	19	6	1.1	18	6	1.6
7	Oct 5-14	18	7	1.4	18	6	1.0	17	6	0.9	17	7	0.9
8	Oct 16 -30	17	14	0.8	18	10	1.4	14	5	1.0	14	5	1.0
9	Oct 31-Nov 8	18	7	1.1	17	7	0.9	18	8	1.3	18	8	1.2
10a	Jan 21-Feb 2	22	6	0.5	-	-	-	17	11	1.4	18	11	1.0
10	Feb 4-13	18	10	1.1	17	9	1.2	18	11	1.1	19	11	1.0
11	Feb17-Mar 2	18	12	1.4	17	7	0.7	17	11	0.9	17	11	0.7
12	Mar 18-28	19	9	1.6	19	5	1.1	18	10	1.6	20	10	1.5
13	Apr 1- 13	20	12	1.1	25	10	0.8	22	11	0.8	23	11	0.7
14	Apr 19-May 15	17	10	1.8	19	9	0.9	21	15	0.7	21	15	0.6
15	May 19-31	-	-	-	19	8	1.0	19	17	0.9	19	17	0.7
16	12 June-1 July	21	17	0.6	22	7	1.9	19	8	1.0	18	8	0.6
17	July 2-21	23	17	0.7	27	10	0.6	19	11	1.1	19	11	0.7
18	Jul 25-Aug 9	20	8	1.2	26	11	1.5	19	10	0.6	20	10	0.5
19	Aug 12-30	24	10	1.1	24	9	1.5	25	5	1.4	27	6	1.8
20	Sept 1-15	21	6	1.9	22	10	1.1	23	8	0.8	23	9	1.1
21	Sept 16-2 Oct	21	10	1.1	20	8	0.8	16	10	0.6	16	10	0.6
22	12-20 Oct	-	-	-	20	4	0.5	-	-	-	-	-	-
23	21 Oct-3 Nov	19	9	1.9	18	8	1.3	-	-	-	-	-	-

Table 6.2: Statistical significance tests on the difference between the mean RBCOD from the flow–through square wave and the flocculation–filtration methods for the different batches of sewage.

Sewage Batch	Dates of Tests	std. error of diff.(0.45)	std. error of diff.(gf)	diff. of means(0.45)	diff. of means(gf)	conf. level	significance of diff.(0.45)	significanc of diff.(g/f)	conclusion 0.45 filter	conclusion g/f filter
3	Aug 25-Sep 3	2.5	-	2	-	95	-3.0	-	not stat.sig.	-
4	Sep 8-13	2.3	-	0	-		-4.6	-	not stat.sig.	-
5	16-23 Sep	1.7	1.4	2	1		-1.4	-1.8	not stat.sig.	not stat.sig
6	Sep 26-Oct 3	1.9	1.6	3	2		-0.8	-1.2	not stat.sig.	not stat.sig
7	5-14 Oct	1.7	1.7	1	2		-2.4	-1.4	not stat.sig.	not stat.sig
8	16-30 Oct	1.3	1.3	3	3		0.4	0.4	stat.sig	stat.sig
9	Oct 31-Nov 8	1.6	1.7	0	0		-3.2	-3.4	not stat.sig.	not stat.sig
10a	Jan 21-Feb 2	1.1	1.5	4	5	-	-	-	-	-
10	Feb 4-13	1.5	1.6	1	0		-2.0	-3.2	not stat.sig.	not stat.sig
11	Feb 17-Mar 2	1.6	1.7	1	1		-2.2	-2.4	not stat.sig.	not stat.sig
12	Mar 18-28	2.2	2.3	0	1		-4.4	-3.6	not stat.sig.	not stat.sig
13	Apr 1- 13	1.3	1.4	3	2		0.4	-0.8	stat.sig	not stat.sig
14	19 Apr-15 May	1.9	1.9	4	4		0.2	0.2	stat.sig	stat.sig
15	May 19-31		-	-	-		-	-	-	-
16	Jun 12- Jul 1	0.8	1.1	3	2		1.4	-0.2	stat.sig	not stat.sig
17	july2-21	1.0	1.3	4	4		2.0	1.4	stat.sig	stat.sig
18	Jul 25-Aug 9	1.3	1.3	0	2		-2.6	-0.7	not stat.sig.	not stat.sig
19	Aug 12-30	2.1	1.8	3	1		-1.2	-2.7	not stat.sig.	not stat.sig
20	Sept 1-15	2.2	2.1	2	2		-2.4	-2.2	not stat.sig.	not stat.sig
21	sept 16-2 Oct	1.3	1.3	5	5		2.4	2.4	stat.sig	stat.sig

Table 6.3: Statistical significance tests on the difference between the mean RBCOD from the batch test and the flocculation–filtration methods for the different batches of sewage.

Sewage Batch	Dates of Test	std. error of diff.(0.45)	std. error of diff.(gf)	diff. of means(0.45)	diff. of means (gf)	conf. level	significance of diff.(0.45)	significan of diff.(gf)	conclusion 0.45	conclusion gf
3	Aug 25-Sep 3	2.1	-	2	-	95	-2.2	-	not stat.sig	-
4	8-13 Sep	1.9	-	3	-		-0.8	-	not stat.sig	-
5	16-23 Sep	1.7	1.4	3	2		-0.4	-0.8	not stat.sig	not stat.sig
6	26- Oct 2	1.6	1.2	5	4		1.8	1.6	stat.sig	stat.sig
7	Oct 5-14	1.3	1.3	1	2		-1.6	-0.6	not stat.sig	not stat.sig
8	Oct 16-30	1.7	1.7	4	4		0.6	0.6	stat.sig	stat.sig
9	Oct 31-8 Nov	1.5	1.5	2	1		-1.0	-2.0	not stat.sig	not stat.sig
10a	Jan 21-Feb 2	-	-	-	-	-	-	-	-	-
10	Feb 4-13	1.6	1.6	2	1		-1.2	-2.1	not stat.sig	not stat.sig
11	Feb17-Mar 2	1.0	1.1	0	0		-2.0	-2.2	not stat.sig	not stat.sig
12	Mar 18-28	1.9	1.9	1	1		-2.8	-2.8	not stat.sig	not stat.sig
13	Apr 1- 13	1.1	1.1	2	3		-0.2	0.7	not stat.sig	stat.sig
14	Apr 19-May 15	1.1	1.1	2	2		-0.2	-0.2	not stat.sig	not stat.sig
15	May 19-31	1.2	1.4	0	1		-2.4	-1.8	not stat.sig	not stat.sig
16	23 Jun-1 Jul	2.1	2.1	4	3		-0.2	-1.2	not stat.sig	not stat.sig
17	July 2-21	0.9	1.3	8	8		6.2	5.4	stat.sig	stat.sig
18	Jul 25-Aug 9	1.6	1.6	6	7		2.8	3.8	stat.sig	stat.sig
19	Aug 12-30	2.3	2.1	3	1		-1.6	-3.2	not stat.sig	not stat.sig
20	Sept 1-15	1.6	1.4	1	1		-2.2	-1.8	not stat.sig	not stat.sig
21	Sept 16-2 Oct	1.0	1.0	4	4		2.0	2.0	stat.sig	stat.sig

CHAPTER 7

EXTENSION OF THE BATCH TEST TO DETERMINE UNBIODEGRADABLE SOLUBLE COD

7.1 INTRODUCTION

In operation of the wastewater treatment plant, the effluent COD concentration is of prime importance – this is one of the parameters that invariably has a maximum permissible concentration set by legislation (e.g. South African Water Act, 1956). The effluent COD is made up of two fractions, particulate and soluble. The particulate fraction is due to inadequate settling in the secondary settling tank because of either hydraulic organic overload or bulking sludges (Casey *et al.*, 1995). With regard to the effluent soluble COD, three possible sources have been identified: (1) influent, (2) microbial intermediate and end products, and (3) cell lysis products (see Chapter 3). In the review of the experimental information available in the literature on this aspect, in Chapter 3 it was concluded that for municipal wastewater treatment plants the principal source of soluble COD in the effluent is the influent. In other words, an appreciable fraction of the influent COD is unbiodegradable soluble, will be unaffected by biological action in the activated sludge system and will appear in the effluent. Furthermore, from Chapter 3 generation of unbiodegradable soluble COD through biological action in the system is small compared to the influent unbiodegradable soluble COD and can be neglected. Accordingly, the effluent soluble COD from an activated sludge system with sludge age longer than 10 days provides a good estimate of the influent unbiodegradable soluble COD (Ekama *et al.*, 1986). This approach of determining unbiodegradable soluble COD requires operation of a continuous flow activated sludge system, a time consuming and costly task. The intention in this Chapter is to develop a more practical and simple method.

The success with the adapted Mamais *et al.* (1993) flocculation–filtration method to determine RBCOD (Chapter 6) indicated that perhaps the method could be applied to the batch test method (Chapter 4) to determine unbiodegradable soluble COD: From the OUR–time profiles in the batch test (see Fig 4.1, Chapter 4) it is evident that the RBCOD is depleted after ±10 hours (indicated by the precipitous drop in OUR), and after this time the only soluble COD remaining should be unbiodegradable. If a sample is drawn from the batch test after the precipitous drop in OUR and subjected to the flocculation–filtration method set out in Chapter 6, the

filtrate COD should provide an estimate of the unbiodegradable soluble COD. In this Chapter this proposal will be evaluated by comparing the unbiodegradable soluble COD derived in this manner from the batch test with that derived from the effluent of a long sludge age activated sludge system.

7.2 TEST PROCEDURE

At the end of the batch test (1 or more days, see Chapter 4 for method), one litre of the batch reactor contents was drawn from the reactor and the flocculation–filtration method applied using 0,45μm filter papers (see Chapter 6 for method). Effluent from a laboratory–scale aerobic activated sludge system at 12 days sludge age treating the same sewage used for the batch test was also subjected to the flocculation–filtration method (for system configuration and operation details, see Appendix D). To assess the results obtained from the batch test, these were compared to the results from the laboratory–scale system effluent, taking due account of the time taken for the batch test and the retention time for the laboratory–scale system, that is, the batch test and the effluent samples were matched to the same starting day and influent wastewater respectively.

7.3 RESULTS

Comprehensive data for total COD and unbiodegradable soluble COD determined from the batch test and the laboratory–scale system effluent are listed in Appendix G, Table G.1. In Fig 7.1 the unbiodegradable soluble COD concentrations determined from the batch test after 1 and 2 or more days are shown plotted against those determined from the effluent of the laboratory–scale completely aerobic activated sludge system; taking due account of the total COD concentration (±500 mgCOD/ℓ), reasonable correlation was obtained: In Fig 7.2 the data are plotted with the axes extended to 500 mgCOD/ℓ, the approximate total COD concentration, and in Fig 7.3 as % of the total COD. From Figs 7.1 and 7.2 it is evident that increasing the length of time of the batch test from 1 day to 2 or more days did not significantly influence the values obtained for the unbiodegradable soluble COD.

In Chapter 6, in refining and developing the flocculation–filtration procedure it was proposed and demonstrated that the 0,45μm filters can be replaced with glass fibre (GF/C) filters to reduce costs and make the filtration easier. To evaluate whether the 0,45μm filters could be replaced with glass fibre filters in determining the unbiodegradable soluble COD in the batch test, the samples taken from the batch

test for unbiodegradable soluble COD were flocculated as described in Chapter 6, and then filtered through glass fibre filters followed by 0,45μm filters. The filtrate CODs after glass fibre filtration and after 0,45μm filtration were determined, and are shown plotted against each in Fig 7.4; close correlation was obtained. Evidently, the 0,45μm filters can be replaced with glass fibre filters in this test also.

For each wastewater batch, statistical plots of the unbiodegradable soluble COD were constructed from both test methods (see Appendix C for method), for example see Figs 7.5 and 7.6 for the batch test and laboratory-scaled methods respectively (both 0,45μm filtered). From the statistical plots, for each wastewater batch the means of unbiodegradable soluble COD and standard deviations of the means were determined for both methods; these are listed in Table 7.1 (see Table 5.1 for wastewater source). The means from the two methods are shown plotted against each other in Fig 7.7 – the batch test method gives values for unbiodegradable soluble COD that tend to be slightly higher than those from the activated sludge system method; this may be due to the inability of the organisms within the batch test to degrade some of the soluble biodegradable material in the wastewater. However, the differences in unbiodegradable soluble COD between the two methods are relatively small – the estimates provided by the batch test are acceptable for design and modelling purposes. Furthermore, values for unbiodegradable soluble COD as a fraction of total COD from the batch test (f_{us} = 0,07 to 0,10) fall within the range of values to be expected for a South African raw municipal wastewater (f_{us} = 0,04 to 0,10; WRC, 1984).

7.4 CONCLUSIONS

At the end of the batch test, by drawing a sample and applying the flocculation-filtration method (see Chapter 6 for method), an estimate of the unbiodegradable soluble COD for the wastewater can be obtained. It is recommended that the batch test be run for about 1 day before the sample is drawn. Increasing the length of time of the batch test above 1 day does not significantly influence the estimate of the unbiodegradable soluble COD.

The batch test method has the advantage over the previous methods in that it is not necessary to obtain effluent from an activated sludge system. Also, using the batch test procedure, the readily biodegradable COD, heterotroph active biomass and unbiodegradable soluble COD can be quantified simultaneously.

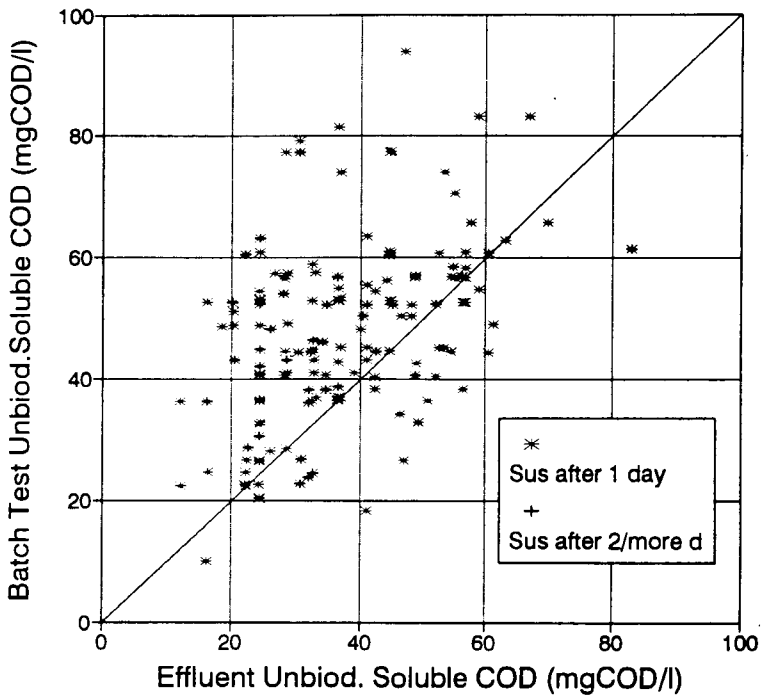

Fig 7.1: Unbiodegradable soluble COD concentrations determined from the batch test versus those determined from the effluent of a laboratory-scale completely aerobic activated sludge unit operated at a sludge age of 12 days. Each data point is single measurement.

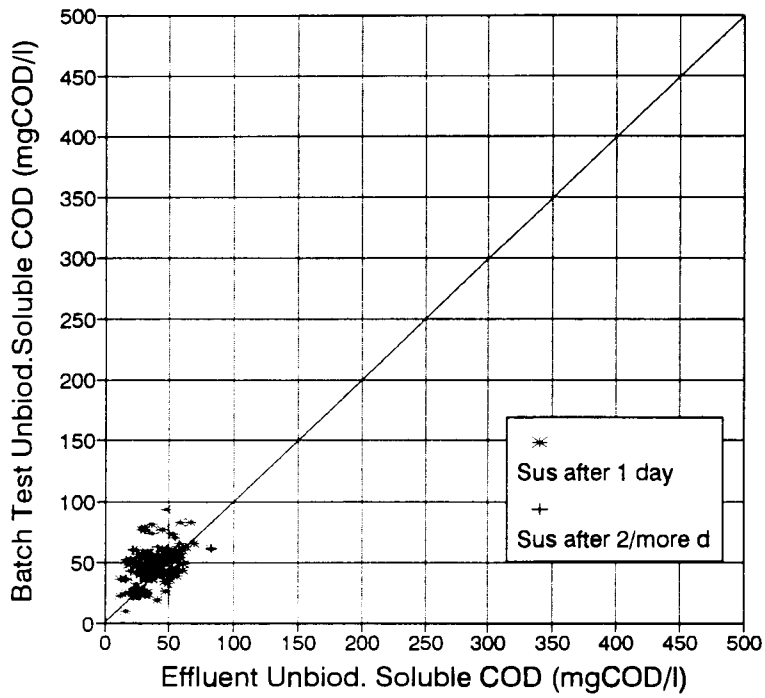

Fig 7.2: Duplicate plot of Fig 7.1 with axes extended to 500 mgCOD/ℓ, the approximate total COD concentration of the sewage in the tests.

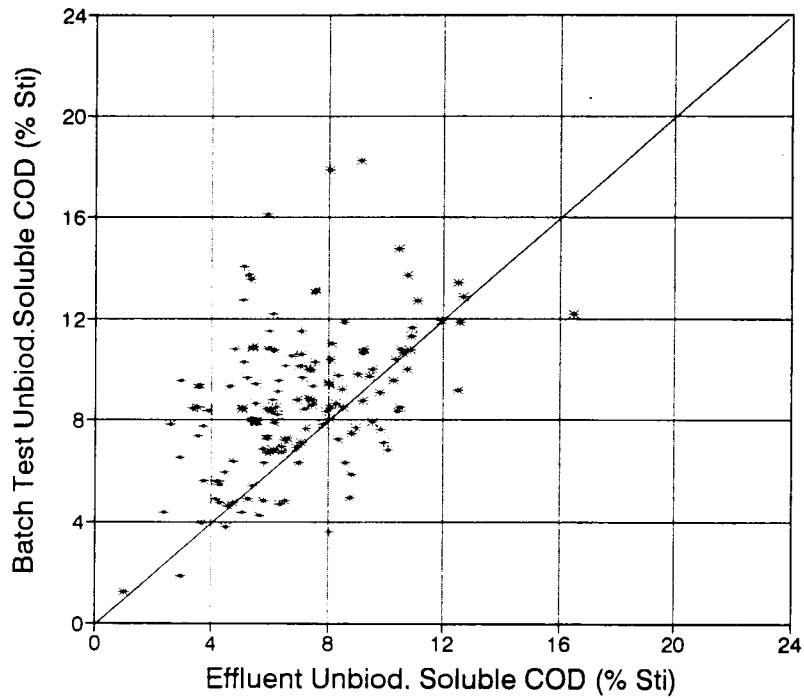

Fig 7.3: Data in Fig 7.1 plotted as % of the total COD (S_{ti}).

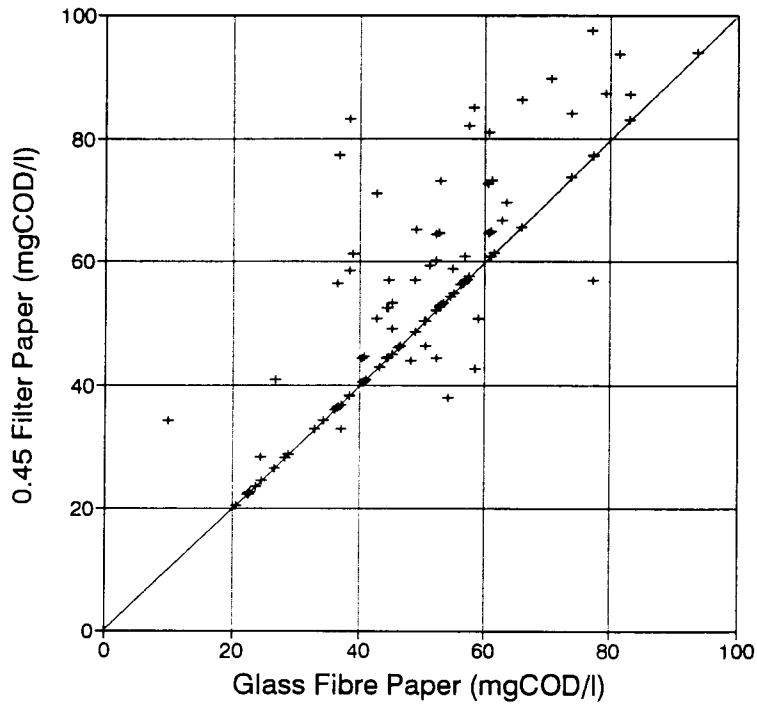

Fig 7.4: Unbiodegradable soluble COD concentrations derived from the batch test using 0,45μm filtration versus those using glass fibre filtration.

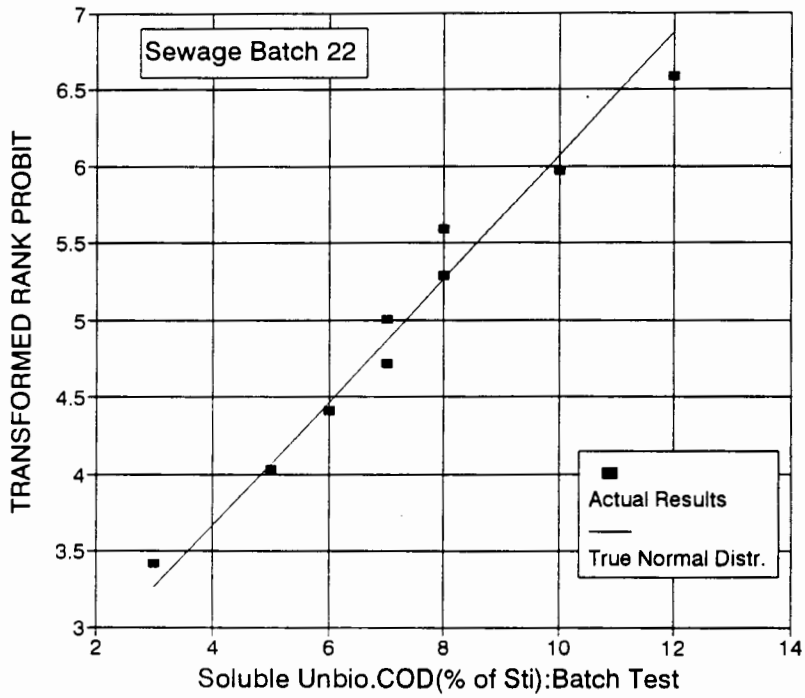

Fig 7.5: Probability plot of soluble unbiodegradable COD for batch tests on one batch of sewage from Mitchell's Plain Treatment Plant. (Sewage batch No.22).

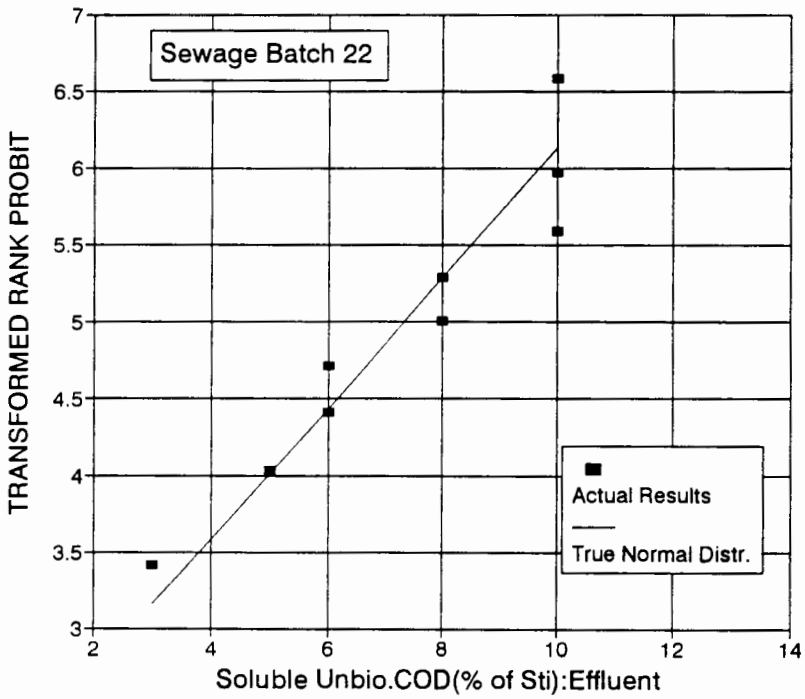

Fig 7.6: Probability plot of the soluble unbiodegradable COD derived from the aerobic unit effluent for one batch of sewage from Mitchell's Plain Treatment Plant. (Sewage batch No.22).

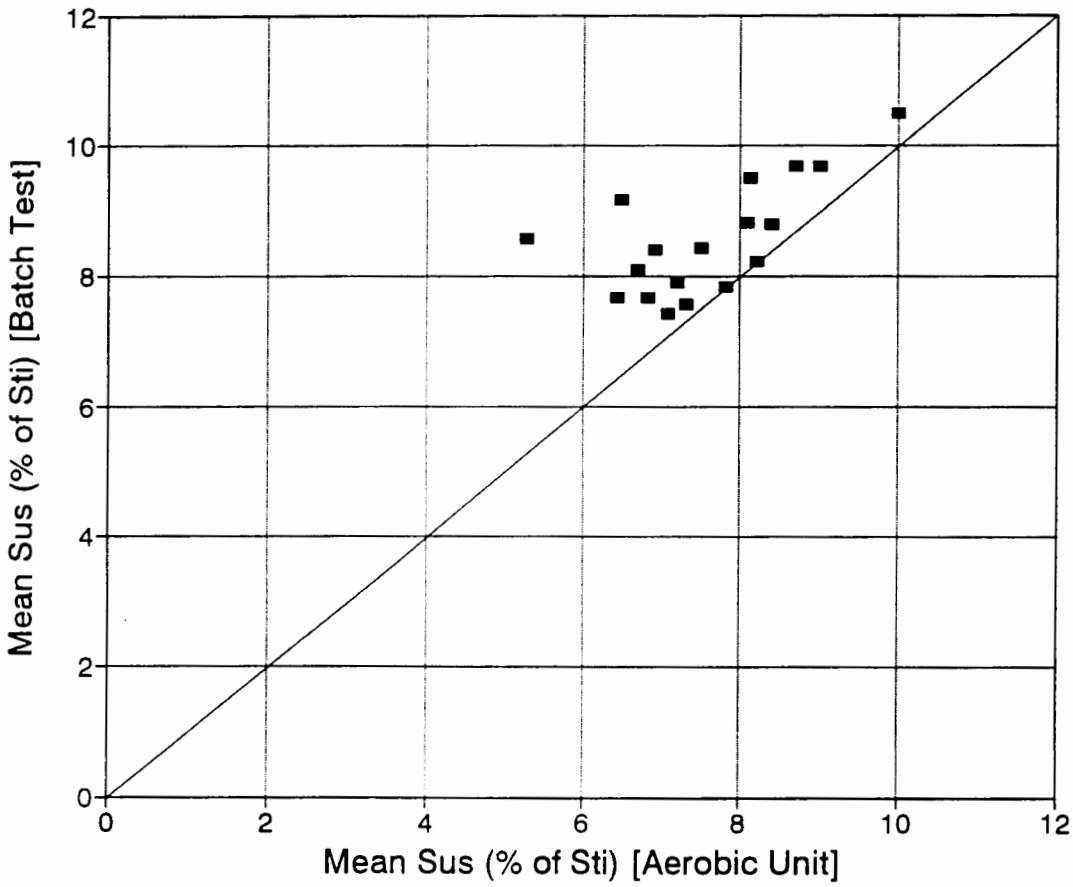

Fig 7.7: Soluble unbiodegradable COD from the batch test versus that from the aerobic unit. Each data point is the mean of a number of tests on one batch of sewage.

Table 7.1: Mean unbiodegradable soluble COD (S_{us}) (as % of S_{ti}), number of tests and standard deviation of the means for the batch tests and the aerobic unit method for the different sewage batches.

Sewage	Mean Soluble Unbiodegradable COD (% of Sti)					
	Batch Test			Activated Sludge System		
Batch	Mean Sus	No of Tests	Std.dev. of mean	Mean Sus	No of Tests	Std.dev. of mean
5	10	6	0.8	9	6	0.7
6	10	6	1.0	9	6	0.8
7	8	6	0.5	8	6	0.5
8	11	4	0.3	10	4	0.8
9	10	8	0.4	8	8	0.6
10	8	9	0.9	8	9	0.6
11	9	5	0.9	8	5	0.9
12	9	11	0.7	8	11	0.7
13	9	12	0.7	7	12	0.5
14	8	12	0.4	7	12	0.6
15	7	12	0.5	7	12	0.6
16	9	7	0.8	5	7	0.5
17	8	14	0.7	8	14	0.4
18	8	10	0.7	7	10	0.8
19	8	6	0.6	7	6	0.7
20	8	10	0.6	7	10	0.4
21	8	9	0.6	6	9	0.5
22	8	9	0.9	7	9	0.8

CHAPTER 8

EXTENSION OF THE BATCH TEST TO DETERMINE UNBIODEGRADABLE PARTICULATE AND SLOWLY BIODEGRADABLE COD FRACTIONS

8.1 INTRODUCTION

With the batch test procedure developed thus far, three of the five influent COD fractions can be quantified, namely readily biodegradable COD, heterotroph active biomass and unbiodegradable soluble COD, see Chapters 4, 5 and 7. The remaining two COD fractions, unbiodegradable particulate and slowly biodegradable COD, still need to be determined. Conventional methods to quantify these two COD fractions involve running laboratory–scale activated sludge systems (Ekama *et al.*, 1986; see Chapter 3) a time–consuming and costly exercise. In this Chapter it is the intention to explore possible options to extend the batch test procedure to provide estimates for these two COD fractions.

8.2 BACKGROUND

At the start of the batch test procedure, the total COD is made up of the five influent COD fractions:

$$S_{ti} = S_{usi} + S_{upi} + S_{bsi} + S_{bpi} + Z_{BHi} \qquad (8.1)$$

where

S_{ti} = influent total COD (mgCOD/ℓ)
S_{usi} = influent unbiodegradable soluble COD (mgCOD/ℓ)
S_{upi} = influent unbiodegradable particulate COD (mgCOD/ℓ)
S_{bsi} = influent readily biodegradable soluble COD (mgCOD/ℓ)
S_{bpi} = influent slowly biodegradable particulate COD (mgCOD/ℓ)
Z_{BHi} = influent heterotroph active biomass (mgCOD/ℓ)

For the influent, even with S_{usi}, S_{bsi} and Z_{BHi} determined using the procedures set out earlier, with the information available it is not possible to differentiate between S_{bpi} and S_{upi}. Furthermore, physical filtration techniques such as those set out in Chapter 6 also cannot separate these two fractions – since both COD fractions are particulate, they cannot be separated by filtration procedures.

During the course of the batch test the two unbiodegradable COD fractions (S_{usi}

and S_{upi}) remain unaffected by biological action. The two biodegradable COD fractions (S_{bsi} and S_{bpi}) are utilized, consuming oxygen and generating heterotroph active biomass (Z_{BH}) in the process. The heterotrophic active biomass undergoes death/decay/lysis/endogenous respiration producing endogenous residue (Z_E) and slowly biodegradable COD (S_{bp}) which is utilized in the same fashion as the influent slowly biodegradable COD.

At the end of the batch test (after the precipitous drop in OUR), all the readily biodegradable COD has been consumed and the total COD is made up of

$$S_{te} = S_{use} + S_{upe} + S_{bpe} + Z_{BHe} + Z_{Ee} \tag{8.2}$$

where

e = denotes end of test
S_{te} = total COD concentration at end of test (mgCOD/ℓ)
S_{use} = unbiodegradable soluble COD concentration at end of test (mgCOD/ℓ)
S_{upe} = unbiodegradable particulate COD concentration at end of test (mgCOD/ℓ)
S_{bpe} = slowly biodegradable particulate COD concentration at end of test (mgCOD/ℓ)
Z_{BHe} = heterotroph active biomass COD concentration at end of test (mgCOD/ℓ)
Z_{Ee} = endogenous residue COD concentration at end of test (mgCOD/ℓ)

Since the unbiodegradable COD fractions remain unaffected in the test, and unbiodegradable COD generation in the test can be considered negligible (see Chapter 3),

$$S_{te} = S_{usi} + S_{upi} + S_{bpe} + Z_{BHe} + Z_{Ee} \tag{8.3}$$

In Eqs (8.1) and (8.3) the parameters S_{usi}, S_{bsi}, Z_{BHi}, S_{ti} and S_{te} are known from measurement or calculation (see Chapters 4, 5 and 7), but the parameters S_{upi}, S_{bpi}, S_{bpe}, Z_{BHe} and Z_{Ee} are unknown. It is evident that to quantify the unknown parameters, additional information has to be obtained from the batch test. In this Chapter a number of methods are developed to attempt to obtain the necessary information. In all the methods presented, it has to be assumed that all the slowly biodegradable COD has been consumed in the batch test, i.e. $S_{bpe} = 0$. In terms of the death–regeneration hypothesis of Dold *et al.* (1980), the slowly biodegradable

COD is derived either from the influent, or is generated by the endogenous processes (see Table 4.1, Chapter 4). For the influent slowly biodegradable COD, it will be assumed that sufficient time has elapsed by the end of the batch test for this COD to have been completely consumed. For the slowly biodegradable COD generated by endogenous processes, the rate of generation is slower than the rate of utilization. Thus, if all the influent slowly biodegradable COD has been consumed in the batch test, then the slowly biodegradable COD generated by endogenous processes will be used as fast as it is generated, and the residual concentration will be negligible. Accordingly, S_{bpe} will be close to zero. To simplify interpretation and analysis of the data from the batch tests, the death–regeneration approach (Dold *et al.*, 1980) will be replaced with the endogenous–respiration approach (Marais and Ekama, 1976). In the endogenous–respiration approach, the heterotroph active biomass "dies" at a certain rate; of the biomass lost, the biodegradable portion gives rise directly to oxygen utilization (there is no substrate intermediate) and the unbiodegradable portion to endogenous residue. Under the aerobic conditions present in the batch test, both the death–regeneration and endogenous–respiration approaches give the same nett result, i.e. same loss of heterotroph active biomass, utilization of oxygen and generation of endogenous residue. However, the endogenous–respiration approach allows the oxygen utilization rate to readily separate into that for endogenous–respiration and that for heterotroph active biomass synthesis. Also, in the endogenous respiration approach the only source of slowly biodegradable COD in the batch test is from the influent wastewater. As will be seen, these consequences facilitate analysis of the batch test data.

Accepting the endogenous respiration approach, then the basic assumption is that all the influent slowly biodegradable COD has been consumed in the batch test, i.e. $S_{bpe} = 0$. This reduces the number of unknowns to four, i.e. S_{upi}, S_{bpi}, Z_{BHe} and Z_{Ee}. The methods developed below attempt to quantify these four unknowns.

8.3 METHOD 1: DIVISION OF OUR

In the batch test, the OUR–time plot (e.g. Fig 4.1, Chapter 4) represents the oxygen utilized in the consumption of the two influent biodegradable COD fractions (S_{bsi} and S_{bpi}) for heterotroph active biomass synthesis, and that utilized in endogenous processes. (As noted earlier in Chapter 4, there is no nitrification so that nitrification does not exert an OUR in the batch test). If the OUR can be divided between that for heterotroph active biomass synthesis from the influent biodegradable COD and that for endogenous processes, then with the assumption

that all the influent biodegradable COD is consumed in the batch test, it should be possible to derive estimates for the influent biodegradable COD. Since the influent readily biodegradable COD (S_{bsi}) can be quantified (see Chapters 4 and 5), then the difference between the biodegradable COD and S_{bsi} should give the influent slowly biodegradable COD (S_{bpi}). With S_{bpi} quantified the unbiodegradable particulate COD (S_{upi}) can be found by subtracting S_{bpi}, S_{bsi}, S_{usi} and Z_{BHi} from the total COD (S_{ti}).

8.3.1 Test procedure

The batch tests were run using the procedure set out in Chapter 4; the batch tests were run for 2 or more days in order to ensure all the influent biodegradable COD is consumed (a condition necessary for application of this procedure). Comprehensive data for all batch tests are listed in Appendix A. A typical OUR versus time profile is shown in Fig 8.1. From the graph it can be seen that the initial period (< 18h) corresponds to that detailed in Chapter 4, i.e. exponential increase in OUR, precipitous drop followed by an OUR plateau then decrease. As the batch test continues to run for a longer period (except for a small increase at ± 20h) the OUR continually decreases to reach an approximately constant value after about 60 hours. From the low OUR values at the end of the test (± 60 hours), a line was back projected to the start of the test, i.e. time = 0 hours (see Fig 8.1). This line represents the division between the OURs associated with endogenous respiration and utilization of the biodegradable COD in the influent wastewater, i.e. the part of the graph above the line represents the OUR due to the utilization of influent biodegradable COD and that below the line the OUR due to endogenous processes, as shown in Fig 8.1.

8.3.2 Data interpretation

At the end of the batch test *it is assumed that all the influent biodegradable COD has been consumed.* The OUR at the end of the test therefore is the OUR due to endogenous respiration only. By back projecting this OUR to the start of the test (for example see Fig 8.1), it was hoped that the measured oxygen consumption would be divided into that for heterotroph active biomass synthesis from the influent biodegradable COD and that for endogenous processes, as described above. Now, for the OUR associated with heterotroph active biomass synthesis,

$$MO_{synthesis} = (1-Y_{ZH})\, S_{bi} \qquad (8.4)$$

where

$MO_{synthesis}$ = oxygen consumed for heterotroph active biomass synthesis from influent biodegradable COD (mgO/ℓ)

Y_{ZH} = heterotroph active biomass yield (mgCOD/mgCOD)
= 0,666 mgCOD/mgCOD

S_{bi} = influent wastewater biodegradable COD concentration (mgCOD/ℓ)

Therefore, solving Eq (8.4) for S_{bi},

$$S_{bi} = MO_{synthesis}/(1-Y_{ZH}) \tag{8.5}$$

From Eq (8.5) if $MO_{synthesis}$ is known, then S_{bi} can be determined; $MO_{synthesis}$ is obtained from the OUR–time profile (see Fig 8.1) as the area under the OUR–time curve minus the oxygen consumed for endogenous processes, see Fig 8.1. With S_{bi} quantified following the procedure above and with S_{bsi} available from the procedures set out in Chapter 4, S_{bpi} can be determined as follows:

$$S_{bpi} = S_{bi} - S_{bsi} \tag{8.6}$$

With S_{bpi} quantified, S_{upi} can be calculated from the measured influent total COD concentration (S_{ti}), i.e.

$$S_{upi} = S_{ti} - S_{bi} - S_{usi} - Z_{BHi} \tag{8.7a}$$

Also, the fraction of the total influent COD that is unbiodegradable particulate (f_{up}) can be calculated:

$$f_{up} = S_{upi}/S_{ti} \tag{8.7b}$$

Thus, by subdividing the oxygen consumption in the batch between that for synthesis and that for endogenous processes, the remaining two COD fractions, S_{bpi} and S_{upi} can be quantified, and hence the wastewater COD fractions completely characterized.

8.3.3 Results

A number of batch tests were run; detailed data are listed in Appendices A and B.

For the batch tests, the results were calculated using Eqs (8.4) to (8.7) above; results for the tests are shown in Table 8.1 (see Table 5.1 for wastewater batch source).

From Table 8.1 it can be seen that the values for f_{up} are very variable, ranging from –0,14 to +0,45. Also, four batch tests (Table 8.1, wastewater batch No. 11, Feb 23rd, and batch No. 13, 3rd, 7th and 9th April) gave negative values for the unbiodegradable particulate COD in the influent; this is because the OUR due to endogenous processes was underestimated. Furthermore, even for the same wastewater batch the calculated f_{up} values varied considerably; for example, for wastewater batch No. 13, the f_{up} varied from –0,14 to +0,39. Clearly this method does not provide consistent, reasonable estimates for f_{up} and was rejected for further development.

8.3.4 Conclusions

This method to quantify the remaining two influent COD fractions did not prove successful. The technique used to divide the measured OUR between that for synthesis from influent biodegradable COD and that for endogenous processes probably is not valid – the heterotroph active biomass concentration varies considerably during the course of the batch test and therefore so will the OUR associated with endogenous processes; in both the endogenous respiration and death regeneration approaches, the OURs arising from these processes are directly proportional to the heterotroph active biomass concentration. Furthermore, for this method it has to be assumed that all the influent biodegradable COD has been consumed by the end of the test – this assumption could not be verified.

8.4 METHOD 2: PASTEURIZATION OF INFLUENT WASTEWATER

In Method 1 above, the problem was estimation of the endogenous respiration OUR, made by subdividing the OUR between that for heterotroph active biomass synthesis and endogenous respiration. It was hypothesized that if the OUR due to endogenous respiration could be reduced to such low values that it makes a negligible contribution to the measured OUR, then a more reliable estimate of the OUR for heterotroph active biomass synthesis on influent biodegradable COD could be obtained. For the batch test it can be proposed that predation will dominate the OUR for endogenous respiration. This proposal arises from the work of Bhatla and Gaudy (1965a,b) on BOD–time profiles in the standard BOD test. A typical BOD–time profile is shown plotted in Fig 8.2. In the BOD test, oxygen uptake

normally occurs in two distinct phases, see Fig 8.2, with a plateau between the two phases (Busch, 1958; Wilson *et al.*, 1960; McWhorter *et al.*, 1962; Butterfield *et al.*, 1931; Zehnpfennig *et al.*, 1953 and Javornicky *et al.*, 1963). Many causes for this phenomenon have been hypothesized. To evaluate these hypotheses, Bhatla and Gaudy (1965) did tests with pasteurized sewage; the BOD test was run with and without pre–pasteurization of sewage at 50° C for 5 minutes. Bhatla and Gaudy demonstrated that pre–pasteurization of sewage samples eliminates the second plateau in the plot of oxygen consumed against time, and that this elimination did not have any effect on the magnitude of the first stage oxygen uptake; for example see Fig 8.3. Noting that the pasteurization was selective in that it eliminated the growth of protozoa (predators) in the test, but not that of heterotrophs (see Figs 8.2 and 8.3), Bhatla and Gaudy concluded that the first stage of oxygen uptake in BOD tests with heterogeneous populations is due to the growth of heterotrophic bacteria on the sewage substrate and that the second state is due to protozoa predating the heterotrophs. Furthermore, from their results and from enumeration of bacteria and protozoa (see Figs 8.2 and 8.3), Bhatla *et al.* concluded that in both high and low energy systems using heterogeneous populations, the plateau between the first and second stages of oxygen uptake is brought about by a lag between sequential growth of the bacterial population in the first stage which metabolize the exogenous substrate (i.e. influent sewage COD) for heterotroph active biomass synthesis and the predator population in the second stage which metabolize the bacterial population produced in the first stage. They also hypothesized that the plateau actually represents the "true" endogenous respiration phase of bacterial metabolism which, if no protozoa were present, would be manifested as an oxygen uptake of low magnitude.

The BOD test corresponds closely to the batch test developed here; both tests are started with influent wastewater with a low concentration of heterotroph active biomass – in the BOD test this is provided by seeding with activated sludge, in the batch test by the influent wastewater itself. From the work of Bhatla and Gaudy, if the predation effect in the batch test can be eliminated, the OUR associated with predation will also be eliminated and only the "true" endogenous respiration OUR will remain. From the work of Bhatla and Gaudy the "true" endogenous respiration OUR probably will be negligible compared to that associated with the consumption of exogenous substrate for heterotroph active biomass synthesis. Accordingly, if the predation effect in the batch test can be eliminated, the OUR for endogenous respiration may be so small it can be neglected. If this is true, then the oxygen

consumption for heterotroph active biomass synthesis on wastewater biodegradable COD ($MO_{synthesis}$) will simply be the area under the OUR–time profile in the batch test. With $MO_{synthesis}$ determined, S_{bi}, S_{bpi} and S_{upi} can be calculated using Eqs (8.5), (8.6) and (8.7) respectively.

8.4.1 Test procedure

Bhatla and Gaudy (1965) demonstrated that selective pasteurization of sewage samples eliminated the growth of predators in BOD type tests, see above. Accordingly, it was decided to selectively pasteurize the wastewater samples prior to the batch test procedure set out in Chapter 4. Selective pasteurization was achieved by heating the wastewater to 50° C for 5 minutes, then cooling the wastewater to 20° C for the batch test – this pasteurization procedure selectively kills protozoa (predators) and not bacteria (Bhatla and Gaudy, 1965).

8.4.2 Results

A number of these batch tests were run, all exhibited similar behavioural patterns. Comprehensive data are listed in Appendix A. A typical OUR–time profile is shown plotted in Fig 8.4. From Fig 8.4, the OUR–time profile with pasteurization differs considerably from those of batch tests without pasteurization (cf Chapter 4, Fig 4.1). For the batch tests with prior pasteurization, from the start of the batch test the OUR follows the typical exponential increase to the peak OUR at time = ± 10h. However, the OUR–time profile then exhibits a very much reduced precipitous drop in OUR whereafter the OUR increases to a second peak, a feature not seen in any of the non–pasteurized batch tests. It was hypothesized that this second OUR peak was due to a change in the wastewater COD characteristics caused by heating the wastewater during pasteurization; it would seem that the pasteurization step resulted in breakdown of some of the complex organics that constitute the SBCOD making these more easily biodegradable by the biomass. In this method, because the precipitous drop in OUR could not be clearly identified the influent readily biodegradable COD concentration (S_{bsi}) could not be quantified using the procedures set out in Chapter 4. Because S_{bsi} could not be determined, S_{bpi} and S_{upi} also could not be determined, see Eq (8.6) and (8.7) respectively.

8.4.3 Conclusion

Pasteurization of the wastewater prior to the batch test to reduce the endogenous respiration effect results in behavioural patterns that deviate considerably from those in batch tests without prior pasteurization. Thus, this method was rejected

for further development.

8.5 METHOD 3: EXTENDED AERATION

In this method the basic assumption is that the heterotroph active biomass at the end of the batch test is so small that it can be neglected (i.e. $Z_{BHe} = 0$). If this assumption is valid, then enough information can be obtained from the batch test to quantify the remaining unknown parameters.

8.5.1 Test procedure

The test procedures set out in Chapters 4, 5 and 7 were followed, except that the length of the batch was extended to at least 3 days. After 3 days it was hoped that the heterotroph active biomass concentration in the batch test would be minimal. A number of batch tests were run. Comprehensive data are listed in Appendices A and B. A typical OUR–time plot for the extended batch test is shown in Fig 8.5. Even with extended aeration, an increase in nitrate was not detected in any of the batch tests indicating that no nitrification occurred in the batch test, i.e. an absence of autotrophic biomass.

8.5.2 Data interpretation

The area under the OUR–time curve is the mass of oxygen consumed (MO_c). In the absence of nitrification the MO_c is due to oxygen consumption for heterotroph active biomass synthesis on the influent biodegradable COD ($MO_{synthesis}$) and for endogenous respiration (MO_e), i.e.

$$MO_c = MO_{synthesis} + MO_e \tag{8.8}$$

Assuming that all the influent biodegradable COD (S_{bi}) is consumed in the batch test, then

$$MO_{synthesis} = (1-Y_{ZH})\, S_{bi} \tag{8.9}$$

The heterotroph active biomass that is produced in this growth process (ΔZ_{BH}) is

$$\Delta Z_{BH} = Y_{ZH}\, S_{bi} \tag{8.10}$$

From the assumption that the heterotroph active biomass concentration at the end of the test is negligible, all the heterotroph active biomass in the influent (Z_{BHi}) or

generated in the growth process (ΔZ_{BH}) must be endogenously respired. Accepting that a fraction (f) of the heterotroph active biomass is unbiodegradable endogenous residue (WRC, 1984), then a fraction (1–f) must contribute to the oxygen consumption in endogenous respiration, i.e.

$$\begin{aligned} MO_e &= (1\text{–}f)\ \Delta Z_{BH} + (1\text{–}f)\ Z_{BHi} \\ &= (1\text{–}f)\ Y_{ZH}\ S_{bi} + (1\text{–}f)\ Z_{BHi} \end{aligned} \tag{8.11}$$

Substituting Eqs (8.9) and (8.11) into Eq (8.8)

$$MO_c = (1\text{–}Y_{ZH})\ S_{bi} + (1\text{–}f)\ Y_{ZH}\ S_{bi} + (1\text{–}f)\ Z_{BHi} \tag{8.12}$$

Solving Eq (8.12) for S_{bi}

$$S_{bi} = \{MO_c - (1\text{–}f)\ Z_{BHi}\}/\{(1\text{–}Y_{ZH}) + (1\text{–}f)\ Y_{ZH}\} \tag{8.13}$$

In Eq (8.13), MO_c and Z_{BHi} are available from measurements made in the batch test (see Chapter 4). Values have to be assumed for the constants Y_{ZH} and f:

Y_{ZH} = 0,666 mgCOD/mgCOD

f = 0,2 mgCOD/mgCOD (WRC, 1984)

Thus, S_{bi} can be determined based on the assumption for this extended aeration batch test, namely that the heterotroph active biomass concentration at the end of the test is negligible (i.e. $Z_{BHe} = 0$). From S_{bi} and S_{bsi}, S_{bpi} can be determined

$$S_{bpi} = S_{bi} - S_{bsi} \tag{8.14}$$

With S_{bpi} quantified, S_{upi} can be determined

$$S_{upi} = S_{ti} - S_{bpi} - S_{usi} - S_{bsi} - Z_{BHi} \tag{8.15}$$

and

$$f_{up} = S_{upi}/S_{ti} \tag{8.16}$$

8.5.3 Results

A number of the extended aeration batch tests were run using raw (unsettled)

municipal wastewater obtained from Mitchell's Plain (Cape Town). Comprehensive data are listed in Appendices A and B. A typical OUR–time profile is given in Fig 8.5. Using the procedures detailed in Chapters 4 and 7 and those set out above, the influent wastewater COD fractions for the different batch tests were quantified and are listed in Table 8.2. From Table 8.2, values for f_{up} using this method show some consistency; standard deviation of the mean (SD_m) = 0,07, 0,05 and 0,03 for sewage batches 12, 13 and 14 respectively. However, the values are considerably higher (mean f_{up} = 0,36 to 0,49) than expected for a typical South African raw municipal wastewater (f_{up} ± 0,13, WRC, 1984). In examining the procedure for calculation for S_{upi}, it is evident that the main assumption is that the heterotroph active biomass concentration at the end of the batch test is negligible. If, contrary to this assumption, appreciable heterotroph active biomass is present at the end of the batch test, then the calculation procedure will incorporate the heterotroph active biomass in S_{upi} leading to overestimation of this value and the associated f_{up}. Clearly, the heterotroph active biomass concentration at the end of the batch test is not negligible and this causes S_{upi} to be overestimated.

8.5.4 Conclusion

From this study it can be concluded that the basic assumption, that after 3 days of aeration in the batch test the quantity of heterotroph active biomass is so small that it can be neglected, is not valid. Therefore, the method for determining S_{bpi} and S_{upi} based on this assumption will not be successful. In any event, having to run the batch test for longer than 3 days would greatly reduce its attractiveness for practical application.

8.6 METHOD 4: OUR AT THE END OF THE BATCH TEST

From METHOD 3 above it is apparent that appreciable heterotroph active biomass is present after 3 days of running the batch test. If it is possible to quantify this heterotroph active biomass, then sufficient information should be available from the batch test to quantify the remaining unknown parameters, provided it is assumed that all the influent biodegradable COD has been consumed. In this method it is proposed to use the absolute value of the OUR at the end of the batch test to quantify the heterotroph active biomass concentration at the end of the test.

8.6.1 Test procedure

The data from METHOD 3 above was used for METHOD 4.

8.6.2 Data interpretation

Assuming that all the influent biodegradable COD (S_{bi}) has been consumed by the end of the test, then the OUR at the end of the test is due to endogenous respiration only. The endogenous respiration OUR (O_e) can be formulated as (WRC, 1984)

$$O_{e(t)} = (1-f)\, b_h^*\, Z_{BH(t)} \qquad (8.17)$$

where

$O_{e(t)}$ = endogenous respiration OUR at time t (mgO/ℓ/h)
b_h^* = net specific endogenous mass loss rate
= 0,24/d
$Z_{BH(t)}$ = heterotroph active biomass at time t (mgCOD/ℓ)

At the end of the batch test t=e, solving Eq (8.17) for Z_{BHe} gives

$$Z_{BHe} = O_{ee}/\{(1-f)\, b_h^*\} \qquad (8.18)$$

Thus, from Eq (8.18) if the OUR at the end of that batch test is known and it is assumed that this OUR is due to endogenous respiration only, OUR = O_{ee} (i.e. all the influent biodegradable COD has been consumed), the heterotroph active biomass concentration at the end of the batch test (Z_{BHe}) can be calculated. What is still required is to determine the influent biodegradable COD (S_{bi}) concentration.

Conducting a mass balance around the heterotroph active biomass (Z_{BH}) over the batch test: At the start of the batch test, Z_{BH} is present in the influent wastewater (Z_{BHi}); during the course of the batch test Z_{BH} is synthesized from the biodegradable COD [Z_{BH}(synthesized)] and is endogenously respired; at the end of the batch test some Z_{BH} remains (Z_{BHe}). From the mass balance, the Z_{BH} lost in endogenous respiration [Z_{BH}(lost)] is given by

$$Z_{BH}(\text{lost}) = Z_{BHi} - Z_{BHe} + Z_{BH}(\text{synthesized}) \qquad (8.19)$$

Now, from the assumption that all the biodegradable COD (S_{bi}) is consumed in the batch test,

$$Z_{BH}(\text{synthesized}) = Y_{ZH}\, S_{bi} \qquad (8.20)$$

Therefore, substituting Eq (8.20) into Eq (8.19)

$$Z_{BH}(\text{lost}) = Z_{BHi} - Z_{BHe} + Y_{ZH}\, S_{bi} \tag{8.21}$$

Noting that a fraction (f) of the heterotrophic active biomass is unbiodegradable (WRC, 1984), then the oxygen demand associated with the Z_{BH} loss in endogenous respiration is

$$\begin{aligned} MO_e &= (1\text{–}f)\, Z_{BH}\ (\text{lost}) \\ &= (1\text{–}f)\, (Z_{BHi} - Z_{BHe} + Y_{ZH}\, S_{bi}) \end{aligned} \tag{8.22}$$

Substituting Eqs (8.22) and (8.9) into (8.8)

$$MO_c = (1\text{–}Y_{ZH})\, S_{bi} + (1\text{–}f)\, (Z_{BHi} - Z_{BHe} + Y_{ZH}\, S_{bi}) \tag{8.23}$$

Solving Eq (8.23) for S_{bi}

$$S_{bi} = \{MO_c - (1\text{–}f)\, (Z_{BHi} - Z_{BHe})\}/\{(1\text{–}Y_{ZH}) + (1\text{–}f)\, Y_{ZH}\} \tag{8.24}$$

In Eq (8.24), MO_c is the area under the OUR–time plot which is available from measurement, Z_{BHi} can be determined using the procedures set out in Chapter 4, and Z_{BHe} can be determined from the OUR at the end of the batch test (O_e) using Eq (8.18). Accordingly, S_{bi} can be calculated from Eq (8.24). From S_{bi}, S_{bsi} and Z_{BHi} (determined using the procedures in Chapter 4), S_{bpi} can be calculated using Eq (8.14) and S_{upi} calculated using Eq (8.15). Also, f_{up} can be calculated from the measured total influent COD concentration (S_{ti}) using Eq (8.16).

8.6.3 Results

The data from the batch tests presented for METHOD 3 were recalculated using the procedure set out above to quantify the five influent COD fractions; results are listed in Table 8.3 for the various batch tests. The revised procedure to determine f_{up} results in f_{up} values that are considerably lower than those derived with METHOD 3 (cf Tables 8.2 and 8.3 respectively). However, the values for f_{up} still show considerable variability (for example, ranging from –0,12 to 0,23 for sewage batch 13). In examining the calculation procedure it is evident that the procedure is sensitive to the absolute value for the OUR at the end of the test (O_{ee}). From Table 8.3, O_{ee} has a very low value (0,7 to 1,8 mgO/ℓ/h); relatively small errors in

the measurement of O_{ee} (± 0,5 mgO/ℓ/h) are significant compared to the absolute value, and cause significant errors in the calculated f_{up}. To illustrate the sensitivity of the f_{up} value calculated using the procedure above to errors in the measurement of O_{ee}, a theoretical plot of f_{up} versus O_{ee} is shown in Fig 8.6; a relatively small absolute error in the measurement of O_{ee} gives rise to a large error in the calculated f_{up} value.

8.6.4 Conclusion

Although this method provides estimates for f_{up} that are an improvement over the previous methods, the measured OUR at the end of the batch test cannot be successfully used to determine heterotroph active biomass at the end of the test, thereby to calculate unbiodegradable particulate and slowly biodegradable COD. The proposed method is too sensitive to small absolute errors (± 0,5 mgO/ℓ/h) in the measurement of the OUR because the value for the OUR at the end of the test is small (< 2,0 mgO/ℓ/h). This sensitivity results in f_{up} values that show considerable variability.

8.7 METHOD 5: ACETATE ADDITION

In METHOD 4 it was shown that if the heterotroph active biomass at the end of the batch test can be quantified, then the five influent COD fractions can be calculated using the data available from the batch test. In METHOD 4 it was attempted to quantify this heterotroph active biomass from the measured absolute OUR value at the end of the batch test; this technique was not successful due to the sensitivity of the calculation procedure to relatively small absolute errors in the measured OUR. It was decided to explore other techniques to quantify the heterotroph active biomass remaining at the end of the batch test.

In the batch test, the heterotroph active biomass at the start of the test can be quantified from the exponential increase in OUR caused by the growth of heterotrophs on the readily biodegradable COD (RBCOD) present in the influent wastewater (see Chapter 4). It was proposed to duplicate this technique at the end of the batch test by adding the artificial RBCOD sodium acetate. On addition of the sodium acetate, the OUR should show an exponential increase as it does at the start of the batch test. Using the procedures developed in Chapter 4, the heterotroph active biomass concentration at the time of addition of the sodium acetate can be determined from the exponential increase in OUR. With the heterotroph active biomass concentration determined, S_{bi}, S_{bpi} and S_{upi} (and f_{up})

can be calculated using the procedures set out in METHOD 4 above.

8.7.1 Biomass behaviour with acetate addition – preliminary investigation

With addition of an artificial substrate (in this case sodium acetate), the possibility exists that the biomass behaviour will deviate from that with wastewater substrate. Accordingly, it was decided to assess in some manner whether the biomass behaviour with acetate addition conforms to that with wastewater, before the full batch test procedure was implemented.

To evaluate the biomass behaviour with acetate addition, the normal batch test procedure as set out in Chapters 4, 5 and 7 was followed until after the precipitous drop in OUR. The batch test was continued for about 2 hours whereafter sodium acetate was added to the batch test at a concentration of 102 mgCOD/ℓ batch reactor taking due account of the reduced batch volume because of sampling. The batch test was then continued for a further 12 hours following the standard procedure set out in Chapter 4. This procedure was repeated for 11 batch tests. Comprehensive data are listed in Appendix A and B; a typical OUR–time profile is shown plotted in Fig 8.7a.

From Fig 8.7a, following the addition of sodium acetate there is a step increase in the OUR, whereafter the OUR shows an exponential increase. The exponential increase in OUR conforms to the exponential increase at the beginning of the test, therefore, qualitatively it would seem that the analytical procedures set out in Chapter 4 can be used to estimate the heterotroph active biomass present at the time of sodium acetate addition.

To provide some quantitative assessment of whether the biomass behaviour conforms to that with wastewater, from the area under the OUR–time curve due to acetate consumption, Area A, Fig 8.7a, the heterotroph active biomass yield on acetate can be calculated:

$$Y_{ZH} = 1 - \frac{\int \text{OUR (acetate) dt}}{\text{COD (acetate)}} \qquad (8.25a)$$

where

Y_{ZH} = heterotroph active biomass yield on acetate

$$Y_{ZH} = \frac{\int \text{OUR (acetate)}\, dt}{\text{COD (acetate)}} \quad \text{(mgCOD/mgCOD)}$$

$\int$ OUR (acetate) dt = area under OUR–time curve due to acetate consumption, Area A, Fig 8.7a (mgO/ℓ)

COD (acetate) = known COD concentration of added sodium acetate (mgCOD/ℓ)

For the batch tests, the data and calculated heterotroph yield (Y_{ZH}) are listed in Table 8.4; the mean yield for the 11 batch tests was 0,646 mgCOD/mgCOD with standard deviation of the mean of 0,007. Thus, the yield with sodium acetate (0,646 mgCOD/mgCOD) is very close to that measured with wastewater (0,666 mgCOD/-mgCOD; Dold and Marais 1986). It would appear that the behaviour of the heterotrophs with acetate as substrate does conform to the behaviour with wastewater. Furthermore, that the yield obtained with the acetate closely equals the "standard" value for the yield quoted in the literature (e.g. WRC, 1984; Dold and Marais 1986), would lend support to using the "standard" value of Y_{ZH} = 0,666 mgCOD/mgCOD in all other calculations.

8.7.2 Test procedure

Having ascertained that the heterotroph biomass behaviour with acetate as substrate can be expected to be similar to that with wastewater as substrate, the full batch test procedure could be implemented. The normal batch test procedure as set out in Chapters 4, 5 and 7 was followed for 1 or 2 days. Thereafter, a sample was drawn from the batch test and total COD and flocculated–filtered COD (see Chapter 6) determined. Sodium acetate was then added to the batch test at a concentration of 102 mgCOD/ℓ batch reactor taking due account of the reduced batch volume because of sampling. The batch test was then continued for a further 12 hours following the standard procedures set out in Chapter 4. The procedure was repeated for 10 batch tests. Comprehensive data for the batch tests are listed in Appendix A and B. Typical OUR–time profiles are shown plotted in Fig 8.7b and c.

8.7.3 Data evaluation

Following the addition of sodium acetate there is a step increase in the OUR, whereafter the OUR shows an exponential increase, see Fig 8.7b and c. The exponential increase in the OUR–time profile can be analyzed to determine the heterotroph active biomass concentration as set out in Chapter 4 – the time of sodium acetate addition is set to zero, the OUR is plotted ℓn OUR versus time and

the y-intercept and slope determined by linear regression; from the y-intercept and slope the heterotroph active biomass concentration can be calculated using Eq (4.9) in Chapter 4.

The heterotroph active biomass concentration at the time of sodium acetate addition is the heterotroph active biomass at the end of the batch test (Z_{BHe}) in METHOD 4 above. Having quantified this parameter, the calculation procedure set out for METHOD 4 can be followed to estimate the five influent COD fractions, i.e. S_{bsi} and Z_{BHi} from Chapter 4; S_{bi} from Eq (8.24); S_{bpi} from Eq (8.14); S_{upi} from Eq (8.15); and f_{up} from Eq (8.16).

To provide a cross check for the measured data, the COD recovery for the acetate addition can be calculated, by rearranging Eq (8.25a).

$$\% \text{ COD recovery} = \frac{\int_p^a \text{OUR (acetate) dt}/(1-Y_{ZH})}{\text{COD (acetate)}} \qquad (8.25b)$$

where

$\int_p^a$ OUR (acetate) dt = area under OUR-time curve due to acetate consumption, area A Fig 8.7 (mgO/ℓ)

Y_{ZH} = heterotroph active biomass yield on acetate = 0,666 mgCOD/mgCOD

COD (acetate) = known COD concentration of added sodium acetate (mgCOD/ℓ)

Also, a theoretical COD concentration prior to acetate addition (S_{te}) can be calculated and compared to the measured value, as follows: From Eq (8.3) assuming all the influent biodegradable COD has been consumed in the batch test prior to the acetate addition (i.e. $S_{bpe} = 0$) then

$$S_{te} = S_{usi} + S_{upi} + Z_{BHe} + Z_{Ee} \qquad (8.26)$$

In Eq (8.26) S_{te} and S_{usi} are available from measurement as the unfiltered and flocculated-filtered COD respectively; Z_{BHe} and S_{upi} will be determined using the

procedure set out above. An equation for Z_{Ee} can be formulated as follows: Noting that a fraction (f) of Z_{BH} is unbiodegradable and generates Z_E in endogenous respiration (WRC, 1984), then the amount of Z_E generated in the batch test (ΔZ_E) is given by

$$\Delta Z_E = f Z_{BH} \text{ (lost)} \tag{8.27a}$$

Assuming that the amount of Z_E at the start of the batch test is negligible (a reasonable assumption because any Z_E present will be lumped into S_{upi}), then

$$Z_{Ee} = \Delta Z_E \tag{8.27b}$$

Substituting Eq (8.27a) and (8.21) into (8.27b)

$$Z_{Ee} = f\,(Z_{BHi} - Z_{BHe} + Y_{ZH}\, S_{bi}) \tag{8.28}$$

Thus, in Eq (8.26) S_{usi}, S_{upi}, Z_{BHe} and Z_{Ee} can be calculated from the batch test data using the procedures set out above. The sum of these parameters will give a theoretical total COD concentration immediately prior to the acetate addition (S_{te}). This theoretical value can be compared to the measured value, to provide a cross check on the reliability of the data.

8.7.4 Results

Comprehensive data for the batch tests are listed in Appendices A and B. For the ten batch tests the calculated values for the various parameters are listed in Table 8.5a. COD recoveries for the acetate addition, calculated using Eq (8.25b) are listed in Table 8.5b; generally COD recoveries were good (mean % COD recovery = 99%; standard deviation of mean = 4,0%), lending support to the reliability of the measurements. Also, the good COD recoveries indicate that the value for the heterotroph yield used in Eq (8.25b) (Y_{ZH} = 0,666 mgCOD/mgCOD) is acceptable – this provides support for using this value for the yield in the other calculations. However, from Table 8.5a calculated values for f_{up} varied considerably (f_{up} = 0,05 to 0,49) and were considerably higher (mean f_{up} = 0,28) than expected (f_{up} = ± 0,13; WRC, 1984), and higher than the values estimated using METHOD 4 above (see Table 8.3a). Furthermore, the calculated theoretical COD concentrations (S_{te}) prior to acetate addition usually were significantly higher than those measured (COD_{end}) (see Table 8.5). It would appear that this method underestimates the

heterotróph active biomass present when the acetate is added. This in turn leads to an overestimation of the f_{up} value and accordingly, the total COD concentration at the end of the test. It can be hypothesized that in the batch test there was selective utilization of the artificial substrate acetate, that is, not all the heterotroph active mass present in the batch test had the ability to utilize acetate – the heterotrophic active biomass determined from the exponential increase in OUR following acetate addition will include only those heterotrophs that can utilize the acetate. This hypothesis would appear to be supported by an apparent lag phase following acetate addition, see Fig 8.8a and c. Probably some acclimatization to the acetate substrate is required, a requirement that cannot be accommodated within the structure of the batch test method.

8.7.5 Conclusions

The method proposed to determine heterotroph active biomass at the end of the batch test by adding the artificial substrate acetate underestimates the heterotroph active biomass concentration, leading to an overestimation of the unbiodegradable particulate COD. It would appear that not all the heterotroph active biomass present in the batch test has the ability to metabolize acetate – some kind of acclimatization to the acetate is required. Acclimatization of the heterotrophs in the batch test to acetate can not be accommodated in the calculation procedures – this method was rejected for further development.

8.8 METHOD 6: RAW SEWAGE FILTRATE ADDITION

In METHOD 4, a procedure was developed whereby the values for the five influent COD fractions can be calculated provided that the heterotroph active biomass at the end of the batch test can be quantified. In an attempt to quantify the heterotroph active biomass at the end of the batch test, in METHOD 4 the OUR at the end of the batch test was used and in METHOD 5 sodium acetate was added. The techniques in METHOD 4 and METHOD 5 used for this quantification did not prove successful. With METHOD 4, the proposed procedure proved too sensitive to small absolute errors in the measurement of the OUR. With METHOD 5, the artificial substrate acetate appeared to be used selectively by some of the bacteria leading to an underestimation of the heterotroph active biomass. To overcome the problem of selective utilization, it was decided to replace the addition of acetate at the end of the batch test with the addition of wastewater. To eliminate addition of heterotroph active biomass with the wastewater, the wastewater was first filtered through 0,45μm filters and the filtrate added to the batch test. To confirm that the

0,45μm filtrate did not contain heterotroph active biomass, the filtrate itself was subjected to a separate batch test following the procedure set out in Chapter 4 – the filtrate exhibited no measurable OUR indicating an absence of heterotroph active biomass.

8.8.1 Test procedure

The batch test procedure as set out in Chapters 4, 5 and 7 was followed for 2 days. Raw (unsettled) municipal wastewater from the same source (Mitchell's Plain) and batch used to start the batch test was filtered through glass fibre filters (Whatman's GF/C) and the filtrate refiltered through 0,45μm (Millipore HVLP); the prefiltration with glass fibres is to reduce blinding of the 0,45μm filters.

After 2 days of the batch test, 1ℓ of the batch reactor mixed liquor was drawn off and analyzed for total COD and flocculation–filtration COD (see Chapter 6). The 1ℓ drawn off was replaced with 1ℓ of wastewater 0,45μm filtrate. The batch test was then run for a further 12h or until after the second precipitous drop in OUR. A number of batch tests were run. For detailed data see Appendices A and B. A typical OUR–time profile is shown in Fig 8.8a.

8.8.2 Data interpretation

Following addition of the wastewater 0,45μm filtrate, the OUR–time profile (e.g. Fig 8.8a) was analyzed using the procedures set out in Chapter 4, to determine heterotroph active biomass immediately after filtrate addition – the time of filtered wastewater addition is set to zero, the OUR plotted ℓn OUR versus time and the y–intercept and slope determined by linear regression; from the y–intercept and slope the heterotroph active biomass concentration immediately after filtered wastewater addition could be calculated using Eq (4.9) in Chapter 4. To convert this value to that immediately prior to wastewater filtrate addition (i.e. the heterotrophic active biomass concentration at the "end" of the batch test), the dilution effect of adding the filtrate had to be taken into account as follows:

$$Z_{BH_p} = Z_{BH_a} \cdot \frac{V_a}{V_p} \tag{8.29}$$

where

Z_{BH_p} = heterotroph active biomass immediately prior to filtrate addition (mgCOD/ℓ)

Z_{BHa} = heterotroph active biomass immediately after filtrate addition (mgCOD/ℓ), i.e. that determined from OUR–time profile after filtrate addition

V_a = batch reactor volume after filtrate addition (ℓ)

V_p = batch reactor volume prior to filtrate addition (ℓ)

Having determined Z_{BHp}, this serves as the heterotroph active biomass at the end of the batch test (Z_{BHe}) and the calculation procedures set out for METHOD 4 can be followed to estimate the five influent COD fractions, i.e. S_{bsi} and Z_{BHi} from Chapter 4; S_{bi} from Eq (8.24); S_{bpi} from Eq (8.14); S_{upi} from Eq (8.15); and f_{up} from Eq (8.16).

8.8.3 Improvements to test procedure

Difficulties were experienced in filtering the raw wastewater through 0,45μm filters; even with prefiltration through the glass fibre filters, the 0,45μm filters were rapidly blinded so that at least 10 filter papers had to be used to filter 1ℓ of wastewater, making the filtration arduous and expensive. To resolve this problem it was proposed to flocculate the wastewater by addition of aluminium sulphate prior to 0,45μm filtration. The flocculation procedure and dosages set out in Chapter 6 were followed. Preflocculation reduced blinding of 0,45μm filters considerably. To test whether residual aluminium, if any, would affect the behavioural patterns in the batch test, two parallel tests were run with addition of unflocculated 0,45μm filtrate to one batch and preflocculated 0,45μm filtrate to the other. The OUR–time profiles for the two tests are compared in Fig 8.8a and b; no significant difference is evident so that flocculation prior to filtration was adopted as a standard procedure. To further reduce filtration costs, it was proposed that from the observations in Chapter 6, the 0,45μm filter be replaced by glass fibre filters (in Chapter 6 it was shown that with preflocculation 0,45μm and glass fibre filters gave near identical filtrate COD concentrations). For the two filter papers, the COD concentrations of both filtrates were identical, and starting batch tests with the two filtrates only indicated no OUR – heterotroph active biomass was not present in either filtrate. To check that the response induced by the preflocculated 0,45μm and glass fibre filtrates was the same, two batch tests were run in parallel, one with addition of preflocculated 0,45μm filtrate and the other with preflocculated glass fibre filtrate. The OUR–time profiles using the two filter paper filtrates are shown in Fig 8.9a and b; no significant difference between these two profiles is evident. Accordingly, for the batch tests raw municipal wastewater was flocculated by addition of aluminium

sulphate and then filtered through glass fibre filter papers – the filtrate was added to the batch test after 2 days, following the procedures set out above.

8.8.4 Results

Comprehensive data for the batch tests are listed in Appendices A and B. A typical OUR–time profile for one batch test is shown plotted in Fig 8.9a. Following the procedure set out above, data calculated for the batch tests are listed in Table 8.6. For each batch of wastewater, the mean f_{up} and standard deviations of the means were determined, see Table 8.8. From Table 8.8, the mean values for f_{up} for the different wastewater batches (0,08 to 0,23) are considerably lower than those calculated from the batch tests with acetate addition, (mean f_{up} = 0,28, see Table 8.5) – it would appear that the problem of acclimatization with acetate addition has been overcome by adding filtered wastewater. However, for the same wastewater batch the f_{up} values still exhibit considerable variability; for example, from Table 8.8 for wastewater batch 17, f_{up} varies from 0,03 to 0,43. To explain this variability it was hypothesized that perhaps the basic assumption in this batch test, that all the influent biodegradable COD has been consumed prior to addition of the wastewater preflocculated filtrate, was not valid. Accordingly, it was decided to repeat the batch test, but to run the batch test for a longer period before adding the wastewater filtrate.

A number of batch tests were run for 2, 3 and 4 days, see Table 8.7. Comprehensive data are listed in Appendices A and B. Following the procedures set out above, data calculated for the batch tests are listed in Table 8.7. Two wastewater batches were tested, Batch Nos. 21 and 23, see Table 8.7. For Batch No. 21, the batch tests were run for either 2 or 3 days prior to addition of wastewater preflocculated filtrate. For Batch No. 23, two batch tests were run in parallel for 3 and 4 days respectively (on 25 and 28 October, see Table 8.7) prior to addition, and three batch tests were run in parallel for 2, 3 and 4 days respectively prior to addition (on 3 November, see Table 8.7). OUR–time profiles for the three batch tests run in parallel for 2, 3 and 4 days are shown in Fig 8.10a, b and c respectively.

Comparing the f_{up} values derived for the different batch tests (see Table 8.7), it would appear that the effect of increasing the duration of the batch test from 2 to 3 to 4 days does not influence the estimate for f_{up} consistently – for some tests the f_{up} decreases (e.g. 3rd Nov.) and for others it increases (e.g. 28th Oct.).

Accepting that increasing the duration of the batch test above 2 days does consistently influence the estimate for S_{bpi} and S_{bupi} (and f_{up}), the mean f_{up} and standard deviations of the means for wastewater batch Nos. 21 and 23 were determined and are listed also in Table 8.8. From Table 8.8 the range of f_{up} mean values derived from the various batch tests (0,08 to 0,23) compare reasonably with the expected values (±0,13). Furthermore, comparing the theoretical total COD concentration at the end of the test [Eq (8.26)] with the measured values (see Tables 8.6 and 8.7, and Fig 8.11), there is close correlation indicating that there is consistency between the calculated and measured data. Thus, this method does appear to hold promise, but requires more intensive evaluation.

8.8.5 Conclusion

It would appear that this method may provide a reasonable estimate for the five influent COD fractions. The batch test method is relatively simple compared to existing methods and does not require mixed liquor acclimatized to the wastewater, nor that a laboratory–scale system be operated – both are requirements of existing methods. As with previous methods, the batch test method does require an uncompromising vigilance in operation to ensure measured data are reliable. This batch test method will have to be evaluated by comparing the estimates derived for f_{up} with those from conventional methods.

8.9 CONCLUSION

In this Chapter it has been attempted to extend the batch test to provide estimates of the unbiodegradable particulate and slowly biodegradable COD fractions. A number of methods have been proposed and evaluated through trial and error, and the less promising rejected. One proposed method appears to hold promise, that in which preflocculated glass fibre filtered wastewater is added after 2 days. Values for the influent unbiodegradable particulate COD fraction (f_{up}) derived with this method need to be evaluated, by comparing the results with those from conventional methods.

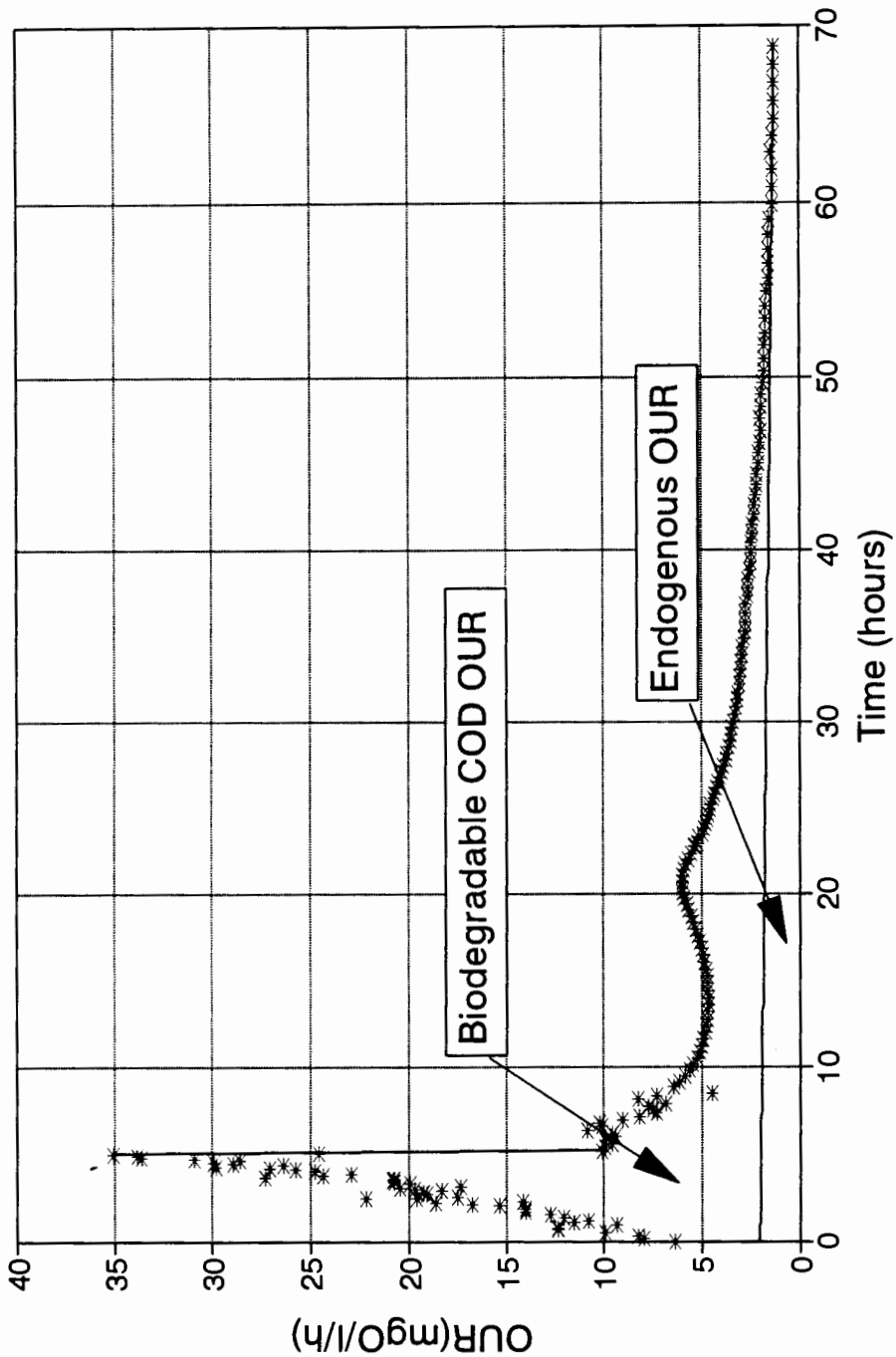

Fig 8.1: OUR–time plot for an aerobic batch test run for an extended period showing the division of the area under the OUR graph according to METHOD 1.

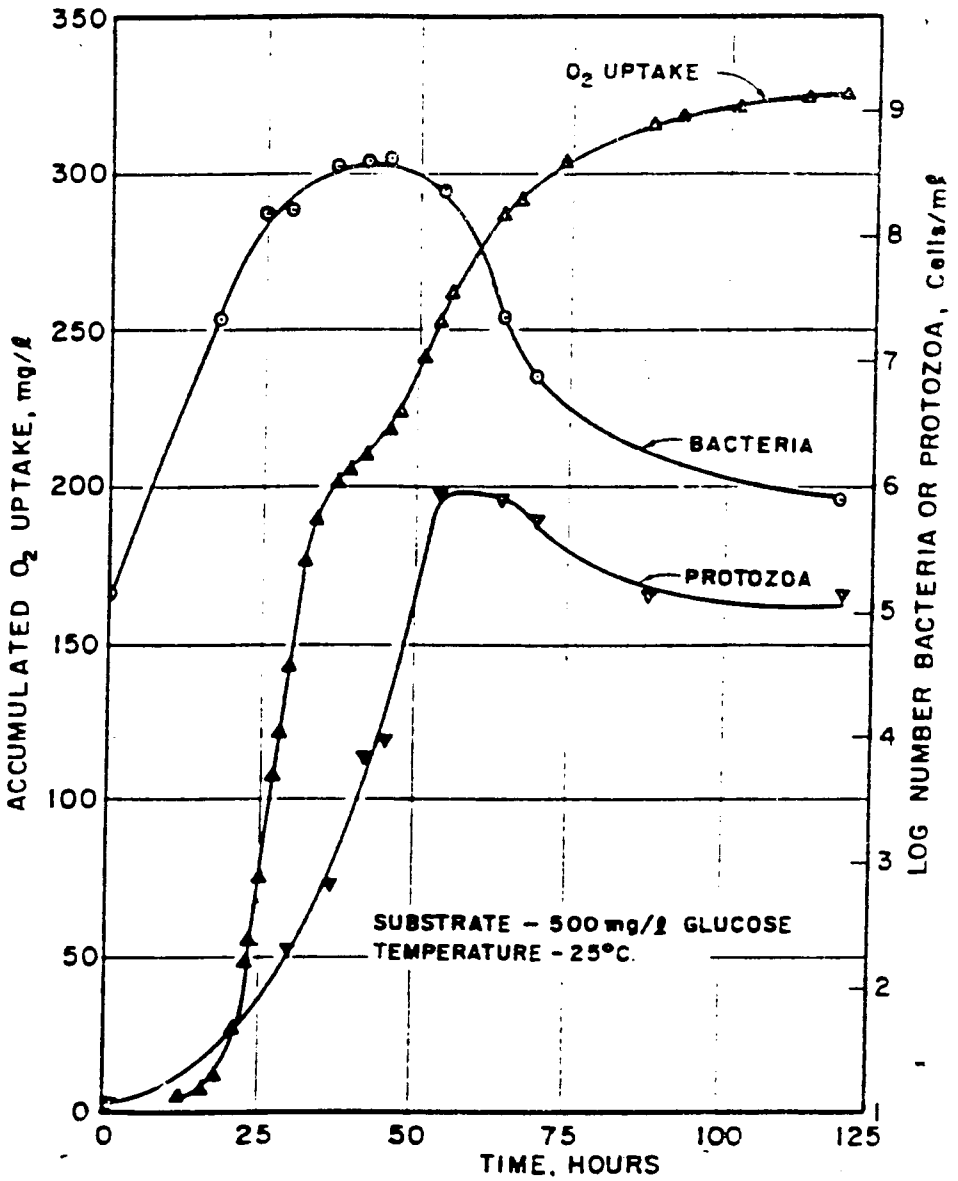

Fig 8.2: BOD, bacteria and protozoa counts during a WARBURG study with non-pasteurized sewage seed used for the BOD test determination. (From Bhatla *et al.*, 1965).

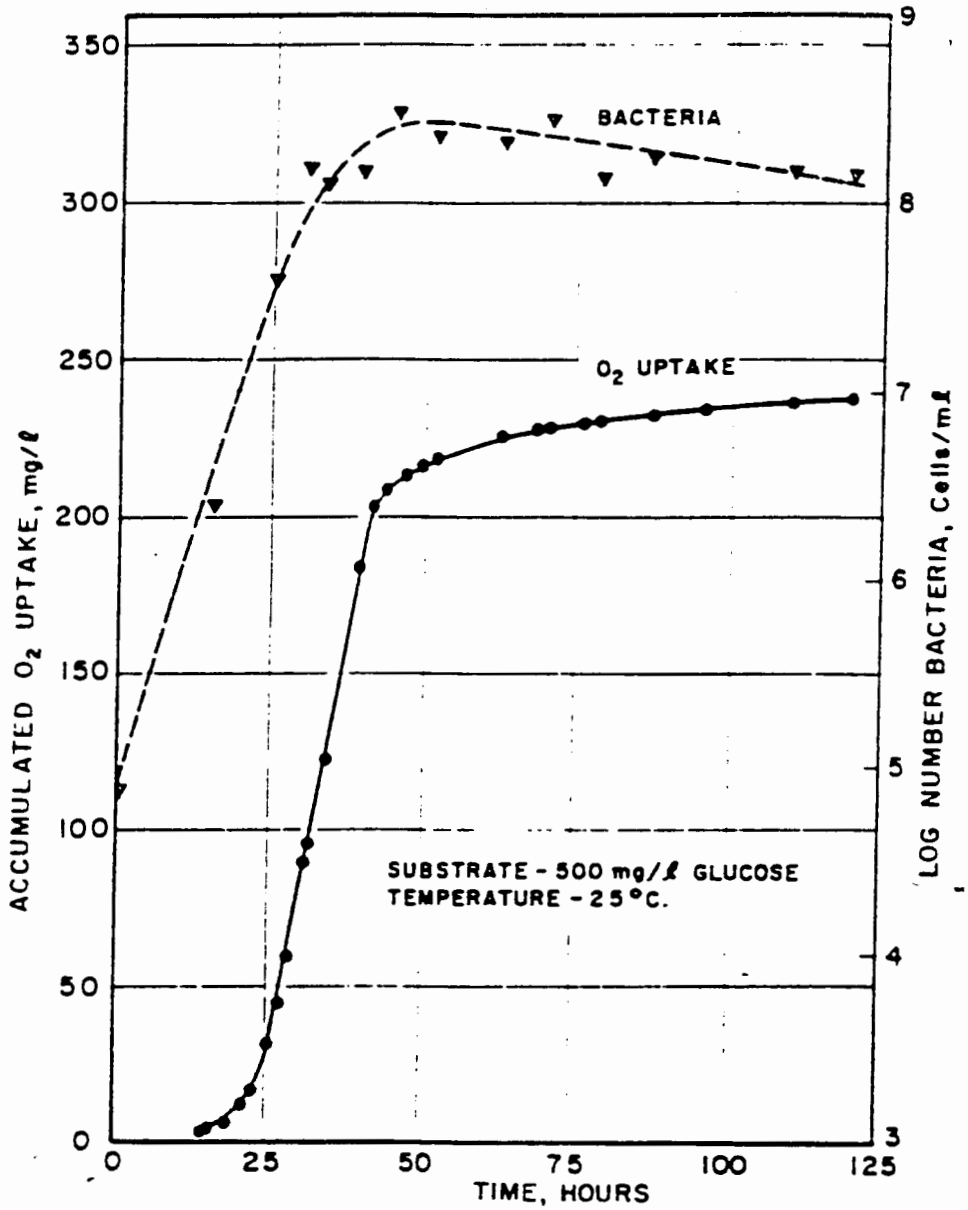

Fig 8.3: BOD and bacteria count during a WARBURG study with pasteurized sewage seed used for the BOD test determination. (From Bhatla *et al.*, 1965).

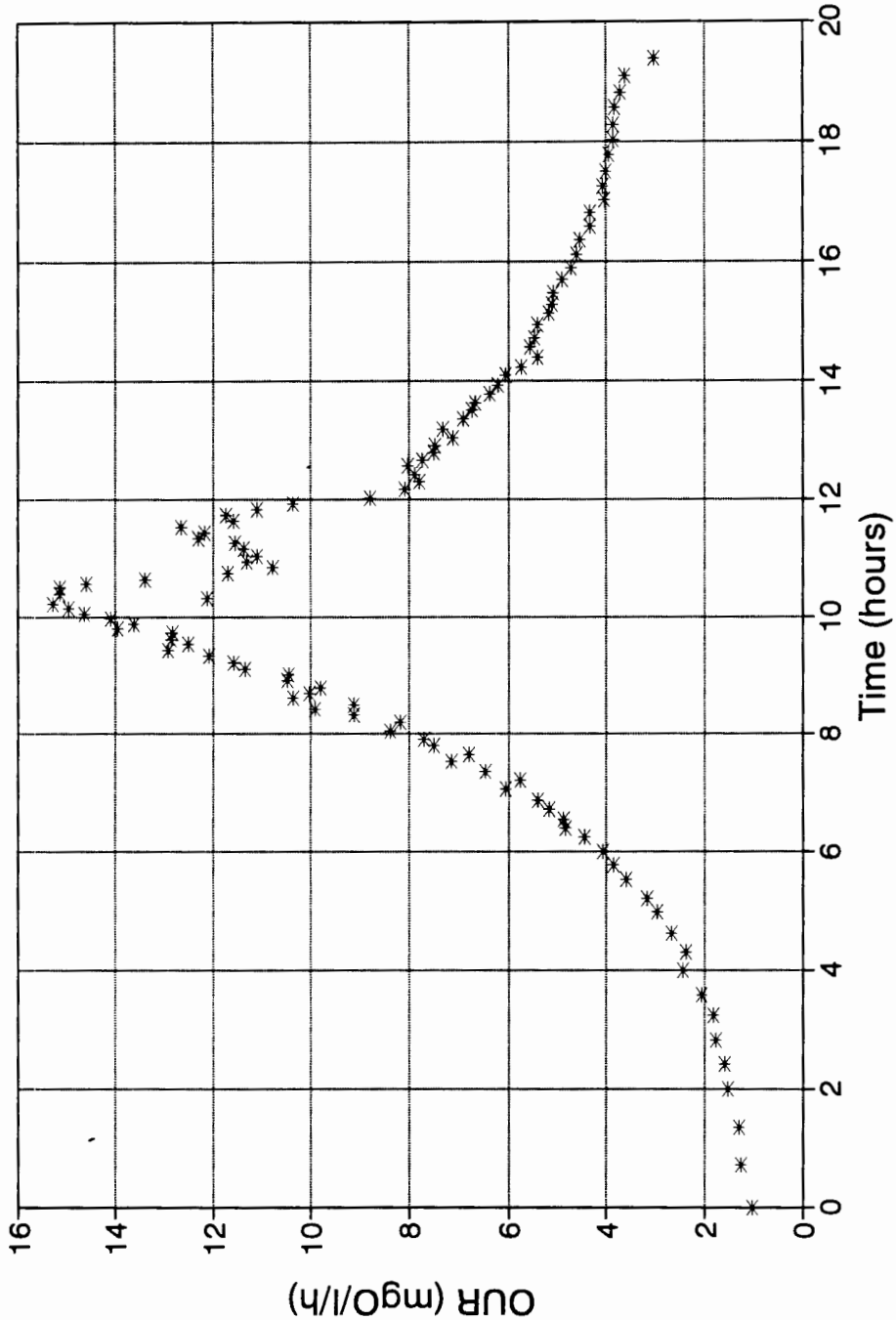

Fig 8.4: OUR–time plot for an aerobic batch test with pasteurized sewage.

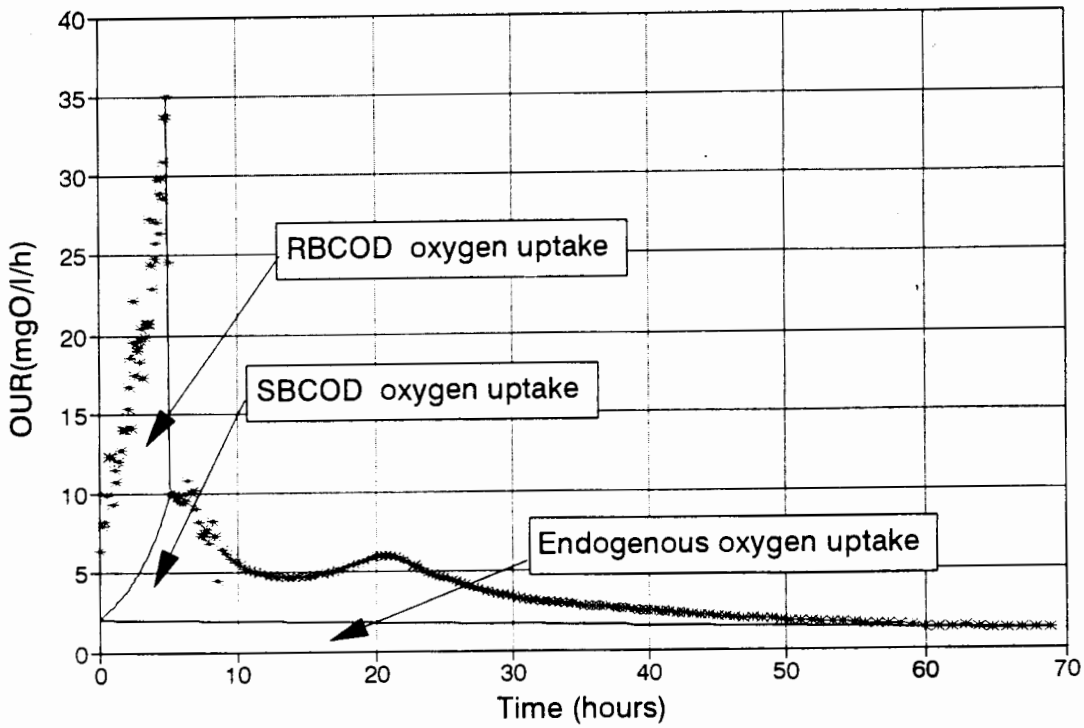

Fig 8.5: OUR–time plot for an aerobic batch test run for an extended period showing the division of the OUR area into the different OUR uptakes for the various COD utilizations.

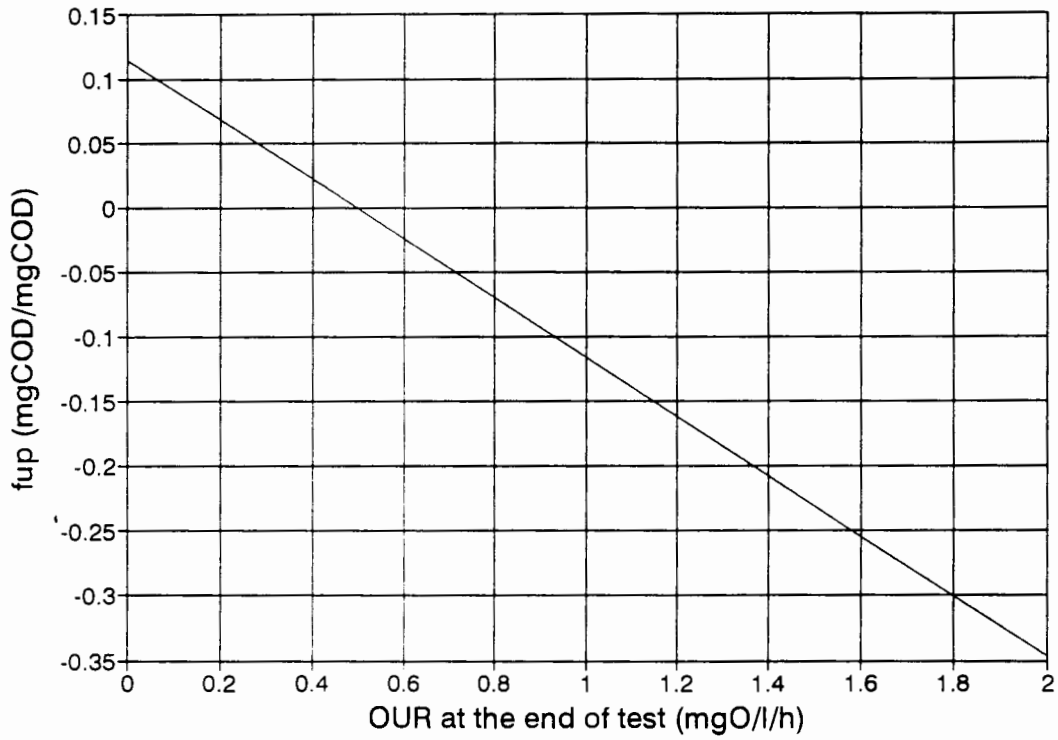

Fig 8.6: Theoretical variation of unbiodegradable particulate COD fraction (f_{up}) with variation in the absolute value of the OUR at the end of the batch test (O_{ee}).

