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THE EFFECT OF HIGH TEMPERATURES (30°C) ON BIOLOGICAL NUTRIENT REMOVAL PERFORMANCE

by

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Research supported by the
TECHNICAL DEVELOPMENT ACENCY (TEKES) OF FINLAND
and
THE MUNICIPALITY OF KAJAANI (FINLAND)
and
WATER RESEARCH COMMISSION (SOUTH AFRICA)

Department of Civil Engineering
University of Cape Town

March, 1998

DST 620 MELL

99/1129

SYNOPSIS

The main objective of this investigation was to evaluate activated sludge biological nutrient removal (BNR) performance at elevated temperatures for possible application of nitrification denitrification (ND) and ND biological excess phosphorus removal (NDBEPR) systems to municipal wastewater treatment in the equatorial and tropical regions or to combined treatment of municipal and anaerobically (thermophilic) pretreated paper and pulp industry wastewaters in the very cold northern forested regions. To accomplish this objective, a ND Modified Ludzack Ettinger (MLE) system and a NDBEPR University of Cape Town (UCT) system were operated at 30°C and 10 days sludge age for a period of 582 days. During the investigation 41 sewage batches, each lasting about two weeks, of real sewage from the Mitchells Plain municipal wastewater treatment plant (Western Cape, South Africa) were fed to the systems. The two systems were sampled and tested almost daily for Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Free and Saline Ammonia (FSA), nitrate, nitrite, Total Phosphorus, Volatile Settleable Solids (VSS), Total Settleable Solids (TSS), pH, Oxygen Utilization Rate (OUR) and diluted sludge volume index (DSVI) in the influent, anaerobic, anoxic and aerobic reactors and effluent as appropriate. Also, in order to determine the kinetic rates of nitrification, denitrification and readily biodegradable COD (RBCOD) conversion to Volatile Fatty Acids (VFA), aerobic, anoxic and anaerobic batch tests were conducted at 30°C on sludge harvested from the two systems and microscopic examination of the sludges was undertaken every four weeks to identify the filamentous organisms in the systems. These kinetic rates at 30°C were then compared with equivalent process rates measured in 20°C ND and NDBEPR systems operated in parallel as part of this investigation or in separate investigations before and after this one. From the 20°C and 30°C process rates, the temperature sensitivity coefficients θ of some of the biological kinetic processes were determined for the 20 to 30°C range and compared with those determined in earlier investigations in the 12 to 20°C range.

Examining the average experimental results of each of the 41 sewage batches, it was noticed that during the winter months (May to June) the UCT system showed a very poor P removal performance. The data were therefore divided into 3 long term periods with long term period I including sewage batches 1 to 23 (360 days), long term period II including sewage batches 24 to 33 (130 days) and long term period III including sewage batches 34 to 41 (92 days). The poor P removal performance occurred during period II, with periods of good (though not "normal", see 16 below) P removal during periods I and III. The UCT system BEPR performance was therefore evaluated with the aid of steady state and dynamic simulation models for period I only.

1. **Overall system performance**

While the effluent ammonia concentrations were significantly higher, the overall performances of the two systems in terms of COD and N balances, and filtered and unfiltered effluent COD, TKN, nitrate and total P concentrations were not significantly different to those expected from similar systems at 20°C. The biological processes of COD degradation, nitrification, denitrification and biological excess P removal proceeded similarly as at 20°C. Quantitatively all the biological processes recognized in the steady state ND (WRC, 1984) and NDBEPR (Wentzel *et al.*,

1990) models were faster at 30°C than at 20 °C and temperature sensitivity coefficients for important process rates were estimated from the batch test results at 30°C in relation to their generally accepted (standard) rates at 20 C°. Once calibrated by giving the important sewage characteristic and kinetic constants measured in the two systems and the batch tests, the ND and NDBEPR dynamic simulation models predicted the overall system performance of COD degradation, nitrification, denitrification and BEPR processes reasonably closely. More specifically, it was found that:

2. Carbonaceous (COD) material degradation processes by OHOs and PAOs

The COD degradation by the ordinary heterotrophic organisms (OHOs) and polyphosphate accumulating organisms (PAOs), which includes sludge production, oxygen utilization and effluent COD concentration, were well predicted by accepting that the standard endogenous respiration rate b_{H20}, b_{G20} and their temperature sensitivity coefficients θ_{bH} and θ_{bG} apply, viz. $b_{HT} = b_{H20}(1.029)^{(T-20)}$ where $b_{H20} = 0.24$ /d and 0.62 /d for the steady state and dynamic simulation models respectively and $b_{GT} = b_{G20}(1.029)^{(T-20)}$ where $b_{G20} = 0.04$ /d. The stoichiometric constants for OHO and PAO kinetics at 20°C were found satisfactory for 30°C, viz. yield coefficient $Y_H = Y_G = 0.45$ mgVSS/mgCOD, unbiodgradable endogenous fractions of the OHOs ($f_{Ep,H}$) and PAOs ($f_{Ep,G}$) with $f_{Ep,H} = 0.20$ for the steady state model and 0.08 for the dynamic simulation model, and $f_{Ep,G} = 0.25$ for both models, the COD/VSS ratio of the various components of the VSS $f_{cv} = 1.48$ mgCOD/mgVSS and the nitrogen content of the VSS (f_n) = 0.10 mgN/mgVSS, the last two confirmed by measurement on the MLE and UCT systems.

3. Nitrification

Monod kinetics for nitrification were found applicable at 30°C. It was assumed that the standard 20°C values for the yield coefficient Y_n (=0.10 mgVSS/mgN) and endogenous respiration rate b_n with its temperature sensitivity coefficient applied viz. $b_{nT} = b_{n20}(1.029)^{(T-20)}$ where $b_{n20} = 0.04$ /d. While the maximum specific growth rate of the nitrifies at 20°C (μ_{nm20}) does vary from wastewater to wastewater, it's standard temperature sensitivity coefficient $\theta_{\mu nm} = 1.10$ was found applicable in the 20 to 30°C range; the μ_{nm30} rate measured in the 30°C systems was around 0.81 /d. However, the half saturation coefficient for nitrification K_n, which influences the effluent ammonia concentration, was found to be significantly higher at 30°C than at 20°C. Accepting the standard 20°C K_n value of 1.0 mgN/ℓ, required its θ_{Kn} value to be increased from its standard value of 1.123 in the 12 to 20°C range to 1.215 in the 20 to 30°C range to correctly predict the effluent ammonia concentration of 2.3 mgN/ℓ from the two systems at 30°C.

4. Denitrification

The anoxic reactors were mostly underloaded with nitrate during the investigation except for the sewage batches that had high TKN concentrations (>70 mgN/ℓ). For underloaded anoxic reactors, the denitrification is system (recycle) limited, not biological (kinetic) rate controlled. The favourable comparison between the predicted and experimental system and effluent nitrate concentrations is therefore more a consequence of the hydraulics of the system than a test of the biological denitrification kinetics. From the anoxic batch tests on the MLE system sludge, the specific denitrification rates K_1 and K_2 were determined at 0.775 and 0.445 mgNO_3-N/(mgOHOAVSS.d) respectively. In relation to the standard 20°C K_1 and K_2 rates, these 30°C K rates give temperature sensitivity coefficients θ_{K1} and θ_{K2} of 1.03 and 1.15 respectively, which are significantly different from the standard $\theta_{K1} = 1.20$ and $\theta_{K2} = 1.080$ in the 12 to 20°C range. A significantly different θ_{K1} in the 20 to 30°C range is not of serious concern in design (except in the design of anoxic selectors) because the influent readily biodegradable COD (RBCOD) is usually completely utilized in the anoxic reactor. However, the higher θ_{K2} coefficient is of major concern to design because it governs the biological denitrification potential of the anoxic reactor. The higher θ_{K2} coefficient results from the very high K_2 rate measured at 30°C. In fact, this is the first time that the K_2 rate in the MLE system was observed to be higher than it's K'_2 rate counterpart in the UCT system. Even though this high K_2 rate at 30°C is the average of 17 batch test results, it is recommended that the standard K_2 rate and its θ_{K2} coefficient are adopted for the 20 to 30°C range until such time as the very high K_2 rate at 30°C can be confirmed in further research at 30°C.

From the anoxic batch tests on the UCT system, the specific denitrification rate K'_2 was determined at 0.250 mgNO_3-N/(mgOHOAVSS.d). Comparison of this rate with a 20°C rate is problematic because the K'_2 rate in NDBEPR systems has been found to be very variable and dependent on the estimated active OHO fraction of the VSS. By comparing the 30°C K'_2 rate obtained in this investigation with K'_2 rates obtained in five other investigations on NDBEPR systems at 20°C, it was found that (i) the K'_2 rate is inversely related to the active OHO fraction of the VSS, which, in turn, is inversely related to the influent unbiodegradable particulate COD fraction, (ii) the temperature affect on K'_2 rate is very small ($\theta_{K'2} = 1.035$), much smaller than the uncertainty caused by the consistent but inexplicable variation caused by the influent unbiodegradable particulate COD fraction and (iii) the K'_2 rate was increased by an uncertain magnitude due to a PAO contribution to the denitrification rate because significant anoxic P uptake (~40%) was observed in the anoxic reactor.

5. Biological excess P removal by the PAOs

In the BEPR processes, the RBCOD to VFA conversion rate (K) and the PAO endogenous respiration rate (b_G) were adjusted to 30°C with the OHO and nitrifier endogenous respiration rate temperature sensitivity coefficient value $\theta_K = \theta_{bG} = 1.029$. The stoichiometric constants for the PAOs viz. yield coefficient $Y_G = 0.45$ mgVSS/mgCOD, endogenous residue fraction $f_{Ep,G} = 0.25$ were kept at their standard 20°C values. The P content of the PAOs was determined from the measured P removal in the UCT system and found to be around 0.22 to 0.28 mgP/mgPAOAVSS, which is much lower than the standard model value of 0.38. Lower than predicted P removal has been observed also in a number of earlier

NDBEPR system investigations at 20°C and in all of these, significant anoxic P uptake was observed. In contrast, in the investigations where negligible anoxic P uptake took place, the calculated P content of the PAOs was close to the BEPR model standard value of 0.38 mgP/mgPAOAVSS. Factors that stimulate anoxic P uptake are not known at this stage, but from the results so far it appears that denitrifying PAOs are less efficient as BEPR organisms than their aerobic counterparts.

From the anaerobic P release batch tests with sewage, the RBCOD to VFA conversion rate by the OHOs (K) at 30°C was determined at 0.070 ℓ/(mgOHOAVSS.d), which in relation to the standard 20°C rate of 0.060 gives a θ_K coefficient of 1.016. While this value is lower than that originally assumed for K (i.e. $\theta_K = 1.029$) to determine the OHO and PAO active fractions of the VSS, repeating the calculations with a $\theta_K = 1.016$ would not change the results significantly.

From the investigation it can be concluded that the steady state and dynamic simulation ND and NDBEPR models can be applied in the 20 to 30°C range with reasonable confidence provided the wastewater characteristics are well defined and the temperature sensitivity coefficients of the kinetic constants adjusted as indicated above (these provisos of course apply equally to the 12 to 20°C range!). The models will then with reasonable accuracy predict the system OHO and PAO carbonaceous material degradation and autotrophic nitrification system response yielding sludge production (or system VSS concentration), oxygen demand and effluent COD, TKN (ammonia and organic N) nitrate and total P concentrations. *However, it must be noted* that (i) although the steady state denitrification rates K_1 and K_2 (ND system) and K'_2 (NDBEPR system) were measured, the denitrification kinetics of the steady state and dynamic simulation models were *not* tested because the anoxic reactors of the MLE and UCT systems were underloaded with nitrate and (ii) the steady state and dynamic simulation NDBEPR models are based on aerobic P uptake BEPR behaviour which not only significantly overestimates the biological P removal, but also predicts completely different reactor P concentrations when significant P uptake takes place in the anoxic reactor, which was the case in the UCT system of this investigation.

DECLARATION

I, Hannu Kaarlo Olavi Mellin, declare that the work in this masters dissertation is my own and has not been submitted for examination at any other University.

Date: 10/4/1998

Signed: Signed by candidate

TABLE OF CONTENTS

CHAPTER 4: KINETIC STATE EVALUATION OF ND AND NDBEPR SYSTEMS

APPENDICES:

ACKNOWLEDGEMENTS

The writer wishes express his appreciation and gratitude to the following persons for their contribution to the research work contained in this thesis:

- Emeritus Prof Matti Viitasaari (Technical University of Tampere) and Prof Jukka Rintala (University of Jyvaskyla), Project manager and co-worker respectively for the overall research project on integrated treatment, for initiating and participating in the research, and providing invaluable guidance.

- Prof G A Ekama and Prof M C Wentzel, thesis supervisors, for their invaluable guidance and assistance which they so often readily rendered, without whom this thesis could not have been written.

- Mr Taliep Lakay, Chief Technical Officer, for his full support in operating and in maintaining of experimental systems and equipment and for his invaluable help in the acquisition of data, and to Mr Percival Wilscnach, Laboratory Assistant, for his supporting work in this.

- Messrs Eike von Geurard and Denis Botha, Technical Officers, for their construction and modification of laboratory equipment.

- Mrs Moira Zaudman-Segal of Cydna Laboratory, Johannesburg Metropolitan Council, for her very important contribution of filament identification during investigation.

- Messrs Peter Tapscott of the Scientific Services Branch of the Cape Metropolitan Council for his invaluable work with regard to the identification of filament organisms.

- Emeritus Prof GvR Marais, for his friendship, interest and invaluable assistance in every aspect (including hospitality).

- My wife Tuula and our children Mio and Mikaela without whose support and patience this would not be possible.

Also, the writer wishes to acknowledge the interest and support of a number of persons in the Municipality of Kajaani and UPM-Kymmene Oy, Kajaani Mill.