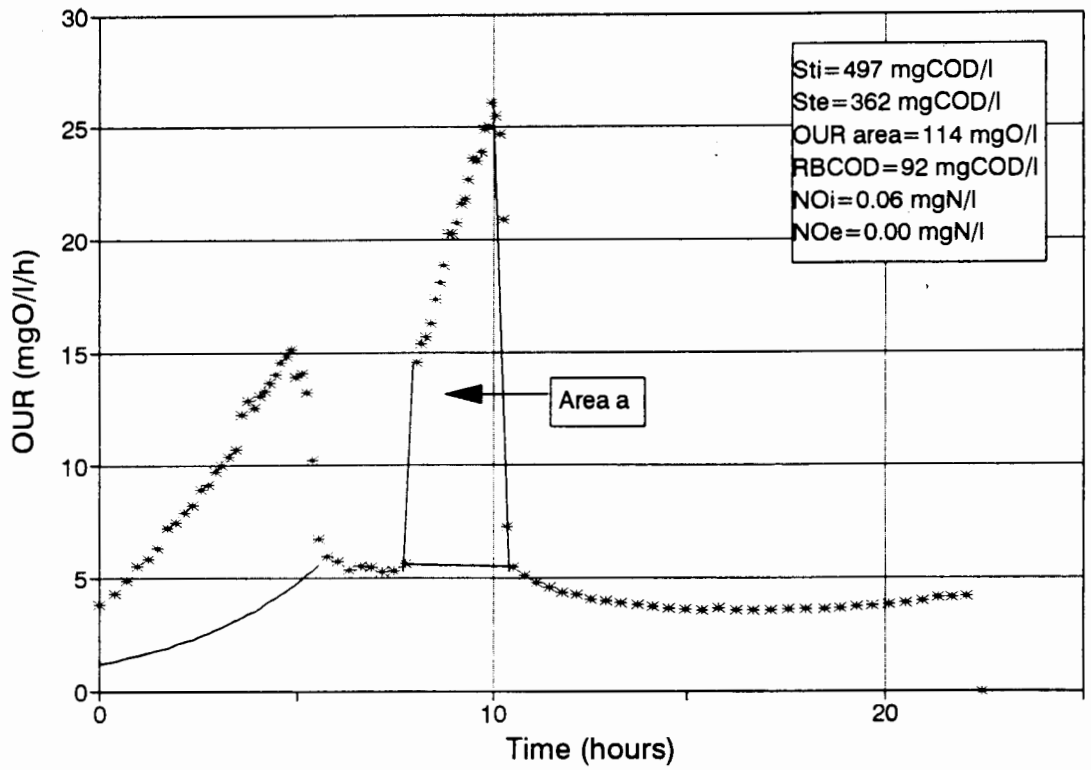

Fig 8.7a: OUR–time plot for an aerobic batch test with acetate added after the precipitous drop in OUR, to determine the yield coefficient with acetate as substrate.

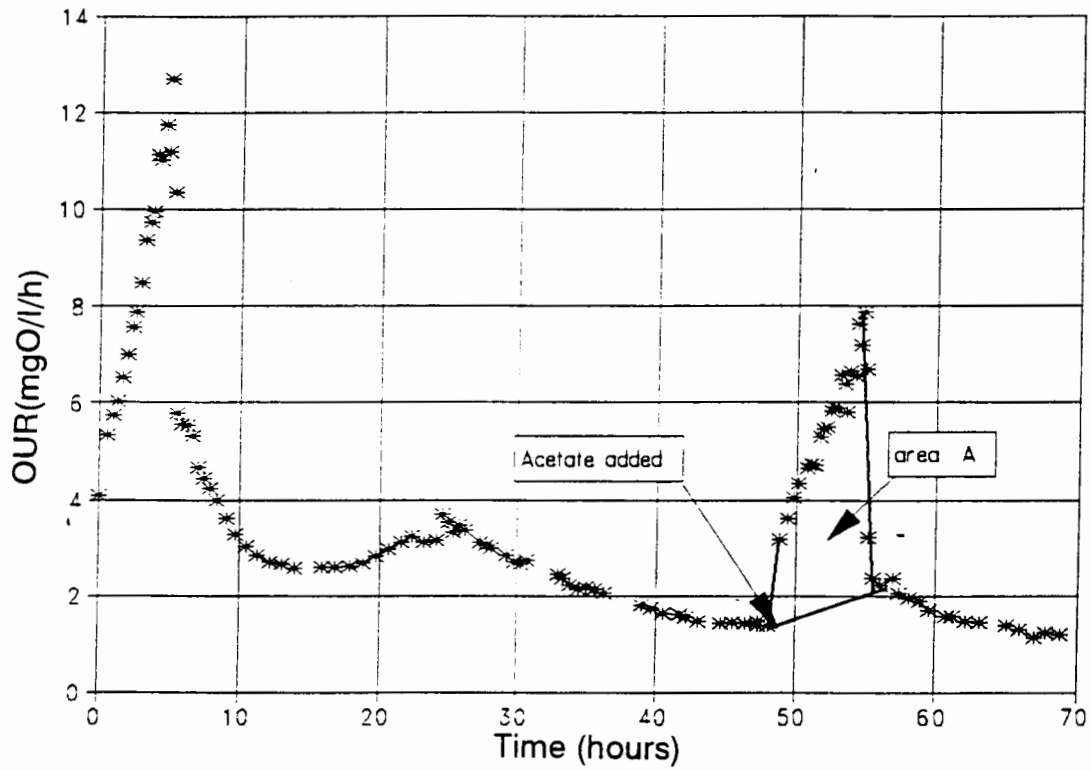

Fig 8.7b: OUR–time plot for an aerobic batch test with acetate added at the end of the batch test to stimulate exponential heterotroph growth due to the utilization of the acetate RBCOD.

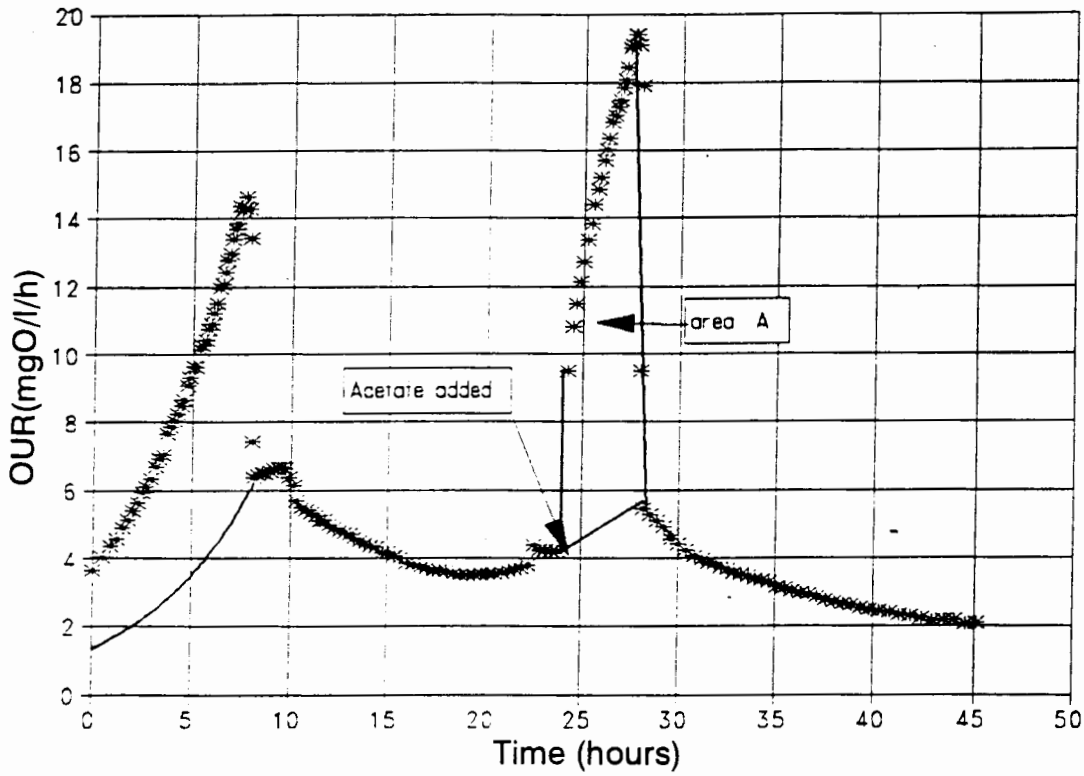

Fig 8.7c: OUR–time plot for an aerobic batch test with acetate added at the end of the batch test to stimulate exponential heterotroph growth due to the utilization of the acetate RBCOD.

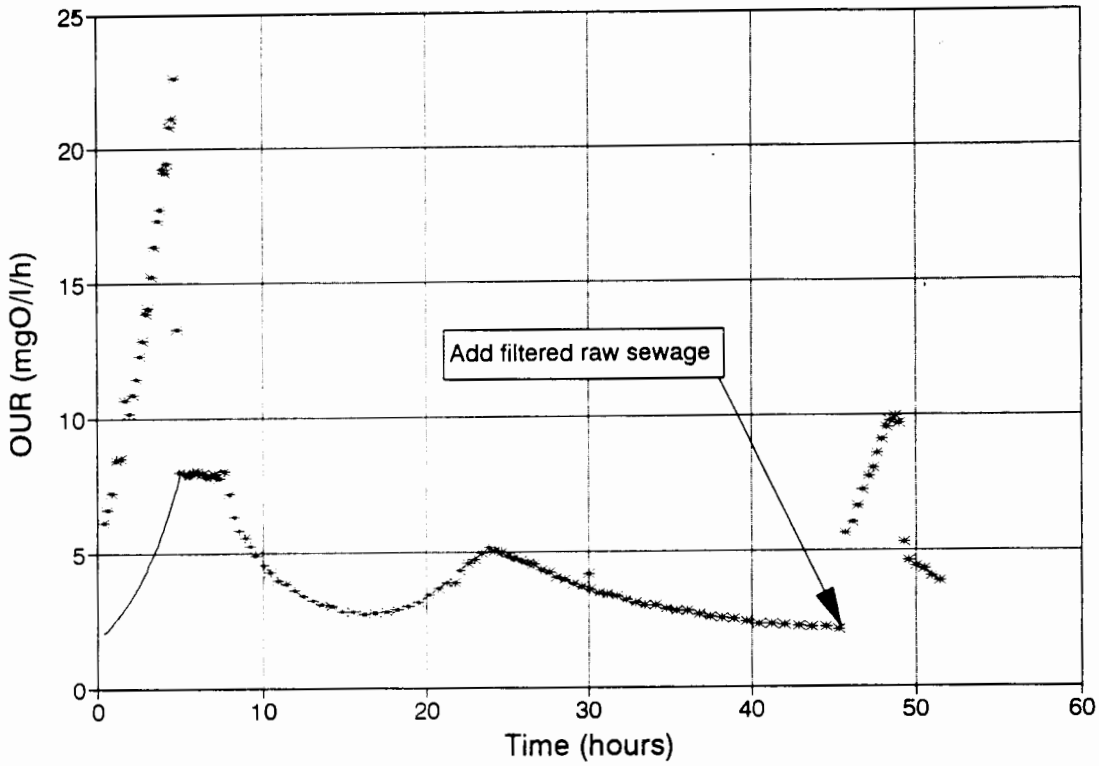

Fig 8.8a OUR–time plot for an aerobic batch test with raw sewage filtrate (0,45μm) added at the end of the batch test to stimulate exponential heterotroph growth due to the utilization of the filtrate RBCOD.

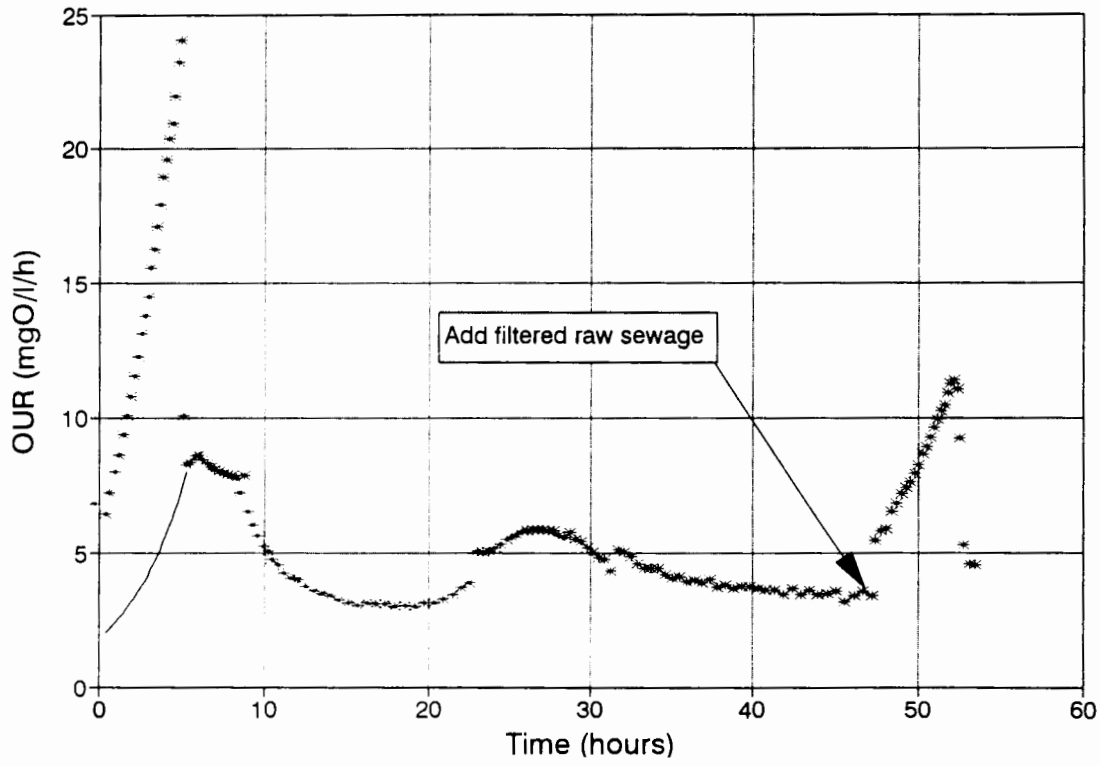

Fig 8.8b: OUR–time plot for an aerobic batch test with flocculated–filtered (0,45μm) raw sewage filtrate added at the end of the batch test to stimulate exponential heterotroph growth due to the utilization of the filtrate RBCOD.

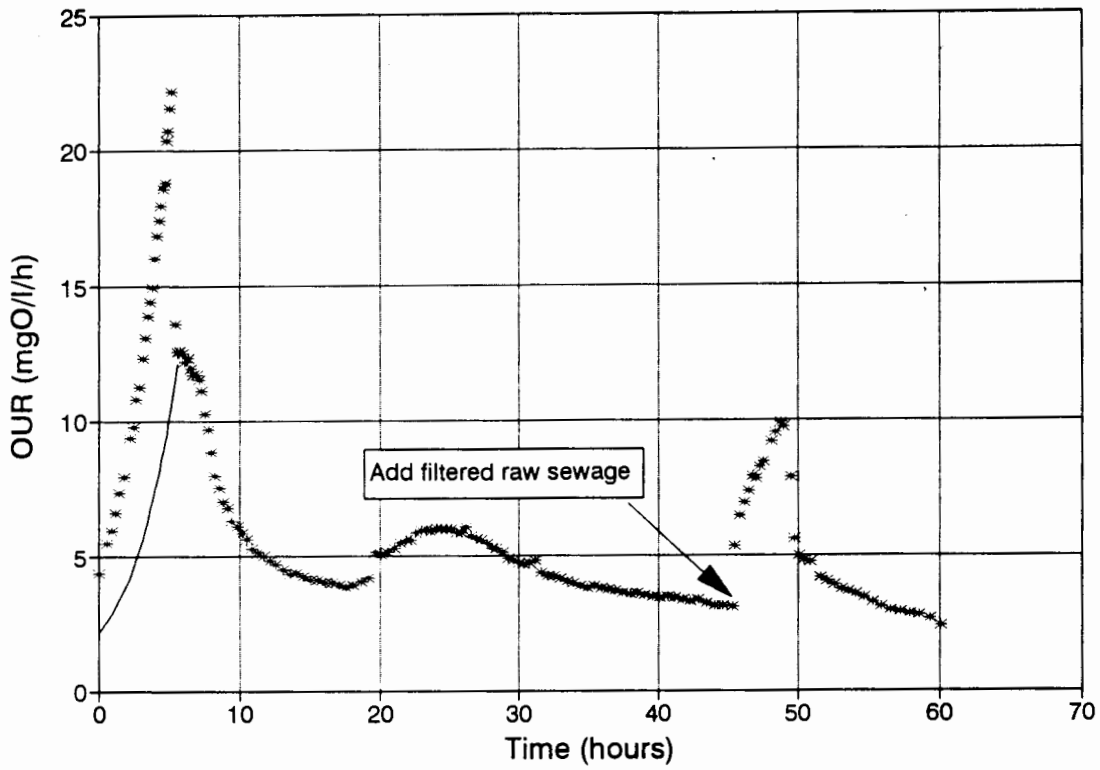

Fig 8.9a: OUR–time plot for aerobic batch test with flocculated–filtered (glass fibre filter paper) raw sewage filtrate added at the end of the batch test.

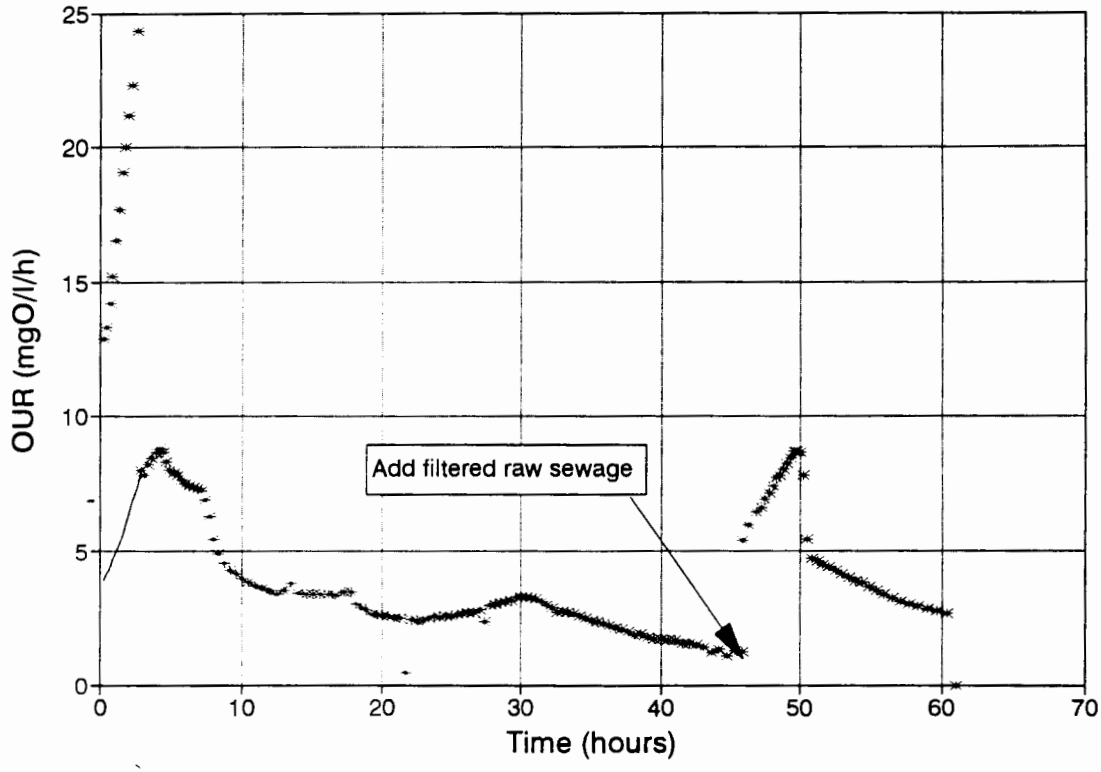

Fig 8.9b: OUR–time plot for aerobic batch test with flocculated–filtered (0,45μm filter paper) raw sewage filtrate added at the end of the batch test.

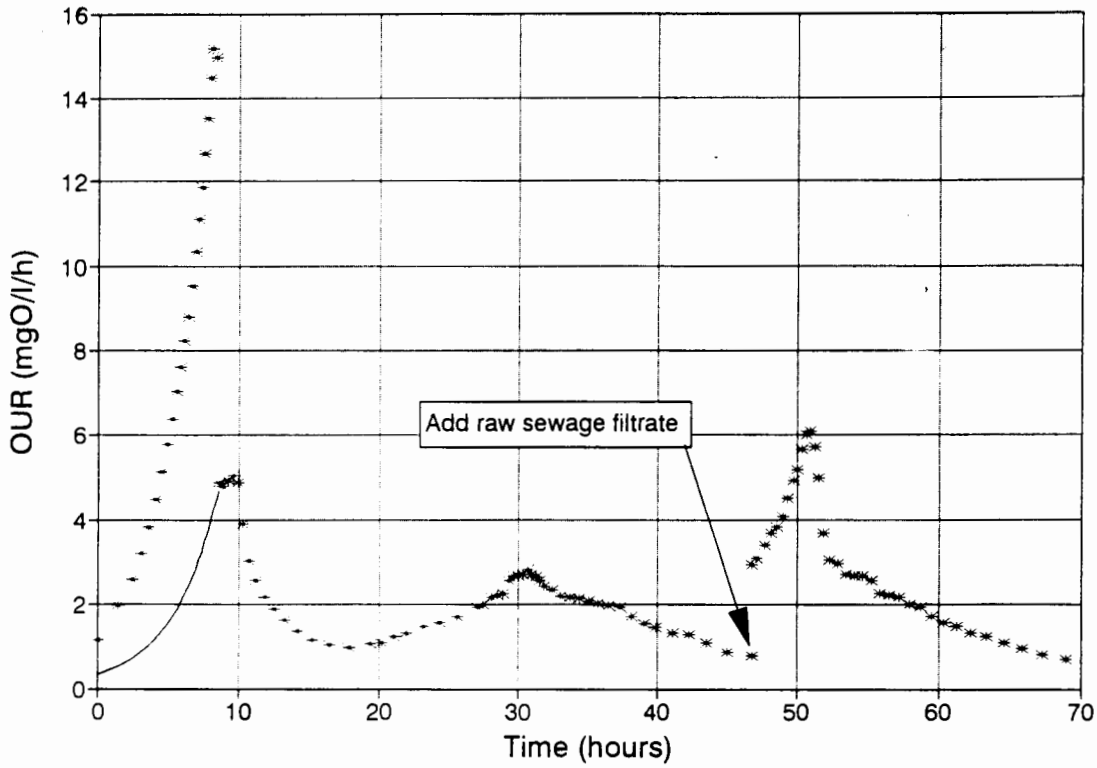

Fig 8.10a: OUR–time plot for aerobic batch test with flocculated–filtered (glass fibre filter paper) raw sewage filtrate added at the end of the batch test (after 2 days of running the batch test).

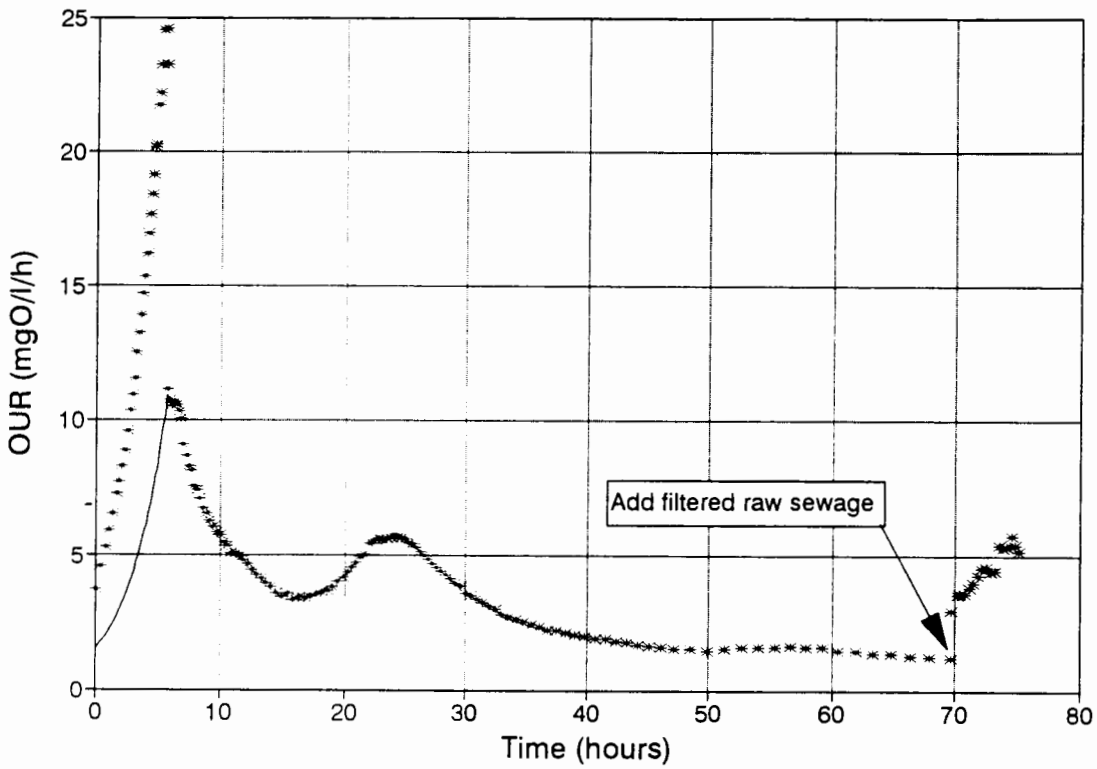

Fig 8.10b: OUR–time plot for aerobic batch test with flocculated–filtered (glass fibre filter paper) raw sewage filtrate added at the end of the batch test (after 3 days of running the batch test).

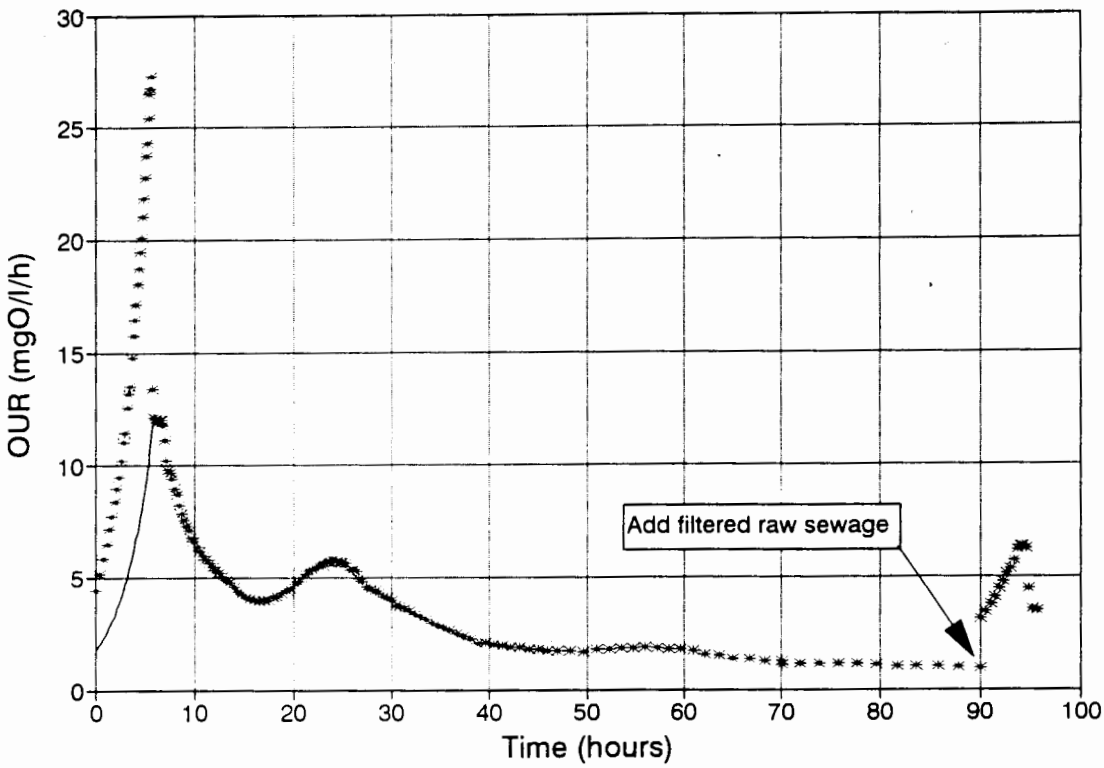

Fig 8.10c: OUR–time plot for aerobic batch test with flocculated–filtered (glass fibre filter paper) raw sewage filtrate added at the end of the batch test (after 4 days of running the batch test).

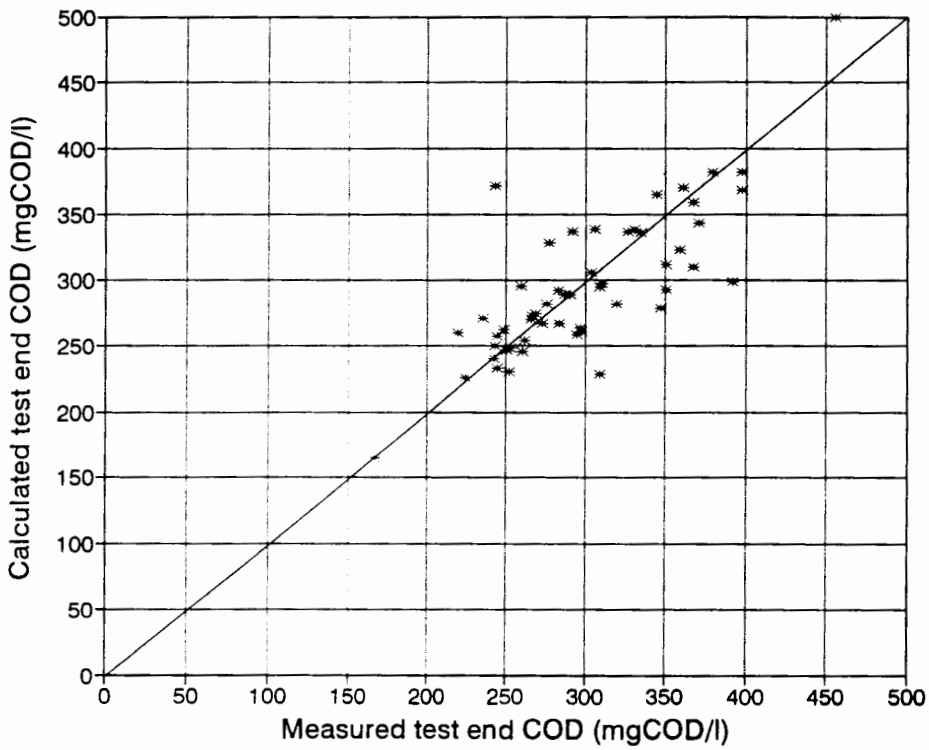

Fig 8.11: Comparison of measured end of test COD for the batch test versus theoretically calculated end of test COD. Each data point represents an individual measurement.

Table 8.1: Wastewater characteristics for the different batch tests using METHOD 1: Division of the OUR.

Sewag Batch	Dates of test	Sti (mgCOD/l)	Sbsi (mgCOD/l)	T-our (mgO/l)	Oe (mgO/l)	Sbi (mgCOD/l)	Sus (mgCOD/l)	Zbhi (mgCOD/l	Supi (mgCOD/l)	fup
11	Feb 23	526	111	285	129	468	45	15	-1	-0.00
	Feb 28	617	70	176	89	262	47	30	277	0.45
	March 18	459	87	243	173	212	53	82	113	0.25
12	March 26	514	62	198	118	241	73	80	120	0.23
	March 28	588	82	172	95	231	85	126	145	0.25
	April 1	562	131	261	108	457	41	22	42	0.07
	April 3	524	127	242	98	433	77	46	-32	-0.06
	April 5	506	130	271	140	393	78	29	6	0.01
13	April 7	502	146	261	117	431	86	54	-68	-0.14
	April 9	554	196	313	146	499	57	47	-49	-0.09
	April 11	574	149	244	119	377	61	110	26	0.05
	April 13	554	137	182	96	261	41	37	215	0.39

Note: T-our =Total area under the OUR-time plot.
Oe =OUR area due to endogenous respiration.

Table 8.2: Wastewater characteristics for the different batch tests using METHOD 3: Extended aeration.

Sewage Batch	Date of test	Sti (mgCOD/l)	Susi (mgCOD/l)	Sbsi (mgCOD/l)	Zbhi (mgCOD/l)	MOc (mgO/l)	Sbi (mgCOD/l)	Sbpi (mgCOD/l)	Supi (mgCOD/l)	fup
11	Feb 23	526	45	111	15	285	271	161	195	0.37
	Feb 28	617	47	70	30	276	248	178	291	0.47
12	Mar 18	459	53	87	82	319	244	157	81	0.18
	Mar 23	585	57	129	55	284	232	103	240	0.41
	Mar 26	514	73	62	80	180	106	44	255	0.50
	Mar 28	588	85	82	126	294	178	96	198	0.34
13	April 1	570	41	131	22	261	240	109	266	0.47
	April 3	524	77	127	46	242	200	73	201	0.38
	April 5	506	78	130	29	271	245	115	155	0.31
	April 7	502	86	146	54	261	210	65	152	0.30
	April 9	554	57	196	47	322	278	82	172	0.31
	April 11	574	61	149	110	244	142	-7	-	-
	April 13	554	41	137	37	183	148	11	327	0.59
14	April 21	664	52	106	140	253	124	18	347	0.52
	April 28	504	69	131	27	232	207	76	201	0.40
	April 29	645	52	110	27	217	192	82	374	0.58
	May 08	548	49	123	29	221	195	72	275	0.50
	May 11	552	46	110	39	251	215	105	251	0.46
15	May 27	560	41	86	39	217	181	95	299	0.53
	May 30	525	49	95	33	180	150	55	293	0.56

Table 8.3: Wastewater characteristics for the different batch tests using METHOD 4: OUR at end of test used to calculate heterotrophic active biomass.

Sewage Batch	Date of test	Sti (mgCOD/l)	Susi (mgCOD/l)	Zbhi (mgCOD/l)	Oe end of test (mgO/l/h)	Zbh end of test (mgCOD/l)	MOc (mgO/l)	Sbsi (mgCOD/l)	Sbi (mgCOD/l)	Sbpi (mgCOD/l)	Supi (mgCOD/l)	fup
	Feb 23	526	45	15	1.3	158	285	111	461	350	6	0.01
11	Feb 28	617	47	30	0.7	90	276	70	374	304	166	0.27
	Mar 18	459	53	82	0.7	89	319	87	375	288	-50	-0.11
12	Mar 23	585	57	55	1.3	163	284	129	426	297	47	0.08
	Mar 26	514	73	80	0.9	106	180	62	232	170	129	0.25
	Mar 28	588	85	126	1.8	220	294	82	427	345	-50	-0.09
	April 1	570	41	22	1.3	156	261	131	425	294	82	0.14
	April 3	524	77	46	1.5	185	242	127	408	281	-7	-0.01
	April 5	506	78	29	1.5	190	271	130	462	332	-62	-0.12
13	April 7	502	86	54	1.3	159	261	146	397	251	-35	-0.07
	April 9	554	57	47	1.2	153	322	196	469	273	-19	-0.03
	April 11	574	61	110	1.1	138	244	149	307	158	96	0.17
	April 13	554	41	37	1.5	184	183	137	346	209	130	0.23
	April 21	664	52	140	1.4	176	253	106	326	220	146	0.22
	April 28	504	69	27	1.4	179	232	131	407	276	1	0.00
14	April 29	645	52	27	1.2	148	217	110	361	251	205	0.32
	May 07	558	78	21	1.3	159	294	123	467	344	-7	-0.01
	May 11	552	46	39	1.0	129	251	110	372	262	94	0.17

Table 8.4: Heterotroph active biomass yield coefficient for acetate added to the batch test.

Acetate OUR area (mgO/l)	Equivalent COD (mgCOD/l)	Amount of COD added (mgCOD/l)	Heterotroph yield (Yzh) (mgCOD/mgCOD)
33	99	102	0.676
38	114	102	0.627
36	108	102	0.647
39	117	102	0.618
31	93	102	0.696
39	117	102	0.618
37	111	102	0.637
34	102	102	0.667
37	111	102	0.637
38	114	102	0.627
35	105	102	0.657
		Mean=	0.646
		SDmean=	0.007

Table 8.5a: Wastewater characteristics for the batch tests using METHOD 5: Acetate addition at the end of the batch test.

Sewage Batch	Dates of tests	Sti (mgCOD/l)	Sus (mgCOD/l)	Zbhi (mgCOD/l)	Zbhe (mgCOD/l)	Oc (mgO/l)	Sbi (mgCOD/l)
14	May 7	558	78	21	38	148	303
	May 27	534	41	39	36	156	289
15	May 30	525	49	33	57	98	219
	June 24	469	38	11	21	93	191
	June 26	497	44	27	44	132	274
	June 27	533	36	44	45	128	242
16	June 29	441	28	29	113	125	360
	June 30	545	32	34	95	137	349
	July 1	464	36	64	99	120	278
17	July 5	504	38	49	123	137	367

Sewage Batch	Dates of tests	Zee (mgCOD/l)	Supi (mgCOD/l)	fus	fup	Ste (mgCOD/l)	CODend (mgCOD/l)
14	May 7	37	156	0.14	0.28	410	286
	May 27	39	165	0.08	0.31	377	332
15	May 30	24	224	0.09	0.43	427	263
	June 24	23	229	0.08	0.49	376	329
	June 26	33	152	0.09	0.31	365	313
	June 27	32	210	0.07	0.39	405	337
16	June 29	31	24	0.06	0.05	316	282
	June 30	34	129	0.06	0.24	408	282
	July 1	30	85	0.08	0.18	343	294
17	July 5	34	50	0.08	0.1	367	359

Ste= theoretical end of test COD

CODend=measured end of test COD.

Table 8.5b: COD recovery for acetate added to batch tests (see Table 8.5a).

Sewage Batch	Dates of tests	Acetate OUR area (mgO/l)	Equivalent COD (mgCOD/l)	Amount of COD added (mgCOD/l)	% COD recovery
14	7 May	35	104	102	102
	27 May	37	110	102	108
15	30 May	29	87	102	86
	24 June	25	75	102	74
	26 June	34	102	102	100
16	27 June	35	105	102	103
	29 June	33	98	102	96
	30 June	31	94	102	92
	1 July	39	117	102	115
17	5 July	38	115	102	113
				Mean=	99
				SDmean=	4

Table 8.6: Wastewater characteristics for different batch tests using METHOD 6: Flocculated–filtered raw sewage filtrate addition at the end of the batch test.

Sewage Batch	Dates of tests	Sti (mgCOD/l)	Sus (mgCOD/l)	Zbhi (mgCOD/l)	Zbhe (mgCOD/l)	Oc (mgO/l)	Sbi (mgCOD/l)
	july 7	492	52	70	181	213	324
	july 9	504	24	44	303	160	419
	july 12	530	40	18	267	148	397
	july 13	514	45	20	158	146	284
17	july 14	534	45	28	196	211	379
	july 15	567	49	36	110	195	269
	july 16	551	53	57	116	169	228
	july 18	461	61	44	200	164	319
	july 19	486	12	42	114	149	221
	july 21	518	37	77	122	219	264
	july 25	469	37	50	183	176	309
	july 27	545	29	38	172	175	309
	july 28	555	43	40	113	219	292
	july 29	451	43	16	161	177	322
	Aug 1	437	25	10	136	197	322
18	Aug 2	519	25	29	73	246	289
	Aug 4	503	49	40	91	257	308
	Aug 5	443	49	36	71	213	247
	Aug 6	511	41	80	116	247	282
	Aug 7	510	41	27	93	264	331
	Aug 16	545	37	22	186	273	438
	Aug 18	506	45	26	169	246	389
19	Aug 19	549	33	65	200	291	426
	Aug 20	579	56	56	141	297	382
	Aug 28	584	39	59	195	288	424
	Aug 30	567	39	55	185	202	333
	Sept 2	606	57	66	137	339	410
	Sept 4	526	49	29	233	231	435
	Sept 6	520	41	24	69	231	275
20	Sept 7	520	27	17	61	259	302
	Sept 8	525	31	29	74	296	342
	Sept 9	508	41	38	126	241	330
	Sept 11	483	53	53	59	250	257
	Sept 13r	525	45	40	55	197	213
	Sept 13l	525	45	54	104	187	237
	Sept 15	411	41	69	87	245	263

Table 8.6 (cont.): Wastewater characteristics for different batch tests using METHOD 6: Flocculated-filtered raw sewage filtrate addition at the end of the batch test.

Sewage Batch	Dates of tests	Zee (mgCOD/l)	Supi (mgCOD/l)	fus	fup	Ste (mgCOD/l)	CODend (mgCOD/l)
	july 7	24	46	0.11	0.09	279	347
	july 9	5	17	0.05	0.03	344	371
	july 12	4	75	0.08	0.14	382	397
	july 13	12	166	0.09	0.32	368	397
17	july 14	20	83	0.08	0.16	323	259
	july 15	24	213	0.09	0.38	372	243
	july 16	21	213	0.10	0.39	382	379
	july 18	13	36	0.13	0.08	298	310
	july 19	17	210	0.03	0.43	337	326
	july 21	30	141	0.07	0.27	300	392
	july 25	17	73	0.08	0.16	293	228
	july 27	17	169	0.05	0.31	370	361
	july 28	28	180	0.08	0.33	336	334
	july 29	16	70	0.10	0.16	274	269
	Aug 1	21	80	0.06	0.18	240	242
18	Aug 2	35	176	0.05	0.34	273	267
	Aug 4	36	106	0.10	0.21	246	260
	Aug 5	30	111	0.11	0.25	231	252
	Aug 6	35	108	0.08	0.21	264	297
	Aug 7	35	112	0.08	0.22	246	301
	Aug 16	29	48	0.07	0.09	271	236
	Aug 18	27	46	0.09	0.09	260	219
19	Aug 19	34	25	0.06	0.05	258	295
	Aug 20	39	85	0.10	0.15	282	319
	Aug 28	34	62	0.07	0.11	296	260
	Aug 30	21	141	0.07	0.25	365	344
	Sept 2	47	73	0.09	0.12	267	283
	Sept 4	20	13	0.09	0.02	295	309
	Sept 6	32	180	0.08	0.35	289	287
20	Sept 7	37	174	0.05	0.33	261	297
	Sept 8	42	123	0.06	0.24	228	309
	Sept 9	30	100	0.08	0.20	267	273
	Sept 11	38	121	0.11	0.25	233	244
	Sept 13r	29	228	0.09	0.43	328	277
	Sept 13l	25	190	0.09	0.36	338	305
	Sept 15	36	38	0.10	0.09	166	167

Ste = Theoretical end of test COD.

CODend= measured end of test COD.

Table 8.7: Wastewater characteristics for different batch tests using METHOD 6: Raw sewage filtrate addition at the end of the batch test after 2 or more days.

Sewage Batch	Dates of tests	Sti mgCOD/l	Susi mgCOD/l	Zbhi mgCOD/l	Zbhe mgCOD/l	Oc mgO/l	Sbi mgCOD/l	Zee mgCOD/l	Supi mgCOD/l	fus	fup	Ste mgCOD/l	CODend mgCOD/l
	Sep 16 (3)	484	33	96	81	230	251	37	104	0.07	0.21	254	262
	Sep 19(2)	583	44	93	81	245	245	39	175	0.08	0.30	338	330
	Sep 21(2)	583	37	31	102	246	246	32	166	0.06	0.28	337	291
21	Sep 23l(3)	517	58	55	152	259	259	33	16	0.11	0.03	258	244
	Sep 23r(2)	517	72	43	202	211	211	20	12	0.14	0.02	306	303
	Sep 27r(2)	556	41	65	105	197	197	27	186	0.07	0.33	359	367
	Sep 27l(3)	556	43	57	85	244	244	35	149	0.08	0.27	312	351
	Sep 30r(2)	523	49	65	90	213	213	31	141	0.09	0.27	310	367
	Sep 30l(3)	523	26	49	73	230	230	33	161	0.05	0.31	294	351
	25 Oct(4)	561	45	52	109	313	313	44	51	0.08	0.09	248	253
	25 Oct(3)	561	41	49	105	272	272	38	106	0.07	0.19	289	290
	28 Oct(4)	506	53	47	69	243	243	36	105	0.09	0.21	263	249
23	28 Oct(3)	506	31	39	118	256	256	33	68	0.06	0.13	250	243
	3 Nov(2)	539	63	7	44	256	256	37	139	0.13	0.26	282	275
	3 Nov(3)	539	37	22	67	268	268	38	130	0.07	0.24	271	266
	3 Nov(4)	539	41	25	46	312	312	46	93	0.08	0.17	226	224

(2,3,4)indicates length of time(d)batch test is run prior to filtered wastewater additio Ste = Theoretical end of test COD.
CODend = measured end of test COD.

Table 8.8: Mean unbiodegradable particulate COD fraction of influent COD (f_{up}), number of tests and standard deviation of the mean for the different sewage batches (see Tables 8.6 and 8.7).

Sewage Batch	Unbiodegradable Particulate COD as % of Total COD (fup)		
	Batch test		
	mean %	no. of tests	std. dev. of mean
17	0.20	10	0.04
18	0.18	10	0.02
19	0.08	6	0.03
20	0.22	9	0.04
21	0.23	9	0.04
23	0.18	7	0.02

CHAPTER 9

EVALUATION OF BATCH TEST EXTENSION TO DETERMINE SLOWLY BIODEGRADABLE AND UNBIODEGRADABLE PARTICULATE COD

9.1 INTRODUCTION

In Chapter 8 extensions to the batch test procedure have been proposed to quantify influent wastewater slowly biodegradable COD and unbiodegradable particulate COD. Initial indications are that the values derived from the batch test compare reasonably well with those expected for the raw (unsettled) municipal wastewater tested. In this Chapter values derived from the batch test procedure will be evaluated, by comparing these to values obtained from conventional methods. The only conventional method to determine unbiodegradable particulate COD (and concomitantly slowly biodegradable COD) is that of Ekama *et al.* (1986) and this method is adopted here.

9.2 METHOD

As described in Chapter 4, batches of wastewater were collected from the Mitchell's Plain Wastewater Treatment Plant and stored in stainless steel tanks at 4° C; this served as influent for testing for a period of about two weeks. (Experience has shown that storing the wastewater for a period longer than about three weeks would result in the characteristics of the wastewater changing). Daily, after thorough mixing, wastewater samples were drawn from the storage tanks and diluted to the desired COD concentration (±500 mgCOD/ℓ) using tap water. Using the same wastewater at the same COD concentration, the extended batch tests as proposed in Chapter 8 and a laboratory–scale unit were run in parallel.

The laboratory–scale unit was a completely aerobic single reactor system at 12 days sludge age and 20° C temperature. Operational procedures as described in detail by Ekama *et al.* (1986), Burke *et al.* (1986), Clayton *et al.* (1989) and others were followed. The layout and operational data for the system are summarized in Fig 9.1; details are given in Appendix D. The following measurements were made on the system:

a) The COD concentration (Standard Methods, 1985) of the feed and filtered and unfiltered COD concentration of the effluent.

b) The influent and effluent TKN concentration (Standard Methods, 1985).

c) The effluent nitrate concentration (Technicon Auto Analyzer).

d) The reactor mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) (Standard Methods, 1985).

e) The oxygen utilization rate (OUR) in the aerobic reactor was measured twice a day and the two readings averaged.

Detailed experimental data for the laboratory-scale unit are listed in Tables D.1a and b, Appendix D. From Ekama *et al.* (1986), the daily results for a particular wastewater batch were averaged (see Tables D.1 and D.2, Appendix D). From the average, for each wastewater batch, COD and nitrogen mass balances were calculated using the procedure set out by Ekama *et al.* (1986). Mass balance results are listed in Table D.2, Appendix D. Mass balances falling in the range 90–110% are considered acceptable. For the nitrogen mass balances, with the exception of sewage batch No.21 the mass balances were acceptable; sewage batch No.21 was rejected for further analysis. However, the COD mass balances all were too high (average mass balance 119%). The high COD mass balances were unexpected; usually for completely aerobic activated sludge systems acceptable COD mass balances can be obtained without undue difficulty. A number of parallel completely aerobic activated sludge systems operated in the UCT laboratory by undergraduate research students gave very similar COD mass balances (Ubisi, 1994; Jadav, 1994; Hercules, 1994). The COD mass balance contains four elements (Ekama *et al.*, 1986) – COD of influent and effluent, oxygen utilization rate (OUR) for carbonaceous material consumption (i.e. measured OUR minus the OUR for nitrification) and sludge production (i.e. mixed liquor volatile suspended solids concentration measured as COD multiplied by the waste flow rate). The acceptable nitrogen mass balances indicated the OUR for nitrification was reasonable. Investigations showed that the COD measurement technique was accurate (checked with standard potassium hydrogen phthalate, Standard Methods, 1985); the COD data could be accepted. Simulations of the system response with the UCTOLD computer programme (Dold *et al.*, 1991) indicated that the problem with the COD mass balance was located in errors in measurement of the oxygen utilization rate (OUR). Thus, the OUR parameter could not be used to determine the unbiodegradable COD fraction (f_{up}) (Ekama *et al.*, 1986). Accepting that the error

in the COD mass balance was due to errors in OUR measurement, the measured mixed liquor volatile suspended solids (MLVSS) parameter was accepted as reasonable, and used to determine the f_{up} (Ekama *et al.*, 1986); using this method, errors in the OUR measurement will not affect the estimate for f_{up}. Accordingly, from the averaged data the unbiodegradable soluble COD fraction (f_{us}) was calculated as the effluent COD concentration divided by the influent COD concentration. From the averaged data and calculated f_{us}, the f_{up} was calculated using the following equation (Ekama *et al.*, 1986):

$$MX_v = \frac{MS_{ti}\ (1-f_{us}-f_{up})\ Y_h{}^* R_s}{(1+b_h{}^* R_s)}\ (1 + f b_h{}^* R_s) + f_{up}\ MS_{ti}\ R_s/f_{cv} \qquad (9.1)$$

where

MX_v = total volatile solids mass (mgVSS)
= $X_v \cdot V_p$

X_v = MLVSS concentration (mgVSS/ℓ)

V_p = system volume (ℓ)
= 10 ℓ

$Y_h{}^*$ = heterotroph active biomass yield (VSS units)
= 0,45 mgVSS/mgCOD

R_s = sludge age (d)
= 12 d

$b_h{}^*$ = net specific endogenous mass loss rate
= 0,24/d

f = endogenous residue fraction
= 0,2

f_{cv} = COD/VSS ratio of mixed liquor
= 1,48 mgCOD/mgVSS

MS_{ti} = total influent COD mass fed per day (mgCOD/d)
= $Q \cdot S_{ti}$

Q = influent flow rate
= 10 ℓ/d

S_{ti} = influent COD concentration (mgCOD/ℓ)

For each batch of wastewater tested, successive values for f_{up} were substituted into Eq (9.1); the f_{up} value that gave a theoretical MLVSS mass (MX_v) equal to the measured value was accepted. The f_{up} values for the different wastewater batches

are listed in Table 9.1.

In parallel to the steady state unit, batch tests were run using the same wastewater at the same COD concentration as fed to the steady state unit, and using the extended procedure set out in Chapter 8, Section 8.8. Detailed data for the batch tests are listed in Table 8.6. Data from the batch tests were analyzed using the procedures set out in Chapter 8, Section 8.8, and the f_{up} values for each batch test were determined. For each wastewater batch, the f_{up} values from the different batch tests were averaged, and are listed in Table 9.1.

9.3 COMPARATIVE ANALYSIS

For the different batches of wastewater tested, the average f_{up} values for the different wastewater batches from the conventional laboratory–scale system and the batch tests are listed in Table 9.1; the f_{up} values from the two methods are plotted against each other in Fig 9.2.

Comparing the f_{up} values derived from the two methods, the values for f_{up} from the batch test (f_{up} = 0,08–0,22) and the conventional completely aerobic system (f_{up} = 0,05–0,19) fall within the same range. Furthermore, the ranges of f_{up} values from both tests compare reasonably with those quoted in the literature for South African raw municipal wastewaters (f_{up} = 0,07–0,20; WRC, 1984). However, it is evident that, with the exception of sewage batch No. 23, the direct correlation between the f_{up} values from the two tests for the individual batches of wastewater is poor. For all the batches of wastewater tested, the f_{up} values for the two methods were averaged, see Table 9.1; on average the batch test gave f_{up} values that tend to be higher (average f_{up} = 0,17) than those from the conventional method (average f_{up} = 0,11). However, from Fig 9.2 no absolute discernible trend can be identified in the relationship between the f_{up} values from the two test methods. To identify clear trends a more extensive experimental investigation is required, so that more data are available. One aspect that will need to be investigated is the basic assumption made in the batch test, that all the influent biodegradable (in particular slowly biodegradable) COD has been consumed in the batch test prior to the addition of the filtered raw wastewater. If this assumption is not correct, then the unmetabolized influent slowly biodegradable COD will be reflected as unbiodegradable particulate COD, leading to an overestimation of this COD fraction, a general trend observed in the batch test. The degradation kinetics for the slowly biodegradable COD will depend on a number of factors, *inter alia*, the

heterotroph active biomass concentration, acclimatization of this biomass to the specific organic compounds making up the slowly biodegradable COD, and the degradability of these specific organic compounds. To ensure in the batch test that all the slowly biodegradable COD has been consumed, the batch test would have to be run for a considerable period, which would make the batch test less attractive for practical application. In any event, it was shown in Chapter 8 that increasing the length of time of the batch test did not provide consistent results.

Since the unbiodegradable particulate COD tends to be overestimated in the batch test compared to the continuous test (accepted as the datum), the slowly biodegradable COD should be underestimated; the slowly biodegradable COD (S_{bpi}) is found by subtracting all the other COD fractions from the total COD (S_{ti}), i.e.

$$S_{bpi} = S_{ti} - S_{bsi} - S_{usi} - Z_{BHi} \tag{9.2a}$$

$$= S_{ti}\,(1 - f_{ts} - f_{us} - f_{Zbh}) \tag{9.2b}$$

where

f_{ts} = fraction of influent total COD which is readily biodegradable
$= S_{bsi}/S_{ti}$

f_{us} = fraction of influent total COD which is unbiodegradable soluble
$= S_{usi}/S_{ti}$

f_{Zbh} = fraction of influent total COD which is heterotroph active biomass
$= Z_{BHi}/S_{ti}$

For the batch test method, all the information required to calculate S_{bpi} in Eq (9.2b) can be determined from the test procedure, see Table 9.1. For the completely aerobic activated sludge system, however, estimates for f_{ts} and f_{Zbh} cannot be obtained from measurements made on this system – for the purposes of calculation, f_{Zbh} from the batch test was used and f_{ts} from a parallel flow-through square wave system (WRC, 1984), see Table 9.1. The slowly biodegradable COD as a fraction of total COD (f_{bp}) from the batch tests and conventional completely aerobic system for the different wastewater batches are listed in Table 9.1. For the different wastewater batches, in Fig 9.3 the average slowly biodegradable COD as a fraction of total COD (f_{bp}) from the batch test are plotted against those from the conventional test; again the direct correlation between the values for f_{bp} from the

two test methods is poor. For all the batches of wastewater tested, the f_{bp} values for the two methods were averaged, see Table 9.1; as expected, the average f_{bp} estimate from the batch test (average f_{bp} = 0,44) is lower than that from the completely aerobic system (average f_{bp} = 0,51). Again, as for the f_{up} values, from Fig 9.3 no discernible trend can be identified in the relationship between the f_{bp} values from the two test methods. However, because the absolute values for f_{bp} are very much larger than those for f_{up}, the relative difference between f_{bp} estimates from the two tests are smaller than the relative difference between f_{up} estimates.

9.4 CONCLUSIONS

Although the proposed extension to the batch test method to determine slowly biodegradable (S_{bpi}) and unbiodegradable particulate (S_{upi}) COD fractions in the influent, provides estimates for S_{bpi} and S_{upi} that fall in the same range as estimates from the conventional completely aerobic activated sludge system method (Ekama *et al.*, 1986), the direct correlation between the estimates from the two methods is poor. The batch test method provides estimates for S_{upi} that tend to be higher than those derived from the conventional activated sludge method, and correspondingly provides estimates for S_{bpi} that tend to be lower than those derived from the conventional activated sludge method. A more extensive experimental evaluation is required to discern if these trends are consistent, but they would suggest that the basic assumption for the batch test – that the slowly biodegradable COD has been consumed prior to addition of the filtered raw wastewater – may not be valid. This requires further investigation. For the present, the batch test does not provide estimates for f_{up} that are sufficiently accurate and precise for use in design and simulation of activated sludge systems. For design and simulation, f_{up} should be able to be quantified into the ranges 0–0,05; 0,05–0,10; 0,10–0,15; etc. As yet, there is not sufficient surety that the estimate for f_{up} from the batch test will meet this requirement.

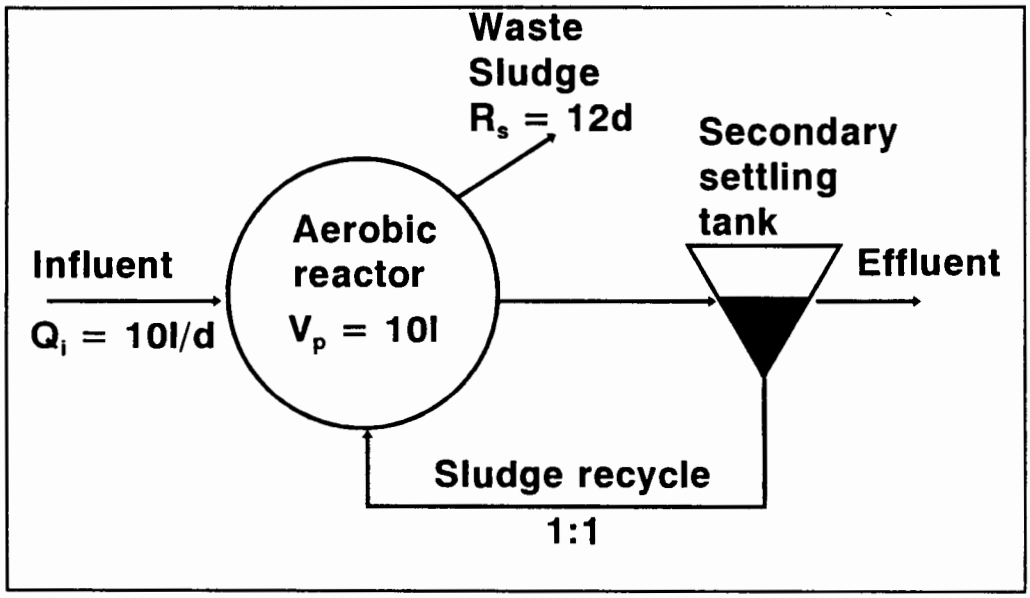

Fig 9.1: Configuration of aerobic activated sludge unit used for the conventional method (Ekama *et al.*, 1986) for determination of effluent COD and unbiodegradable particulate COD.

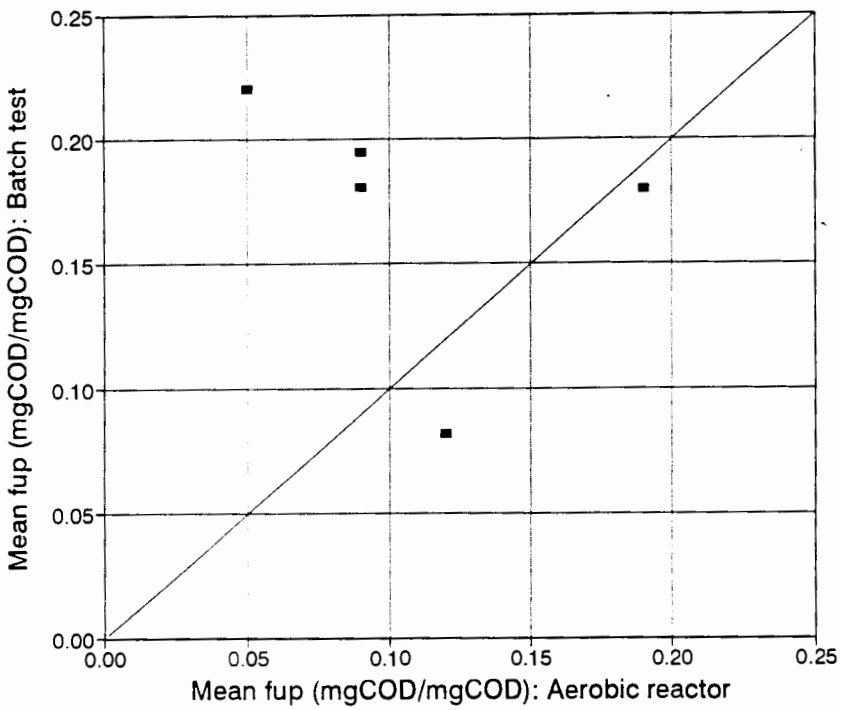

Fig 9.2: Comparison of the particulate unbiodegradable COD fractions (f_{up}) from the batch test versus those from the completely aerobic activated sludge unit. Each data point represents the mean of a number of tests on one batch of sewage.

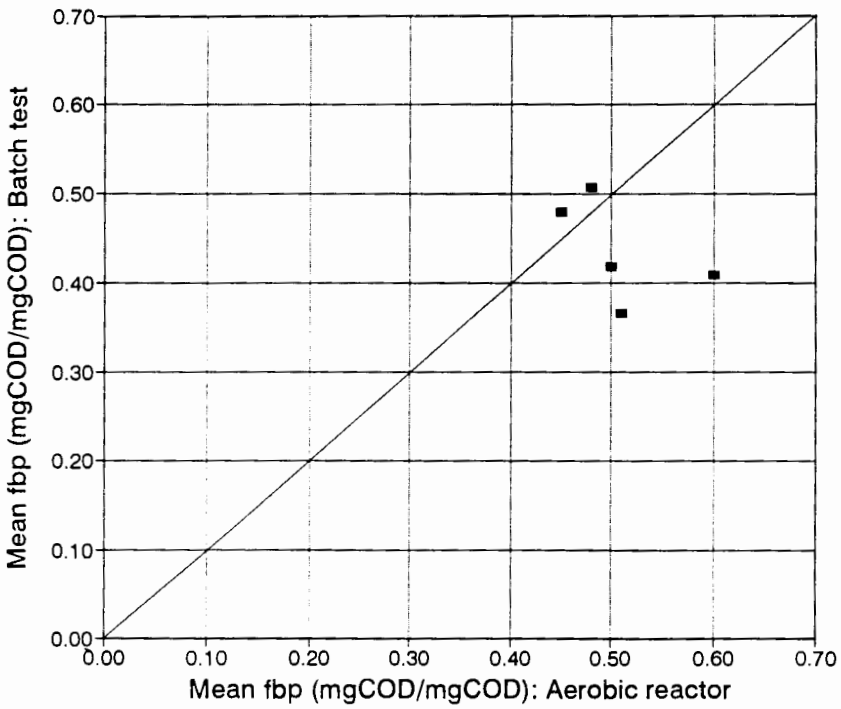

Fig 9.3: Comparison of particulate biodegradable COD fractions (f_{bp}) from the batch test versus those from the completely aerobic activated sludge unit. Each data point represents an average of a number of tests on a batch of sewage.

Table 9.1: Mean unbiodegradable soluble (f_{us}), readily biodegradable (f_{ts}), unbiodegradable particulate (f_{up}) and biodegradable particulate (f_{bp}) COD fractions from batch test and aerobic unit, and heterotroph active biomass COD fraction (f_{ZBH}*) from batch test, all mgCOD/mg total influent COD. Each value represents a mean of a number of tests on a batch of sewage.

SEWAGE	WASTEWATER COD FRACTIONS (mgCOD/mgCOD)								
		Aerobic Unit				Batch Test			
BATCH	mean fzbh*	mean fup	mean fus	mean fts	mean fbp	mean fup	mean fus	mean fts	mean fbp
17	0.09	0.09	0.08	0.23	0.51	0.20	0.08	0.27	0.37
18	0.07	0.09	0.08	0.26	0.50	0.18	0.08	0.25	0.42
19	0.08	0.12	0.08	0.24	0.48	0.08	0.08	0.25	0.51
20	0.07	0.05	0.07	0.21	0.60	0.22	0.08	0.22	0.41
23	0.08	0.19	0.08	0.2	0.45	0.18	0.08	0.18	0.48
Average	0.08	0.11	0.08	0.23	0.51	0.17	0.08	0.24	0.44

mean fzbh*= from the batch test

mean fts for aerobic unit from the square wave test

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

10.1 OBJECTIVES

To comply with more stringent legislations controlling discharges of nutrients with municipal effluents, over the past two decades there have been extensive developments in the activated sludge method for wastewater treatment; the system configuration and operation have increased considerably in complexity. With such complexity, designs based on experience or semi–empirical methods no longer give optimal performances; fundamentally based design procedures are required. Also, it is not possible to make reliable quantitative or even qualitative predictions as to the effluent quality to be expected from a design or to assess the effect of a modification on a system without a kinetic model that simulates the system behaviour accurately.

To meet these requirements, increasingly sophisticated design and simulation models have been developed. As input to these models, it is necessary to characterize the wastewater, that is, to quantify the various influent carbonaceous (C), nitrogenous (N) and phosphorus (P) constituents making up the wastewater – the design or simulation will be only as reliable as the wastewater characteristics that serve as input.

The principal objective of this investigation was to evaluate and develop methods to quantify the influent C material fractions (measured in terms of the COD parameter). In reviewing the literature it was evident that existing methods to quantify the C material fractions were either too elaborate or approximate; the need exists for simple reliable methods for accurate estimation of these parameters.

To meet this requirement, a batch test method has been developed to quantify the five influent COD fractions, namely heterotroph active biomass, readily biodegradable COD (RBCOD), slowly biodegradable COD (SBCOD), unbiodegradable particulate COD and unbiodegradable soluble COD. Also, the physical flocculation–filtration method of Mamais *et al.* (1993) to quantify RBCOD was evaluated and refined.

10.2 BATCH TEST METHOD

The batch test developed here has advantages over previous methods in that:

- The experimental procedure is relatively simple.

- No mixed liquor acclimatized to the wastewater is required.

- The only independent constants required for calculation are the heterotroph yield (Y_{ZH}), endogenous residue fraction for heterotroph active biomass (f), and specific death rate (b_H): Dosing the batch test with known concentrations of acetate showed that the standard value for Y_{ZH} in the literature (Y_{ZH} = 0,666 mgCOD/mgCOD; Dold and Marais, 1986) can be accepted; the batch test procedure is relatively insensitive to the value for b_H. All other constants required for calculations are obtained from the experimental data. However, it is unlikely that these constants (i.e. maximum specific growth rate of heterotrophs on RBCOD, $\hat{\mu}_H$, and maximum specific growth rate of heterotrophs on SBCOD, K_{MP}) will be of much value in modelling and design of activated sludge systems – most probably a population will develop in the activated sludge system that differs appreciably from that in the wastewater since the conditions in the wastewater (high COD, low active mass) differ significantly from those in the activated sludge system (low COD, high active mass).

The batch test method was evaluated by comparing results from this method with those from conventional methods accepted as the "standard" in the literature. Results from a number of batch tests on municipal wastewater from Mitchell's Plain and Borcherds Quarry (Cape Town, South Africa) indicate that:

- Autotrophic biomass is not present in either wastewater.

- Measured RBCOD concentrations correlate closely with those from the conventional flow–through square wave test (WRC, 1984, Ekama *et al.*, 1986).

- For Mitchell's Plain wastewater, usually heterotroph active biomass was present in low concentrations, ranging from 3% to 10% of total COD. However, on occasion concentrations > 10% of total COD were measured. These high values could be traced to operational procedures at the Mitchell's Plain Wastewater Treatment Plant – sludge handling facilities were shut down for maintenance and

repairs and waste sludge recycled to the head of the works upstream of the point where the wastewater was collected for the batch tests.

- For Borcherds Quarry wastewater, heterotroph active biomass concentration was very variable, ranging from 7% to 16% of total COD. From an investigation of operational procedures at the Borcherds Quarry Wastewater Treatment Plant, it was found that intermittently waste activated sludge was recycled to the head of the works and mixed with the incoming wastewater upstream of the point where wastewater was drawn for the batch test.

- Although the values for wastewater heterotroph active biomass could not be compared to conventional methods (none are available), the batch test was able to detect correctly variations in heterotroph active biomass caused by changes in plant operational procedures, as described above.

- Values for unbiodegradable soluble COD derived from the batch test compared reasonably well with those derived from the effluent of a long sludge age activated sludge system (Ekama *et al.*, 1986).

- Values for unbiodegradable particulate COD derived from the batch test fall in the same range as estimates from the conventional completely aerobic activated sludge system method (Ekama *et al.*, 1986). However, the direct correlation between the values from the two tests is poor. For the present, the batch test does not provide estimates for unbiodegradable particulate COD that are sufficiently accurate and precise for use in design and simulation of activated sludge systems. For design and simulation, unbiodegradable particulate COD as a fraction of total COD (f_{up}) should at least be able to be quantified into the ranges 0–0,05; 0,05–0,10; 0,10–0,15; etc. As yet, there is not sufficient surety that the estimate for f_{up} from the batch test will meet this requirement; more data are required.

- The errors in unbiodegradable particulate COD are reflected in the estimate from the batch test for slowly biodegradable COD. However, because the absolute value for the slowly biodegradable COD concentration is very much larger than that for the unbiodegradable particulate COD concentration, the relative error in the estimate for slowly biodegradable COD is very much less. The estimate for slowly biodegradable COD can be accepted for design and simulation.

10.3 FLOCCULATION–FILTRATION METHOD

The flocculation–filtration method proposed by Mamais *et al.* (1993) to determine RBCOD was evaluated and refined also:

- The zinc sulphate flocculannt recommended by Mamais *et al.* (1993) can be replaced with aluminium sulphate. This has the advantage that pH adjustment after flocculation is not required.

- Measured RBCOD correlate reasonably with those from the conventional flow–through square wave method (WRC, 1984; Ekama *et al.*, 1986) and the batch test method.

- The method is relatively simple and easy to apply, but requires independent determination of unbiodegradable soluble COD, from effluent samples which may not always be available.

- The 0,45μm filter papers recommended by Mamais *et al.* (1993) can be replaced with glass fibre filter papers (Whatman's GF/C) to reduce costs, without any loss in accuracy.

10.4 RECOMMENDATIONS

From this investigation, the following recommendations can be made:

- The batch test can be used successfully to determine the heterotroph active biomass, RBCOD and the soluble unbiodegradable COD in the influent wastewater. In this investigation, the estimates for RBCOD and unbiodegradable soluble COD from the batch test could be compared to results from conventional test methods. However, the heterotroph active biomass could not be evaluated against any tests, because no such tests are available. To evaluate estimates for heterotroph active biomass, it is recommended that an inoculum of activated sludge mixed liquor from a defined continuous flow steady state system is introduced into the batch test. From the steady state model (WRC, 1984) the concentration of the heterotroph active biomass in the continuous flow system and therefore added into the batch test can be calculated, and compared to the concentration obtained from the batch test. However, due account must be taken of nitrification, since the mixed liquor dosed to the batch test may nitrify.

- For the batch test method, a technique has been developed to quantify the unbiodegradable particulate COD and slowly biodegradable COD fractions. However, direct correlation of estimates for these parameters from the batch test and conventional tests were poor. Also, no discernible trends could be identified in the relationship between values from the two tests. To identify clear trends, a more extensive experimental investigation is required, so that more data are available.

- This investigation has been restricted to quantifying the influent carbonaceous material fractions. Similar studies need to be undertaken on the influent nitrogenous and phosphoruos materials.

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APPENDIX A

OUR-TIME PROFILES FOR THE BATCH TESTS.

FIG A.1a OUR–time Plot for batch test
12 Jul'93–Sewage Batch No.1

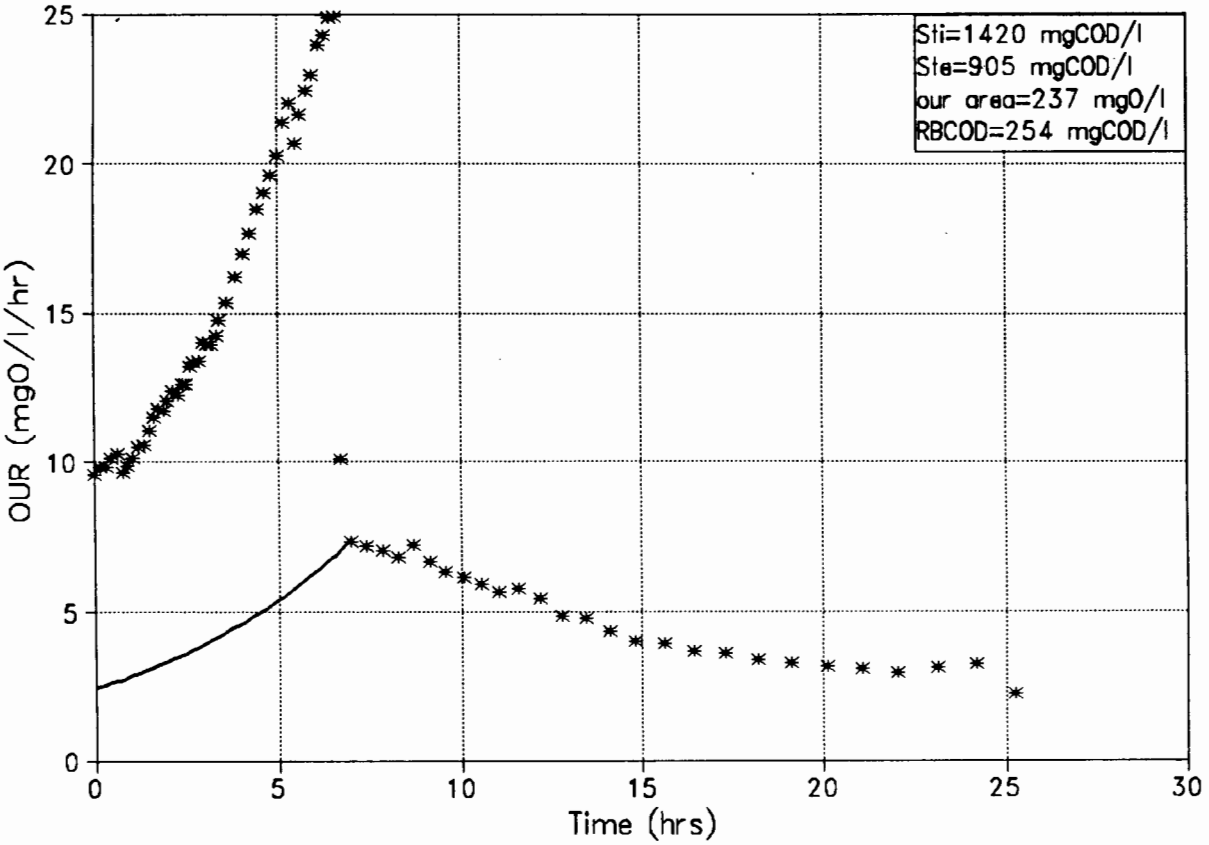


FIG A.1b OUR–time Plot for batch test
19 Jul'93–Sewage Batch No.1

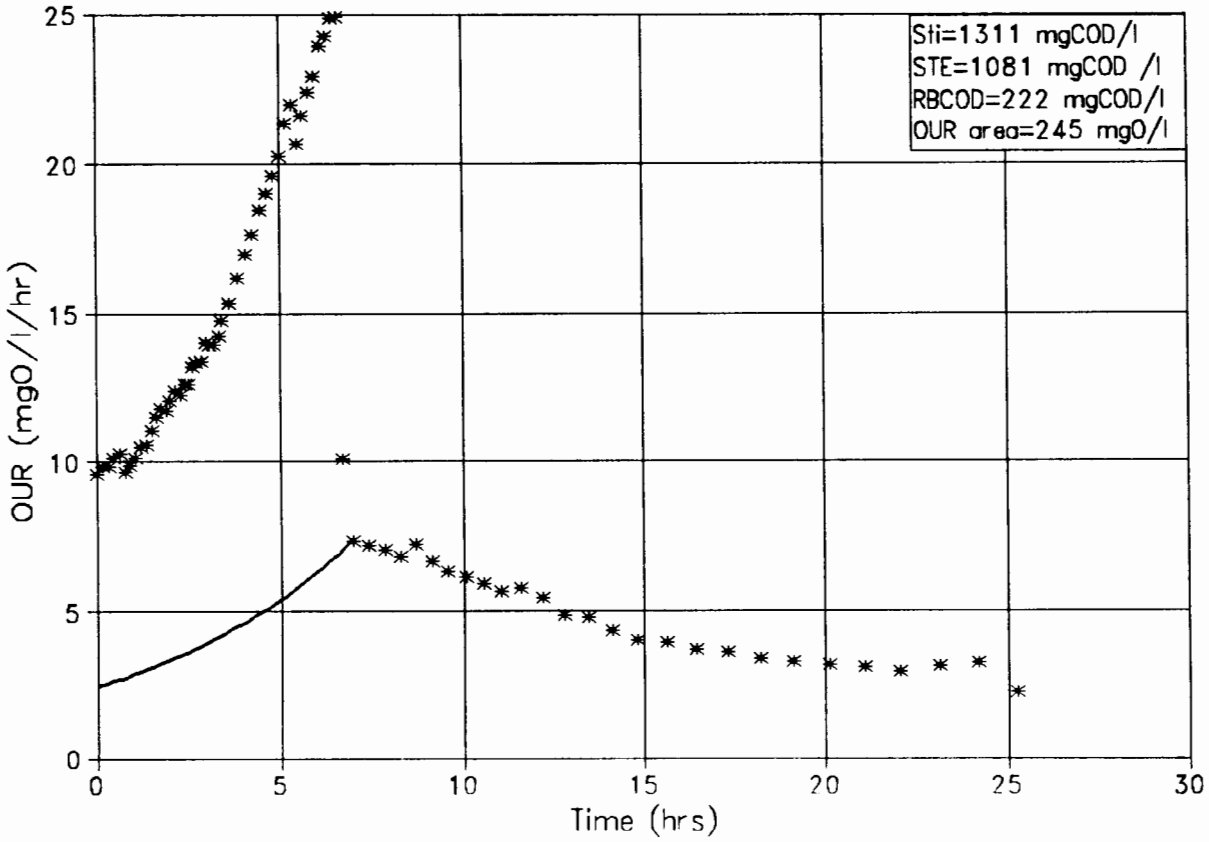


FIG A.1c OUR–time Plot for batch test
21 Jul'93–Sewage Batch No.1

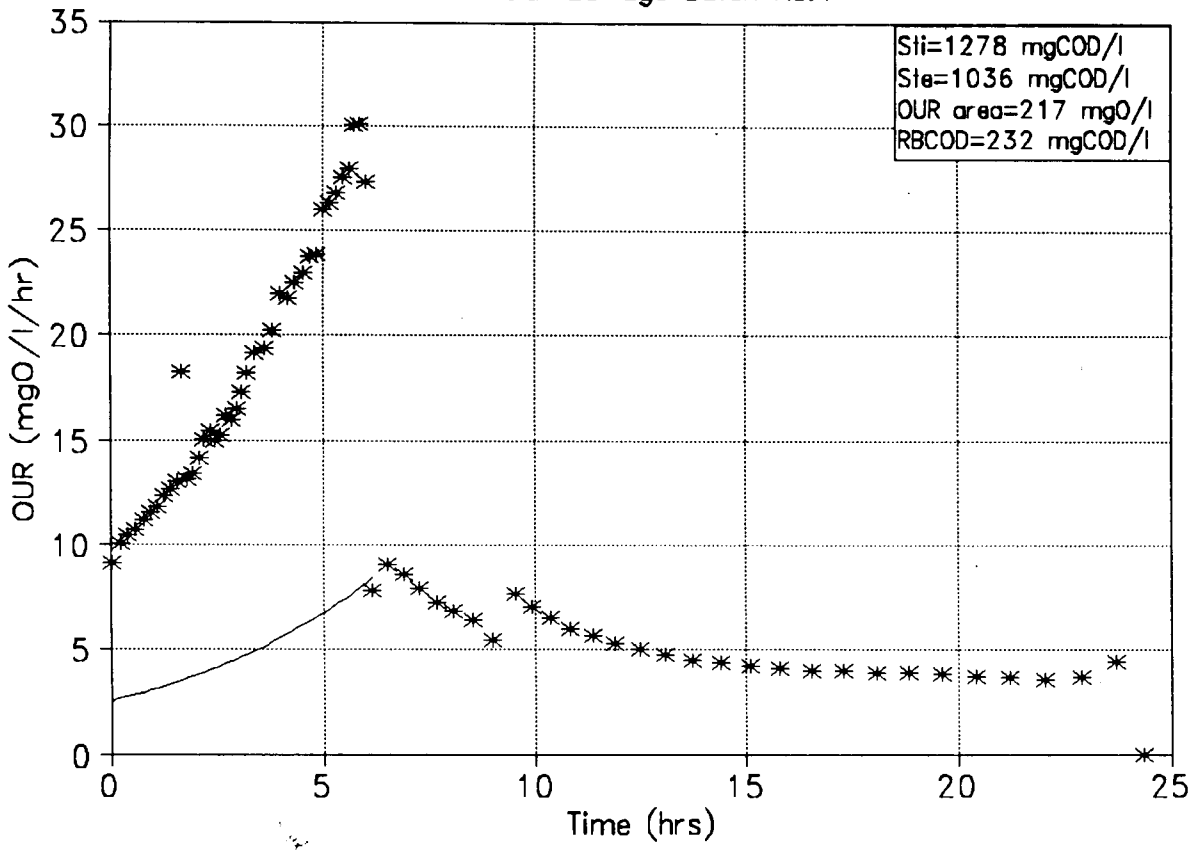


FIG A.1d OUR–time for batch test
22 Jul'93–Sewage Batch No.1

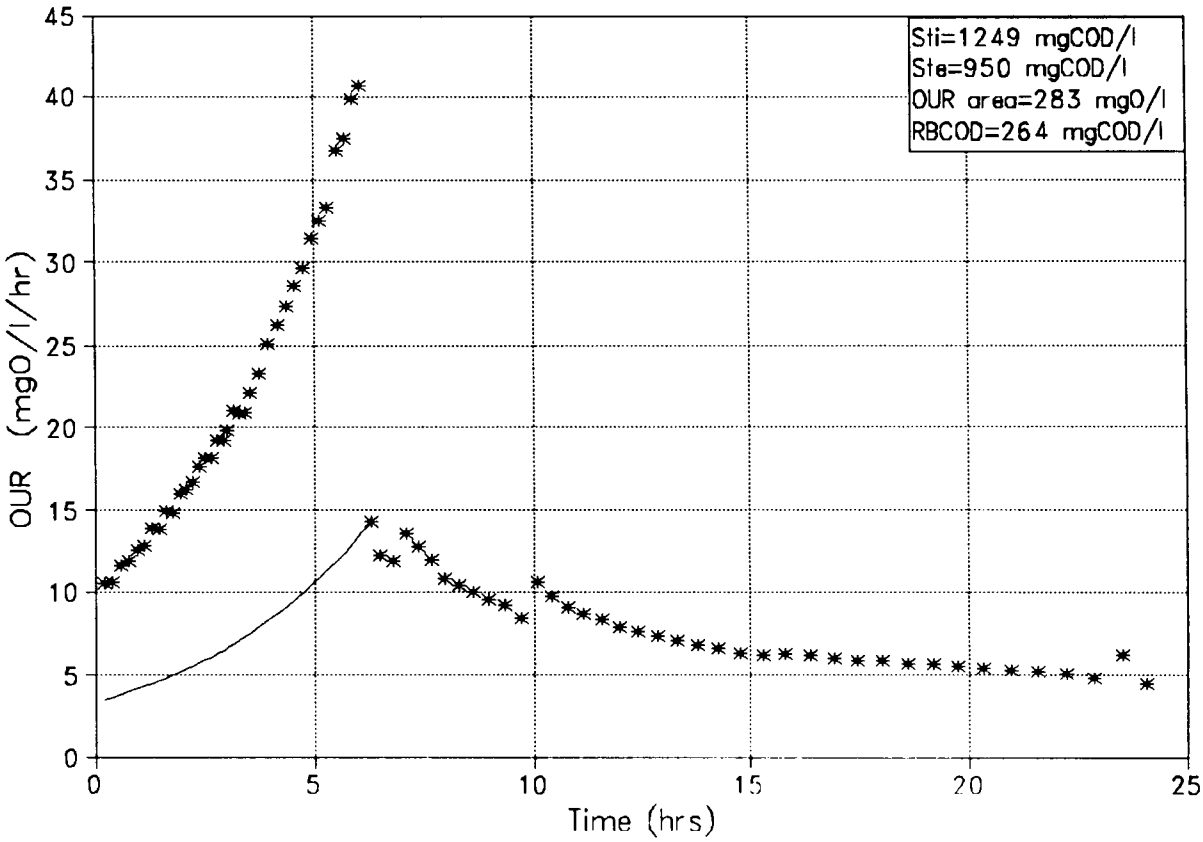


FIG A.1e OUR–time for batch test
26 Jul'93–Sewage Batch No.1

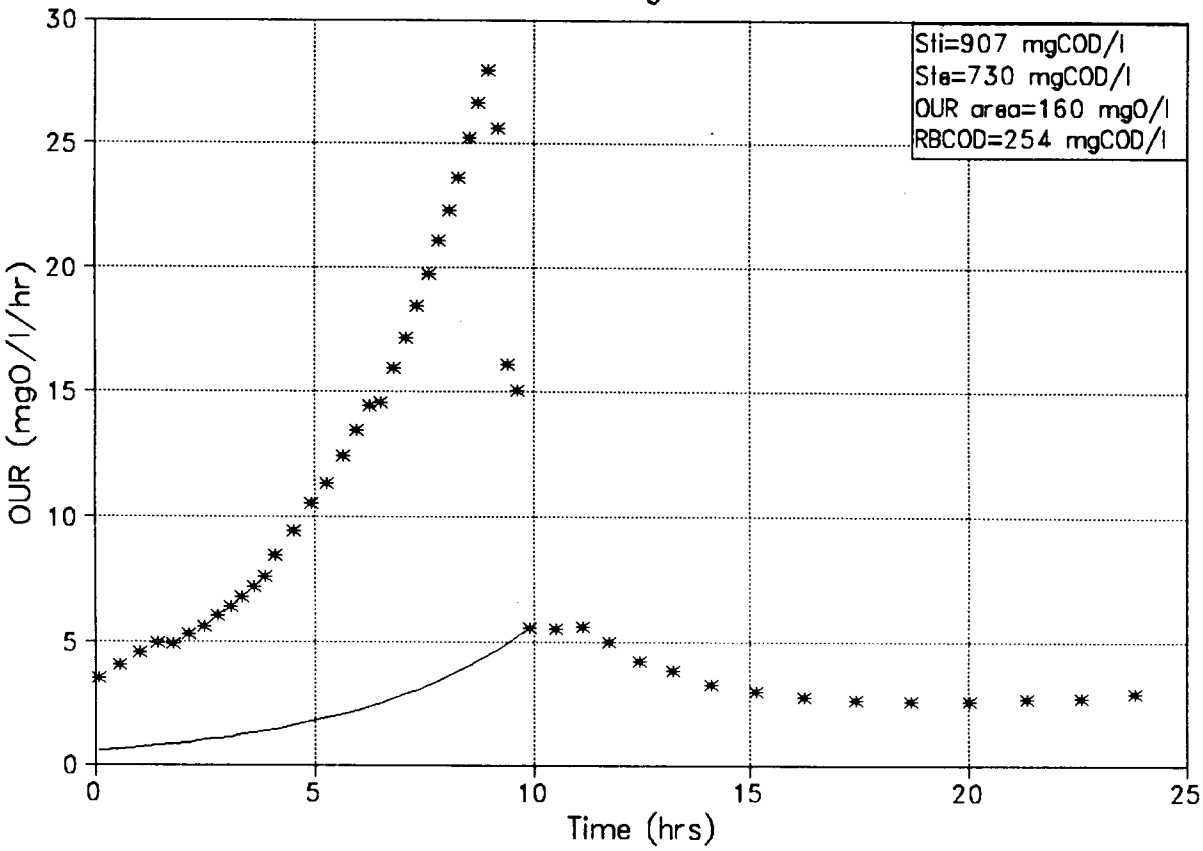


FIG A.1f OUR–time for batch test
28 Jul'93–Sewage Batch No. 1

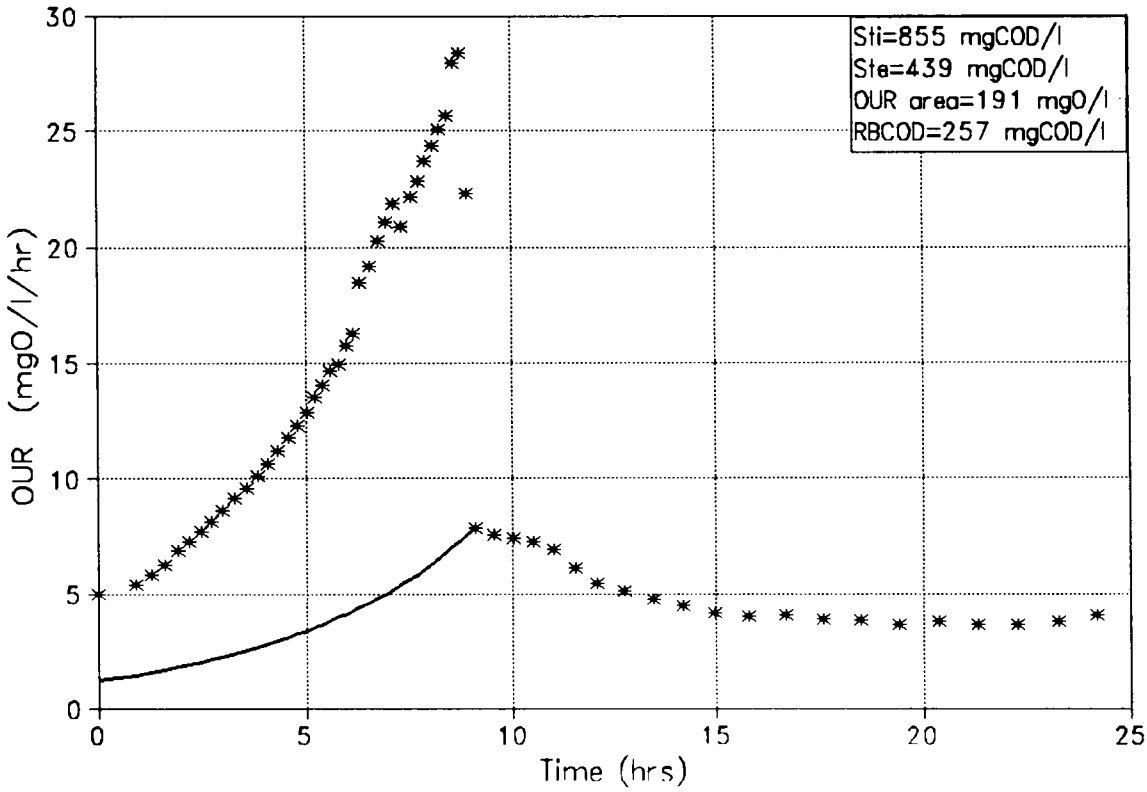
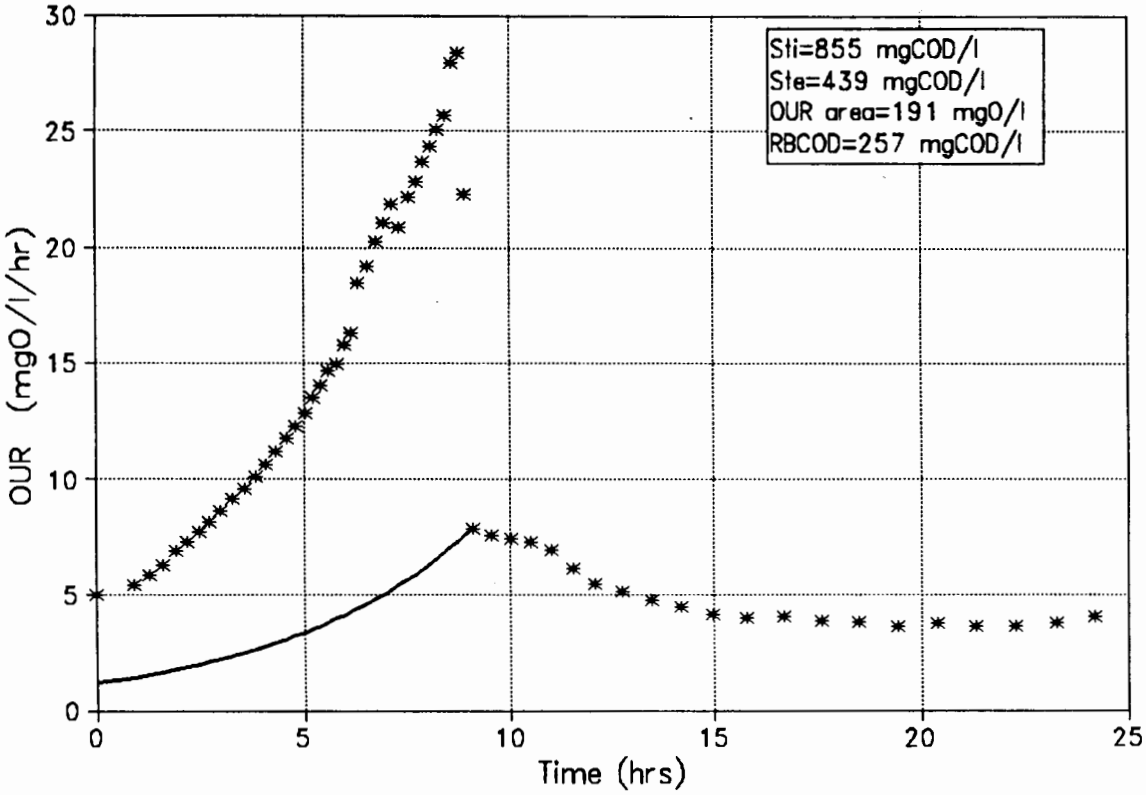


FIG A.1f OUR–time for batch test
28 Jul'93–Sewage Batch No. 1



FIGA.2a OUR–time Plot for batch test
6 Aug'93–Sewage Batch No. 2

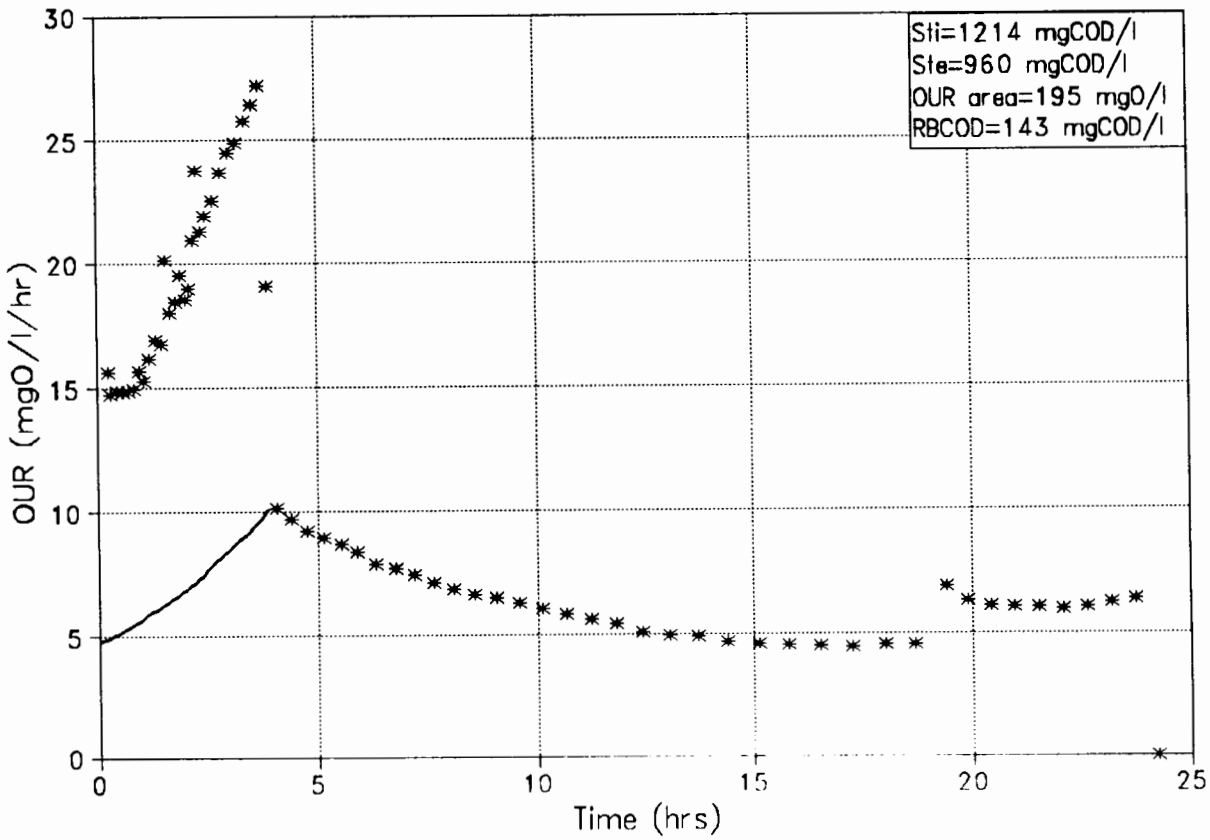


Fig A.2b OUR–time Plot for batch test
9 Aug'93–Sewage Batch No.2

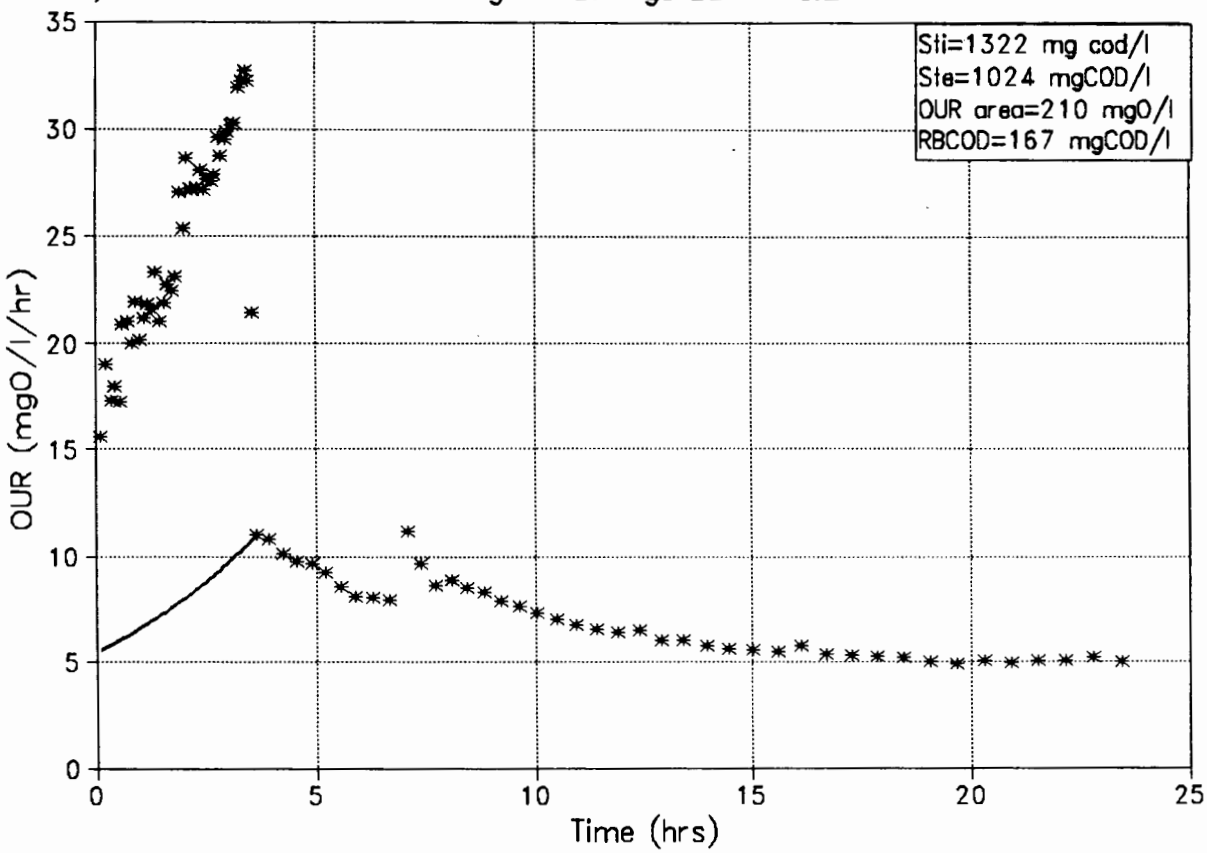


FIG A.2c OUR–time Plot for batch test
13 Aug'93–Sewage Batch No.2

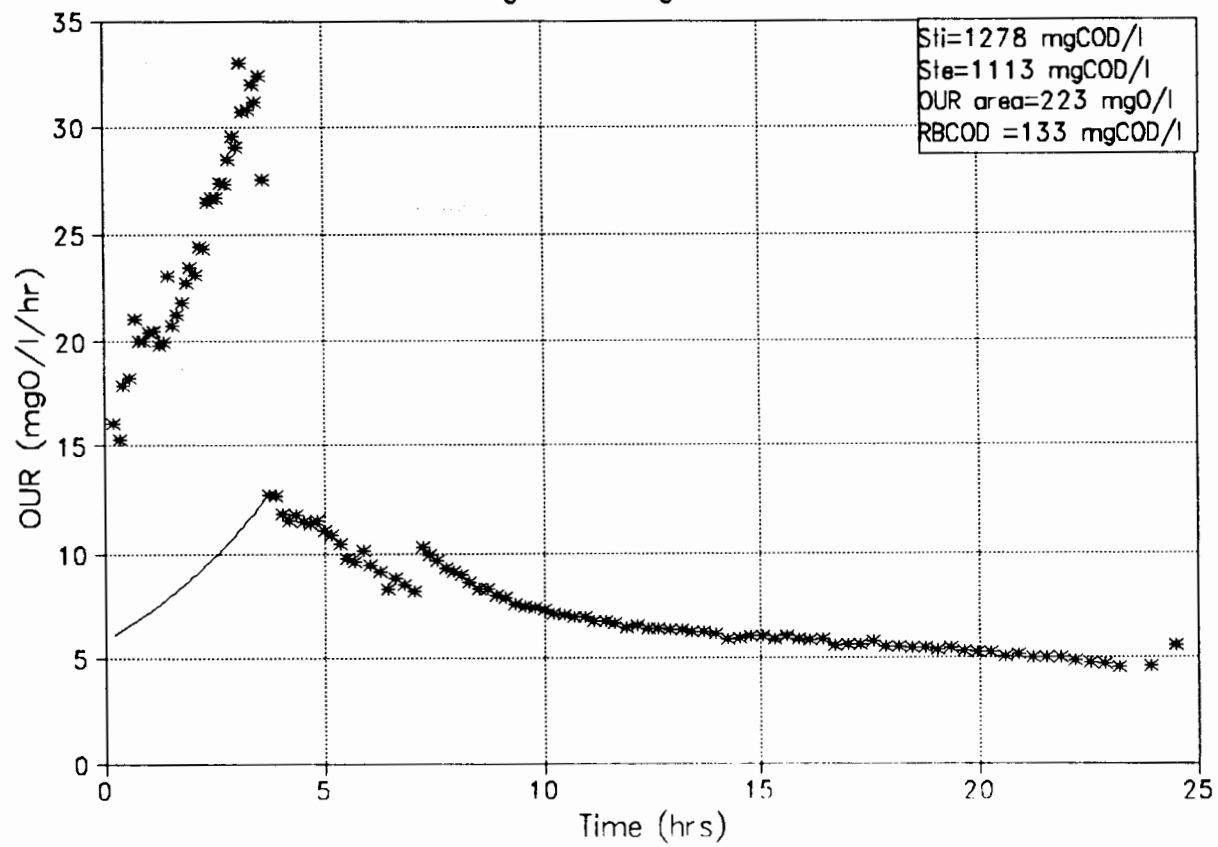


FIG A.2d OUR–time Plot for batch test
17 Aug'93–Sewage Batch No.2

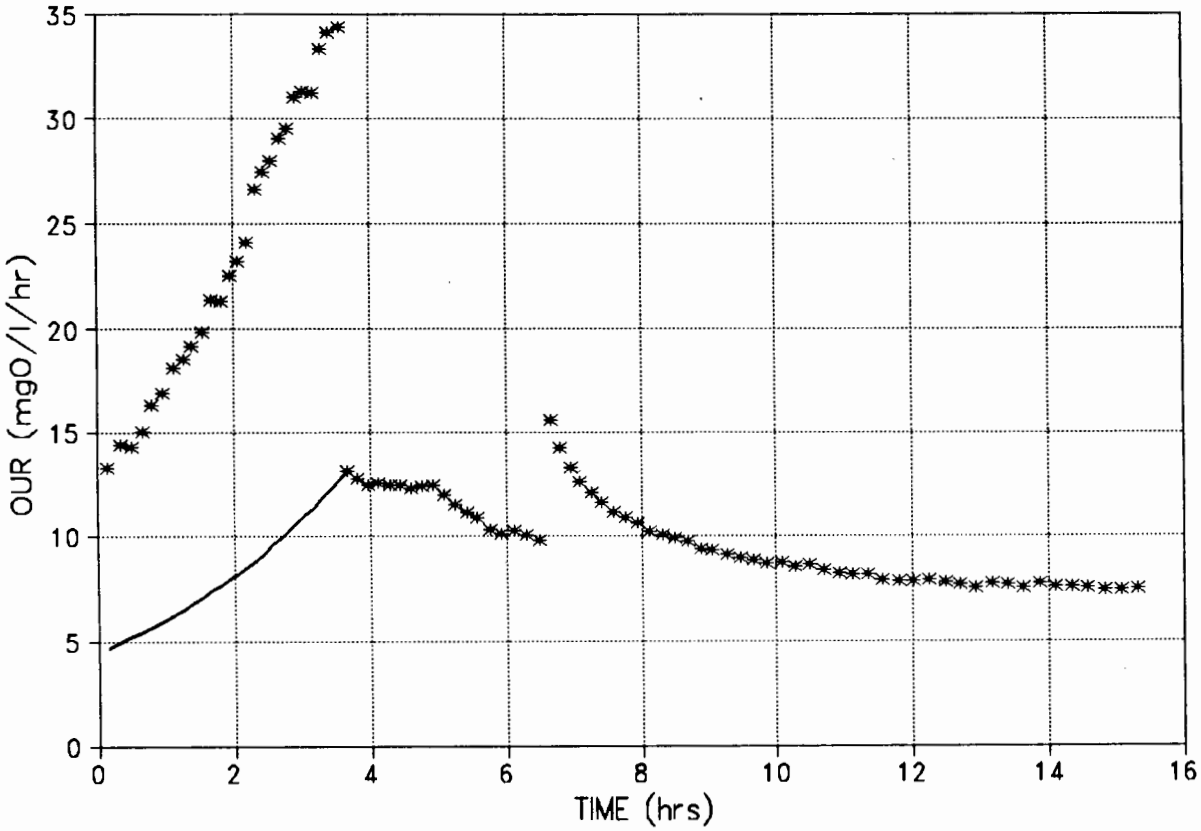


FIG A.3a OUR–time Plot for batch test
25 Aug'94–Sewage Batch No.3

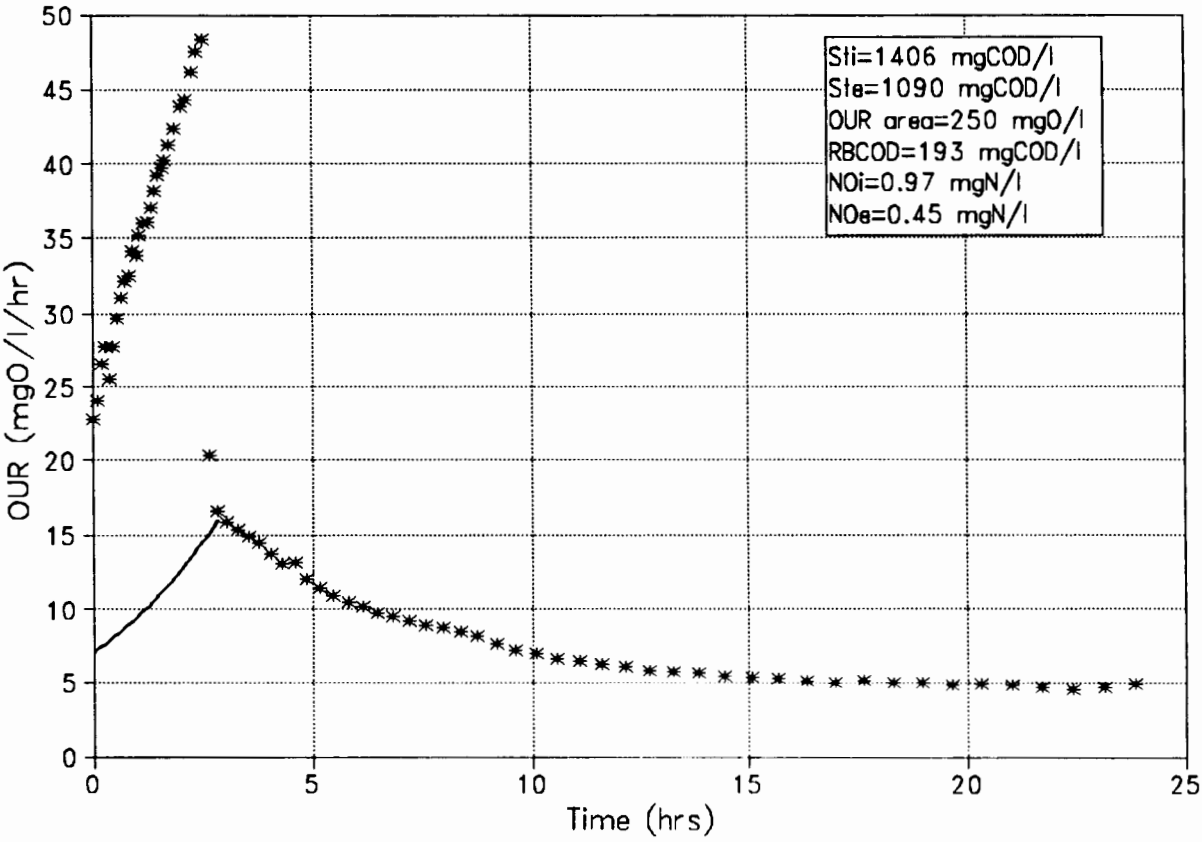


FIG 1.3b OUR –time Plot for batch test
28 Aug'93–Sewage Batch No. 3

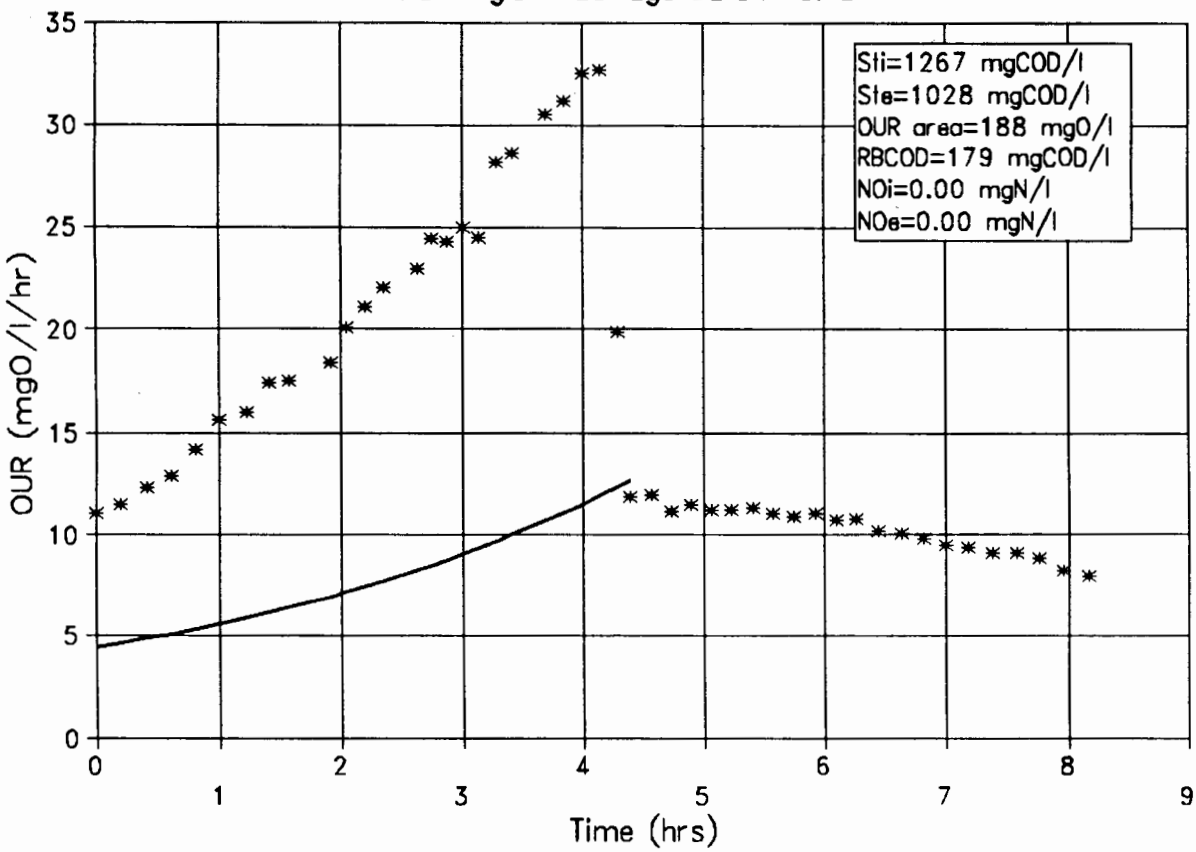


FIG A.3c OUR–time Plot for batch test
29 Aug'93–Sewage Batch No.3

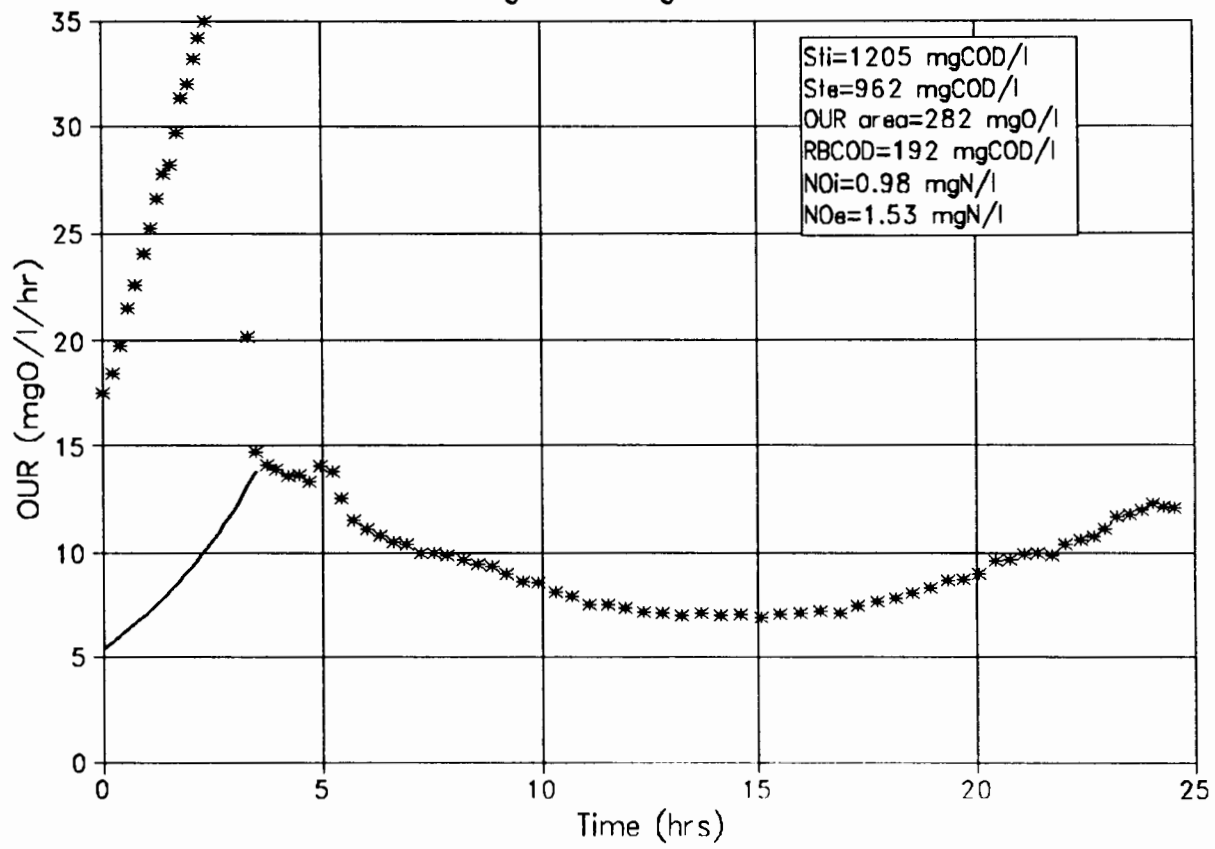


FIG A.3d OUR–time Plot for batch test
31 AUGUST'93–Sewage Batch No.3

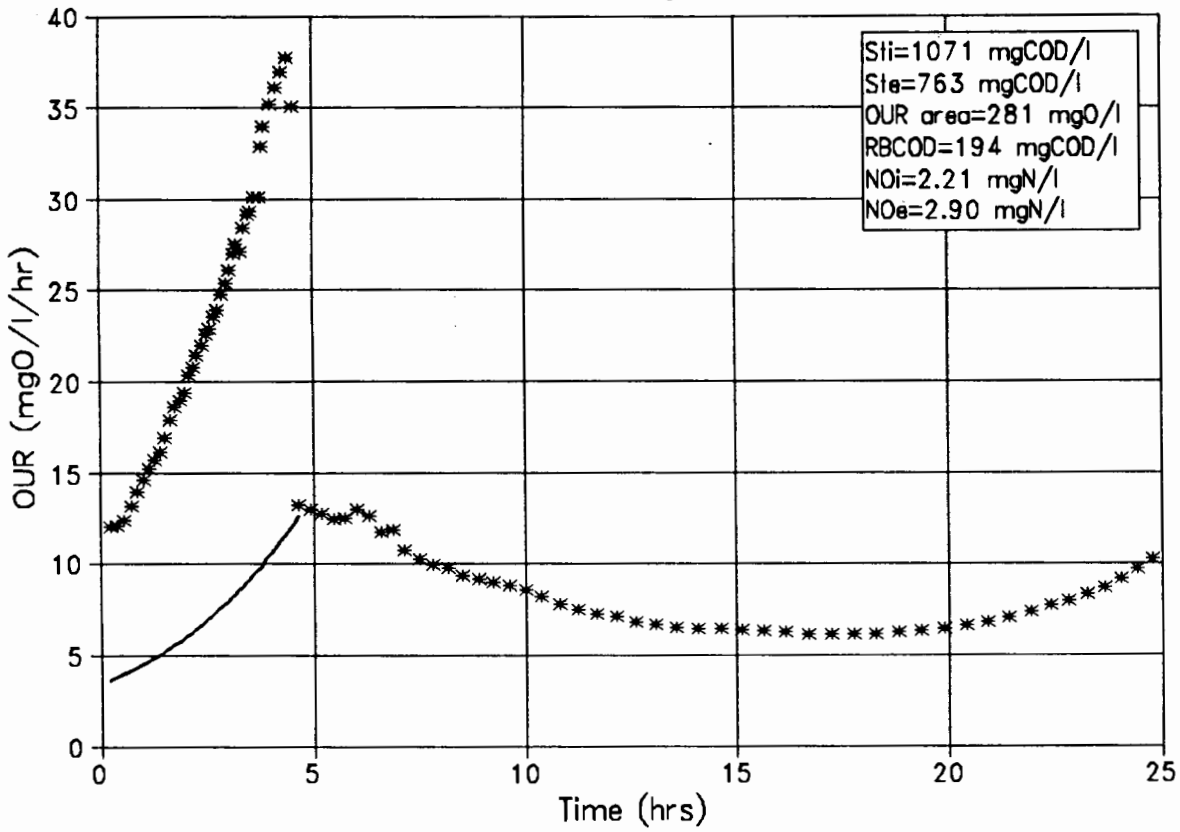


FIG A.3e OUR–time Plot for batch tes
1 Sept'93–Sewage Batch No.3

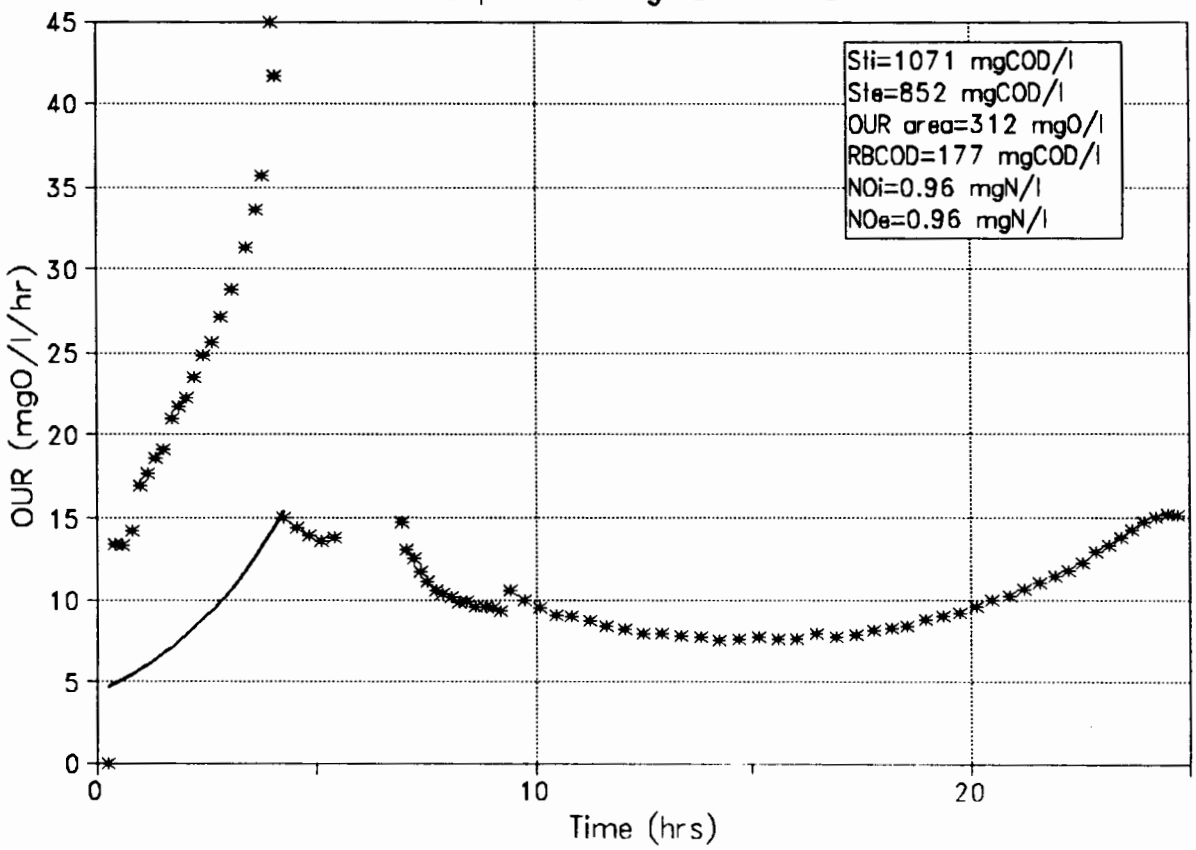


FIG A.3f OUR–time Plot for batch test
2 Sept'93–Sewage Batch No.3

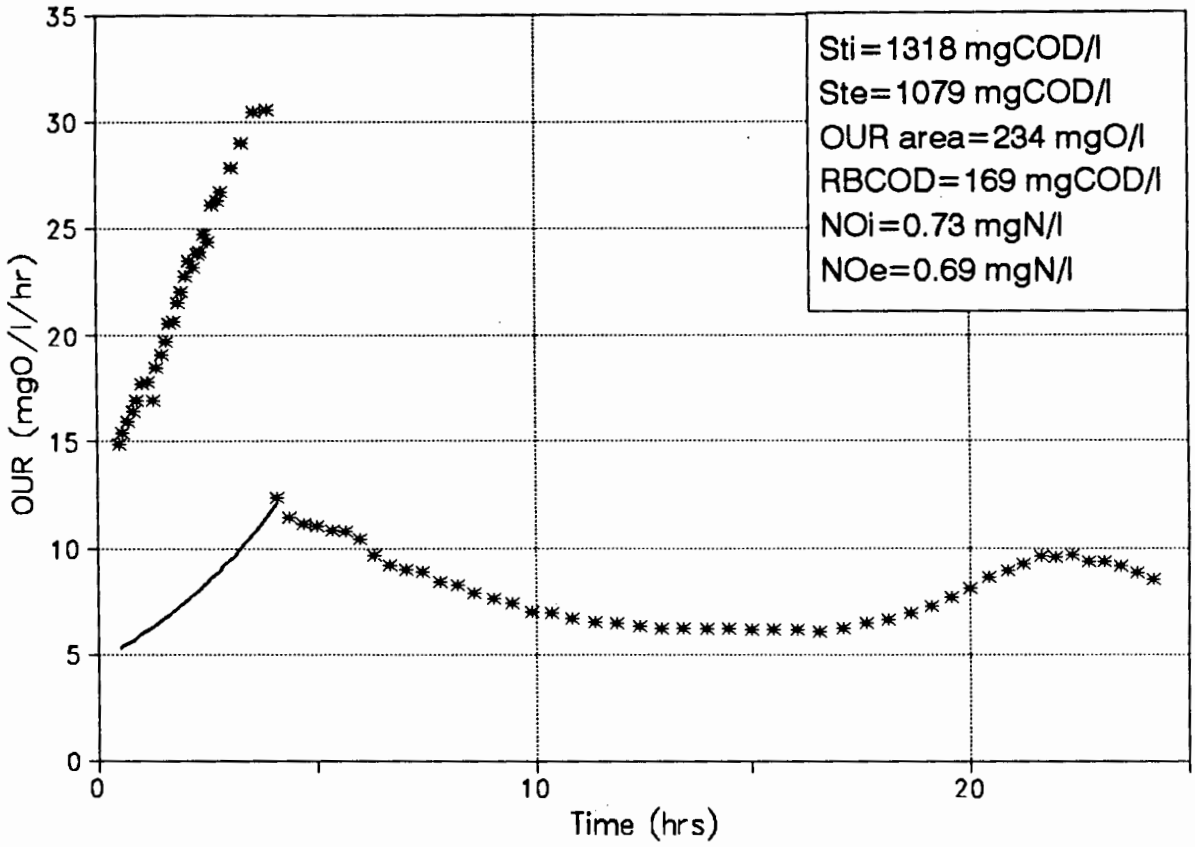


FIG A.4a OUR–time Plot for batch test
10 Sept'93–Sewage Batch No. 4

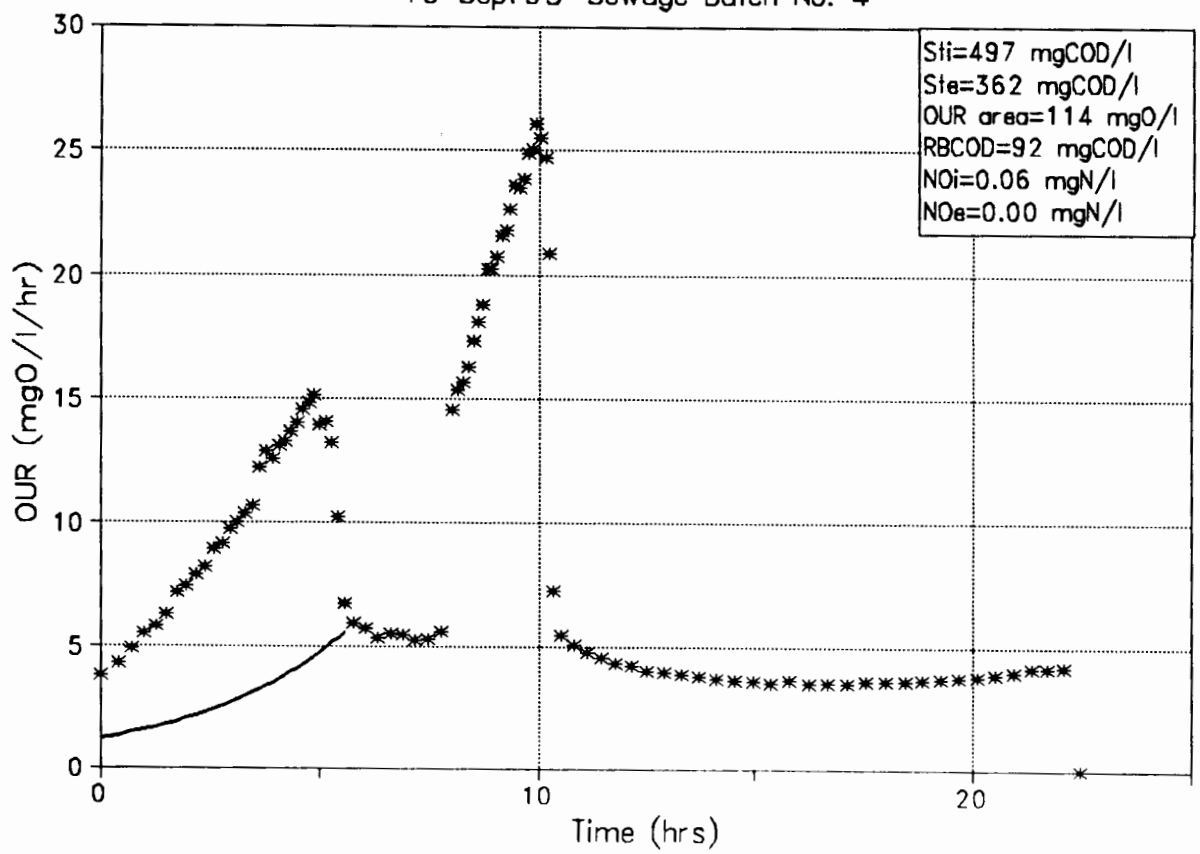


FIG A.4b OUR–time Plot for batch test
11 Sept'93–Sewage Batch No.4

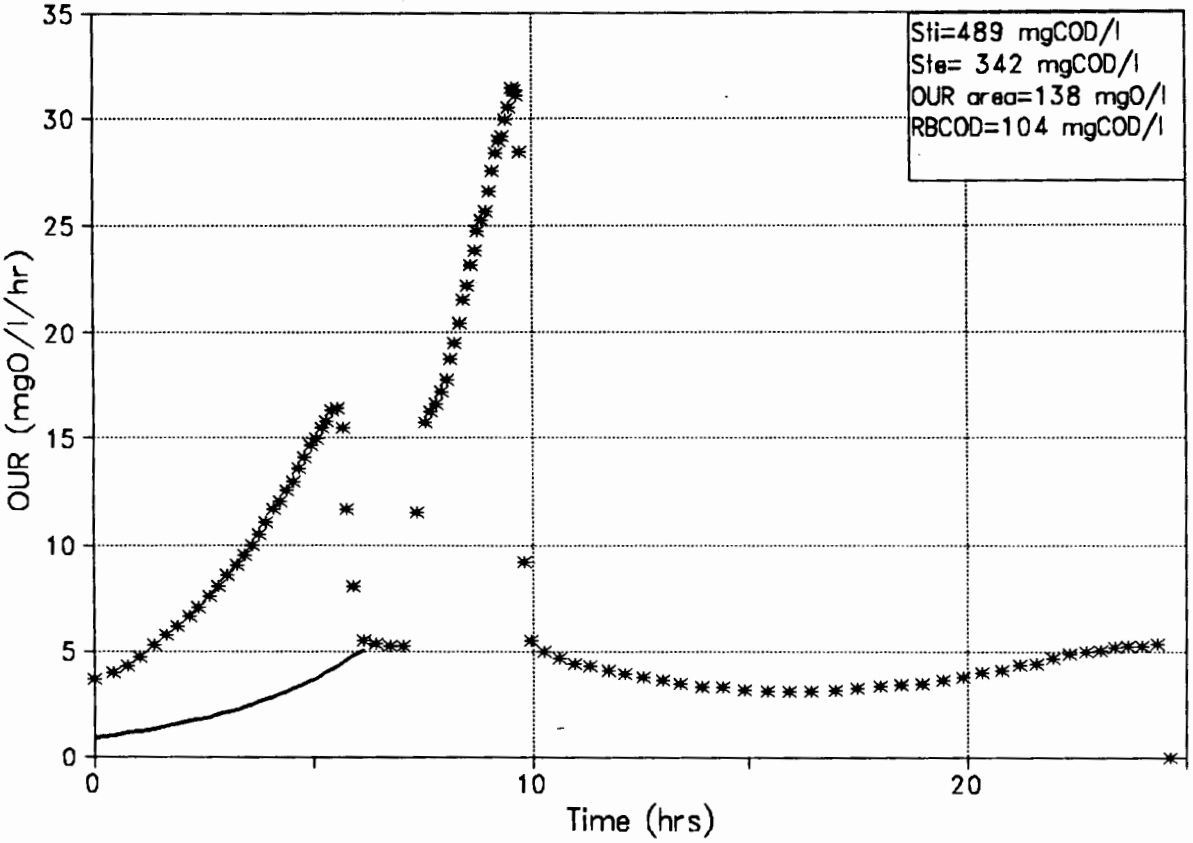


FIG A.4c OUR–time Plot for batch test
12 Sept'93–Sewage Batch No. 4

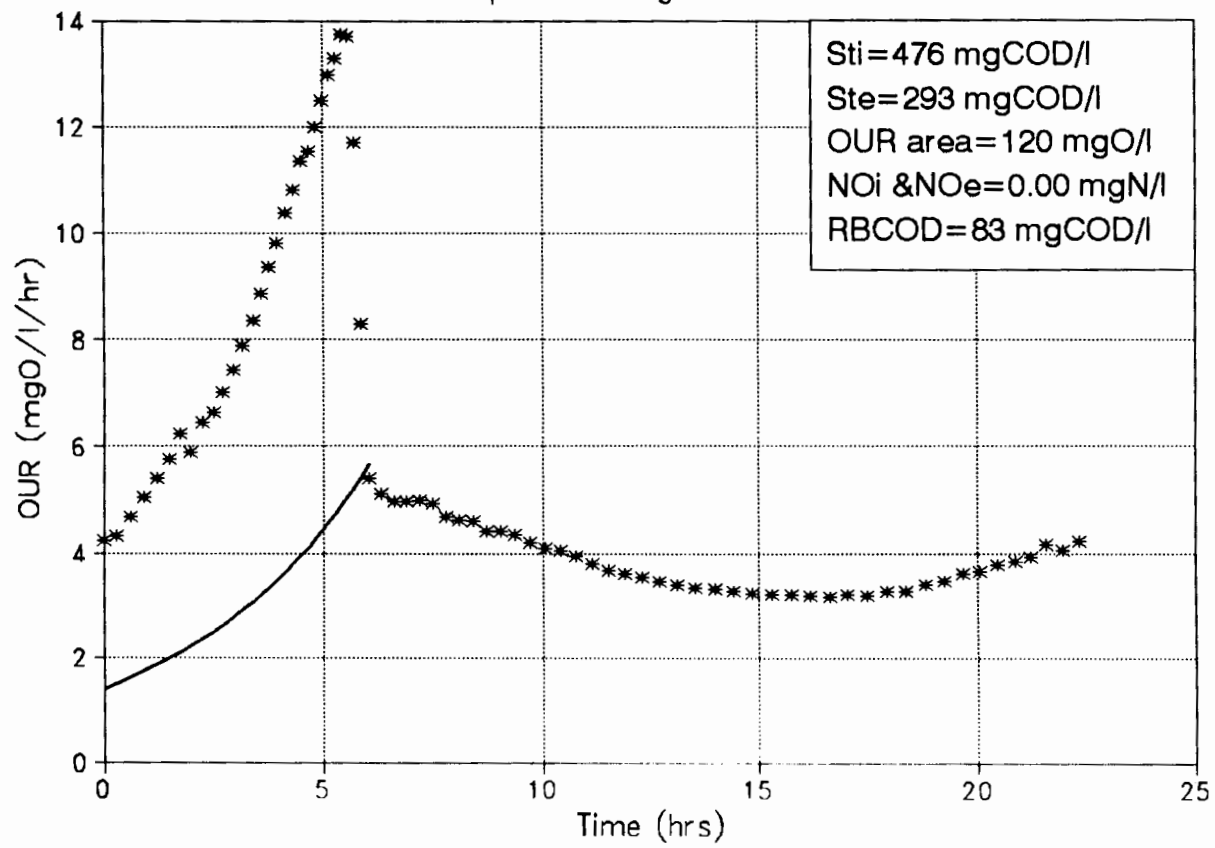


FIG A.4d OUR–time Plot for Batch test
9 Sept'93r–Sewage Batch No. 4

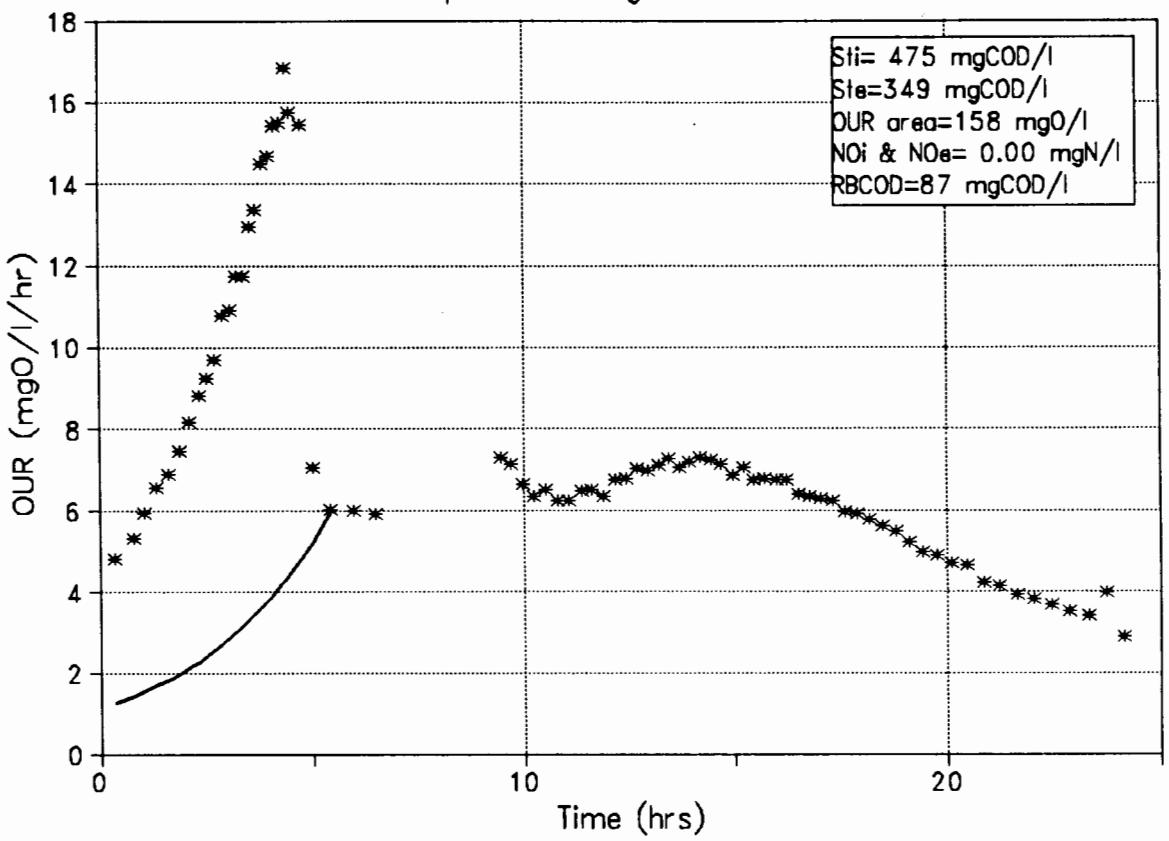


FIG A.4e OUR–time Plot for batch test
9 Sept'93L–Sewage Batch No.5

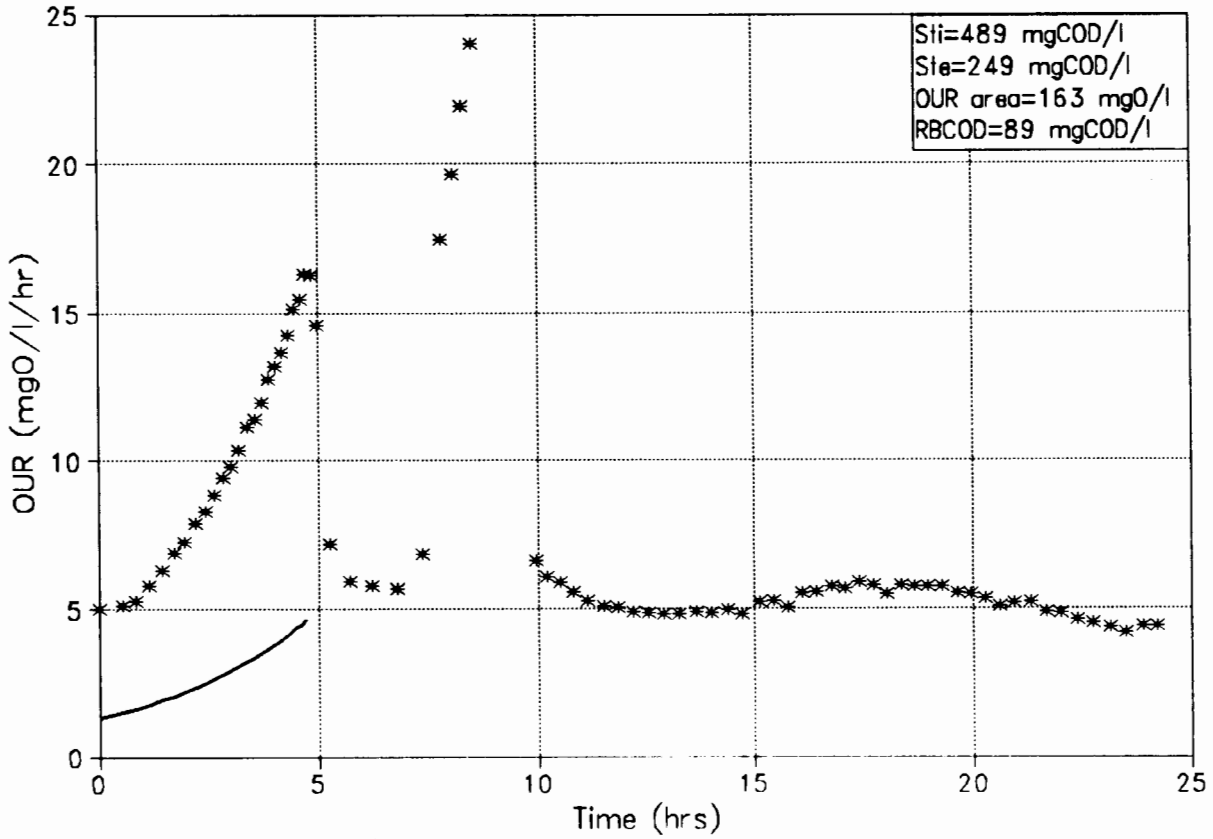


FIG A.4f OUR–time Plot for batch test
13 Sept'93–Sewage Batch No.4

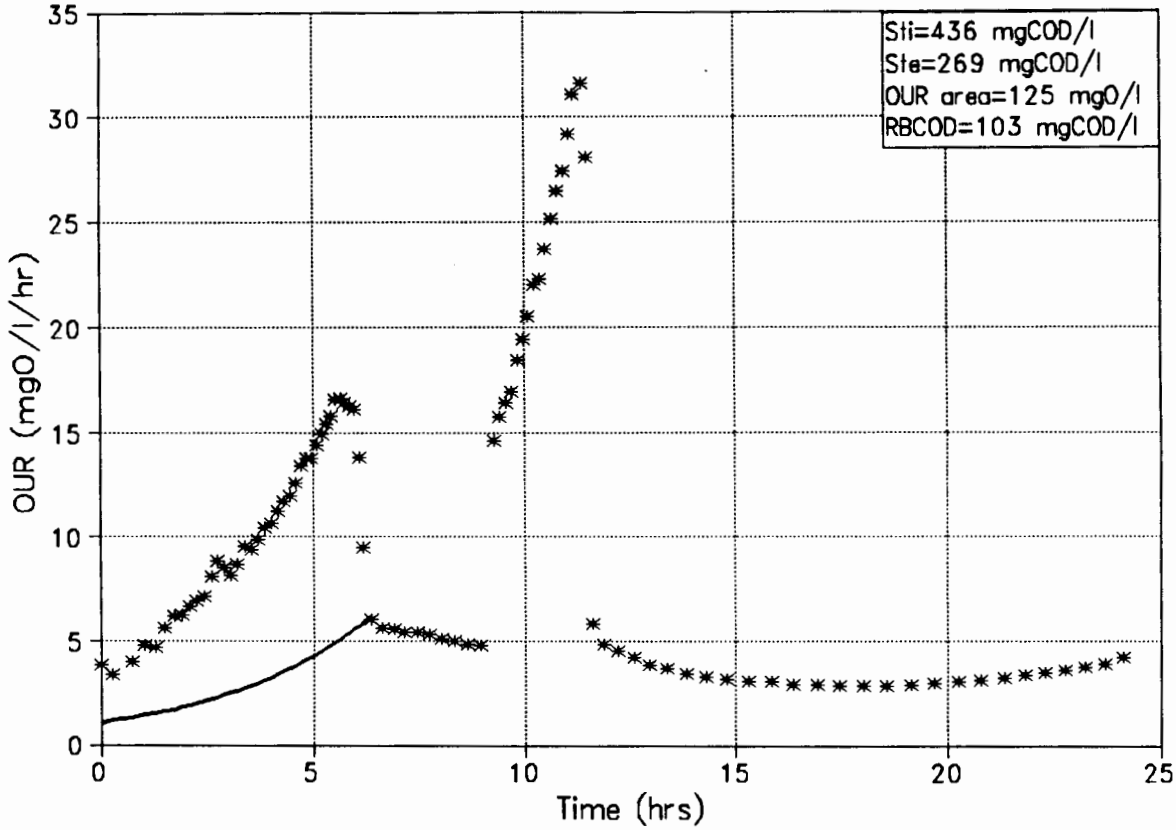


FIG A.5a OUR–time Plot for batch test
21 Sept'93–Sewage Batch No.5

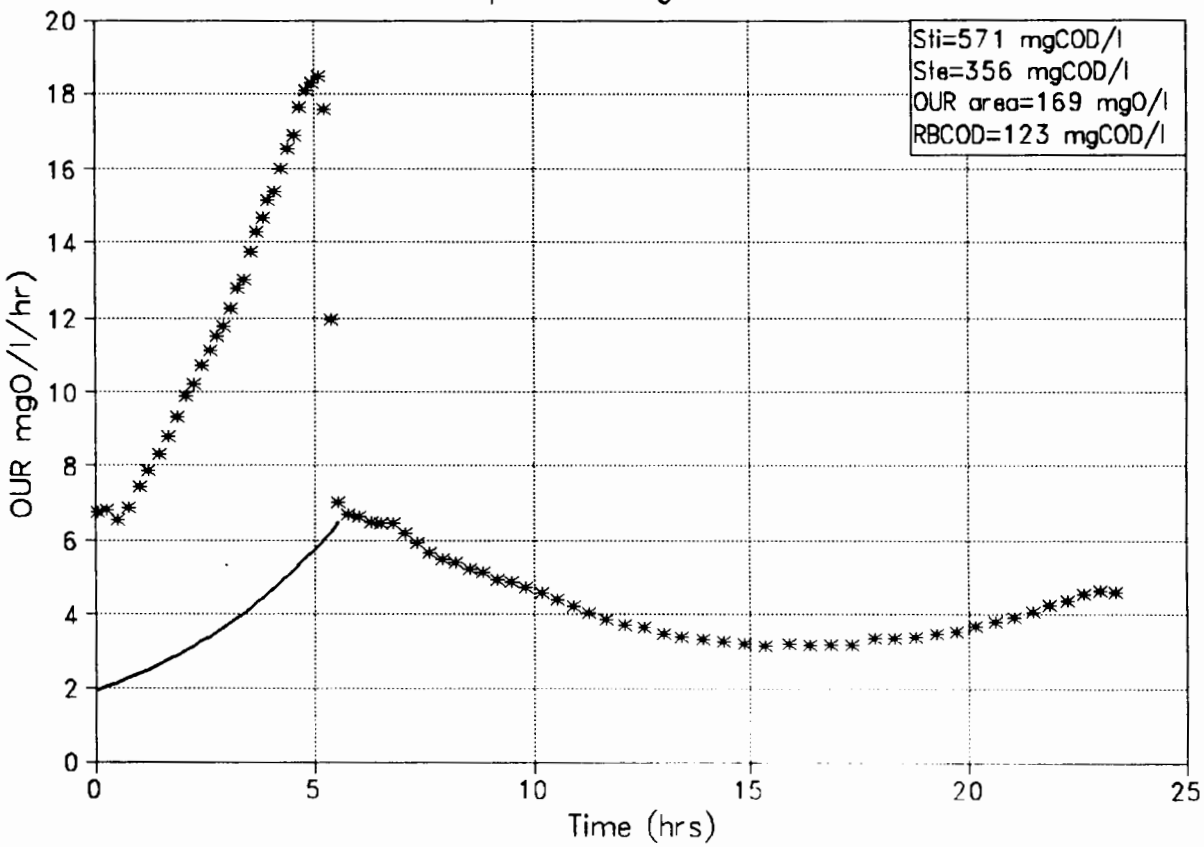


FIG A.5b OUR–time Plot for batch test
19 Sept'93–Sewage Batch No.5

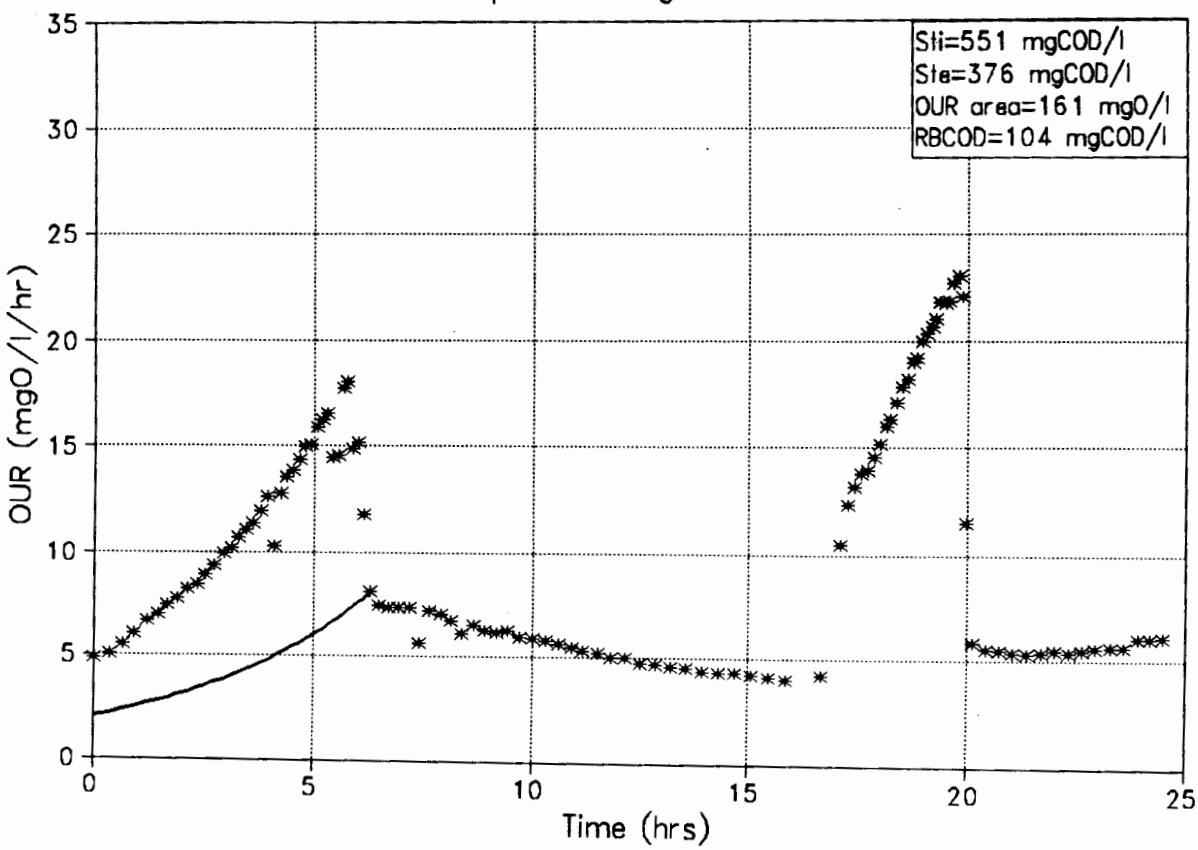


FIG A.5c OUR–time Plot for batch tes
23 SEPT'93–Sewage Batch No.5

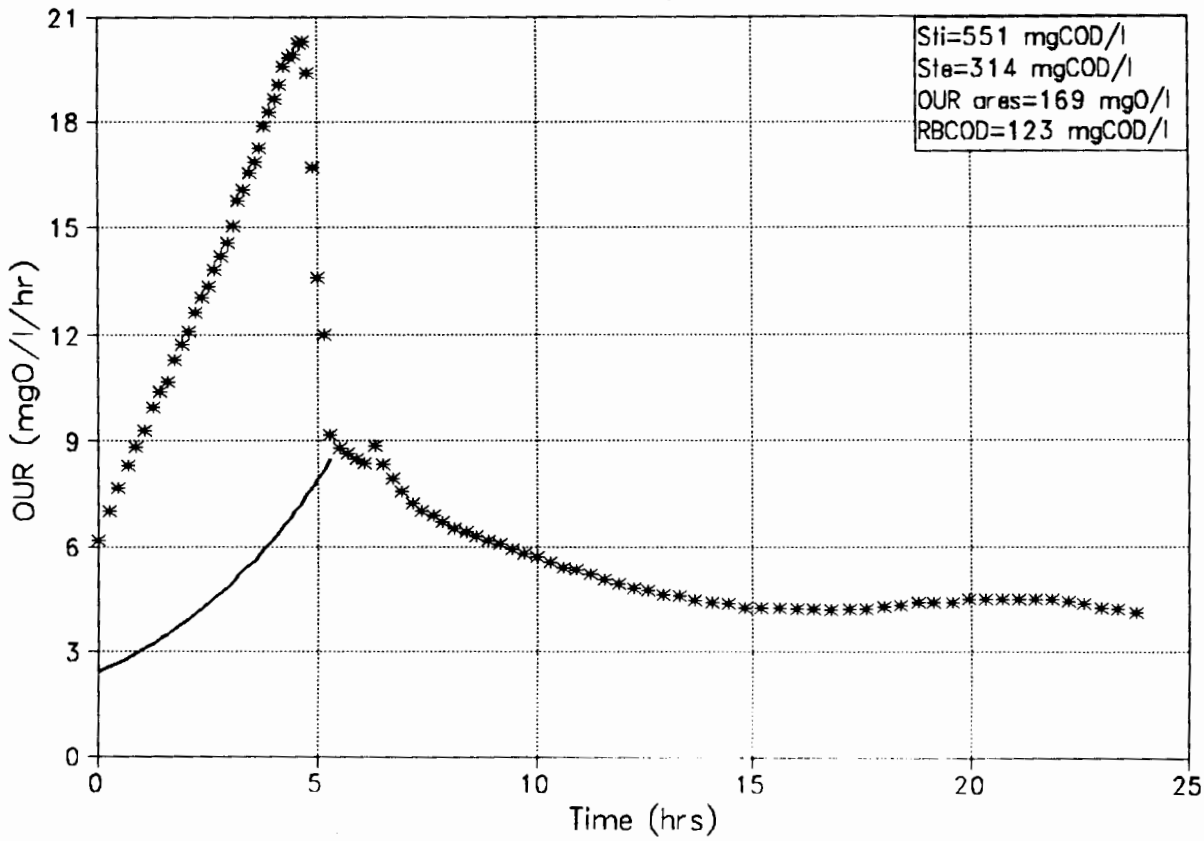


FIG A.5d OUR–time Plot for batch test
16 Sept'93–Batch No.5

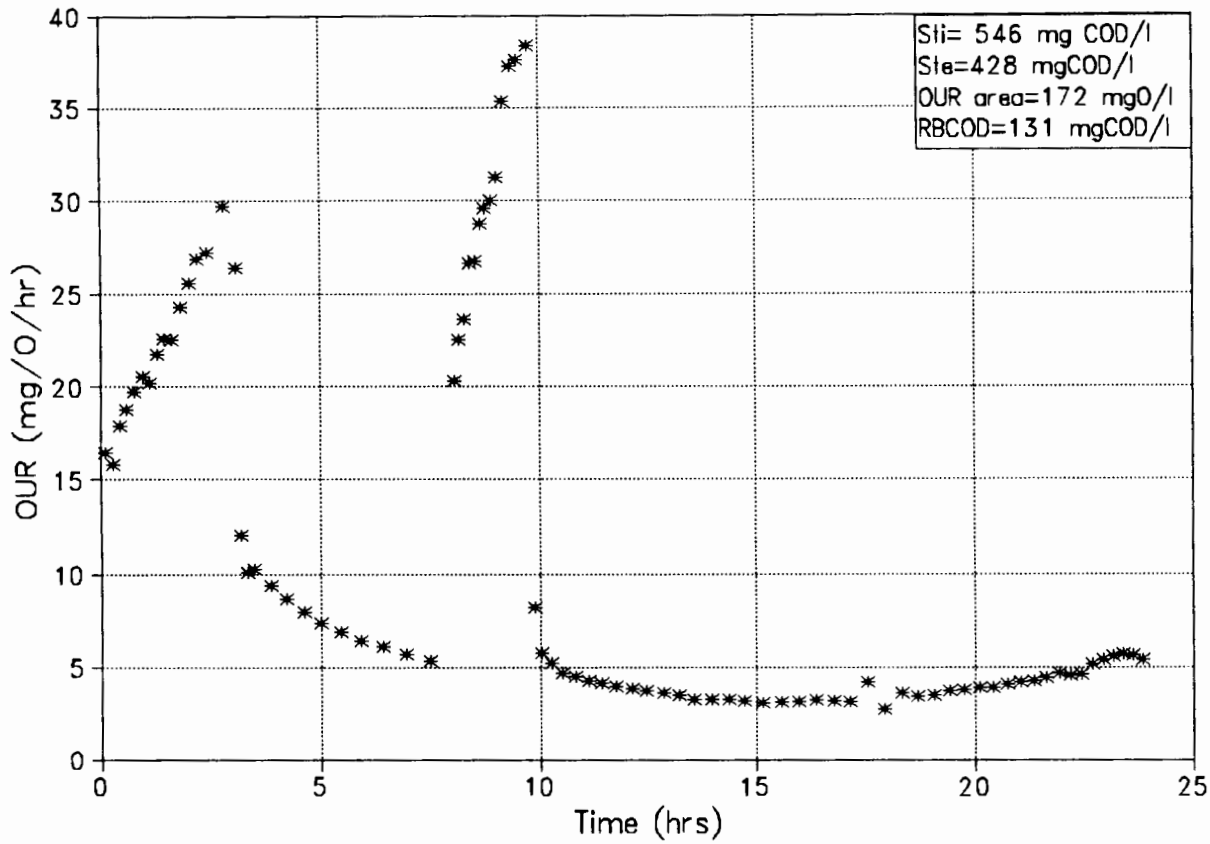


FIG A.6a OUR–timePlot for batch test
27 Sept'93–Sewage Batch No.6

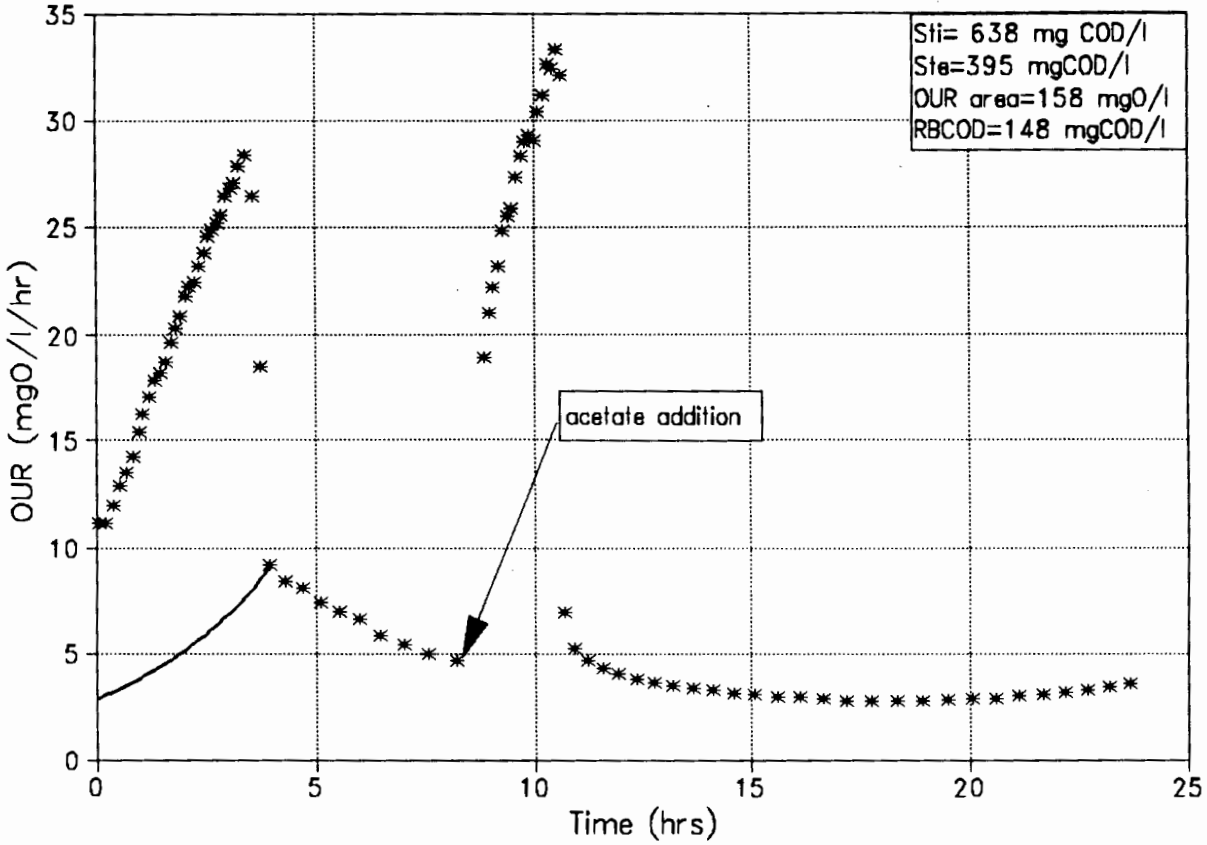


FIG A.6b OUR–time Plot for batch test
28 Sept'93–Sewage Batch No.6

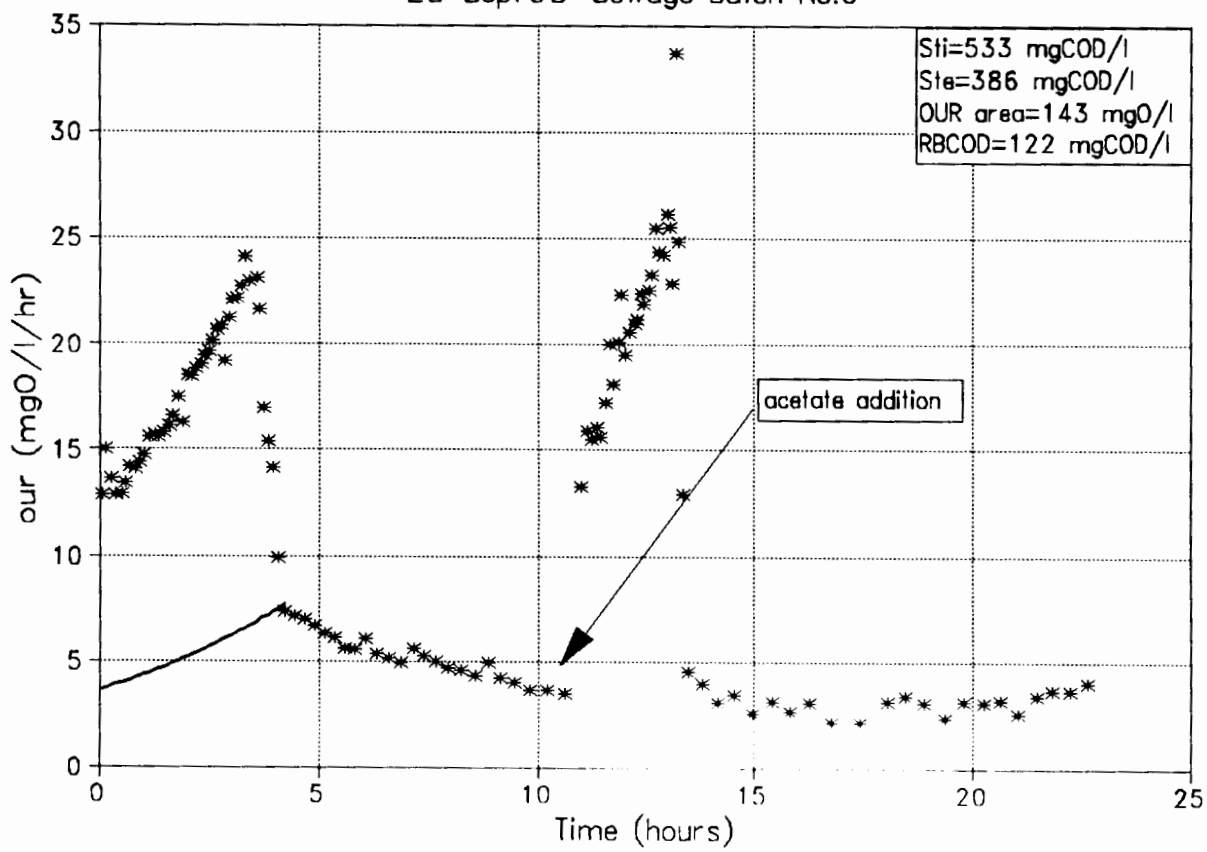


FIG A.6e OUR–time Plot for batch test
2 Oct'93–Sewage Batch No. 6

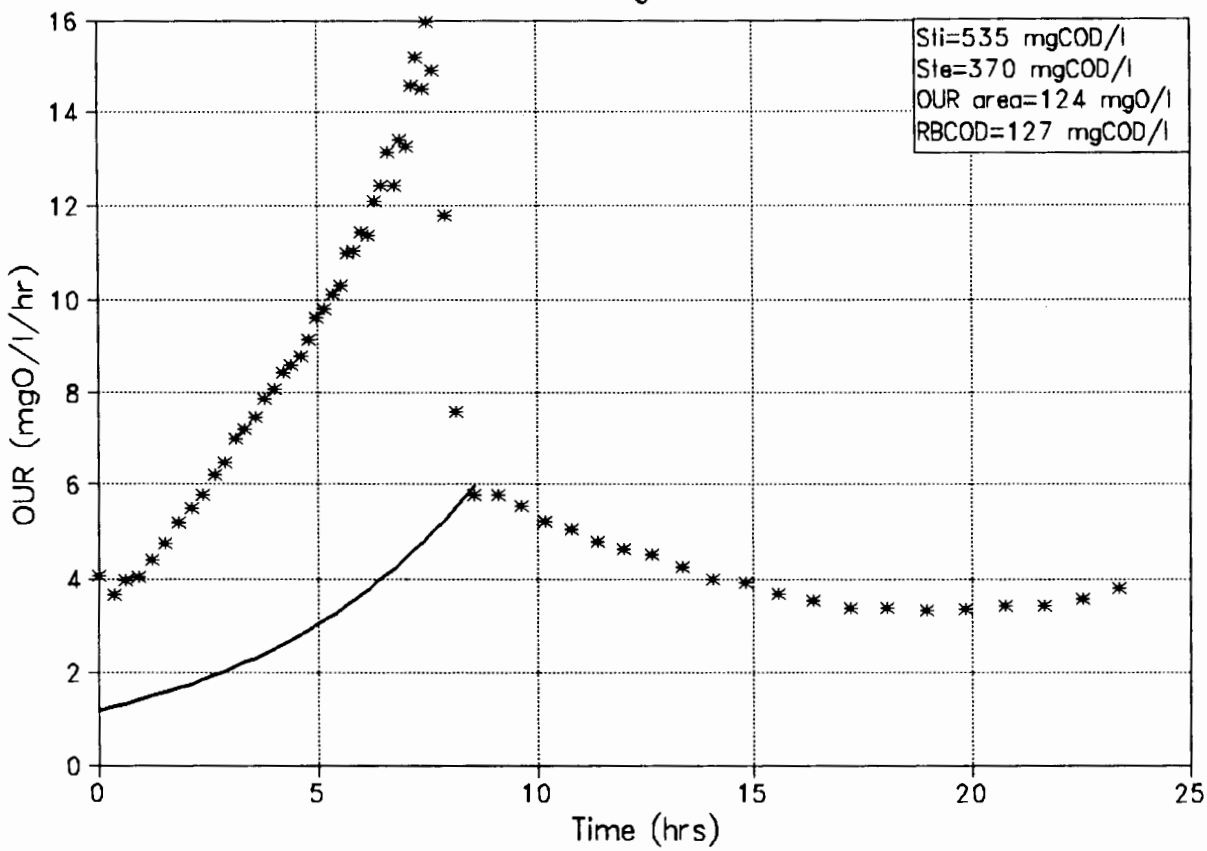


FIG A.7a OUR–time Plot for batch test
5 Oct'93–Sewage Batch No.7 (diluted)

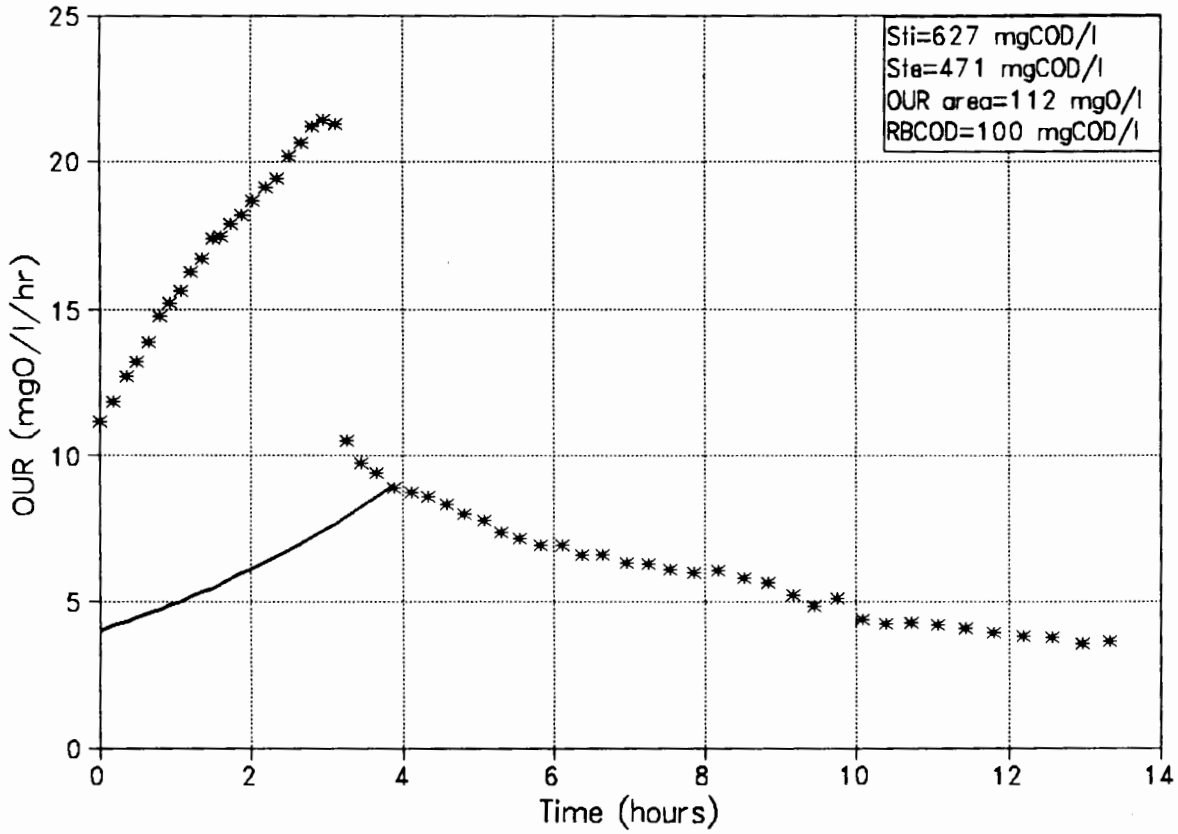


FIG A.7b OUR–time Plot for batch test
5 Oct'93–Sewage Batch No.7(undiluted)

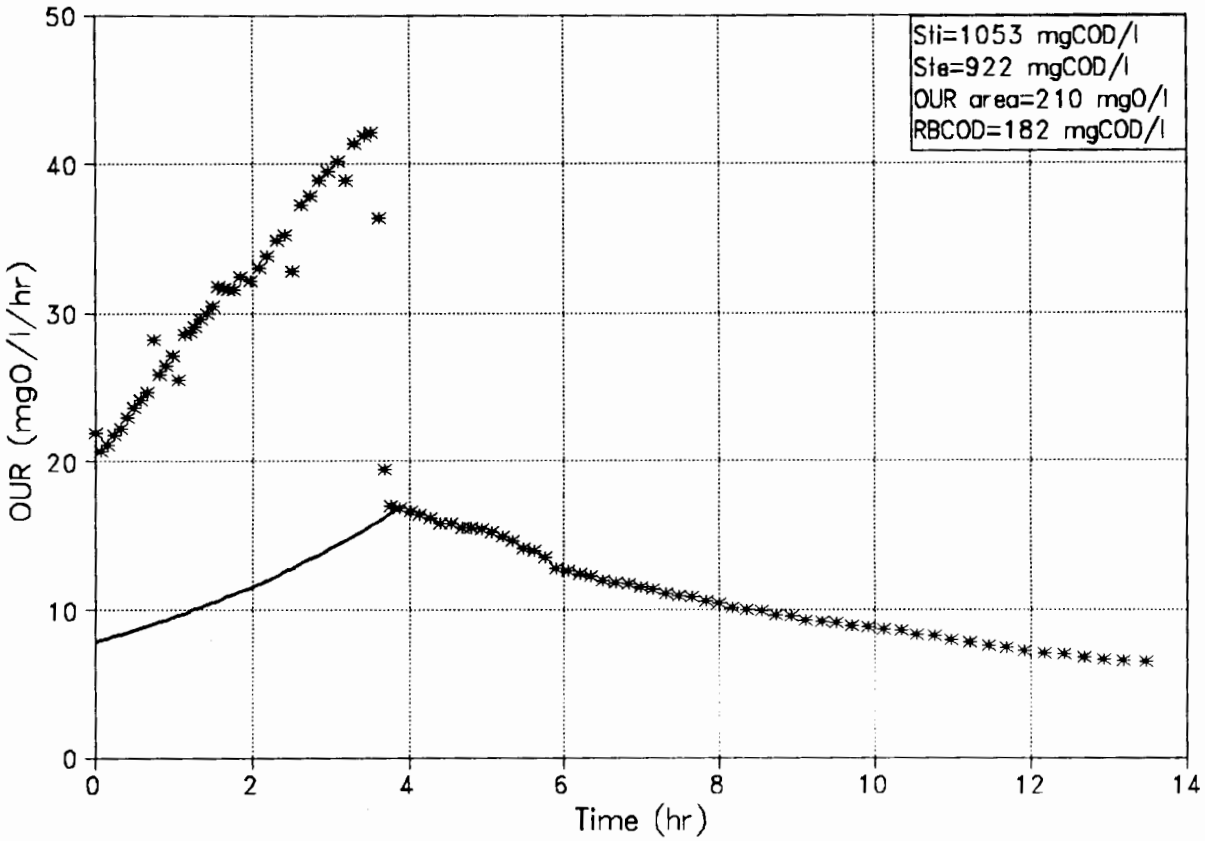


FIG A.7c OUR–time Plot for batch test
6 Oct'93–Sewage Batch No.7(diluted)

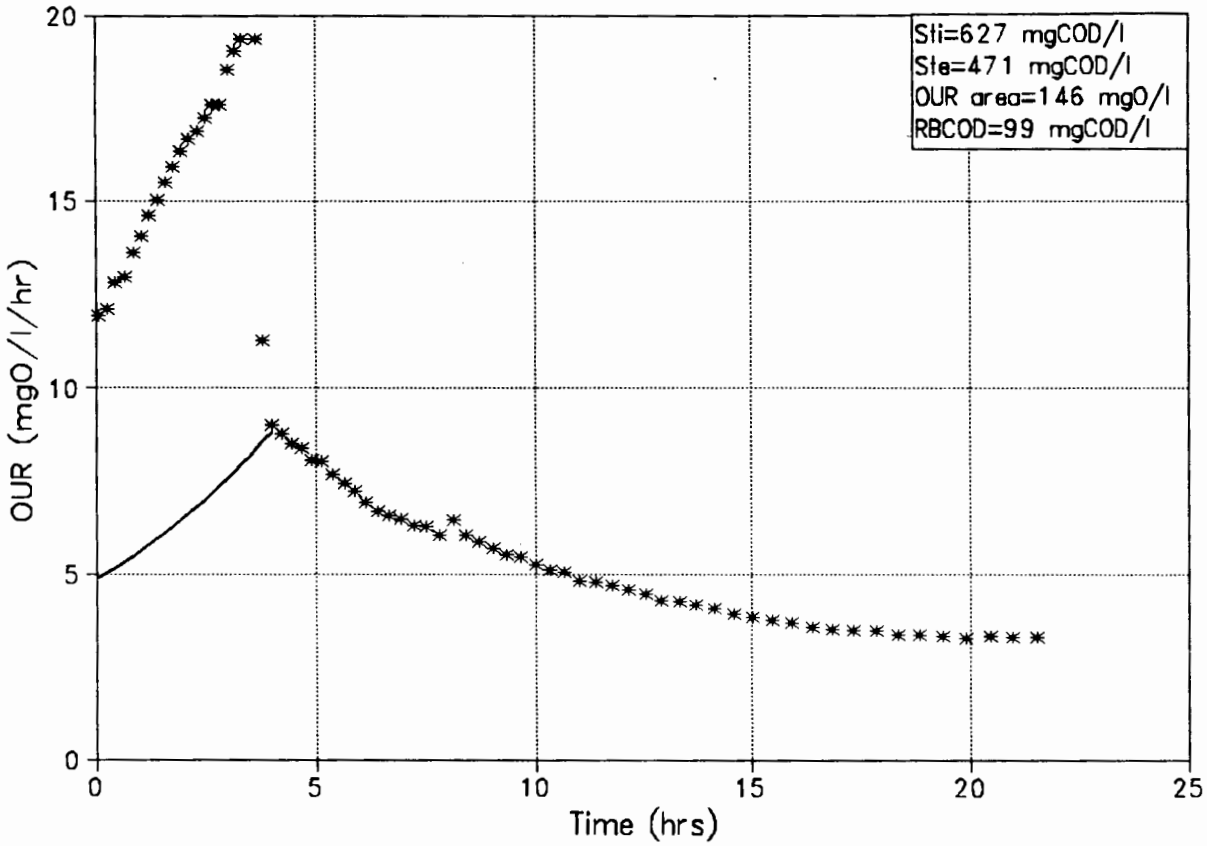


FIG A.7d OUR–time Plot for batch test
6 Oct'93–Sewage Batch No.7d (undiluted)

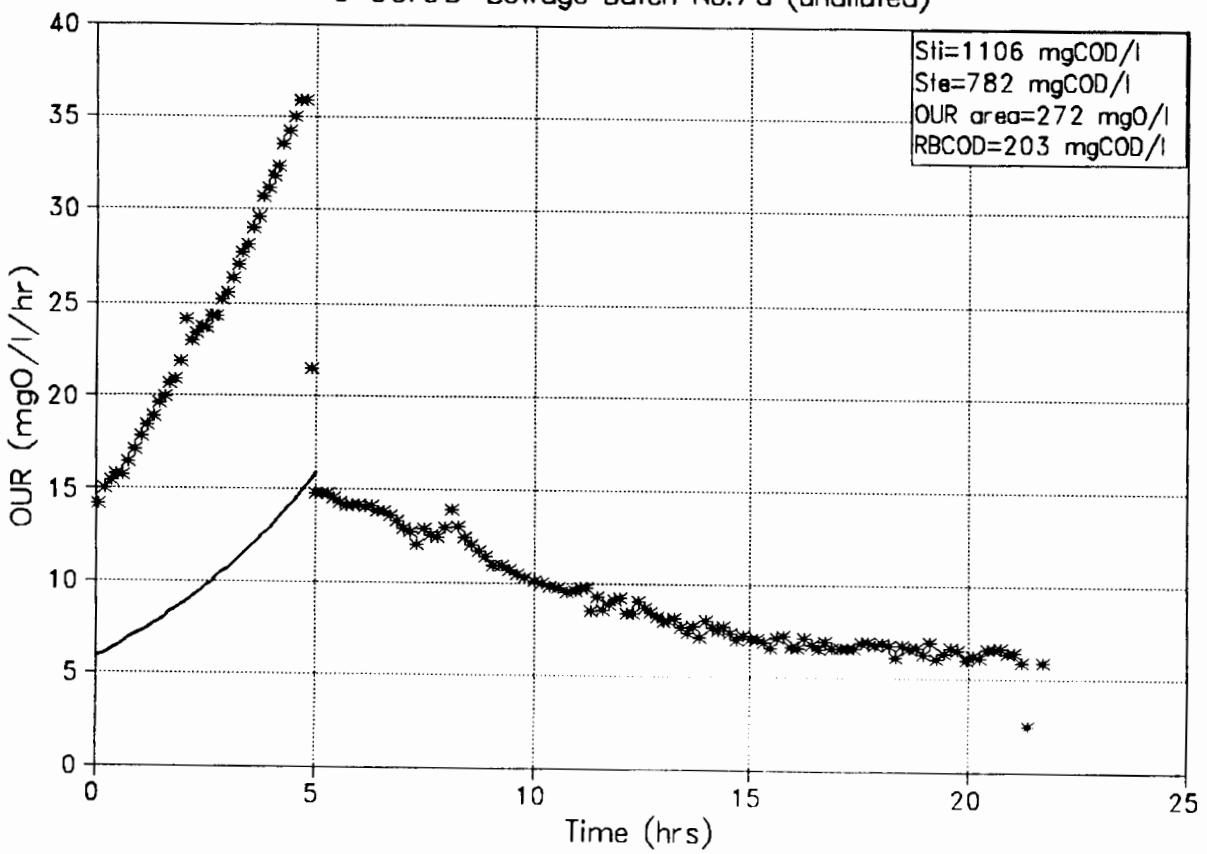


FIG A.7e OUR–time Plot for batch test
7 Oct'93–Sewage Batch No.7 (diluted)

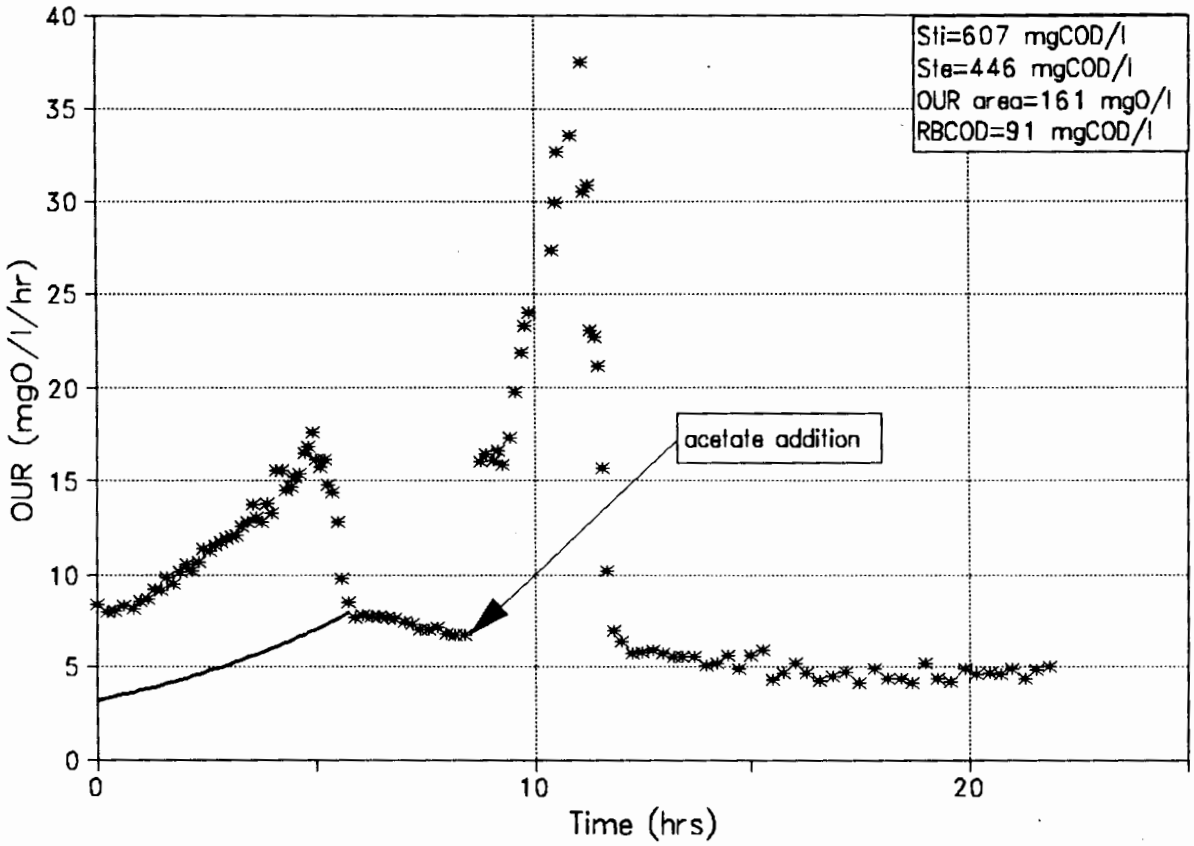


FIG A.7f OUR–time Plot for batch test
8 Oct'94–Sewage Batch No.7

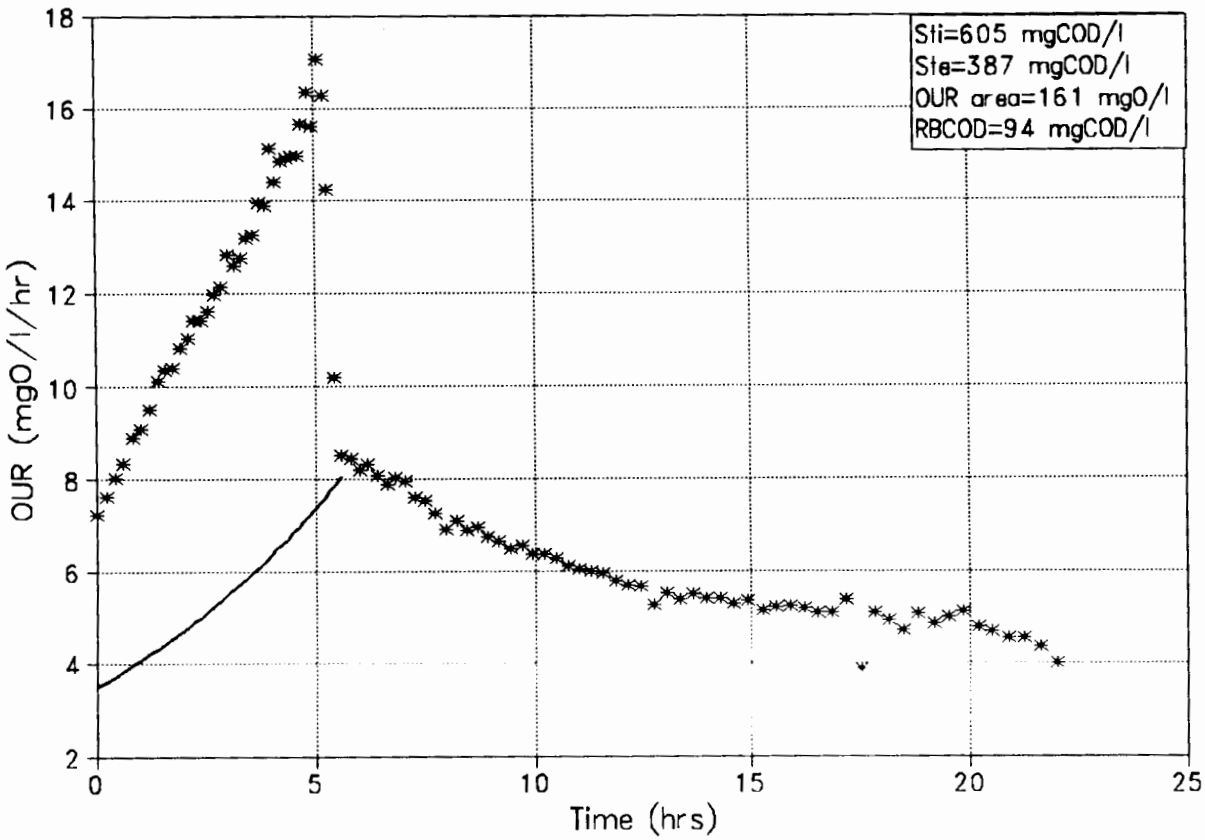


FIG A.7g OUR–time Plot for batch test
9 Oct'93–Sewage Batch No.7

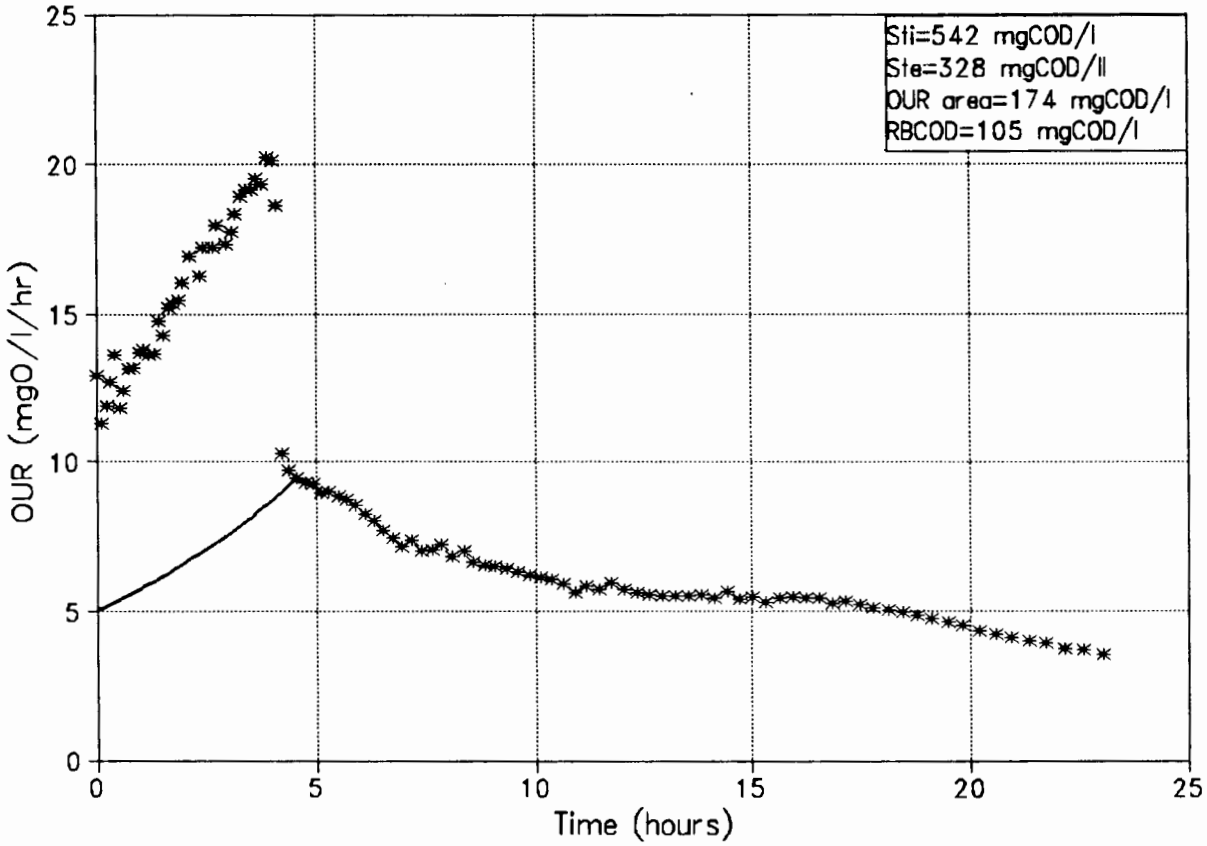


FIG A.8a OUR–time Plot for batch test
22 Oct'93–Sewage Batch No.8(diluted)