A special word of acknowledgement is also due for the financial support and assistance of Technical Development Agency in Finland (TEKES) and the following agencies:

1. KV Lindholmin lampo ja vesijohtoteknillisen tutkimuksen edistamissaatio.
2. SULVI:n tutkimussaatio.
3. Maa- ja vesitekniikan tuki ry.

and, the Municipality of Kajaani (Finland)

LIST OF SYMBOLS

Symbol	Description
a	Mixed liquor recycle ratio from aerobic to anoxic reactors
b_h	Specific endogenous mass loss rate for heterotrophs (/d)
BCOD	Biodegradable COD
COD	Chemical oxygen demand (mgCOD/*l*)
DO	Dissolved oxygen concentration (mgO/*l*)
DSVI	Diluted sludge volume index (m*l*/g)
f	Endogenous residue fraction in the steady state model of Marais and Ekama (1976) (mgVSS/mgVSS)
f_{av}	Active fraction of the volatile suspended solids (mgAVSS/mgVSS)
$f_{av,OHO}$	Active fraction of ordinary heterotrophic organisms
f_{bs}	Readily biodegradable COD fraction with respect to the biodegradable COD (mgCOD/mgCOD)
f_{cv}	COD to VSS ratio of the mixed liquor (mgCOD/mgVSS)
f_n	TKN to VSS ratio of the mixed liquor (mgN/mgVSS)
f_{up}	Unbiodegradable particulate fraction of the influent COD (mgCOD/mgCOD)
f_{us}	Unbiodegradable soluble fraction of the influent COD (mgCOD/mgCOD)
$f_{XBG,P}$	Fractional P content of polyP organism biological active mass (mgP/mgVASS)
HA_c	Undissociated acetic acid
K_1	Specific denitrification rate (due to RBCOD) present for the first phase of denitrification in the primary anoxic reactor of N removal systems {mgNO_3-N/(mgAVSS*d)}
K_2	"Background" specific denitrification rate (due to SBCOD) manifested during the second phase of denitrification in the primary anoxic reactor of N removal systems

	{$mgNO_3$-N/(mgAVSS*d)}
K_2’	The single accepted denitrification rate in the primary anoxic zone of the UCT nutrient removal system {$mgNO_3$-N/(mgAVSS*d)}.
MLE	Modified Lutzack-Ettinger
MLSS or MLTSS	Mixed liquor total suspended solids concentration (mgTSS/*l*)
MLVSS or VSS	Mixed liquor volatile suspended solids concentration (mgVSS/*l*)
MNO_2	Mass of nitrite denitrified per day ($mgNO_2$-N/d)
MNO_3	Mass of nitrate denitrified per day ($mgNO_3$-N/d)
MO_c	Carbonaceous oxygen demand (mgO/d)
MO_d	Equivalent oxygen demand of denitrification (mgO/d)
MO_n	Nitrification oxygen demand (mgO/d)
MN_c	Mass of nitrate generated from nitrification ($mgNO_3$-N/d)
MN_{nd}	Mass of nitrate denitrified ($mgNO_3$-N/d)
MN_{ne}	Mass of nitrate in effluent ($mgNO_3$-N/d)
MN_{te}	Mass of TKN in effluent (mgN/d)
MN_{ti}	Mass of TKN in influent (mgN/d)
MS_{te}	Mass of COD in effluent (mgCOD/d)
MS_{ti}	Mass of COD in influent (mgCOD/d)
MX_{NW}	Mass of nitrogen in waste sludge (mgN/d)
MX_{SVW}	Mass of COD in waste sludge (mgCOD/d)
MX_V	Mass of volatile suspended solids in system (mgVSS)
MX_{VW}	Mass of sludge wasted per day (mgVSS/d)
N	Nitrogen
NO_3 anaer	Nitrate concentration in outflow of anaerobic reactor ($mgNO_3$-N/*l*)
N_{n2} aer	Nitrite concentration in outflow of aerobic reactor ($mgNO_2$-N/*l*)
N_{n3} aer	Nitrate concentration in outflow of aerobic reactor ($mgNO_3$-N/*l*)
N_{n2} anox	Nitrite concentration in outflow of anoxic reactor ($mgNO_2$-N/*l*)
N_{n3} anox	Nitrate concentration in outflow of anoxic reactor ($mgNO_3$-N/*l*)

NO_2-N	Nitrite as N
NO_3-N	Nitrate as N
No_e-N	Nitrate concentration in effluent (mgN/*l*) as N
O_c	Carbonaceous oxygen utilization rate (mgO/$l_{reactor}$/d)
OHO	Ordinary heterotrophic organisms, also called non polyP organisms
OUR	Oxygen utization rate (mgO/$l_{reactor}$/h)
P	Phosphorus
ΔP	Change in P concentration relative to influent flow; -ve = uptake, +ve = release (mgP/$l_{influent}$)
P_{max}	Maximum potential phosphorus concentration (mgP/*l*)
P_o	Initial phosphorus concentration (mgP/*l*)
PolyP	Polyphoshate
Q	Daily influent wastewater flow rate (*l*/d)
r	Mixed liquor recycle ratio from anoxic to anaerobic reactors
RBCOD	Readily biodegradable COD
R_s	System sludge age (d)
s	Sludge underflow recycle ratio with respect to the feed flow rate
SBCOD	Slowly (particulate) biodegradable COD
S_{bi}	Influent biodegradable COD concentration (mgCOD/*l*)
S_{bsi}	Influent readily biodegradable COD concentration (mgCOD/*l*)
S_{NOe} or N_{ne}	Nitrate concentration in the effluent of the MLE or UCT system
S_{Nte}, N_t or N_{te}	Effluent TKN concentration (mgN/*l*)
S_{Nti}, N_{ti}	Influent TKN concentration (mgN/*l*)
TCOD	Total COD (mgCOD/*l*)
TKN	Total Kjedahl Nitrogen
TSS	Total suspended solids
UCT	University of Cape Town
UPCOD	Unbiodegradable particulate COD (mgCOD/*l*)
USCOD	Unbiodegradable soluble COD (mgCOD/*l*)

Va	Aerobic reactor volume (*l*)
VASS	Volatile active suspended solids
VSS	Volatile suspended solids
X or X_v	Volatile suspended solids concentration of the mixed liquor (mgVSS/*l*)
Y_h	Heterotrophic yield coefficient (mgVSS/mgCOD)
μ_{nmT}	Maximum specific growth rate of the nitrifiers (/d) at T°C

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Worldwide, increasing awareness of the adverse effects of the discharge to the environment of the nutrients nitrogen (N) and phosphorus (P) in wastewaters, has led to the introduction of more stringent legistlations controlling the quality of discharges from wastewater treatment plants. To meet these effluent qualities, wastewater treatment plants have become increasingly complex, incorporating considerable more processes. With this expansion in function and complexity the design and operation of these plants has moved from the reality of empirical rules based on experience to ones based on sophisticated fundamentally founded kinetic models.

In Finland current effluent quality standards are under review and can be expected to follow the worldwide trend to become more strict. This will require a revaluation of current wastewater treatment practises, and the upgrading of existing treatment plants and construction of new treatment plants. In these developments, modern design procedures and models inevitably will be required. However, these procedures and models and the wastewater treatment schemes selected for implementation will need to take account of the specific conditions and problems that will be encountered in Finland.

1.2 WASTE WATER TREATMENT IN FINLAND

1.2.1 Municipal waste water

In Finland prior to 1970, the great majority of plants receiving municipal wastewaters treated these waste flows chemically and physically, by adding principally aluminium - or ferro-sulphate to precipitate the phosphorus, flocculating the particulate material and removing resulting settleable material by primary sedimentation. Following primary settlement, the supernatant was discharged to rivers, lakes or the sea without further treatment. From 1970, a number of modifications were introduced to improve the quality of treatment: In some plants a short sludge age aerobic activated sludge system with secondary settler was added down-stream of the primary treatment and received the supernatant from the chemically treated primary settled influent. In other plants chemicals were added not at the primary settlement stage but at the down stream activated sludge stage. In only a few instances have activated sludge plants been constructed or modified to nitrify or to remove nitrogen by biological nitrification-denitrification. In these instances the designs have been largely empirical. There are no reports in which modern kinetic activated sludge theories and models have been applied in design or operation of these plants; neither those for steady state conditions viz. WRC (1984) for N removal or Wentzel *et al.* (1990) for biological excess P removal (BEPR) nor those for cyclic loading conditions viz. IAWQ ASM No1 (Henze *et al.*, 1987), UCTOLD (Dold *et al.*, 1991) for N removal or ASM No2 (Henze *et al.*, 1995), or UCTPHO (Wentzel *et al.*, 1992).

There are principally two reasons why nitrification and/or nitrification-denitrification has not been applied more widely in Finland:

1) The temperatures in the municipal wastewaters may range from about 20°C in summer to as low as 4°C in winter. With the winter temperatures the sludge age to achieve nitrification need to be very long which increases the cost of the plants particularly if the plants are to be covered to counter the severe cold winter air temperatures, as low as -20°C to -30°C. Furthermore, in general, the water supplies to the municipalities have low alkalinities. At Kajaani (central Finland) for example, the underground and surface water supplies have alkalinities of about 40mg/l as $CaCO_3$, and are distributed without alkalinity addition; hence the municipal wastewaters also have relatively low alkalinities. With nitrification, the alkalinity will decrease to below 30 to 40mg/l as $CaCO_3$, thus causing the pH to become unstable and decrease below 6, which in turn will inhibit nitrification. Consequently once nitrification is specified, either denitrification must be incorporated to regain some alkalinity and stabilize the pH at values higher than 7, or, chemicals must be added to increase the alkalinity and pH. Incorporating nitrification-denitrification or chemical addition increases the cost of wastewater treatment.

2) The technical difficulties and costs associated with nitrification-denitrification plants necessarily would have had to be faced by the municipalities if the environmental protection or the pollution control agencies had stipulated the removal of nitrogen from the effluent. However, in Finland up to about 1994 nitrification only or nitrogen removal was not legally required. The view was held that phosphorus was the limiting nutrient for eutrophication and accordingly there were regulations limiting only phosphorus discharges and these were dealt with by chemical precipitation.

Since 1994 research indicated that in the southern coastal region nitrogen can become the limiting nutrient during some part of the yearly cycle and therefore regulations on nitrogen removal in this region have now been promulgated. Furthermore, there is increasing pressure from the Nordic countries bordering on the Baltic sea and from the European Community to reduce the nitrogen load in discharges from waste water treatment plants in Finland (Alison, 1998). It is to be expected that in the future there will be increasing pressure on municipalities to incorporate nitrogen removal in both existing and new plants.

1.2.2 Pulp and paper mill waste water

A major producer of industrial wastewater in Finland is the pulp and paper industry. The industry is responsible for the treatment of its wastewaters. The wastewater from a pulp and paper mill has a very large biodegradable carbonaceous component, but is severely deficient in the nutrients nitrogen and phosphorus; also the influent temperature is high, 50°C to 60°C. After appropriate pre-treatment of waste streams that contain toxic substances, the different waste streams are cooled and combined and usually treated biologically in an aerobic activated sludge system.

Experience with aerobic activated sludge systems treating pulp and paper mill wastewaters has led to empirical rules for the design and operation of these plants: The influent temperature needs to be reduced prior to treatment (for example, for the pulp and paper mill in Kajaani the influent temperature is reduced from about 50°C to about 38°C) and nitrogen and phosphorus need to be added. With regard to the N and P addition, experience has shown that the additions required for adequate performance are considerably less than that normally accepted for satisfactory biological treatment. There are no reports describing the kinetic behaviour of these activated sludge systems.

1.3 COMBINED WASTE WATER TREATMENT CONCEPT

From the brief description above it will be evident that the process requirements for the treatment of the two waste streams, municipal or pulp and paper mill, differ appreciably.

- For the pulp and paper mill waste, the waste temperatures are high so that precooling is required; the wastewaters are deficient in nitrogen and phosphorus necessitating additions of these. Because the waste flows are deficient in nitrogen and phosphorus, no nitrogen and phosphorus removals are required and generally aerobic activated sludge systems with relatively short sludge ages provide adequate treatment.

- For municipal wastewaters, temperatures are extremely low in the spring season and generally nitrogen and phosphorus contents are in excess of metabolic treatment requirements. If nitrogen is to be removed in addition to phosphorus, nitrification-denitrification (ND) biological excess phosphorus removal (NDBEPR) or, ND plus chemical phosphorus removal systems are required. The winter temperatures govern the design of NDBEPR and ND plants, and generally give rise to plants considerably larger than when biological removal of N and P are not required. Where the minimum wastewater temperature is high, biological N and P removal are possible in much smaller plants, because nitrification can be achieved at much shorter sludge ages.

The different treatment requirements for the two wastewaters have led to a conceptual treatment proposal for combined treatment of the two waste flows in a single activated sludge system (Mellin *et al.*, 1995). At Kajaani, for example, estimation of the temperature of the combined waste flow indicates 20°C in the winter and 30°C in the summer. Hence, with combined treatment there may be no need to precool the pulp and paper waste flow and the system will operate at a favourably high minimum temperature. Furthermore, depending on the magnitudes of the waste loads, the nitrogen and phosphorus content in the municipal flow may be adequate for treatment of the combined flow so that little or no nutrient additions may be required. However, should the nutrients still be in excess, an NDBEPR configuration can be incorporated in the design to remove the excess nitrogen and phosphorus biologically.

One may summarise the following advantages that may arise from combined treatment:

For the pulp and paper mill component,

1. No need to cool the influent.
2. No or only little addition of nitrogen and phosphorus to satisfy activated sludge biological process requirements.

For the municipal component,

1. A warmer wastewater hence more economical biological treatment, in particular, for nitrification - denitrification.
2. Significantly reduced nitrogen and phosphorus removal requirements so that there may be no need to nitrify or to incorporate ND or NDBEPR processes; however, if additional nitrogen and phosphorus removal is required, then ND or NDBEPR configuration can be incorporated economically because of the elevated minimum temperature.

Due to the high temperatures (20°C to 30°C) the sludge age of the system treating the combined flow will be significantly shorter than that treating a municipal wastewater only in a NDBEPR system at 5°C. An example where combined treatment of municipal and pulp and paper mill wastewater would seem particularly feasible is at Kajaani. The present activated sludge wastewater treatment plant (WWTP) for the pulp and paper at Kajaani apparently operates at a sludge age of approximately 18 days at 38°C. It is possible that this existing plant might accommodate the municipal wastewater without enlargement because the additional municipal COD load is only approximately 10 percent of the industrial COD load. Furthermore a reduction in sludge age is possible so that the volume requirement may still be less than that available at present even though the load will be higher. This however must be taken as conjecture until such time as the combined flow has been experimentally evaluated in laboratory or pilot scale activated sludge studies.

There is clear indication that the COD load from the pulp and paper mill at Kajaani will increase in the near future. Should the industrial load increase significantly, then there is the option that a fraction (at least hot and clear waste streams) of the pulp and paper mill wastewaters can be pre-treated anaerobically e.g. in an upflow anaerobic sludge bed (UASB) system before re-combining with the other wastewater streams. The UASB pre-treatment of this waste stream could reduce its COD load by 50% to 65%, a reduction of about 20 tons COD per day. In Kajaani, a rough calculation indicates that at present the activated sludge system should be adequate for treatment the pulp and paper mill plus municipal COD load of 70+6 = 76tons COD per day (Mellin *et al.*, 1995). If a UASB system should be incorporated, preliminary indications are that the present pulp and paper mill load can be reduced by at least 20 tons COD per day. The increase in production, the pulp and paper load therefore can increase by at least 20 tons COD per day without requiring augmentation of the activated sludge system. Pilot scale studies on the treatability of the pulp and paper mill wastewater on UASB systems have been undertaken Jahren and Rintala (1997) and mesophilic UASB system treating pulp and paper mill waste waters have been successfully operated for 6 years at Kotka in Finland.

1.4 OBJECTIVES OF THIS INVESTIGATION

From the above, it would appear that combined treatment of municipal and pulp and paper wastewaters offers an attractive alternative to their separate treatment. At Kajaani for example, this combined treatment can be expected to operate in the temperature range 20°C to 30°C. However, at present there are no reports or papers available on the behaviour of ND and NDBEPR plants operating at 30°C. Accordingly, the principle aim of this investigation was to:

- Examine the behaviour of ND and NDBEPR activated sludge systems at 30°C.

This investigation must be looked upon as constituting the first step in developing design data for the ND/NDBEPR treatment of combined wastewater flows at 30°C. The enquiry is restricted to evaluating the behaviour of activated sludge ND and NDBEPR systems at 30°C treating municipal wastewaters.

CHAPTER 2

EXPERIMENTAL PROTOCOL

2.1 INTRODUCTION

The primary objective in this investigation was to determine experimentally the behaviour of ND and NDBEPR systems treating municipal wastewater at 30°C. In this Chapter the experimental protocol is developed to achieve this objective taking due account of limitations imposed by time and resources available.

2.2 ACTIVATED SLUDGE MODELS

The theoretical models in terms of which the behaviour of activated sludge systems (aerobic, ND and NDBEPR) are described, and which have been widely accepted for design and simulation of activated sludge plants treating municipal wastewaters are the steady state models at the University of Cape Town viz. Marais and Ekama (1976), WRC (1984) and Wentzel *et al.*, (1990) and the cyclic flow and loading (dynamic) models developed viz. IAWQ ASM No1 (Henze *et al.*, 1987) and UCTOLD; Dold *et al.*, (1991) for biological N removal and UCTPHO Wentzel *et al.*, (1992) and IAWQ ASM No2 (Henze *et al.*, 1995) for biological P removal. A review of activated sludge kinetics and system models is not given here; a succinct review is given by Wentzel *et al.* (1992). At the end of this Chapter a reading list is supplied for those requiring a detailed discussion of the theory, model development and design of activated sludge systems.

The steady state and dynamic state models of kinetic behaviour were developed from experimental investigations over a wide range of systems, influent flows and influent characteristics in the temperature range 13°C to 22°C, using real municipal wastewater. The models comprise *inter alia* a set of mathematically formulated kinetic processes which incorporate constants that require calibration. These constants often are temperature dependent and much of the experimental work has been oriented to determine values for the constants and their temperature dependencies. These have been estimated with fair reliability for municipal wastewaters but only in the temperature range 13°C to 22°C.

With regard to the validity of the activated sludge models outside their calibrated temperature range, little information is available. Model calibration and evaluation studies have been undertaken in the low temperature range 6°C to 12°C due to the increasing interest in applying activated sludge nutrient removal technology in Northern Europe and North America; however, for the high temperature range application in equatorial and tropical regions (22-30°C) very little information is available. One may be justified to accept that the formulations of the kinetic processes- in the model remain valid outside the calibrated temperature range (13-22°C) but uncertainties arise with the kinetic and stoichiometric constants in that they may have temperature dependencies in the higher temperature range 22°C to 30°C (our region of interest) that deviate from those found by calibration in the range 13°C to 22°C. These uncertainties may extend further to the degree that there is no surety even that some of the processes in the activated sludge will operate at temperatures of say 30°C and above due to for example, high temperature inhibition of enzymes. There is reasonable certainty that the processes involved in carbonaceous material removal do operate at 38°C, as demonstrated in the aerobic activated sludge plants treating the pulp and paper mill wastewater though the information does not allow relevant estimates of kinetic parameters. With regard to biological excess phosphorus removal processes there is no information at 30°C.

The usual expectation is that process kinetic rates speed up with increase in temperature, but there must be a critical temperature above which a particular process rate commences to decline and at yet higher temperatures ceases to operate. Referring to ND and NDBEPR processes, there is no knowledge as to whether some of these processes do not decline significantly or cease as the temperature approaches 30°C. Our first objective should be to determine the measure in which these processes function at 30°C. Once this is established it may attempted, within the model structure, to determine by calibration the values of some significant constants to give improved model predictions, and to provide quantitative evaluation of temperature dependencies within the higher temperature range.

The most reliable evaluation of the processes and temperature dependencies in the model, requires simultaneous operation of aerobic, ND, and NDBEPR systems, under steady and dynamic states at 20°C and 30°C over a range of sludge ages. This would be the ideal solution, but also the one demanding extended time and extensive manpower and experimental facilities. By accepting that the kinetic response of the systems at 20°C, as determined on a selected municipal wastewater, is adequately described by the existing models and their calibrated constants, then using the same municipal wastewater and conducting experiments at 30°C would allow estimation of the temperature effects between 20°C and 30°C, although a measure of uncertainty will be introduced because the investigation is not done simultaneously at both temperatures.

With regard to the experiments at 30°C the following comments can be made: Aerobic system studies under both steady and cyclic loading states, at one or more sludge ages, are in themselves time consuming. In principle they allow assessment of all the kinetic and stoichiometric constants relating to aerobic carbonaceous removal and nitrification processes. However, sludge ages at which nitrifying aerobic plants normally are operated are so long that with the exception of the endogenous mass loss process, the carbonaceous material degradation processes all have gone to completion. Usually the minimum sludge age is determined from the aerobic sludge age necessary to ensure nitrification. Experience has shown that the specific nitrification rate constant, basic to determining the minimum aerobic sludge age, is heavily dependent on the influent wastewater and cannot be stipulated *ab initio* but must be found from experiment (WRC, 1984). The same situation applies for ND and NDBEPR systems, but the sludge age problem is compounded in that additional sludge age is required to provide an unaerated sludge mass in the system for denitrification and phosphorus release.

With regard to the influence of temperature on the aerobic, nitrification, denitrification and BEPR processes, with the possible exception of the BEPR process, the specific rates for all the other processes increase/decrease with increase/decrease in temperature. With the exception of BEPR, if the processes have progressed to completion at a lower temperature then it is very likely that they will do so also at a higher temperature and that conversions are virtually stoichiometric. Conversely, processes going to completion at a higher temperature may not do so at a lower temperature. This has been the experience with processes when the temperature decreases from 22°C to 12°C (Pilson *et al.*, 1995). This behaviour forms the basis for design - if the design is adequate at the lower winter temperature, it is accepted that the design would very likely be adequate at the high summer temperature. This approach has been used in design for plants operating in the temperature range 13 to 22°C (WRC, 1984). However, the approach may not be satisfactory for plants operating in the temperature range of 20 to 30°C

The kinetic models to simulate ND and NDBEPR systems appear to define the different processes adequately and, by calibration, have quantified the kinetic constants and their temperature dependencies in the temperature range 13 to 22°C. The constants in the temperature dependency formulations in the temperature range above 20°C may deviate from those below 20°C, the measure of deviation can be determined only from experiment. Furthermore, in the higher temperature range there necessarily must come a temperature where the kinetic conversion rate of a process may commence to decline, possibly to zero due to the temperature inhibition of enzymes, so that there is an increasing likelihood of this happening as the temperature rises above 20°C. This is more likely to happen with the BEPR and nitrification processes because these processes are mediated by a restricted species of organisms whereas the other processes are driven by a wide spectrum of organisms species.

To obtain an assessment of ND and NDBEPR systems at 30°C the simplest approach would appear to be to design a steady state system to give "optimal" removal of N and P at the lowest temperature (20°C) and then operate this system at 30°C. This approach, however, would not supply direct information on the kinetic constants, only a 'black box' performance. However, information on the constants could be obtained from batch tests using the sludge from the system with and without wastewater addition. This also may allow approximate evaluation of temperature dependencies should the constants be quantified at a lower wastewater temperature.

2.3 PROPOSED EXPERIMENTAL PROTOCOL

For Kajaani (in Finland) with combined treatment, the focus will be on the behaviour of ND and NDBEPR systems in the temperature range 20 to 30°C. The combined wastewater is not available in South Africa but, as a preliminary to studying these systems in Finland, it seemed a good policy to investigate the systems behaviour at 30°C using a municipal wastewater for which the systems responses are reasonable well established at 20°C such as that from the Mitchells Plain WWTP, Cape Town, South Africa. This influent has served as waste water source for many years in the wastewater laboratory at the University of Cape Town. Hence extension to 30°C would be from a known base. In recent years batch test procedures, for assessing maximum specific growth rate of the nitrifiers at reference temperature 20°C, μ_{nm20} , and indeed most of the other kinetic constants particularly those connected with NDBEPR, have been developed and have been shown to be reliable. Accordingly it was decided to focus on ND and NDBEPR systems at 30°C run in parallel at <u>constant flow and load</u>. The systems would be designed such that the aerobic, nitrification and denitrification processes would proceed to completion at 20°C; hopefully, these also would do so at higher temperatures. With regard to BEPR processes research indicated that some processes were unlikely to go completion, for example, sequestration (uptake) of RBCOD in the anaerobic zone. Some information on BEPR processes might also be obtained by means of batch tests.

Accepting that ND and NDBEPR systems only are to be tested, it remained to select the system configurations, i.e. the pre-denitrification (Modified Ludzack-Ettinger, MLE) or post-denitrification (Wuhrmann) configurations for the ND systems, and the UCT or Johannesburg configurations for the NDBEPR systems.

With regard to the NDBEPR systems, the UCT configuration was selected principally because extensive investigations at 20°C using this system had been done in the laboratory with the same municipal waste flow as that to be used in this 30°C investigation. From the past 20°C investigations it was concluded that μ_{nm20} was not less than 0.35 per day, and readily biodegradable to biodegradable COD ratio (RBCOD/BCOD), f_{bs} about 0.23, total nitrogen to total COD ratio (TKN/COD) ratio about 0.1, unbiodegradable particulate to total COD ratio (UPCOD/TCOD) about 0.14 and unbiodegradable soluble to total COD ratio (USCOD/TCOD) about 0.05 using the Mitchells Plain sewage. From past experience at 20°C a sludge age of 10 days would give satisfactory performance for an appropriately designed NDBEPR system and that, from simulations, systems with anaerobic-anoxic-aerobic mass fractions of 0.15-0.35-0.50 respectively would nitrify completely at 10 days sludge age and give a high degree of uptake of RBCOD in anaerobic zone for BEPR. For an unsettled wastewater influent COD of 750 mg/*l*, TKN 75 mgN/*l*, with the recycle ratios relative to the influent flow, s-underflow recycle from the settling tank 1:1, a-recycle from the aerobic to the anoxic reactor 2:1 and r-recycle from the anoxic to the anaerobic reactor 1:1, simulation of the NDBEPR system indicated complete nitrification in the aerobic zone and complete denitrification in anoxic zone, (i.e. zero nitrate in anoxic zone) giving an effluent nitrate of 12mgN/*l* and phosphorus removal 17mgP/*l*. In retrospect, a higher a-recycle of 3 or 4:1 would still have given complete denitrification in anoxic zone and hence a lower nitrate concentration in the effluent. The low selected a recycle ratio arose from accepting the lower recycles employed in the 'usual' system in SA operating in the temperature range 12°C to 20°C and the minimum proposed temperature in Kajaani (in Finland) plant being 20°C. The demands of the design interrelations with respect to nitrification and denitrification at 20°C showed a sludge age of 10 days is acceptable. Accordingly, the recycle ratios above and 10 days sludge age were retained for the investigation at 30°C.

With regard to the ND systems, the MLE configuration was selected in preference to the Wuhrmann configuration principally because it is the most efficient in denitrification per unit reactor volume. Also by appropriate subdivision of the anoxic zone it could be converted readily into a UCT system for NDBEPR investigations. The anoxic-aerobic mass fractions for the MLE system were specified as (0.15+0.35):0.5 i.e. 1:1 as given earlier for the UCT system, so that the unaerated mass fractions of the UCT and MLE systems were the same. The a-recycle was increased to 4:1 due to the larger anoxic mass fraction compared with the UCT system. The simulated effluent nitrate came to 8mgN/*l* at 20°C.