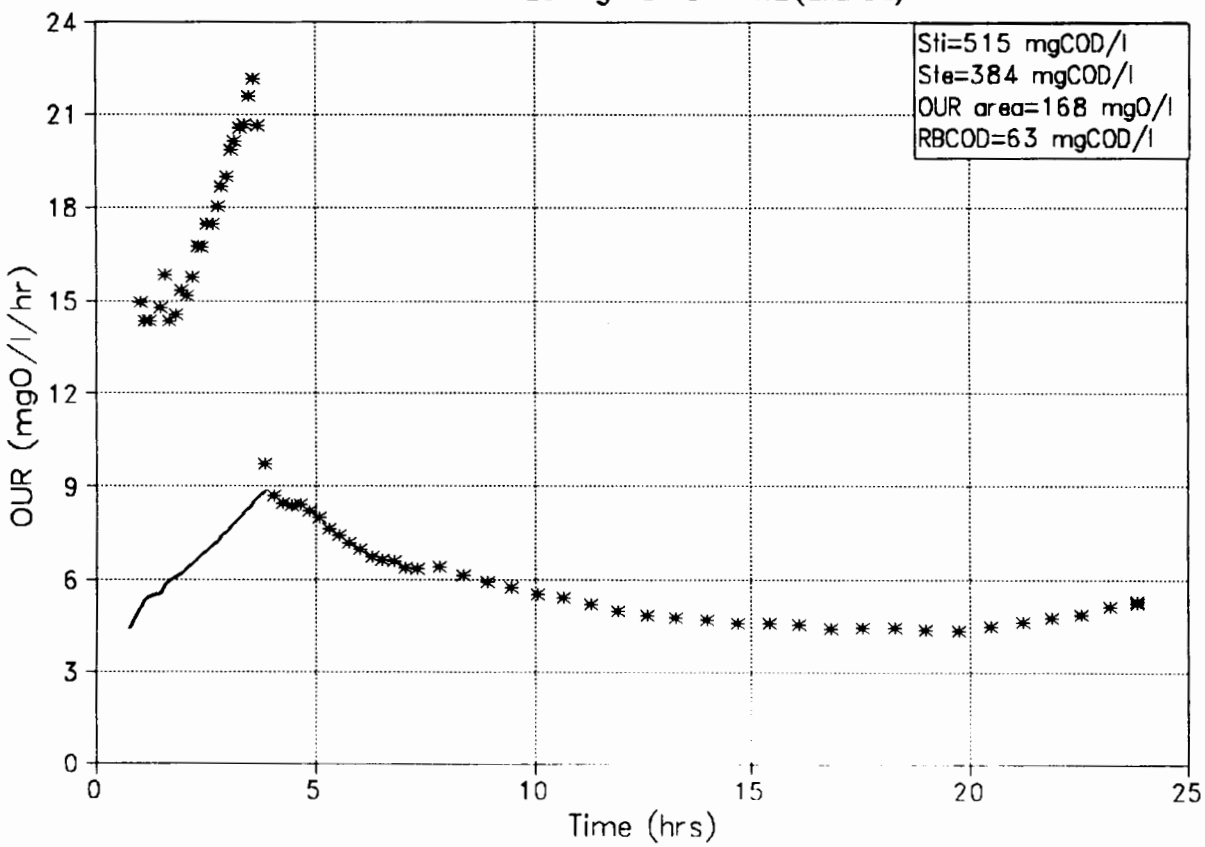


FIG A.8a OUR–time Plot for batch test
22 Oct'93–Sewage Batch No.8(diluted)

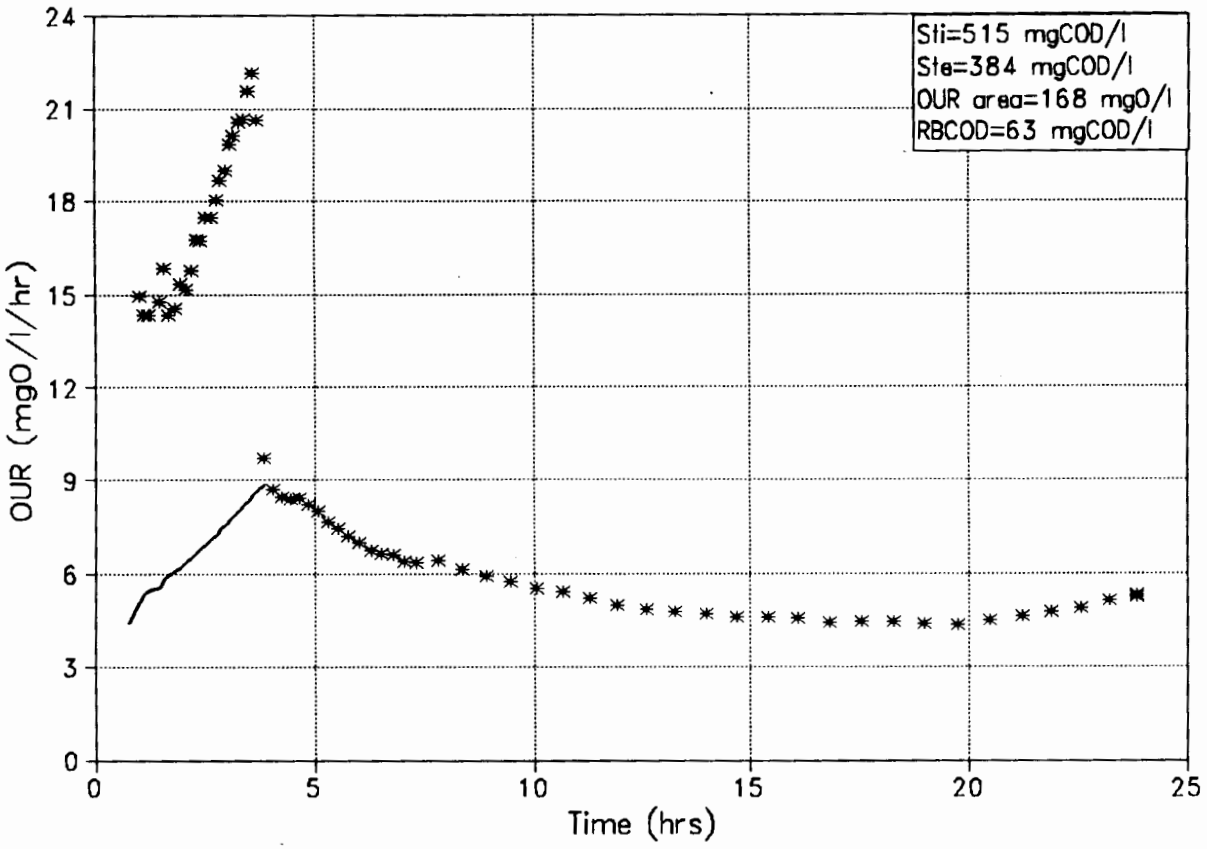


FIG A.8b OUR–time Plot for batch test
22 Oct'93–Sewage Batch No.8(undiluted)

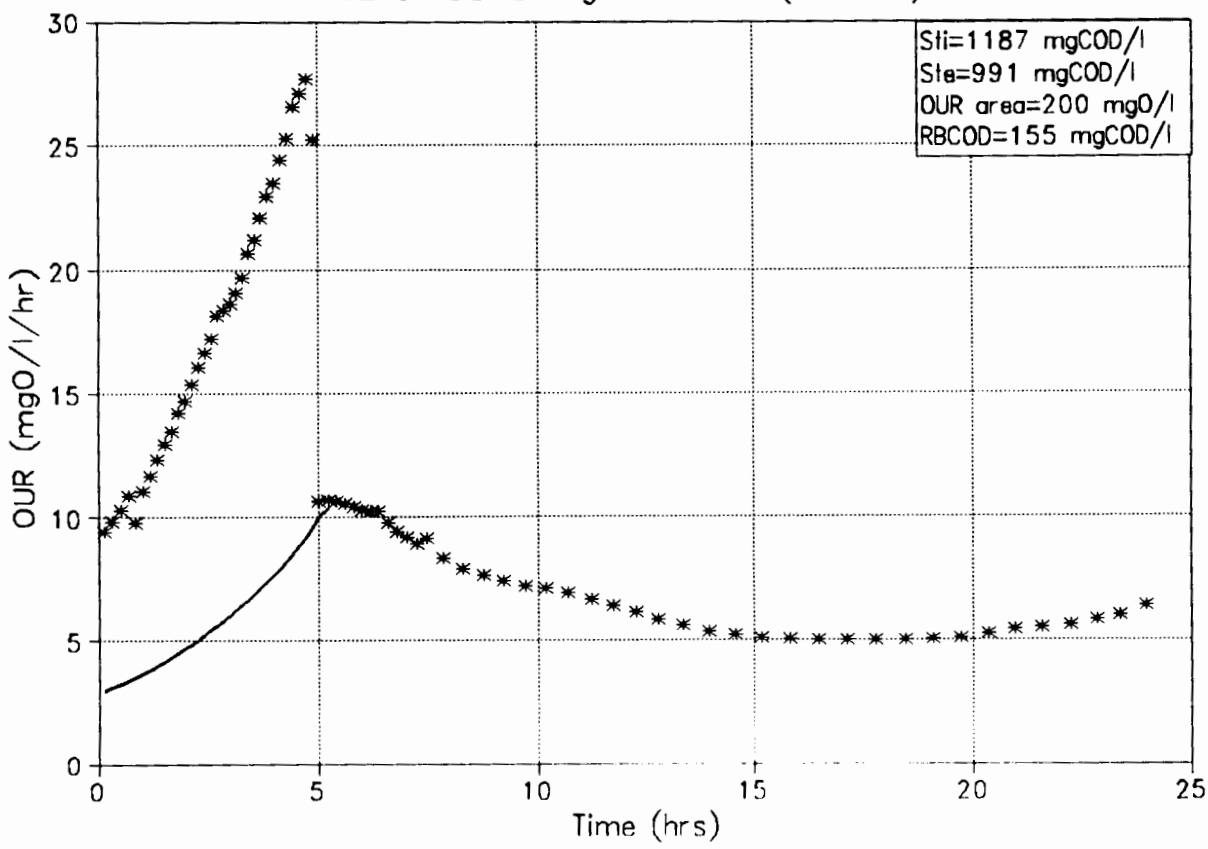


FIG A.8c OUR–time Plot for batch test
24 Oct'93–Sewage Batch No. 8

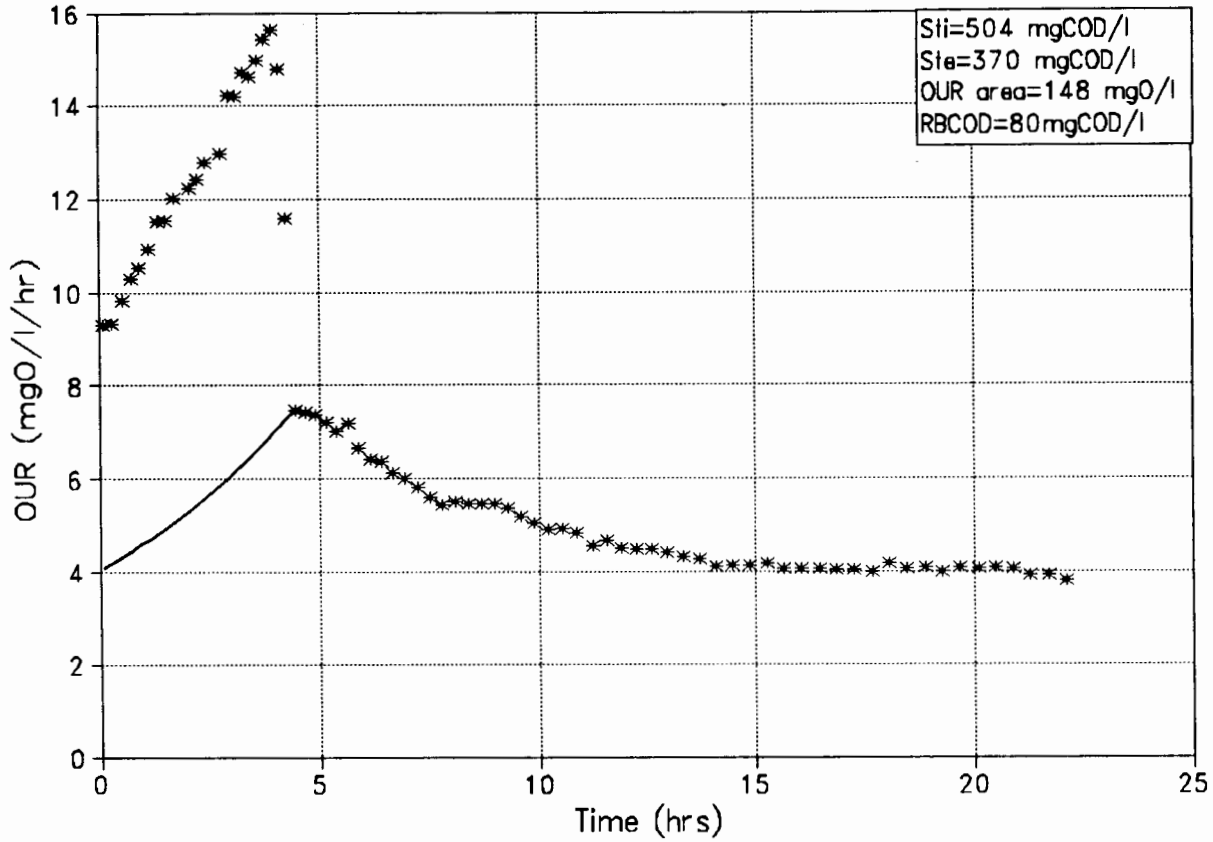


FIG A.8d OUR –time Plot for batch test
25 Oct'93 (undiluted)–Sewage Batch No.8

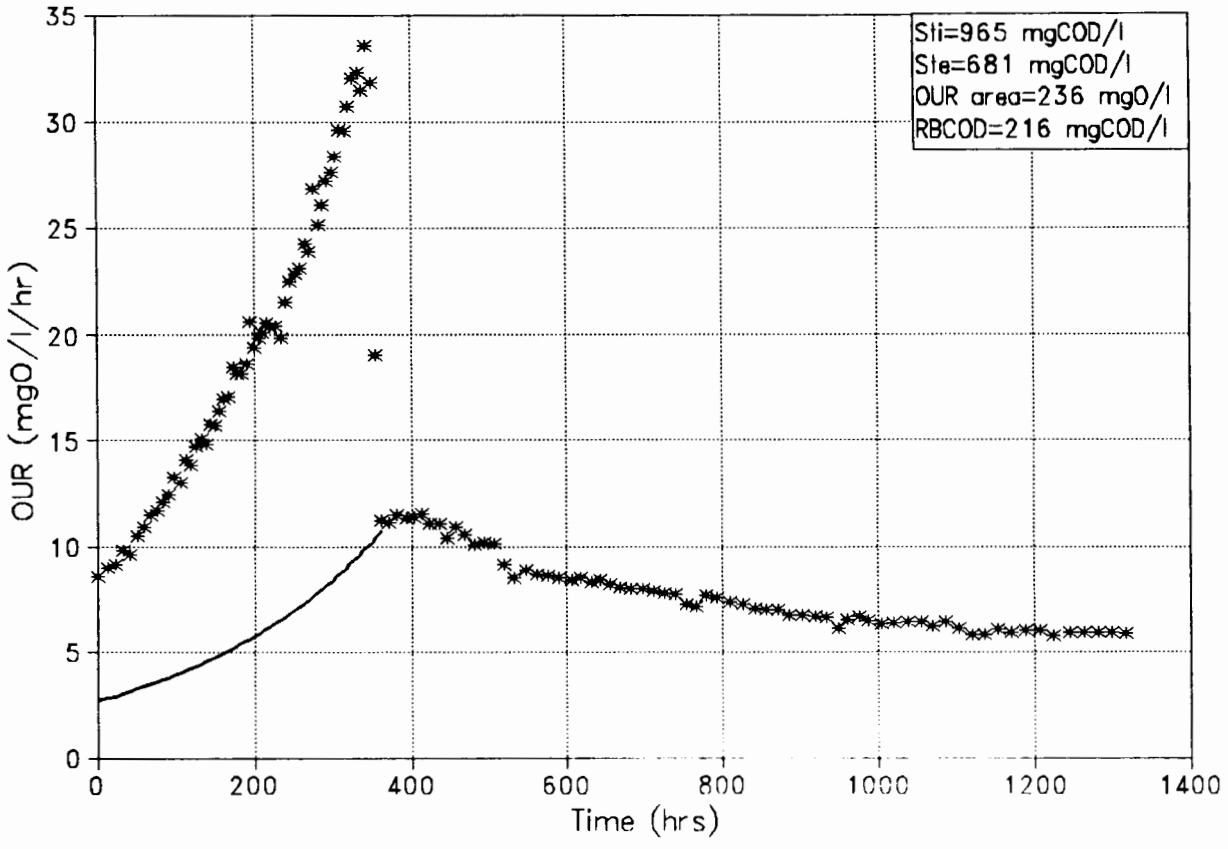


FIG A.8e OUR–time Plot for batch test
28 Oct'93–Sewage Batch No.8(diluted)

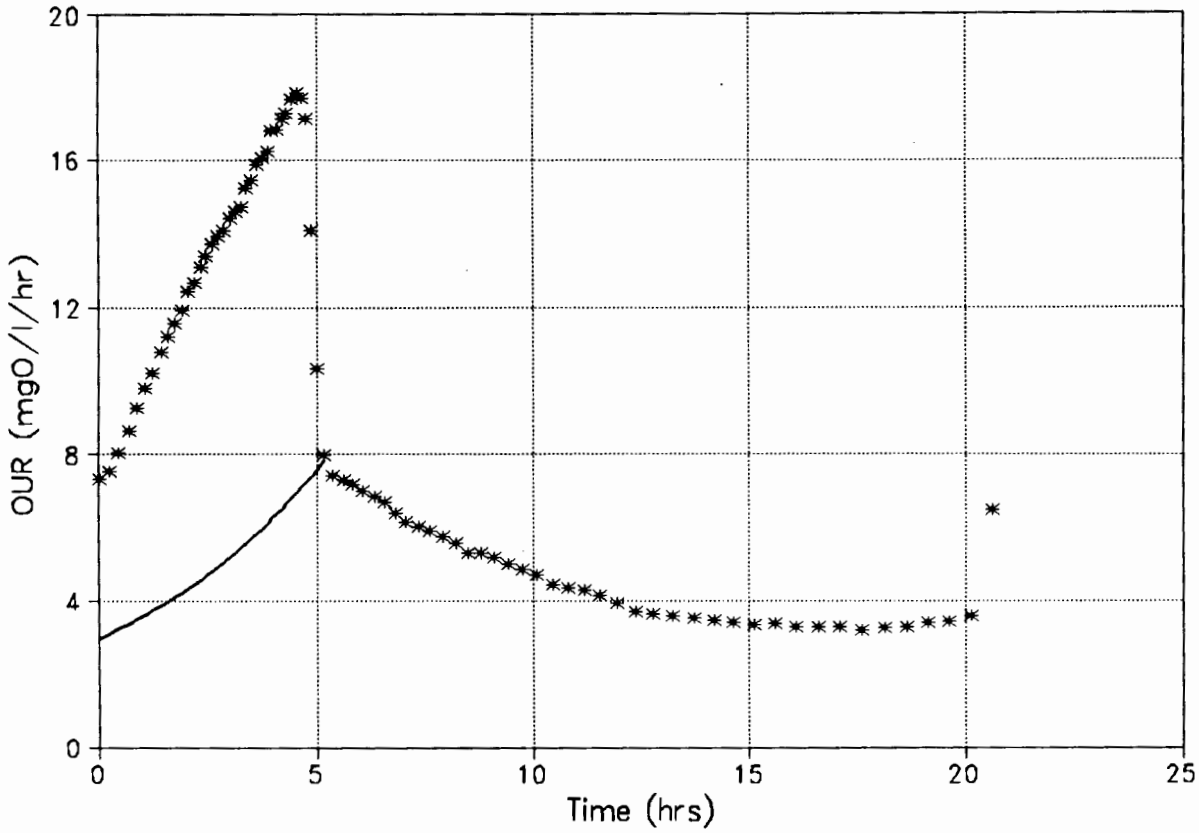


FIG A.9a OUR–time Plot for batch test
31 Oct'93 –Sewage Batch No.9

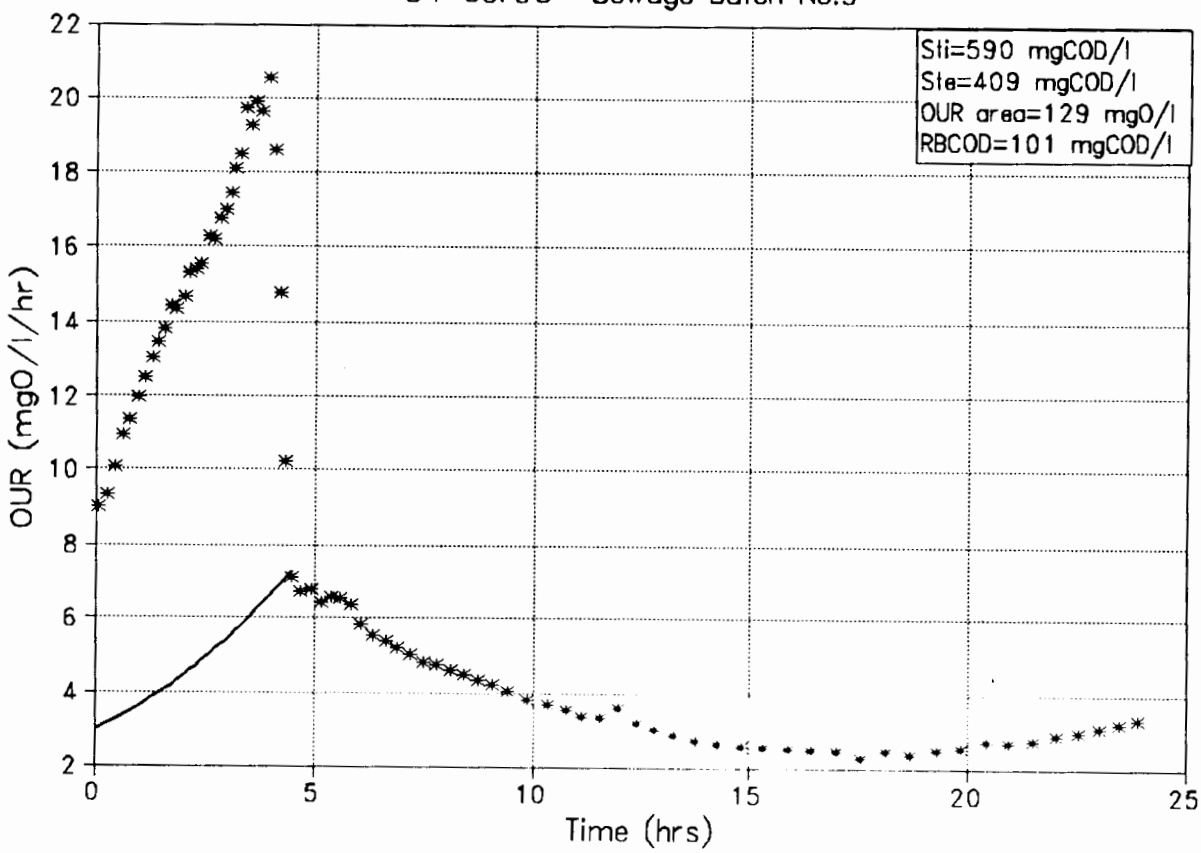


FIG A.9b OUR–time Plot for batch test
4 Nov'93–Sewage Batch No.9

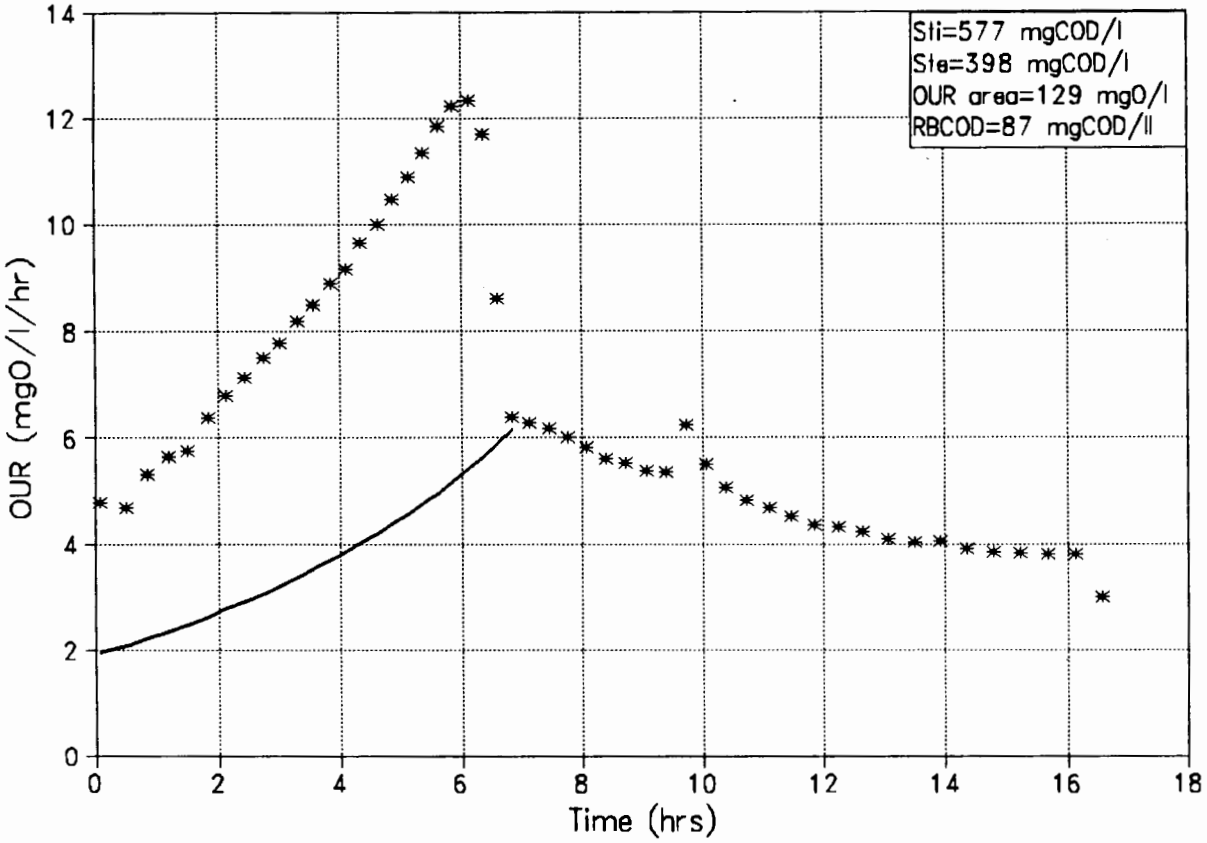


FIG A.10a OUR–time Plot for batch test
5 Feb'94–Sewage Batch No.10

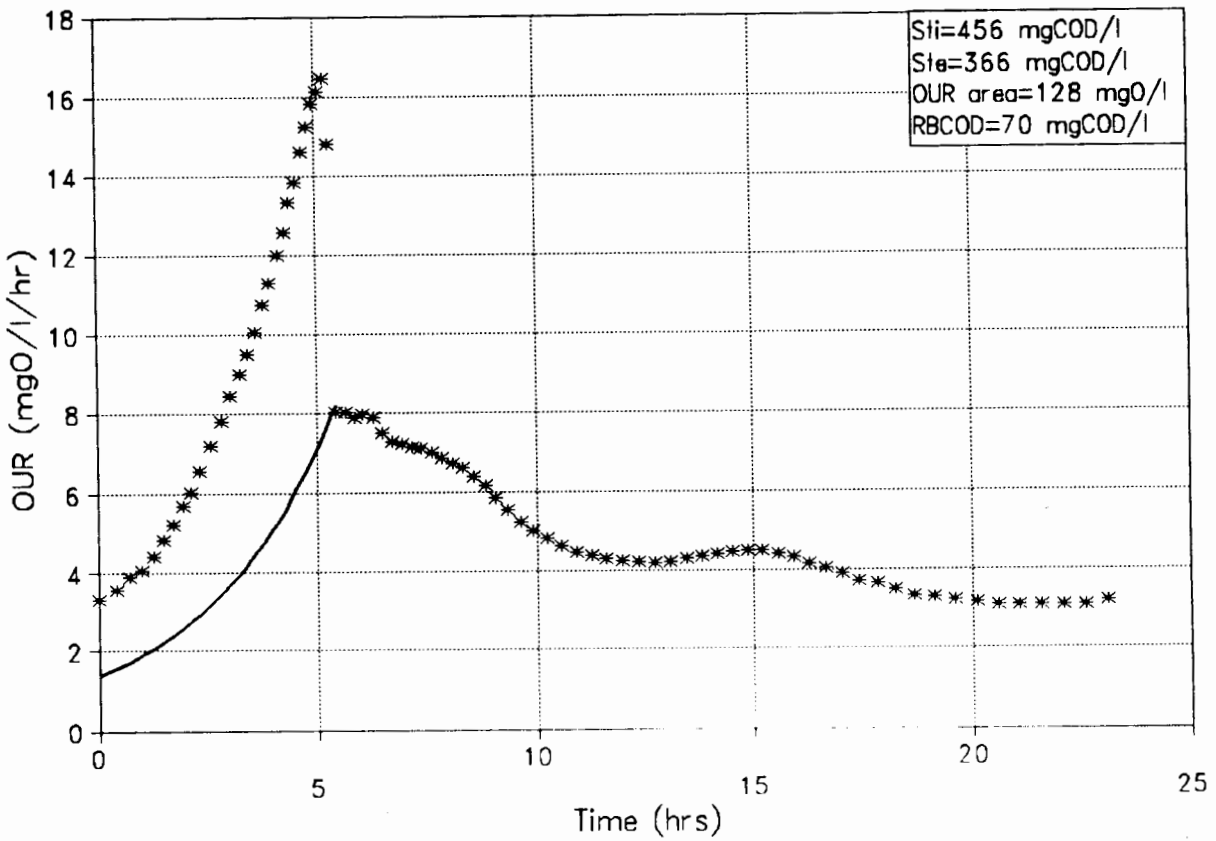


FIG A.10b OUR–time Plot for batch test
6 Feb'94–Sewage Batch No.10

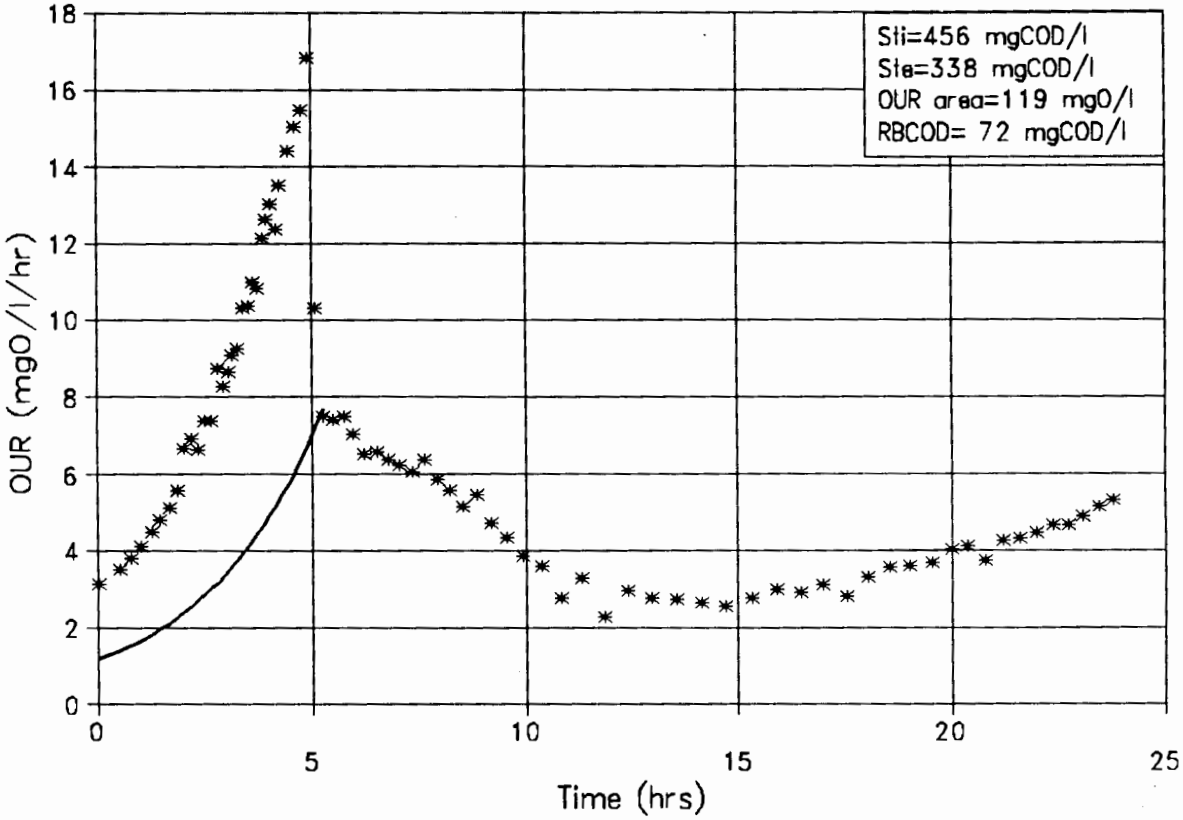


FIG A.10c OUR–time Plot for batch test
7 Feb'94–Sewage Batch NO.10

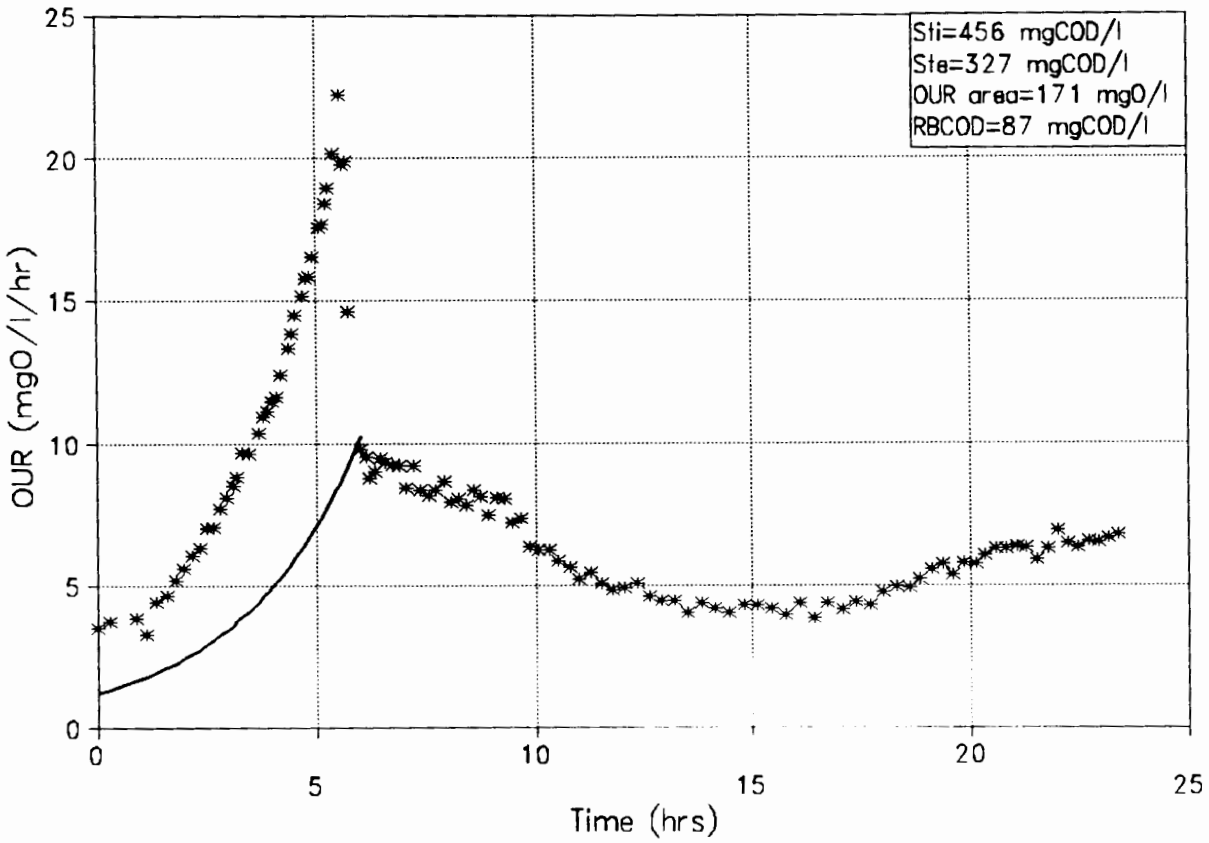


FIG A.10d OUR–time Plot for batch test
8 Feb'94–Sewage Batch No. 10

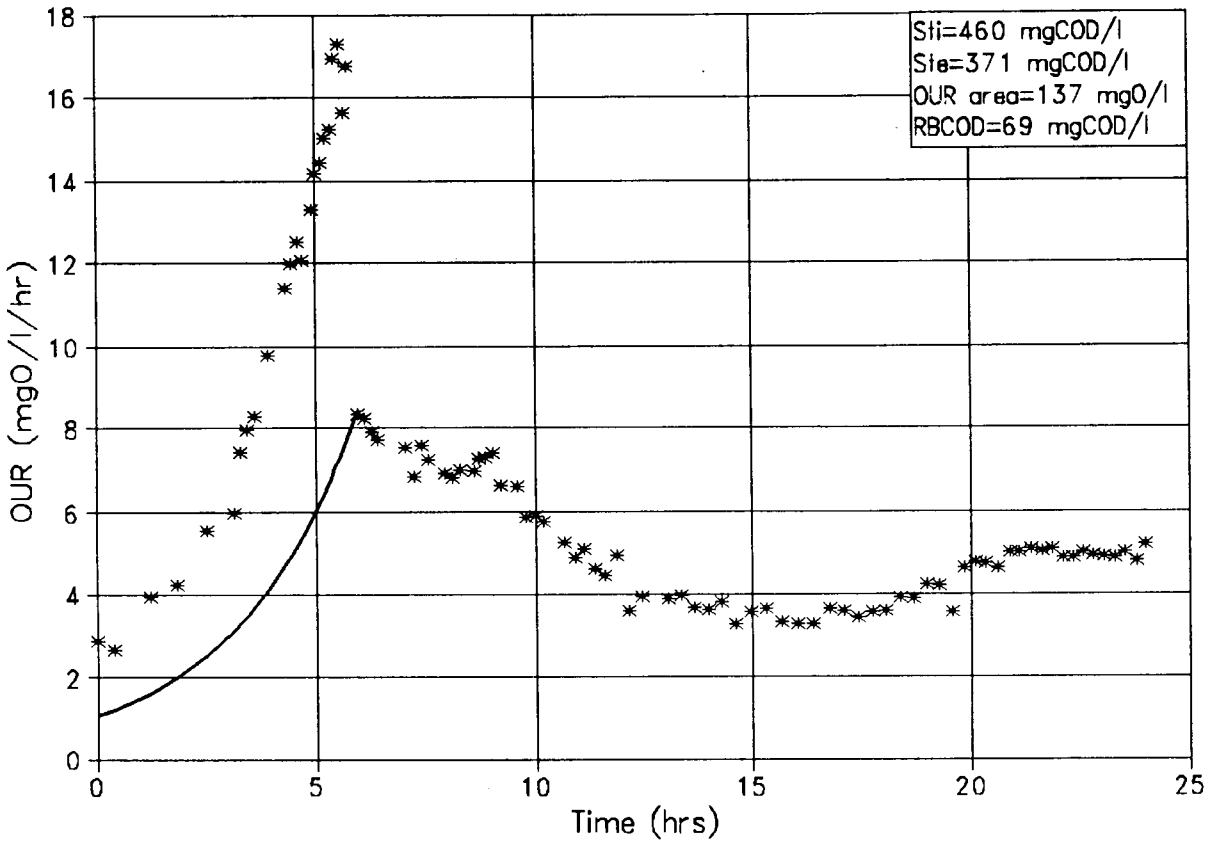


FIG A.10e OUR–time Plot for batch test
10 Feb'94–Sewage Batch No.10

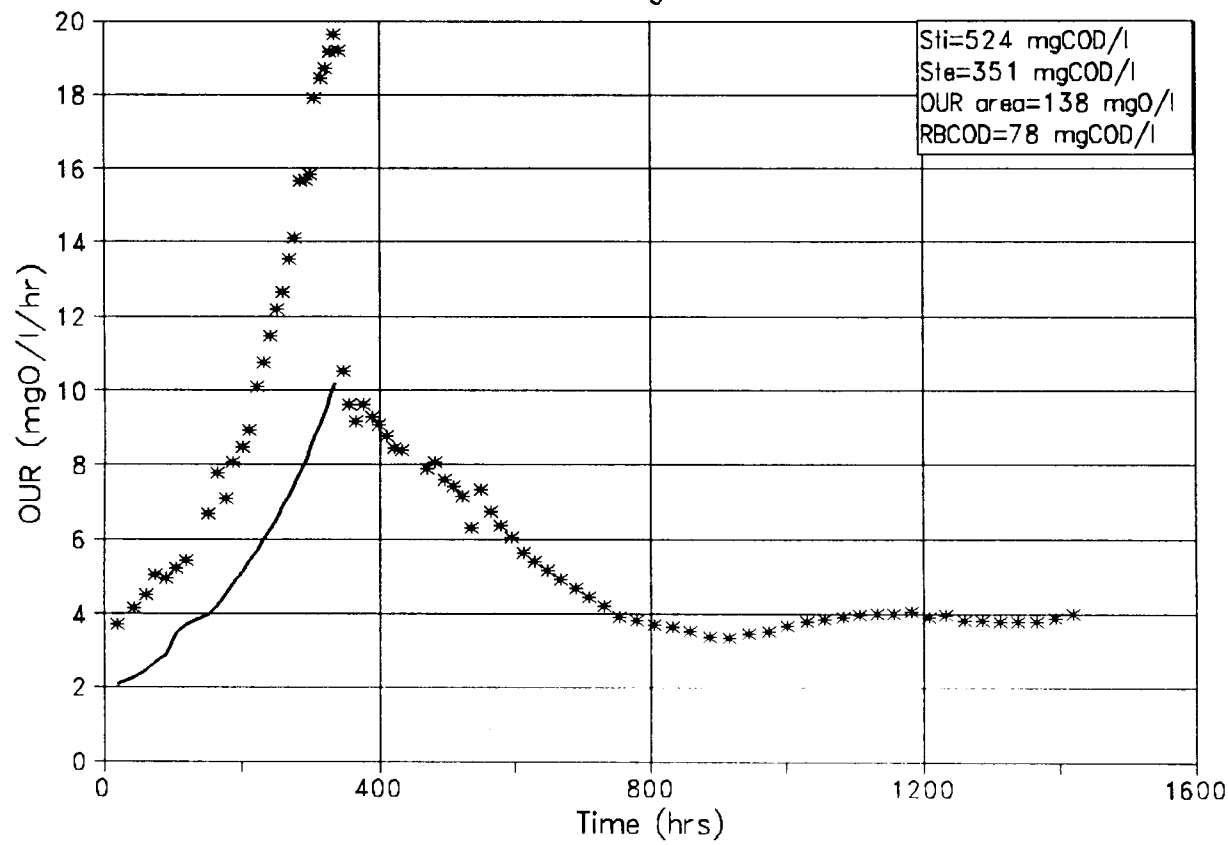


FIG A.10f OUR–time Plot for batch test
13 Feb'94–Sewage Batch No.10

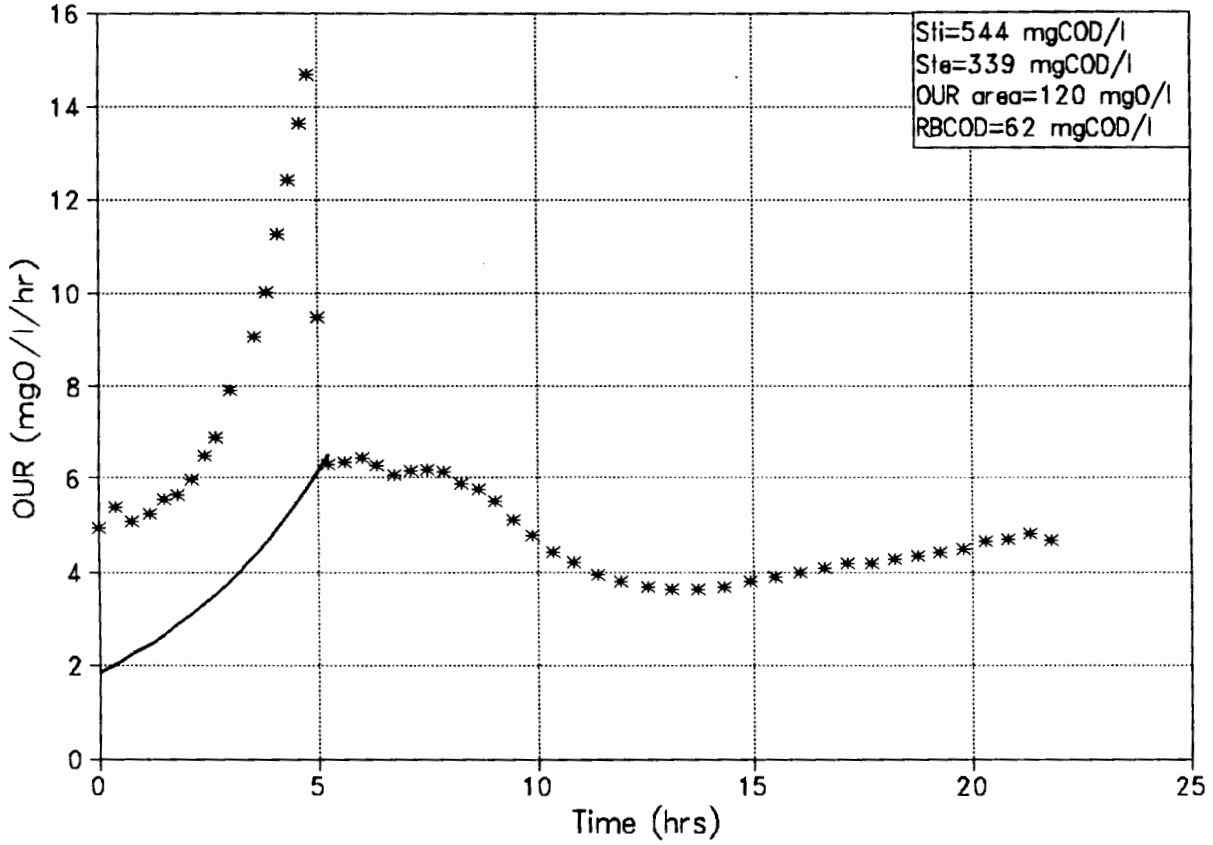


FIG A.11a OUR–time Plot for batch test
17 Feb'94–Sewage Batch No.11

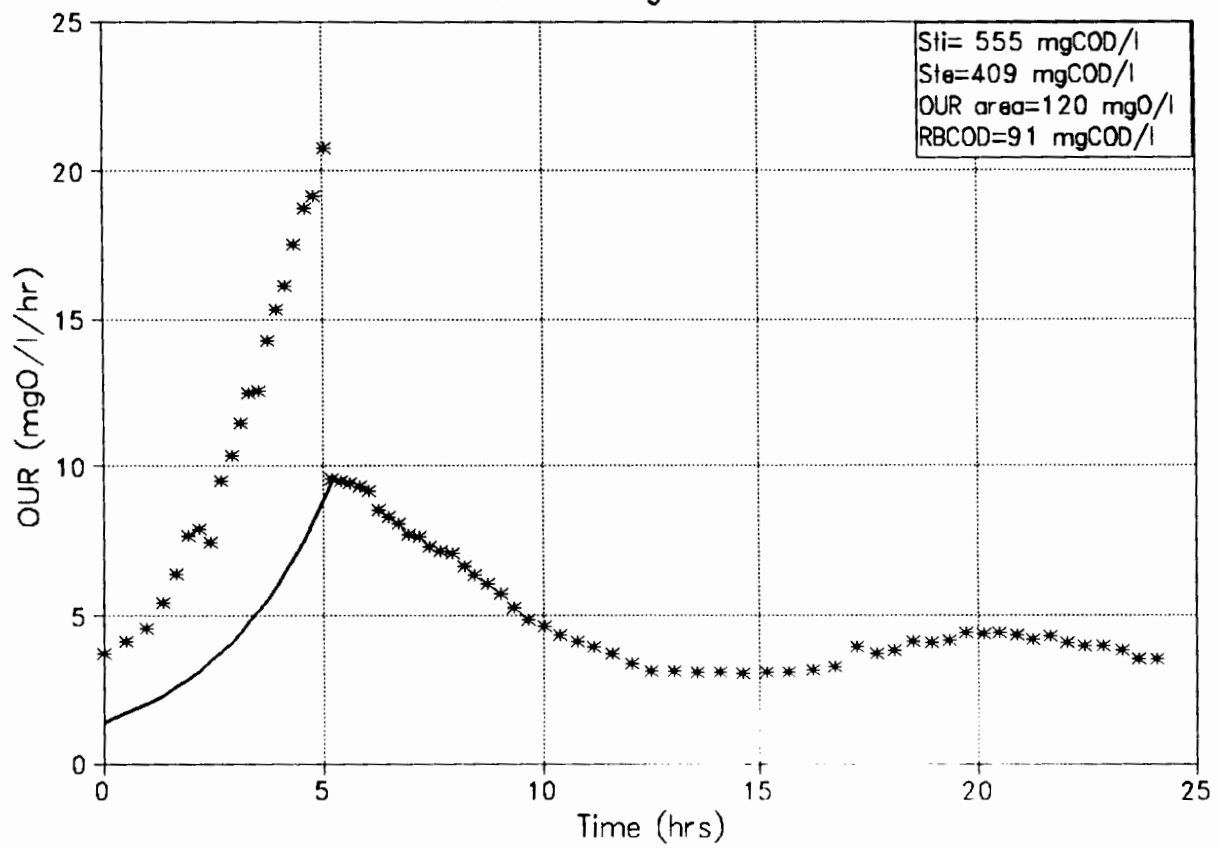


FIG A.11b OUR–time Plot for batch test
22 Feb'94–Sewage Batch No.11

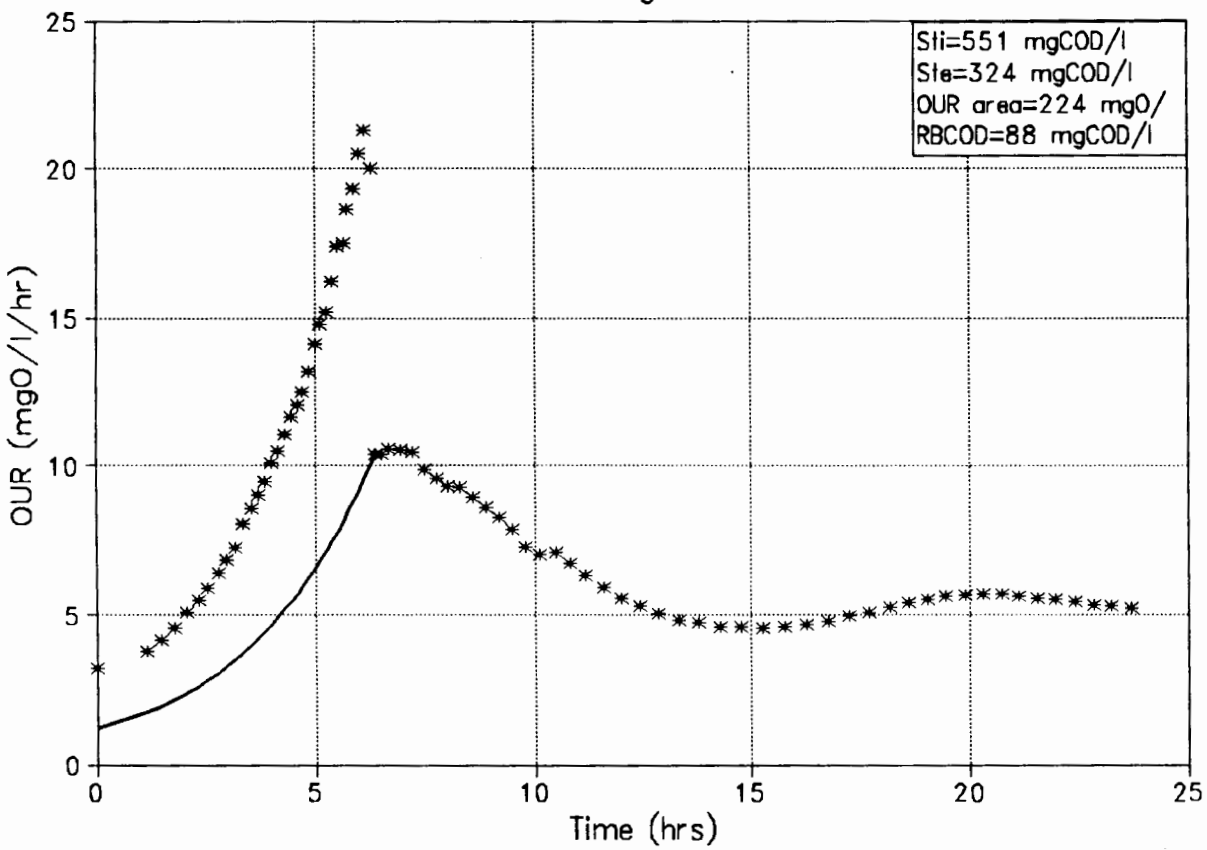


FIG A.11c OUR–time Plot for batch test
18 Feb'94–Sewage Batch No.11

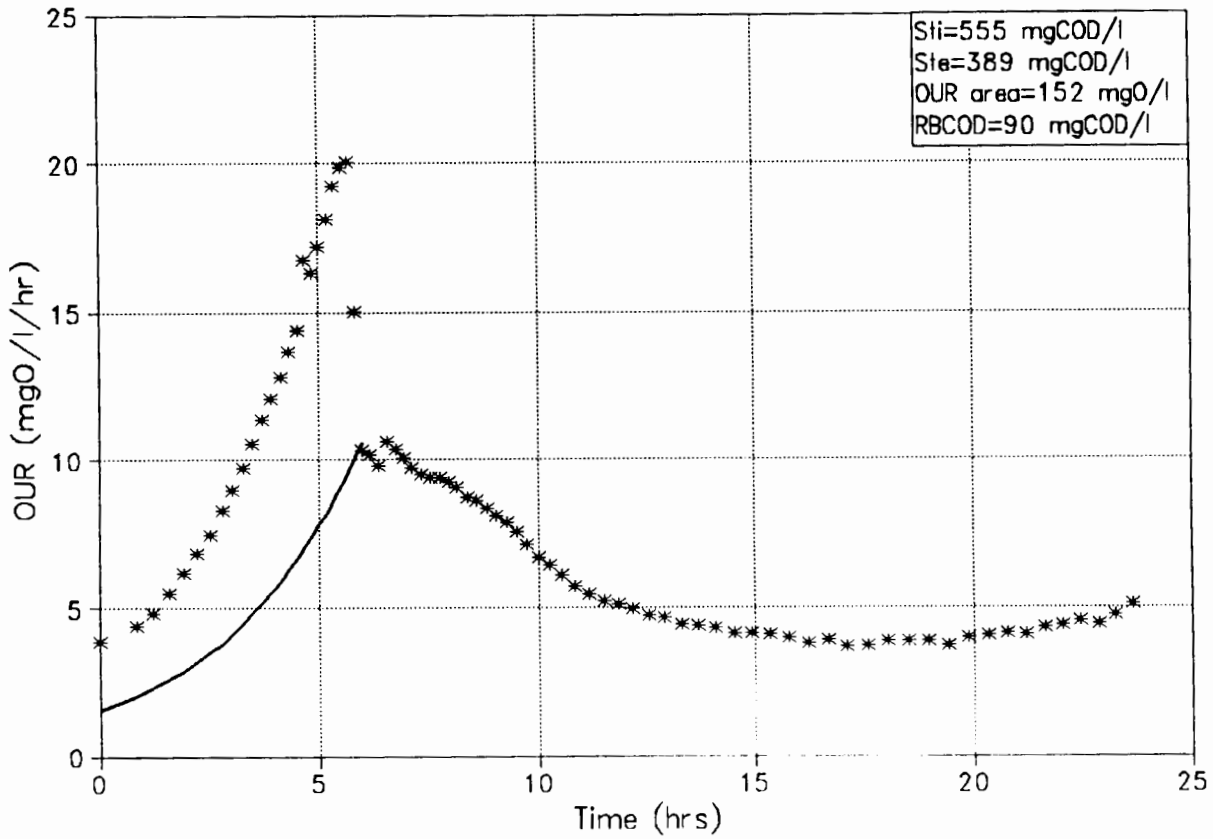


FIG A.11d OUR–time Plot for batch test
19 Feb'94–Sewage Batch No.11

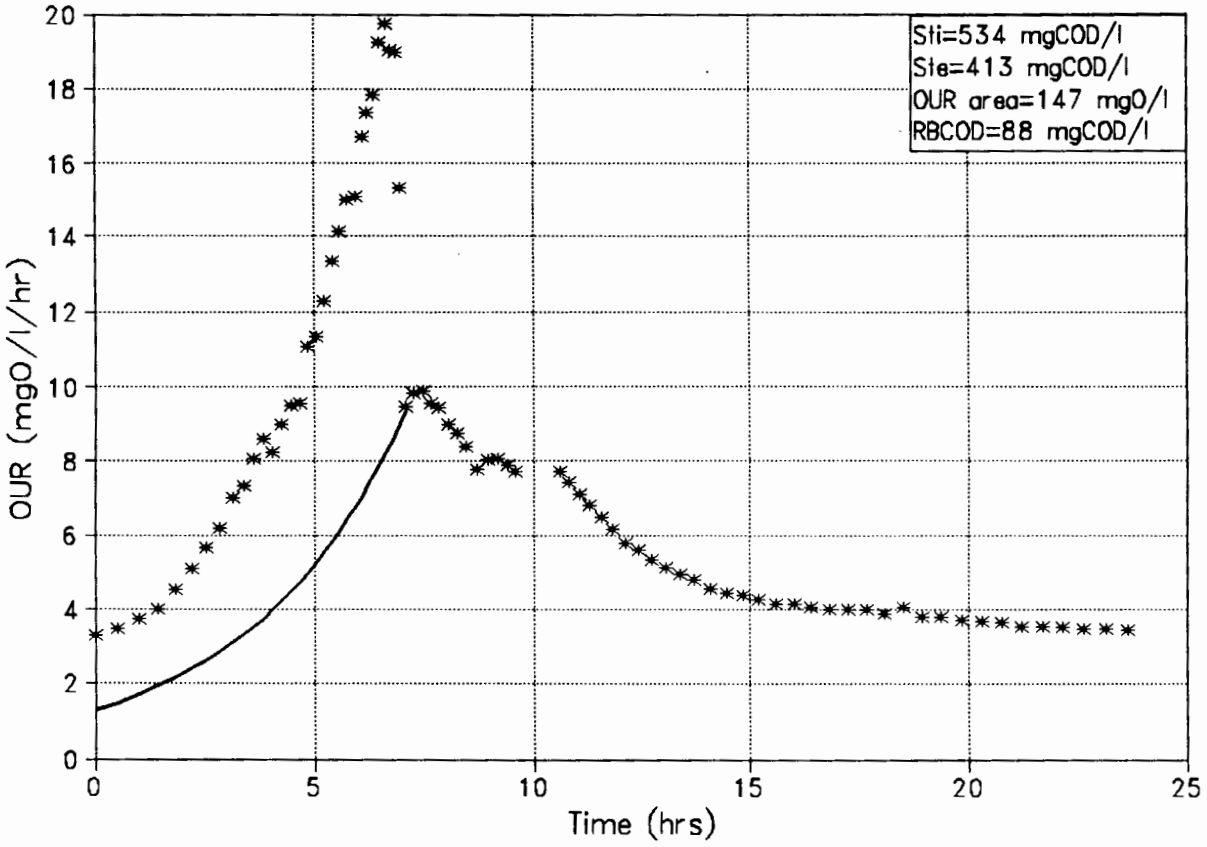


FIG A.11e OUR–time Plot for batch test
20 Feb'94–Sewage Batch No.11

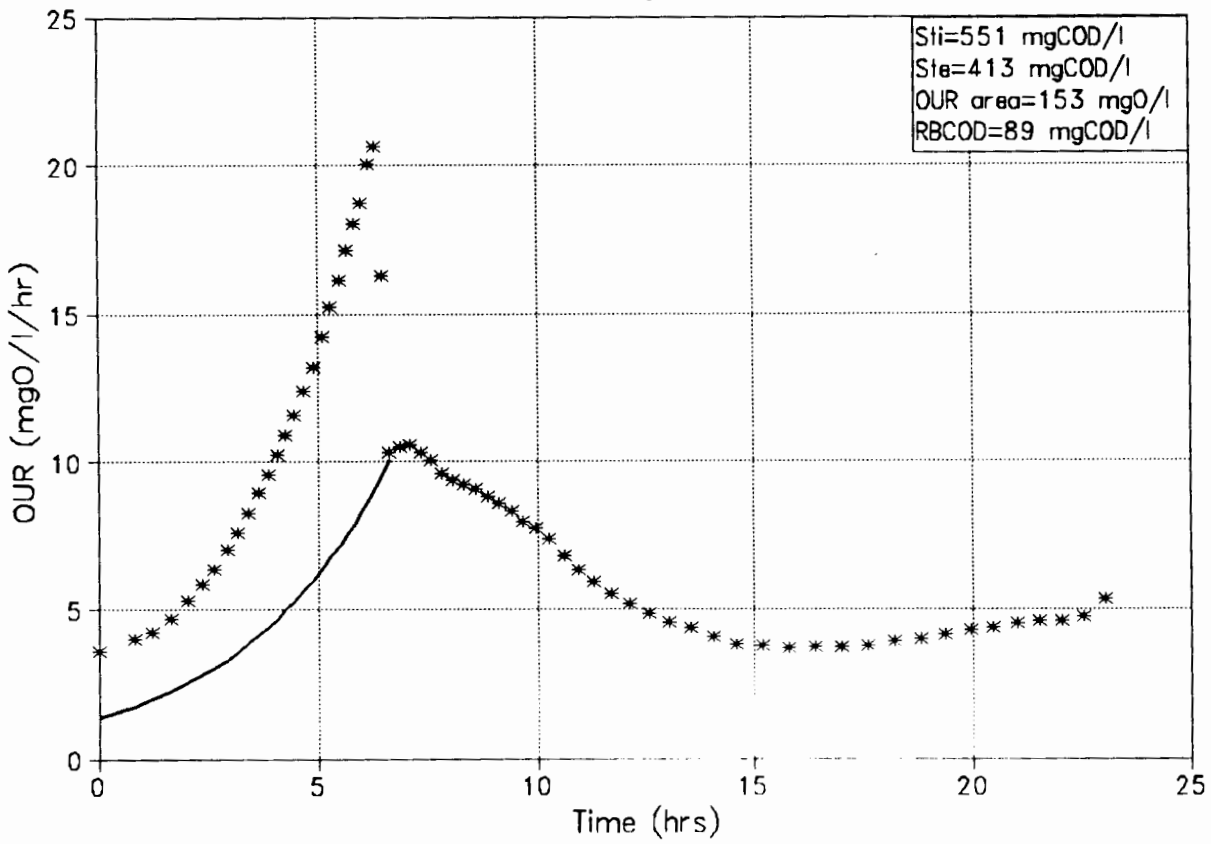


FIG A.11f OUR–time Plot for batch test
1 Mar'94–Sewage Batch No.11

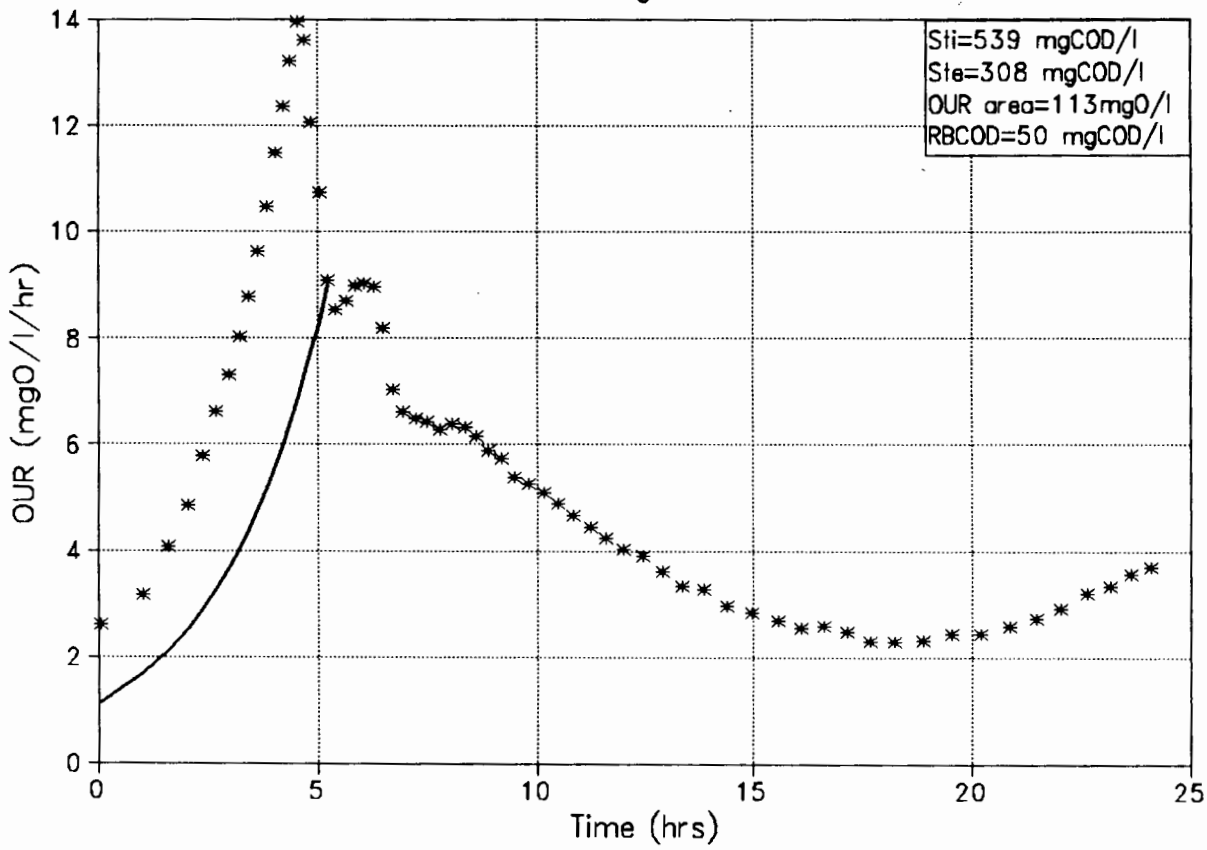


FIG A.12a OUR–time Plot for batch test
18 MAR'94–Sewage Batch No.12

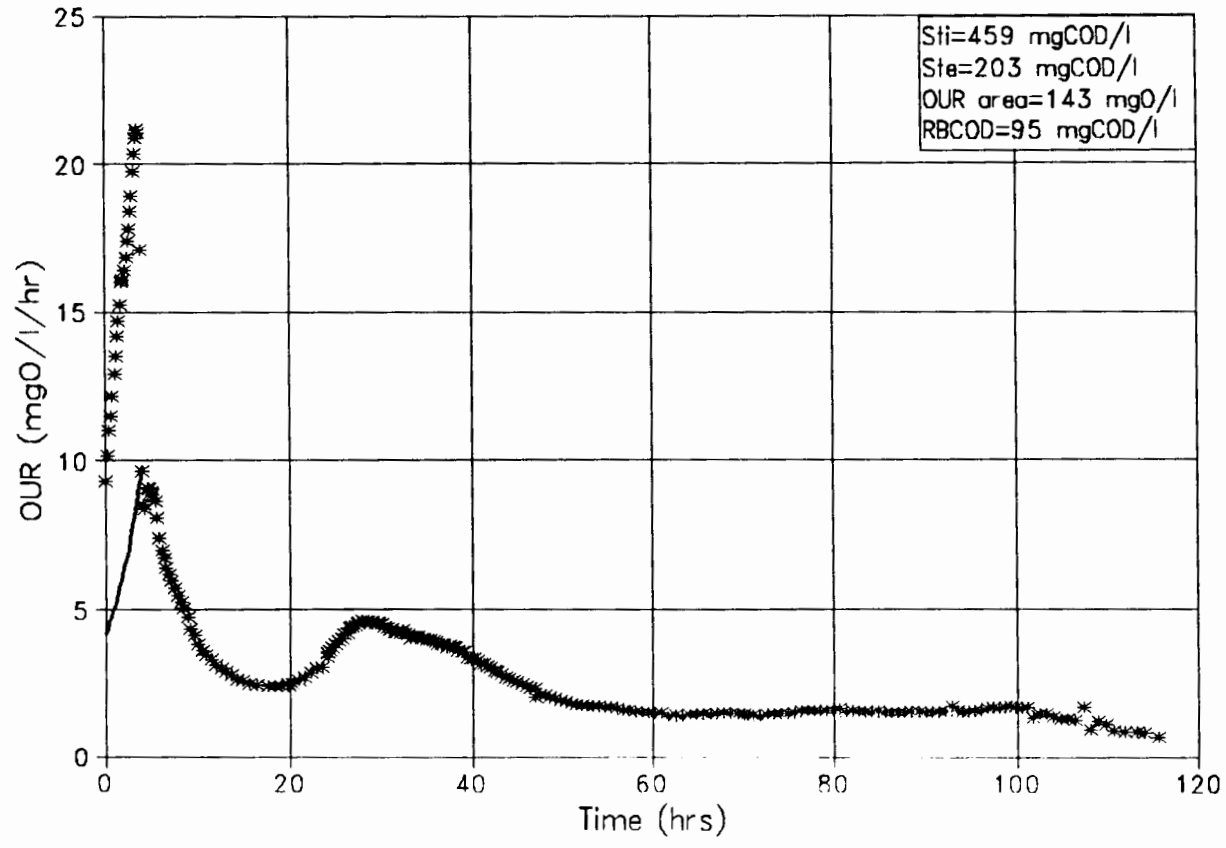


FIG A.12b OUR–time Plot for batch test
19 Mar'94–Sewage Batch No.12

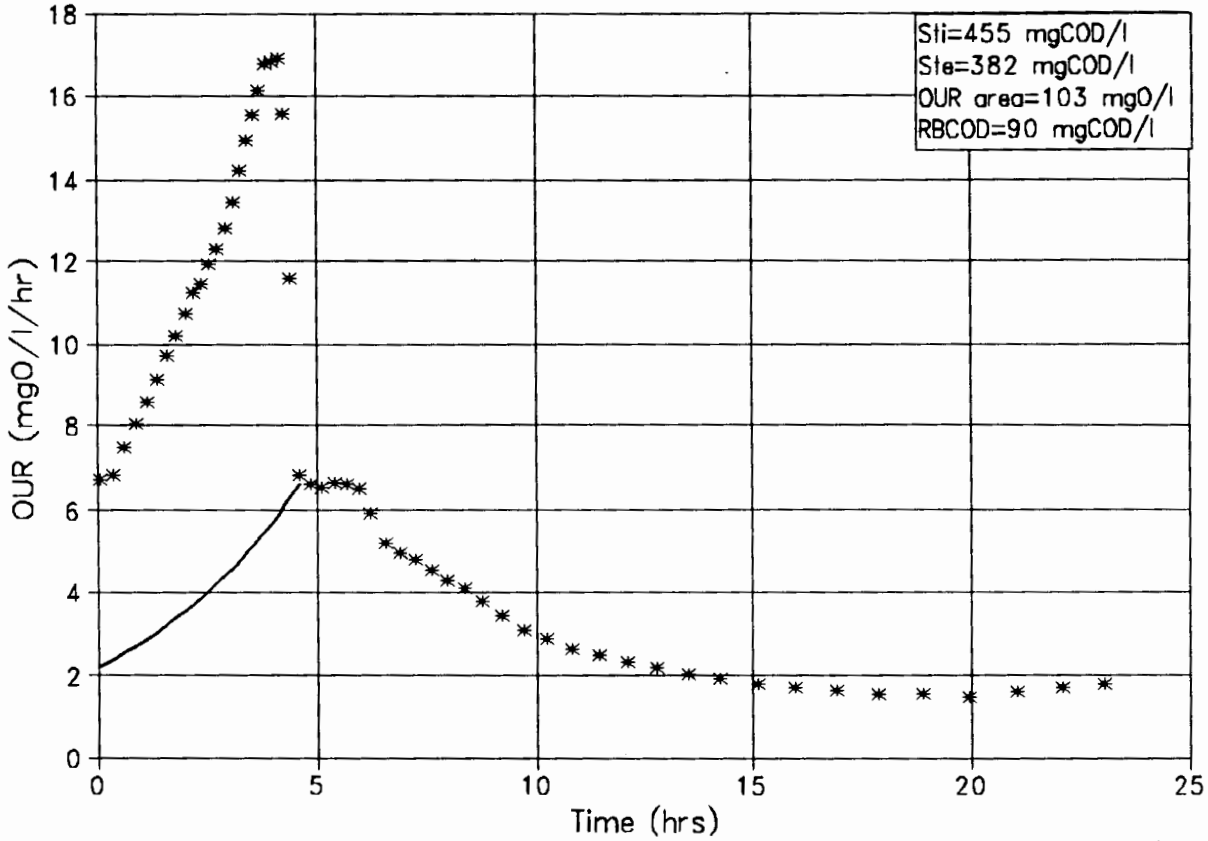


FIG A.12c OUR–time Plot for batch test
20 Mar'94–Sewage Batch No.12

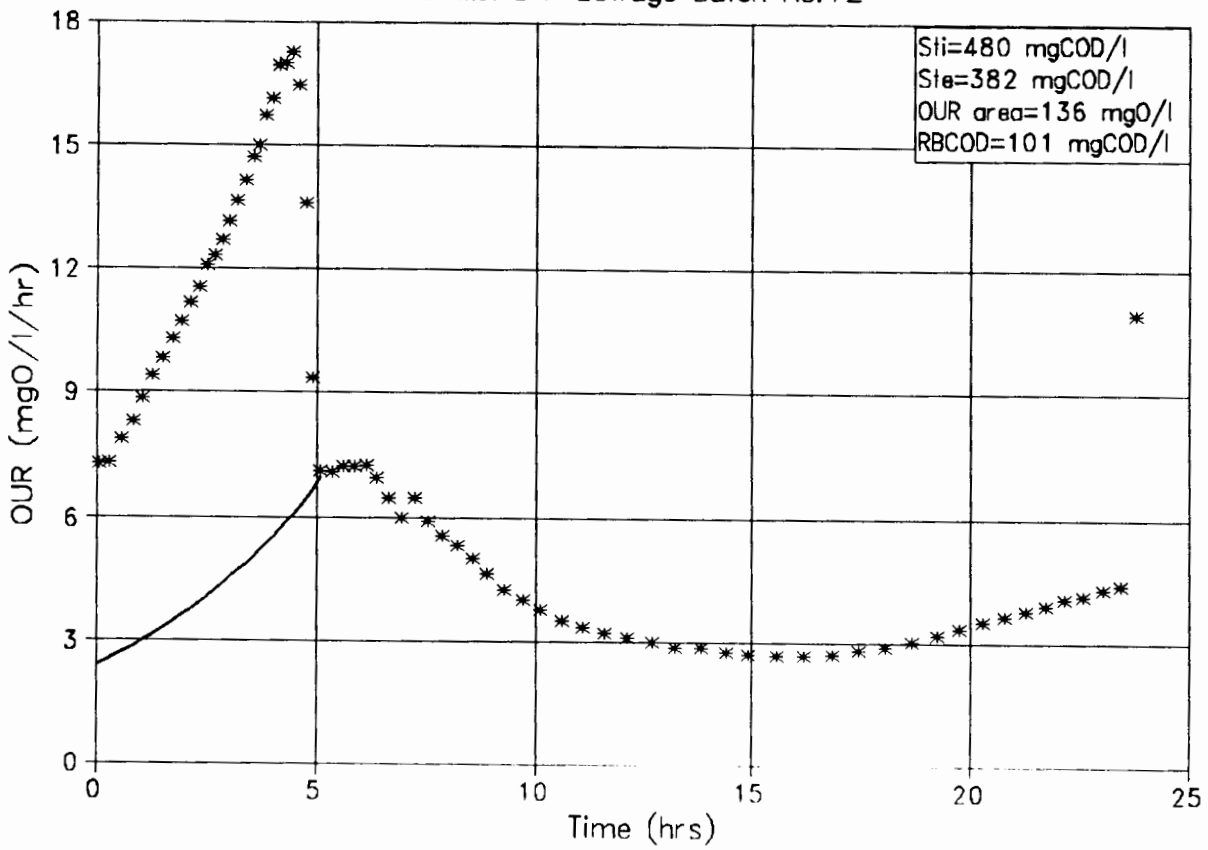


FIG A.12d OUR–time Plot for batch test
22 Mar'94–Sewage Batch No.12

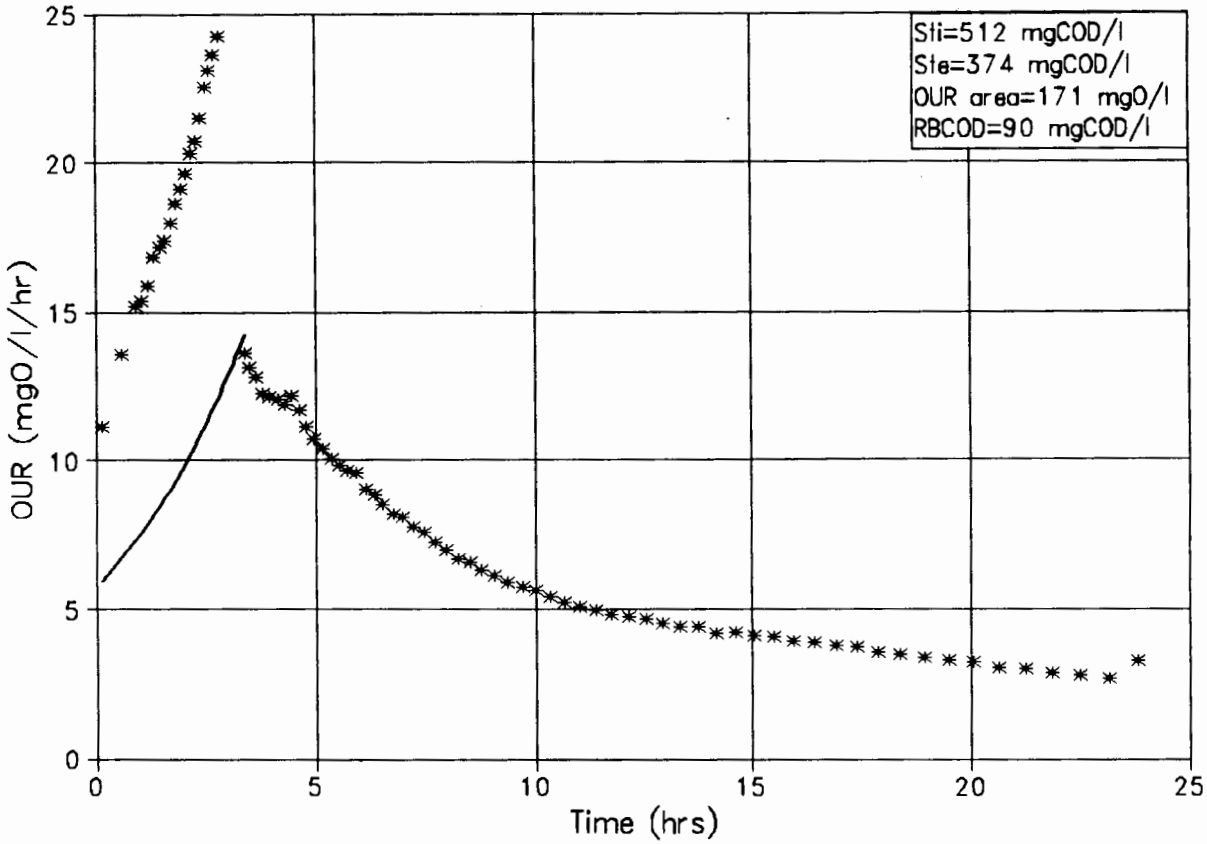


FIG A.12e OUR–time Plot for batch test
24 Mar'94–Sewage Batch No.12

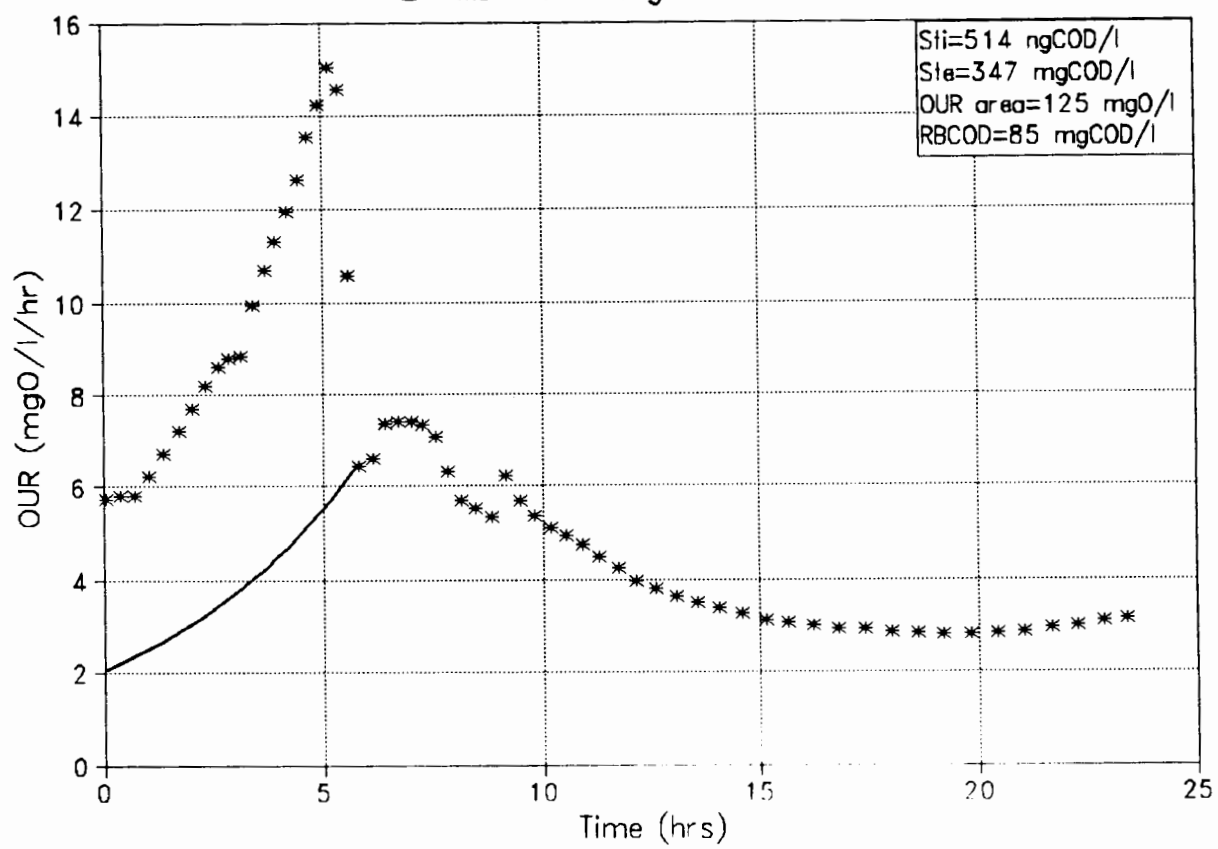


FIG A.12f OUR–time Plot for batch test
26 Mar'94–Sewage Batch No.12

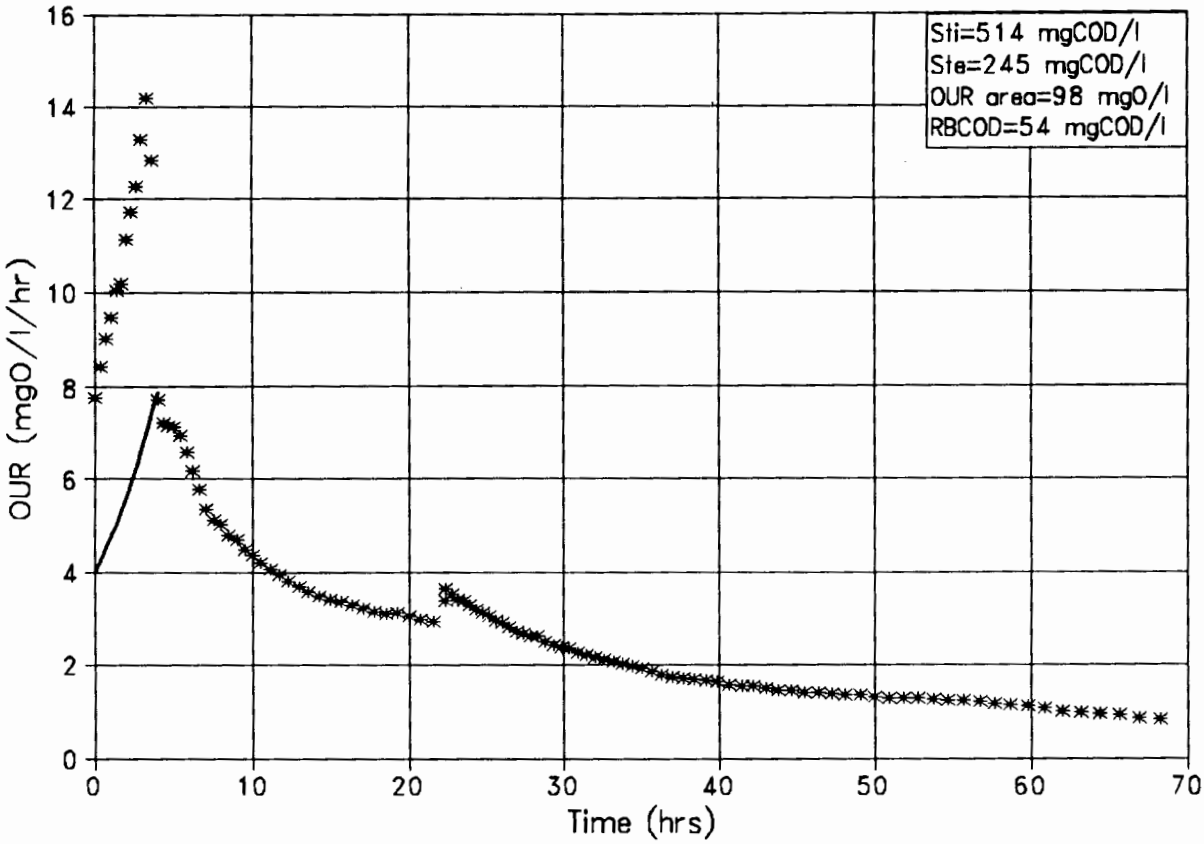


FIG A.12g OUR–time Plot for batch test
26 Mar'94–Sewage Batch No.12

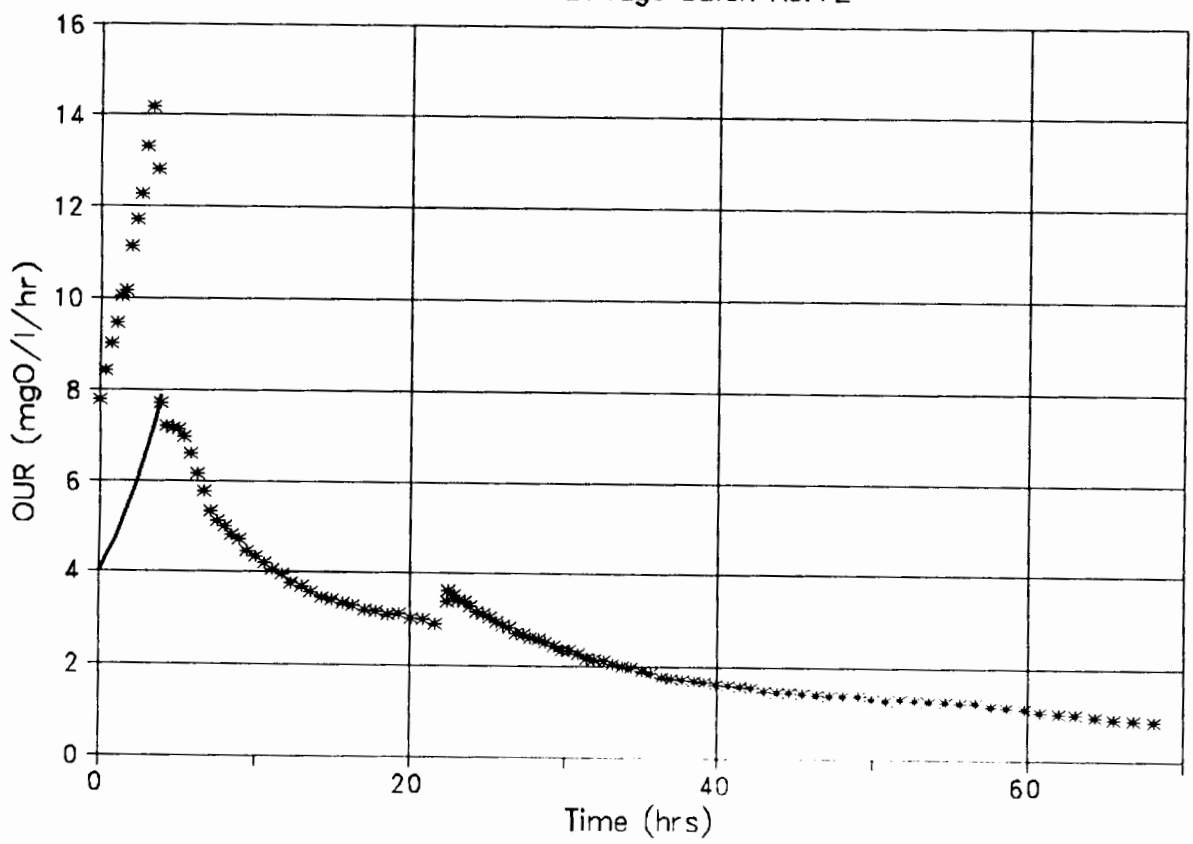


FIG A.13a OUR–time Plot for batch test
4 April'94–Sewage Batch No.13

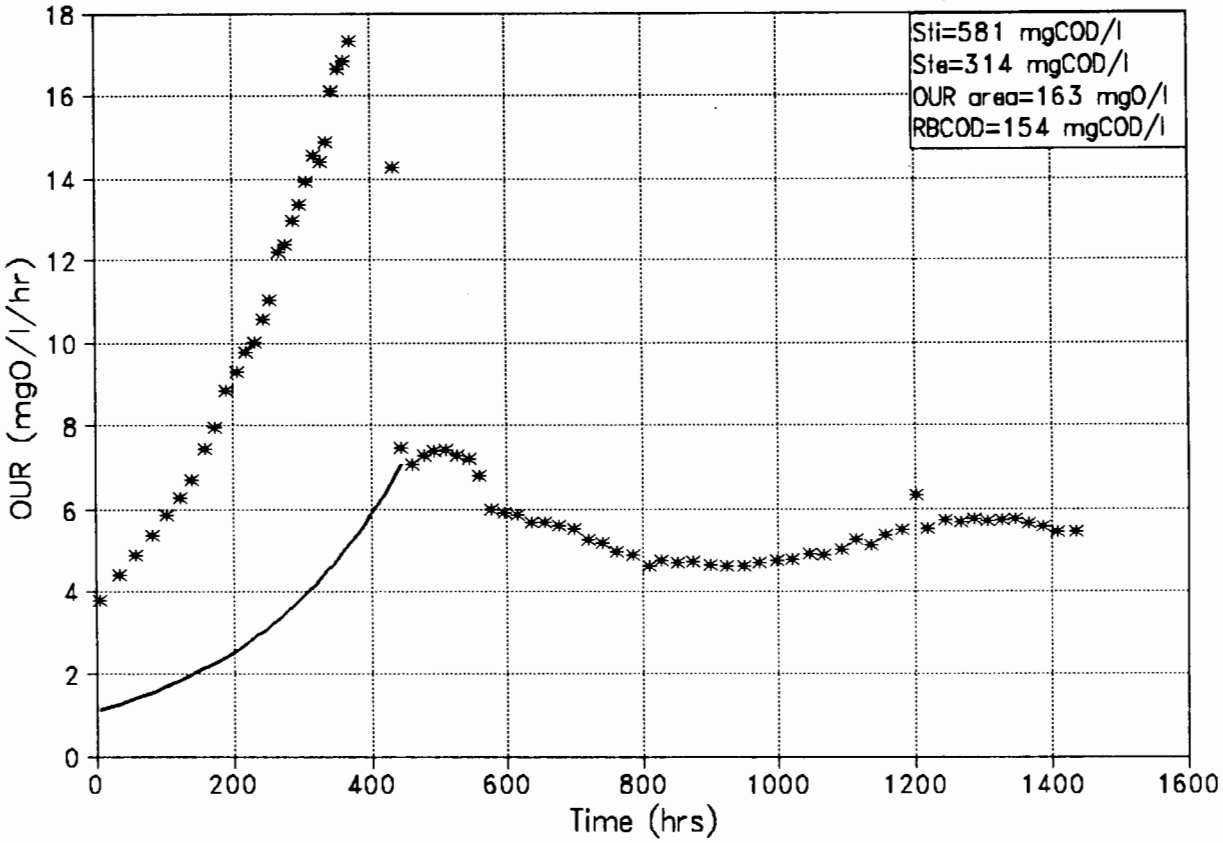


FIG A.13b OUR–time Plot for batch test
1 Apr'94–Sewage Batch No.13

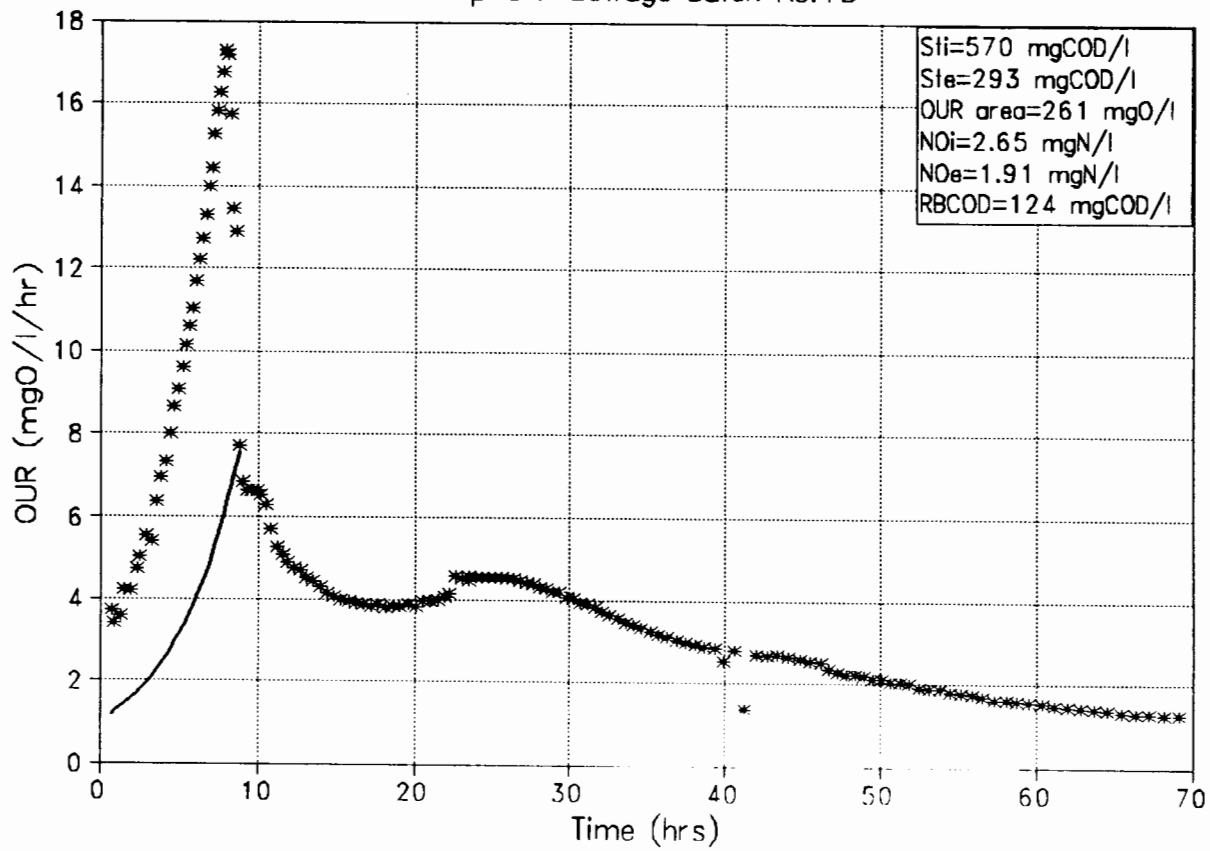


FIG A.13c OUR–time Plot for batch test
3 Apr'94–Sewage Batch No. 13

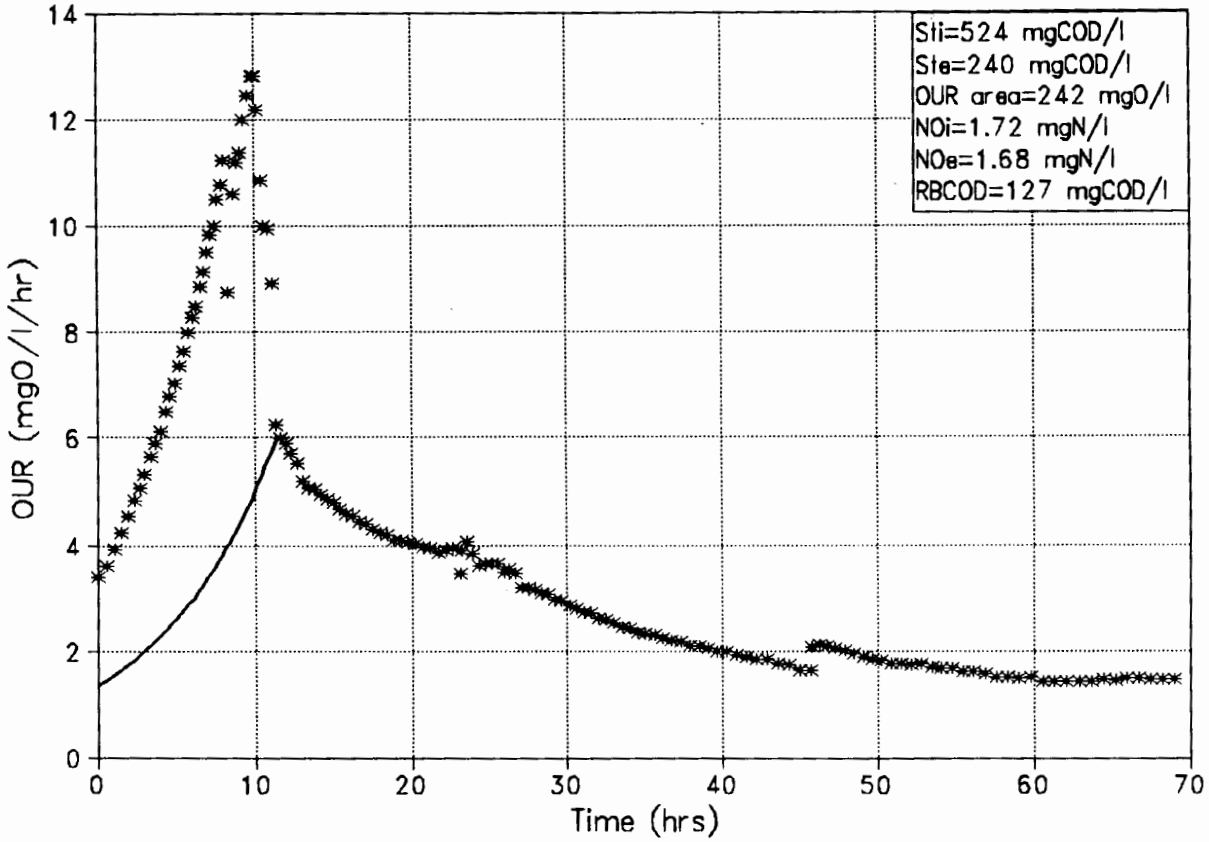


FIG A.13d OUR–time Plot for batch test
7 Apr'94–Sewage Batch No.13

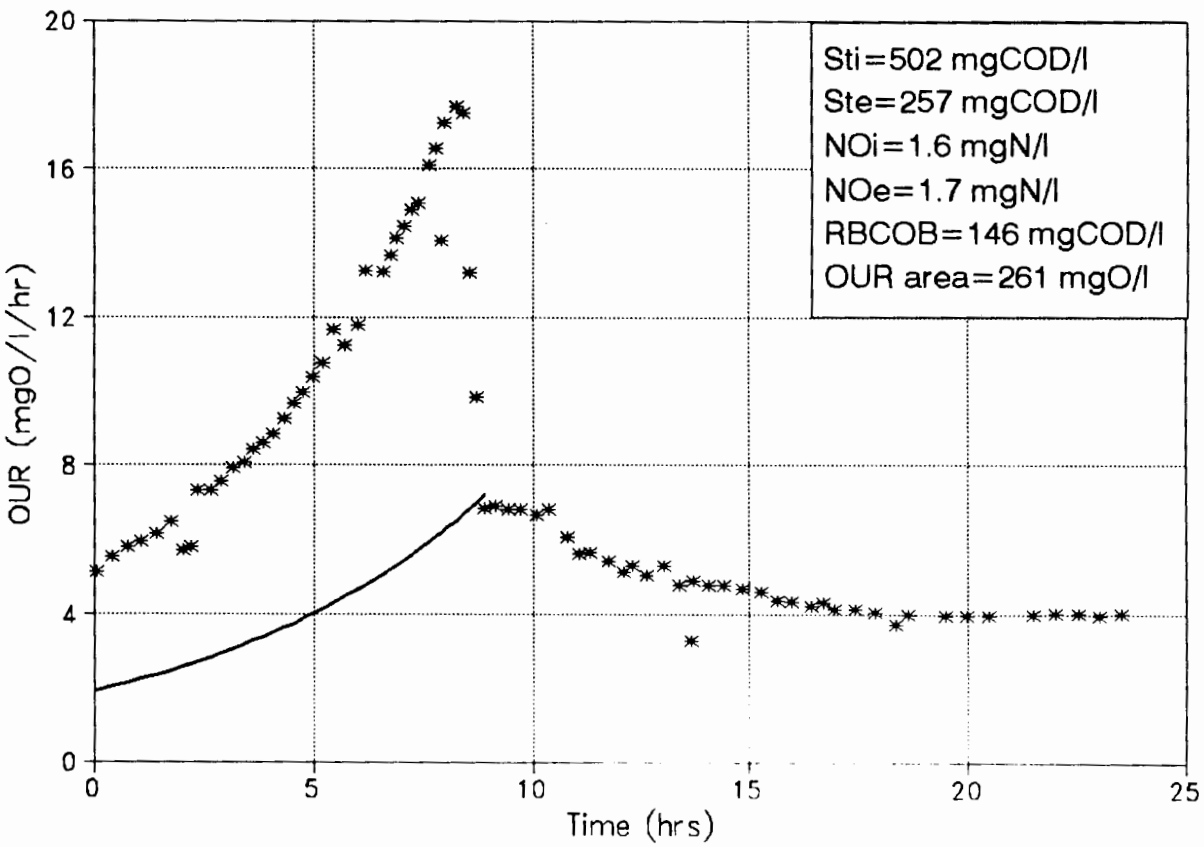


FIG A.13e OUR–time Plot for batch test
11 Apr'94–Sewage Batch No.13

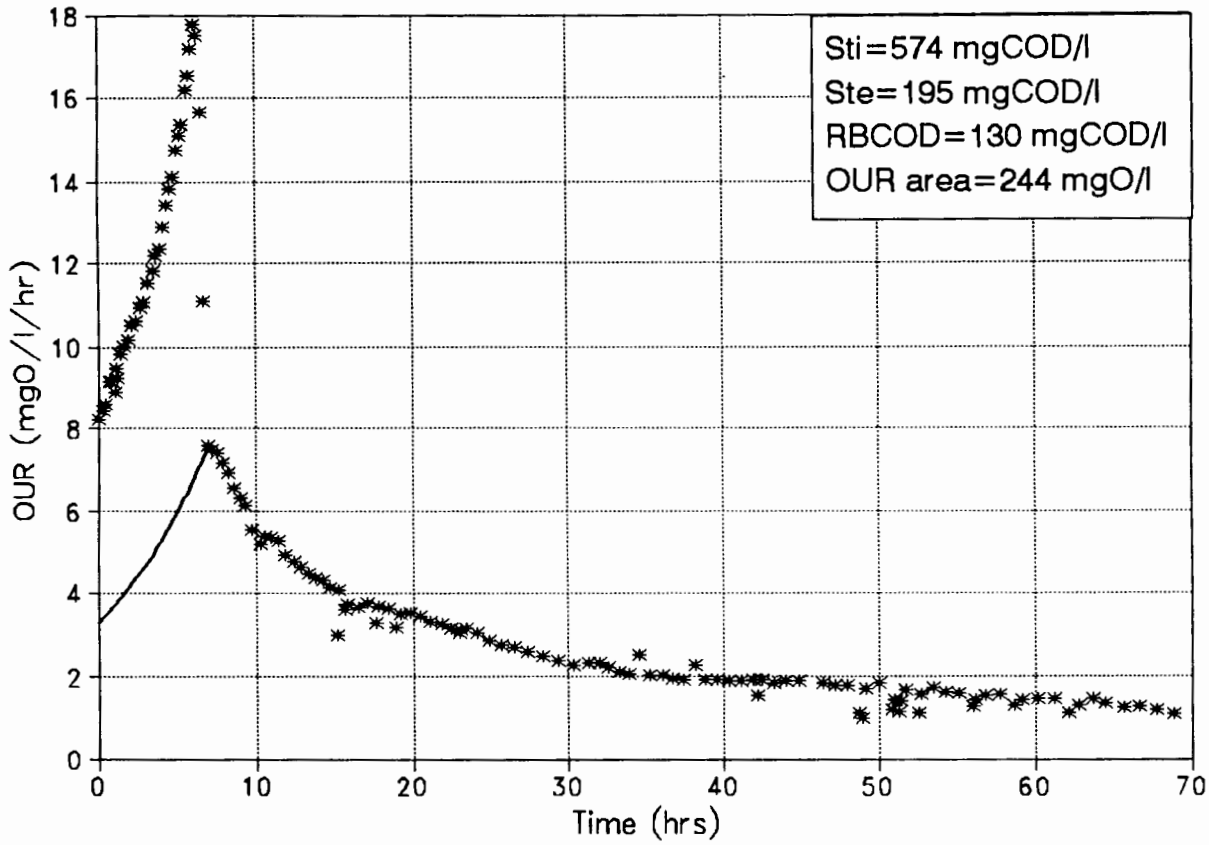


FIG A.13f OUR–time Plot for batch test
8 Apr'94–Sewage Batch No.13

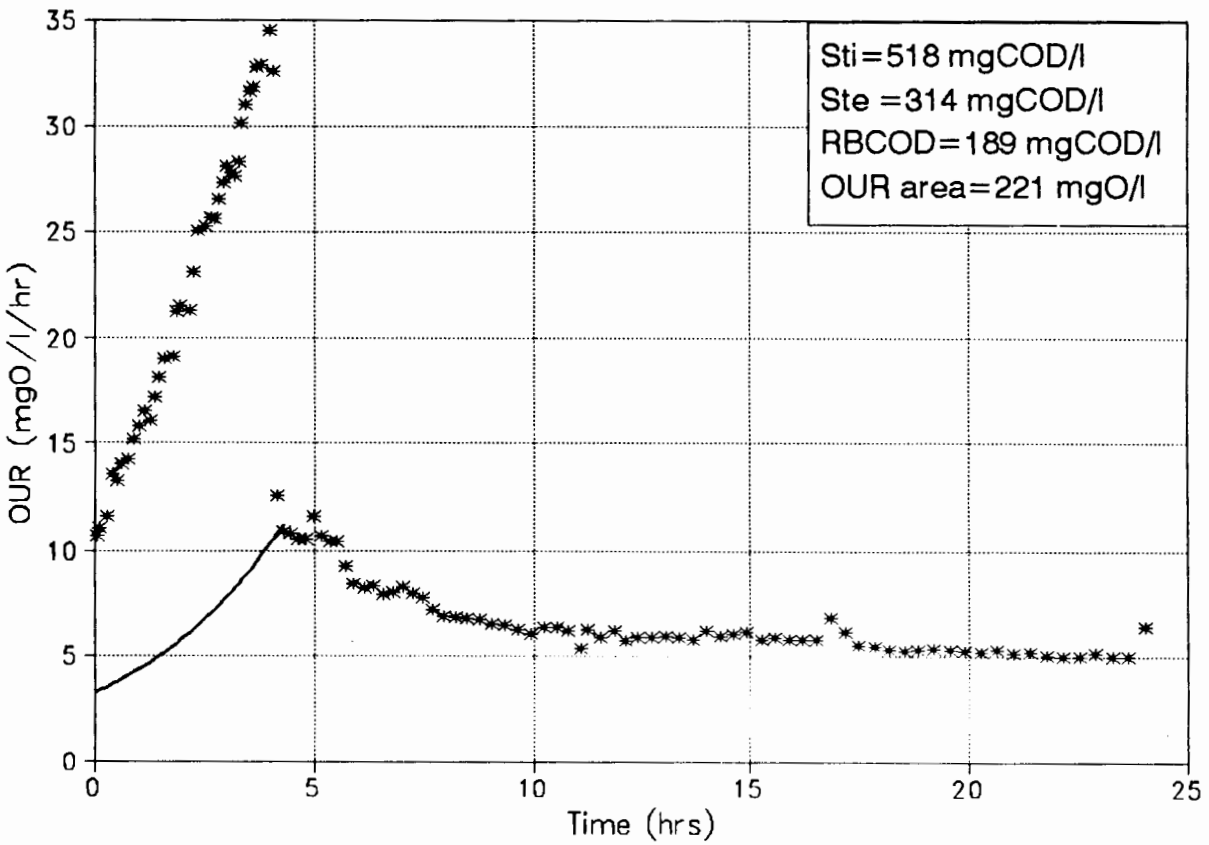


FIG A.14a OUR–time Plot for batch test
22 April'94–Sewage Batch No.14

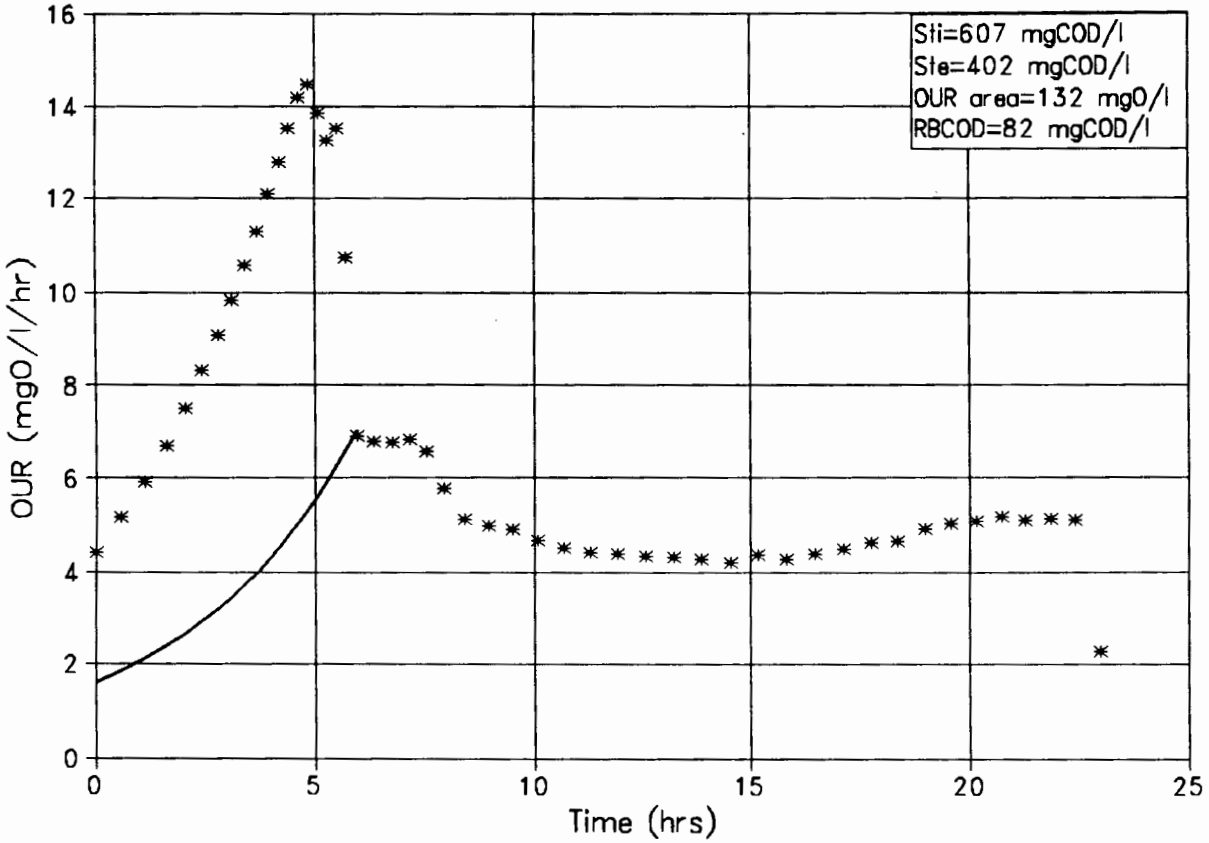


FIG A.14b OUR–time Plot for batch test
12 May'94–Sewage Batch No.14

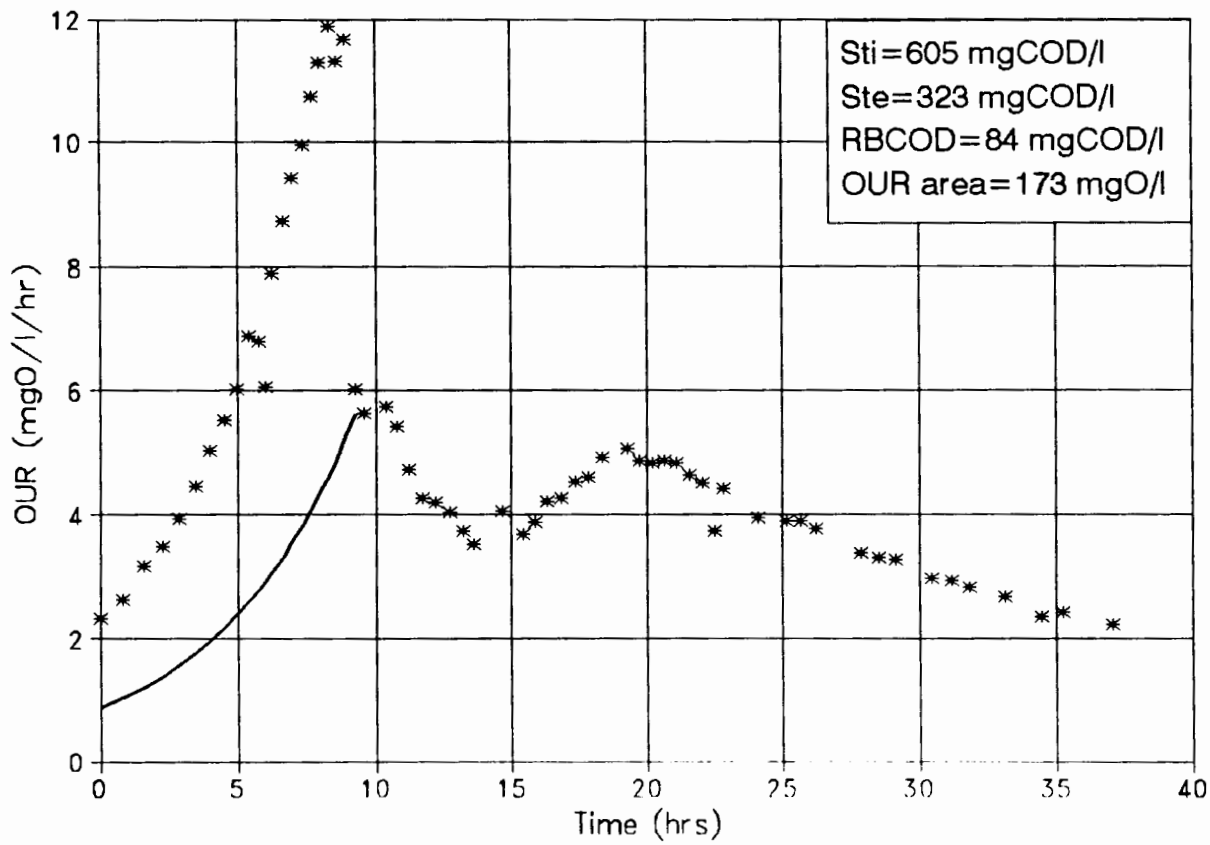


FIG A.14c OUR–time Plot for batch test
28 Apr'94–Sewage Batch No.14

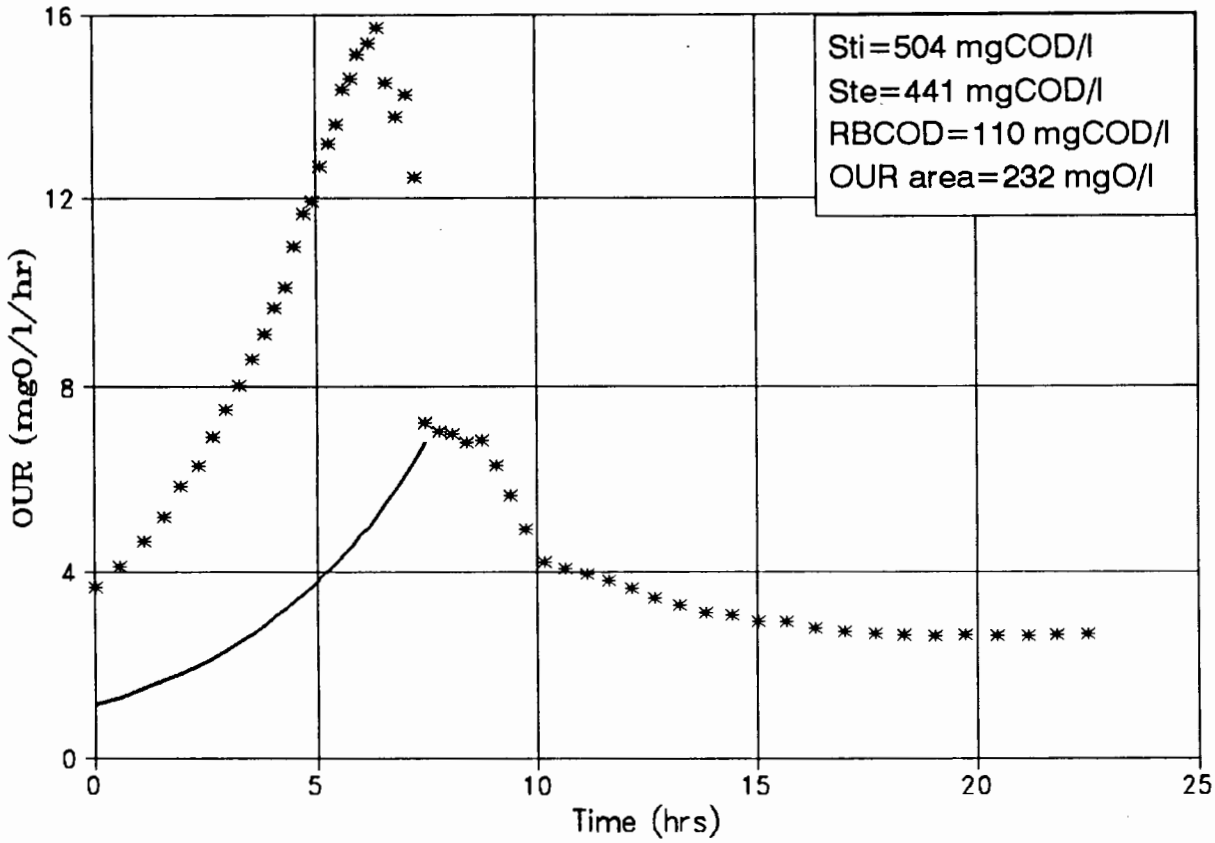


FIG A.14d OUR–time Plot for batch test
29 Apr'94–Sewage Batch No.14

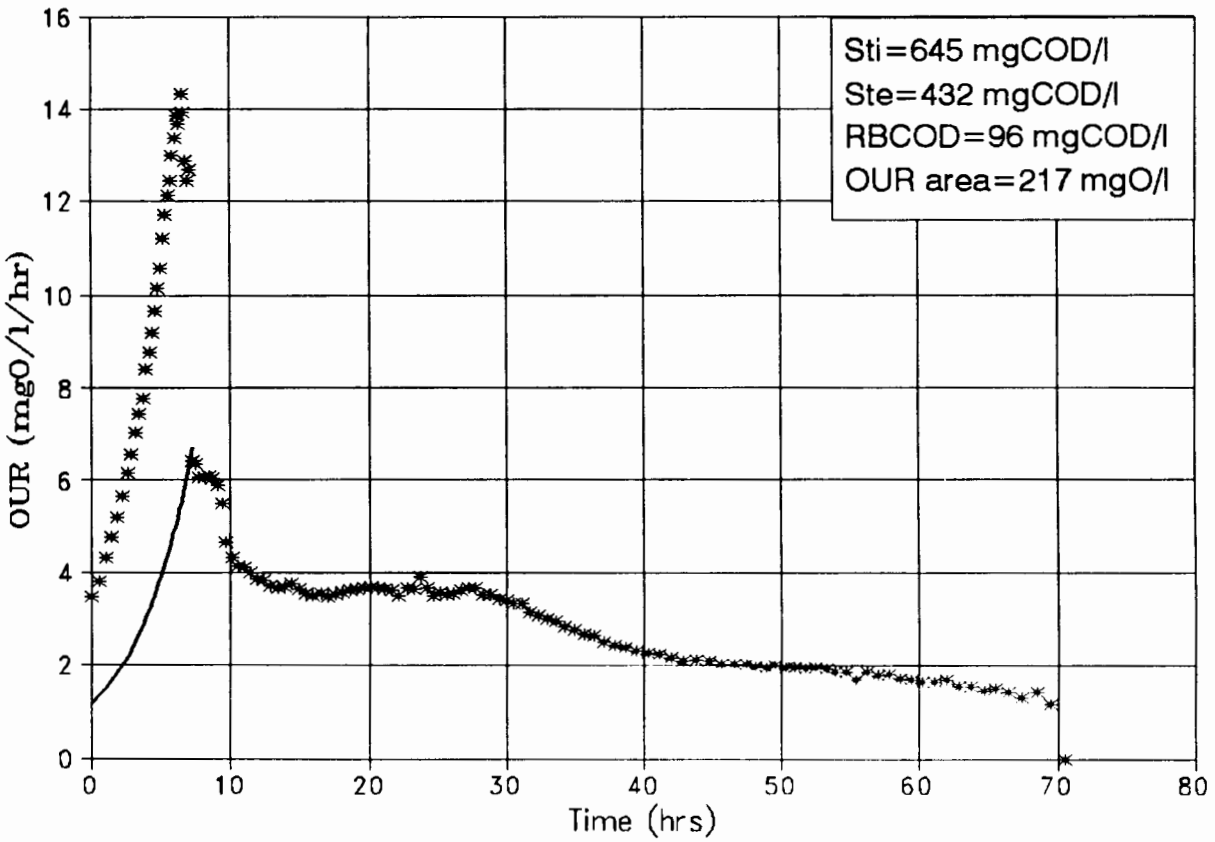


FIG A.14e OUR–time Plot for batch test
8 MAY'94–Sewage Batch No.14

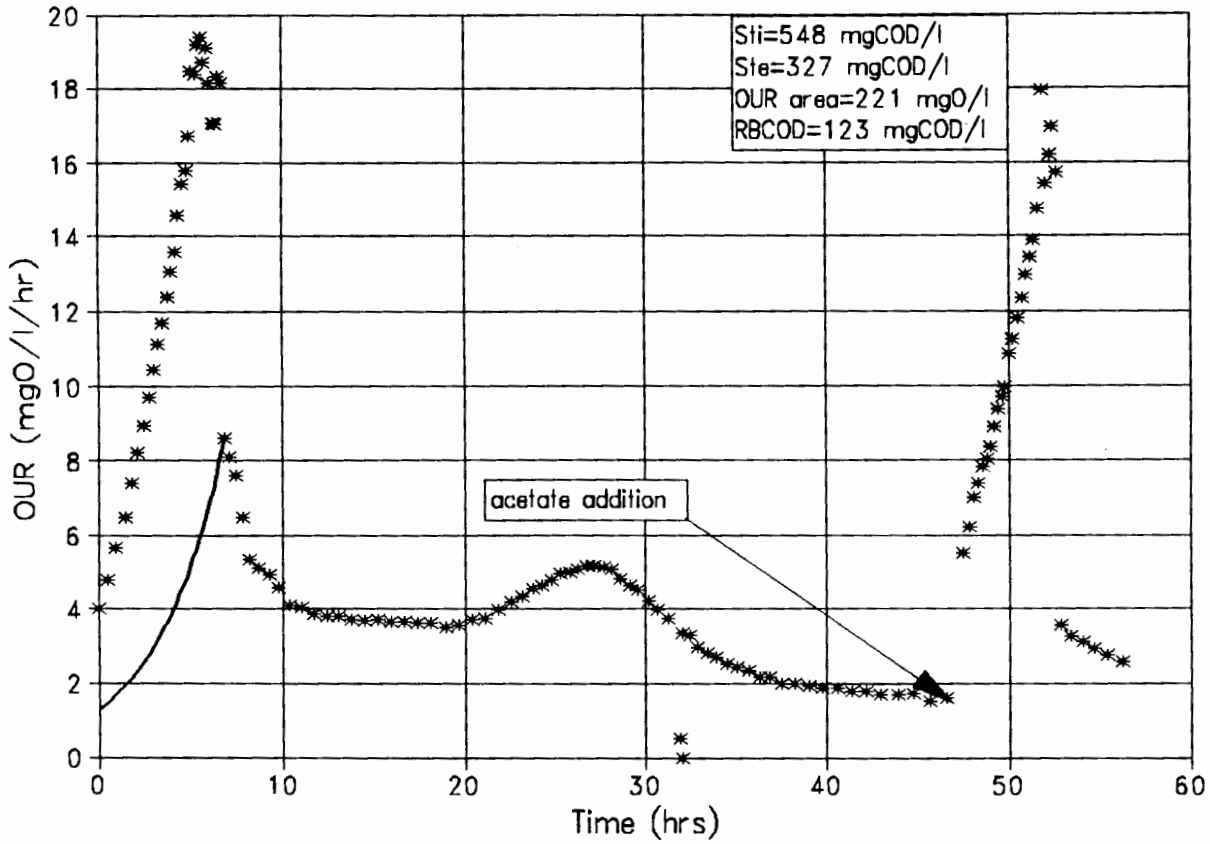


FIG A.15a OUR–time Plot for batch test.
24 May'94–Sewage Batch No.15

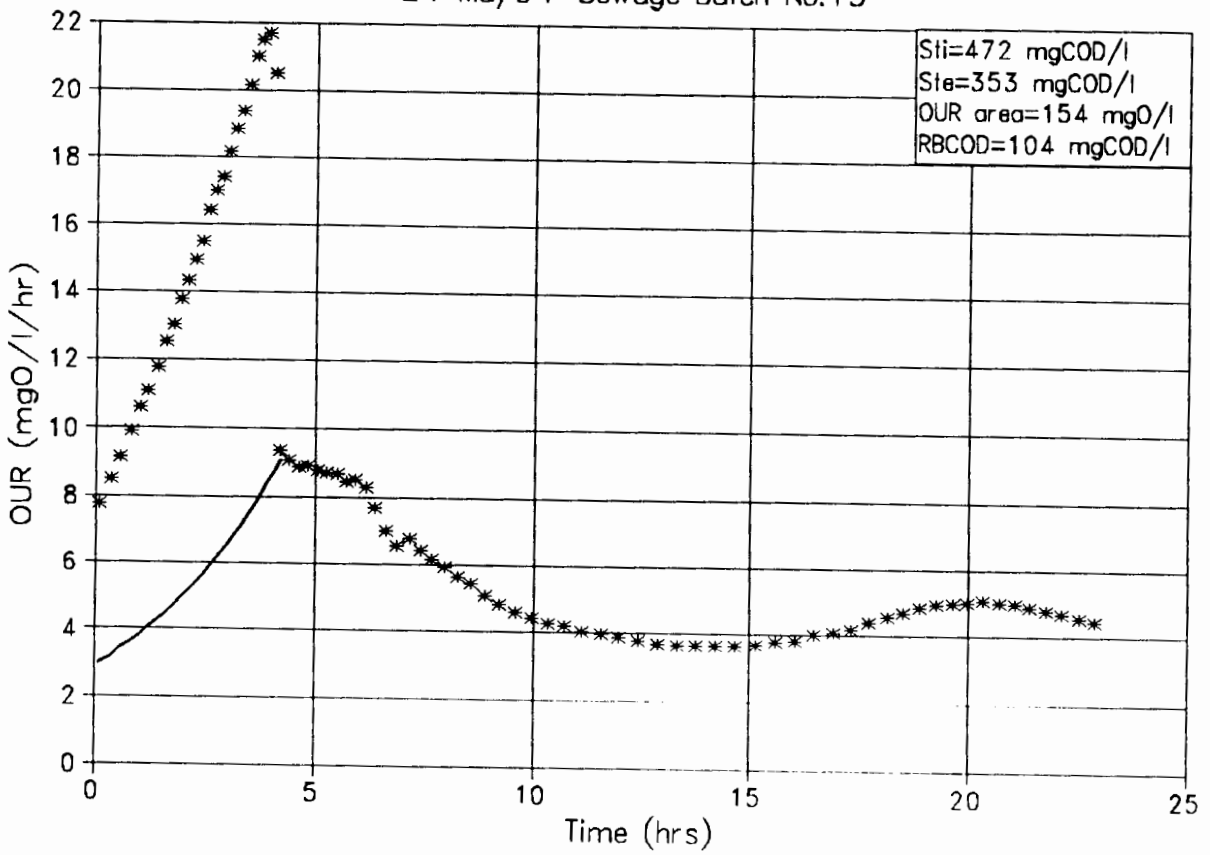


FIG A.15b OUR–time Plot for batch test
19 May'94–Sewage Batch No.15

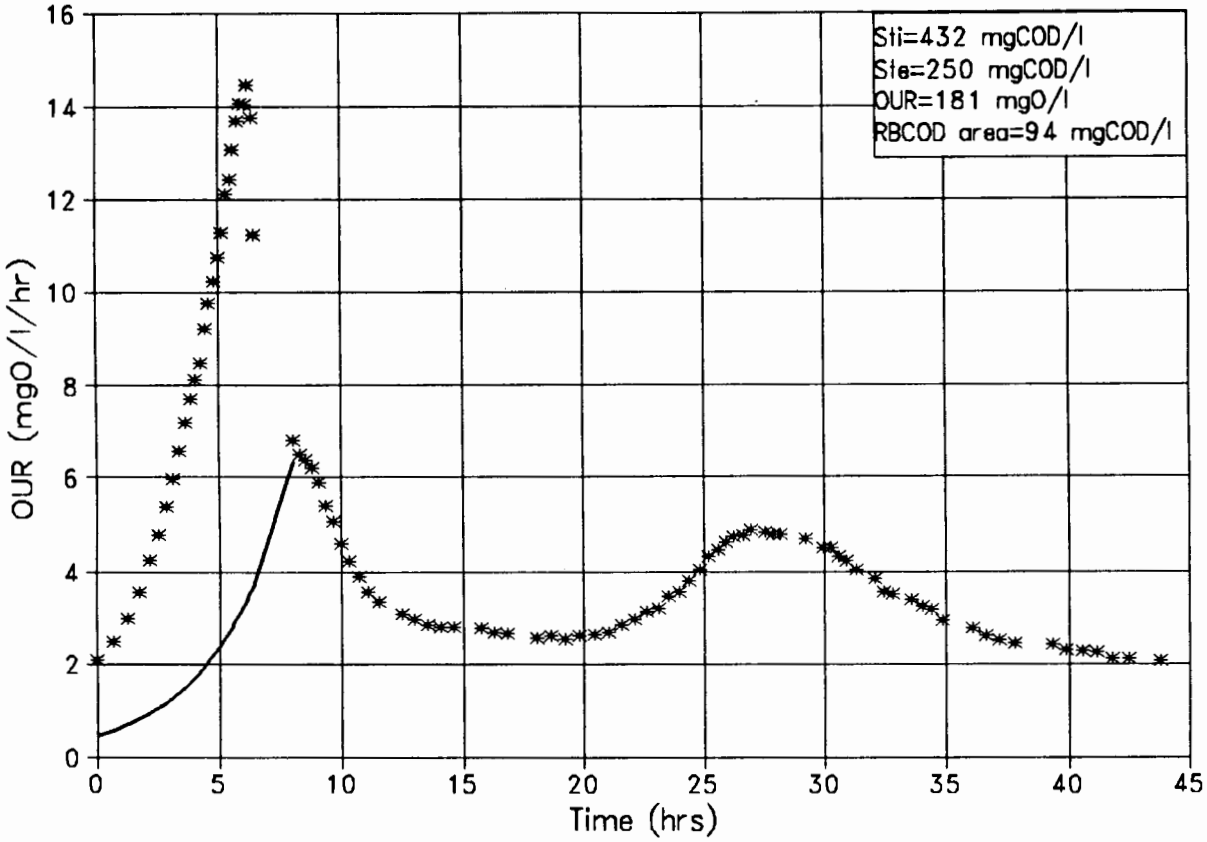


FIG A.15c OUR–time Plot for batch test
27 May'94–Sewage Batch No.15

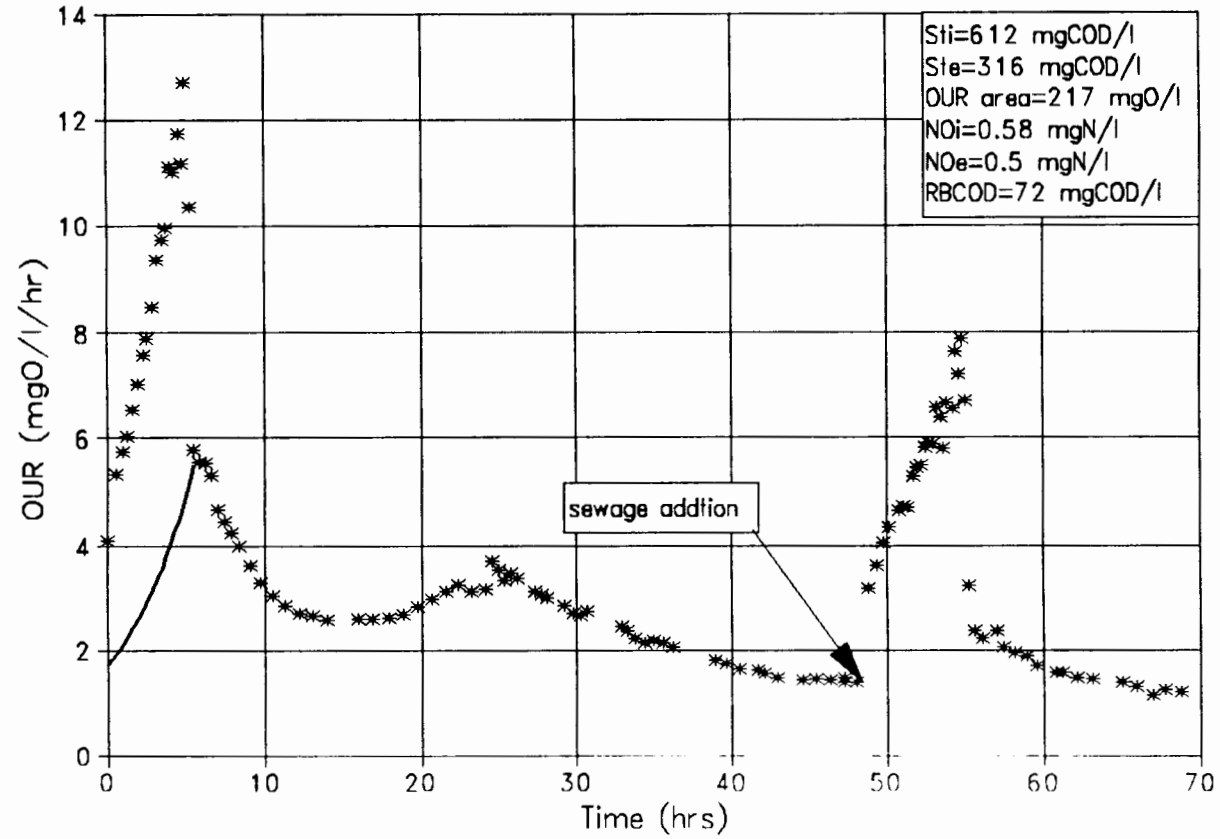


FIG A.15d OUR–time Plot for batch test
22 May'94–Sewage Batch No.15

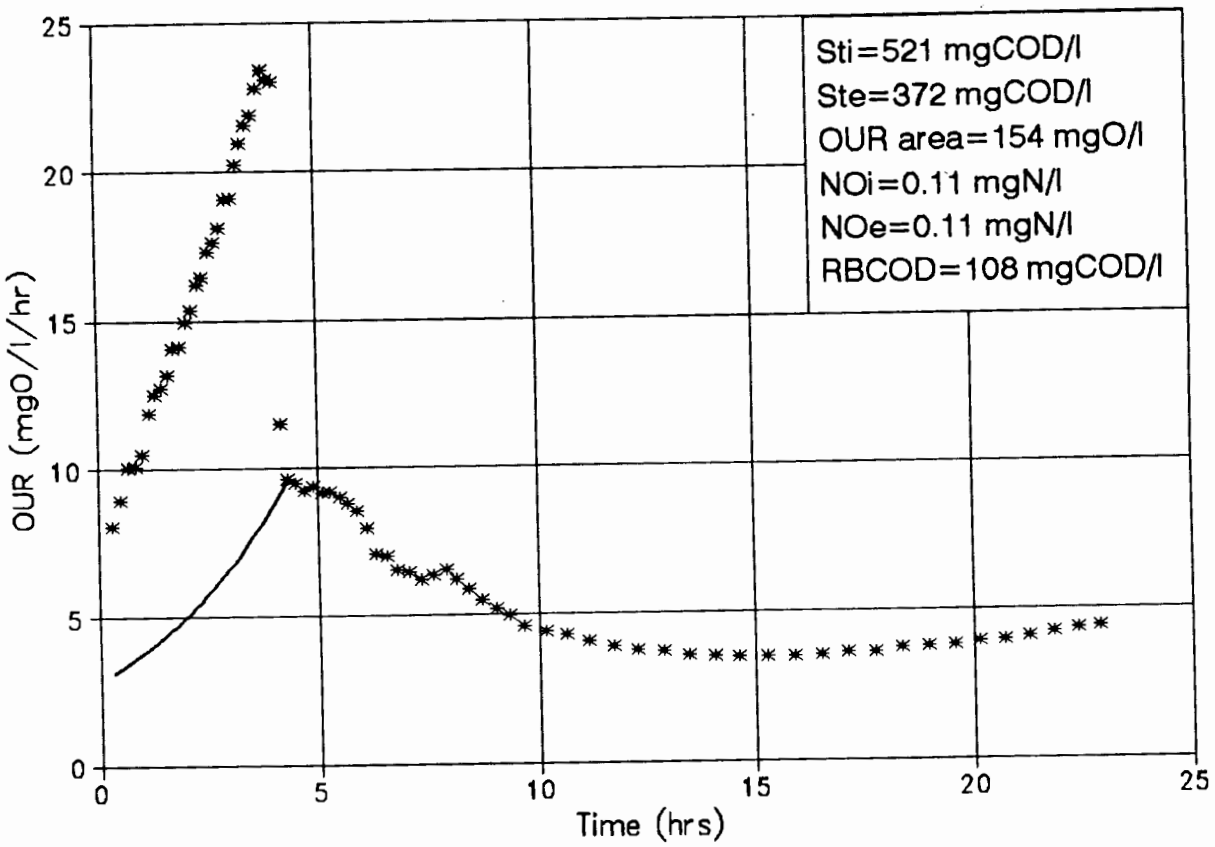


FIG A.15e OUR–time Plot for batch test
23 May'94–Sewage Batch No.15

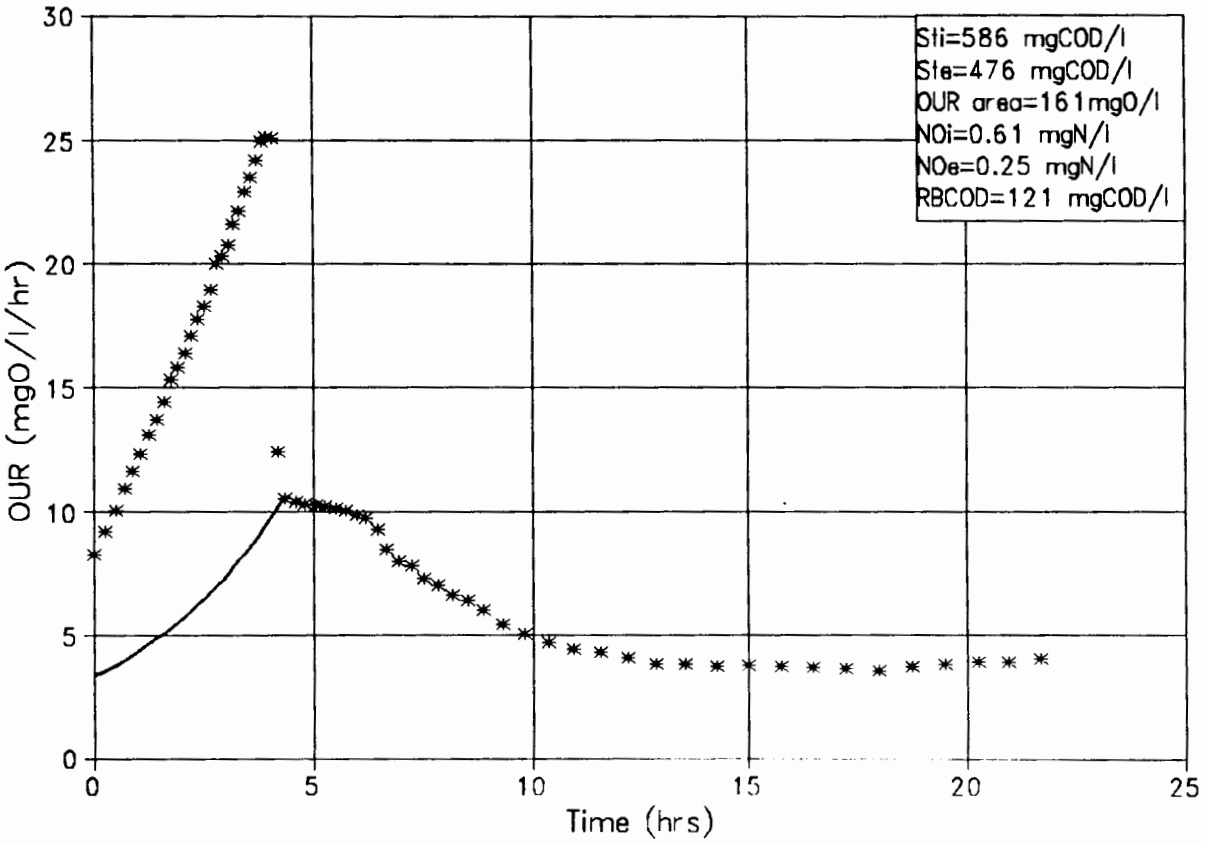


FIG A.16a OUR–time Plot for batch test
29 June'94–Sewage Batch No.16

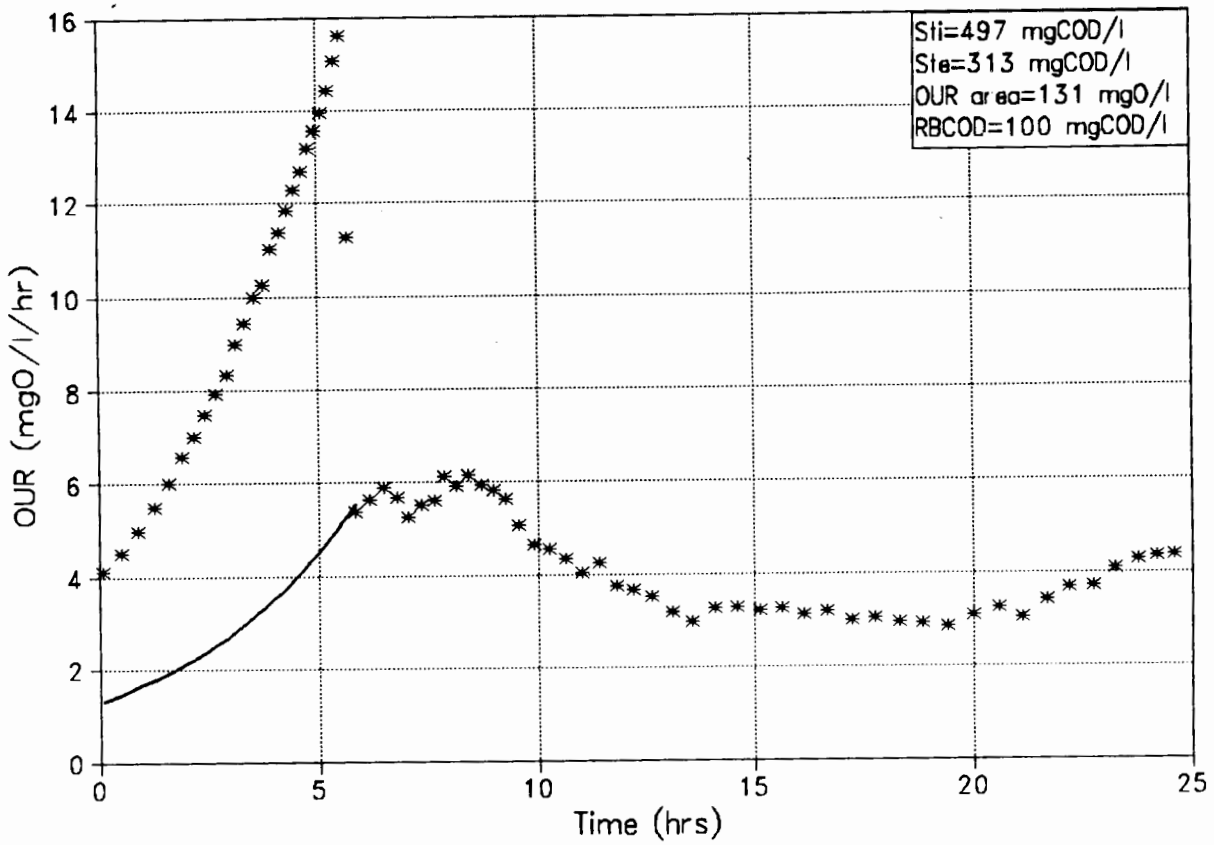


FIG A.16b OUR–time Plot for batch test
23 Jun'94–Sewage Batch No.16

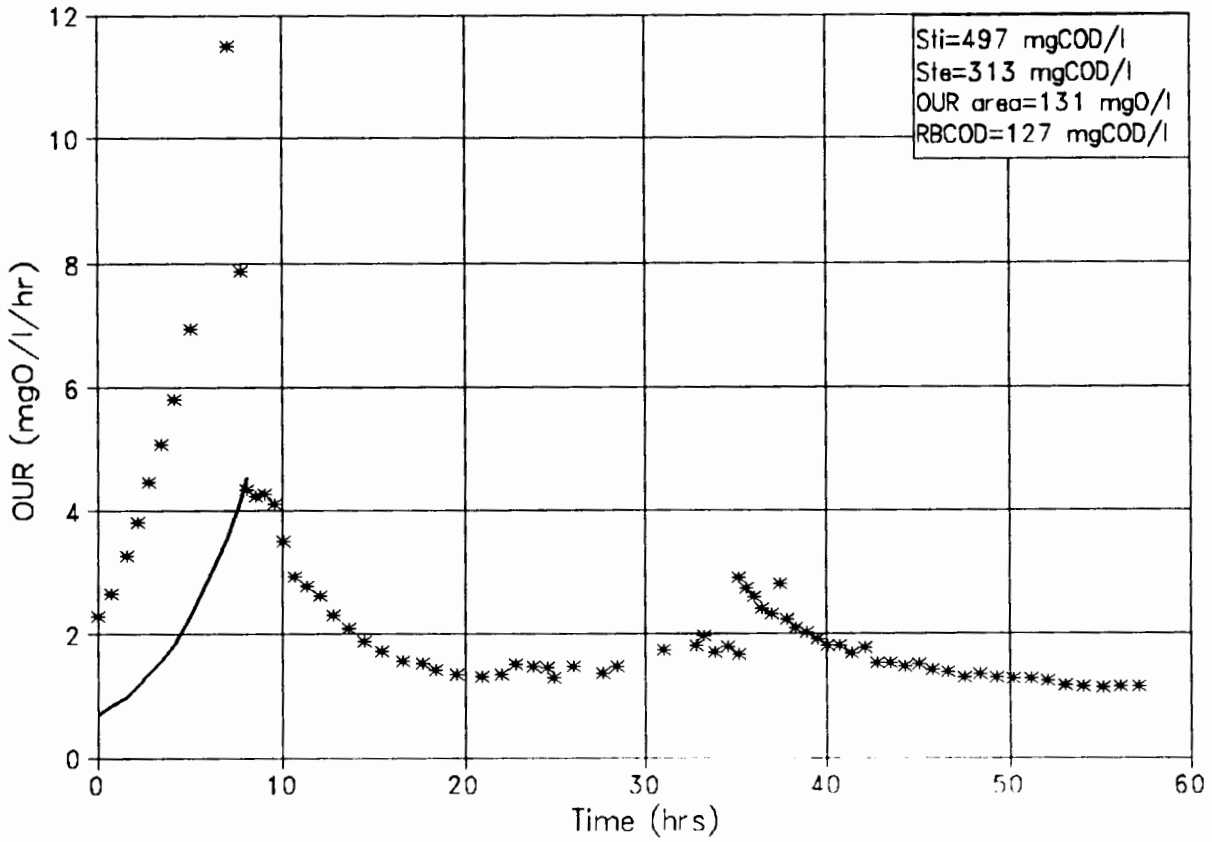


FIG A.16c OUR–time Plot for batch test
24 Jun'94–Sewage Batch No.16