In summary, two laboratory-scale systems would be operated in parallel with a 10 days sludge age and at steady state, an ND MLE system and an NDBEPR UCT system, both at 30°C, receiving the same wastewater as influent. The steady state behaviour of these systems would be compared to the behaviour established for existing systems at 20°C. Further, the systems would be used to provide sludge for batch tests, to investigate kinetic behaviour at 30°C to compare with theoretical batch behaviour from past tests at 20°C or with batch tests from identical existing systems operated at 20°C in parallel for other research project.

2.4 READING LIST

1. Marais GvR and Ekama GA (1976). The activated sludge process, Part 1- steady state behaviour. Water SA, 2(4), 163-200.
2. Dold PL, Ekama GA and Marais GvR (1980). A general model for the activated sludge process. Prog.Wat.Tech., 12, 47-77.
3. Van Haandel AC, Ekama GA and Marais GvR (1981). The activated sludge process Part 3 - single sludge denitrification. Water Research, 15(10), 1135-1152.
4. WRC (1984). Theory, Design and Operation of Nutrient Removal Activated Sludge Processes. Water Research Commission, P O Box 824, Pretoria, South Africa.
5. Wentzel MC, Dold PL, Ekama GA and Marais GvR (1985). Kinetics of biological phosphorus release. Water Sci. Technol., 17(11/12), 57-71.
6. Ekama GA, Dold PL and Marais GvR (1986). Procedures for determining influent COD fractions and the maximum specific growth rate of heterotrophs in activated sludge systems. Water Sci. Technol., 18(6), 91-114.
7. Henze M, Grady CPL Jr, Gujer W, Marais GvR and Matsuo T (1987). Activated sludge model No1, IAWQ Scientific and Technical Report No1, IAWQ, London.

8. Wentzel MC, Dold PL, Loewenthal RE, Ekama GA and Marais GvR (1989a). Enhanced polyphosphate organism cultures in activated sludge systems. Part II: Experimental behaviour. Water SA, 15(2), 71-88.
9. Wentzel MC, Dold PL, Ekama GA and Marais GvR (1989a). Enhanced polyphosphate organism cultures in activated sludge systems. Part III: Kinetic model. Water SA, 15(2), 89-102.
10. Wentzel MC, Dold PL, Ekama GA and Marais GvR (1990). Biological excess phosphorus - Steady state process design. Water SA, 16(1), 29-48.
11. Dold PL, Wentzel MC, Billing AE, Ekama GA and Marais GvR (1991). Activated sludge simulation programs: Nitrification and nitrification/ denitrification systems (Version 1.0). Water Research Commission, P O Box 824, Pretoria, South Africa. TT 52/91, ISBN 0 947447 19 9.
12. Wentzel MC, Dold PL, Ekama GA and Marais GvR (1992). Processes and modelling of nitrification denitrification biological excess phosphorus removal systems - A review. Water Sci. Technol., 25(6), 59-82.
13. Henze M, Gujer W, Mino T, Matsuo T, Wentzel MC and Marais GvR (1995). Activated sludge model No2, IAWQ Scientific and Technical Report No3, IAWQ, London

CHAPTER 3

EXPERIMENTAL INVESTIGATION - STEADY STATE OPERATION

3.1 EXPERIMENTAL SET-UP AND CONTROL

Two laboratory scale activated sludge systems were set up in a temperature controlled room at 30°C, a nitrification-denitrification (ND) Modified Lutzack-Ettinger (MLE) system (MLE30, Fig.3.1a) and a ND biological excess P removal (NDBEPR) University of Cape Town (UCT) system (UCT30, Fig.3.1b). Design and operating parameters for both systems are given in Table 3.1. The two systems were operated for a period of 582 days under constant flow and load conditions at 30°C. Both systems were fed with unsettled sewage at the same COD concentration from the same source, the sewer serving Mitchell's Plain WWTP (Cape Town, South Africa).

Unsettled sewage was collected from a manhole immediately upstream of the WWTP, by tanker in $1m^3$ batches. A batch was collected over a period of 2 to 3 hours, between 11AM and 2PM. Experience had shown that during these collection times the concentration ratios of TKN to COD approximated the daily mean ratios. At the laboratory, the batch was macerated and stored in stainless steel tanks, in a cold room at 4°C and the batch COD and TKN concentrations were measured. These sewage batches were needed to make up the influent feed to the laboratory-scale systems. On average a batch lasted about 2 weeks, but in any event a batch was not stored for longer because experience indicated that from 2 weeks onwards significant changes commenced in the sewage characteristics. Collection over the selected time usually assured a COD concentration of >1000mgCOD/*l*.

Altogether 41 sewage batches were used as feed for the two systems over the 582 days. The days over which the different batches of sewage were fed to the systems are shown in Fig 3.2.

A relatively constant influent COD concentration was intended for each day's feed. Both systems were to receive 20*l* of sewage daily at a target average concentration of 750 mgCOD/*l*. This was done by drawing a volume of sewage from the storage tanks and appropriately diluting it with tap water, from the measured sewage batch COD concentration (ranging from 900 to1100mgCOD/*l*), to the feed concentration of 750mgCOD/*l*. The TKN concentration was not adjusted to a fixed value in the diluted 'constant' COD daily feed. Because the sewage had a relatively low Total Alkalinity the diluted influent was buffered with the addition of sodium bicarbonate (1,5 teaspoonful per 40*l*) to prevent possible reduction of Total Alkalinity in the system below about 40mg/*l* as $CaCO_3$, due to nitrification which would cause the pH to decline and in turn adversely effect nitrification. The diluted sewage was thoroughly mixed and a sample drawn for analysis of COD, TKN-N, free and saline ammonia (FSA) and total phosphorus (TP). For each system a measured volume of 20*l* was placed in a PVC feed drum kept at +/-8°C. The contents of the feed drum was covered with a floating plastic disk to limit oxygen entrainment from the air, and the contents stirred gently. The influents were fed at a constant flow rate to each system over the 24h period.

It should be noted that the diluted feed at 750mgCOD/*l* was prepared for a number of investigations in the laboratory. The total feed volume was prepared independently by laboratory assistants, not too efficiently, so that over the period of the investigation there was a spread of daily feed concentrations around the target 750 mgCOD/*l*, the spread differing when there was a change of laboratory assistant making up the feed. The experimental measurement of readily biodegradable COD (RBCOD) in the feed was measured in a parallel investigation (see Ubisi *et al.*, 1997). This should have been done on every sewage batch, but unfortunately this was not possible. Ubisi *et al.*, (1997) did 88 RBCOD tests on 12 sewage batches from batch 12 to 27 so that estimation of this parameter, one of vital importance to BEPR, had to be supplemented with estimate from earlier and later investigations on the same sewage (see Section 3.5) for details.

With regard to design and operating parameters of the systems, no changes were made over the period of the investigation; the parameters listed in Table 3.1 applied throughout. Operating procedures, detailed by Burke *et al.*, (1986) and Clayton *et al.*, (1989) were followed.

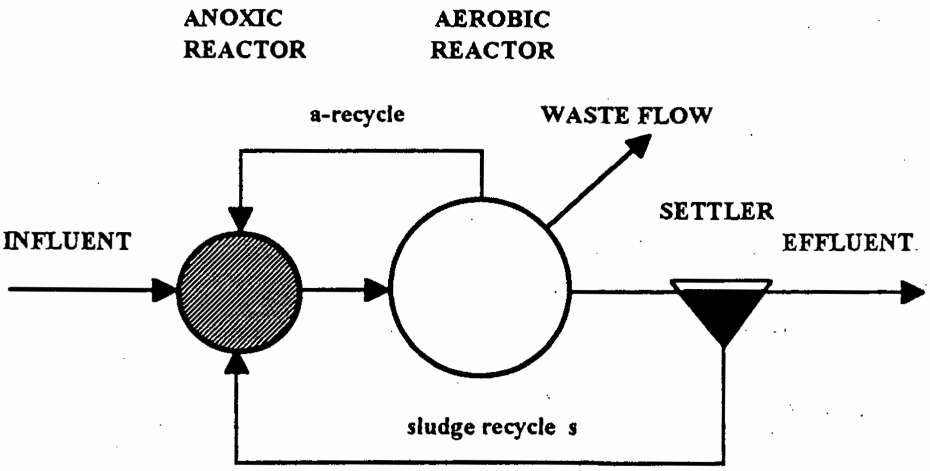


Fig 3.1a Schematic layout of the Modified Ludzack-Ettinger (MLE) system.

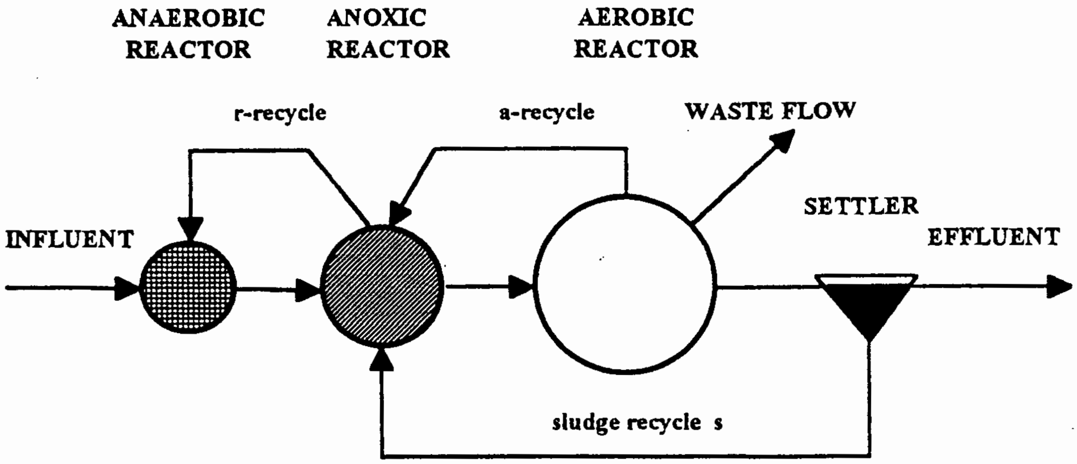


Fig 3.1b Schematic layout of the UNIVERSITY OF CAPE TOWN (UCT) system.

Table 3.1 Design and operating parameters of the laboratory scale MLE and UCT systems.

Parameter		
System:	**MLE** (Fig3.1a)	**UCT** (Fig3.1b)
Sludge age (d)	10	10
Temperature (°C)	30	30
pH of aerobic reactor	7.1- 8.3	7.1- 8.3
DO in aerobic reactor (mgO/*l*)	1.5-4.5	1.5-4.5
Reactors volume (*l*) ; mass fraction (%):		
Anaerobic	0 ; 0%	3*; 15%
Anoxic	10 ; 50%	7 ; 35%
Aerobic	10 ; 50%	10 ; 50%
Total unaerated	10 ; 50%	10* ; 50%
Recycles ratios		
Underflow (s-recycle)	1:1	1:1
Aerobic to anoxic (a-recycle)	4:1	2:1
Anoxic to Anaerobic (r-recycle)	-	1:1
Influent (Raw sewage, the same for both systems)		
Source	Mitchell's Plain (Cape Town, South Africa)	
Flow (*l*/d)	20	
COD concentration (Proposed) (mgCOD/*l*)	750	
TKN concentration (Expected) (mgN/*l*)	60-90	
TKN/COD ratio	0.08-0.12	
Total P concentration (Expected) (mgP/*l*)	12-16	

* Equivalent volume, actual anaerobic volume is 6*l*, but with r-recycle ratio 1:1 the MLVSS concentration in the anaerobic reactor is half that in the remainder of the system. Therefore the equivalent anaerobic volume of 3*l* has the same MLVSS concentration in the anoxic and aerobic reactors.

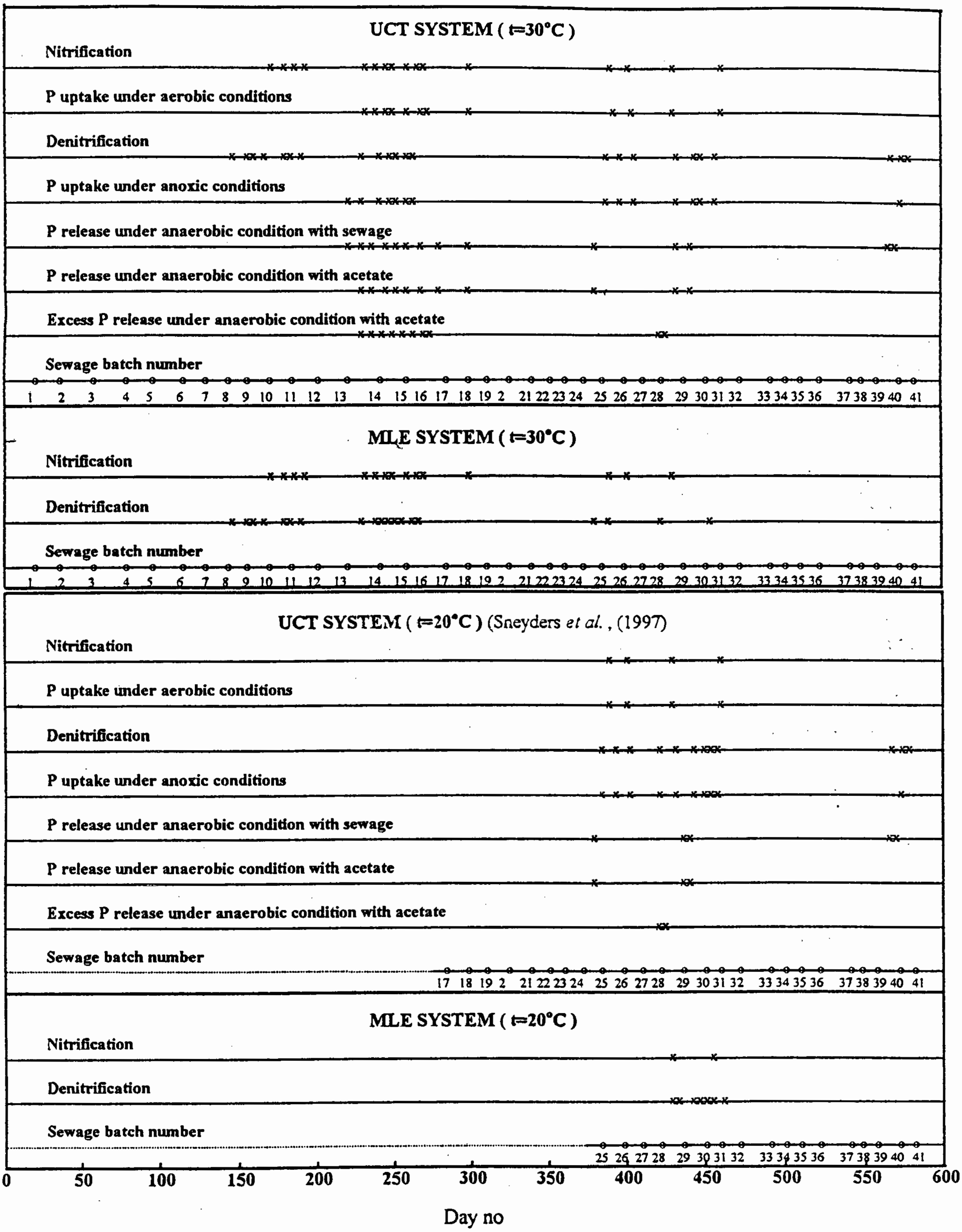


Fig 3.2 Summary of sewage batches and tests undertaken versus time.

The systems were operated in a temperature controlled room at 30°C. To determine nitrification and denitrification rates for the MLE and UCT systems, and phosphorus release and uptake behaviour for the UCT system, appropriate batch tests were carried out. These tests started on day number 145 (batch of sewage 8) and ended day 572 (batch of sewage 41), see Fig 3.2. All the batch tests were conducted on mixed liquor samples drawn from the systems. The volume of mixed liquor used in a test was generally 1,5*l*. The volume of mixed liquor daily wasted from each of the systems was 2*l*, so that the volumes drawn for the tests did not disturb the sludge age. For a nitrification batch test the volume of mixed liquor for a test was more than 2*l*, i.e. 3*l*, in this event after finishing the test an appropriate volume of the batch test mixed liquor was returned to the each system to provide a net 2*l* wastage.

Duration of these batch tests was exactly 5,5 hours (330 minutes). Depending on the test 14 to 16 samples were collected during this period. Sampling commenced at the beginning of the test, thereafter at 5 minute intervals, later at 10, 15, 30 and 60 minutes intervals. The intervals selected developed from experience with these tests. Details on the operation and performance of the batch tests are given in Appendix G.

The following batch tests were performed on the MLE and UCT systems mixed liquor:

1) **Anoxic batch test:** This test was performed to determine denitrification rates in the anoxic zones. For example in the UCT system the mixed liquor for the test was with drawn from the anaerobic and aerobic reactors in proportion to the magnitudes of the respective recycles to the anoxic reactors. Excess nitrate was added to the test mixed liquor at the start to ensure availability of nitrate throughout the test period. From the nitrate and nitrite concentration-time plots and the calculated system active ordinary heterotrophic organism active biomass (OHOAVSS), AVSS, the K_1 and K_2 denitrification rate constants for the MLE system and K_2' denitrification rate constants for the UCT system were determined and expressed as mg(NO_3-N)/mgOHOAVSS/d.
2) **Aerobic batch test:** This test was performed anoxic reactor mixed liquor to determine the maximum specific growth rate of the nitrifiers μ_{nmT} for the MLE and UCT systems. Excess ammonia was added to the batch mixed liquor at the start of the test and the increase of nitrate and nitrite concentrations with batch time was monitored. Throughout the test the oxygen utilisation rate (OUR) was measured automatically (Randall *et al.*, 1991).

On mixed liquor from the UCT system in the two tests above, the following additional measurements were taken:

1) **P uptake in anoxic reactor:** Phosphate was analysed additionally in the anoxic batch tests of (1) above, to observe if there was any P uptake under anoxic conditions. The decrease in phosphorus concentration with batch time was monitored from samples taken from the batch liquor.
2) **P uptake in aerobic reactor:** Phosphate was also analysed in the aerobic batch tests of (2) above, to observe P uptake rate under aerobic conditions. Excess phosphorus was added to the anoxic mixed liquor at the start of a test to ensure availability of P throughout the test. The decrease in phosphorus concentration with batch time was monitored from samples taken from the batch liquor.
3) **P release with sewage and acetate addition:** This test was performed using mixed liquor from the anoxic reactor and dosing (a) raw sewage and (b) acetate at the

start of the test, and monitoring with time the concentration of P release per acetate or per sewage COD added (ratio: $P_{released}/HAc_{added}$ and $P_{released}/sewageCOD_{added}$)

One further independent batch test was undertaken:

Excess P release in anaerobic reactor: This test was performed using anaerobic mixed liquor, dosing excess acetate as a substrate source, to observe if there was still any P available for release to the bulk liquid.

A total of 149 batch tests were conducted on the 30°C systems, 37 on the MLE and 112 on the UCT system. The specific dates on which the batch tests were undertaken and the data obtained in the tests are listed in Appendix H.

About 230 days (batch of sewage 17) after the commencement of the investigation described above, a different but parallel system investigation by Sneyders *et al.* (1997) was commenced at 20°C, with identical MLE and UCT systems to the ones above, fed from the same sewage batches (see Figs3.1a and 3.1b and Table 3.1). The two 20°C systems served as a mixed liquor source for batch tests at 20°C identical to those at 30°C. It was envisaged that comparison of the respective rates would allow temperature effects to be assessed between the 30°C and 20°C systems. A total of 52 batch tests were conducted on mixed liquor drawn from the two 20°C systems, 10 on the MLE systems, and 42 on the UCT system by the writer in this report. The days on which these batch tests were carried out and the type of batch test, are shown in Fig 3.2.

The performance of UCT system at 20°C was extensively analysed by Sneyders *et al.*, (1997) but they did not analysed the performance of the MLE system, the MLE system was operated by them only to provide mixed liquor for the batch tests reported in this thesis.

3.2 STEADY STATE SYSTEM OPERATION

To monitor the steady state performance of the systems at 30°C, samples were taken virtually daily from the influent, effluent and each of the reactors of the two systems, for analysis. Table 3.2 lists the parameters measured. Descriptions of the tests and testing procedures are given in Appendix F.

The day to day monitored results are listed in Appendix A. Time plots of these results are shown in Figs A.55 to A.83. Figures A.37 to A.40 show the daily mass of oxygen utilised per mass of VSS in the aerobic reactors in mgO/(gVSS.d); these were calculated from the measured daily mean observed OUR recorded automatically, Randall *et al.*, (1991) and VSS concentrations. For ready reference, Table A.1 lists the figure numbers on which the monitored parameters are plotted.

Table 3.2 Collected sample position and parameter measurement.

Test	Influent	Anaerobic reactor	Anoxic reactor	Aerobic reactor	Effluent
COD	•			•	• O
TKN	•			•	• O
NH_3	•				O
NO_3		Ø	Ø	Ø	O
Total P	•	Ø	Ø	Ø	• O
pH				*	
OUR				*	
VSS				*	
TSS				*	
DSVI				*	

•	Unfiltered samples
O	Samples filtered through prefilter glass fiber- GF50
Ø	Samples centrifuged and filtered through glass fiber- GF50
*	Measurement taken

During the investigation examination of the measured response data (see Figs 3.3 and 3.4 abstracted from Figs A.49 and A.50), indicated that the P release declined and effluent P concentration increased in the UCT system from about sewage batch 24 (day 361). The cause of this was traced, eventually, to a change in the influent sewage characteristics: At about the time batch 24 was collected there was a change in the operational procedure at the Mitchells Plain WWTP - the supernatant from the waste activated sludge centrifuge (containing considerable mixed liquor) was recycled to a point upstream of the manhole where the 1m^3 batches for the laboratory investigation were taken. This caused that activated sludge was introduced into the sewage flow and started biological action on the RBCOD, prior to the collection point. This situation was verified by Ubisi *et al.*, (1997) who measured the influent ordinary heterotrophic organism active concentration (OHOAVSS) and RBCOD concentration. This reduction in RBCOD had a marked detrimental effect on the observed P removal. When this effect was identified, the sewage collection point was changed so that the collected sewage batches no longer contained the recycled centrifuged flow. This was done from batch 34 (day 490) and the response pattern obtained on the laboratory scale systems reverted to that observed during the first period. The 41 batches fed to the two systems over the 582 days investigation, in effect can be divide into 3 long term periods: period I from batch 1 to 23 (day 1 to 360), period II from batch 24 to 33 (day 361 to 489), and period III from batch 34 to 41 (day 490 to 582), with the third period reflecting approximately the same situation as the first period (Fig 3.3 and 3.4). Considering the data as a group from day 1 to day 582; this is designated as period IV. The start and end day of each sewage batch period and its duration are given in Table 3.8 with the COD and N balance results.

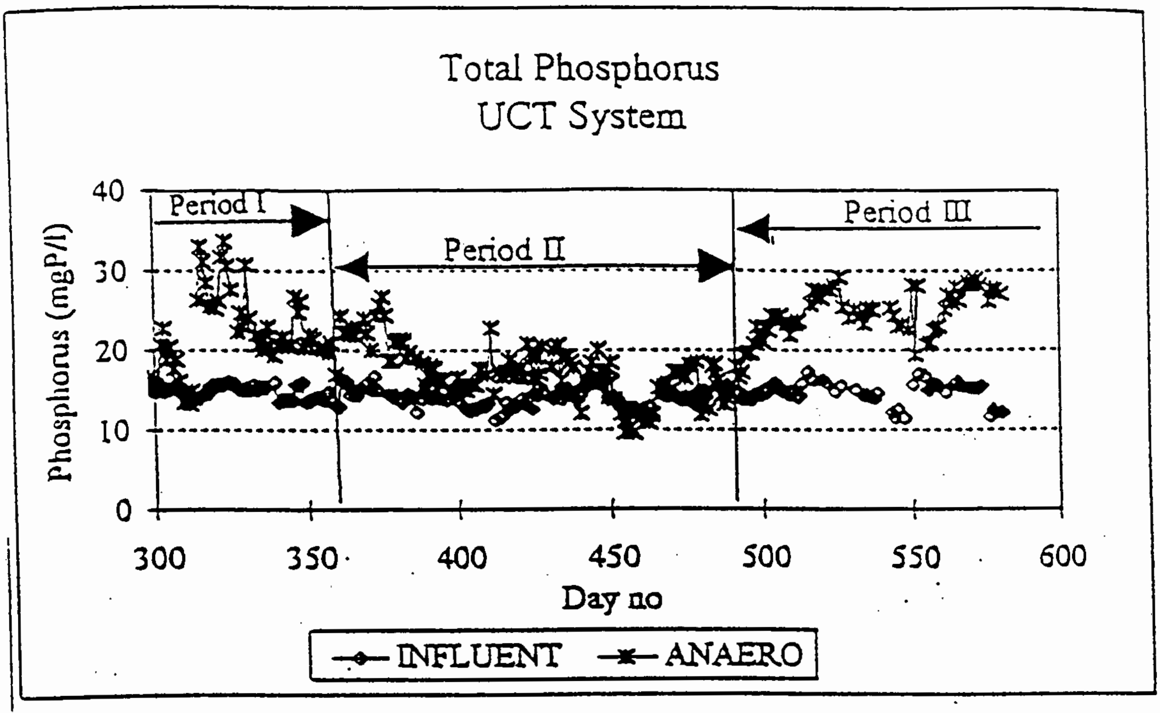


Fig 3.3 Daily influent and anaerobic Total P concentrations in UCT system from day 298 to day 582.

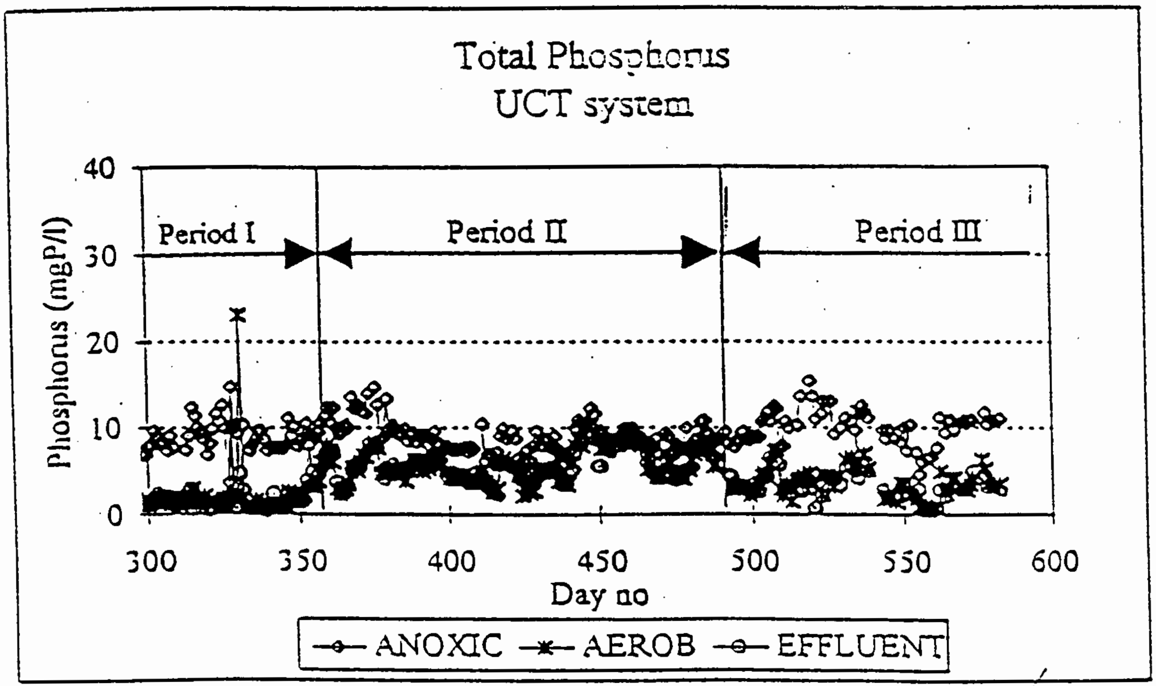


Fig 3.4 Daily aerobic, anoxic and effluent Total P concentrations in UCT system from day 298 to day 582.