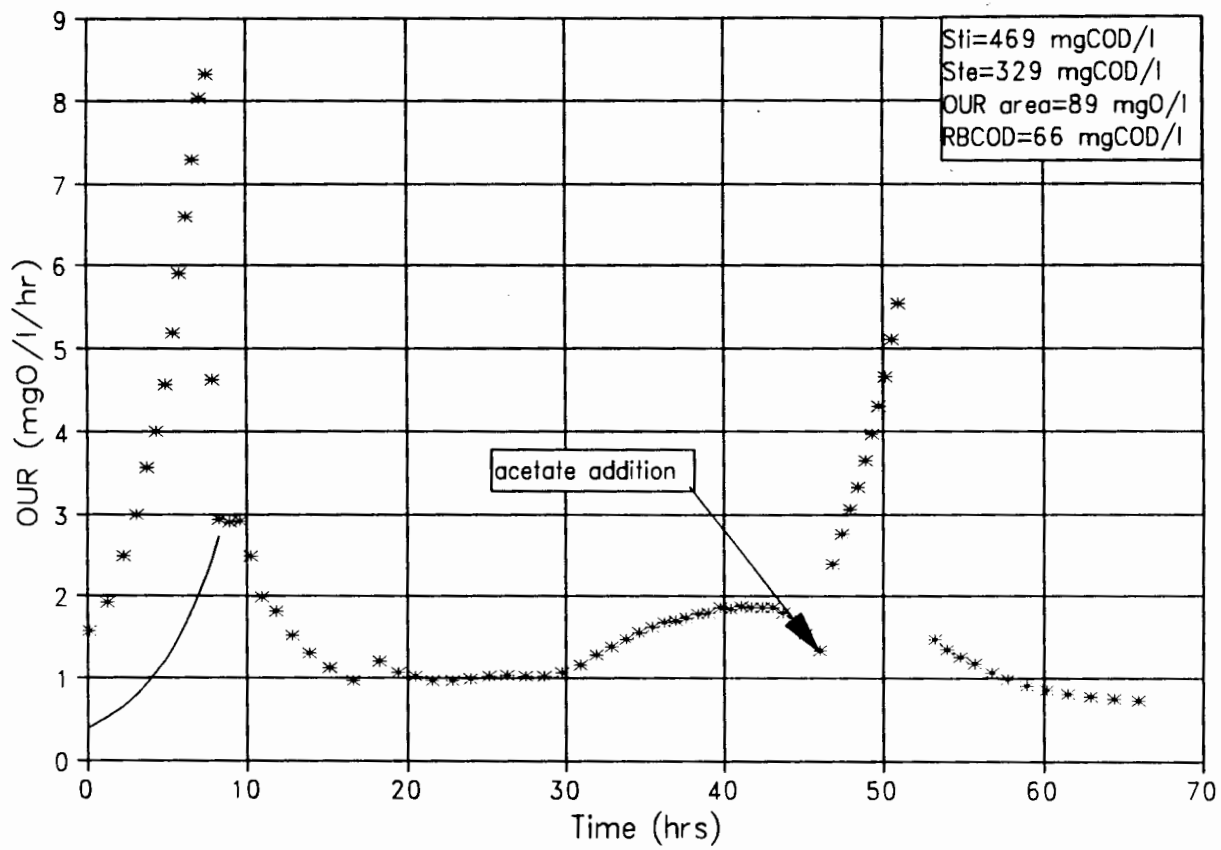


FIG A.16d OUR–time Plot for batch test
27 Jun'94–Sewage Batch NO.16

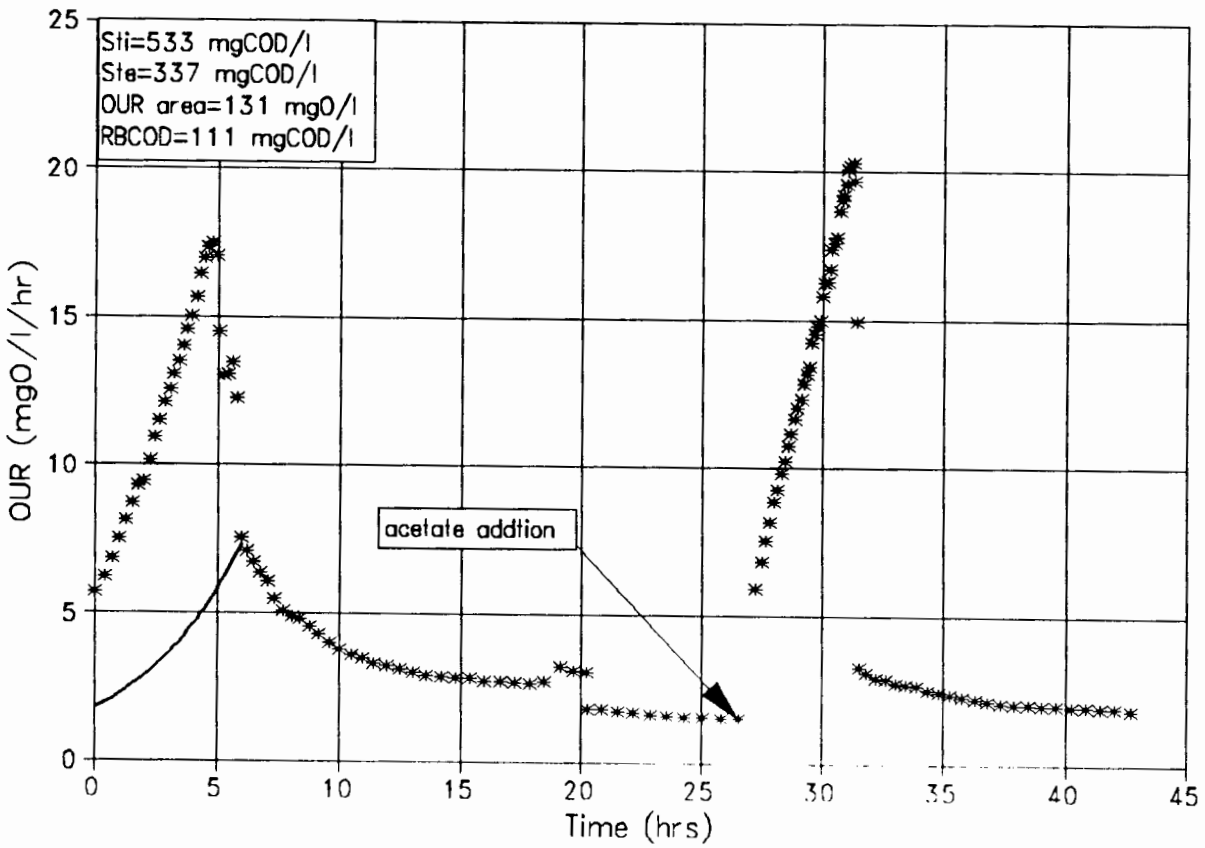


FIG A.16e OUR–time Plot for batch test
1 Jul'94–Sewage Batch No.16

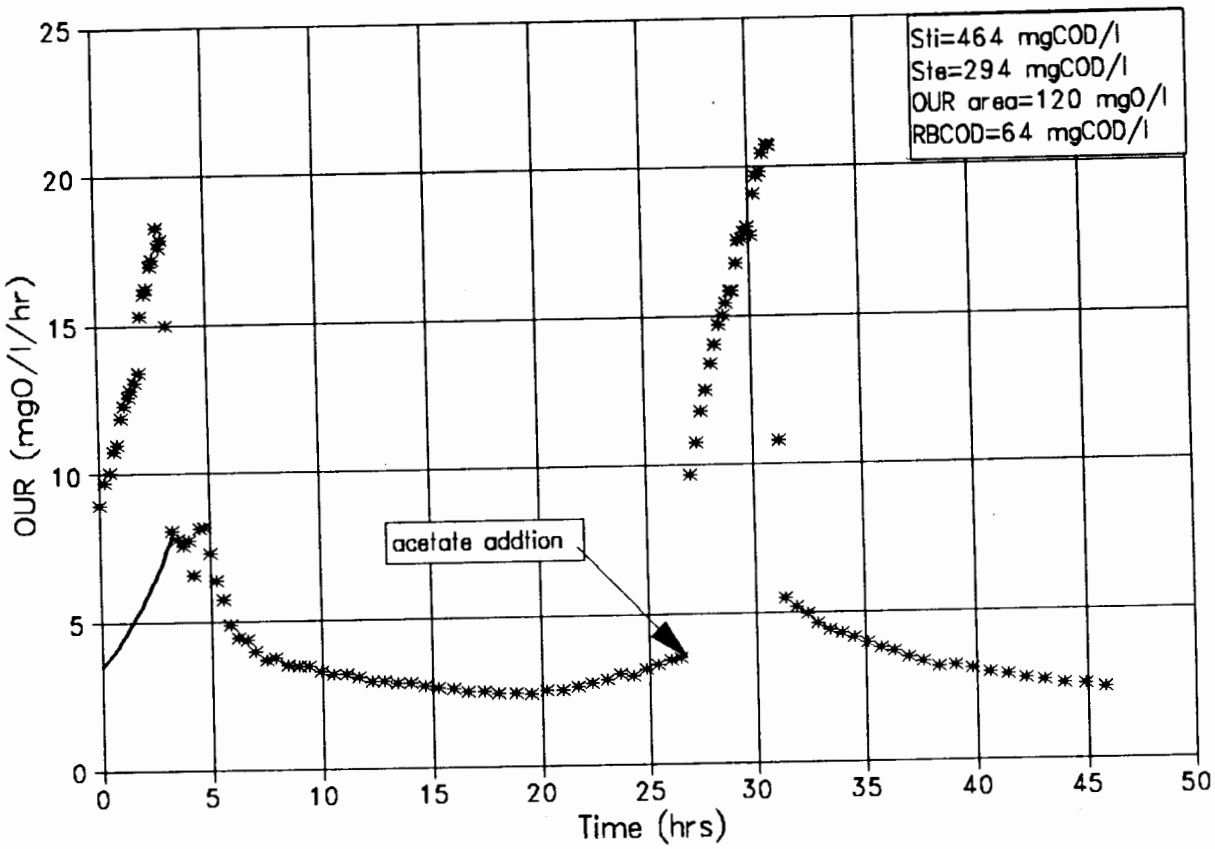


FIG A.17a OUR–time Plot for batch test
8 Jul'94–Sewage Batch No.17

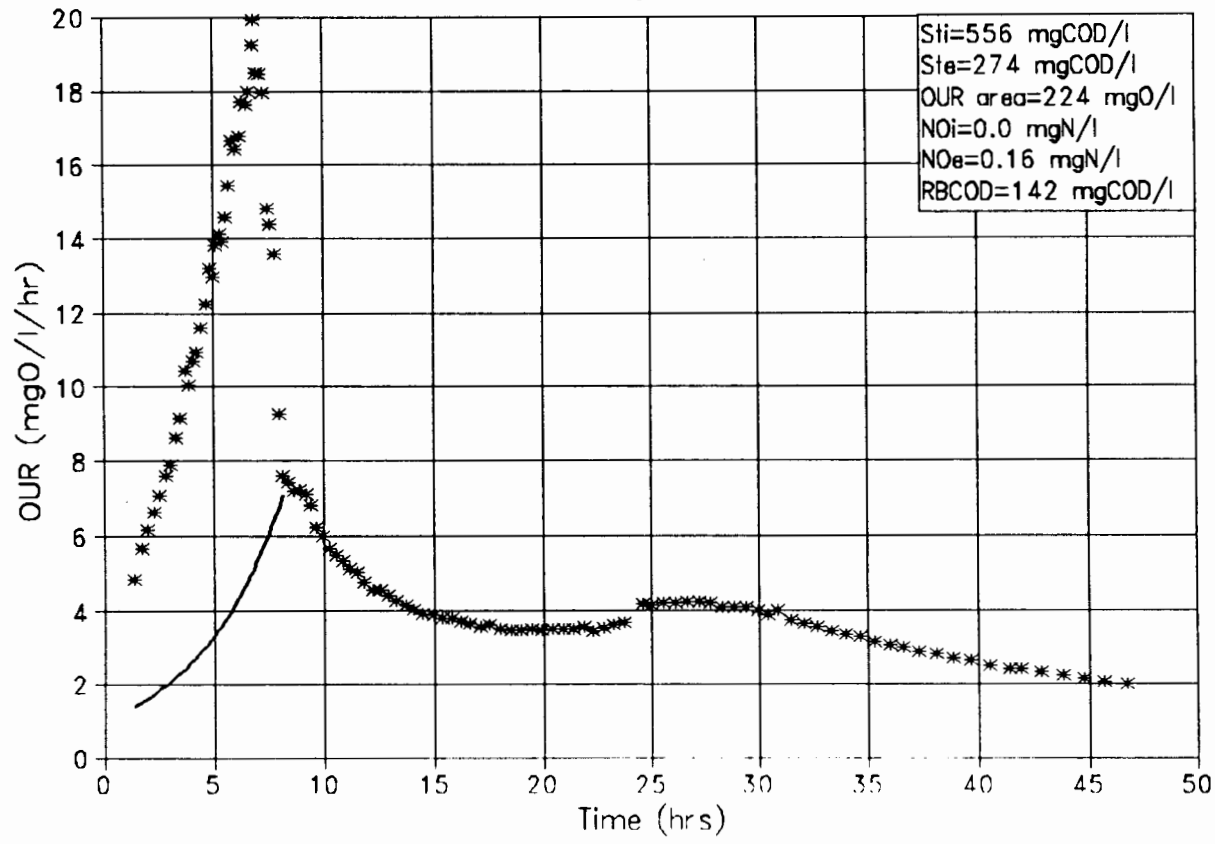


FIG A.17b OUR–time Plot for batch test
5 Jul'94–Sewage Batch No.17

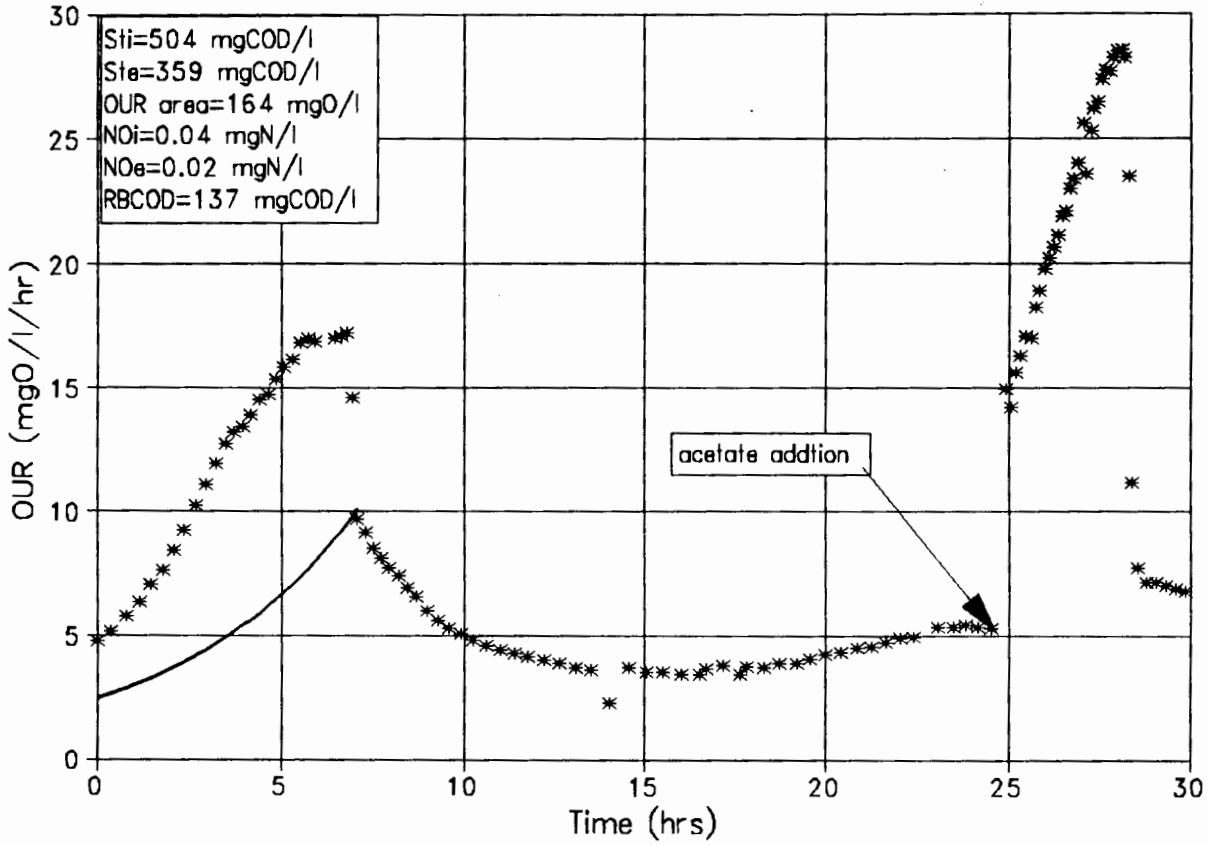


FIG A.17c OUR–time Plot for batch test
7 Jul'94–Sewage Batch No.17

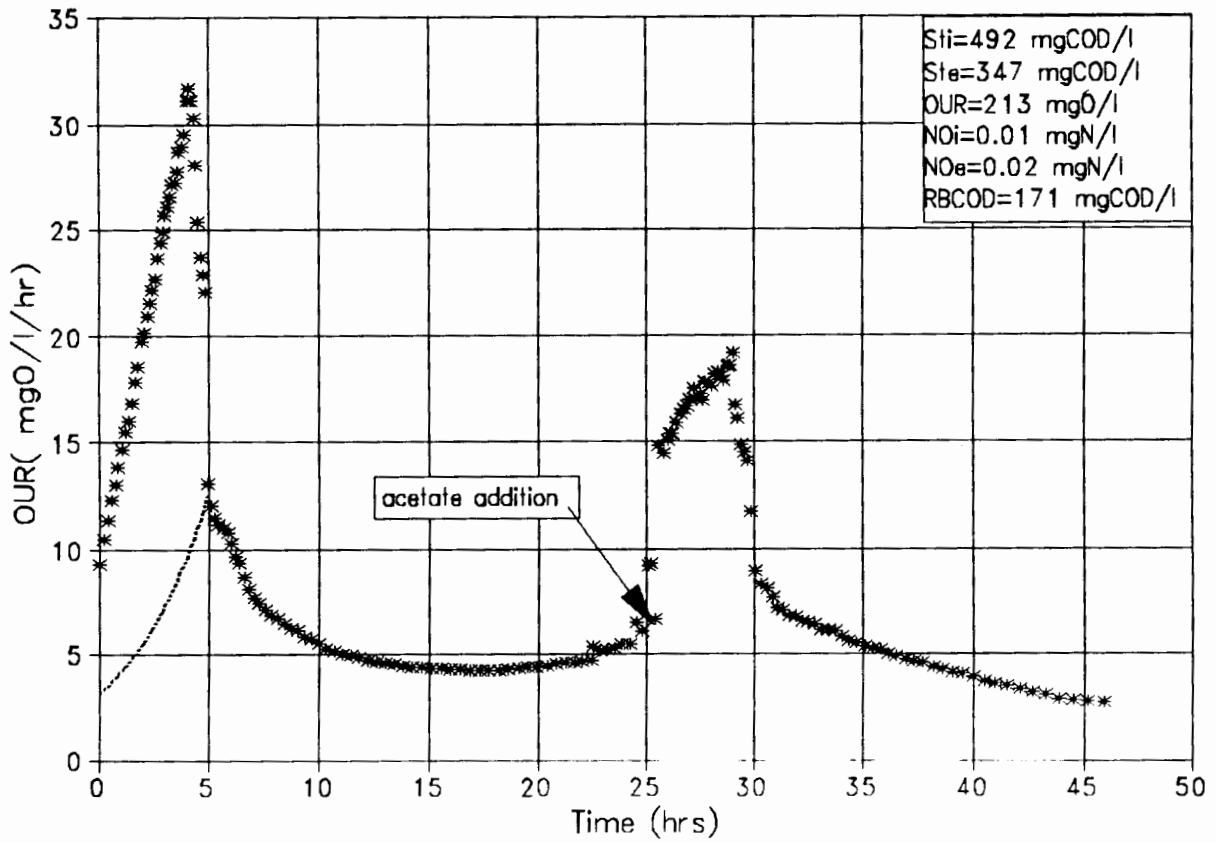


FIG A.17d OUR–time Plot for batch test
9 Jul–Sewage Batch No.17

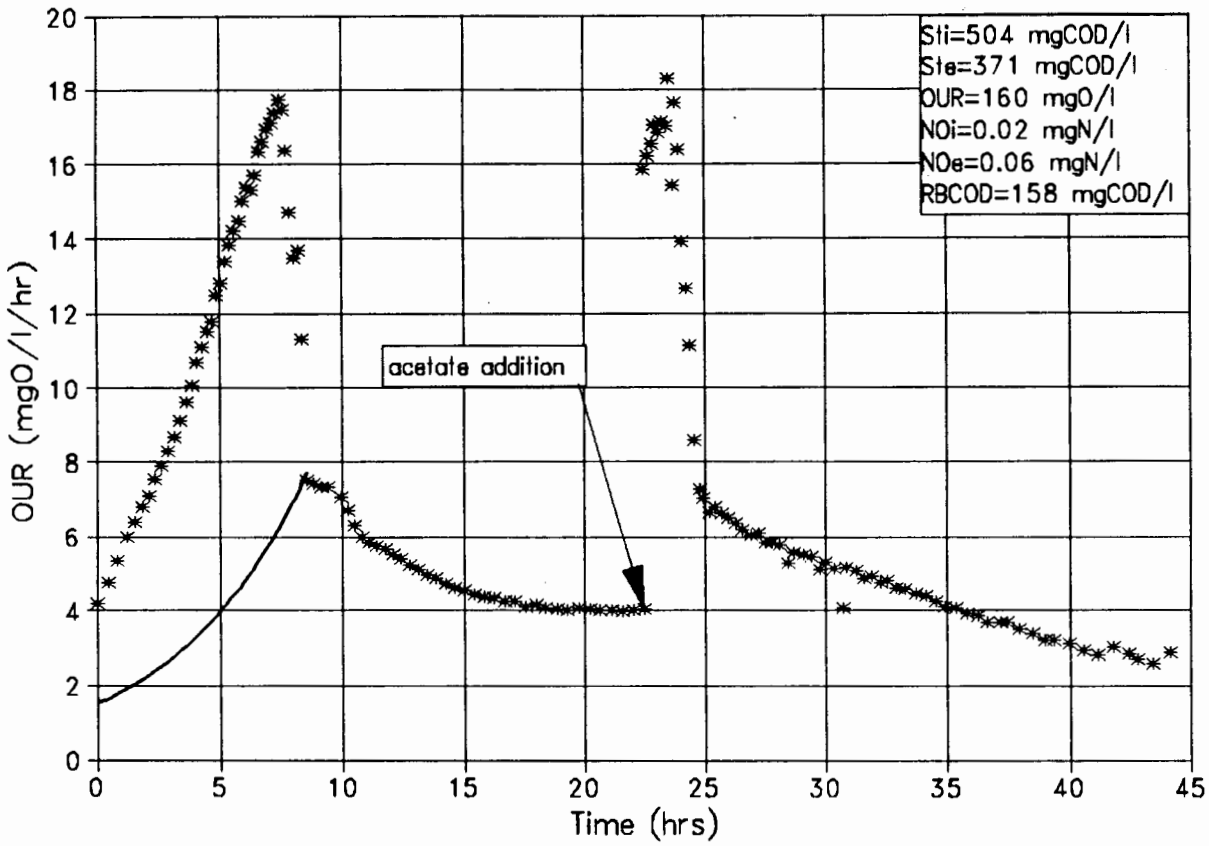


FIG A.17e OUR–time Plot for batch test
13 Jul'94–Sewage Batch No.17

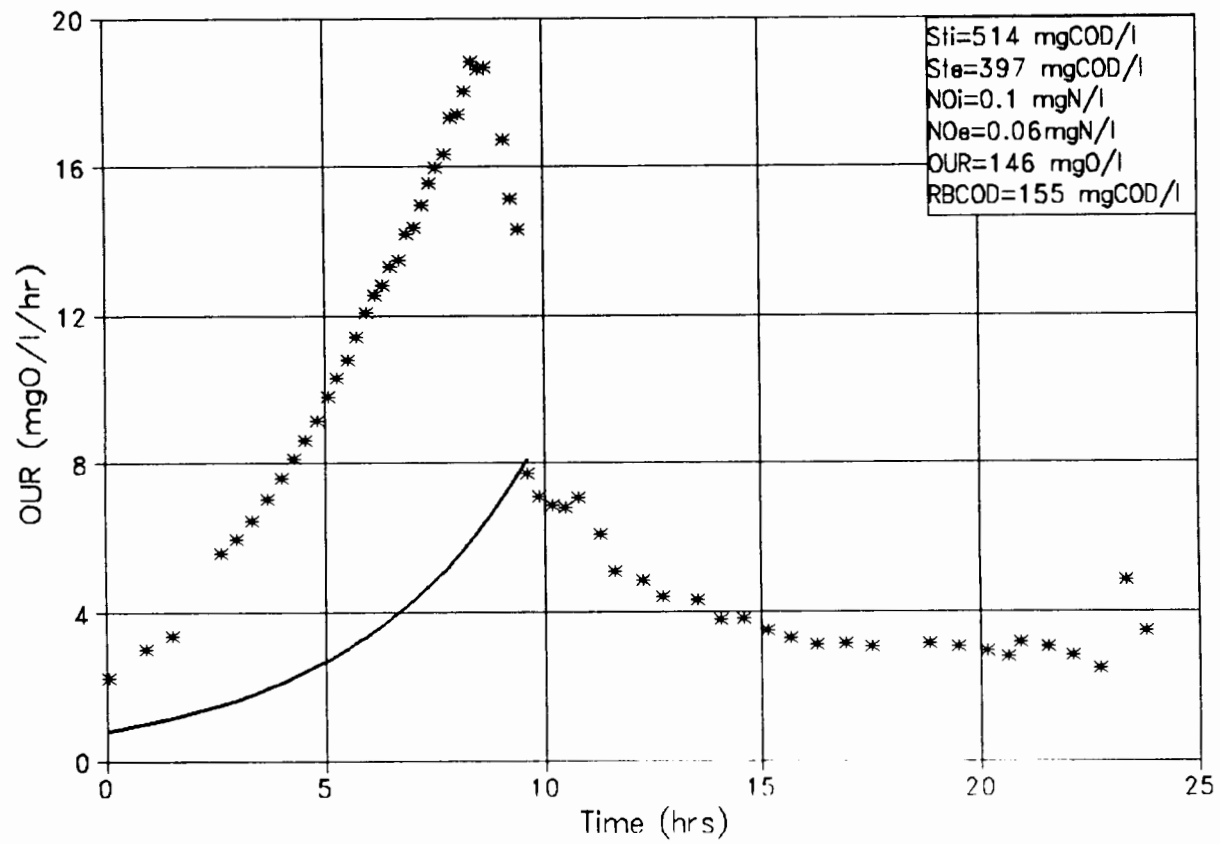


FIG A.17f OUR–time Plot for batch test
14 Jul'94–Batch No.17

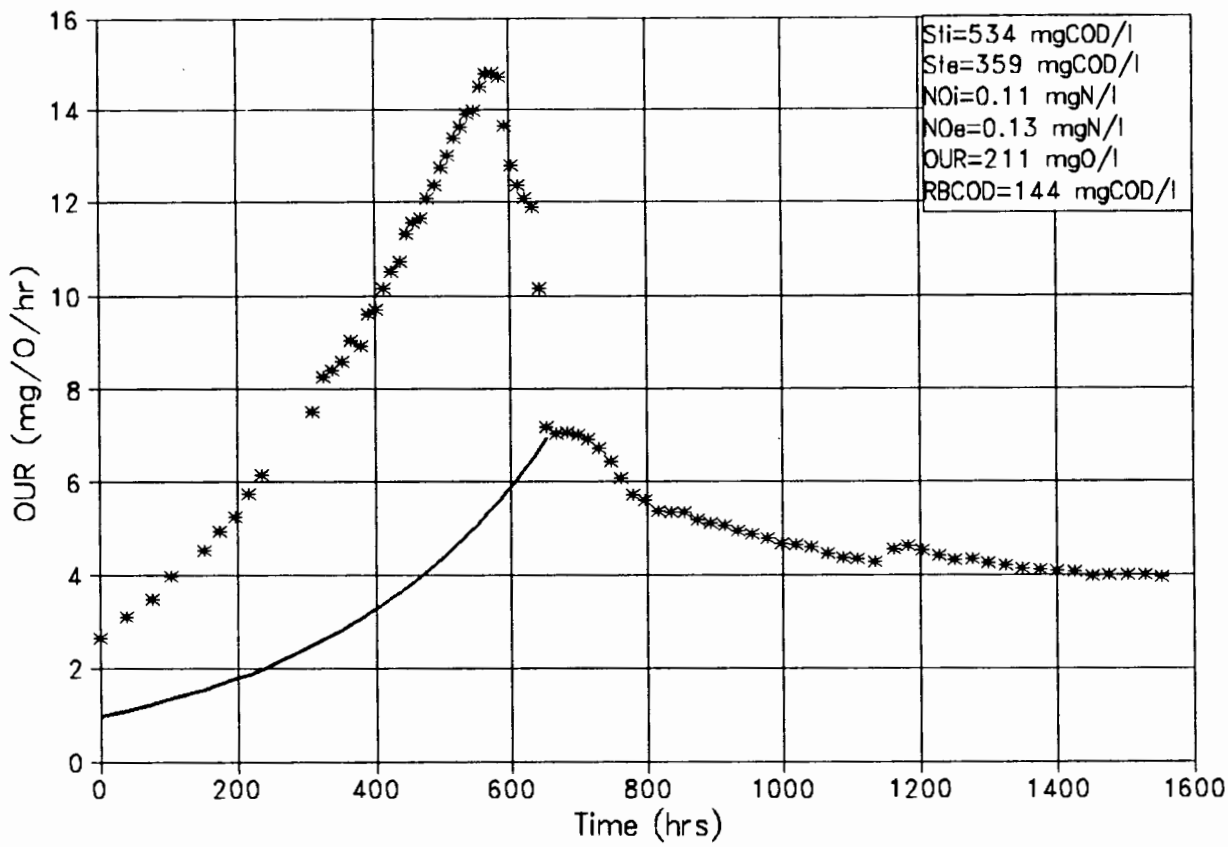


FIG A.17g OUR–time Plot for batch test
18 Jul'94–Sewage Batch No.17

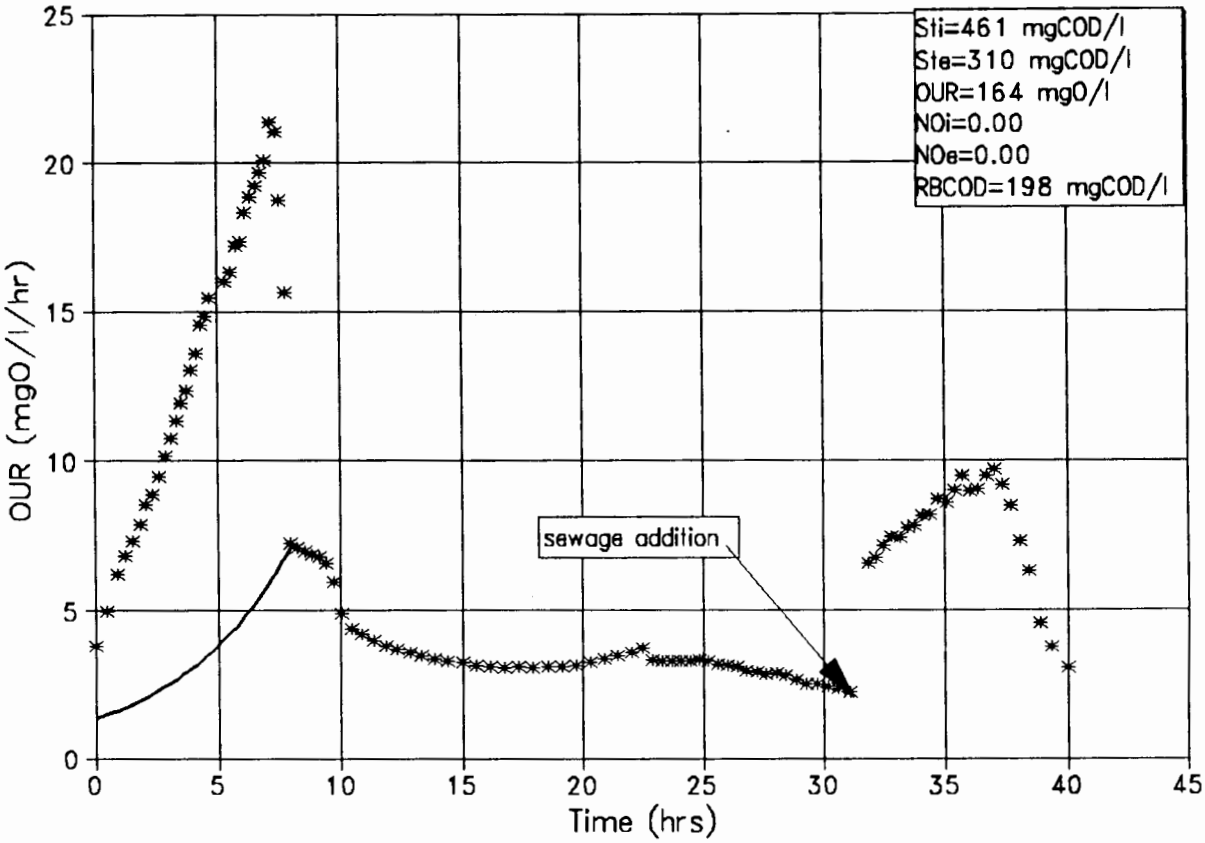


FIG A.17j OUR–time Plot for batch test
19 Jul'94–Sewage Batch No.17

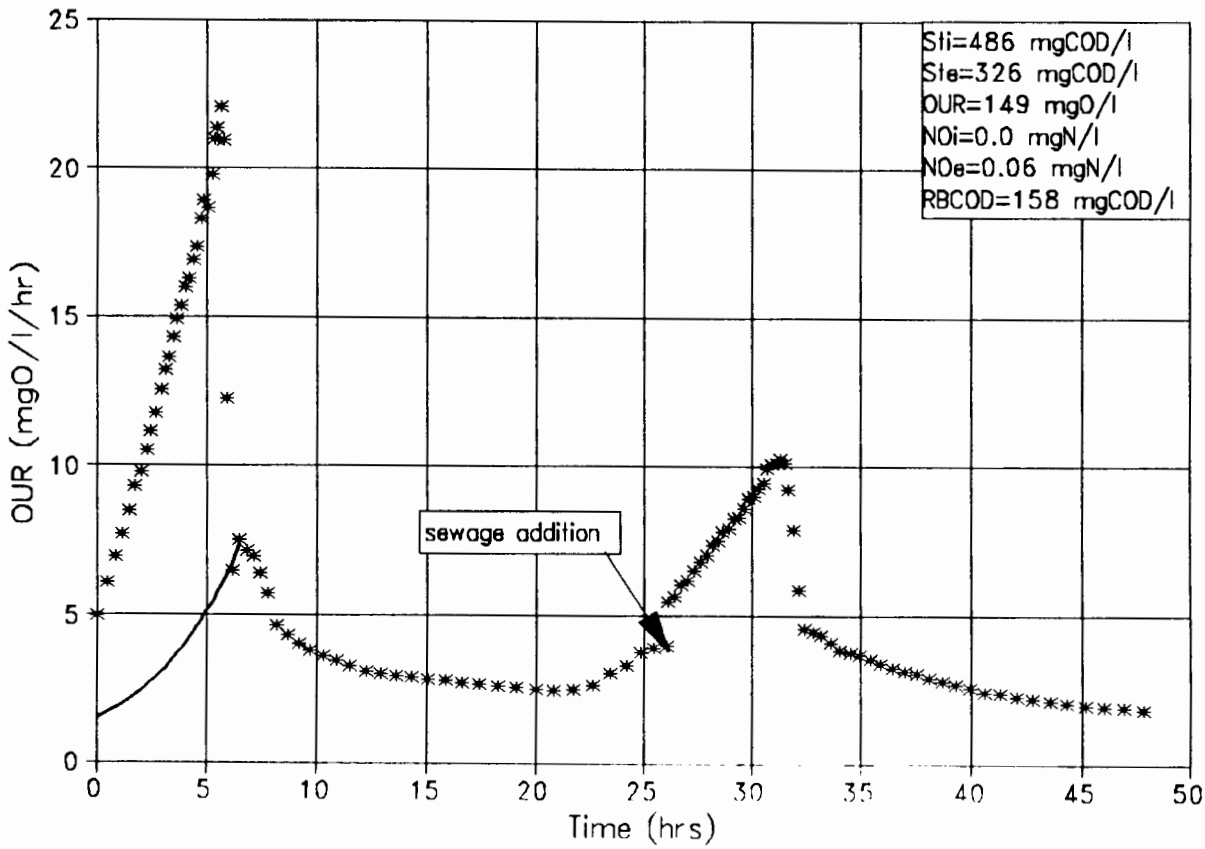


FIG A.17k OUR–time Plot for batch test
21 Jul'94–Sewage Batch No.17

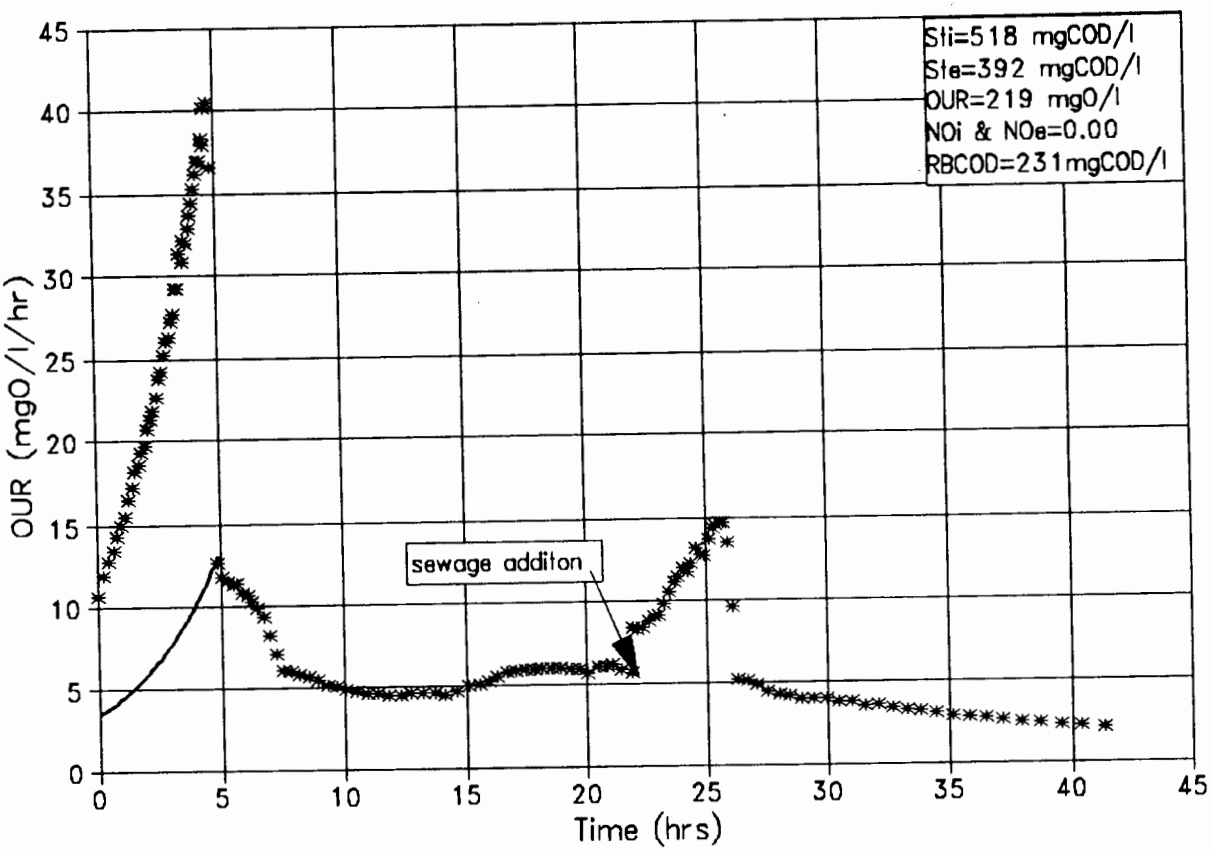


Fig A.18a OUR–time Plot for batch test
29 Jul'94–Sewage Batch No.18

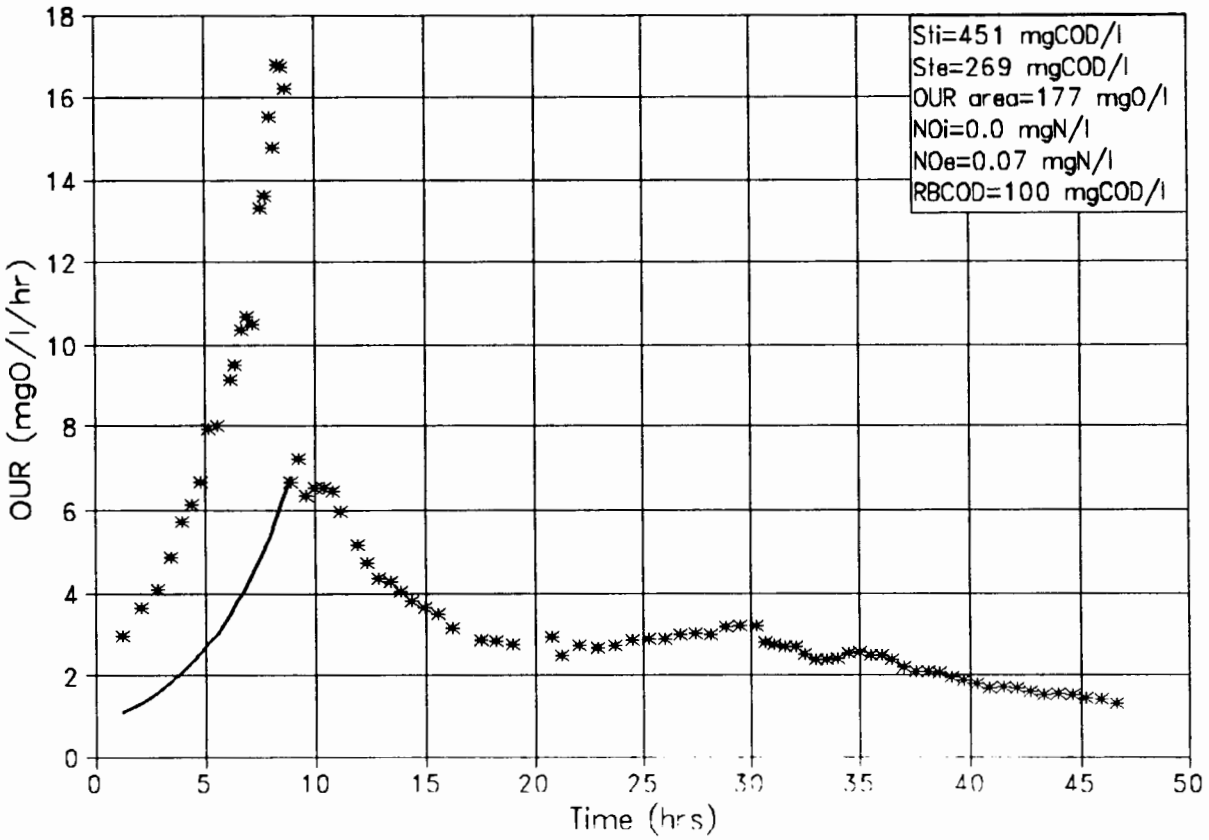


FIG A.18b OUR–time Plot for batch test
25 Jul'94–Sewage Batch No.18

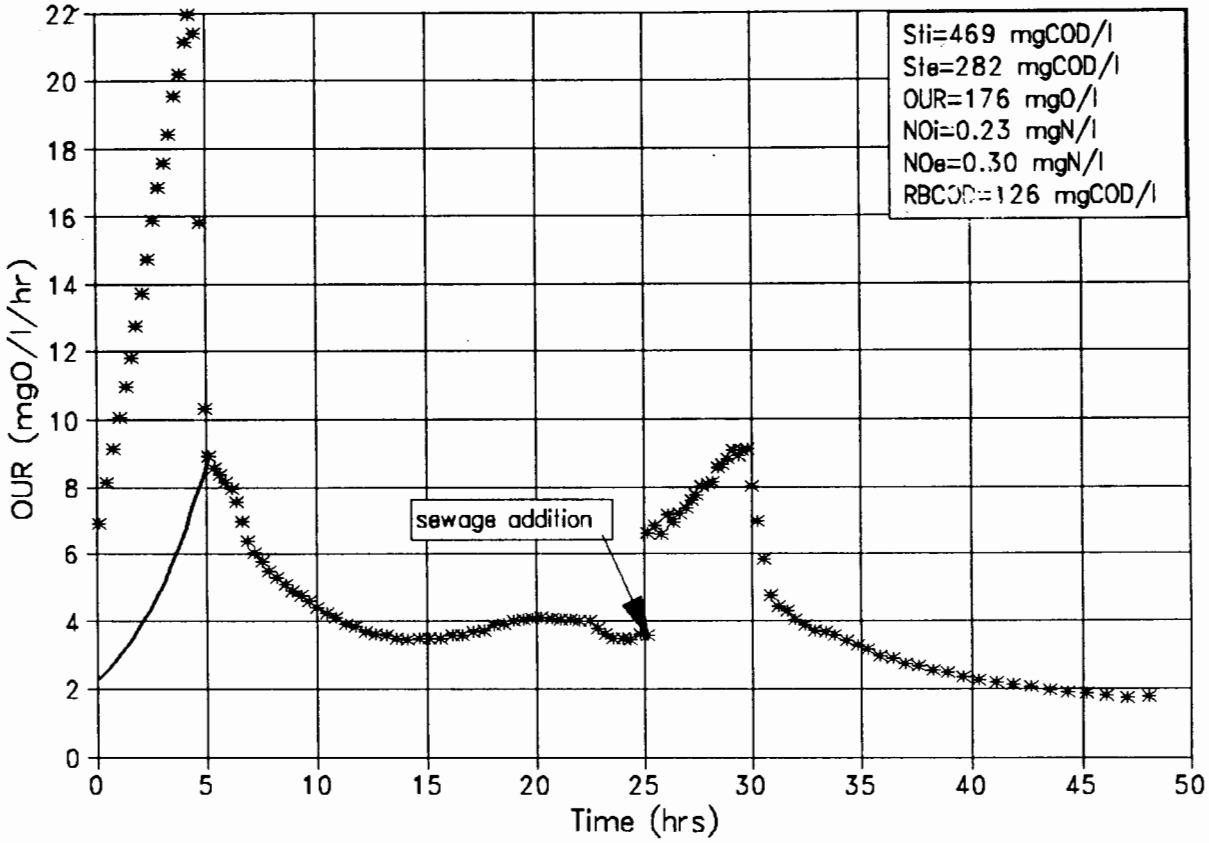


FIG A.18c OUR–time Plot for batch test
26 Jul'94–Sewage Batch No.18

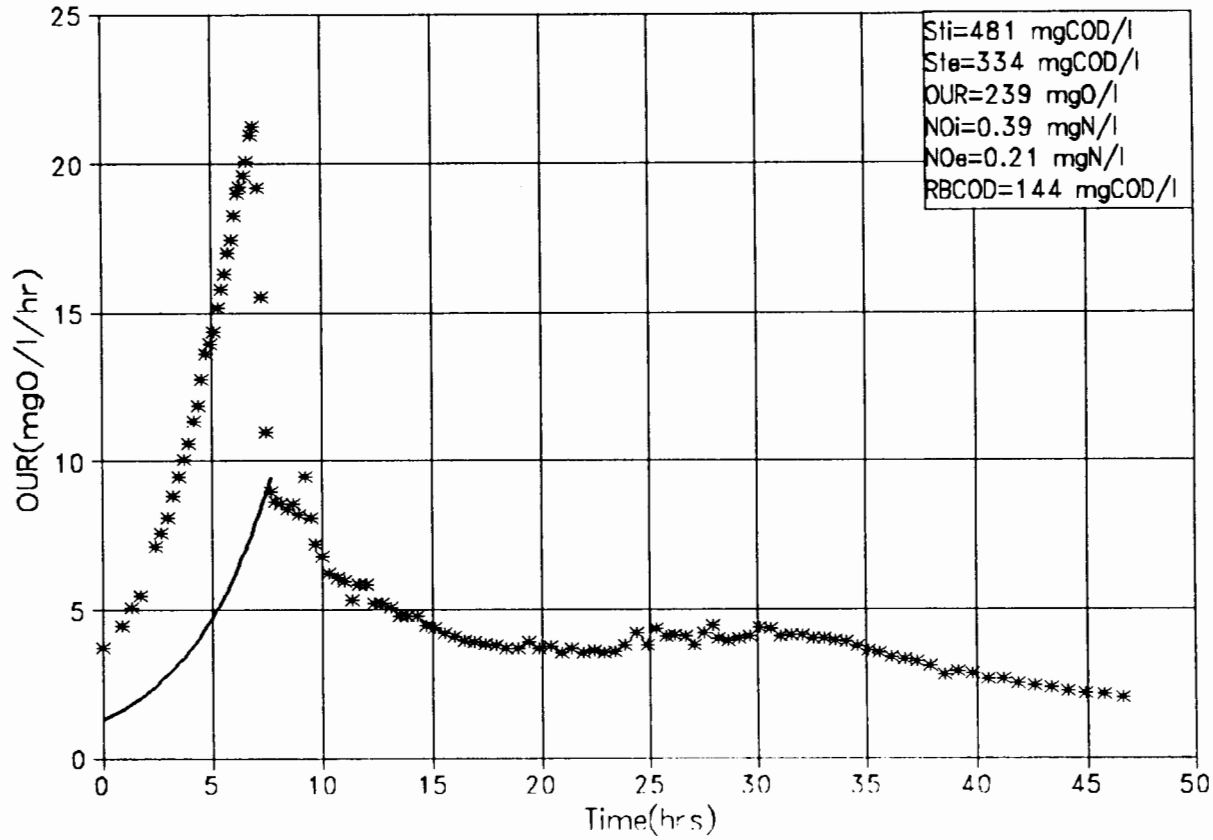


FIG A.18d OUR–time Plot for batch test
27 Jul'94–Sewage Batch No.18

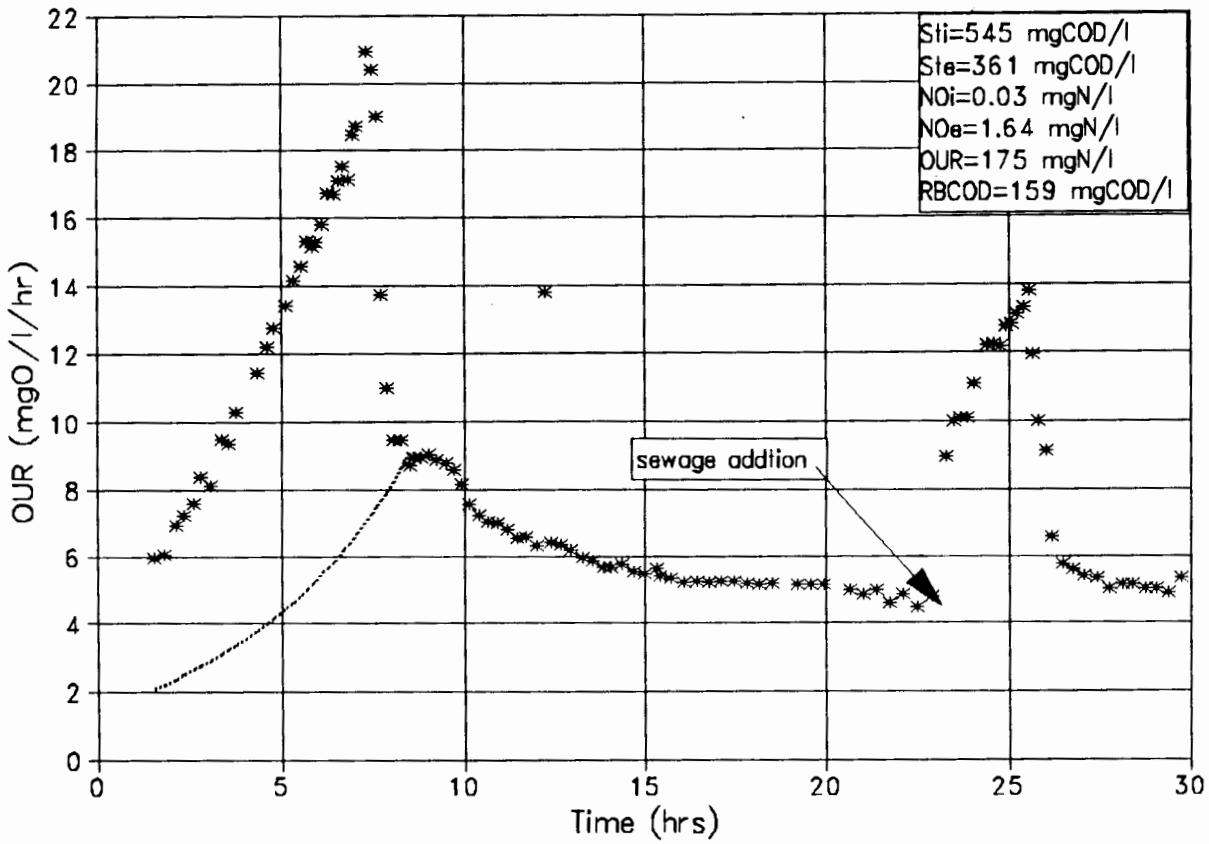


FIG A.18e OUR–time Plot for batch test
28 Jul'94–Sewage Batch No.18

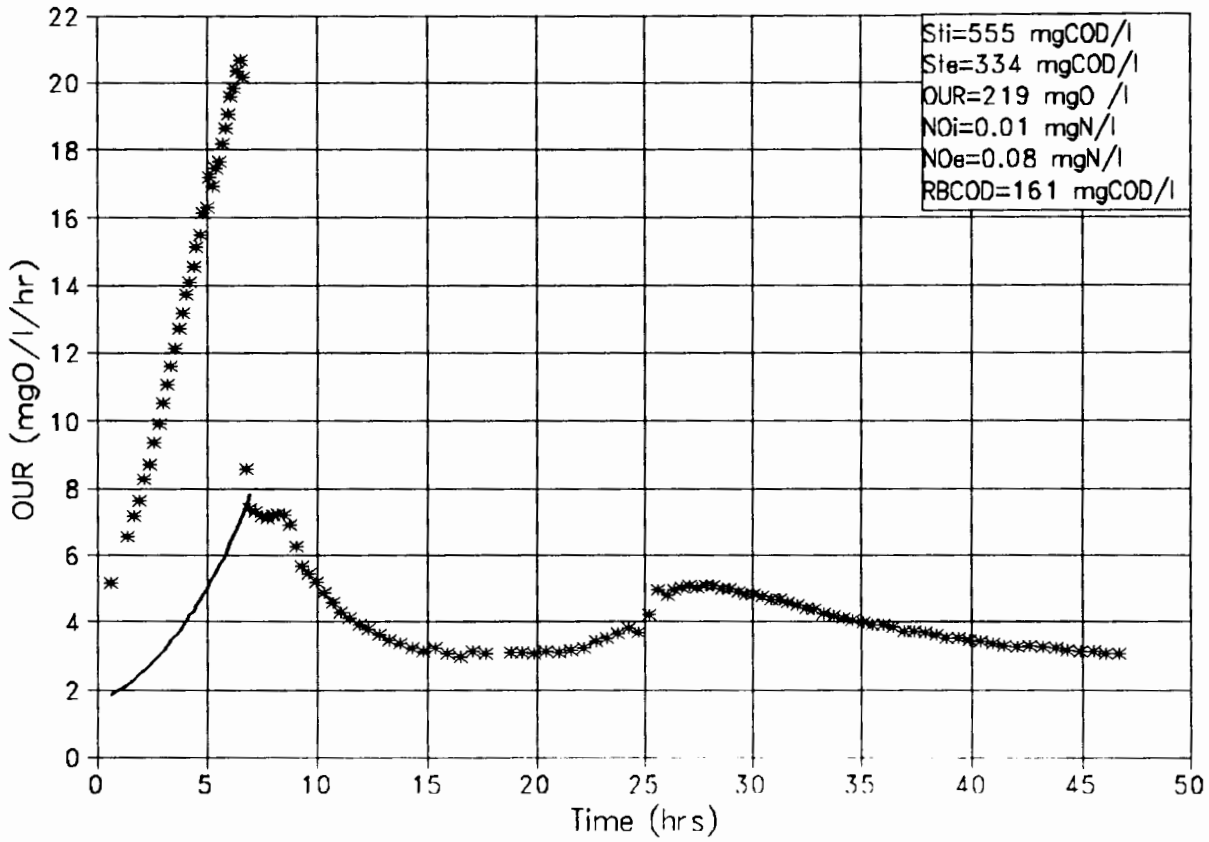


FIG A.18f OUR–time Plot for batch test
4 Aug'94–Sewage Batch No.18

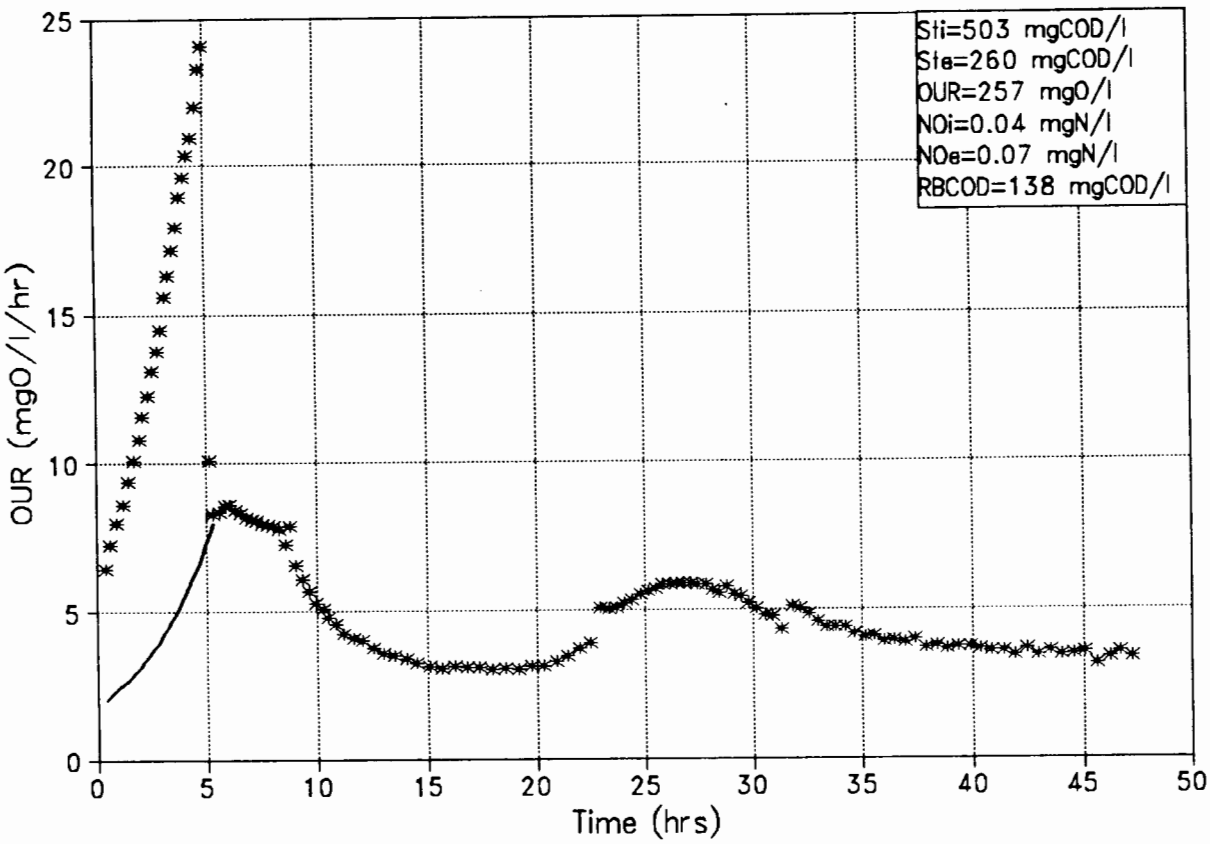


FIG A.18g OUR–time Plot for batch test
5 Aug'94–Sewage Batch No.18

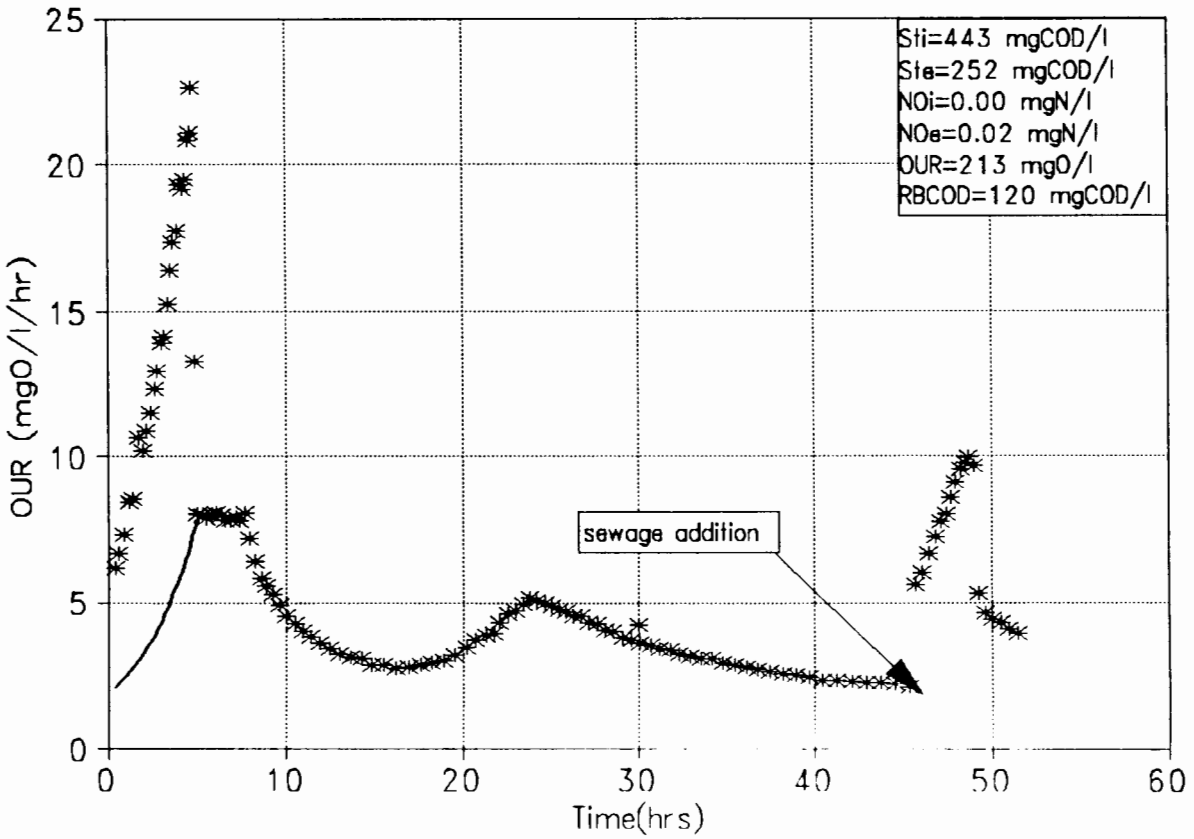


FIG A.18h OUR–time Plot for batch test
6 Aug'94–Sewage Batch No.18

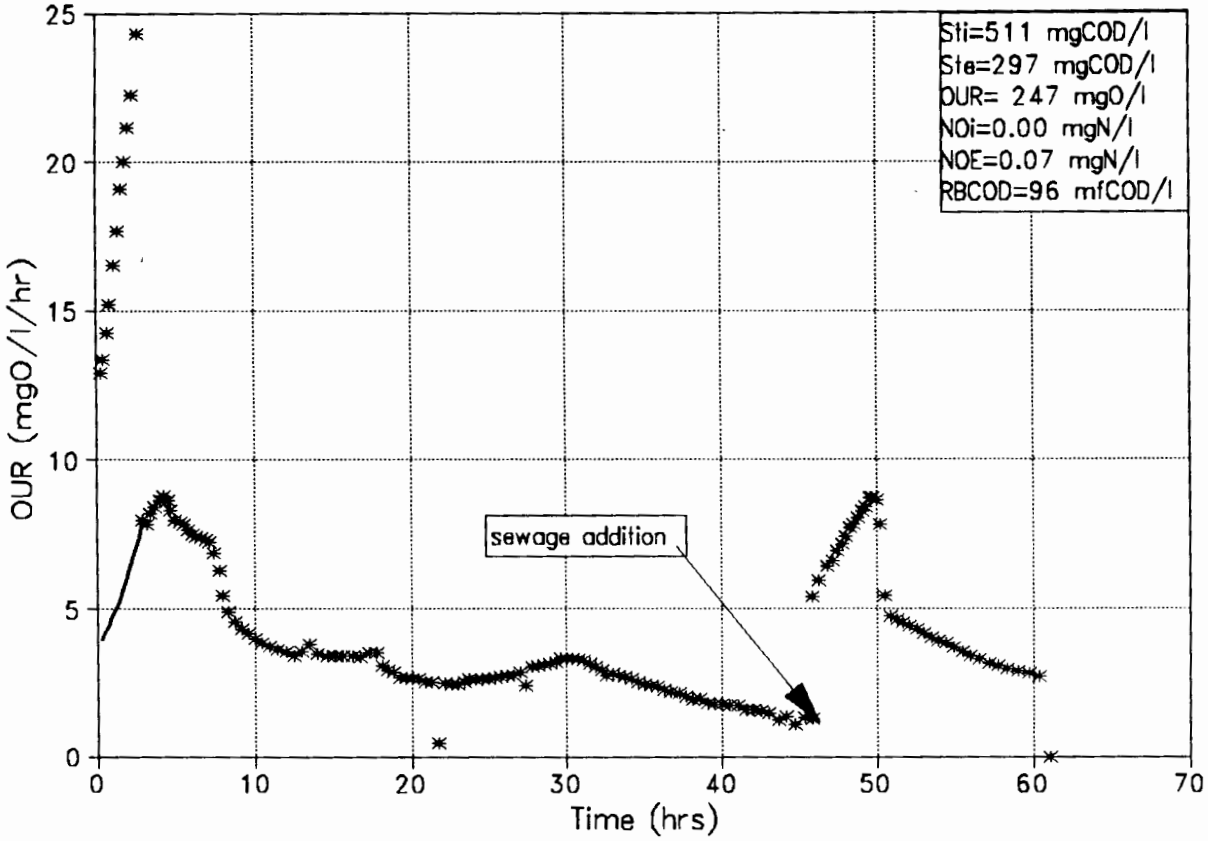


FIG A.18j OUR–time Plot for batch test
7 Aug'94–Sewage Batch No.18

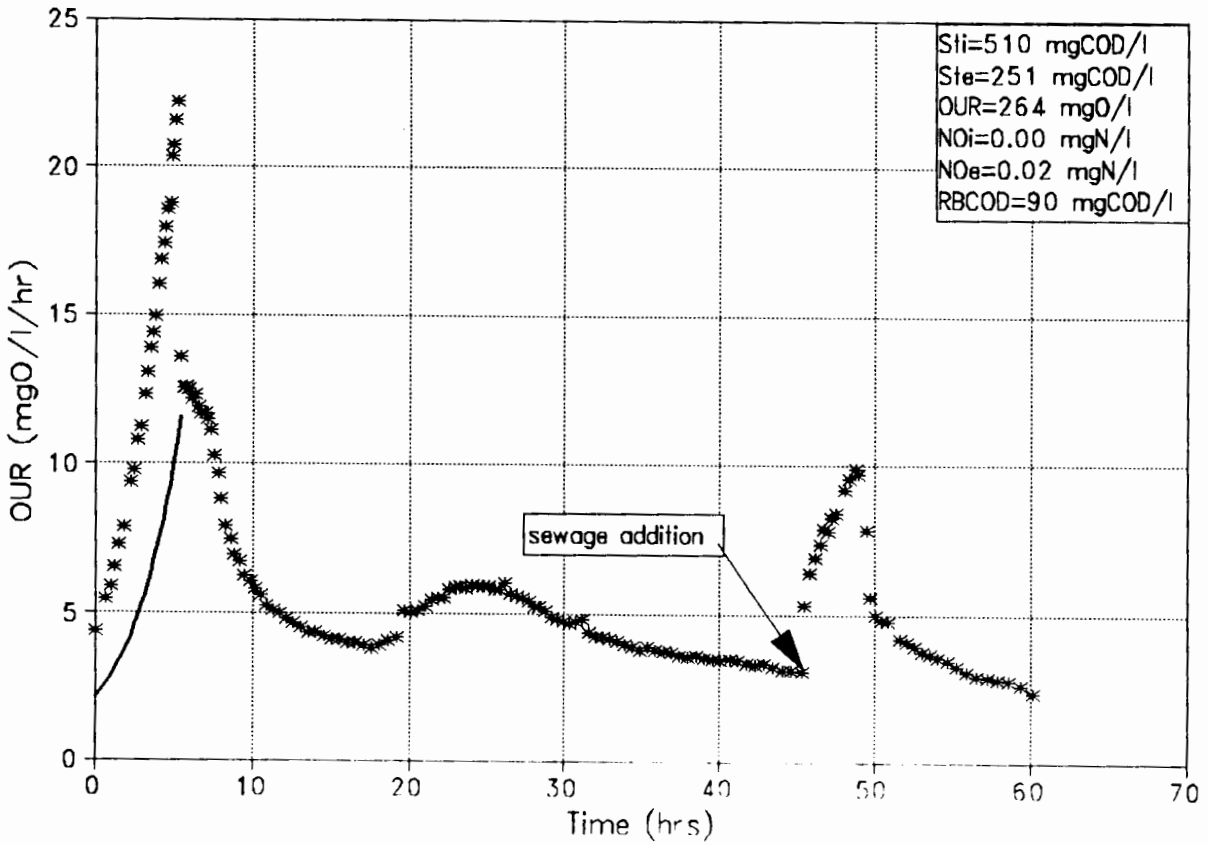


FIG A.19a OUR–time Plot for batch test
18 Aug'94–Sewage Batch No.19

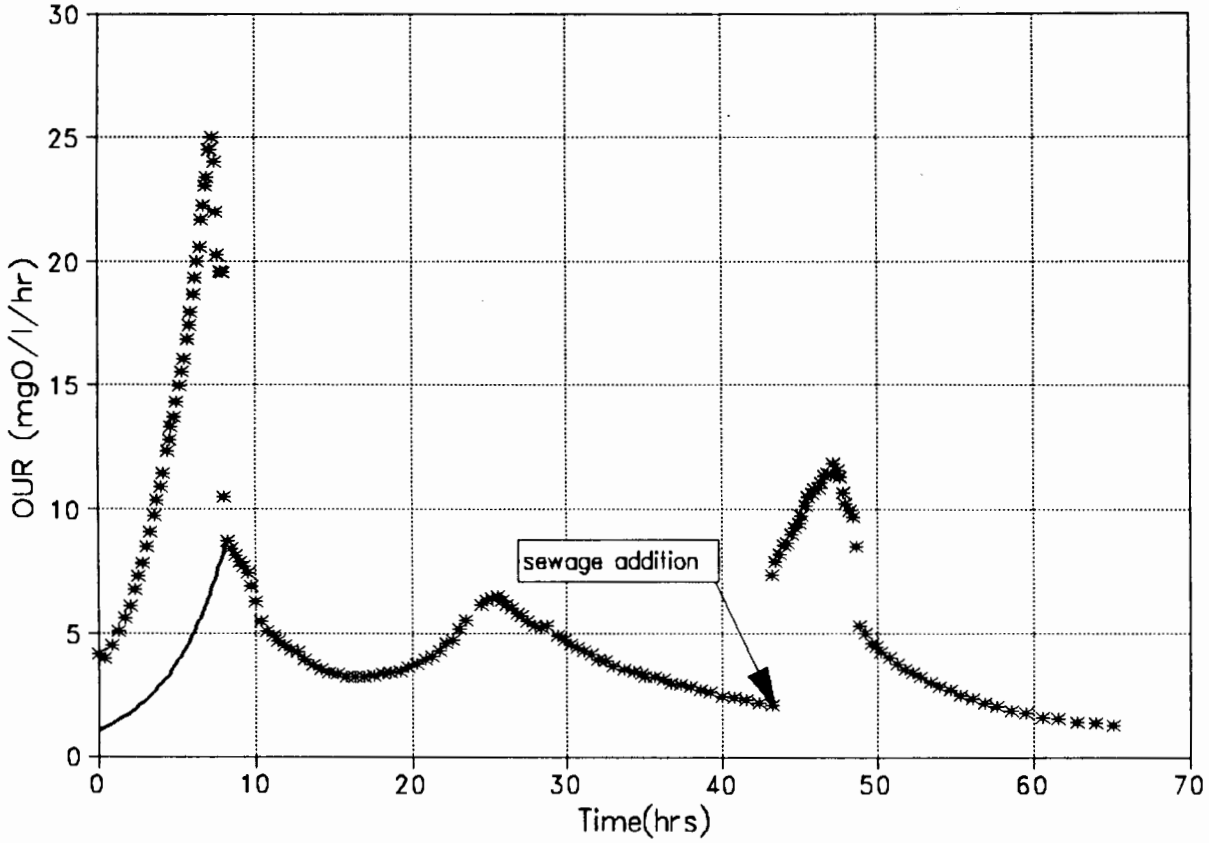


FIG A.19b OUR–time Plot for batch test
13 Aug'94–Sewage Batch No.19

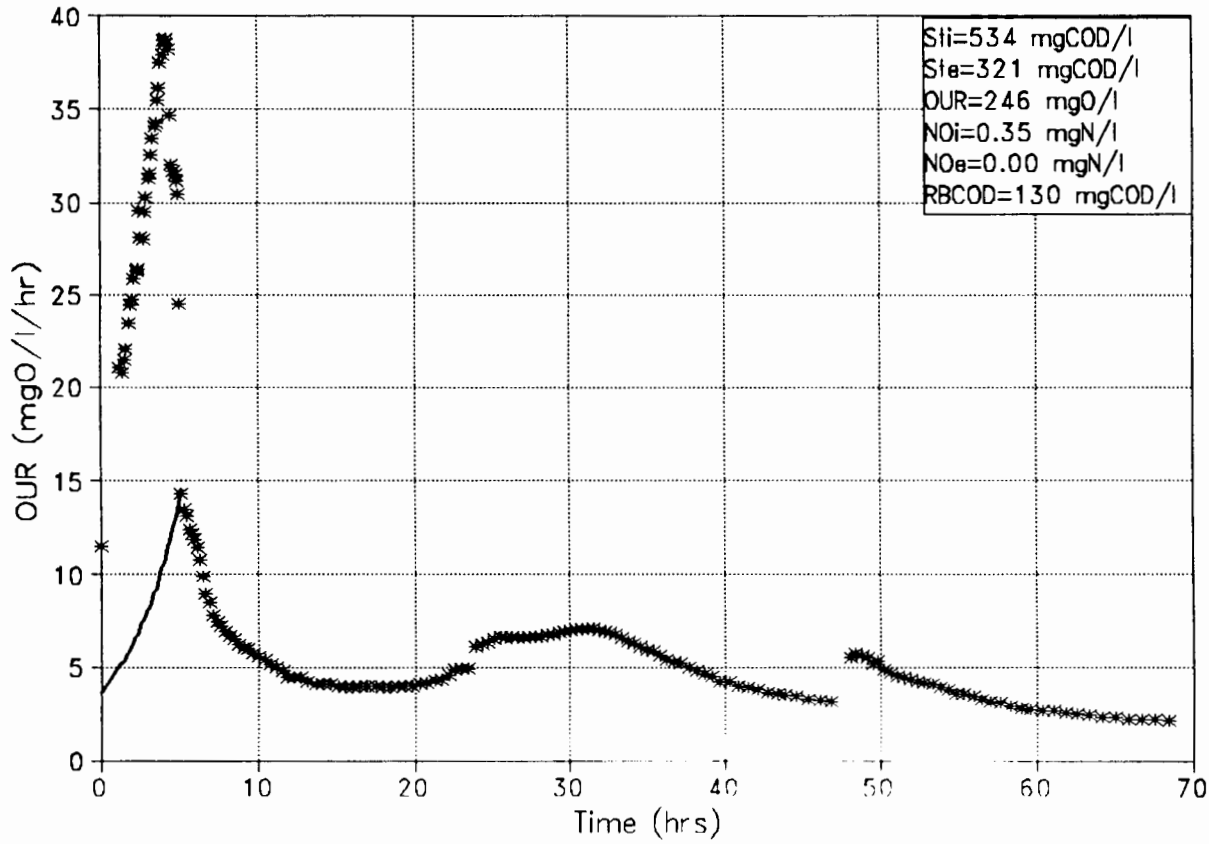


FIG A.19c OUR–time Plot for batch test
15 Aug'94–Sewage Batch No.19

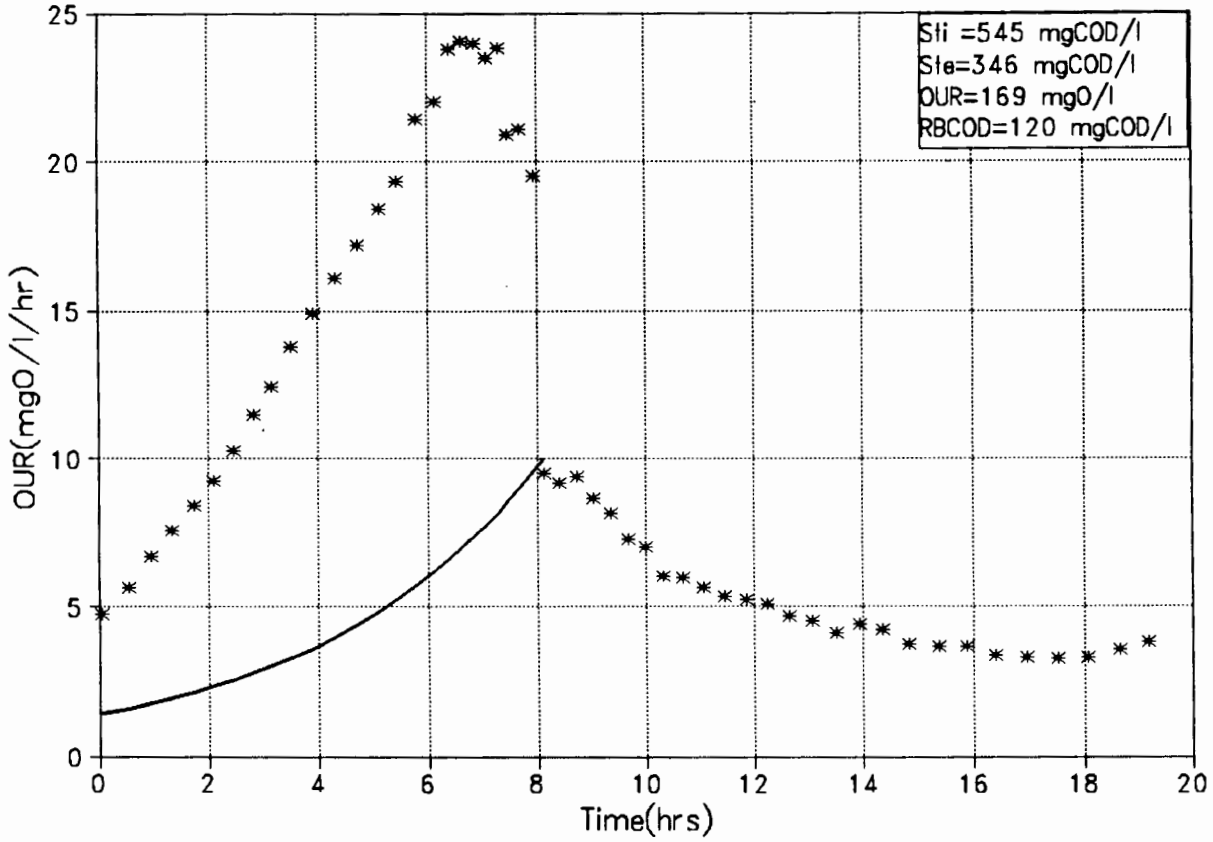


FIG A.19d OUR–time Plot for batch test
16 Aug'94–Sewage Batch No.19

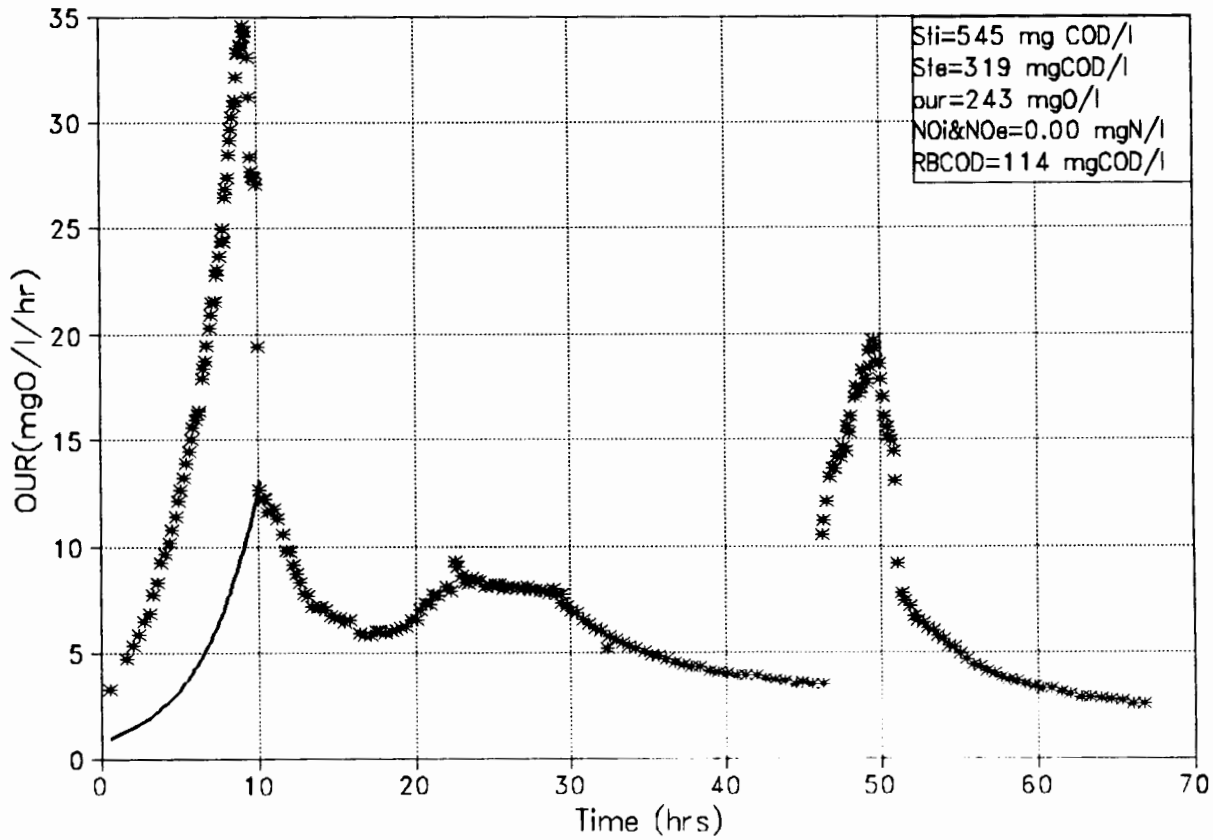


FIG A.19e OUR–time Plot for batch test
19 Aug'94–Sewage Batch No.19

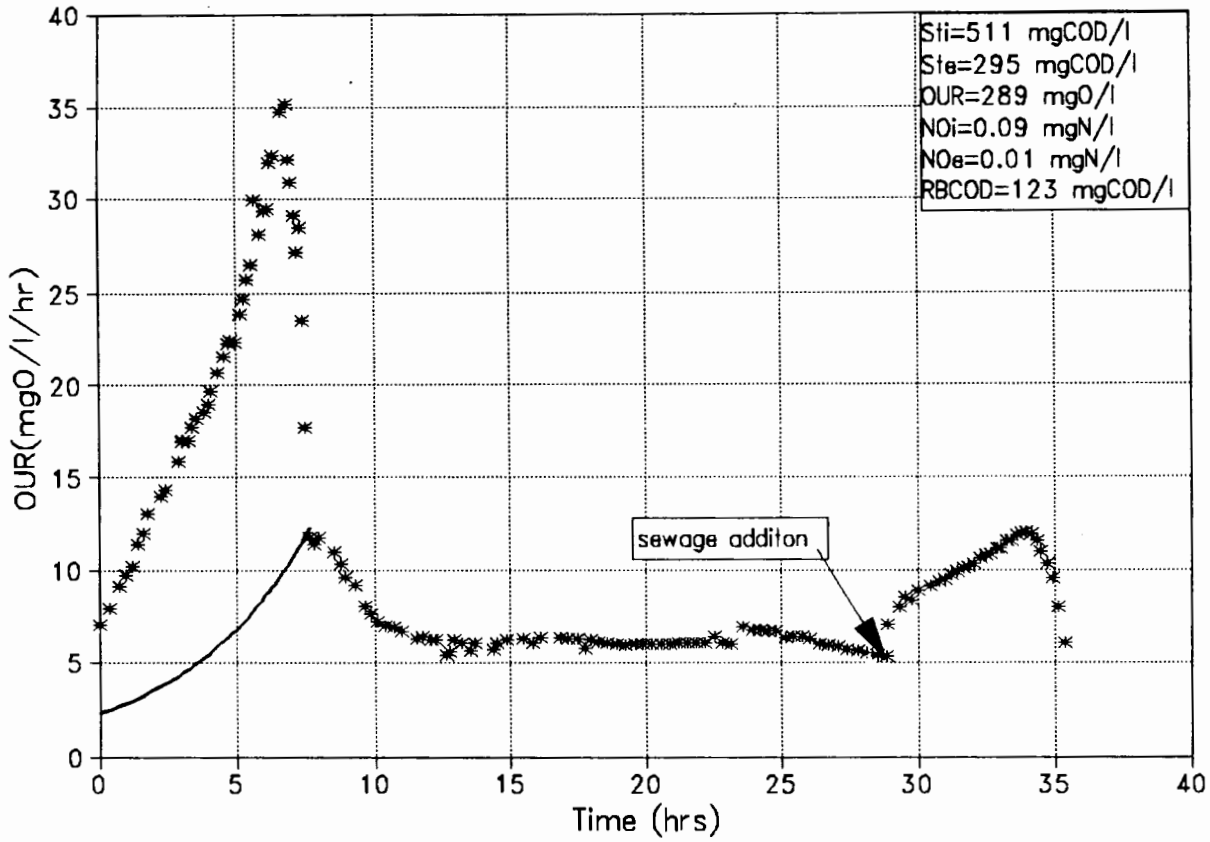


FIG A.19f OUR–time Plot for batch test
20 Aug'94–Sewage Batch No.19

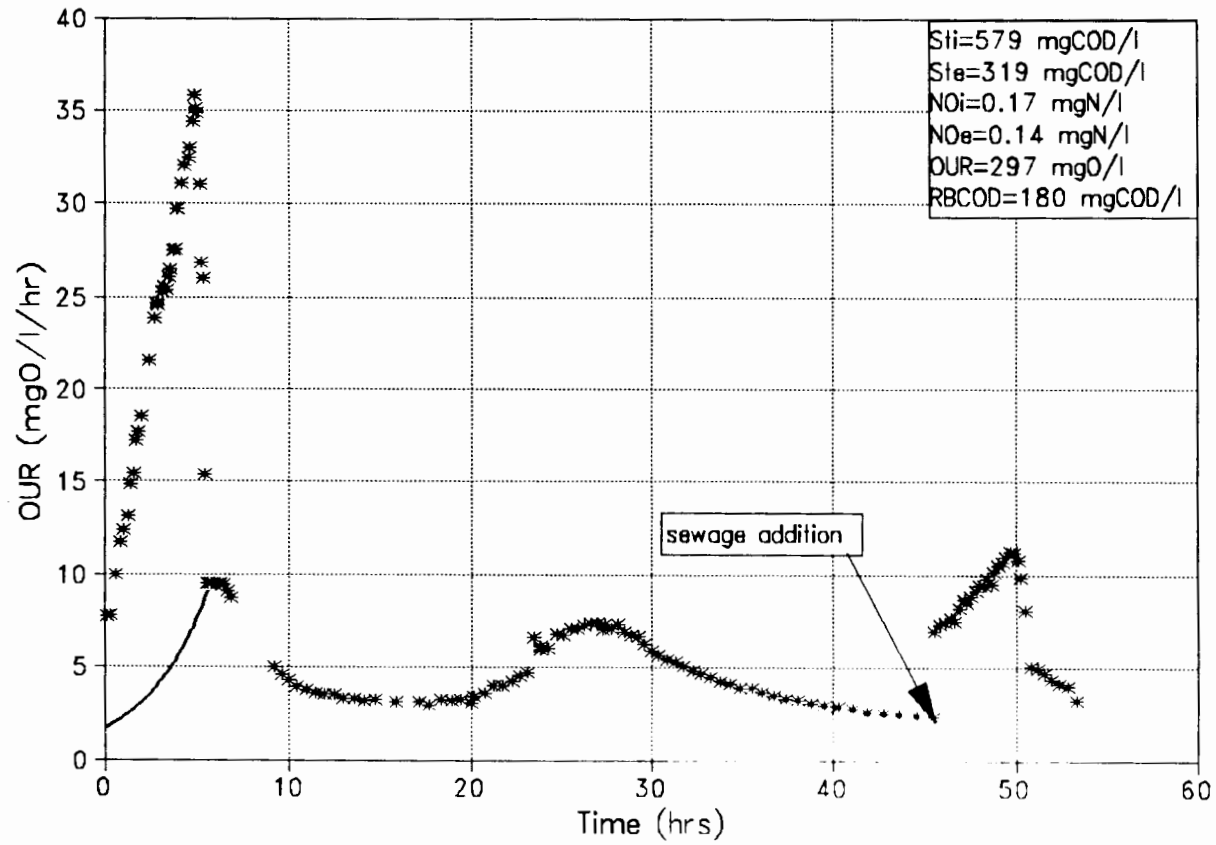


Fig A.19g OUR–time Plot for batch test
16 Aug'94–Sewage Batch No.19

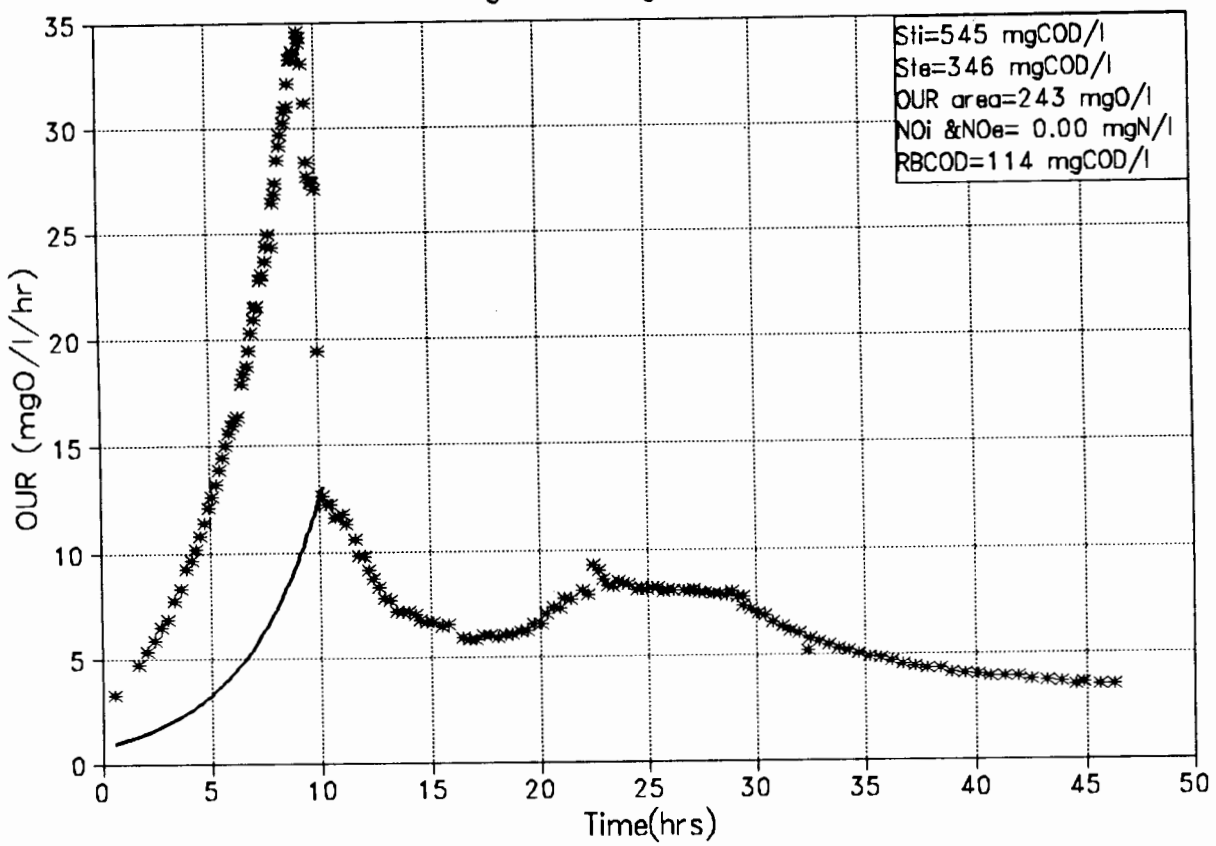


FIG A.19h OUR–time Plot for batch test
23 Aug'94–Batch No.19 (I)

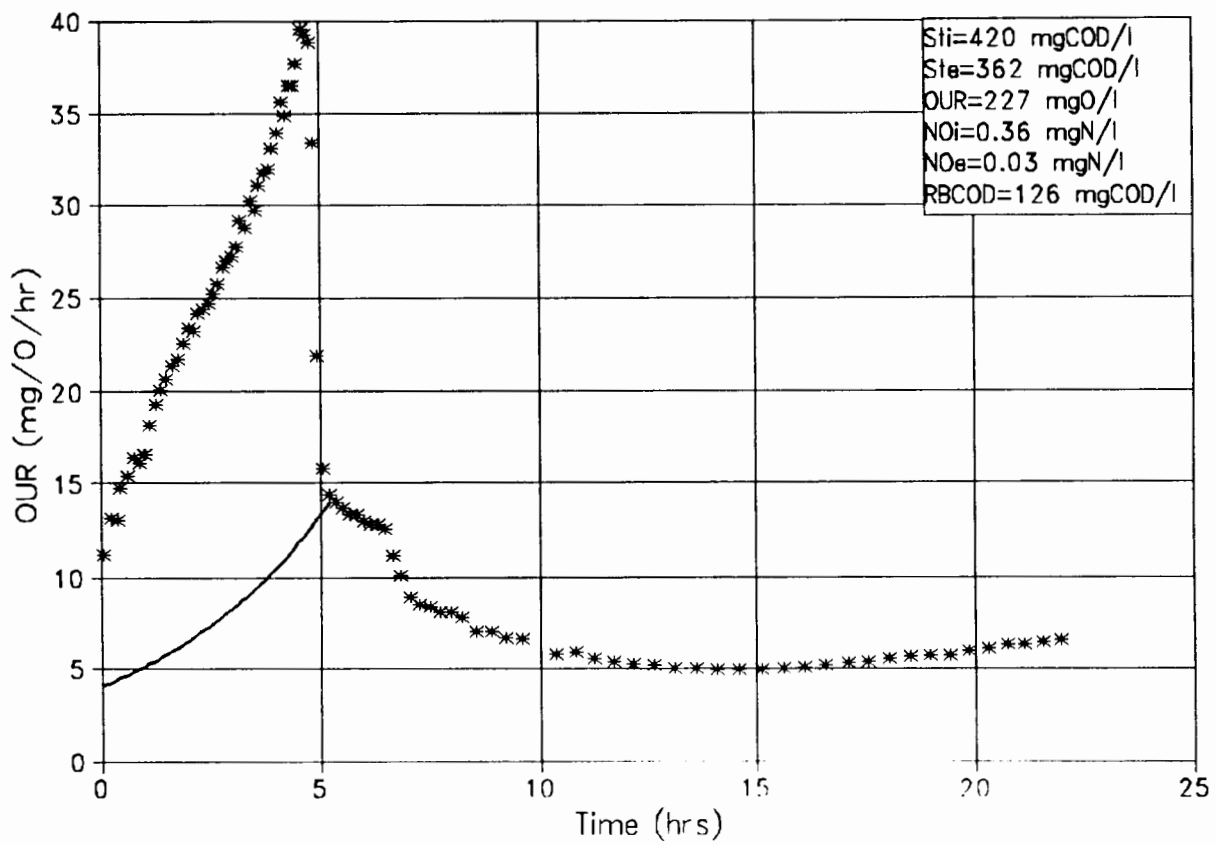


FIG A.19j OUR–time Plot for batch test
25 Aug'94–Sewage Batch No.19

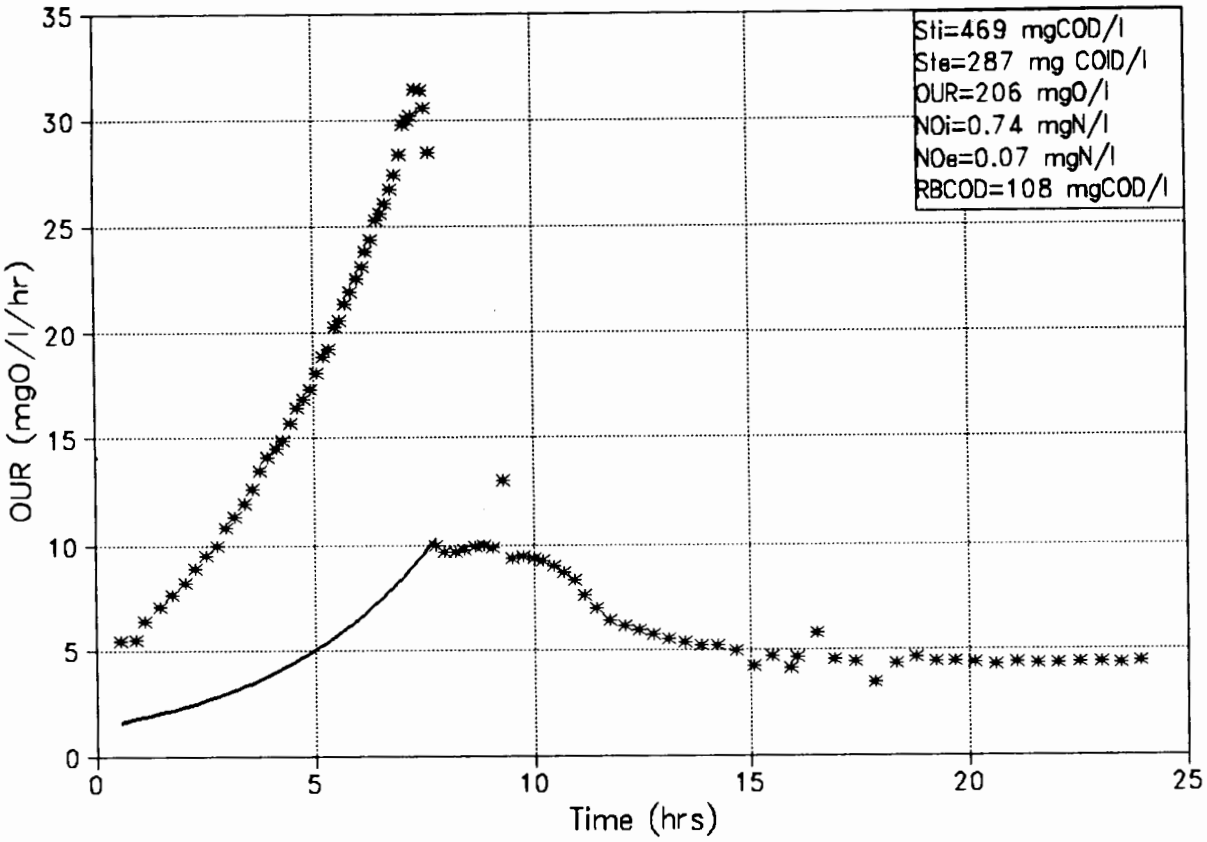


FIG A.19k OUR–time Plot for batch test
28 Aug'94–Sewage Batch No.19

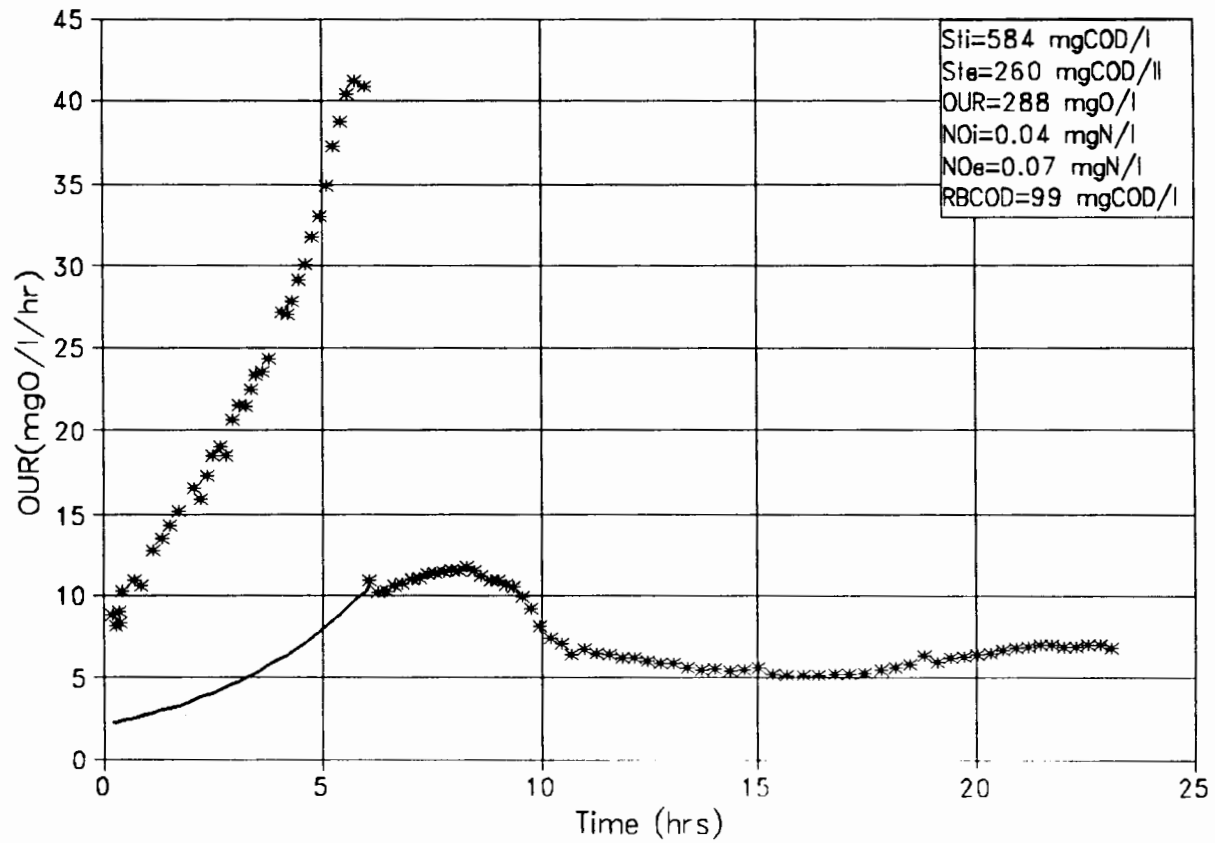


FIG A.19m OUR–time Plot for batch test
30 Aug'94–Sewage Batch No.19

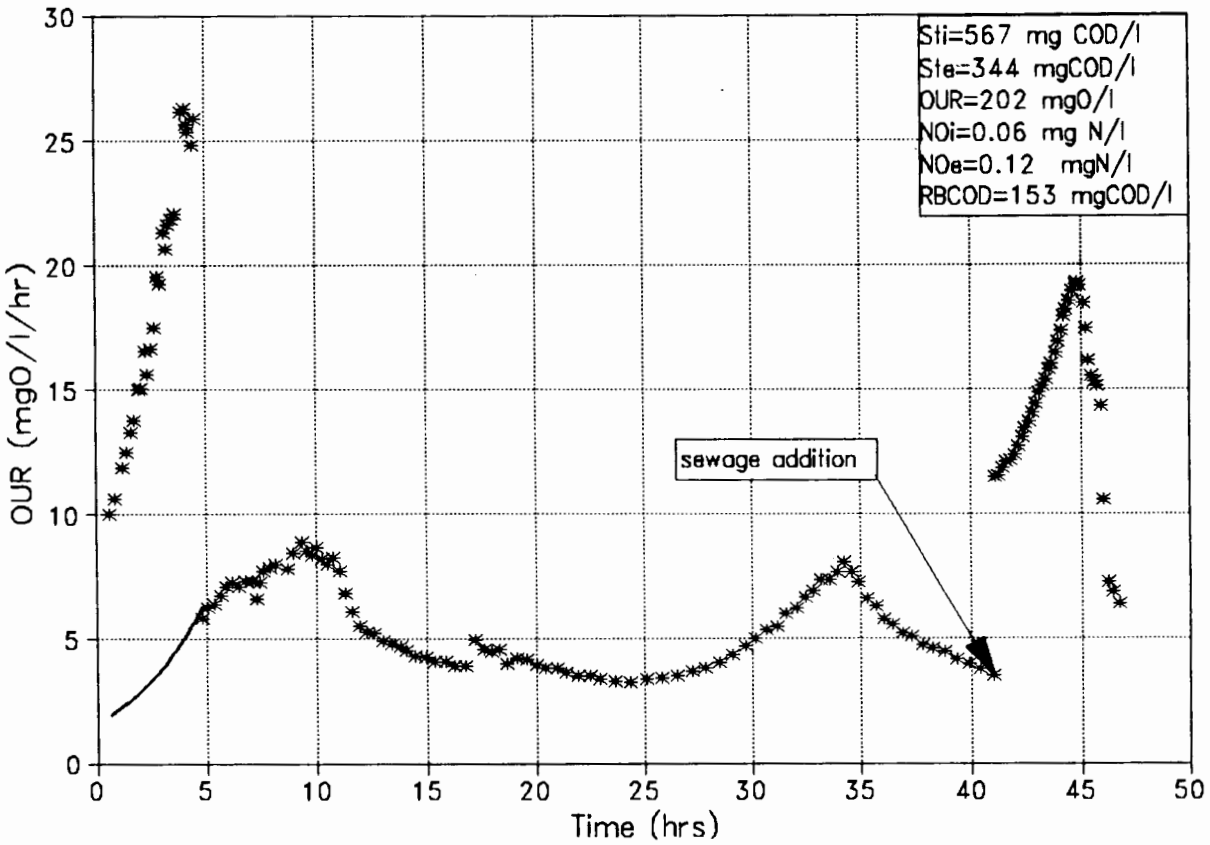


FIG A.20a OUR–time Plot for batch test
2 Sept'94–Sewage Batch No.20

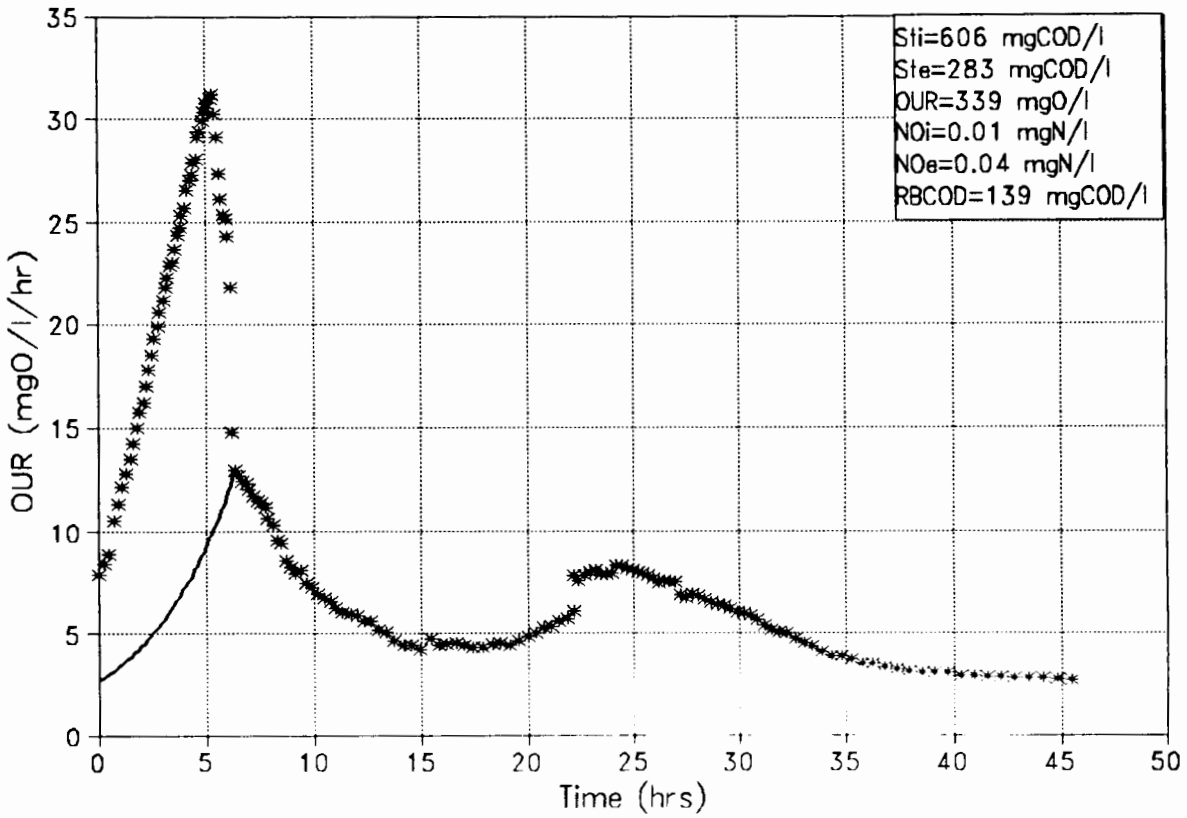


FIG A.20b OUR–time plot for batch test
4 Sept'94–Sewage Batch No.20

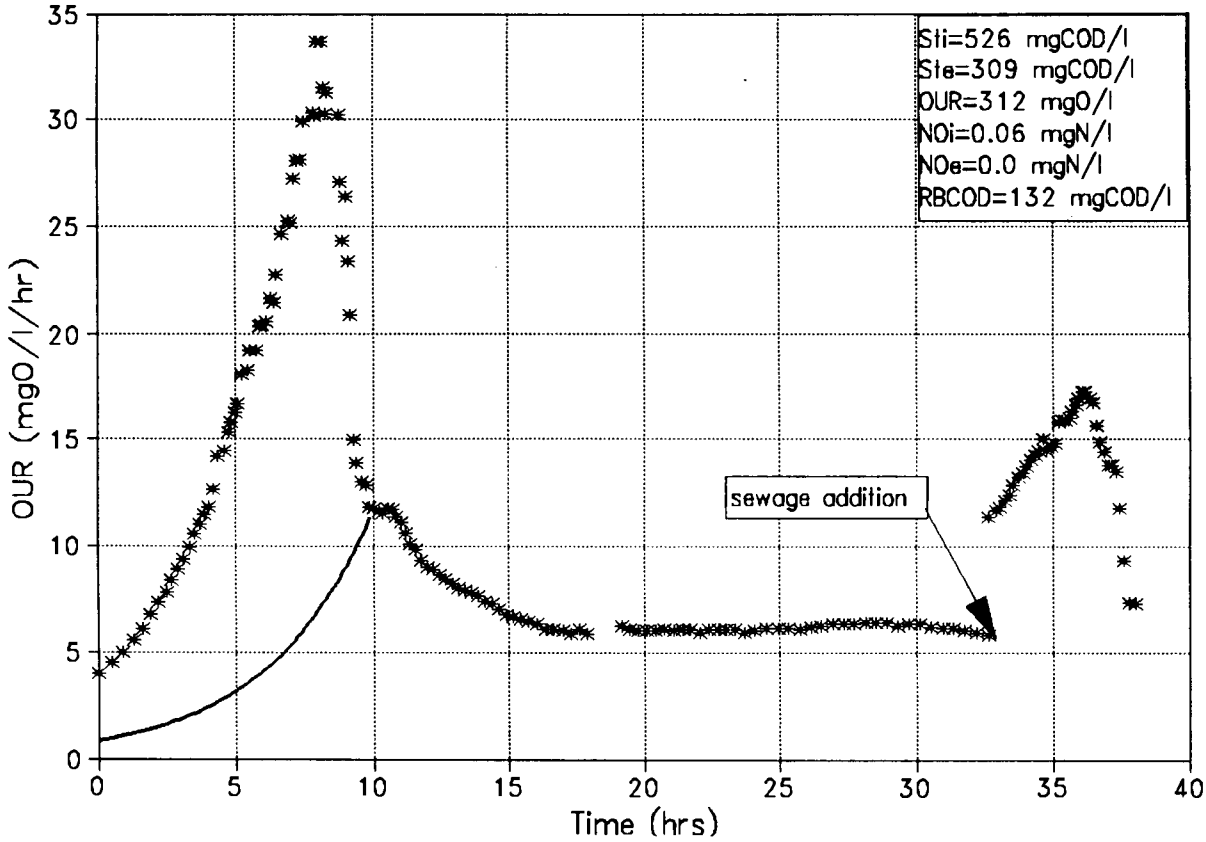


FIG A.20c OUR–time Plot for batch test
6 Sept'94–Sewage Batch No.20

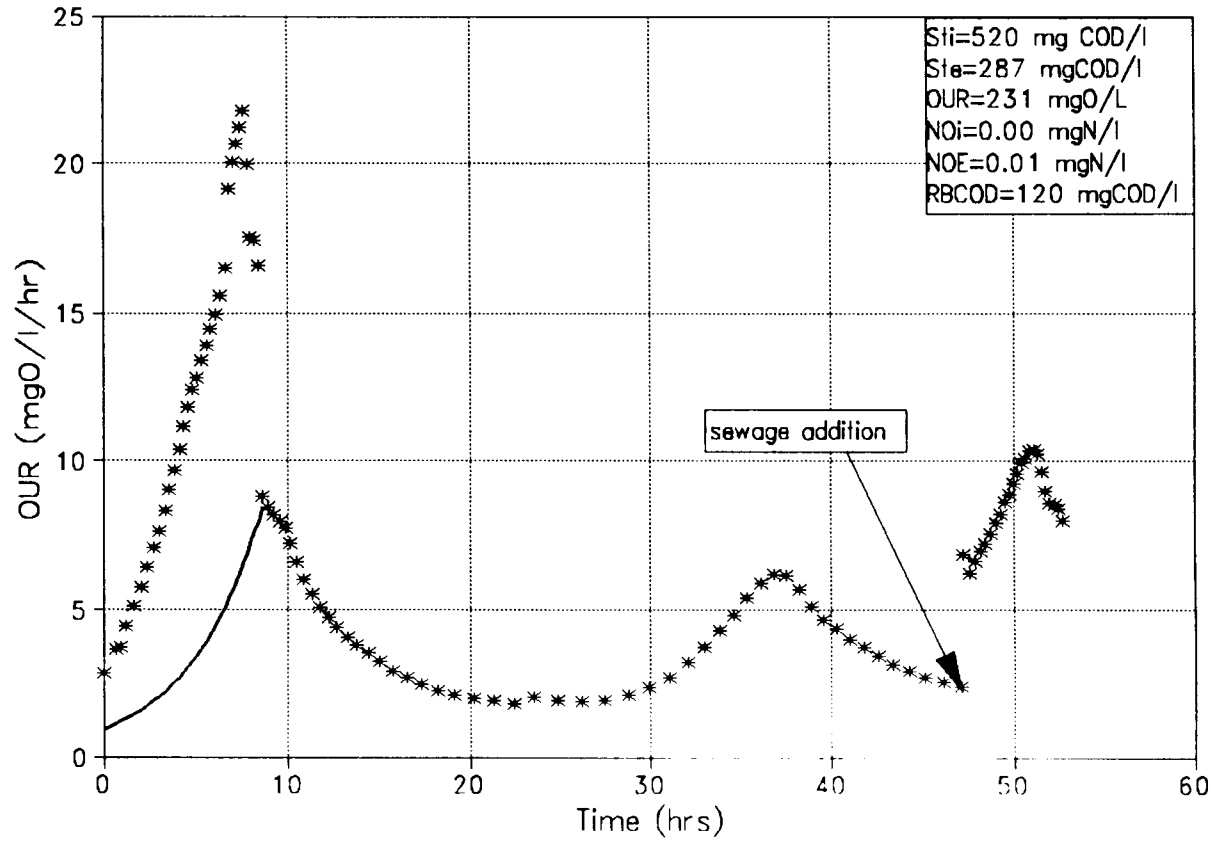


FIG A.20d OUR –time Plot for batch test
7 Sep'94 –Batch No.20

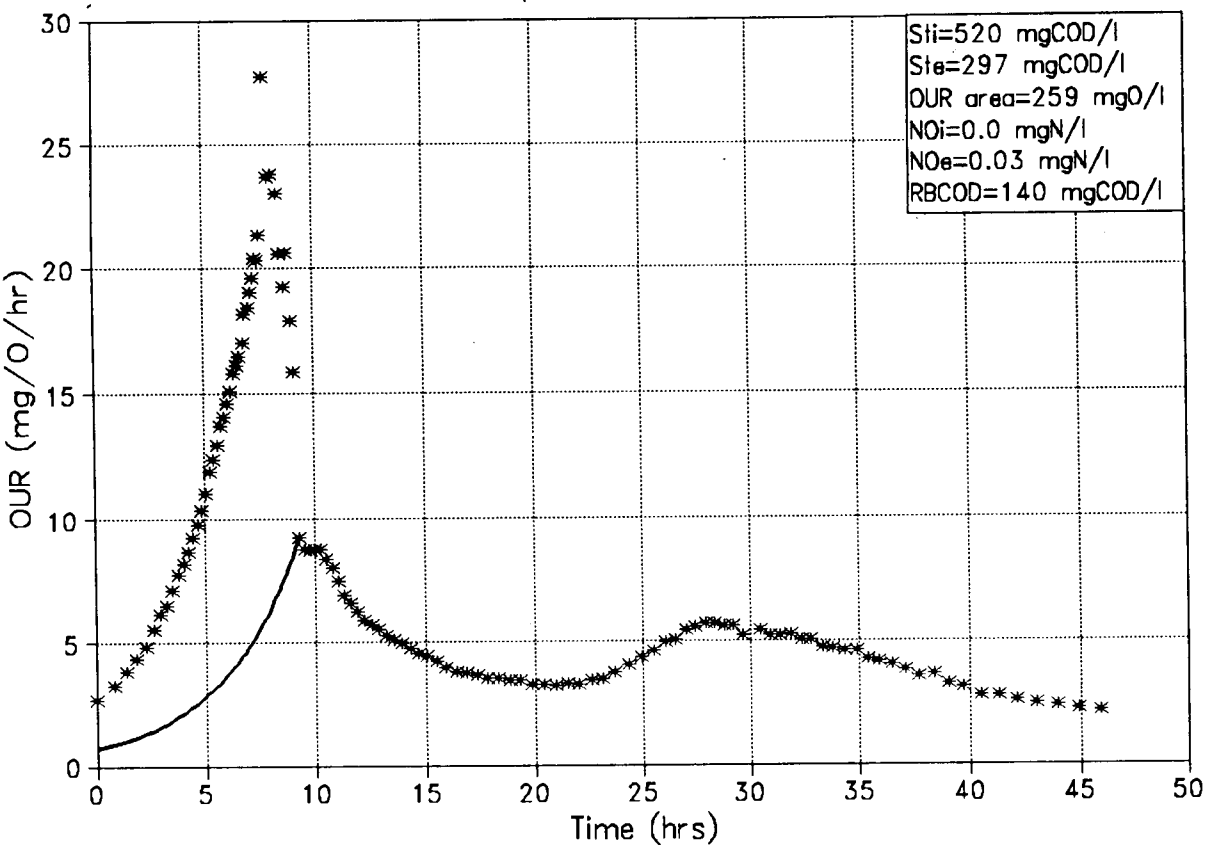


FIG A.20e OUR–time Plot for batch test
8 Sept'94–Sewage Batch No.20

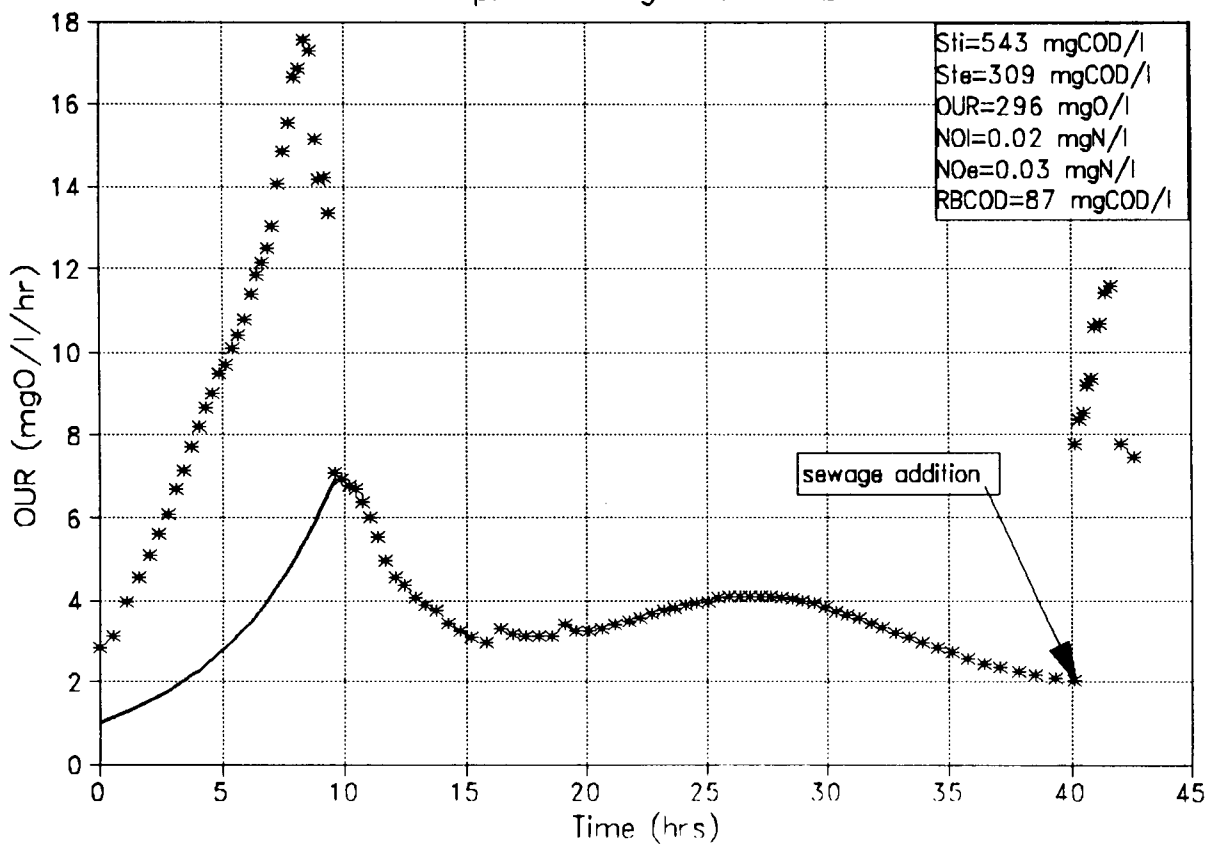


FIG A.20f OUR–time Plot for batch test
9 Sept'94–Sewage Batch No.20

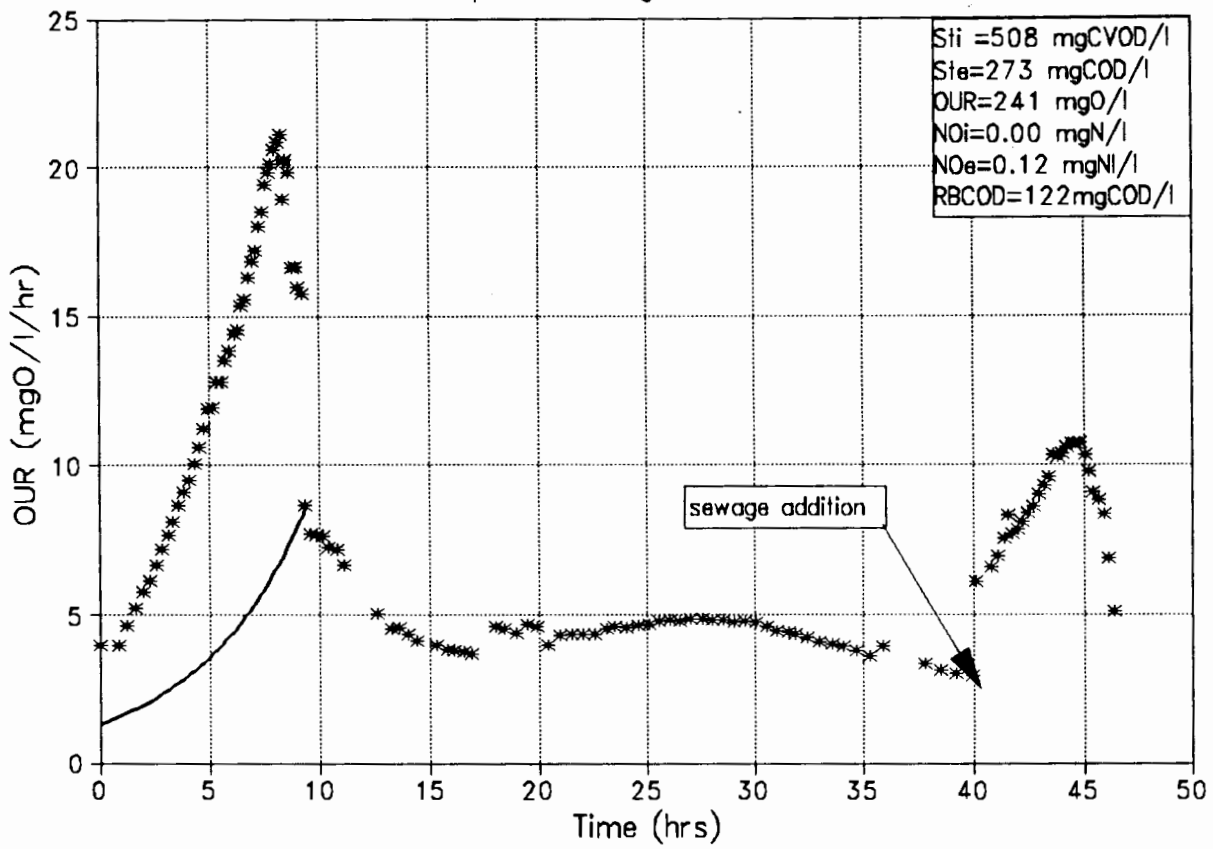


FIG A.21a OUR–time Plot for batch test
19 Sept'94–Sewage Batch No.21

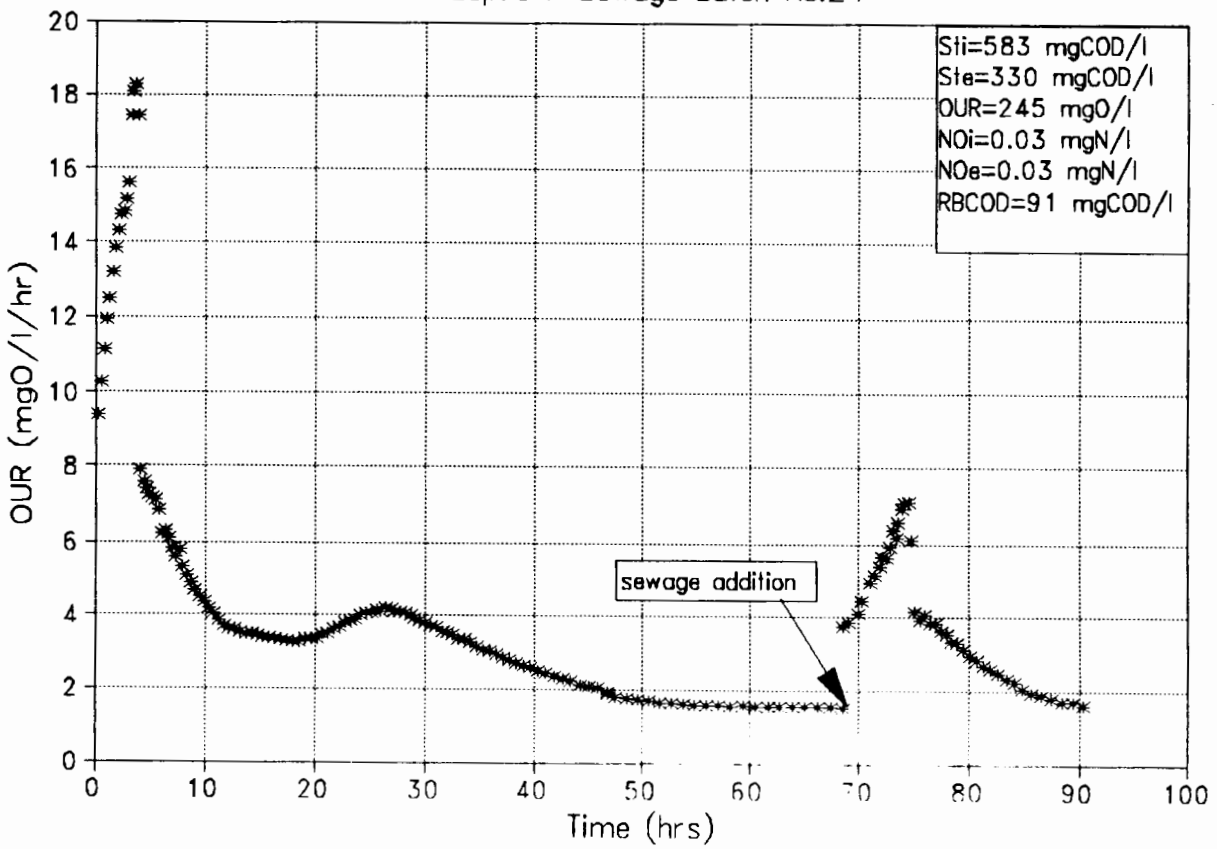


FIG A.21b OUR–time Plot for batch test
21 Sept'94–Sewage Batch No.21

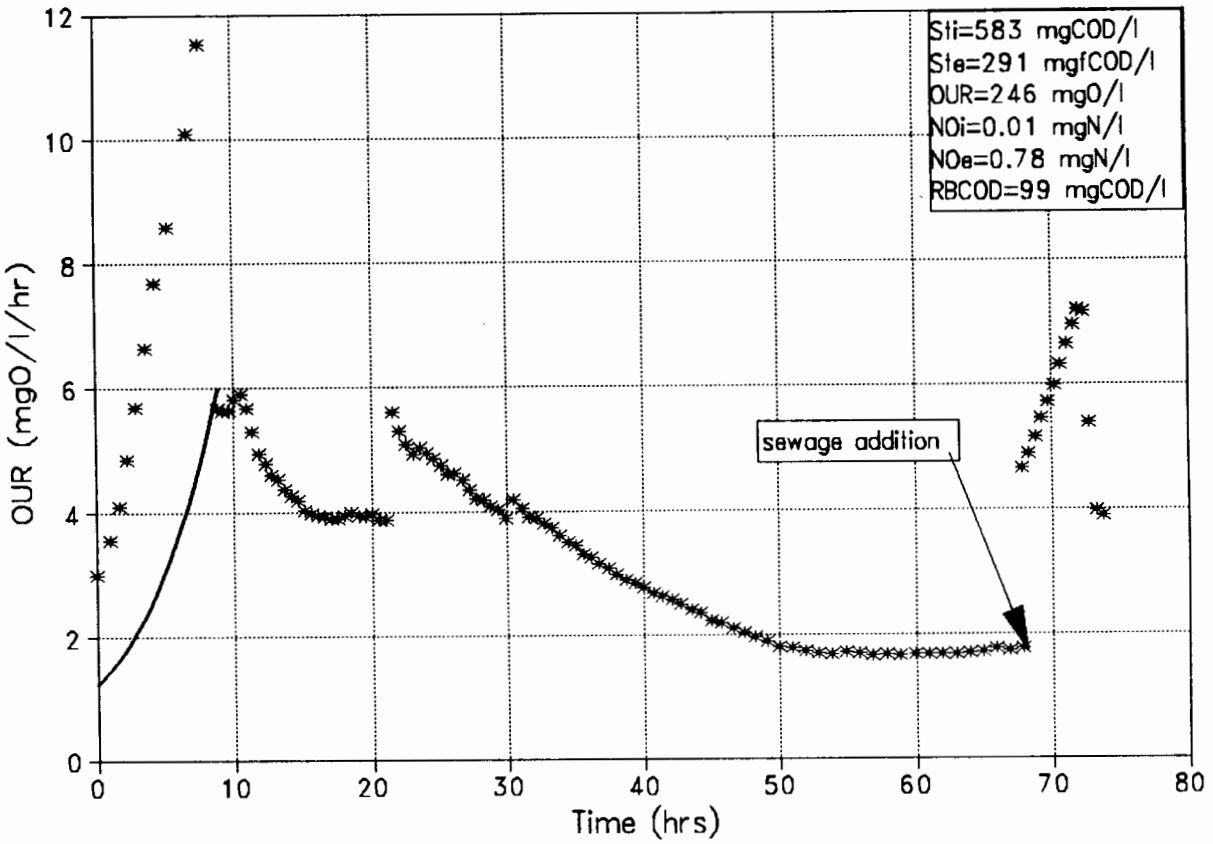


FIG A.21c OUR–time Plot for batch test
23 Sept'94–Sewage Batch NO.21 (L)

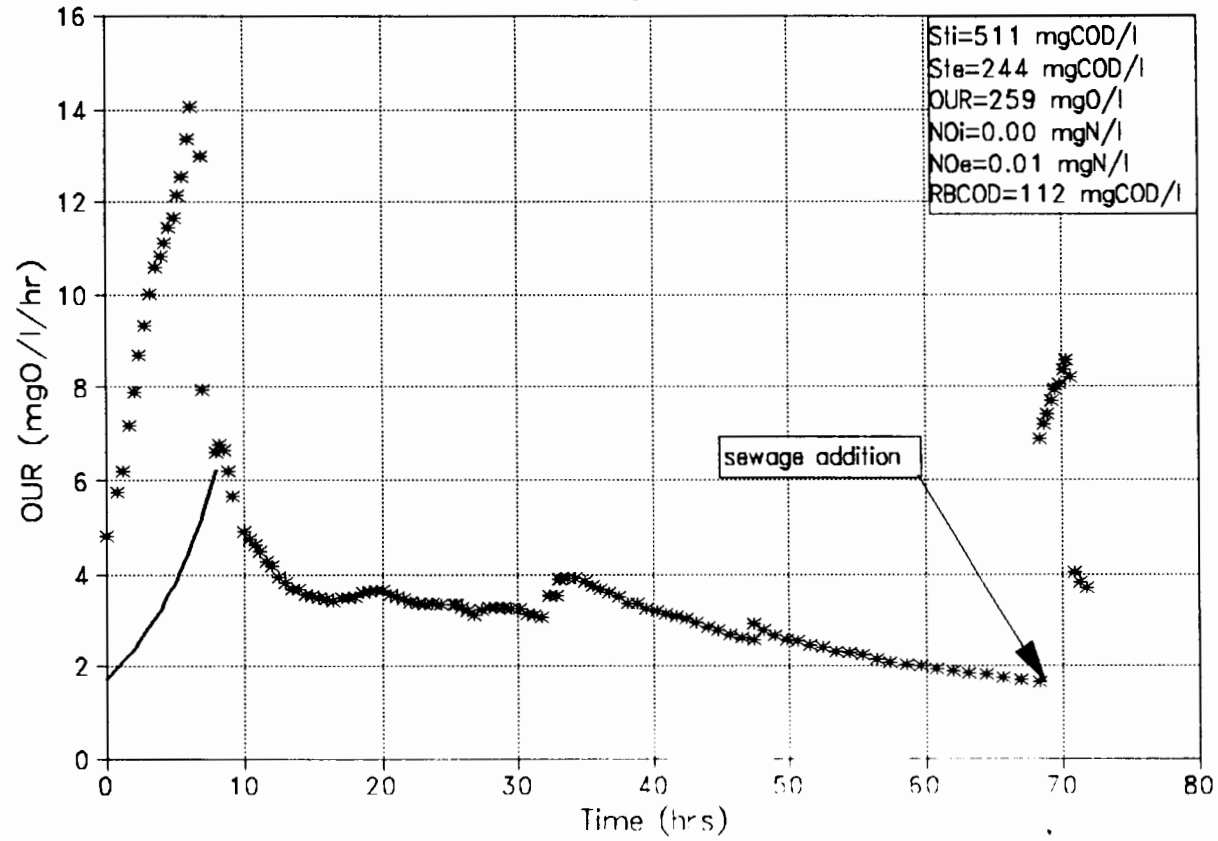


FIG A.21d OUR–time Plot for batch test
23 Sept'94–Sewage Batch No.21 (R)

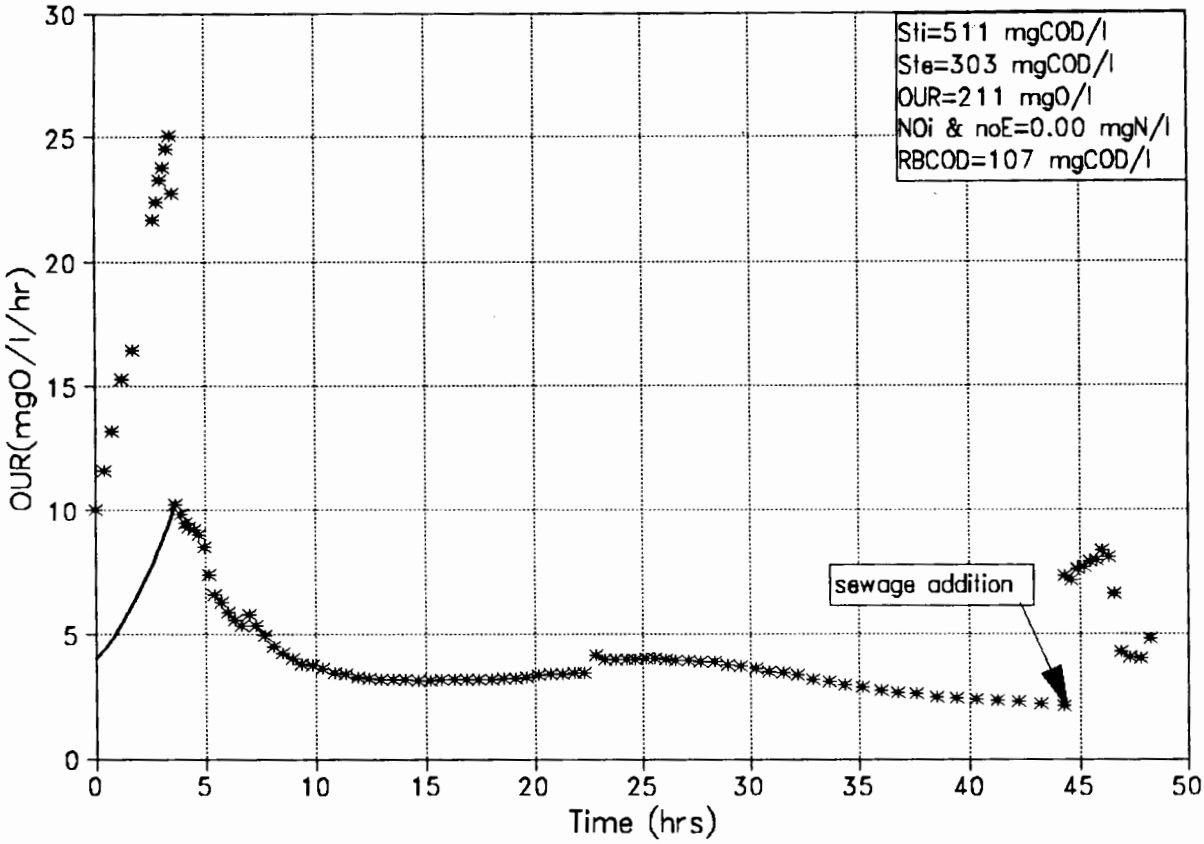


FIG A.21e OUR–time Plot for batch test
27 Sept'94–Sewage Batch No.21

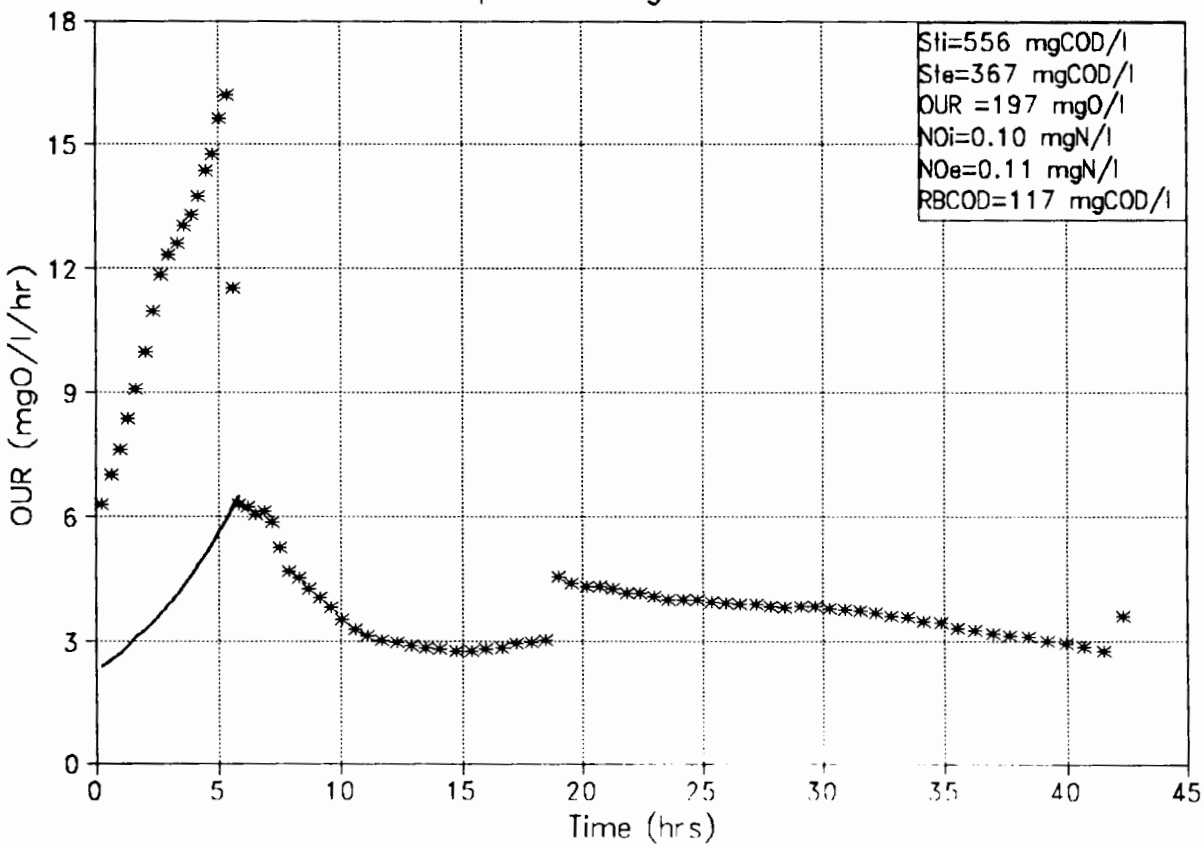


FIG A.21f OUR–time Plot for batch test
27 Sept'94–Sewage Batch No.21 (L)

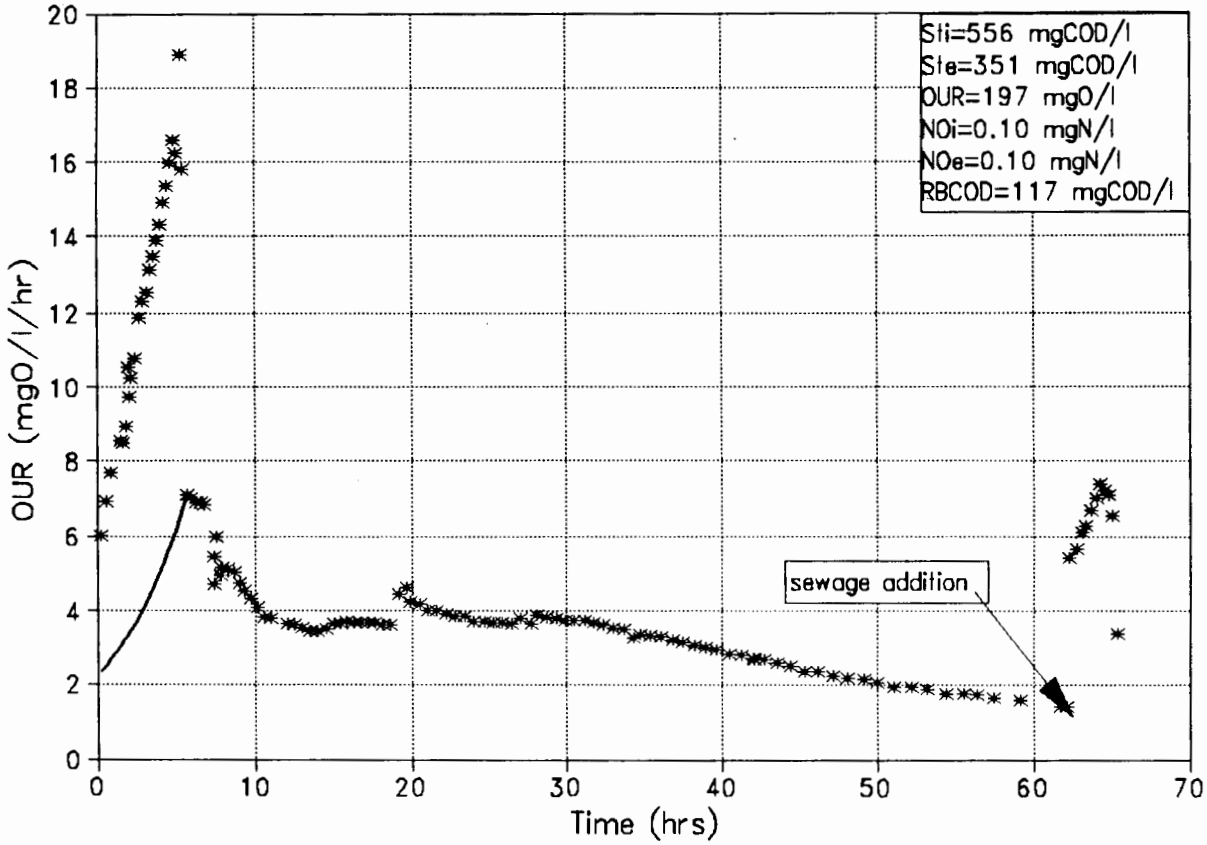


FIG A.21g OUR–time Plot for batch test
30 Sept'94–Sewage Batch No.21 (R)

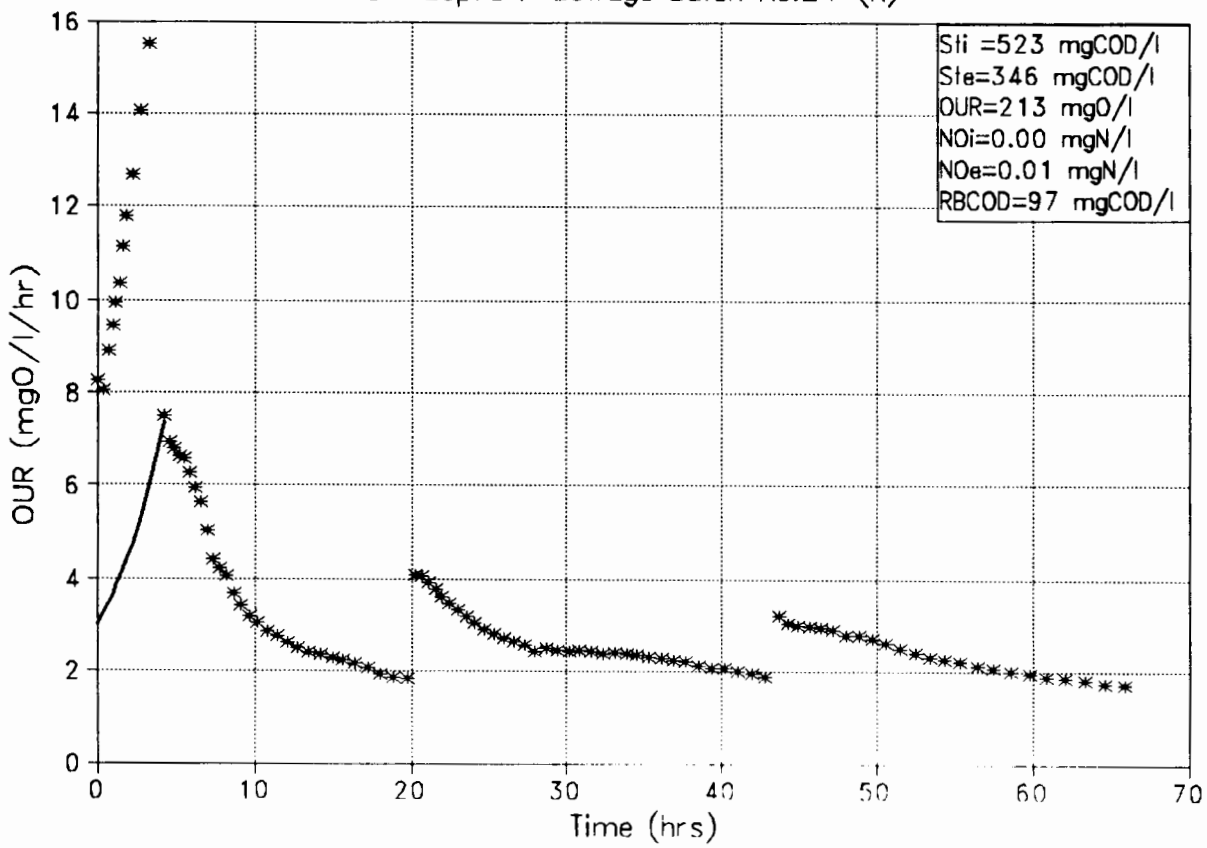


FIG A.21h OUR–time Plot for batch test
30 Sept'94–Batch No.21 (I)

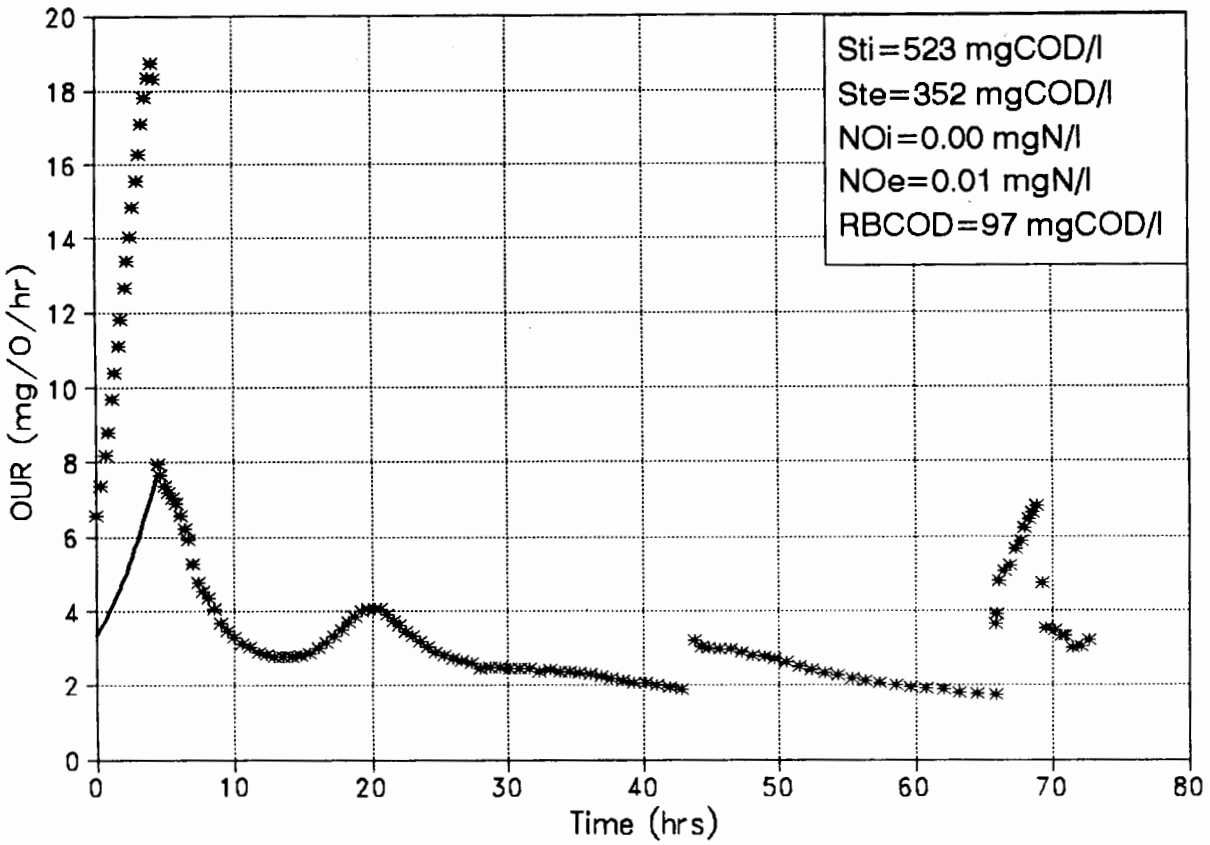


FIG A.22a OUR–time Plot for batch test
12 Oct'94–Sewage Batch No.22

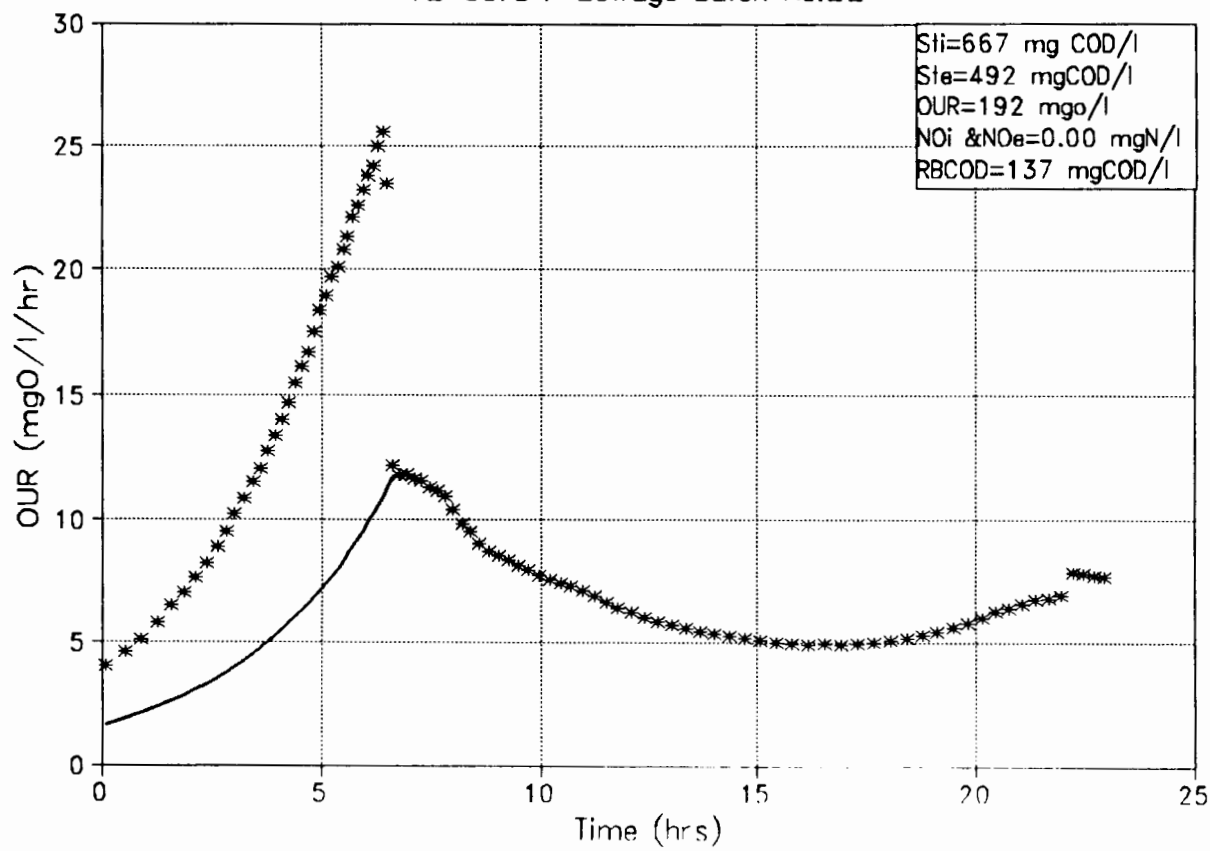


FIG A.22b OUR–time Plot for batch test
13 Oct'94–Sewage Batch No.22

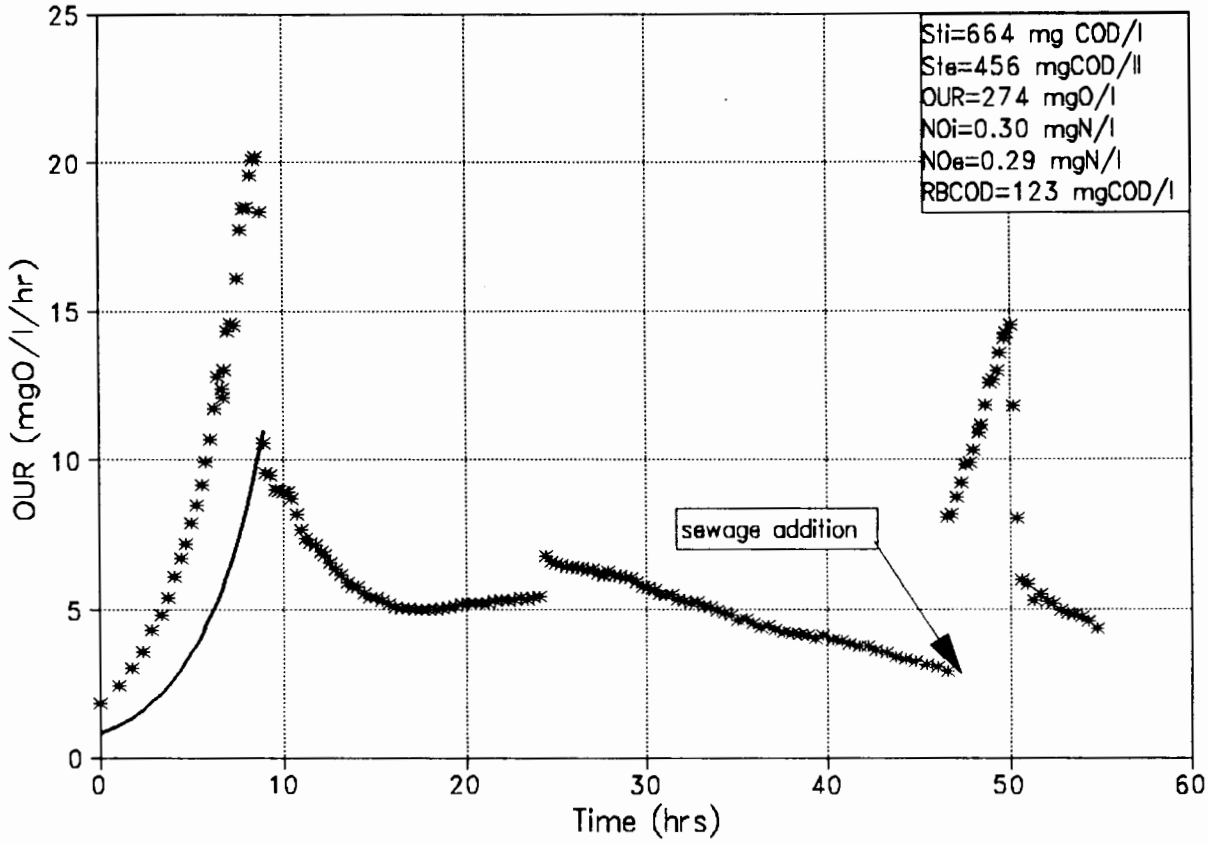


FIG A.22c OUR–time Plot for batch test
17 Oct'94–Sewage Batch No.22 (raw)

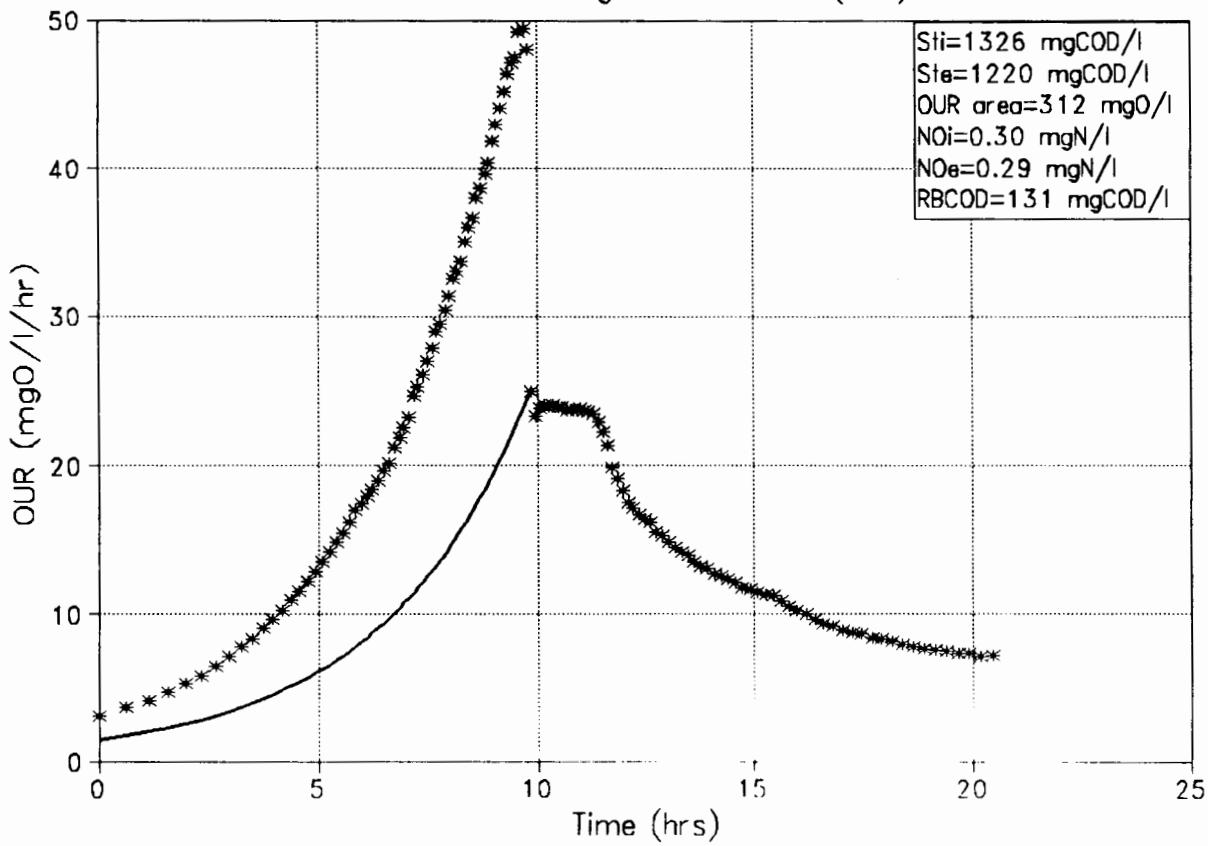


FIG A.22e OUR–time Plot for batch test
19 Oct'94–Sewage Batch No.22

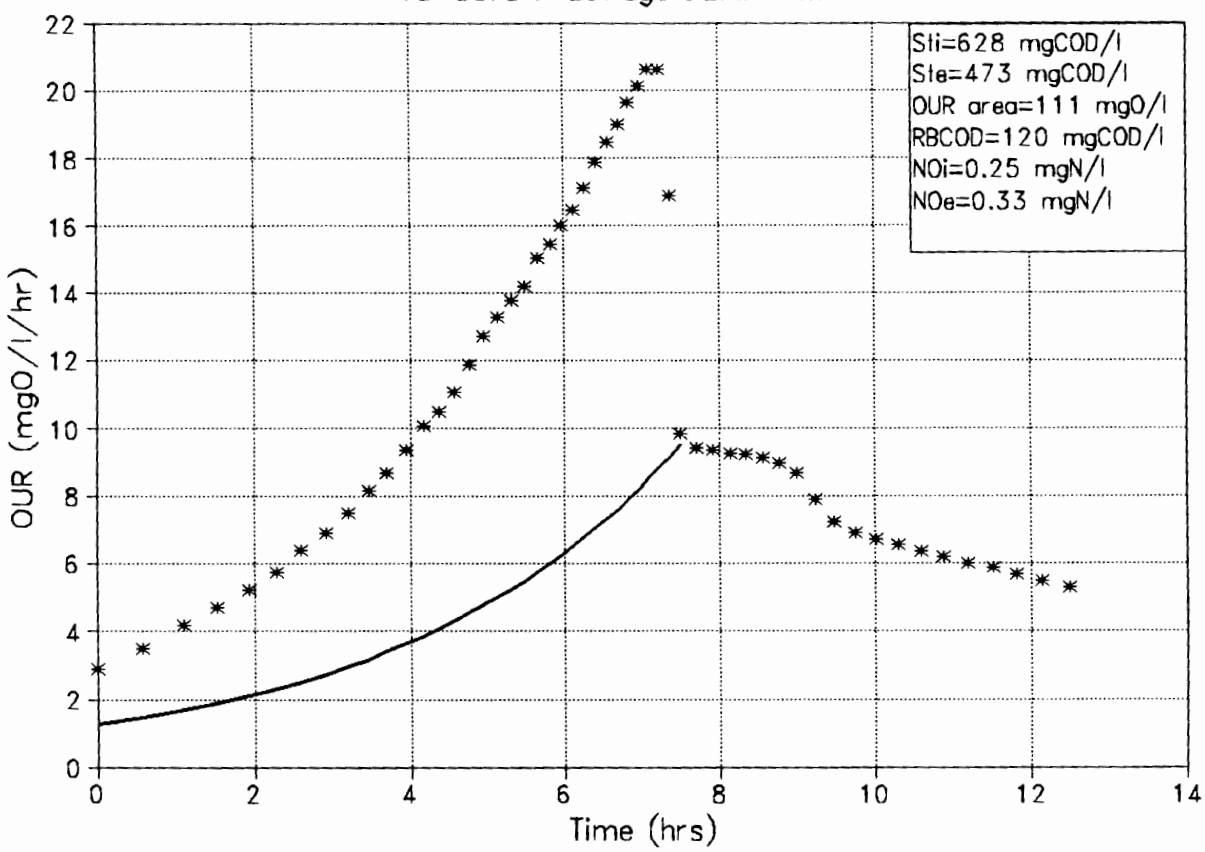


FIG A.23a OUR–time Plot for batch test
21 Oct'94–Sewage Batch No.23 (3 days)

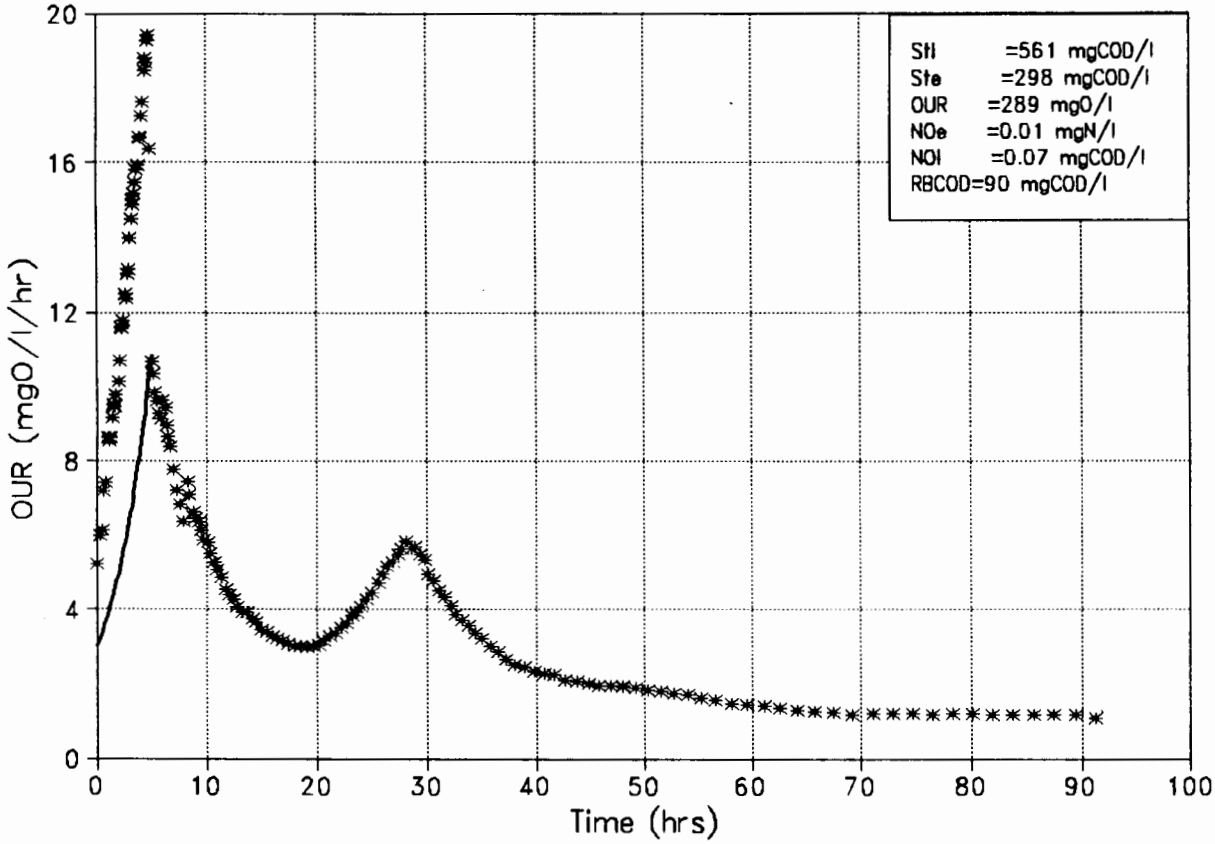


FIG A.23b OUR–time Plot for batch test
21 Oct'94–Sewage Batch No.23 (4 days)

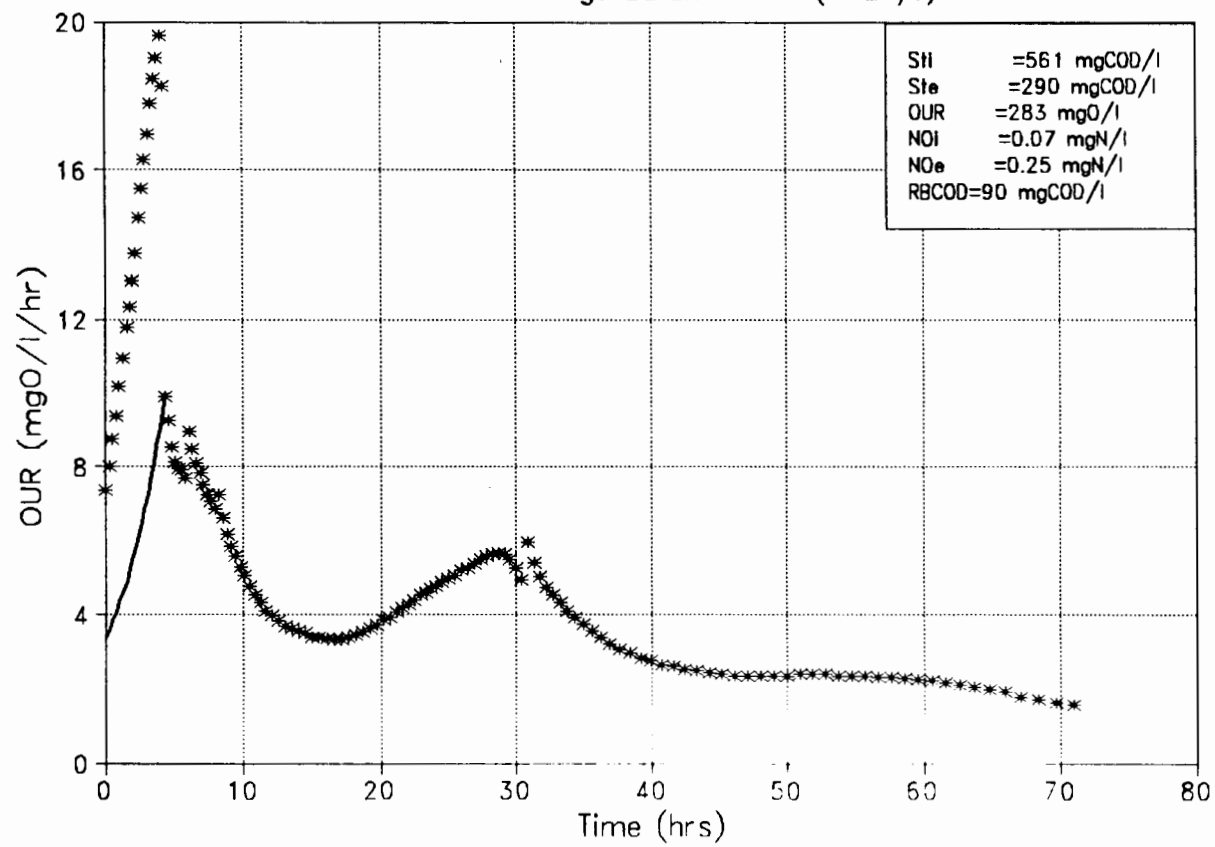


FIG A.23c OUR–time Plot for batch test
3 Nov'94–Sewage Batch No.23 (2 days)

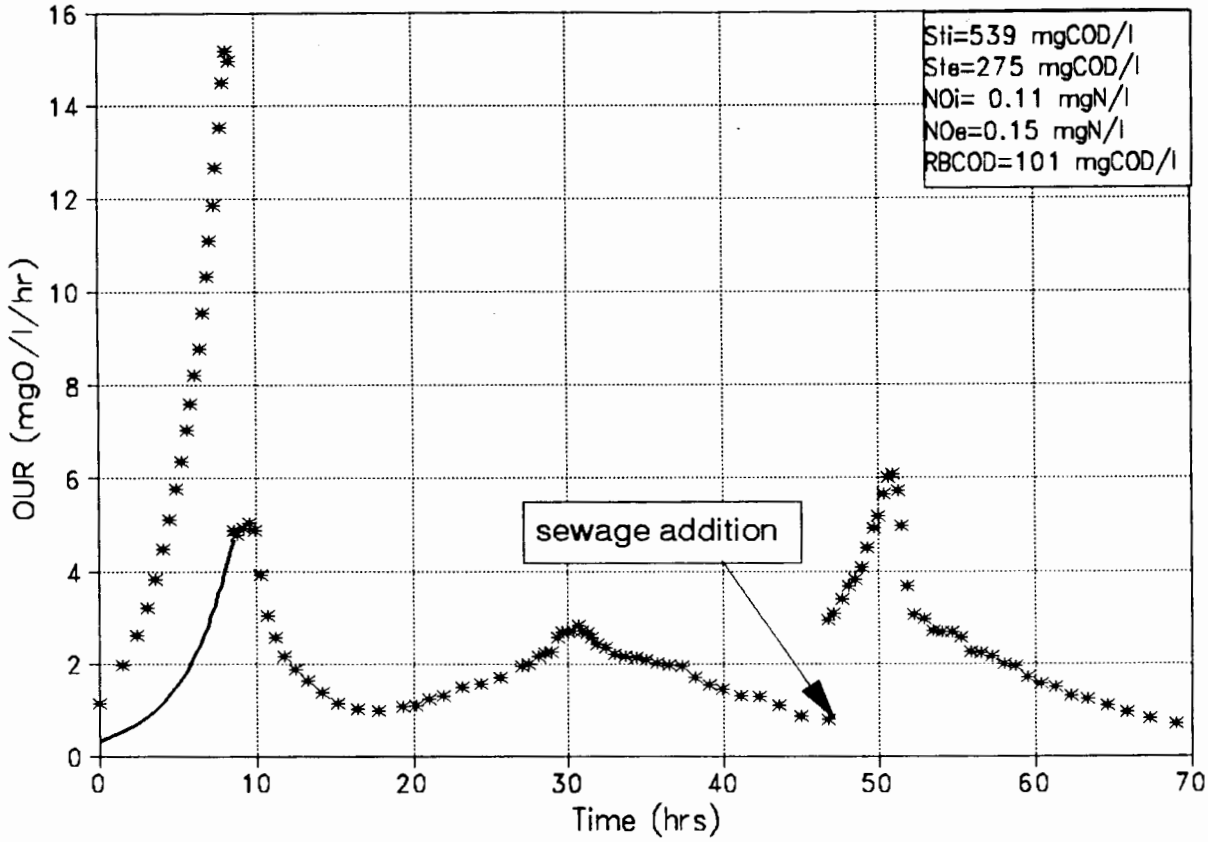


FIG A.23d OUR–time Plot for batch test
3 Nov'94–Sewage Batch No.23 (3 days)

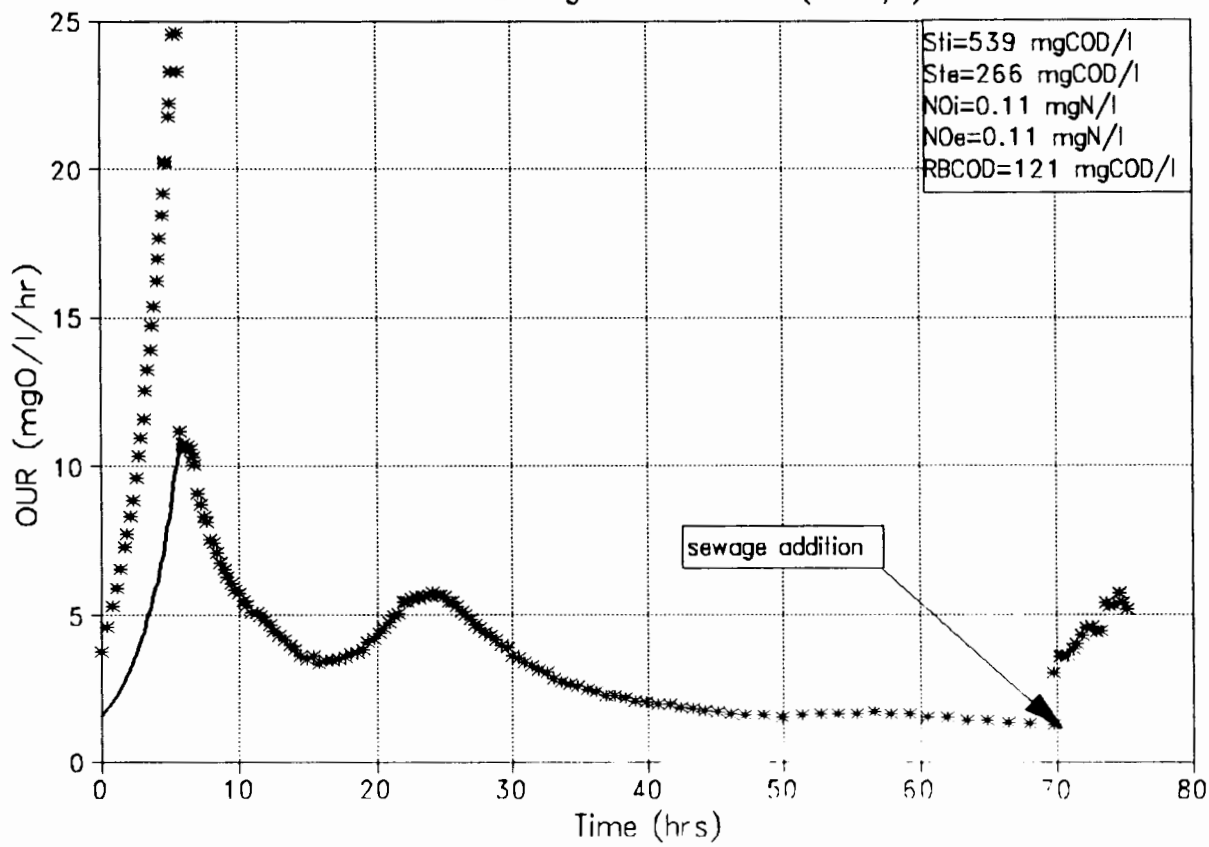


FIG A.23e OUR–time Plot for batch test
3 Nov'94–Sewage Batch No.23 (4 days)

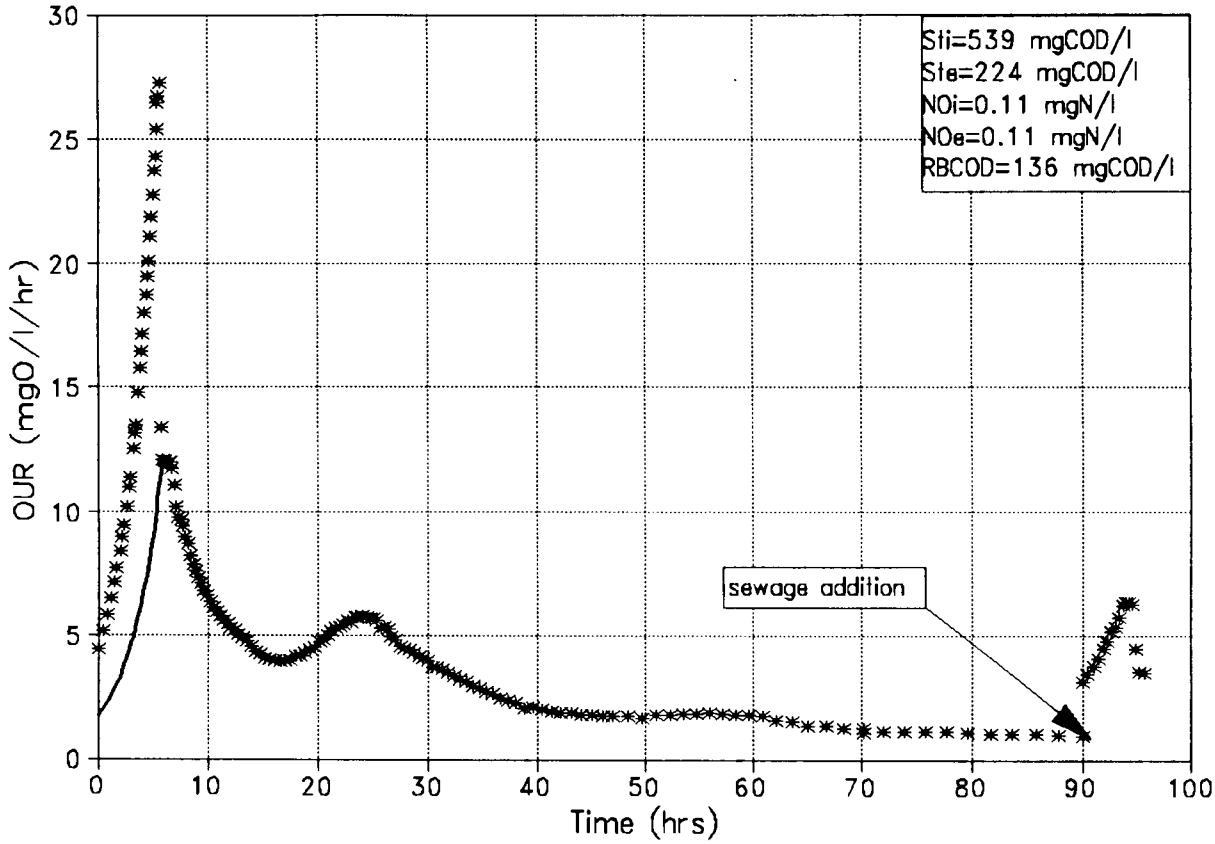


FIG A.23f OUR–time Plot for batch test
25 Oct'94–Sewage Batch No.23 (3 days)

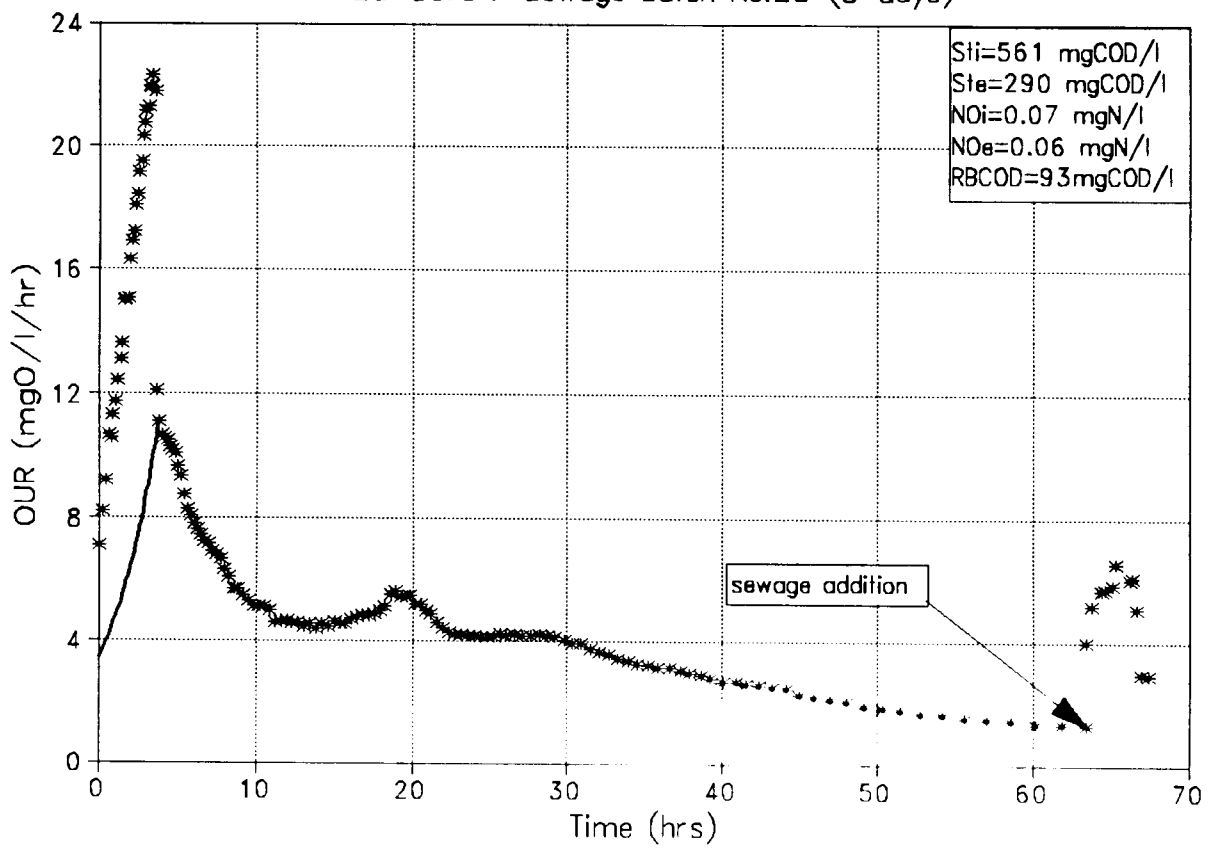
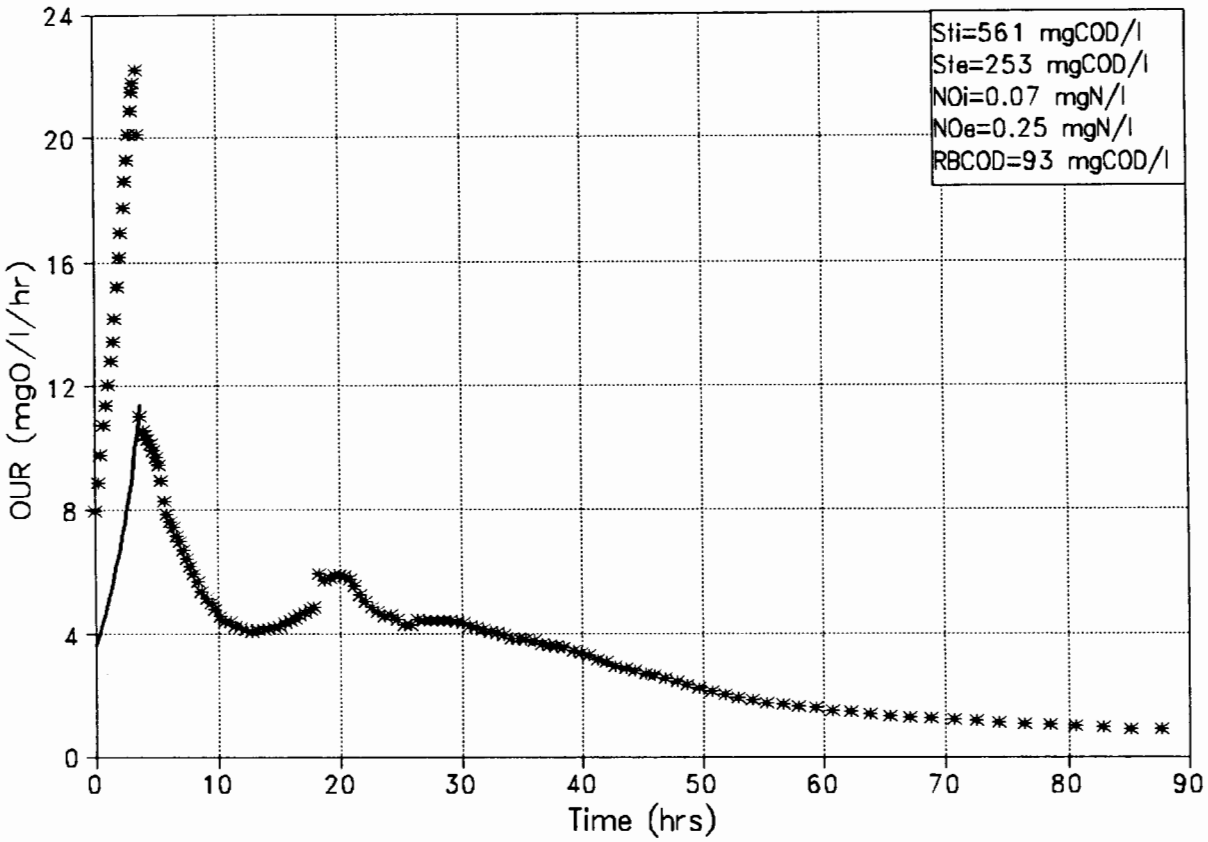


FIG A.23g OUR–time Plot for batch test
25 Oct'94–Sewage Batch No.23 (4 days)



APPENDIX B

COMPREHENSIVE DATA FOR THE BATCH TESTS

TABLE OF CONTENTS

TABLE B1.a BORCHERDS QUARRY
BATCH TEST RESULTS FOR RAW SEWAGE-
% COD recovery.

SEWAGE BATCH	Date of Test	Total COD Conc. (mgCOD/l)		TOTAL OUR area (mgO/l)	COD Recovery (%)
		Start	End		
1	july 12	1420	905	237	80
	july 19	1311	1081	245	101
	july 21	1278	1036	217	98
	july 21	1249	950	283	99
	July 26	907	730	160	98
	july 28	855	439	191	74 *
2	aug 6	1214	960	195	95
	aug 7	1427	1206	231	101
	aug 9	1322	1024	210	93
	aug 13	1278	1113	223	104
	aug 17	1246	1113	195	105
3	aug 25	1406	1090	250	95
	aug 26	1406	1081	208	92
	aug 27	1139	1086	236	116 *
	aug 28	1267	1028	188	96
	aug 29	1205	962	282	103
	aug 30	1213	970	262	102
	aug 31	1071	763	281	97
	sept 1	1071	852	312	109
	sept 2	1318	1079	234	100
4	sep 8r	861	705	122	96
	sep 8l	869	716	109	95
	sep 9r	475	349	158	107
	sep 9l	489	249	163	84
	sep 10	497	362	114	96
	sep 11	489	342	138	98
	sep 12	476	293	120	87
	sep 13	436	269	125	91

* Batch test rejected at 95 % confidence level on the % COD recovery.

TABLE B1.a BORCHERDS QUARRY -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
% COD recovery.

SEWAGE BATCH	Date of Test	Total COD Conc. (mgCOD/l)		TOTAL OUR area (mgO/l)	COD Recovery (%)
		Start	End		
5	sept 16	546	428	172	110
	sept 17	582	389	165	95
	sept 18	595	445	151	100
	sept 19	551	376	161	98
	sept 21	571	356	139	87
	sept 23	551	314	169	88
6	sept 27	638	395	158	87
	sept 28	533	386	143	99
	sept 29	555	395	154	99
	sept 30	559	350	154	90
	oct 1	518	329	151	93
	oct 2	535	370	124	92
7	oct 5	627	471	112	93
	oct 5 u	1053	922	210	107
	oct 6	627	471	146	98
	oct 6 u	1106	782	272	95
	oct 7	607	446	161	100
	oct 7 u	1105	806	291	99
	oct 8	605	387	161	91
	oct 9	542	328	174	93
	oct 10	536	356	184	101
8	oct 22	515	384	168	107
	oct 22 u	1187	991	200	100
	oct 23	492	329	149	97
	oct 24	504	370	148	103
	oct 25	475	357	110	98
	oct 25 u	965	681	236	95
	oct 27	564	439	99	95
	oct 28 d	661	550	92	97
	oct 28	580	507	53	97
	oct 28	580	548	41	101

* Batch test rejected at 95 % confidence level on the % COD recovery.

TABLE B1.a BORCHERDS QUARRY -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
% COD recovery.

SEWAGE BATCH	Date of Test	Total COD Conc. (mgCOD/l)		TOTAL OUR area (mgO/l)	COD Recovery (%)
		Start	End		
9	oct 31	590	409	129	91
	Nov 1	521	330	176	97
	Nov 2	593	394	89	82
	Nov 3	593	400	120	88
	Nov 4	577	398	129	91
	Nov 5	512	378	106	94
	Nov 6	549	367	113	88
	Nov 8	557	244	128	67 *

* Batch test rejected at 95 % confidence level on the % COD recovery.

TABLE B.1b MITCHELL'S PLAIN
BATCH TEST RESULTS FOR RAW SEWAGE-
% COD recovery.

SEWAGE BATCH	Date of Test	Total COD Conc. (mgCOD/l)		TOTAL OUR area (mgO/l)	COD Recovery (%)
		Start	End		
10	feb 05	456	366	128	108
	feb 06	456	338	119	100
	feb 07	456	327	171	109
	feb 08	460	371	137	110
	feb 09	520	363	184	105
	feb 10	524	351	138	93
	feb 11	484	403	152	115
	feb 12	540	335	204	100
	feb 13	544	339	120	84
11	feb 17	555	409	120	95
	feb 18	555	389	152	98
	feb 19	534	413	147	105
	feb 20	551	413	153	103
	feb 21	595	437	98	90
	feb 22	551	324	224	99
	feb 23	526	283	285	108
	feb 28	617	256	176	70 *
	mar 1	539	308	113	78
12	mar 18	459	203	143	75 *
	mar 19	455	382	103	106
	mar 20	480	382	136	108
	mar 22	512	374	171	106
	mar 23	585	419	159	99
	mar 25	514	347	125	92
	mar 26	514	245	98	67 *
	mar 28	588	245	171	71 *

* Batch test rejected at 95 % confidence level on the % COD recovery.

TABLE B.1b MITCHELL'S PLAIN -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
% COD recovery.

SEWAGE BATCH	Date of Test	Total COD Conc. (mgCOD/l)		TOTAL OUR area (mgO/l)	COD Recovery (%)
		Start	End		
13	april 1	570	293	261	97
	april 2	524	293	136	82
	april 3	524	240	242	92
	april 5	506	339	271	121
	april 6	545	394	123	95
	april 7	502	257	261	103
	april 8	518	314	221	103
	april 9	554	285	313	108
	april 10	603	334	145	79
	april 11	574	195	244	77
	april 13	554	334	183	93
14	april 19	685	378	181	81
	april 20	587	394	134	90
	april 21	664	312	253	85
	april 22	607	402	132	88
	april 24	624	402	148	88
	april 28	504	441	232	133 *
	april 29	645	432	217	101
	May 07	560	343	294	114
	May 08	548	327	221	100
	May 11	552	271	251	95
	May 12	605	323	173	82
15	May 19	432	250	184	100
	May 20	400	260	130	98
	May 21	541	315	238	102
	May 22	521	372	154	101
	May 23	586	476	161	109
	May 24	472	353	154	107
	May 27	612	316	217	87
	May 30	525	238	181	80

* Batch test rejected at 95 % confidence level on the % COD recovery.

TABLE B.1b MITCHELL'S PLAIN -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
% COD recovery.

SEWAGE BATCH	Date of Test	Total COD Conc. (mgCOD/l)		TOTAL OUR area (mgO/l)	COD Recovery (%)
		Start	End		
	june 23	461	301	153	98
	june 24	469	329	89	89
	june 26	497	313	131	89
	june 27	533	337	131	88
	june 29	405	282	125	101
16	june 30	545	282	137	77
	July 1	464	294	120	89
	july 4	556	371	135	91
	july 5	504	359	164	104
	july 7	492	347	213	114
	july 8	556	274	224	90
	july 9	504	371	160	105
	july 12	530	397	148	103
17	july 13	514	397	146	106
	july 14	534	359	211	107
	july 15	567	243	195	77
	july 16	551	379	169	99
	july 18	461	310	164	103
	july 19	486	326	149	98
	july 21	518	392	219	118
	july 25	469	282	176	98
	july 26	481	334	239	119
	july 27	545	361	175	98
	july 28	555	334	219	100
	july 29	451	269	177	100
	aug 1	437	242	197	99
18	aug 2	519	267	246	100
	aug 4	503	260	257	99
	aug 5	443	252	213	103
	aug 6	511	297	247	105
	aug 7	510	251	264	101

* Batch test rejected at 95 % confidence level on the % COD recovery.

TABLE B.1b MITCHELL'S PLAIN -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
% COD recovery.

SEWAGE BATCH	Date of Test	Total COD Conc. (mgCOD/l)		TOTAL OUR area (mgO/l)	COD Recovery (%)
		Start	End		
19	aug 13	543	321	246	104
	aug 15	545	346	169	95
	aug 16	545	319	243	103
	aug 18	480	219	246	97
	aug 19	511	295	289	114
	aug 20	579	319	297	106
	aug 23l	420	362	236	142 *
	aug 23r	420	334	227	134 *
	aug 25	469	287	206	105
	aug 28	584	260	288	94
	aug 30	567	344	202	96
20	sept 2	606	283	339	103
	sept 4	526	309	312	118
	sept 6	520	287	231	99
	sept 7	520	297	259	107
	sept 8	543	309	296	112
	sept 9	508	273	241	101
	sept 11	483	244	250	102
	sept 13l	525	277	187	88
	sept 13r	525	305	197	96
	sept 15	411	167	245	100
21	Sept 16	484	262	230	101
	Sept 19	583	330	245	99
	Sept 21	583	291	246	92
	Sept 23l	511	244	259	99
	Sept 23r	511	303	211	101
	Sept 27r	556	367	197	101
	Sept 27l	556	351	244	107
	Sept 30r	523	346	213	107
	Sept 30l	523	352	230	111

* Batch test rejected at 95 % confidence level on the % COD recovery.

TABLE B.1b MITCHELL'S PLAIN -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
% COD recovery.

SEWAGE BATCH	Date of Test	Total COD Conc. (mgCOD/l)		TOTAL OUR area (mgO/l)	COD Recovery (%)
		Start	End		
22	Oct 12	667	492	192	103
	Oct 13	664	456	274	110
	Oct 17	1326	1220	312	116
	Oct 20	628	473	111	93
23	Oct 21(3)	561	298	289	105
	Oct 21(4)	561	290	283	102
	Oct 25(3)	561	290	272	100
	Oct 25(4)	561	253	313	101
	Oct 28(3)	506	243	256	99
	Oct 28(4)	506	249	243	97
	Nov 3(2)	539	275	256	99
	Nov 3(3)	539	266	268	99
	Nov 3(4)	539	224	312	100

* Batch test rejected at 95 % confidence level on the % COD recovery.

TABLE B.2a BORCHERDS QUARRY.
Batch test results for raw sewage-
nitrate concentrations

Sewage Batch	Date of Test	Nitrate Concentrations. (mgN/l) start	end
3	aug 25	0.97	0.45
	aug 27	0.39	0.13
	aug 28	0.58	0.86
	aug 29	0.98	1.53
	aug 30	2.09	2.09
	aug 31	2.21	2.90
	sept 1	0.73	0.66
	sept 2	0.73	0.69
4	sept 8l	0.00	0.00
	sept 8r	0.06	0.00
	sept 9r	0.45	0.00
	sept 9l	0.00	0.00
	sept 10	0.06	0.00
	sept 12	0.00	0.00
	sept 13	0.00	0.00
5	sept 17	0.00	0.13
	sept 19	0.00	0.00
	sept 21	0.19	0.19
	sept 23	1.98	0.38
6	sept 27	0.00	0.32
	sept 28	0.51	0.00
	sept 29	1.08	0.18
	sept 30	0.19	0.19
	oct 1	0.96	0.96
	oct 2	0.45	0.45
7	oct 5	0.00	0.25
	oct 5 u	0.45	0.06
	oct 6	0.00	0.00
	oct 6 u	0.00	0.19
	oct 7	0.25	0.19
	oct 7 u	0.00	0.19
	oct 8	0.00	0.00
	oct 9	0.45	0.45

TABLE B.2a BORCHERDS QUARRY. -continued
Batch test results for raw sewage-
nitrates concentrations.

Sewage Batch	Date of Test	Nitrate Concentrations. (mgN/l)	
		influent	effluent
8	oct 22	0.30	0.61
	oct 22 u	0.71	0.52
	oct 23	0.34	0.30
	oct 24	0.25	0.40
	oct 25	0.61	0.39
	oct 25 u	0.43	0.43
	oct 27	0.20	0.39
	oct 28 d	0.52	1.38
	oct 28	0.57	0.66
	oct 28	0.48	0.71
9	oct 31	0.71	0.43
	nov 1	0.39	0.39
	nov 2	0.61	0.61
	nov 3	0.48	0.52
	nov 4	0.39	0.39
	nov 5	0.61	0.61

TABLE B.2b MITCHELL'S PLAIN
Batch test results for raw sewage-
nitrates concentrations.

Sewage Batch	Date of Test	Nitrate Concentration (mgN/l)	
		start	end
13	april 1	2.65	1.91
	april 3	1.72	1.68
	april 5	1.65	3.63
	april 7	1.58	1.75
	april 9	2.09	5.46
15	may 20	0.75	0.35
	may 21	1.24	0.34
	may 22	0.11	0.11
	may 23	0.61	0.25
	may 24	0.57	0.25
	may 27	0.58	0.50
	may 30	0.66	0.35
17	july 4	0.07	0.05
	july 5	0.04	0.02
	july 7	0.01	0.02
	july 8	0.00	0.16
	july 9	0.02	0.06
	july 12	0.05	0.07
	july 13	0.10	0.06
	july 14	0.11	0.13
	july 15	0.02	0.14
	july 16	0.00	0.06
	july 18	0.00	0.00
	july 19	0.00	0.06
	july 21	0.00	0.00
18	july 25	0.23	0.30
	july 26	0.39	0.21
	july 27	0.03	1.64
	july 28	0.01	0.08
	july 29	0.00	0.07
	august 1	0.00	0.14
	august 2	0.00	1.27
	august 4	0.04	0.07
	august 5	0.00	0.02
	august 6	0.00	0.07
	august 7	0.00	0.02

TABLE B.2b MITCHELL'S PLAIN -continued
Batch test results for raw sewage-
nitrates concentrations.

Sewage Batch	Date of Test	Nitrate Concentration (mgN/l)	
		influent	effluent
19	august 13	0.35	0.00
	august 16	0.00	0.00
	august 18	0.16	0.00
	august 19	0.09	0.01
	august 20	0.17	0.14
	august 23	0.36	0.03
	august 25	0.74	0.07
	august 28	0.04	0.07
	august 30	0.06	0.12
20	sept 2	0.01	0.04
	sept 4	0.06	0.00
	sept 6	0.00	0.01
	sept 7	0.00	0.03
	sept 8	0.02	0.03
	sept 9	0.00	0.12
	sept 11	0.04	0.00
	sept 13l	0.00	0.00
	sept 13r	0.00	0.00
	sept 15	0.00	0.22
21	sept 16	0.02	0.05
	sept 19	0.03	0.03
	sept 21	0.01	0.78
	sept 23l	0.00	0.01
	sept 23r	0.00	0.00
	sept 27r	0.10	0.10
	sept 27l	0.10	0.11
	sept 30r	0.00	0.01
	sept 30l	0.00	0.01

TABLE B.2b MITCHELL'S PLAIN -continued
Batch test results for raw sewage-
nitrates concentrations.

Sewage Batch	Date of Test	Nitrate Concentration (mgN/l)	
		influent	effluent
22	Oct 12	0.00	0.00
	Oct 13	0.30	0.29
	Oct 17	0.30	0.29
	Oct 20	0.25	0.33
23	Oct 21(3)	0.07	0.01
	Oct 21(4)	0.07	0.03
	Oct 25(3)	0.07	0.06
	Oct 25(4)	0.07	0.25
	Oct 28(3)	0.07	0.05
	Oct 28(4)	0.07	0.35
	Nov 3(2)	0.11	0.15
	Nov 3(3)	0.11	0.11
	Nov 3(4)	0.11	0.11

TABLE B.3a BOUCHERDS QUARRY
Batch test results for raw sewage
In-OUR plot regression parameters and heterotroph active biomass as a % of wastewater total COD concentration (Sti)

Sewage Batch	Date of Test	REGRESSION			Biomass at start of test (% of Sti)	% Mean Biomass std dev.of mean
		Y-inter	slope	R^2		
	july 12	2.72	0.12	0.97	12	
	july 19	2.18	0.16	0.99	7	
1	july 21	2.26	0.19	0.97	7	7.0
	july 21	2.30	0.23	1.00	6	1.5
	july 26	1.19	0.24	1.00	3	
*	july 28	1.52	0.21	1.00	5	
	aug 2	3.19	0.33	0.77	10	
	aug 6	2.59	0.20	0.94	10	
2	aug 9	2.83	0.19	0.93	12	9.8
	aug 13	2.77	0.21	0.92	11	1.0
	aug 17	2.55	0.29	0.99	6	
	aug 25	3.22	0.29	0.97	11	
	aug 26	3.26	0.5	0.45	7	
*	aug 27	2.49	0.25	0.95	8	
	aug 28	2.98	0.24	0.99	12	9.3
	aug 29	2.90	0.27	1.00	10	0.7
3	aug 30	2.84	0.26	0.96	10	
	aug 31	2.39	0.28	1.00	7	
	sept 1	2.48	0.30	0.98	7	
	sept 2	2.62	0.23	0.98	8	
	sep 8l	2.31	0.28	0.99	8	
	sep 8r	2.86	0.29	1.00	13	
	sep 9r	1.44	0.31	1.00	5	6.8
	sep 9l	1.48	0.27	0.99	6	1.0
4	sep 10	1.42	0.28	0.99	5	
	sep 11	1.28	0.28	1.00	5	
	sep 12	1.39	0.23	0.99	7	
	sep 13	1.28	0.28	0.99	5	

** tests reject as outliers at 95 % confidence level on the active mass % (of Sti)

* tests rejected at 95% confidence level on the % COD recovery

TABLE B.3a BOUCHERDS QUARRY (continued)
Batch test results for raw sewage
ln-OUR plot regression parameters and heterotroph active biomass as a % of wastewater total COD concentration (Sti)

Sewage Batch	Date of Test	REGRESSION			Biomass at start of test (% of Sti)	% Mean Biomass std dev.of mean
		Y-inter	slope	R^2		
**	sept 16	2.77	0.23	0.98	23	
	sept 17	1.95	0.23	0.98	9	
	sept 18	1.77	0.21	0.98	9	8.8
5	sept 19	1.61	0.22	0.98	7	0.5
	sept 21	1.81	0.22	0.99	9	
	sept 23	1.96	0.24	0.99	10	
	sept 27	2.44	0.29	0.98	11	
**	sept 28	2.52	0.18	0.95	23	
	sept 29	1.76	0.16	0.94	11	10.8
6	sept 30	2.06	0.16	0.96	15	1.4
	oct 1	1.94	0.22	1.00	11	
	oct 2	1.30	0.19	0.99	6	
	oct 5	2.49	0.21	0.96	16	
	oct 5 u	3.09	0.20	0.96	19	
	oct 6	2.49	0.15	0.99	22	
	oct 6 u	2.68	0.20	0.99	12	16.1
7	oct 7	2.01	0.16	0.97	13	1.7
	oct 7 u	2.59	0.16	0.95	13	
	oct 8	2.05	0.15	0.98	14	
	oct 9	2.47	0.14	0.96	26	
	oct 10	1.96	0.23	0.99	10	
	oct 22	2.15	0.19	0.91	16	
	oct 22 u	2.19	0.25	0.99	6	
	oct 23	2.01	0.12	0.99	21	
	oct 24	2.23	0.14	0.99	23	13.7
8	oct 25	1.83	0.14	0.88	16	1.8
	oct 25 u	2.17	0.23	0.99	7	
	oct 27	2.70	0.10	0.93	14	
	oct 28 d	2.07	0.19	0.97	11	
	oct 28	1.76	0.20	0.99	9	
	oct 28	2.00	0.15	0.96	14	

** tests reject as outliers at 95 % confidence level on the active mass % (of Sti)

* tests rejected at 95% confidence level on the % COD recovery

TABLE B.3a BOUCHERDS QUARRY (continued)
Batch test results for raw sewage
ln-OUR plot regression parameters and heterotroph active biomass as a % of wastewater total COD concentration (Sti)

Sewage Batch	Date of Test	REGRESSION			Biomass at start of test (% of Sti)	% Mean Biomass std dev.of mean
		Y-inter	slope	R^2		
	oct 31	1.70	0.15	0.98	10	
	Nov 1	2.06	0.13	0.98	19	
	Nov 2	1.45	0.18	0.94	7	
9	Nov 3	1.16	0.21	0.99	5	9.6
	Nov 4	1.53	0.17	0.99	8	1.7
	Nov 5	1.47	0.14	1.00	10	
	Nov 6	1.39	0.15	0.96	8	
*	Nov 8	1.00	0.22	0.99	4	

** tests reject as outliers at 95 % confidence level on the active mass % (of Sti)

* tests rejected at 95% confidence level on the % COD recovery

TABLE B.3b MITCHELL'S PLAIN
Batch test results for raw sewage
ln-OUR plot regression parameters and heterotroph active biomass as a % of wastewater total COD concentration (Sti)

Sewage Batch	Date of Test	REGRESSION			Biomass at start of test (% of Sti)	% Mean Biomass std dev.of mean
		Y-inter	slope	R^2		
	feb 05	1.12	0.33	1.00	4	
	feb 06	1.08	0.36	0.99	3	
	feb 07	1.04	0.36	0.99	3	
	feb 08	0.90	0.35	0.99	3	
	feb 09	1.15	0.36	0.99	3	
10	feb 10	1.15	0.33	0.99	3	4.0
	feb 11	1.67	0.26	0.91	3	0.6
	feb 12	1.61	0.29	0.92	8	
	feb 13	1.42	0.24	0.92	6	
	feb 17	1.25	0.37	0.99	3	
	feb 18	1.23	0.32	0.99	4	
	feb 19	1.04	0.28	0.99	3	
	feb 20	1.11	0.30	0.99	3	
11	feb 21	1.41	0.31	0.99	4	3.1
	feb 22	0.96	0.34	0.99	3	0.2
	feb 23	1.11	0.37	1.00	3	
*	feb 28	1.53	0.28	0.99	5	
	mar 1	0.82	0.40	0.99	2	
*	mar 18	2.31	0.22	0.98	18	
	mar 19	1.88	0.24	1.00	11	
	mar 20	1.96	0.21	1.00	13	
12	mar 22	2.44	0.27	0.99	15	
	mar 23	1.88	0.21	1.00	9	11.4
	mar 24	1.65	0.20	0.98	9	1.2
*	mar 26	2.06	0.17	0.99	16	
*	mar 28	2.70	0.21	0.83	21	

** tests reject as outliers at 95 % confidence level on the active mass % (of Sti)

* tests rejected at 95% confidence level on the % COD recovery

TABLE B.3b MITCHELL'S PLAIN -continued
Batch test results for raw sewage
ln-OUR plot regression parameters and heterotroph active mass as a % of wastewater total COD concentration (Sti)-continued

Sewage Batch	Date of Test	REGRESSION			Biomass at start of test (% of Sti)	% Mean Biomass std dev.of mean
		Y-inter	slope	R^2		
	april 1	1.05	0.23	1.00	4	
	april 2	1.82	0.19	0.99	11	
	april 3	1.27	0.13	0.98	9	
	april 4	1.35	0.25	1.00	5	
	april 5	1.27	0.22	0.99	6	
13	april 6	1.78	0.16	0.99	12	
	april 7	1.57	0.15	0.98	11	
	april 8	2.45	0.29	0.98	14	10.3
	april 9	2.04	0.30	0.97	8	1.4
	april 10	2.31	0.17	0.99	17	
	april 11	2.09	0.12	0.99	19	
	april 13	1.44	0.20	0.99	7	
**	april 19	2.42	0.20	0.96	14	
	april 20	1.75	0.20	1.00	9	
**	april 21	2.57	0.16	0.99	21	
	april 22	1.50	0.25	1.00	5	
14	april 24	1.72	0.19	0.98	8	
*	april 28	1.28	0.24	1.00	5	
	april 29	1.22	0.23	1.00	4	5.6
	May 07	1.13	0.27	1.00	4	0.8
	May 08	1.47	0.27	1.00	5	
	May 11	1.76	0.27	1.00	7	
	May 12	0.81	0.20	0.99	3	
	May 19	0.74	0.32	1.00	3	
**	May 20	2.47	0.26	0.99	21	
	May 21	2.39	0.24	0.99	15	
	May 22	2.10	0.28	0.99	10	8.7
	May 23	2.20	0.27	0.99	10	1.5
15	May 24	2.08	0.27	0.99	11	
	May 27	1.52	0.21	0.98	6	
	May 30	1.45	0.23	0.85	6	

** tests reject as outliers at 95 % confidence level on the active mass % (of Sti)

* tests rejected at 95% confidence level on the % COD recovery

TABLE B.3b MITCHELL'S PLAIN -continued
Batch test results for raw sewage
In-OUR plot regression parameters and heterotroph active
mass as a % of wastewater total COD concentration (Sti)-continued

Sewage Batch	Date of Test	REGRESSION			Biomass at start of test (% of Sti)	% Mean Biomass std dev.of mean
		Y-inter	slope	R^2		
	june 23	0.83	0.23	1.00	4	
	june 24	0.38	0.24	1.00	2	
	june 26	1.39	0.27	0.98	5	
16	june 27	1.78	0.24	0.98	8	5.3
	june 29	1.40	0.25	1.00	7	0.9
	june 30	1.31	0.19	1.00	6	
**	July 1	2.18	0.25	0.97	14	
	july 4	1.43	0.25	0.98	5	
	july 5	1.71	0.20	0.93	10	
	july 7	2.37	0.28	0.98	14	
	july 8	1.35	0.24	0.99	5	
	july 9	1.55	0.19	0.99	9	
	july 12	0.90	0.25	0.99	3	7.9
17	july 13	0.99	0.24	0.98	4	1.1
	july 14	1.06	0.18	0.99	5	
	july 15	1.35	0.19	0.98	6	
**	july 16	1.98	0.12	0.97	18	
	july 18	1.66	0.21	0.96	10	
	july 19	1.76	0.25	0.98	9	
	july 21	2.43	0.27	1.00	15	
	july 25	2.01	0.27	0.98	11	
	july 26	1.31	0.26	1.00	5	
	july 27	1.50	0.21	0.99	7	
	july 28	1.63	0.23	0.98	7	6.3
	july 29	0.77	0.24	0.99	4	0.8
	august 1	0.39	0.26	0.99	2	
18	august 2	1.16	0.19	0.99	6	
	august 4	1.82	0.28	1.00	8	
	august 5	1.75	0.29	0.99	8	
**	august 6	2.48	0.27	0.99	16	
	august 7	1.50	0.31	1.00	5	

** tests rejected as outliers at 95 % confidence level on the active mass % (of Sti)

* tests rejected at 95% confidence level on the % COD recovery

TABLE B.3b MITCHELL'S PLAIN -continued
Batch test results for raw sewage
In-OUR plot regression parameters and heterotroph active mass as a % of wastewater total COD concentration (Sti) -continued

Sewage Batch	Date of Test	REGRESSION			Biomass at start of test (% of Sti)	% Mean Biomass std dev.of mean
		Y-inter	slope	R^2		
	august 13	2.6	0.27	0.96	17	
	august 15	1.69	0.24	0.98	7	
	august 16	1.15	0.27	1.00	4	
	august 18	1.31	0.26	1.00	5	
	august 19	2.08	0.22	0.99	13	
19	august 20	2.21	0.30	0.95	10	
*	august 23l	2.60	0.24	0.97	24	9.2
*	august 23r	2.56	0.27	0.94	21	1.4
	august 25	1.59	0.26	1.00	7	
	august 28	2.17	0.27	0.99	10	
	august 30	2.13	0.28	0.99	10	
	sept 2	2.21	0.25	0.97	11	
	sept 4	1.42	0.26	0.99	5	
	sept 6	1.21	0.25	0.99	5	
	sept 7	0.97	0.28	0.94	3	
	sept 8	1.19	0.20	0.98	5	7.2
20	sept 9	1.45	0.20	0.99	7	1.0
	sept 11	1.87	0.22	0.96	11	
	sept 13l	1.55	0.21	0.99	8	
	sept 13r	1.81	0.20	0.95	10	
**	sept 15	2.46	0.31	0.95	17	
	Sept 16	2.66	0.27	0.98	20	
	Sept 19	2.26	0.18	0.97	16	
	Sept 21	1.15	0.18	0.98	5	
	Sept 23l	1.68	0.16	0.96	11	
21	Sept 23r	2.34	0.26	0.99	14	12.2
	Sept 27r	1.90	0.18	0.96	12	1.4
	Sept 27l	1.86	0.20	0.98	10	
	Sept 30r	2.06	0.21	0.98	13	
	Sept 30l	1.94	0.26	0.98	9	

** tests rejected as outliers at 95 % confidence level on the active mass % (of Sti)

* tests rejected at 95% confidence level on the % COD recovery

TABLE B.3b MITCHELL'S PLAIN -continued
Batch test results for raw sewage
In-OUR plot regression parameters and heterotroph active
mass as a % of wastewater total COD concentration (Sti) -continued

Sewage Batch	Date of Test	REGRESSION			Biomass at start of test (% of Sti)	% Mean Biomass std dev.of mean
		Y-inter	slope	R^2		
22	Oct 12	1.4	0.3	1	4	
	Oct 13	0.62	0.29	1	2	2.8
	Oct 17	1.11	0.29	1	2	0.5
	Oct 20	1.13	0.27	1	3	
23	Oct 21(3)	1.81	0.26	0.98	8	
	Oct 21(4)	2.04	0.25	0.99	10	
	Oct 25(3)	2.11	0.31	0.97	9	
	Oct 25(4)	2.11	0.31	0.99	9	
	Oct 28(3)	2.14	0.3	1.00	8	7.0
	Oct 28(4)	1.92	0.32	0.95	9	1.0
	Nov 3(2)	0.21	0.34	1.00	1	
	Nov 3(3)	1.4	0.34	1.00	4	
	Nov 3(4)	1.49	0.32	1.00	5	

** tests rejected as outliers at 95 % confidence level on the active mass % (of Sti)

* tests rejected at 95% confidence level on the % COD recovery

TABLE B.4a BORCHERDS QUARRY
BATCH TEST RESULTS FOR RAW SEWAGE-
kinetic constants, Kmp and Uh (/d)

Sewage Batch	Date of test	Kmp (/d)	Uh (/d)
	july 12	0.96	2.64
	july 19	1.20	3.12
1	july 21	1.44	3.84
	july 21	2.16	4.08
	july 26	0.96	5.28
*	july 28	1.44	4.08
	aug 6	1.92	3.36
	aug 7	2.16	6.24
2	aug 9	1.68	3.60
	aug 13	2.16	3.36
	aug 17	2.64	5.04
	aug 25	2.16	5.28
	aug 26	2.40	4.80
*	aug 27	2.16	4.32
3	aug 28	2.16	4.32
	aug 29	2.16	5.04
	aug 30	2.16	4.80
	aug 31	2.40	7.20
	sep 1	2.88	5.04
	sep 2	2.16	4.08
	sep 8l	2.40	5.04
	sep 8r	2.16	5.28
	sep 9r	2.16	6.00
	sep 9l	2.16	5.04
4	sep 10	2.16	5.28
	sep 11	1.92	5.52
	sep 12	2.16	3.84
	sep 13	2.16	5.04
	sept 16	1.68	4.56
	sept 17	1.92	4.32
	sept 18	2.16	3.36
5	sept 19	2.40	3.60
	sept 21	1.92	4.08
	sept 23	2.16	4.32

* tests rejected at 95% confidence level on the % COD recovery.

TABLE B.4a BORCHERDS QUARRY
BATCH TEST RESULTS FOR RAW SEWAGE-
kinetic constants, Kmp and Uh (/d)

Sewage Batch	Date of test	Kmp (/d)	Uh (/d)
	sept 27	1.92	5.76
	sept 28	1.44	3.60
	sept 29	1.44	3.12
6	sept 30	1.44	3.12
	oct 1	1.92	4.08
	oct 2	1.68	3.60
	oct 5	1.92	3.84
	oct 5 u	1.92	3.36
	oct 6	1.68	2.40
	oct 6 u	2.16	3.12
7	oct 7	1.92	2.64
	oct 7 u	2.16	2.16
	oct 8	1.92	2.40
	oct 9	1.68	2.16
	oct 10	1.92	4.32
	oct 22	2.64	2.40
	oct 22 u	2.16	4.32
	oct 23	1.92	1.68
	oct 24	1.68	2.16
8	oct 25	1.68	2.16
	oct 25 u	1.92	4.32
	oct 27	1.20	1.92
	oct 28 d	1.92	3.36
	oct 28	2.40	3.12
	oct 28	1.92	2.40
	oct 31	1.68	2.64
	Nov 1	1.68	2.16
	Nov 2	1.92	3.12
9	Nov 3	1.92	3.60
	Nov 4	1.92	2.64
	Nov 5	1.44	2.40
	Nov 6	1.68	2.40
*	Nov 8	2.16	3.60

* tests rejected at 95% confidence level on the % COD recovery.

TABLE B.4b MITCHELL'S PLAIN
BATCH TEST RESULTS FOR RAW SEWAGE-
kinetic constants, Kmp and Uh (/d)

Sewage Batch	Date of test	Kmp (/d)	Uh (/d)
	feb 05	3.84	4.80
	feb 06	3.60	5.76
	feb 07	3.84	5.52
	feb 08	3.84	5.28
	feb 09	3.60	5.76
10	feb 10	4.32	4.32
	feb 11	3.36	3.60
	feb 12	2.88	4.80
	feb 13	2.88	3.60
	feb 17	3.84	5.76
	feb 18	3.84	4.56
	feb 19	3.36	4.08
	feb 20	3.84	4.08
	feb 21	4.08	4.08
11	feb 22	4.08	4.80
	feb 23	4.32	5.28
*	feb 28	4.08	3.36
	mar 1	5.28	5.04
*	mar 18	2.40	3.60
	mar 19	2.16	4.32
	mar 20	1.92	3.84
12	mar 22	3.36	3.84
	mar 23	2.16	3.60
	mar 24	2.16	3.36
*	mar 26	2.40	2.40
*	mar 28	2.16	3.60

* tests rejected at 95% confidence level on the % COD recovery.

TABLE B.4b MITCHELL'S PLAIN
BATCH TEST RESULTS FOR RAW SEWAGE-
kinetic constants, Kmp and Uh (/d)

Sewage Batch	Date of test	Kmp (/d)	Uh (/d)
13	april 1	2.16	4.08
	april 2	1.92	3.36
	april 3	1.44	2.40
	april 4	2.16	4.56
	april 5	1.92	4.08
	april 6	1.68	2.88
	april 7	1.68	2.64
	april 8	2.16	5.52
	april 9	2.16	5.76
	april 10	1.44	3.36
	april 11	1.44	2.16
	april 13	1.92	3.60
14 *	april 19	2.16	3.36
	april 20	1.92	3.60
	april 21	1.68	2.88
	april 22	2.40	6.48
	april 24	1.92	3.36
	april 28	2.16	4.32
	april 29	2.16	4.08
	May 08	2.16	5.04
	May 09	2.16	5.04
	May 12	2.40	6.96
	May 13	2.16	3.36
15	May 19	2.16	6.24
	May 20	2.16	4.80
	May 21	2.64	3.84
	May 22	2.64	4.80
	May 23	2.64	4.56
	May 24	2.64	4.56
	May 27	2.40	3.36
	May 30	2.64	3.60

* tests rejected at 95% confidence level on the % COD recovery.

TABLE B.4b MITCHELL'S PLAIN
BATCH TEST RESULTS FOR RAW SEWAGE-
kinetic constants, Kmp and Uh (/d)

Sewage Batch	Date of test	Kmp (/d)	Uh (/d)
	june 23	1.92	4.32
	june 24	1.92	4.56
	june 26	1.92	5.28
	june 27	1.92	4.56
	june 29	2.16	4.56
16	june 30	1.92	3.36
	July 1	2.64	4.08
	july 4	1.92	4.80
	july 5	2.40	3.12
	july 7	2.16	5.04
	july 8	1.68	4.56
	july 9	1.68	3.60
	july 12	1.92	4.56
17	july 13	1.92	4.56
	july 14	1.68	3.12
	july 15	1.92	3.36
	july 16	1.20	2.40
	july 18	1.44	4.08
	july 19	1.68	4.80
	july 21	2.16	5.04
	july 25	2.16	5.04
	july 26	2.40	4.56
	july 27	1.92	3.84
	july 28	1.92	4.32
	july 29	2.40	4.08
	august 1	1.92	4.80
18	august 2	1.68	3.60
	august 4	2.16	5.04
	august 5	2.40	5.04
	august 6	2.16	5.04
	august 7	3.84	4.08

* tests rejected at 95% confidence level on the % COD recovery.