3.3 ACCURACY AND PRECISION OF DATA

This investigation extended over a protracted period, 582 days, in which it was endeavoured to maintain the influent COD concentration to as near 750mgCOD/*l* as possible. Practically, absolute constancy in input is impossible; variability in an input concentration is introduced from: (1) the laboratory assistant making up the daily feed from a specific batch to the required concentration by dilution, (2) a natural variability found even with repeated testing on the same diluted feed, and (3) a variability from one sewage batch to another. The time plot of the influent COD (Appendix A Fig A.1 to A.4) shows a spread of values around the desired influent value 750mgCOD/*l*. A study of the influent data indicated that source of variability of the feed arose principally between sewer batches so that it was decided to (1) determine the means for each of the measured parameters for each sewage batch (41 batches), (2) group the sewage batch means into long term periods; I, II, III and IV identified above, and (3) do the analysis for each of the long term periods on the mean sewage batch values of these periods.

When statistically analysing sets of experimental data there can be data points which apparently deviate significantly from the general spread. Such extreme data points (called outliers) do arise statistically but there may be an assignable cause. If an assignable cause can be identified, such as an overt error in an experimental determination, then the observation should be removed. Sometimes, however, an assignable cause cannot be identified. If the data are approximately normally distributed, one may then apply a statistical test, such as the one proposed by Laubscher (undated), to identify outliers arising at a certain level of significance. From experience a reasonable level of significance to identify outliers appears to be 10%, and this was the significance level for rejection used in this investigation.

From the day to day results listed in Appendix A, the distribution of the day to day results of each sewage batch were checked for outliers and values identified as outliers omitted from subsequent analysis. (The rejected data are marked '¤' in the day to day data lists in Appendix A). The average value for each measured parameter for each sewage batch was then calculated. These average values are also listed in Appendix A, and are abstracted and listed in Tables 3.3 to 3.7. From these tables, for the each of the long term periods and for each measured parameter, the distributions of the sewage batch means were examined for outliers by making graphical statistical plots and applying Laubscher's test for outliers. The means and standard deviations for each long term period were calculated from the sewage batch mean values, together with the median values. Statistical plots of the sewage batch means in each long term period, together with the associated period means, medians, standard deviations and 95% confidence intervals of the means are shown in Appendix C. The means and 95% confidence of the means for periods I, II, III and IV are listed in Table 3.16.

Table 3.3 Mean sewage batch unfiltered influent (UFI), unfiltered effluent (UFE), filtered effluent (FE) and unfiltered aerobic reactor mixed liquor COD concentrations for the 41 sewage batches in the MLE and UCT systems at 30°C.

SEWAGE BATCH	UFI INFLUENT [mgCOD/*l*]	MLE system UFE [mgCOD/*l*]	MLE system FE [mgCOD/*l*]	UCT system UFE [mgCOD/*l*]	UCT system FE [mgCOD/*l*]	Aerobic reactor MLE* [mgCOD/*l*]	Aerobic reactor UCT* [mgCOD/*l*]
1	744	56.5	51.7	55.8	43.2	-	-
2	747	50.8	47.5	73.7	48.7	-	-
3	737	48.5	43.5	70.7	47.1	2433	2430
4	767	47.5	38.1	65.4	47.4	2949	2893
5	759	50.8	47.6	74.7	50.0	2944	2491
6	692	49.6	41.2	70.2	53.6	2194	2392
7	776	42.0	31.1	40.0	34.7	2383	2783
8	739	44.9	38.8	44.9	39.2	2381	2433
9	738	43.0	36.4	43.4	39.1	2763	2644
10	807	50.3	43.7	46.3	42.5	2992	3028
11	779	37.2	36.1	42.5	37.8	3115	3174
12	780	40.0	39.0	41.8	36.5	2553	2778
13	746	45.5	38.1	46.3	39.0	2588	2957
14	768	40.2	33.2	40.8	37.2	2824	2880
15	765	38.4	35.1	37.2	33.9	3029	2931
16	840	37.7	34.1	39.7	36.9	2995	2861
17	757	38.8	32.5	37.5	29.9	2831	2810
18	746	42.4	34.4	43.2	40.4	2757	2980
19	755	34.7	28.5	36.7	32.9	2649	2848
20	752	35.1	32.2	41.0	37.2	2964	2944
21	767	36.9	32.8	44.6	38.6	3320	3601
22	710	37.1	35.6	41.7	40.1	2886	3237
23	696	43.3	39.3	42.0	38.2	2823	3083
24	695	41.1	35.7	42.5	36.2	2382	2619
25	676	44.2	43.4	42.7	42.4	2649	3045
26	704	43.4	39.4	46.1	43.2	2601	2984
27	653	38.7	33.9	39.2	36.7	2824	2891
28	682	35.5	35.0	34.7	36.3	3117	3112
29	682	34.1	30.9	37.3	33.9	2895	3046
30	692	30.2	30.6	36.9	34.1	2906	2881
31	639	35.8	34.0	37.1	34.7	2628	2558
32	665	37.5	33.4	36.9	35.1	2602	2264
33	721	34.9	29.7	34.7	29.7	2575	2207
34	671	32.3	28.3	34.0	30.6	2681	2250
35	647	37.4	31.1	37.9	31.1	2331	2095
36	783	44.5	35.0	54.3	46.4	2181	2546
37	697	38.0	35.9	47.8	46.8	1999	2346
38	820	42.2	38.9	36.5	36.3	1986	2689
39	685	39.8	34.4	40.2	29.2	1616	2479
40	690	43.0	36.4	43.4	32.0	1866	2601
41	617	44.6	36.3	48.3	41.1	1879	2517

* COD of the mixed liquor.

AVERAGE	727	41.2	36.4	45.1	38.5	2618	2751

Table 3.4 Mean sewage batch unfiltered influent, unfiltered effluent (UFE), filtered effluent (FE) and unfiltered aerobic reactor TKN concentrations for the 41 sewage batches in the MLE and UCT system at 30°C.

	TKN CONCENTRATIONS						
		MLE system		**UCT system**		AEROBIC REACTORS	
SEWAGE BATCH	INFLUENT [mgN/l]	UFE [mgN/l]	FE [mgN/l]	UFE [mgN/l]	FE [mgN/l]	**MLE*** [mgN/l]	**UCT*** [mgN/l]
1	58	3.9	3.3	3.5	2.9		
2	55	3.3	2.8	3.0	2.5	112	110
3	62	3.9	3.1	3.9	3.2	159	142
4	78	3.1	2.7	3.4	2.9	187	154
5	98	3.2	2.7	3.9	3.3	178	152
6	63	2.8	2.3	3.2	2.4	138	134
7	61	2.7	2.3	2.9	2.5	163	170
8	73	3.4	3.0	3.9	3.5	171	170
9	71	4.2	3.4	4.2	3.8	170	171
10	66	3.6	3.0	3.8	3.2	195	197
11	59	3.7	2.9	3.6	3.1	212	210
12	71	3.4	2.9	3.7	3.2	173	196
13	66	3.1	2.7	3.2	2.7	176	197
14	60	3.1	2.5	3.3	2.8	194	196
15	50	3.0	2.2	2.7	2.3	195	189
16	68	3.0	2.5	2.8	2.2	198	188
17	56	2.6	2.1	2.6	2.3	194	188
18	61	2.8	2.5	2.8	2.4	195	206
19	68	2.9	2.6	3.2	2.7	184	196
20	68	3.6	3.3	3.9	3.5	201	206
21	63	3.7	3.4	4.1	3.7	225	238
22	84	3.4	3.1	4.4	4.3	215	222
23	71	3.4	2.9	3.4	3.0	203	212
24	63	2.8	2.6	3.0	2.6	179	181
25	65	3.7	2.9	3.6	3.1	179	200
26	82	3.8	2.9	3.3	2.9	184	202
27	58	3.2	2.6	2.9	2.6	196	187
28	68	3.0	2.9	3.3	3.2	212	202
29	72	3.5	3.0	3.4	3.2	203	202
30	85	3.3	2.9	3.1	2.7	189	175
31	78	3.4	3.0	3.1	2.8	179	162
32	77	3.5	2.9	3.5	3.0	181	157
33	92	3.9	3.2	4.2	3.2	178	153
34	62	3.3	2.7	3.5	3.0	179	152
35	68	3.4	2.6	3.5	3.1	165	141
36	59	3.4	3.3	4.5	3.9	163	177
37	81	4.0	3.3	4.5	4.0	138	168
38	59	3.5	3.1	3.4	3.4	141	161
39	72	3.7	3.2	4.6	3.7	130	179
40	72	3.1	2.8	3.2	2.9	120	161
41	69	3.6	3.1	3.5	3.3	140	175

* TKN of the mixed liquor.

AVERAGE	69	3.4	2.9	3.5	3.0	177	179

Table 3.5 Mean sewage batch Free and Saline Ammonia (FSA) in influent and filtered effluent (FE) and Nitrate (NO_3-N) plus Nitrite (NO_2-N) concentrations in filtered mixed liquor of each reactor and filtered effluent of the MLE and UCT systems at 30°C.

	FSA CONCENTRATIONS			REACTORS NO_3-N plus NO_2-N CONCENTRATIONS						
		MLE	**UCT**	**MLE system**			**UCT system**			
SEWAGE BATCH	*NFLUEN* [mgN/*l*]	FE [mgN/*l*]	FE [mgN/*l*]	ANOXIC [mgN/*l*]	AEROB [mgN/*l*]	EFFLUE [mgN/*l*]	ANAERO [mgN/*l*]	ANOXIC [mgN/*l*]	AEROB [mgN/*l*]	EFFLUEN [mgN/*l*]
1	44	1.9	1.8	0.5	4.6	4.6	0.2	0.6	7.1	7.9
2	40	2.0	1.9	0.5	5.2	5.7	0.2	0.7	6.1	7.2
3	45	2.4	2.3	0.4	5.2	6.0	0.2	0.9	8.3	8.6
4	59	1.9	1.9	0.7	7.9	8.2	0.2	1.4	11.6	13.1
5	74	1.8	2.2	2.0	11.2	15.2	1.0	9.4	22.4	23.7
6	48	1.9	2.4	0.5	6.5	7.0	0.2	1.2	9.8	10.4
7	45	1.7	2.0	0.4	5.6	6.8	0.3	0.8	9.8	9.9
8	53	2.3	2.6	1.0	7.4	8.8	0.3	0.8	6.8	9.9
9	52	2.8	2.6	0.5	5.0	6.8	0.2	0.4	6.3	8.6
10	51	2.2	2.3	0.4	4.8	4.8	0.1	0.7	6.2	9.8
11	44	2.3	2.3	0.3	3.3	4.3	0.1	0.6	5.4	6.9
12	54	2.1	2.5	0.5	5.2	5.9	0.2	1.0	9.7	10.9
13	50	2.0	1.9	0.6	6.2	6.2	0.3	0.9	8.3	9.3
14	47	2.0	1.9	0.4	4.6	4.9	0.2	0.7	6.3	7.6
15	37	1.4	1.6	0.3	4.1	3.9	0.3	0.2	5.1	5.5
16	51	1.5	1.3	0.3	5.4	6.1	0.2	0.4	8.1	9.4
17	34	1.6	1.6	0.5	3.1	3.4	0.2	0.3	4.4	5.3
18	43	1.8	2.0	0.4	4.0	5.2	0.1	0.5	5.6	6.9
19	48	2.1	2.2	1.2	5.3	6.0	0.2	0.5	6.4	8.3
20	54	2.5	2.6	0.9	5.9	6.0	0.1	0.6	8.5	8.8
21	43	2.7	3.1	0.4	4.7	5.4	0.1	0.7	7.6	8.5
22	70	2.5	3.2	2.0	8.7	9.8	0.7	2.5	16.0	17.6
23	57	2.3	2.3	0.7	6.9	8.0	0.5	3.6	12.4	14.0
24	51	2.0	2.0	0.6	5.5	6.4	0.2	0.9	8.7	9.4
25	51	2.2	2.2	0.7	5.6	6.5	0.2	0.9	8.3	9.8
26	60	2.3	2.4	3.2	8.3	10.4	0.7	5.1	15.0	16.3
27	42	2.2	2.3	0.7	4.5	5.8	0.2	0.9	6.7	7.7
28	48	2.3	2.6	0.7	5.2	6.2	0.5	3.3	10.6	11.0
29	52	2.3	2.6	0.8	6.4	7.2	0.4	4.3	12.8	13.8
30	62	2.4	2.3	2.1	9.0	10,1	0.9	8.3	18.9	20.0
31	59	2.2	2.3	8.9	15.3	17.9	1.3	11.6	22.6	25.0
32	58	2.2	2.3	1.2	7.7	8.9	0.5	4.0	12.9	14.8
33	65	2.6	2.5	6.9	12.9	13.7	0.7	7.8	19.3	22.8
34	46	2.1	2.2	0.5	5.2	5.3	0.2	0.6	7.7	8.7
35	54	2.1	2.3	0.5	6.8	7.4	0.2	0.9	9.4	10.3
36	43	2.6	2.7	0.3	5.6	5.8	0.2	0.4	7.9	8.2
37	62	2.7	2.9	0.6	6.8	7.6	0.3	1.7	10.9	12.2
38	37	2.5	2.5	0.2	5.8	5.7	0.1	0.2	6.3	6.6
39	52	2.5	2.9	0.2	6.3	6.7	0.1	0.3	10.1	11.0
40	52	2.4	2.4	0.5	7.6	7.7	0.3	0.5	13.3	14.0
41	56	2.8	2.7	1.2	8.3	7.9	0.4	0.5	13.7	13.6
AVERAGE	51	2.2	2.3	1.1	6.4	7.2	0.3	2.0	10.1	11.3

Table 3.6 Mean sewage batch Total Settleable Solids (TSS), Volatile Settleable Solids (VSS) an Diluted Sludge Volume Index (DSVI) and OUR values of the aerobic reactors in the MLE and UCT systems at 30°C.