TABLE B.4b MITCHELL'S PLAIN
BATCH TEST RESULTS FOR RAW SEWAGE-
kinetic constants, Kmp and Uh (/d)

Sewage Batch	Date of test	Kmp (/d)	Uh (/d)
	august 13	1.92	5.28
	august 15	1.68	4.80
	august 16	1.92	5.28
	august 18	1.92	5.04
	august 19	1.68	4.32
19	august 20	1.44	6.24
*	august 23 l	1.92	4.32
*	august 23r	1.92	5.04
	august 25	1.92	5.04
	august 28	1.68	5.28
	august 30	1.44	6.00
	sept 2	1.92	4.80
	sept 4	1.44	5.28
	sept 6	1.92	4.56
	sept 7	1.92	5.52
	sept 8	1.68	3.60
20	sept 9	1.68	3.84
	sept 11	1.44	4.32
	sept 13l	1.68	4.08
	sept 13r	1.68	3.60
	sept 15	2.88	5.28
	Sept 16	2.64	4.32
	Sept 19	1.92	2.88
	Sept 21	1.92	3.12
	Sept 23l	1.44	2.88
21	Sept 23r	2.64	4.32
	Sept 27r	1.68	3.36
	Sept 27l	1.92	3.60
	Sept 30r	2.16	3.60
	Sept 30l	2.40	4.32

* tests rejected at 95% confidence level on the % COD recovery.

TABLE B.4b MITCHELL'S PLAIN
BATCH TEST RESULTS FOR RAW SEWAGE-
kinetic constants, Kmp and Uh (/d)

Sewage Batch	Date of test	Kmp (/d)	Uh (/d)
22	Oct 12	3.12	4.56
	Oct 13	3.36	4.32
	Oct 17	3.60	4.08
	Oct 20	2.88	4.08
23	Oct 21(3)	3.36	3.60
	Oct 21(4)	2.88	3.84
	Oct 25(3)	3.36	4.80
	Oct 25(4)	3.36	4.56
	Oct 28(3)	3.36	4.80
	Oct 28(4)	3.36	5.28
	Nov 3(2)	2.16	5.76
	Nov 3(3)	3.36	5.28
	Nov 3(4)	3.36	5.28

* tests rejected at 95% confidence level on the % COD recovery.

TABLE B.5a BOUCHERDS QUARRY
BATCH TEST RESULTS FOR RAW SEWAGE-
RBCOD % of total COD (Sti) Concentration.

Sewage Batch	Date of test	Start Total COD (mgCOD/l)	RBCOD Conc. mgCOD/l	RBCOD (% of Sti)
	july 12	1420	254	18
	july 19	1311	222	17
1	july 21	1278	232	18
	july 21	1249	264	21
	july 26	907	254	28
*	july 28	855	257	30
	aug 6	1214	143	12
	aug 7	1427	131	9
2	aug 9	1322	166	13
	aug 13	1278	133	10
	aug 17	1246	155	12
	aug 25	1406	193	14
	aug 26	1406	194	14
*	aug 27	1139	194	17
	aug 28	1267	179	14
3	aug 29	1205	192	16
	aug 30	1213	124	10
	aug 31	1071	194	18
	sept 1	1071	177	17
	sept 2	1318	169	13
	sep 8l	869	181	21
	sep 8r	861	200	23
	sep 9r	475	87	18
	sep 9l	489	89	18
4	sep 10	497	92	19
	sep 11	489	105	21
	sep 12	476	83	17
	sep 13	436	103	24
	sept 16	546	131	24
	sept 17	582	128	22
	sept 18	595	107	18
5	sept 19	551	104	19
	sept 21	571	115	20
	sept 23	551	123	22

** tests rejected as outliers at 95 % confidence level on % RBCOD (of Sti).

* tests rejected at 95 % confidence level on the % COD recovery.

TABLE B.5a BOUCHERDS QUARRY -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
RBCOD % of total COD (Sti) Concentration.

Sewage Batch	Date of test	Start Total COD (mgCOD/l)	RBCOD Conc. mgCOD/l	RBCOD (% of Sti)
	sept 27	638	148	23
	sept 28	533	122	23
	sept 29	555	123	22
6	sept 30	559	123	22
	oct 1	518	126	24
	oct 2	535	127	24
	oct 5	627	100	16
	oct 5u	526	92	17
	oct 6	627	99	16
	oct 6u	553	111	20
7	oct 7	607	91	15
	oct 7u	552	127	23
	oct 8	605	94	16
	oct 9	542	108	20
	oct 10	536	123	23
	oct 22	515	93	18
	oct 22u	593	95	16
	oct 23	492	74	15
	oct 24	504	80	16
8	oct 25	475	51	11
	oct 25u	965	216	22
	oct 27	564	94	17
	oct 28	661	139	21
	oct 28	580	132	23
	oct 28	580	147	25
	oct 31	590	118	20
	Nov 1	521	97	19
	Nov 2	593	101	17
9	Nov 3	593	83	14
	Nov 4	577	98	17
	Nov 5	512	87	17
	Nov 6	549	77	14
*	Nov 8	557	106	19

** tests rejected as outliers at 95 % confidence level on % RBCOD (of Sti).

* tests rejected at 95 % confidence level on the % COD recovery.

TABLE B.5b MITCHELL'S PLAIN
BATCH TEST RESULTS FOR RAW SEWAGE-
RBCOD % of total COD (Sti) Concentration.

Sewage Batch	Date of test	Total COD (mgCOD/l)	RBCOD Conc. (mgCOD/l	RBCOD % of Sti COD
	feb 05	456	73	16
	feb 06	456	72	16
	feb 07	456	96	21
	feb 08	460	74	16
10	feb 09	520	94	18
	feb 10	524	68	13
	feb 11	484	75	15
	feb 12	540	131	24
	feb 13	544	71	13
	feb 17	555	91	16
	feb 18	555	90	16
	feb 19	534	96	18
	feb 20	551	99	18
	feb 21	595	95	16
11	feb 22	551	88	16
	feb 23	526	111	21
*	feb 28	617	70	11
**	mar 1	539	50	9
*	mar 18	459	101	22
	mar 19	455	90	20
	mar 20	480	101	21
	mar 22	512	82	16
12	mar 23	585	129	22
	mar 24	514	93	18
*	mar 26	514	62	12
*	mar 28	588	82	14

** tests rejected as outliers at 95 % confidence level on % RBCOD (of Sti).

* tests rejected at 95 % confidence level on the % COD recovery.

TABLE B.5b MITCHELL'S PLAIN -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
RBCOD % of total COD (Sti) Concentration.

Sewage Batch	Date of test	Total COD (mgCOD/l)	RBCOD Conc. (mgCOD/l	RBCOD % of Sti COD
	april 1	570	131	23
	april 2	524	116	22
	april 3	524	127	24
	april 4	581	154	26
	april 5	506	130	26
13	april 6	545	109	20
	april 7	502	146	29
**	april 8	518	189	36
**	april 9	554	196	35
	april 10	603	148	25
	april 11	574	149	26
	april 13	554	137	25
	april 19	685	137	20
	april 20	587	88	15
	april 21	664	106	16
	april 22	607	97	16
14	april 24	624	125	20
*	april 28	504	131	26
	april 29	645	110	17
	May 07	560	123	22
	May 08	548	110	20
	May 11	552	127	23
	May 12	605	111	18

** tests rejected as outliers at 95 % confidence level on % RBCOD (of Sti).

* tests rejected at 95 % confidence level on the % COD recovery.

TABLE B.5b MITCHELL'S PLAIN -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
RBCOD % of total COD (Sti) Concentration.

Sewage Batch	Date of test	Total COD (mgCOD/l)	RBCOD Conc. (mgCOD/l	RBCOD % of Sti COD
	May 19	432	94	22
	May 20	400	76	19
	May 21	541	90	17
	May 22	521	108	21
	May 23	586	121	21
15	May 24	472	104	22
	May 27	612	86	14
	May 30	525	95	18
	june 23	461	101	22
	june 24	469	70	15
	june 26	497	139	28
16	june 27	533	139	26
	june 29	405	100	25
	june 30	545	125	23
	July 1	464	74	16
	july 4	556	135	24
	july 5	504	137	27
**	july 7	492	171	35
	july 8	556	147	26
	july 9	504	158	31
	july 12	530	143	27
17	july 13	514	155	30
	july 14	534	144	27
	july 15	567	158	28
	july 16	551	151	27

** tests rejected as outliers at 95 % confidence level on % RBCOD (of Sti).

* tests rejected at 95 % confidence level on the % COD recovery.

TABLE B.5b MITCHELL'S PLAIN -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
RBCOD % of total COD (Sti) Concentration.

Sewage Batch	Date of test	Total COD (mgCOD/l)	RBCOD Conc. (mgCOD/l	RBCOD % of Sti COD
17 cont.	july 19	486	126	26
**	july 21	518	231	43
	july 25	469	126	27
	july 26	481	144	30
	july 27	545	159	29
	july 28	555	161	29
	july 29	451	113	25
	august 1	437	149	34
18	august 2	519	107	21
	august 4	503	138	27
	august 5	443	120	27
	august 6	511	96	19
	august 7	510	90	18
	august 13	543	130	24
	august 15	545	120	22
	august 16	545	114	21
	august 18	480	115	24
19	august 19	511	158	31
	august 20	579	179	31
*	august 23	420	126	30
*	august 23	420	130	31
	august 25	469	108	23
	august 28	584	99	17
	august 30	567	153	27
	sept 2	606	139	23
	sept 4	526	132	25
	sept 6	520	120	23
	sept 7	520	140	27
	sept 8	543	87	16
20	sept 9	508	122	24
	sept 11	483	106	22
	sept 13l	525	89	17
	sept 13r	525	105	20
	sept 15	411	87	21

** tests rejected as outliers at 95 % confidence level on % RBCOD (of Sti).

* tests rejected at 95 % confidence level on the % COD recovery.

TABLE B.5b MITCHELL'S PLAIN -continued
BATCH TEST RESULTS FOR RAW SEWAGE-
RBCOD % of total COD (Sti) Concentration.

Sewage Batch	Date of test	Total COD (mgCOD/l)	RBCOD Conc. (mgCOD/l	RBCOD % of Sti COD
**	Sept 16	484	74	15
	Sept 19	583	91	16
	Sept 21	583	99	17
	Sept 23l	511	112	22
21	Sept 23r	511	107	21
	Sept 27r	556	120	22
	Sept 27l	556	117	21
	Sept 30r	523	107	20
	Sept 30l	523	97	19
	Oct 12	667	137	21
22	Oct 13	664	123	19
	Oct 17	663	130	20
	Oct 20	628	120	19
	Oct 21(3)	561	90	16
	Oct 21(4)	561	90	16
	Oct 25(3)	561	76	14
	Oct 25(4)	561	93	17
**	Oct 28(3)	506	47	9
23	Oct 28(4)	506	90	18
	Nov 3(2)	539	101	19
	Nov 3(3)	539	121	22
	Nov 3(4)	539	136	25

** tests rejected as outliers at 95 % confidence level on % RBCOD (of Sti).

* tests rejected at 95 % confidence level on the % COD recovery.

APPENDIX C

CONSTRUCTION AND INTERPRETATION OF STATISTICAL PLOTS FOR DATA ANALYSIS

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APPENDIX C

CONSTRUCTION AND INTERPRETATION OF STATISTICAL PLOTS FOR DATA ANALYSIS

C.1 INTRODUCTION

Data from the 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 statistical 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 analyzed 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 differnce between the means from two data sets is statistically significant at a selected confidence level, or not.

C.2 CONTRUCTION 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 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, for example, see Fig C.1. Alternatively, probability paper can be used on which the y-axis has been linearized.

C.3 INTERPRETATION OF THE STATISTICAL PLOT

The plotted data 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 the distribution (i.e. the data are normally distributed), it is possible to determine graphically (refer Fig C.1)

- 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. value of x that gives $y = 5$) and the value of x that gives $y = 4$ (or $y = 6$).

C.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 the 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:

  $SD(difference) = \sqrt{\{ (SDmean1)^2 + (SDmean2)^2 \}}$

- Compute the absolute value (i.e. positive) of difference between the two means:

  $mean\ (difference) = | mean\ 1 - mean\ 2 |$

- 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 [mean(difference)], twice the standard deviation of the difference between the two means [SD(difference)], i.e. [mean(difference) - 2·SD(difference)] - if a 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 occurs, 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.

C.5 ILLUSTRATION BY AN EXAMPLE

An example plot is given in Fig C.1.

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, i.e. in this case:

from the graph the mean = 18%

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 C.1, i.e. from the graph

the x value at y = 6 = 22,6
the x value at y = 4 = 13,4
the standard deviation therefore is either (22,6–18) or (18–13,4) = 4,6

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 of data in the set = 12
the SDmean = $4,6/\sqrt{(12)}$ = 1,33.

Say a second set of 10 data is analyzed as above to give:
mean = 16%
standard deviation = 5,1%

Standard deviation of the mean is calculated:
SDmean = $5,1/\sqrt{(10)}$ = 1,61

Now, comparing the data from the two ssets:

$$\text{SD(difference)} = \sqrt{\{(\text{SDmean1})^2 + (\text{SDmean2})^2\}}$$
$$= \sqrt{\{1,33^2 + 1,61^2\}}$$
$$= 2,09$$
$$\text{mean(difference)} = |18 - 16| = 2\%$$

Selecting the confidence level at 95%:

$$\text{test} = \text{mean(difference)} - 2 \cdot \text{SD(difference)}$$
$$= 2 - 2 \cdot 2,09$$
$$= -2,18$$

Since the resultant value is negative, it can be concluded that the two means are not significantly different at the 95% confidence level.

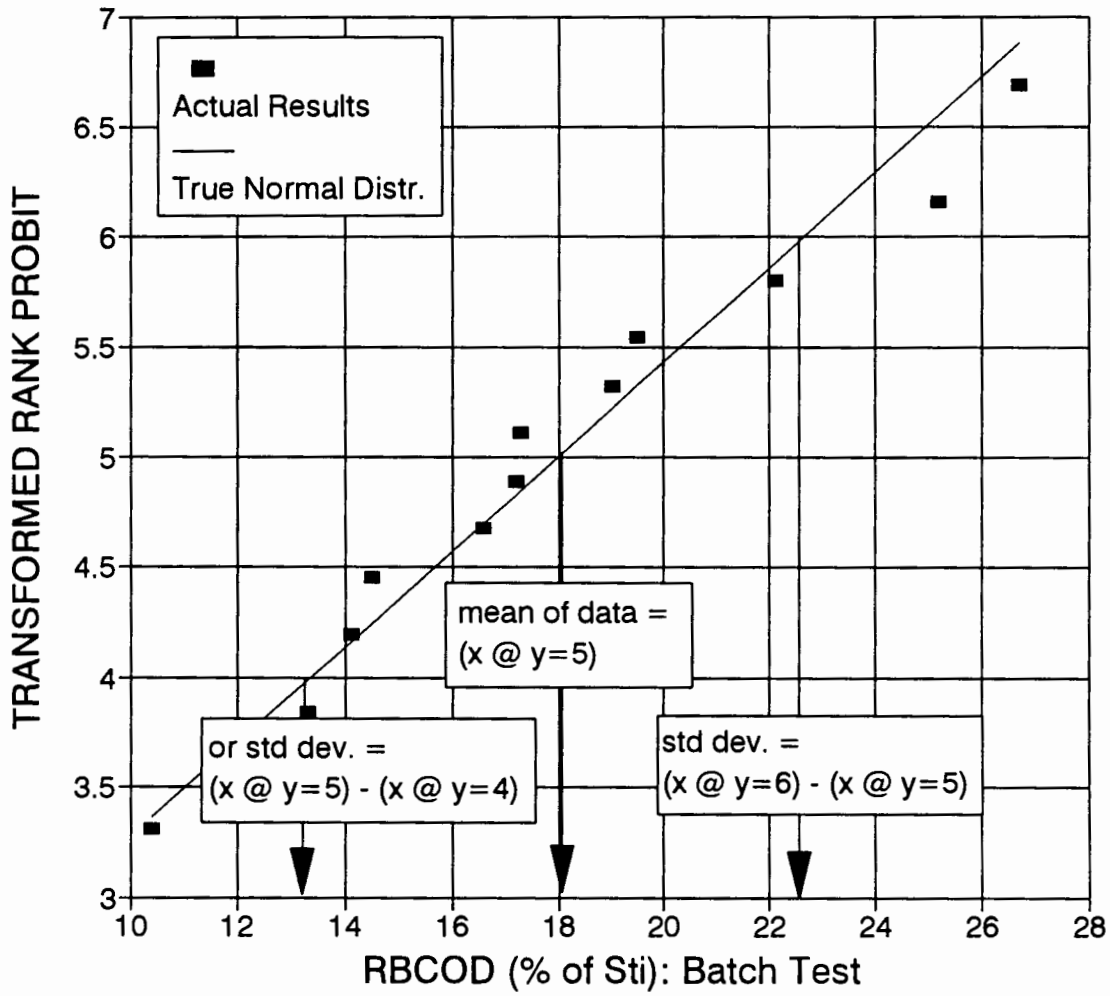

Fig C.1: Example of a statistical probability plot for a number of RBCOD (% of total COD, Sti) derived from the batch test.

APPENDIX D

COMPLETELY AEROBIC ACTIVATED SLUDGE SYSTEM

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APPENDIX D

COMPLETELY AEROBIC ACTIVATED SLUDGE SYSTEM

D.1 SYSTEM LAYOUT

The physical construction of the system was as described in detail by Burke *et al.* (1986) and Clayton *et al.* (1989). The layout of the system consisted of a biological reactor and secondary settling tank in series, with a recycle from the settling tank to the biological reactor of 1:1 with respect to influent flow, see Fig D.1. The contents of the biological reactor were completely mixed by means of independent stirring, and aerated by passing low pressure air through a porous stone. The secondary tank settling was an inclined tube at 60° to the horizontal and fitted with an intermittent slow stirring (1,33 rpm) wiper blade (for details see Burke *et al.*, 1986). Operational details for the system are shown in Fig D.1.

D.2 WASTEWATER COLLECTION AND STORAGE

The influent for the activated sludge system was raw (unsettled) wastewater from Borcherds Quarry and Mitchell's Plain Treatment Works in Cape Town. These wastewaters are primarily domestic, with a very small industrial component. The sewage was collected from the head of the works, after the screens but before the primary sedimentation tanks. The sewage was stored at 4°C in stainless steel tanks in a cold room at the laboratory for 10 to 14 days, then discarded and a new batch of sewage collected; experience has shown that storage of sewage for periods longer than about 3 weeks leads to hydrogen sulphide build-up in the tanks and a change in the characteristics of the sewage. Immediately after storage in the cold room a COD test was done on every batch of sewage (COD ranged from 900 to 1 400 mgCOD/ℓ).

D.3 FEED PREPARATION

The total COD concentration for the four test methods (i.e. square wave, batch test, flocculation-filtration test and the aerobic unit) was set at 500±50 mgCOD/ℓ. Knowing the total COD concentration of the sewage batch collected, volumes of wastewater and tap water required to dilute the wastewater to the required concentration could be calculated. The contents of the storage tank were thoroughly mixed and the calculated volume of wastewater was then drawn from the storage tank daily: The wastewater was drawn from a tap at the bottom of the tank, passed through a sieve (1mm) into a graduated 20ℓ plastic bucket. Then the

calculated volume of tap water was added to dilute the wastewater to the COD concentration required for the tests. To increase the alkalinity of the influent (to maintain the pH in the reactor at ±7,5), 1 or 2 teaspoons of sodium bicarbonate were added to the diluted wastewater. After thorough mixing, a sample was drawn for influent analysis.

D.4 SYSTEM FEEDING

From the diluted wastewater above, daily the feed (10ℓ) for the activated sludge system was drawn and stored in an upright PVC bucket which had a stirrer driven by a motor at 10 rpm, to keep the contents in the bucket completely mixed and discourage settling of the solid particles in the bucket. The surface of the bucket was covered by a floating plastic disc to discourage entrainment of air from the atmosphere into the feed. The bucket was placed in a large chest refrigerator at a temperature of 4–8° C to minimize biological degradation of the sewage. The wastewater was pumped at a constant rate from the storage bucket to the activated sludge system over the 24 h period. The feed bucket was cleaned daily with boiling water.

D.5 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.

The volume of the mixed liquor in the system was maintained at 10ℓ, by controlling the level in the reactor. The sludge age was controlled hydraulically (WRC, 1984) at 12 d, by wasting daily from the reactor 0,83ℓ of the mixed liquor (including any samples drawn for analysis). The system was operated in a temperature controlled room, kept constant at 20° C. In the biological reactor, pH was controlled at 7,5 (±0,2) and oxygen concentration at 4 mgO/ℓ (except during OUR tests).

D.6 SAMPLING AND MEASUREMENTS

From the unit the following parameters were measured on a daily basis:

- the feed total COD concentration (Standard Methods, 1985)

- the effluent COD concentration, filtered and unfiltered (Standard Methods, 1985)

- the influent and effluent TKN concentrations , unfiltered and filtered (Standard Methods, 1985)

- the effluent nitrate concentration (Technicon Auto Analyzer)

- the reactor mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) concentrations (Standard Methods, 1985)

- the oxygen utilization rate (OUR) in the reactor.

The OUR in the reactor was measured by immersing in the mixed liquor a DO probe (YSI) connected to a DO meter which was then connected to a Hewlett Packard chart recorder (Model 17500 A). The OUR was measured by raising the DO in the mixed liquor from 4,0 to 6,0 mgO/ℓ (by opening an air valve on the tubing from the pump) then switching off the air. The decrease in the DO concentration with time was recorded. From the slope of the DO concentration time line, the OUR was calculated (mgO/ℓ/h). After about 5 minutes the air was switched back on and the mixed liquor DO maintained at 4,0 mgO/ℓ. The OUR readings were taken twice a day and an average calculated for the day.

D.7 RESULTS

Daily results for the activated sludge system are listed in Tables D.1a and b. For each wastewater batch tested, the daily results were averaged, and the averages are listed in Table D.2. From the averaged data, for each wastewater batch COD and nitrogen balances were calculated using the procedures set out by Ekama *et al.* (1986) and these are also listed in Table D.2. Acceptability of the data is based on the mass balances being within the range of 90–110%. From Table D.2, with the exception of sewage batch No.21 all the nitrogen mass balances fell within this acceptable range; sewage batch No.21 was rejected for analysis. However, the COD mass balances all were too high (average mass balance 119%). The high COD mass balances were unexpected; usually for completely aerobic systems acceptable COD mass balances can be obtained without undue difficulty. A number of parallel completely aerobic units operated in the UCT laboratory by undergraduate research students gave very similar COD mass balances (Ubisi, 1994; Jadav, 1994; Hercules, 1994). Attempts to trace the errors in the measurements contributing to the COD mass balance indicated a problem in measurement of the OUR; however, this problem could not be resolved successfully. Since the problem in the COD mass

balance was located in measurement of the OUR, the OUR parameter could not be used to determine the unbiodegradable particulate fraction of the influent COD (f_{up}) (Ekama *et al.*, 1986). Instead, the measured MLVSS concentration was used to determine f_{up} using Eq (9.1); the error in the OUR measurement will not affect the estimate for f_{up} using this method. Accordingly, from the averaged data f_{us} was calculated as the effluent COD concentration divided by the influent COD concentration, see Table D.2 (daily f_{us} values were also calculated for comparison with batch test results in Chapter 7 and are listed in Appendix G). From the averaged data and with f_{us} calculated, f_{up} was calculated using Eq (9.1) – these values were used for comparison with batch test data, see Chapter 9.

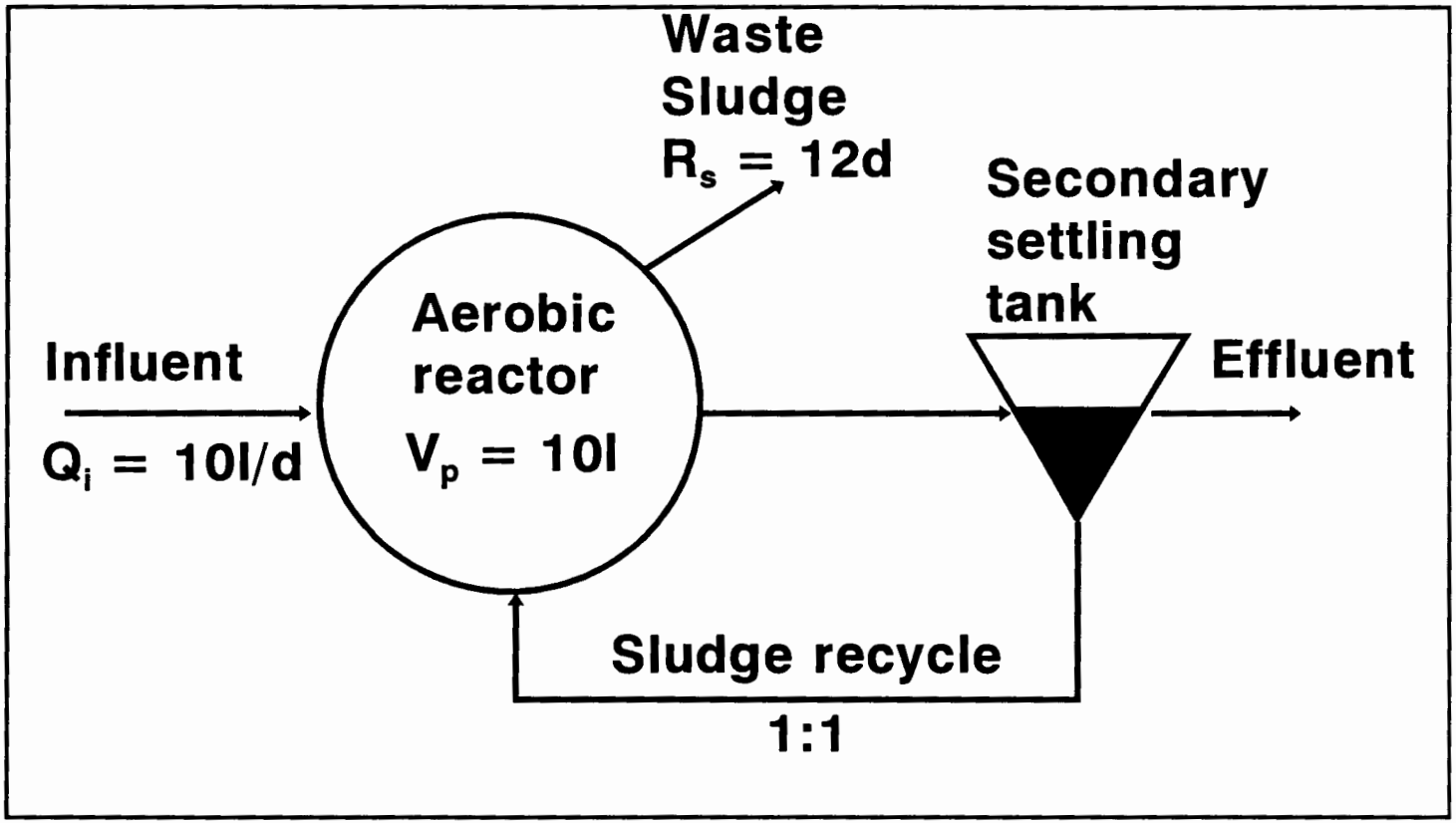

Fig D.1: Configuration and operation of the aerobic activated sludge system used for the conventional method to determine unbiodegradable soluble and particulate COD fractions (Ekama *et al.*, 1986).

TABLE D.1A-
AEROBIC UNIT TKN and COD
RESULTS.

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	TKN (mg N/l)		COD (mgCOD/l)		fus
		influent	effluent	influent	effluent	
15	May 20	56	1	396*	53	0.13
	May 21	59	5	541	49	0.09
	May 22	77	6	521	49	0.09
	May 23	76	6	586	49	0.08
	May 24	78	3	468	47	0.10
	May 25	85	10	456	57	0.13
	May 26	85	9	603	53	0.09
	May 27	81	6	534	47	0.09
	May 28	82	6	538	39	0.07
	May 29	80	6	531	39	0.07
	May 30	70	5	525	47	0.09
	May 31	80	5	538	49	0.09
15 a	June 1	80	5	534	41	0.08
	June 2	79	4	529	38	0.07
	June 3	81	5	501	30	0.06
	June 4	76	5	517	40	0.08
	June 5	73	4	528	48	0.09
	June 6	78	4	508	40	0.08
	June 7	81	8	492	36	0.07
	June 8	79	14	500	58	0.12
	June 9	75	13	464	54	0.12
16	June 10	69	12	367*	48	0.08
	June 11	71	10	548	52	0.10
	June 12	65	7	460	42	0.09
	June 13	75	8	496	44	0.09
	June 14	76	10	500	48	0.10
	June 15	75	5	444	42	0.10
	June 16	76	9	476	56	0.12
	June 17	69	11	508	71	0.14
	June 18	69	6	512	40	0.08
	June 19	68	8	468	40	0.09

TABLE D.1A-continued
AEROBIC UNIT TKN and COD
RESULTS.

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	TKN (mg N/l)		COD (mgCOD/l)		fus
		influent	effluent	influent	effluent	
16 cont.	June 20	68	7	493	40	0.08
	June 21	69	12	493	40	0.08
	June 22	69	10	433	52	0.12
	June 23	68	9	493	42	0.09
	June 24	70	6	461	52	0.11
	June 25	74	6	497	50	0.10
	June 26	69	7	497	30	0.06
	June 27	69	6	533	52	0.10
	June 28	67	5	465	40	0.09
	June 29	69	7	453	40	0.09
	June 30	76	6	545	69	0.13
	July 1	67	7	461	48	0.10
17	July 2	55	6	569	36	0.06
	July 3	56	6	508	28	0.06
	July 4	59	11	516	34	0.07
	July 5	53	12	504	52	0.10
	July 6	56	7	516	48	0.09
	July 7	62	6	492	56	0.11
	July 8	57	6	556	48	0.09
	July 9	57	5	504	36	0.07
	July 10	57	4	508	34	0.07
	July 11	57	4	555	47	0.08
	July 12	55	6	530	57	0.11
	July 13	60	5	514	36	0.07
	July 14	57	7	534	36	0.07
	July 15	57	5	567	45	0.08
	July 16	59	4	551	36	0.07
	July 17	59	4	506	49	0.10
	July 18	58	5	470	33	0.07
	July 19	56	5	518	41	0.08
	July 20	58	5	486	37	0.08
	July 21	57	5	519	34	0.07

TABLE D.1A-continued
AEROBIC UNIT TKN and COD
RESULTS.

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	TKN (mg N/l)		COD (mgCOD/l)		fus
		influent	effluent	influent	effluent	
18	July 22	55	4	481	49	0.10
	July 23	49	5	543	61	0.11
	July 24	55	5	486	75	0.16
	July 25	53	3	469	37	0.08
	July 26	54	3	481	39	0.08
	July 27	56	4	545	41	0.08
	July 28	55	3	555	37	0.07
	July 29	53	4	451	49	0.11
	July 30	54	4	464	43	0.09
	July 31	55	3	484	39	0.08
	August 1	53	5	437	33	0.08
	August 2	55	4	519	33	0.06
	August 3	55	4	488	72	0.15
	August 4	57	2	503	41	0.08
	August 5	51	4	443	24	0.06
	August 6	56	4	511	28	0.06
	August 7	58	2	510	33	0.06
	August 8	53	4	532	35	0.06
	August 9	52	3	514	35	0.07
	August 10	52	5	524	47	0.09
19	August 11	59	6	534	43	0.08
	August 12	57	3	510	26	0.05
	August 13	60	2	543	24	0.04
	August 14	60	3	567	41	0.07
	August15	60	6	545	55	0.10
	August 16	60	4	480	57	0.12
	August 17	60	6	500	45	0.09
	August 18	57	5	480	45	0.09

TABLE D.1A-continued
AEROBIC UNIT TKN and COD
RESULTS.

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	TKN (mg N/l)		COD (mgCOD/l)		fus
		influent	effluent	influent	effluent	
19 cont.	August 19	58	4	511	24	0.05
	August 20	57	3	579	49	0.08
	August 21	59	5	455	36	0.08
	August 22	55	3	524	20	0.04
	August 23	56	5	420	24	0.06
	August 24	50	6	482	31	0.06
	August 25	52	5	469	28	0.06
	August 26	56	6	485	20	0.04
	August 27	57	6	524	25	0.05
	August 28	58	6	543	23	0.04
	August 29	58	6	563	27	0.05
	August 30	58	6	567	45	0.08
	August 31	58	6	567	45	0.08
20	sept 5	45	4	526	41	0.08
	sept 6	44	5	520	41	0.08
	sept 7	45	7	520	33	0.06
	sept 8	45	5	543	41	0.08
	sept 10	43	5	462	45	0.10
	sept 11	43	5	483	45	0.09
	sept 12	43	5	470	37	0.08
	sept 13	44	4	448	37	0.08
	sept 14	44	5	468	37	0.08
	sept 15	44	5	411	26	0.06
21	sept 16	48	4	484	33	0.07
	sept 17	45	5	623	41	0.07
	sept 18	52	4	595	33	0.06
	sept 19	53	4	583	33	0.06
	sept 20	52	4	548	62	0.11
	sept 21	53	6	583	51	0.09
	sept 22	56	4	538	53	0.10
	sept 23	56	5	570	49	0.09
	sept 24	51	5	484	33	0.07

TABLE D.1A-continued
AEROBIC UNIT TKN and COD
RESULTS.

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	TKN (mg N/l)		COD (mgCOD/l)		fus
		influent	effluent	influent	effluent	
21 cont.	sept 25	54	5	579	39	0.07
	sept 26	54	7	478	53	0.11
	sept 27	55	5	556	45	0.08
	sept 28	54	7	523	55	0.11
	sept 29	54	5	566	62	0.11
	sept 30	53	5	523	33	0.06
22	oct 13	54	5	560	36	0.06
	oct 14	59	5	524	32	0.06
	oct 15	59	5	562	40	0.07
23	oct 16	58	5	562	40	0.07
	oct 17	58	5	562	40	0.07
	oct 21	41	7	402	33	0.08
	oct 22	44	6	469	31	0.07
	oct 23	44	4	460	43	0.09
	oct 24	48	7	452	33	0.07
	oct 25	38	5	568	45	0.08
	oct 26	51	7	560	45	0.08
	oct 27	54	6	556	37	0.07
	oct 28	54	6	511	33	0.06
	oct 29	55	5	514	45	0.09
	oct 30	54	6	551	37	0.07
	oct 31	52	7	530	35	0.07
	nov 1	55	5	528	53	0.10
	nov 2	52	5	567	55	0.10

*data ommitted from calculations due to operational problems (eg unit overflow) or transition between batches of sewage.

TABLE D.1B
AEROBIC UNIT MLVSS,OUR,NITRATES
and NITROGEN and COD BALANCES

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	Nitrates (mgN/l)	MLVSS (mgVSS/l)	OUR (mgO/l/hr	% Nitrogen Balance	% COD Balance
15	May 20	40	1340	20	93	130
	May 21	46	1320	26	105	114
	May 22	49	1274	30	86	135
	May 23	54	1206	30	92	114
	May 24	56	1532	28	92	139
	May 25	56	1602	30	94	158
	May 26	55	1550	29	90	113
	May 27	57	1438	31	93	131
	May 28	59	1230	34	92	139
	May 29	62	1370	30	100	121
	May 30	59	1478	29	109	123
	May 31	53	1396	28	88	120
15 a	June 1	54	1846*	27	74	83
	June 2	59	1270	29	93	117
	June 3	56	1306	30	89	131
	June 4	59	1284	25	98	103
	June 5	60	1330	20	102	80
	June 6	60	1500	24	98	104
	June 7	59	1136	24	94	98
	June 8	66	1346	22	115	90
	June 9	56	1370	25	107	121
16	June 10	47	550*	23	86	123
	June 11	46	842*	24	79	74
	June 12	46	894*	31	82	127
	June 13	45	878*	28	71	105
	June 14	48	838*	29	76	106
	June 15	48	908*	30	71	122
	June 16	46	1006*	30	73	119
	June 17	46	1232	35	97	168
	June 18	46	1192	33	90	150
	June 19	47	1082	28	94	137

TABLE D.1B
AEROBIC UNIT MLVSS,OUR,NITRATES
and NITROGEN and COD BALANCES

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	Nitrates (mgN/l)	MLVSS (mgVSS/l)	OUR (mgO/l/hr	% Nitrogen Balance	% COD Balance
16	June 20	45	1396	30	94	147
	June 21	41	1654	30	97	157
	June 22	41	1750	27	96	168
	June 23	48	1632	25	104	126
	June 24	43	1420	23	86	127
	June 25	49	1296	27	88	128
	June 26	49	1296	27	97	123
	June 27	47	1444	25	94	117
	June 28	47	1208	24	93	118
	June 29	44	1306	23	90	122
	June 30	47	1138	26	83	113
	July 1	48	1372	24	99	125
17	July 2	42	1214	20	106	83
	July 3	36	1394	22	95	111
	July 4	31	874*	20	70	73
	July 5	31	1076*	18	80	66
	July 6	30	1016*	20	65	76
	July 7	30	838*	20	57	82
	July 8	27	914*	20	58	73
	July 9	28	1068*	20	58	77
	July 10	28	804*	20	56	76
	July 11	29	824*	20	57	71
	July 12	26	796*	15	59	56
	July 13	29	1228*	30	56	122
	July 14	29	1044*	22	63	81
	July 15	35	1059*	22	71	73
	July 16	34	1018*	25	65	87
	July 17	31	1180*	30	59	124
	July 18	30	1294	35	79	190
	July 19	32	1378	27	87	137
	July 20	32	1356	28	83	150
	July 21	33	1286	20	86	100

TABLE D.1B
AEROBIC UNIT MLVSS,OUR,NITRATES
and NITROGEN and COD BALANCES

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	Nitrates (mgN/l)	MLVSS (mgVSS/l)	OUR (mgO/l/hr	% Nitrogen Balance	% COD Balance
18	July 22	34	1262	20	88	110
	July 23	32	1404	27	99	136
	July 24	32	1344	22	87	129
	July 25	29	1284	21	80	121
	July 26	37	1230	22	93	114
	July 27	38	1322	23	95	108
	July 28	32	1286	20	84	95
	July 29	33	940*	20	69	84
	July 30	32	1440	22	90	129
	July 31	32	1232	20	82	108
	August 1	31	1048	20	84	115
	August 2	36	1314	26	93	125
	August 3	34	1332	28	89	156
	August 4	36	1240	25	84	125
	August 5	36	1406	24	100	138
	August 6	33	1100	24	82	116
	August 7	39	1294	24	88	116
	August 8	36	1268	24	94	114
	August 9	36	1090	20	93	94
	August 10	34	1368	22	96	112
19	August 11	46	1444	38*	108	173
	August 12	46	1346	35*	106	161
	August 13	42	1716	36*	96	168
	August 14	49	1592	30	109	129
	August15	40	1782	27	101	136
	August 16	51	1538	27	112	138
	August 17	43	1516	22	102	113
	August 18	38	1496	20	97	112

TABLE D.1B
AEROBIC UNIT MLVSS,OUR,NITRATES
and NITROGEN and COD BALANCES

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	Nitrates (mgN/l)	MLVSS (mgVSS/l)	OUR (mgO/l/hr	% Nitrogen Balance	% COD Balance
19 cont.	August 19	37	1484	25	92	125
	August 20	41	1738	25	103	117
	August 21	35	1366	20	86	116
	August 22	37	1490	20	96	98
	August 23	39	1164	22	95	124
	August 24	37	1208	20	107	102
	August 25	36	1400	25	101	136
	August 26	37	1330	20	97	102
	August 27	39	1318	24	97	112
	August 28	43	1360	28	103	123
	August 29	43	1450	25	105	109
	August 30	45	1028	21	103	83
	August 31	32	1206	28	82	127
20	sept 5	33	1406	24	108	122
	sept 6	31	1286	20	106	103
	sept 7	31	1068	20	104	97
	sept 8	31	1204	20	103	97
	sept 10	30	1002	28	100	152
	sept 11	31	1002	27	103	140
	sept 12	31	1050	14	103	77
	sept 13	31	1024	20	98	112
	sept 14	30	928*	26	79	112
	sept 15	26	1122	24	92	151
21	sept 16	29	1774*	28	69	118
	sept 17	28	1028	25	92	103
	sept 18	30	1206	27	85	116
	sept 19	28	1292	23	80	106
	sept 20	28	1310	28	83	140
	sept 21	30	1220	25	87	114
	sept 22	28	1254	25	75	127
	sept 23	31	1234	24	82	112
	sept 24	32	1214	23	92	121

TABLE D.1B
AEROBIC UNIT MLVSS,OUR,NITRATES
and NITROGEN and COD BALANCES

Qw	0.833	litres/da	fcv	1.48	mgCOD/mgVSS
Qi	10	litres/da	f	0.2	mgVSS/mgVSS
Vp	10	litres	bh	0.24	/day
IXB	0.1	mgN/mg	yh	0.45	mgVSS/mgCOD

Sewage Batch	Dates of tests	Nitrates (mgN/l)	MLVSS (mgVSS/l)	OUR (mgO/l/hr	% Nitrogen Balance	% COD Balance
21 cont.	sept 25	30	1232	24	84	109
	sept 26	30	1210	24	87	134
	sept 27	30	1258	24	83	115
	sept 28	30	1196	23	86	118
	sept 29	30	1092	22	82	103
	sept 30	31	1140	27	86	130
22	oct 13	37	1352	24	99	109
	oct 14	37	1400	25	91	121
	oct 15	37	1392	25	91	114
23	oct 16	36	1456	22	91	104
	oct 17	37	1678	25	97	120
	oct 21	33	1882	24	136	171
	oct 22	32	1768	24	120	145
	oct 23	32	1678	25	113	151
	oct 24	29	1780	25	106	159
	oct 25	32	1472	25	129	118
	oct 26	31	1648	25	101	126
	oct 27	29	1660	24	91	123
	oct 28	29	1668	24	91	133
	oct 29	29	1598	25	86	138
	oct 30	27	1716	25	87	132
	oct 31	28	1438	24	90	124
	nov 1	29	1528	23	85	125
	nov 2	29	1460	24	89	119

*data ommitted from calculations due to operational problems (eg unit overflow) or transition between batches of sewage.

TABLE D.2
Mean values of the parameters measured from the aerobic unit
i.e TKN(eff. and inf.),COD(eff. and inf.),nitrates,OUR,and MLVSS

Sewage batch	Dates of Tests	TKN mgN/l		COD mgCOD/l		Nitrates effluent mgN/l	MLVSS mg/l	fus	fup	OUR mgO/l/hr	% BALANCES	
		influent	effluent	influent	effluent						N	COD
15	20-31 May	76	6	531	48	54	1395	0.09	0.11	29	94	126
15a	1-9 June	78	7	514	43	59	1318	0.08	0.09	25	99	104
16	10 June-1 Jul	70	8	487	46	46	1361	0.09	0.14	27	93	134
17	2 - 21 July	57	6	521	41	34	1320	0.08	0.09	23	90	115
18	22 July-10 Au	54	4	497	43	34	1261	0.09	0.09	23	90	120
19	11-31 Aug	57	5	517	35	41	1427	0.07	0.12	24	102	116
20	5-15 Sept	44	5	485	38	31	1129	0.08	0.05	22	103	116
21	16-30 Sept *	53	5	549	45	30	1206	0.08	0.03	24	85	115
22	1-12 Oct	57	5	549	36	37	1381	0.07	0.08	25	94	116
23	13 Oct-2 Nov	51	6	519	40	31	1627	0.08	0.19	23	99	125

*rejected batch due to system operational problems.

APPENDIX E

COMPREHENSIVE DATA FOR THE FLOCCULATION-FILTRATION METHOD TO DETERMINE RBCOD

TABLE OF CONTENTS

TABLE E.1a
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filters papers on the INFLUENT samples from Boucherd's Quarry.

Sewage Batch	Date of test	Total COD (mgCOD/l	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
5	sept 16	546	140	140
	sept 17	582	157	153
	sept 18	595	161	161
	sept 19	551	143	159
	sept 21	571	158	154
	sept 22	577	141	125
	sept 23	551	190	173
6	sept 27	638	149	149
	sept 28	638	169	169
	sept 29	533	157	157
	sept 30	559	173	123
	oct 1	518	160	152
	oct 2	535	169	164
7	oct 5	627	135	150
	oct 6	627	131	166
	oct 7	607	144	148
	oct 8	605	174	142
	oct 9	542	130	126
	oct 10	536	131	131
8	oct 26	577	126	126
	oct 27	564	122	122
	oct 28	661	172	160
	oct 29	661	141	137
	oct 30	479	138	138
9	oct 31	590	147	147
	nov 1	521	138	138
	nov 2	593	145	145
	nov 3	593	171	171
	nov 4	577	165	165
	nov 5	512	144	144
	nov 6	549	126	126
	nov 8	557	156	156

TABLE E.1b
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filters papers on the INFLUENT samples from Mitchell's Plain

Sewage Batch	Date of test	Total COD (mgCOD/l	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
	jan 20	536	164	164
	jan 21	557	197	161
	jan 22	569	140	124
	jan 23	667	173	178
	jan 24	504	163	135
10a	jan 25	673	123	141
	jan 26	609	135	125
	jan 27	593	141	131
	jan 28	665	117	182
	jan 31	528	131	179
	feb 1	481	138	128
	feb 2	476	147	136
	feb 4	440	122	120
	feb 5	456	98	124
	feb 6	456	143	130
	feb 7	456	118	109
10	feb 8	460	119	129
	feb 9	520	119	120
	feb 10	524	117	115
	feb 11	484	156	165
	feb 12	540	149	145
	feb 13	544	120	119
	feb 17	555	151	151
	feb 18	555	159	159
	feb 19	534	153	141
	feb 20	551	162	150
	feb 21	595	170	170
11	feb 22	551	142	146
	feb 23	526	146	128
	feb 24	621	132	149
	feb 25	503	118	118
	mar 1	539	136	136
	mar 2	552	134	141

TABLE E.1b- continued
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filters papers on the INFLUENT samples.

Sewage Batch	Date of test	Total COD (mgCOD/l	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
	mar 19	455	134	158
	mar 20	480	138	138
	mar 21	480	154	154
	mar 22	512	110	146
12	mar 23	585	150	172
	mar 24	512	151	151
	mar 25	514	129	129
	mar 26	514	145	143
	mar 27	681	153	153
	mar 28	588	118	118
	apr 1	570	175	159
	apr 2	524	138	138
	apr 3	524	154	156
	apr 4	581	169	163
	apr 5	506	154	154
13	apr 6	545	150	171
	apr 7	502	163	161
	apr 8	518	171	171
	apr 9	554	183	171
	apr 10	603	161	180
	apr 11	574	171	171
	apr 19	685	192	192
	apr 20	587	171	162
	apr 21	664	163	163
	apr 22	607	193	170
	apr 23	636	168	168
	apr 24	624	189	166
	apr 25	624	176	176
	apr 26	602	168	178
14	apr 27	627	193	193
	apr 28	504	151	148
	apr 29	645	204	204
	may 9	560	168	151
	may 10	548	155	155

TABLE E.1b- continued
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filters papers on the INFLUENT samples.

Sewage Batch	Date of test	Total COD (mgCOD/l	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
14 cont.	may 11	552	164	168
	may 12	605	155	155
15	may 13	642	180	180
	may 14	598	194	178
	may 15	598	178	176
	may 16	626	184	164
	may 19	432	115	121
	may 20	400	103	97
	may 21	541	121	121
	may 22	521	147	143
	may 23	586	156	147
	may 24	472	142	147
	may 25	456	145	119
	may 26	603	150	160
	may 27	612	135	135
	may 28	534	113	96
	may 29	531	113	117
	may 30	525	109	109
	june 1	534	103	99
16	jun 23	461	112	108
	jun 24	469	118	122
	jun 26	497	130	124
	jun 27	533	134	126
	jun 28	465	110	110
	jun 29	441	116	104
	jun 30	545	122	102
	jul 1	464	122	102

TABLE E.1b- continued
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filters papers on the INFLUENT samples.

Sewage Batch	Date of test	Total COD (mgCOD/l	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
	jul 4	556	141	133
	jul 5	504	160	140
	jul 6	516	135	111
	jul 7	492	129	129
	jul 8	556	121	141
17	jul 12	530	150	150
	jul 13	514	130	125
	jul 15	567	130	159
	jul 16	551	154	162
	jul 18	461	138	138
	jul 20	477	122	122
	jul 26	481	124	112
	jul 27	545	135	135
	jul 28	555	154	154
	jul 29	451	102	122
	aug 1	437	116	116
18	aug 2	519	125	134
	aug 3	488	103	99
	aug 4	503	147	147
	aug 5	443	149	149
	aug 6	511	128	128
	aug 8	532	102	106
	aug 15	545	139	139
	aug 16	545	174	174
	aug 17	480	185	185
	aug 18	480	160	160
19	aug 19	511	173	173
	aug 22	579	221	221

TABLE E.1b- continued
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filters papers on the INFLUENT samples.

Sewage Batch	Date of test	Total COD (mgCOD/l	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
	Sept 5	484	126	126
	Sept 7	520	153	171
	Sept 8	543	182	182
	Sept 9	508	162	158
20	Sept 11	483	140	140
	Sept 12	508	130	134
	Sept 13	525	113	117
	Sept 14	525	145	145
	Sept 15	411	127	130
	Sept 19	583	135	144
	Sept 20	517	88	88
	Sept 21	548	124	115
	Sept 22	517	141	139
21	Sept 23	511	118	118
	Sept 26	556	130	130
	Sept 27	556	116	128
	Sept 28	523	127	127
	Sept 29	667	138	138
	Sept 30	523	103	103

TABLE E.2a
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filter papers on the EFFLUENT samples from an activated sludge system treating Boucherd's Quarry wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
5	sept 16	546	35	31
	sept 17	582	39	35
	sept 18	595	47	63
	sept 19	551	61	45
	sept 21	571	57	53
	sept 22	577	44	60
	sept 23	551	60	56
6	sept 27	638	56	44
	sept 28	638	56	48
	sept 29	533	62	60
	sept 30	559	49	49
	oct 1	518	58	58
	oct 2	535	49	33
7	oct 5	627	41	41
	oct 6	627	41	41
	oct 7	607	39	37
	oct 8	605	53	53
	oct 9	542	33	49
	oct 10	536	47	47
8	oct 26	577	57	57
	oct 27	564	55	59
	oct 28	661	67	67
	oct 29	661	45	45
	oct 30	479	57	57
9	oct 31	590	45	45
	nov 1	521	41	37
	nov 2	593	45	45
	nov 3	593	49	45
	nov 4	577	30	30
	nov 5	512	55	51
	nov 6	549	63	59
	nov 8	557	49	45

TABLE E.2b
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filter papers on the EFFLUENT samples from an activated sludge system treating Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
	jan 20	536	40	40
	jan 21	557	47	47
	jan 22	569	55	51
	jan 23	667	77	58
	jan 24	504	66	34
10a	jan 25	673	22	22
	jan 26	609	40	40
	jan 27	593	36	40
	jan 28	665	44	42
	jan 31	528	65	63
	feb 1	481	41	41
	feb 2	476	47	25
	feb 4	440	29	29
	feb 5	456	41	37
	feb 6	456	39	37
	feb 7	456	45	37
10	feb 8	460	52	42
	feb 9	520	40	48
	feb 10	524	46	42
	feb 11	484	50	50
	feb 12	540	46	46
	feb 13	544	24	16
	feb 17	555	47	51
	feb 18	555	69	65
	feb 19	534	30	63
	feb 20	551	45	45
	feb 21	595	53	57
11	feb 22	551	67	28
	feb 23	526	47	43
	feb 24	621	37	37
	feb 25	503	49	49
	mar 1	539	57	57
	mar 2	552	47	47

TABLE E.2b-continued
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filter papers on the EFFLUENT samples 8from an activated sludge system treating Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
	mar 19	455	53	53
	mar 20	480	24	24
	mar 21	480	28	28
	mar 22	512	49	49
12	mar 23	585	49	49
	mar 24	512	29	22
	mar 25	514	47	47
	mar 26	514	63	55
	mar 27	681	61	61
	mar 28	588	49	49
	apr 1	570	49	30
	apr 2	524	45	45
	apr 3	524	47	35
	apr 4	581	41	37
	apr 5	506	37	37
13	apr 6	545	33	33
	apr 7	502	59	55
	apr 8	518	41	37
	apr 9	554	41	28
	apr 10	603	45	45
	apr 11	574	20	20
	april 19	685	27	27
	april 20	587	39	39
	april 21	664	41	41
	april 22	607	37	37
	april 23	636	45	45
	april 24	624	53	53
	april 25	624	37	37
	april 26	602	60	60
14	april 27	627	60	60
	april 28	504	44	44
	april 29	645	38	41
	may 9	560	51	51

TABLE E.2b-continued
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filter papers on the EFFLUENT samples 8from an activated sludge system treating Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
	may 10	548	41	41
	may 11	552	43	33
14 cont.	may 12	605	51	51
	may 13	642	46	47
	may 14	598	44	57
	may 15	598	47	47
	may 16	626	30	30
	may 19	432	22	22
	may 20	400	48	19
	may 21	541	46	47
	may 22	521	44	47
	may 23	586	51	53
15	may 24	472	27	37
	may 25	456	41	39
	may 26	603	25	33
	may 27	612	39	31
	may 28	534	23	23
	may 29	531	27	27
	may 30	525	25	23
	may 31	534	18	20
	june 23	461	34	34
	june 24	469	28	28
	june 26	497	30	26
	june 27	533	32	32
16	june 28	465	32	32
	june 29	441	26	26
	june 30	545	38	20
	july 1	464	12	12

TABLE E.2b-continued
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filter papers on the EFFLUENT samples 8from an activated sludge system treating Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
	july 4	556	44	32
	july 5	504	56	48
	july 6	516	36	24
	july 7	492	32	32
	july 8	556	36	36
17	july 12	530	52	52
	july 13	514	61	36
	july 15	567	49	45
	july 16	551	49	49
	july 18	461	24	33
	july 20	477	12	12
	july 26	481	29	31
	july 27	545	24	24
	july 28	555	38	33
	july 29	451	29	33
	august 1	437	25	25
18	august 2	519	29	29
	august 3	488	18	10
	august 4	503	49	49
	august 5	443	57	57
	august 6	511	33	33
	august 8	532	18	35
	august 15	545	24	24
	august 16	545	33	33
	august 17	480	46	46
19	august 18	480	54	45
	august 19	511	45	45
	august 22	579	24	24

TABLE E.2b-continued
COD concentrations after flocculation and filtration through 0.45 micron and glass fibre filter papers on the EFFLUENT samples 8from an activated sludge system treating Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	COD after floc.-filter (mgCOD/l)	
			gf/c filtered	.45 micro filtered
20	sept 5	484	29	29
	sept 8	520	23	41
	sept 7	543	41	41
	sept 9	508	35	31
	sept 11	483	29	29
	sept 12	508	29	33
	sept 13	525	29	33
	sept 14	525	24	24
	sept 15	411	25	27
21	sept 19	583	25	33
	sept 20	517	21	21
	sept 21	548	37	27
	sept 22	517	43	41
	sept 23	511	41	41
	sept 26	556	41	41
	sept 27	556	33	45
	sept 28	523	33	33
	sept 29	667	24	33
	sept 30	523	24	24

TABLE E.3a
COD concentrations after flocculation and filtration through 0.45 micron filters and calculated RBCOD (as a % of total COD,Sti) for Boucherd's Quarry wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent .45 micro filtered	effluent .45 micro filtered	RBCOD (% of Sti)
	aug 26	1118	308	58	22
	aug 27	1143	333	53	24
	aug 28	1217	239	74	14
3	aug 29	1283	204	78	10
	aug 31	1144	267	61	18
	sept 1	1188	281	65	18
	sept 2	1322	218	65	12
	sept 8	817	232	69	20
	sept 9	459	126	69	12
	sept 10	490	126	45	17
4	sept 11	459	125	54	15
	sept 12	476	122	45	16
	sept 13	452	167	57	24
	sept 16	546	140	31	20
	sept 17	582	153	35	20
	sept 18	595	161	63	16
5	sept 19	551	159	45	21
	sept 21	571	154	53	18
	sept 22	577	125	60	11
	sept 23	551	173	56	21
	sept 27	638	149	44	16
	sept 28	638	169	48	19
	sept 29	533	157	60	18
6	sept 30	559	123	49	13
	oct 1	518	152	58	18
	oct 2	535	164	33	25

TABLE E.3a- continued
COD concentrations after flocculation and filtration through 0.45 micron filters and calculated RBCOD (as a % of total COD,Sti) for Boucherd's Quarry wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent .45 micro filtered	effluent .45 micro filtered	RBCOD (% of Sti)
7	oct 5	627	150	41	17
	oct 6	627	166	41	20
	oct 7	607	148	37	18
	oct 8	605	142	53	15
	oct 9	542	126	49	14
	oct 10	536	131	47	16
8	oct 26	577	126	57	12
	oct 27	564	122	59	11
	oct 28	661	160	67	14
	oct 29	661	137	45	14
	oct 30	479	138	57	17
9	oct 31	590	147	45	17
	nov 1	521	138	37	19
	nov 2	593	145	45	17
	nov 3	593	171	45	21
	nov 4	577	165	30	23
	nov 5	512	144	51	18
	nov 6	549	126	59	12
	nov 8	557	156	45	20

TABLE E.3b
COD concentrations after flocculation and filtration through 0.45 micron filters and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent .45 micro filtered	effluent .45 micro filtered	RBCOD (% of Sti)
	jan 20	536	164	40	23
	jan 21	557	161	47	20
	jan 22	569	124	51	13
	jan 23	667	178	58	18
	jan 24	504	135	34	20
10a	jan 25	673	141	22	18
	jan 26	609	125	40	14
	jan 27	593	131	40	15
	jan 28	665	182	42	21
	jan 31	528	179	63	22
	feb 1	481	128	41	18
	feb 2	476	136	25	23
	feb 4	440	120	29	21
	feb 5	456	124	37	19
	feb 6	456	130	37	20
	feb 7	456	109	37	16
10	feb 8	460	129	42	19
	feb 9	520	120	48	14
	feb 10	524	115	42	14
	feb 11	484	165	50	24
	feb 12	540	145	46	18
	feb 13	544	119	16	19
	feb 17	555	151	51	18
	feb 18	555	159	65	17
	feb 19	534	141	63	14
	feb 20	551	150	45	19
	feb 21	595	170	57	19
11	feb 22	551	146	28	21
	feb 23	526	128	43	16
	feb 24	621	149	37	18
	feb 25	503	118	49	14
	mar 1	539	136	57	15
	mar 2	552	141	47	17

TABLE E.3b- continued
COD concentrations after flocculation and filtration through 0.45 micron filters and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent .45 micro filtered	effluent .45 micro filtered	RBCOD (% of Sti)
	mar 19	455	158	53	23
	mar 20	480	138	24	24
	mar 21	480	154	28	26
	mar 22	512	146	49	19
12	mar 23	585	172	49	21
	mar 24	512	151	22	25
	mar 25	514	129	47	16
	mar 26	514	143	55	17
	mar 27	681	153	61	14
	mar 28	588	118	49	12
	apr 1	570	159	30	23
	apr 2	524	138	45	18
	apr 3	524	156	35	23
	apr 4	581	163	37	22
	apr 5	506	154	37	23
13	apr 6	545	171	33	25
	apr 7	502	161	55	21
	apr 8	518	171	37	26
	apr 9	554	171	28	26
	apr 10	603	180	45	22
	apr 11	574	171	20	26
	april 19	685	192	27	24
	april 20	587	162	39	21
	april 21	664	163	41	18
	april 22	607	170	37	22
	april 23	636	168	45	19
	april 24	624	166	53	18
	april 25	624	176	37	22
	april 26	602	178	60	20
14	april 27	627	193	60	21
	april 28	504	148	44	21
	april 29	645	204	41	25
	may 9	560	151	51	18
	may 10	548	155	41	21

TABLE E.3b- continued
COD concentrations after flocculation and filtration through 0.45 micron filters and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent .45 micro filtered	effluent .45 micro filtered	RBCOD (% of Sti)
14 cont.	may 11	552	168	33	24
	may 12	605	155	51	17
	may 13	642	180	47	21
	may 14	598	178	57	20
	may 15	598	176	47	22
	may 16	626	164	30	21
	may 19	432	121	22	23
	may 20	400	97	19	19
	may 21	541	121	47	14
	may 22	521	143	47	19
	may 23	586	147	53	16
15	may 24	472	147	37	23
	may 25	456	119	39	18
	may 26	603	160	33	21
	may 27	612	135	31	17
	may 28	534	96	23	14
	may 29	531	117	27	17
	may 30	525	109	23	16
	june 1	534	99	20	15
	june 23	461	108	34	16
	june 24	469	122	28	20
	june 26	497	124	26	20
	june 27	533	126	32	18
16	june 28	465	110	32	17
	june 29	441	104	26	18
	june 30	545	102	20	15
	july 1	464	102	12	19
	july 4	556	133	32	18
	july 5	504	140	48	18
	july 6	516	111	24	17
	july 7	492	129	32	20
	july 8	556	141	36	19
17	july 12	530	150	52	18
	july 13	514	125	36	17
	july 15	567	159	45	20

TABLE E.3b- continued
COD concentrations after flocculation and filtration through 0.45 micron filters and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent .45 micro filtered	effluent .45 micro filtered	RBCOD (% of Sti)
	july 16	551	162	49	21
17 cont	july 18	461	138	33	23
	july 20	477	122	12	23
	july 26	481	112	31	17
	july 27	545	135	24	20
	july 28	555	154	33	22
	july 29	451	122	33	20
	august 1	437	116	25	21
18	august 2	519	134	29	20
	august 3	488	99	10	18
	august 4	503	147	49	20
	august 5	443	149	57	21
	august 6	511	128	33	18
	august 8	532	106	35	13
	august 15	545	139	24	21
	august 16	545	174	33	26
	august 17	480	185	46	29
	august 18	480	160	45	24
19	august 19	511	173	45	25
	august 22	579	221	24	34
	sept 5	484	126	29	20
	sept 7	520	171	41	25
	sept 8	543	182	41	26
	sept 9	508	158	31	25
20	sept 11	483	140	29	23
	sept 12	508	134	33	20
	sept 13	525	117	33	16
	sept 14	525	145	24	23
	sept 15	411	130	27	25

TABLE E.3b- continued
COD concentrations after flocculation and filtration through 0.45 micron filters and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent .45 micro filtered	effluent .45 micro filtered	RBCOD (% of Sti)
	sept 19	583	144	33	19
	sept 20	517	88	21	13
	sept 21	548	115	27	16
	sept 22	517	139	41	19
21	sept 23	511	118	41	15
	sept 26	556	130	41	16
	sept 27	556	128	45	15
	sept 28	523	127	33	18
	sept 29	667	138	33	16
	sept 30	523	103	24	15

TABLE E.4a
COD concentrations after flocculation and filtration through glass fibre filters (GF/C) and calculated RBCOD (as a % of total COD,Sti) for Boucherd's Quarry wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent GF/C filtered	effluent GF/C filtered	RBCOD (% of Sti)
	sept 16	546	140	35	19
	sept 17	582	157	39	20
	sept 18	595	161	47	19
5	sept 19	551	143	61	15
	sept 21	571	158	57	18
	sept 22	577	141	44	17
	sept 23	551	190	60	24
	sept 27	638	149	56	15
	sept 28	638	169	56	18
	sept 29	533	157	62	18
6	sept 30	559	173	49	22
	oct 1	518	160	58	20
	oct 2	535	169	49	22
	oct 5	627	135	41	15
	oct 6	627	131	41	14
	oct 7	607	144	39	17
7	oct 8	605	174	53	20
	oct 9	542	130	33	18
	oct 10	536	131	47	16
	oct 26	577	126	57	12
	oct 27	564	122	55	12
8	oct 28	661	172	67	16
	oct 29	661	141	45	15
	oct 30	479	138	57	17
	oct 31	590	147	45	17
	nov 1	521	138	41	19
	nov 2	593	145	45	17
9	nov 3	593	171	49	21
	nov 4	577	165	30	23
	nov 5	512	144	55	17
	nov 6	549	126	63	11
	nov 8	557	156	49	19

TABLE E.4b
COD concentrations after flocculation and filtration through glass fibre filters (GF/C) and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent GF/C filtered	effluent GF/C filtered	RBCOD (% of Sti)
	jan 20	536	164	40	23
	jan 21	557	197	47	27
	jan 22	569	140	55	15
	jan 23	667	173	77	14
	jan 24	504	163	66	19
10a	jan 25	673	123	22	15
	jan 26	609	135	40	16
	jan 27	593	141	36	18
	jan 28	665	117	44	11
	jan 31	528	131	65	12
	feb 1	481	138	41	20
	feb 2	476	147	47	21
	feb 4	440	122	29	21
	feb 5	456	98	41	12
	feb 6	456	143	39	23
	feb 7	456	118	45	16
10	feb 8	460	119	52	15
	feb 9	520	119	40	15
	feb 10	524	117	46	14
	feb 11	484	156	50	22
	feb 12	540	149	46	19
	feb 13	544	120	24	18
	feb 17	555	151	47	19
	feb 18	555	159	69	16
	feb 19	534	153	30	23
	feb 20	551	162	45	21
	feb 21	595	170	53	20
11	feb 22	551	142	67	14
	feb 23	526	146	47	19
	feb 24	621	132	37	15
	feb 25	503	118	49	14
	mar 1	539	136	57	15
	mar 2	552	134	47	16

TABLE E.4b- continued
COD concentrations after flocculation and filtration through glass fibre filters (GF/C) and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent GF/C filtered	effluent GF/C filtered	RBCOD (% of Sti)
	mar 19	455	134	53	18
	mar 20	480	138	24	24
	mar 21	480	154	28	26
	mar 22	512	110	49	12
12	mar 23	585	150	49	17
	mar 24	512	151	29	24
	mar 25	514	129	47	16
	mar 26	514	145	63	16
	mar 27	681	153	61	14
	mar 28	588	118	49	12
	apr 1	570	175	49	22
	apr 2	524	138	45	18
	apr 3	524	154	47	20
	apr 4	581	169	41	22
	apr 5	506	154	37	23
13	apr 6	545	150	33	21
	apr 7	502	163	59	21
	apr 8	518	171	41	25
	apr 9	554	183	41	26
	apr 10	603	161	45	19
	apr 11	574	171	20	26
	april 19	685	192	27	24
	april 20	587	171	39	22
	april 21	664	163	41	18
	april 22	607	193	37	26
	april 23	636	168	45	19
	april 24	624	189	53	22
	april 25	624	176	37	22
	april 26	602	168	60	18
14	april 27	627	193	60	21
	april 28	504	151	44	21
	april 29	645	204	38	26
	may 9	560	168	51	21
	may 10	548	155	41	21

TABLE E.4b- continued
COD concentrations after flocculation and filtration through glass fibre filters (GF/C) and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent GF/C filtered	effluent GF/C filtered	RBCOD (% of Sti)
14 cont.	may 11	552	164	43	22
	may 12	605	155	51	17
	may 13	642	180	46	21
	may 14	598	194	44	25
	may 15	598	178	46	22
	may 16	626	184	30	25
	may 19	432	115	22	22
	may 20	400	103	48	14
	may 21	541	121	46	14
	may 22	521	147	44	20
	may 23	586	156	51	18
15	may 24	472	142	27	24
	may 25	456	145	41	23
	may 26	603	150	25	21
	may 27	612	135	39	16
	may 28	534	113	23	17
	may 29	531	113	27	16
	may 30	525	109	25	16
	june 1	534	103	18	16
	june 23	461	112	34	17
	june 24	469	118	28	19
	june 26	497	130	30	20
	june 27	533	134	32	19
16	june 28	465	110	32	17
	june 29	441	116	26	20
	june 30	545	122	38	15
	july 1	464	122	12	24
	july 4	556	141	44	17
	july 5	504	160	56	21
	july 6	516	135	36	19
	july 7	492	129	32	20
	july 8	556	121	36	15
17	july 12	530	150	52	18
	july 13	514	130	61	13
	july 15	567	130	49	14
	july 16	551	154	49	19

TABLE E.4b- continued
COD concentrations after flocculation and filtration through glass fibre filters (GF/C) and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent GF/C filtered	effluent GF/C filtered	RBCOD (% of Sti)
	july 18	461	138	24	25
17 cont.	july 20	477	122	12	23
	july 26	481	124	29	20
	july 27	545	135	24	20
	july 28	555	154	38	21
	july 29	451	102	29	16
	august 1	437	116	25	21
18	august 2	519	125	29	18
	august 3	488	103	18	17
	august 4	503	147	49	19
	august 5	443	149	57	21
	august 6	511	128	33	19
	august 8	532	102	18	16
	august 15	545	139	24	21
	august 16	545	174	33	26
	august 17	480	185	46	29
	august 18	480	160	54	22
19	august 19	511	173	45	25
	august 22	579	221	24	34**
	sept 5	484	126	29	20
	sept 7	520	153	23	25
	sept 8	543	182	41	26
	sept 9	508	162	35	25
20	sept 11	483	140	29	23
	sept 12	508	130	29	20
	sept 13	525	113	29	16**
	sept 14	525	145	24	23
	sept 15	411	127	25	25

TABLE E.4b- continued
COD concentrations after flocculation and filtration through glass fibre filters (GF/C) and calculated RBCOD (as a % of total COD,Sti) for Mitchell's Plain wastewater.

Sewage Batch	Date of test	Total COD (mgCOD/l)	Influent GF/C filtered	effluent GF/C filtered	RBCOD (% of Sti)
	sept 19	583	135	25	19
	sept 20	517	88	21	13
	sept 21	548	124	37	16
	sept 22	517	141	43	19
21	sept 23	511	118	41	15
	sept 26	556	130	41	16
	sept 27	556	116	33	15
	sept 28	523	127	33	18
	sept 29	667	138	24	17
	sept 30	523	103	24	15

APPENDIX F

COMPARISON OF RBCOD DATA FROM THE BATCH TEST, FLOW-THROUGH SQUARE WAVE AND FLOCCULATION-FILTRATION METHODS

TABLE OF CONTENTS

TABLE F.1a.
RBCOD(percentage of total COD) from the four different methods for Boucherd's Quarry wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
	Jul 12	18			
	Jul 13		18		
	Jul 14		20		
	Jul 15				
	Jul 16				
	Jul 17				
	Jul 18		19		
1	Jul 19	17	22		
	Jul 20		24		
	Jul 21	18	27		
	Jul 21	21			
	Jul 22				
	Jul 23		23		
	Jul 24		23		
	Jul 25				
	Jul 26	28	20		
	Jul 27		17		
	Jul 28	30*	13		
	Aug 6	12			
	Aug 7	9			
2	Aug 9	13			
	Aug 13	10			
	Aug 17	12			
	Aug 25	14			
	Aug 26	14			22
	Aug 27	17*	15		24
	Aug 28	14	19		14
	Aug 29	16			10
3	Aug 30	10			
	Aug 31	18			18
	Sept 1	17	18		18
	Sept 2	13	13		12
	Sept 3		10		

** tests rejected at 95% confidence level on RBCOD

* tests rejected at 95% confidence level on the % COD recovery.

TABLE F.1a.-continued
RBCOD(percentage of total COD) from the four different methods for Boucherd's Quarry wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
4	Sept 8l	21	17		20
	Sept 8r	23			
	Sept 9l	18	14		12
	Sept 9r	18			
	Sept 10	19	12		17
	Sept 11	21	16		15
	Sept 12	17	23		16
	Sept 13	24	14		24
	Sept 15		22		
5	Sept 16	24	22	19	20
	Sept 17	22		20	20
	Sept 18	18	17	19	16
	Sept 19	19	22	15	21
	Sept 20		18		
	Sept 21	20	21	18	18
	Sept 22		18	17	11
	Sept 23	22		24	21
6	sept 26		18		
	sept 27	23	20	15	17
	sept 28	23	23	18	19
	sept 29	22	24	18	18
	sept 30	22	17	22	13
	Oct 1	24	21	20	18
	Oct 2	24		22	25
	Oct 3		25		
7	Oct 5	16		15	17
	Oct 5U	17			
	Oct 6	16		14	20
	Oct 6U	20			
	Oct 7	15	12	17	18
	Oct 7U	23			

** tests rejected at 95% confidence level on RBCOD
* tests rejected at 95% confidence level on the % COD recovery.

TABLE F.1a.-continued
RBCOD(percentage of total COD) from the four different methods for Boucherd's Quarry wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
7 Cont.	Oct 8	16	18	20	15
	Oct 9	20	23	18	14
	Oct 10	23	15	16	16
	Oct 11		20		
	Oct 12		20		
	Oct 13				
	Oct 14		16		
8	Oct 16		23		
	Oct 17		19		
	Oct 18		17		
	Oct 19		14		
	Oct 20		13		
	Oct 21		14		
	Oct 22l	18	13		
	Oct 22r	16			
	Oct 23	15			
	Oct 24	16	16		
	Oct 25l	11	17		
	Oct 25r	22			
	Oct 26		21	12	12
	Oct 27	17	15	12	11
	Oct 28	21	17	16	14
	Oct 28	23			
	Oct 28	25			
	Oct 29		16	15	14
	Oct 30		20	17	17

** tests rejected at 95% confidence level on RBCOD
* tests rejected at 95% confidence level on the % COD recovery.

TABLE F.1a.-continued
RBCOD(percentage of total COD) from the four different methods for Boucherd's Quarry wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
9	Oct 31	20	15	17	17
	Nov 1	19	21	19	19
	Nov 2	17	23	17	17
	Nov 3	14	17	21	21
	Nov 4	17	18	23	23
	Nov 5	17		17	18
	Nov 6	14	15	11	12
	Nov 7		19		
	Nov 8	19*		19	20

** tests rejected at 95% confidence level on RBCOD
* tests rejected at 95% confidence level on the % COD recovery.

TABLE F.1b.
RBCOD(percentage of total COD) from the four different methods for Mitchell's Plain wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
10a	jan 20			23	23
	jan 21			27	20
	jan 22			15	13
	jan 23		20	14	18
	jan 24		23	19	20
	jan 25			15	18
	jan 26		23	16	14
	jan 27		22	18	15
	jan 28			11	21
	jan 30		21		
	Jan 31		21	12	22
	feb 1		24	20	18
10	feb2		17	21	23
	feb 4		14	21	21
	feb 5	16		12	19
	feb 6	16	16	23	20
	feb 7	21	20	16	16
	feb 8	16	15	15	19
	feb 9	18	25**	15	14
	feb 10	13	16	14	14
	feb 11	15	17	22	24
	feb 12	24	23	19	18
	feb 13	13	18	18	19
11	feb 17	16		19	18
	feb 18	16	17	16	17
	feb 19	18	17	23	15
	feb 20	18	22	21	19
	feb 21	16	17	20	19
	feb 22	16	20	14	21
	feb 23	21	27	19	16
	feb 24		25	15	18
	feb 25			14	14
	feb 26		19		

** tests rejected at 95% confidence level on RBCOD

* tests rejected at 95% confidence level on the % COD recovery.

TABLE F.1b.-continued
RBCOD(percentage of total COD) from the four different methods for Mitchell's Plain wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
	feb 27		15		
	feb 28	11**	14		
11 cont.	mar 1	9**	13	15	15
	mar 2		10	16	17
	mar 18	22*	19		
	mar 19	20	27	18	23
	mar 20	21	21	24	24
	mar 21		23	26	26
12	mar 22	16	23	12	19
	mar 23	22		17	21
	mar 24	18	19	24	25
	mar 25			16	16
	mar 26	12*	16	16	17
	mar 27		11	14	14
	mar 28	14*	15	12	12
	apr 1	23	17	22	22
	apr 2	22	18	18	18
	apr 3	24	19	20	23
	apr 4	26	17	22	22
	apr 5	26	23	23	23
13	apr 6	20	22	21	25
	apr 7	29	22	21	21
	apr 8	36**	21	25	26
	apr 9	35**	23	26	26
	apr 10	25	20	19	22
	apr 11	26		26	26
	apr 12		21		
	apr 13	25	18		

** tests rejected at 95% confidence level on RBCOD
* tests rejected at 95% confidence level on the % COD recovery.

TABLE F.1b.- continued
RBCOD(percentage of total COD) from the four different methods for Mitchell's Plain wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
14	apr 19	20		24	24
	apr 20	15		22	21
	apr 21	16	16	18	18
	apr 22	16		26	22
	apr 23			19	19
	apr 24	20	17	22	18
	apr 25		28	22	22
	apr 26		26	18	20
	apr 27			21	21
	apr 28	26*		21	21
	apr 29	17		26	25
	apr 30		16		
	may 7	22	12		
	may 8	20	11		
	may 9		16	21	18
	may 10		13	21	21
	may 11	23		22	24
	may 12	18	14	17	17
15	may 13			21	21
	may 14			25	20
	may 15			22	22
	may 16			25	21
	may 19	22		22	23
	may 20	19		14	19
	may 21	17		14	14
	may 22	21		20	18
	may 23	21		18	16
	may 24	22		24	23
	may 25			23	18
	may 26			21	21
	may 27	14		16	17
	may 28			17	14
	may 29			16	17
	may 30	18		16	16
	may 31			16	15

** tests rejected at 95% confidence level on RBCOD

TABLE F.1b.- continued
RBCOD(percentage of total COD) from the four different methods for Mitchell's Plain wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
	june 12		24		
	june 13		20		
	june 14		23		
	june 15		20		
	june 17		18		
	june 19		21		
	june 20		20		
16	june 21		25		
	june 23	22	19	17	16
	june 24	15	17	19	20
	june 25		23		
	june 26	28	20	20	20
	june 27	26	25	19	18
	june 28		18	17	17
	june 29	25	24	20	18
	june 30	23	22	15	15
	july 1	16	18	24	19
	july 2		17		
	july 3		25		
	july 4	24	20	17	18
	july 5	27	21	21	18
	july 6		21	19	17
	july 7	35**	25	20	20
	july 8	26	24	15	19
17	july 9	31	30		
	july 10		26		
	july 11		23		
	july 12	27	22	18	18
	july 13	30	25	13	17
	july 14	27	23		
	july 15	28	21	14	20
	july 16	27	23	19	21

** tests rejected at 95% confidence level on RBCOD

* tests rejected at 95% confidence level on the % COD recovery.

TABLE F.1b.- continued
RBCOD(percentage of total COD) from the four different methods for Mitchell's Plain wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
	july 17		25		
	july 18		22	25	23
17 cont.	july 19	26			
	july 20			23	23
	july 21	45**			
	July 25	27	25		
	July 26	30	18	20	17
	July 27	29	20	20	20
	July 28	29		21	22
	July 29	25	24	16	20
	July 30		16		
	August 1	34		21	21
18	August 2	21	21	18	20
	August 3		18	17	18
	August 4	27		19	20
	August 5	27		21	21
	August 6	19		19	18
	August 7	18	20		
	August 8			16	13**
	August 12		23		
	August 13	24	22		
	August 14		22		
	August 15	22	23	21	21
	August 16	21		26	26
	August 17			29	29
19	August 18	24		22	24
	August 19	31		25	25
	August 20	31	23		
	August 21		29		
	August 22		28	34**	34**
	August 23	23*	29		
	August 23	31*			
	August 24		23		
	August 25	23	18		
	August 28	17			
	August 30	27			

TABLE F.1b.- continued
RBCOD(percentage of total COD) from the four different methods for Mitchell's Plain wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
20	Sept 1				
	Sept 2	23			
	Sept 3				
	Sept 4	25			
	Sept 5			20	20
	Sept 6	23			
	Sept 7	27	16	25	25
	Sept 8	16	23	26	26
	Sept 9	24	23	25	25
	Sept 11	22	22	23	23
	Sept 12		15	20	20
	Sept 13	20		16**	16**
	Sept 13L	17			
	Sept 14			23	23
	Sept 15	21	27	25	25
21	Sept 16	15**	22		
	Sept 17		17		
	Sept 18				
	Sept 19	16		19	19
	Sept 20			13	13
	Sept 21	17	22	16	16
	Sept 22			19	19
	Sept 23	22		15	15
	Sept 23	21			
	Sept 24		22		
	Sept 25		26		
	Sept 26		21	16	16
	Sept 27	22	22	15	15
	Sept 27	21			
	Sept 28		23	18	18
	Sept 29			17	16
	Sept 30	20		15	15

** tests rejected at 95% confidence level on RBCOD

* tests rejected at 95% confidence level on the % COD recovery.

TABLE F.1b.- continued
RBCOD(percentage of total COD) from the four different methods for Mitchell's Plain wastewater.

SEWAGE BATCH	DATE OF TEST	RBCOD (% OF TOTAL COD) TEST METHOD			
		BATCH TEST	SQUARE WAVE	glass fibre filtration	0.45 filtration
21 cont.	Sept 30	19			
	Oct 1		17		
	Oct 2		15		
23	oct 21	16			
	oct 21	16			
	Oct 24		22		
	oct 25	14			
	oct 25	17			
	Oct 26		20		
	Oct 27		12		
	Oct 28	18	18		
	Oct 28	9**			
	Oct 29		13		
	Oct 30		12		
	Oct 31		25		
	Nov 1		24		
	Nov 3	19			
	Nov 3	22			
	Nov 3	25	27		

** tests rejected at 95% confidence level on RBCOD
* tests rejected at 95% confidence level on the % COD recovery.

APPENDIX G

DATA ON UNBIODEGRABLE SOLUBLE COD FROM THE BATCH TEST AND ACTIVATED SLUDGE SYSTEM EFFLUENT

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TABLE G.1
COMPARISON OF UNBIODEGRADABLE SOLUBLE COD from
BATCH TEST and ACTIVATED SLUDGE SYSTEM EFFLUENT

Sewage Batch	Date of Test	TOTAL Sti mgCOD/l	Batch Sus mgCOD/l	Reactor Sus mgCOD/l	Batch Sus % of Sti	Reactor Sus % of Sti
	sept 17	582	37	35	6	6
	sept 18	595	63	63	11	11
5	sept 19	551	55	45	10	8
	sept 21	571	57	53	10	9
	sept 22	577	61	60	11	10
	sept 23	551	53	56	10	10
	sept 27	638	56	44	9	7
	sept 28	638	52	48	8	8
6	sept 29	533	57	60	11	11
	sept 30	559	33	49	6	9
	oct 1	518	66	58	13	11
	oct 2	535	58	33	11	6
	oct 5	627	63	41	10	7
	oct 6	627	45	41	7	7
	oct 7	607	52	37	9	6
7	oct 8	605	45	53	7	9
	oct 9	542	37	49	7	9
	oct 10	536	37	47	7	9
	oct 26	577	57	57	10	10
	oct 27	564	62	59	11	10
8	oct 28	667	68	52	10	8
	oct 30	479	53	57	11	12
	oct 31	590	57	45	10	8
	nov 1	521	53	37	10	7
	nov 2	593	61	45	10	8
9	nov 3	593	57	45	10	8
	nov 4	577	59	30	10	5
	nov 5	512	37	51	7	10
	nov 6	549	55	59	10	11
	nov 8	557	53	45	9	8

TABLE G.1 -continued
COMPARISON OF UNBIODEGRADABLE SOLUBLE COD from
BATCH TEST and ACTIVATED SLUDGE SYSTEM EFFLUENT

Sewage Batch	Date of Test	TOTAL Sti mgCOD/l	Batch Sus mgCOD/l	Reactor Sus mgCOD/l	Batch Sus % of Sti	Reactor Sus % of Sti
	feb 5	456	51	37	11	8
	feb 6	456	37	37	8	8
	feb 7	456	43	37	9	8
	feb 8	460	40	42	9	9
10	feb 9	520	56	48	11	9
	feb 10	524	54	42	10	8
	feb 11	484	44	50	9	10
	feb 12	540	34	46	6	9
	feb 13	544	10	24	2	4
	feb 23	526	45	43	8	8
	feb 24	621	37	37	6	6
11	feb 25	503	47	49	9	10
	mar 1	539	58	57	11	11
	mar 2	552	57	47	10	9
	mar 18	459	53	33	12	7
	mar 19	455	51	53	11	12
	mar 20	480	41	24	9	5
	mar 21	480	40	28	8	6
	mar 22	512	41	49	8	10
12	mar 23	585	57	49	10	8
	mar 24	514	22	22	4	4
	mar 25	514	49	47	10	9
	mar 26	514	57	55	11	11
	mar 27	681	49	61	7	9
	mar 28	588	43	49	7	8

TABLE G.1 -continued
COMPARISON OF UNBIODEGRADABLE SOLUBLE COD from
BATCH TEST and ACTIVATED SLUDGE SYSTEM EFFLUENT

Sewage Batch	Date of Test	TOTAL Sti mgCOD/l	Batch Sus mgCOD/l	Reactor Sus mgCOD/l	Batch Sus % of Sti	Reactor Sus % of Sti
	apr 1	570	77	30	14	5
	apr 3	524	38	35	7	7
	apr 4	581	53	37	9	6
	apr 5	506	39	37	8	7
	apr 6	545	59	33	11	6
13	apr 7	502	59	55	12	11
	apr 8	518	45	37	9	7
	apr 9	554	57	28	10	5
	apr 10	603	53	45	9	7
	apr 11	574	24	33	4	6
	apr 12	574	49	20	9	4
	apr 13	554	45	41	8	7
	apr 19	685	57	27	8	4
	apr 20	587	41	39	7	7
	apr 21	664	52	41	8	6
	apr 22	607	53	37	9	6
	apr 23	636	52	45	8	7
14	apr 24	624	54	53	9	9
	apr 25	624	45	37	7	6
	apr 26	624	60	60	10	10
	apr 28	504	61	44	12	9
	apr 29	645	52	35	8	5
	may 11	552	47	41	8	7
	may 12	605	51	51	8	8
	may 13	642	51	47	8	7
	may 15	560	38	47	7	8
	may 16	626	44	30	7	5
	may 18	605	38	42	6	7
	may 19	432	41	22	9	5
15	may 21	541	51	47	9	9
	may 22	521	44	47	9	9
	may 23	586	45	53	8	9
	may 24	472	37	37	8	8
	may 25	456	41	39	9	9
	may 27	612	27	31	4	5
	may 30	525	29	23	5	4

TABLE G.1 -continued
COMPARISON OF UNBIODEGRADABLE SOLUBLE COD from
BATCH TEST and ACTIVATED SLUDGE SYSTEM EFFLUENT

Sewage Batch	Date of Test	TOTAL Sti mgCOD/l	Batch Sus mgCOD/l	Reactor Sus mgCOD/l	Batch Sus % of Sti	Reactor Sus % of Sti
	June 23	461	36	34	8	7
	June 24	469	54	28	12	6
	June 26	497	48	26	10	5
16	June 27	533	36	32	7	6
	June 29	441	28	26	6	6
	June 30	545	48	20	9	4
	July 1	464	36	12	8	3
	July 4	556	38	32	7	6
	July 5	504	50	48	10	10
	July 6	516	54	24	11	5
	July 7	492	24	32	5	7
	July 8	556	37	36	7	6
	July 9	504	52	52	10	10
	July 12	530	40	52	8	10
17	July 13	514	45	36	9	7
	July 14	534	45	36	8	7
	July 15	567	49	45	9	8
	July 16	551	53	49	10	9
	July 18	461	61	24	13	5
	July 19	486	12	41	3	8
	July 21	477	37	34	8	7
	July 25	469	37	37	8	8
	July 27	545	29	24	5	4
	July 28	555	43	33	8	6
	July 29	451	43	33	10	7
18	Aug 1	437	25	25	6	6
	Aug 2	519	25	29	5	6
	Aug 4	503	49	49	10	10
	Aug 5	443	49	57	11	13
	Aug 6	511	41	33	8	6
	Aug 7	510	41	33	8	6

TABLE G.1 -continued
COMPARISON OF UNBIODEGRADABLE SOLUBLE COD from
BATCH TEST and ACTIVATED SLUDGE SYSTEM EFFLUENT

Sewage Batch	Date of Test	TOTAL Sti mgCOD/l	Batch Sus mgCOD/l	Reactor Sus mgCOD/l	Batch Sus % of Sti	Reactor Sus % of Sti
	Aug 16	545	37	33	7	6
19	Aug 18	480	45	45	9	9
	Aug 19	511	33	45	6	9
	Aug 20	579	56	37	10	6
	Aug 28	584	39	43	7	7
	Aug 30	567	39	29	7	5
	Sept 2	606	47	41	8	7
	Sept 4	526	49	41	9	8
	Sept 6	520	41	41	8	8
	Sept 7	520	27	23	5	4
20	Sept 8	543	31	41	6	8
	Sept 9	508	41	31	8	6
	Sept 11	483	53	37	11	8
	Sept 13r	525	35	33	7	6
	Sept 13l	525	45	33	9	6
	Sept 15	411	41	27	10	6
	Sept 16 *	484	33	25	7	5
	Sept 19	583	44	33	8	6
	Sept 21	548	37	27	7	5
21	Sept 23l*	511	43	41	8	8
	Sept 23r	511	55	41	11	8
	Sept 27r	556	41	45	7	8
	Sept 27l *	556	43	45	8	8
	Sept 30r	523	49	24	9	5
	Sept 30l*	523	26	24	5	5
	13 Oct	664	36	36	5	5
	13 Oct s	1040	36	36	3	3
	25 Oct(4)	561	45	45	8	8
	25 Oct(3)	561	41	45	7	8
22	28 Oct(4)	506	43	33	8	6
	28 Oct(3)	506	53	33	10	6
	3 Nov(2)	539	63	55	12	10
	3 Nov(3)	539	37	55	7	10
	3 Nov(4)	539	41	55	8	10

APPENDIX H

PROCEDURE FOR THE BATCH TEST METHOD

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APPENDIX H

PROCEDURE FOR THE BATCH TEST METHOD

H.1 INTRODUCTION

In this investigation a batch test procedure has been developed to quantify the five influent COD fractions, heterotroph active biomass, readily biodegradable COD (RBCOD), unbiodegradable soluble COD, slowly biodegradable COD (SBCOD), and unbiodegradable particulate COD. The accuracy of these estimates for the five influent fractions has been described in detail in Chapters 5, 7 and 9: The batch test method provides good estimates for heterotroph active biomass, RBCOD and unbiodegradable soluble COD; the estimates for unbiodegradable particulate COD as a fraction of total COD (f_{up}) tend to be higher than those from conventional tests, and consequently the estimate for SBCOD tends to be lower – it remains to be evaluated whether these trends are consistent.

For all the COD fractions derived from the batch test, the accuracy of the values hinges around the accuracy of the experimental data. To obtain acceptable data, the experimental investigation must be conducted with an uncompromising vigilance, a strict discipline and attention to detail and measurements in every aspect; if these are lax or neglected, the results will be largely useless. To facilitate application of the batch test, the procedure for the entire test will be set out in detail.

H.2 TEST PROCEDURE

(1) A sample of raw (unsettled) municipal wastewater is obtained from the source. A defined volume is placed in a continuously stirred batch reactor maintained at a constant temperature of 20° C. Other temperatures may be suitable for the batch test, but this has not been investigated. The wastewater may be diluted or undiluted; in this investigation, the wastewater was diluted to ±500 mgCOD/ℓ, so that the oxygen utilization rates could be readily measured.

(2) A sample is drawn from the batch reactor and the initial total COD concentration determined (Standard Methods, 1985).

(3) The surface of the wastewater in the reactor is covered, to limit surface exchange of oxygen. In this investigation, small hollow plastic balls (20 mm diameter) were found to be most suitable.

(4) The oxygen utilization rate (OUR) is monitored continually. In this investigation, the automated technique of Randall *et al.* (1991) was used: The DO was raised to a high DO set point (±6,0 mgO/ℓ), the air was switched off and the decrease in DO with time monitored. The slope of the DO–time profile defines the OUR and this was automatically recorded. When the DO reached a low DO set point (±2,0 mgO/ℓ), the air was turned on and the cycle repeated.

(5) During an aeration cycle, the aeration rate should be sufficient to ensure that the DO can be raised from the low to the high DO concentration set points without excessive delay, but should not be over vigorous, to limit splashing.

(6) The pH of the batch reactor is monitored and controlled to pH 7,5 (±0,2).

(7) Intermittently, the walls of the reactor are thoroughly brushed during an aeration cycle to prevent particulate matter adhering to them.

(8) In order to check for nitrification, at regular intervals samples are drawn from the reactor, filtered (0,45μm) and analyzed for nitrate and nitrite. Should nitrification be detected, allyl thiourea probably can be used as nitrification inhibitor (due to absence of nitrification, addition of allyl thiourea was not tested in this investigation).

(9) If influent RBCOD and heterotroph active biomass only are to be determined, the batch test is run until the precipitous drop in OUR is observed, and then for a further two hours. The walls of the reactor and the stirrers are brushed of any particulate matter sticking on to them. The mixed liquor is then drawn from the batch reactor, poured into a liquidizer and homogenized. A sample is taken from the homogenized mixed liquor for the determination of total COD (Standard Methods, 1985) at the end of the test, in order to determine the % COD recovery [Eq (4.1), Chapter 4].

(10) If unbiodegradable soluble COD concentration is to be determined as well, the

batch test is run for 1 day, and then treated as in step (9) above. In addition, a representative sample (say 500 mℓ) of the homogenized liquor is drawn off, dosed with 5 mℓ of aluminium sulphate (stock solution of 50 g/ℓ), stirred rapidly (±200 rpm) for 2 minutes and then left to settle for 30 minutes with slow stirring (±2 rpm). A sample is taken from the clear liquid, filtered through glass fibre filter paper and the COD of the filtrate determined (Standard Methods, 1985); this gives the unbiodegradable soluble COD concentration. It was noted in this investigation that the duration of running the test after the precipitous drop does not affect the concentration of this parameter, provided the length of the batch test > 1 day.

(11) If unbiodegradable particulate and slowly biodegradable COD are to be determined, the batch test is run for a total of 2 days, after which a third of the thoroughly mixed contents of the batch reactor are drawn off and treated as in steps (9) and (10) above, to determine total and unbiodegradable soluble COD concentrations. The volume of mixed liquor remaining in the batch reactor is noted, and flocculated–filtered raw wastewater (as described below) is added to bring the batch reactor back to its original volume.

Preparation of the flocculated–filtered wastewater for addition to the batch reactor is as follows:

Raw wastewater from the same source being tested is dosed with aluminium sulphate by adding 20 mℓ of stock aluminium sulphate (stock at concentration of 50 g/ℓ) to 5 litres of wastewater and thoroughly mixed. The mixture is allowed to settle for 1 hour or longer. The clear supernatant liquid is filtered through glass fibre filter paper (Whatman's GF/C), and the filtrate is added to the batch reactor, as described above.

The batch test is continued until a second precipitous drop in the OUR is noted. The total and unbiodegradable COD concentrations are then determined [as in steps (9) and (10) above respectively].

(12) From the data, RBCOD and heterotroph active biomass are calculated using the procedures set out in Chapter 4, the unbiodegradable soluble COD is flocculated filtrate COD in step (10), and unbiodegradable particulate and SBCOD are calculated using the procedures in Chapter 8, Section 8.8.