	TSS		VSS		DSVI		OUR OF AEROB. REACTORS	
SEWAGE	**MLE**	**UCT**	**MLE**	**UCT**	**MLE**	**UCT**	**MLE**	**UCT**
BATCH	[mg/*l*]	[mg/*l*]	[mg/*l*]	[mg/*l*]	[m*l*/g]	[m*l*/g]	[mgO/*l*/h]	[mgO/*l*/h]
1	1808	2011	1593	1663	140	131	38.0	33.7
2	1570	1783	1396	1507	182	116	33.0	33.2
3	1835	1833	1608	1462	196	108	36.4	36.6
4	2247	1997	2006	1654	180	107	40.5	39.2
5	2444	2031	2100	1672	233	156	38.7	38.0
6	1682	1899	1514	1631	241	175	26.5	24.7
7	1897	2276	1683	1916	191	177	35.8	39.5
8	1909	2154	1697	1780	233	201	37.6	42.1
9	2173	2293	1868	1854	258	220	37.4	34.9
10	2296	2542	2002	2105	263	248	47.1	41.8
11	2606	2793	2210	2216	291	293	39.3	38.1
12	2006	2534	1788	2050	430	292	43.2	36.0
13	2015	2554	1738	2042	427	253	41.3	38.5
14	2272	2444	1974	1962	306	260	43.2	37.9
15	2504	2575	2139	2064	287	246	38.0	38.7
16	2618	2636	2246	2166	268	250	40.8	45.2
17	2521	2633	2123	2162	257	205	37.4	39.0
18	2285	2689	1940	2205	331	237	40.9	36.2
19	2295	2736	1957	2180	287	199	38.1	40.8
20	2388	2672	2018	2135	264	204	37.9	38.7
21	2473	2920	2130	2410	243	202	36.4	31.8
22	2245	2656	1928	2205	237	222	35.5	36.9
23	2157	2481	1855	2020	237	214	38.2	35.6
24	1961	2306	1695	1882	205	226	38.7	37.2
25	1993	2423	1683	2011	198	282	36.3	32.9
26	2062	2476	1786	2082	210	260	35.4	34.0
27	2184	2333	1890	1937	187	233	29.4	25.5
28	2360	2420	2039	2012	167	201	28.3	26.3
29	2122	2412	1860	2081	188	164	31.0	31.8
30	2182	2246	1918	1873	213	157	33.6	36.8
31	2020	1911	1760	1668	207	157	35.7	33.3
32	1859	1797	1662	1535	254	166	35.0	31.7
33	1873	1845	1661	1590	207	166	34.8	42.9
34	1914	1921	1748	1654	239	171	35.1	36.6
35	1739	1865	1530	1516	217	162	38.4	37.1
36	1592	2178	1397	1735	181	176	45.0	36.0
37	1630	2164	1456	1780	138	176	46.0	39.4
38	1653	2394	1443	1945	146	173	42.7	38.6
39	1280	2151	1170	1805	161	173	43.5	41.5
40	1478	2238	1289	1790	177	162	45.1	39.0
41	1583	2056	1409	1688	201	175	42.7	40.3
AVERAGE	2042	2300	1778	1894	231	198	38	37

Table 3.7 Unfiltered influent, filtered reactor and unfiltered effluent Total P concentrations for the 41sewage batchperiods in the MLE and UCT systems at 30°C.

	UFI	MLE system			UCT system			
SEWAGE BATCH	INFLUENT [mgP/*l*]	ANOXIC [mgP/*l*]	AEROBIC [mgP/*l*]	EFFLUENT [mgP/*l*]	ANAEROB [mgP/*l*]	ANOXIC [mgP/*l*]	AEROBIC [mgP/*l*]	EFFLUENT [mgP/*l*]
1	14.0	8.9	8.7	8.6	18.9	8.7	3.5	2.9
2	15.9	11.0	9.8	9.2	22.7	10.6	6.0	5.1
3	16.0	11.8	10.0	9.4	24.1	10.2	4.9	3.9
4	14.6	10.8	9.8	9.0	22.9	10.1	5.3	4.1
5	19.6	15.0	13.3	12.3	20.4	13.0	8.8	8.6
6	13.9	10.3	9.7	9.3	21.0	7.7	3.9	3.0
7	13.6	9.3	8.6	7.2	24.3	12.4	6.2	1.8
8	16.3	10.9	10.7	10.2	22.1	9.3	4.8	3.7
9	13.9	8.8	8.4	8.6	18.4	5.5	2.0	2.9
10	17.2	10.5	10.6	9.9	25.1	7.7	2.9	1.5
11	16.4	10.0	10.2	9.3	22.8	6.4	1.9	2.7
12	17.1	11.0	10.8	10.1	29.3	8.1	1.4	1.3
13	14.7	9.4	9.5	8.6	22.8	6.9	1.7	1.5
14	14.6	8.5	8.0	7.7	26.9	7.8	1.0	0.7
15	15.0	9.0	7.8	8.0	22.3	10.0	1.5	0.9
16	14.3	7.6	6.8	6.9	21.6	9.5	1.5	1.0
17	15.6	9.2	7.1	6.8	25.2	10.4	1.8	1.2
18	16.4	11.1	10.6	8.9	26.6	11.5	2.6	2.7
19	15.1	9.3	9.0	8.5	16.8	8.0	1.4	1.6
20	15.1	8.9	8.8	7.9	28.7	10.0	1.7	1.3
21	15.3	8.9	8.9	7.6	22.6	8.9	3.7	1.3
22	14.4	9.4	10.5	8.2	22.7	8.6	1.4	1.5
23	13.8	10.0	10.0	9.5	20.3	9.8	4.3	4.6
24	15.4	10.7	11.6	10.2	22.6	11.5	4.9	4.9
25	13.8	10.8	10.9	10.8	21.4	10.4	5.3	5.3
26	14.3	9.8	10.2	9.7	16.9	8.8	5.8	6.0
27	12.9	9.2	9.4	9.0	15.9	7.6	4.1	4.3
28	12.7	8.5	8.8	8.1	18.0	7.8	4.3	4.3
29	14.4	10.5	10.6	10.1	18.6	7.6	4.2	4.1
30	15.3	10.9	10.8	10.4	16.5	10.1	8.0	7.4
31	12.1	8.6	8.6	8.7	11.0	8.8	8.6	8.6
32	14.0	9.7	9.9	9.4	16.5	7.7	4.7	4.7
33	15.2	10.5	10.3	10.0	14.8	9.2	6.7	6.8
34	14.3	9.9	10.1	9.6	20.0	8.7	2.9	3.1
35	14.9	10.8	10.9	10.9	23.4	10.4	4.2	4.2
36	16.0	11.2	10.9	11.2	27.5	12.7	4.0	2.7
37	14.3	12.0	12.7	11.3	24.7	10.8	6.2	5.0
38	11.9	7.8	7.5	7.2	24.0	9.2	1.7	2.2
39	15.6	11.6	11.4	10.7	23.3	7.4	1.6	1.7
40	15.4	11.5	11.4	11.3	27.6	10.6	3.6	3.2
41	12.2	10.7	10.1	10.0	27.0	11.0	4.3	3.5
AVERAGE	14.8	10.1	9.8	9.3	21.9	9.3	3.9	3.5

Table 3.8 Percentage of COD and N mass balances for the 41 sewage batches in the MLE and UCT systems at 30°C.

SEWAGE BATCH	Start day	End day	Duration in days	MLE		UCT	
				COD	N	COD	N
1	1	19	19	93	76	86	82
2	20	39	20	79	79	85	68
3	40	59	20	90	81	92	79
4	60	82	23	95	84	93	80
5	83	96	14	87	86	82	75
6	97	114	18	73	85	74	83
7	115	130	16	82	86	91	92
8	131	144	14	86	85	97	70
9	145	157	13	94	73	89	70
10	158	170	13	106	75	96	80
11	171	184	14	99	76	98	79
12	185	200	16	96	71	84	86
13	201	219	19	97	82	97	83
14	220	239	20	102	81	94	80
15	240	257	18	98	90	97	84
16	258	271	14	90	81	93	81
17	272	285	14	97	69	98	71
18	286	297	12	101	75	96	76
19	298	312	15	92	70	98	74
20	313	325	13	96	79	96	83
21	326	339	14	97	85	93	91
22	340	348	9	92	81	93	100
23	349	360	12	100	88	97	88
24	361	373	13	97	82	96	85
25	374	386	13	99	81	97	87
26	387	397	11	91	69	90	80
27	398	410	13	94	84	87	80
28	411	424	14	91	78	85	79
29	425	439	15	90	82	91	83
30	440	452	13	90	78	92	77
31	453	464	12	94	83	84	87
32	465	477	13	94	82	80	76
33	478	490	13	95	64	86	79
34	491	501	11	104	81	93	80
35	502	514	13	106	87	94	79
36	515	526	12	93	88	86	87
37	527	540	14	101	70	95	74
38	541	548	8	81	87	85	77
39	549	561	13	90	75	100	88
40	562	575	14	95	80	93	100
41	576	582	7	102	87	105	105
AVERAGE				94	80	92	82

3.4 RELIABILITY OF DATA

While conducting the experimental measurements it was important to assess the accuracy and reliability the analytical techniques and system operational procedures. For this purpose the COD and nitrogen measurements were examined by doing COD and N mass balances over the systems. The COD is proportional to the electron donating capacity (EDC). Because electrons must be conserved, the EDC entering the system must equal the EDC leaving the system. Nitrogen similarly is a conservative substance and there must be a balance between the input nitrogen and the outputs of the different nitrogen compounds measured as N.

3.4.1 COD and Nitrogen Mass Balances

In the COD balance, the daily mass of COD entering the system via the influent flow must be reconciled with the masses of COD leaving the system via (1) nitrate/nitrite denitrified, (2) oxygen utilised, (3) sludge wasted and (4) unfiltered effluent. In the nitrogen balance, the mass of nitrogen (N) in the daily influent flow must be reconciled with the masses of (1) effluent TKN-N (2) effluent nitrate-N, (3) nitrate/nitrite-N denitrified, (4) TKN-N in the sludge wastage. Details of the mass balance calculations are given in Appendix B following the procedure Musvoto *et al.*, (1992).

There are two approaches to calculating the mass balances: The first approach is to calculate a mass balance on the mean values of the measured parameters (COD, TKN, NO_3-N etc.) for each sewage batch and then to calculate the mean period mass balances from the sets of sewage batch mass balances in periods I, II, III and IV. We shall term this Approach 1. In the second approach one (1) determines the mean values of the measured parameters (COD, TKN, NO_3-N etc.) for each sewage batch. (2) Then for each period I, II, III or IV the average values of these mean batch parameters are determined. (3) These long term period mean values are inserted in the mass balance equations to give the mean mass balances.

Approach 1: From the daily data in Appendix A, the mean values for the mass balance parameters for each sewage batch were calculated (and are given in Tables 3.3 to 3.7) and these values used to calculate the COD and N mass balances for each sewage batch, given in Table 3.8. For each of the long term Periods I, II and III, a graphical statistical analysis was done using the mean sewage batch mass balance values to determine the mean long term period mass balances. These long term statistical mass balance analyses are listed in Appendix I. For period IV the mean mass balance was calculated from the means of the batch mass balances.

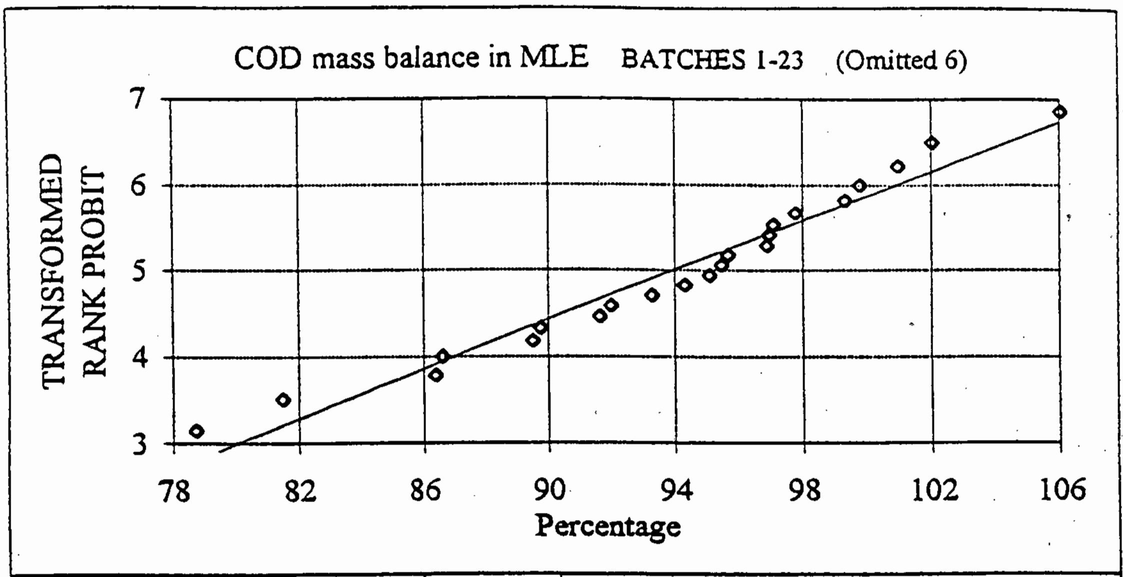
The graphical distributions of sewage batch COD and N mass balances for the MLE and UCT systems for periods I, II and III, are shown in Appendix I. With one exception, the distributions are all approximately normal. As an example, for period I in Figs 3.5 and 3.6, the distribution of the COD and N mass balance results are shown for the MLE system and in Figs 3.7 and 3.8 for the UCT system. Except for the COD balance of the UCT system the distributions over the periods are approximately normal and the best estimate of a parameter for mean behaviour over a period is the mean value. The distribution of the sewage batch COD balances in the UCT system is clearly non-normal in which event the mean loses some value as a measure of the average value and the median forms the better estimate of the average value. The means of the mass balances statistical analyses for Periods I, II, III and IV are listed in Table 3.9.

Approach 2: For each of the long term Periods I, II and III, sewage batch means of each measured parameter entering the mass balance equations (from Tables 3.3 to 3.7) were analysed statistically (means, standard deviations, medians, 95% confidence intervals) in Appendix C (Figs CI.1 to CI.29, CII.1 to CII. 29 and CIII.1 to CIII.29) to determine the mean values for the periods. For period IV the numerical means of the input parameters only were calculated and used as input to the mass balance equation, except in period IV the influent COD was analysed by graphical statistics, mainly to form an opinion on its distribution (Fig CIV.I Appendix C). The long term period mean values were entered into the mass balance equations to give the mean mass balances for the Periods I, II, III and IV. These mass balances are listed also in Table 3.9.

Comparison of the mass balances based on the means of the parameters in each period (Approach 2) with those based on the distribution of the mass balances for each sewage batch in a period (Approach 1) (see Table 3.9) indicates differences, but these cannot be taken as significant. In Chapter 4 the matter of choice between these two approaches is discussed further.

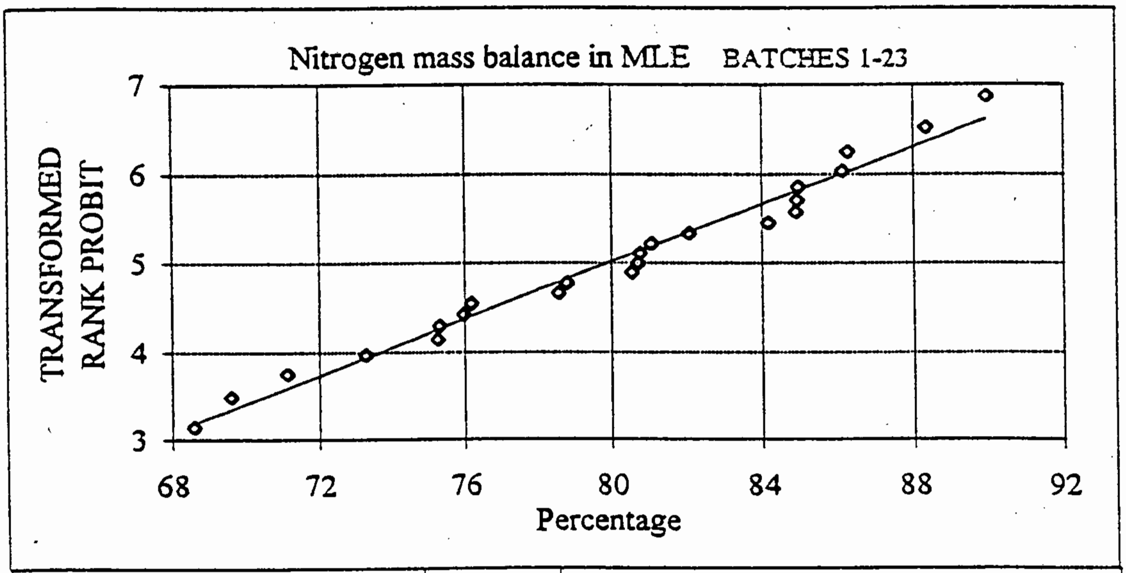
An examination of Table 3.9 indicates that COD mass balances calculated for each period range from 92 to 95 percent for the MLE system, and 86 to 94 percent for UCT system. From past experience mass balances greater than 96 percent are uncommon and one can accept that COD mass balances greater than about 94 percent indicate reliable experimental data. Again from past experience COD mass balances for the NDBEPR systems tend to be lower than those for ND systems and this appears to be so also in this investigation. The COD mass balances for period I are 94 and 93 percent respectively, and COD data in this period can be accepted as reliable. For comparative purposes Table 3.10 lists the COD balance achieved in this and a number of previous investigations. It can be seen that, the COD balances in this investigation are closely the same as those achieved in the past.

The N mass balances for the long term periods for the both MLE and UCT systems are about 83 percent, with one value of 90 percent (Table 3.9). Nitrogen recovery can be taken as below average, a value of about 90 percent is more usual particularly in ND systems (see Table 3.10). The low N balances were detected early in the investigation and several attempts were made to establish the cause. Standard ammonia, nitrate and nitrite concentrations were made up and tested with wet chemical methods in use viz. Standard Methods (1985) for the free and saline (FSA) and Auto-Analyser Industrial method No 33.62W for nitrate and nitrite. The flow rates in the experimental systems were occasionally checked. However, no significant discrepancies were detected. Furthermore, FSA, nitrate and nitrite were tested in parallel with a photometric method (Merck Spectroquant) and compared with the wet chemical methods. Only in the case of low FSA concentrations (i.e. effluent) where differences noted with the photometric method giving lower values. However, effluent FSA concentrations do not effect the N balance because it is included in the effluent TKN - from this source no particular



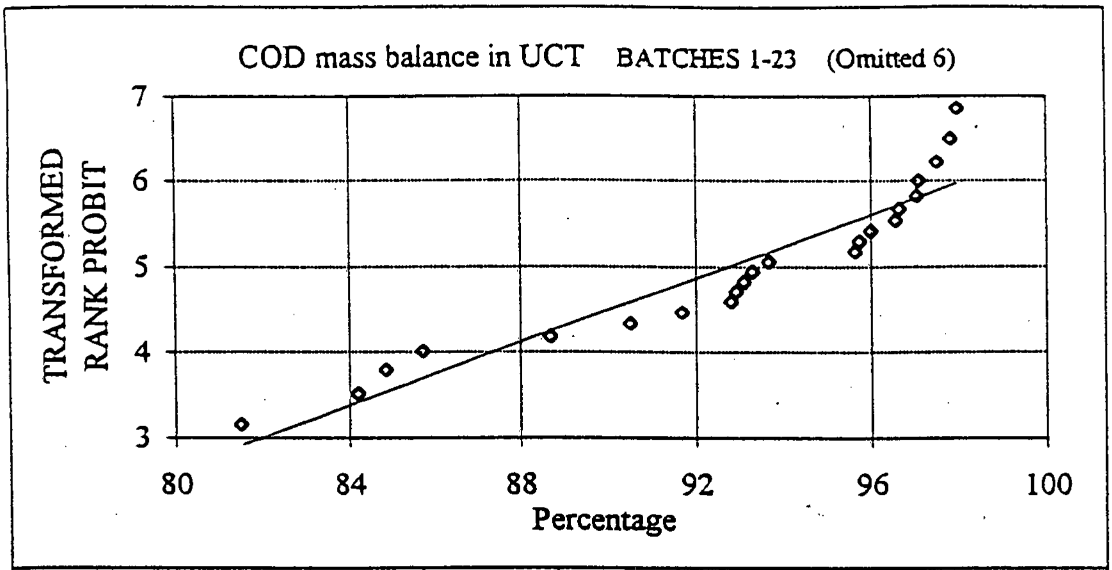
MEDIAN=	95		std dev. of mean = 1.4
MEAN =	94		95% conf. of mean = 94 +/- 2.8
s =	7		

Fig 3.5 Probability distribution of the COD mass balances for the means of average batches 1 to 23 in MLE system at 30°C from day no 1 to day no 360.



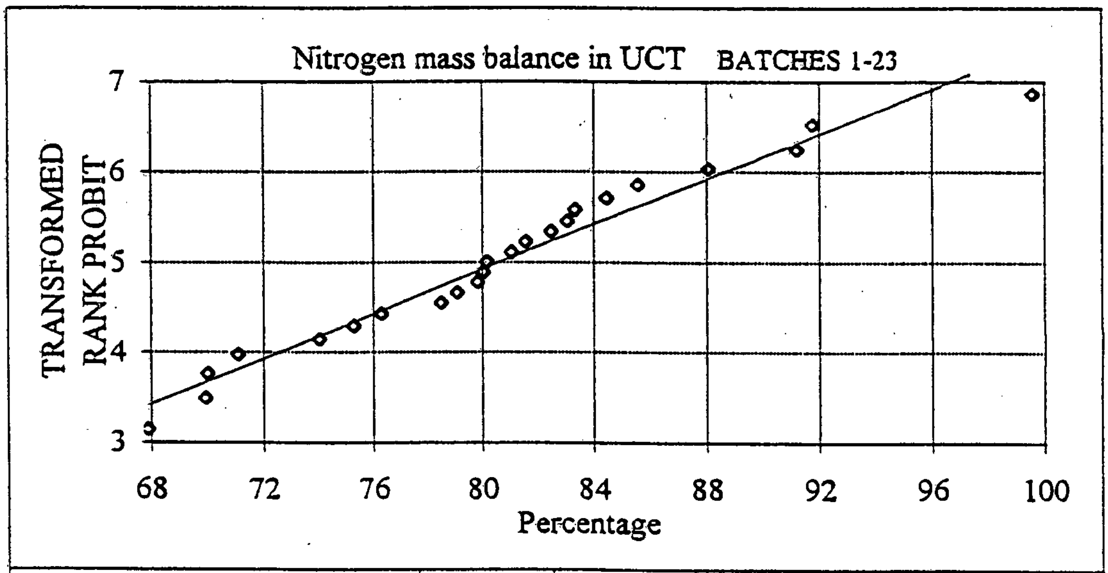
MEDIAN=	81		std dev. of mean = 1.2
MEAN =	80		95% conf. of mean = 80 +/- 2.4
s =	6		

Fig 3.6 Probability distribution of the N mass balances for the means of average batches 1 to 23 in MLE system at 30°C from day no 1 to day no 360.



MEDIAN=	93		std dev. of mean = 1.0
MEAN =	93		95% conf. of mean = 93 +/- 2.1
s =	5		

Fig 3.7 Probability distribution of the COD mass balances for the means of average batches 1 to 23 in UCT system at 30°C from day no 1 to day no 360.



MEDIAN=	80		std dev. of mean = 1.6
MEAN =	81		95% conf. of mean = 81 +/- 3.1
s =	8		

Fig 3.8 Probability distribution of the N mass balances for the means of average batches 1 to 23 in UCT system at 30°C from day no 1 to day no 360.

assignable cause could be found for the low N balances. However, it can be noted that the N balance is very sensitive to nitrate/nitrite concentrations in the anoxic reactor - a 1 mgN/*l* error can contribute up to about 6% error in the N balance in systems with high (>2:1) mixed liquor a-recycle ratios. Therefore small errors in measurement of these concentrations and in the a-recycle ratio can significantly change the estimate of the mass of nitrate denitrified and hence the N balance. This effect has been noted also in previous investigations.

Recovery of less than 100 percent in both COD and N balances has been reported in previous investigations (see Table 3.10). The causes for these <100% recoveries are not clear, but is one of concern. Arkley *et al.*, (1981) gave attention to this matter and identified a number of factors which effect the COD mass balance: (1) deviation from the set recycle ratios, (2) oxygen in recycles, (3) oxygen absorption from the air during OUR tests, (4) calibration error in the OUR instrument, (5) establishment of the sludge age by abstracting sludge daily in one single abstraction or continuously. In this investigation for example, there was (1) no check that the OUR instrument calibrated at 20°C had the correct electronic compensation to give the correct oxygen concentration at 30°C, (2) the recycle flows were not checked regularly except initially. With regard to the nitrogen mass balance similar considerations apply, with additional sources of error in the determinations of TKN, ammonia and nitrate.

3.4.2 Conclusion on Reliability

The general experience is that in ND and NDBEPR systems the recovery of COD and nitrogen usually are less than the respective inputs, with the recovery of COD 90% to 96% and nitrogen 85% to 90%. The experimental data on the systems in this investigation gave an average COD recovery of 94% for the MLE system and 92% for the UCT system. The average nitrogen recovery was 80% for the MLE system and 82% for the UCT system.

One can conclude that the COD recovery is within the normally expected range but that the nitrogen recovery is below expected. Hence the COD data can be accepted as reliable but the nitrogen data are less reliable. Accepting the data as reasonable reliable it is now possible to evaluate the influent sewage characteristics and system performance.

3.5 INFLUENT SEWAGE CHARACTERISTICS

Influent characteristics of importance in ND and NDBEPR systems are:

1) Total COD (TCOD) in the influent, made up of biodegradable COD (BCOD) and unbiodegradable COD (UCOD). The biodegradable COD is subdivided into readily biodegradable COD (RBCOD) and slowly biodegradable COD (SBCOD). The unbiodegradable COD is subdivided into unbiodegradable soluble COD (USCOD) and unbiodegradable particulate COD (UPCOD)

Table 3.9 Mass balances for the 3 long term periods I, II, III and IV.

Period	Mass balances from mean of sewage batch mass balance distribution				Mass balance from mean values over the period of the mass balance parameters			
	MLE system		UCT system		MLE system		UCT system	
	COD	N	COD	N	COD	N	COD	N
	%	%	%	%	%	%	%	%
Period I	94	80	93	81	94	83	93	83
Period II	94	81	89	81	92	83	86	90
Period III	97	82	94	86	95	79	94	87
Period IV	-	-	-	-	94	80	92	82

Table 3.10 COD and N balances achieved in this and a number of previous investigations.

Reference	System	Temperature	Balance %	
			COD	N
Clayton *et.al.*, (1989)	M/UCT (NDBEPR)	20°C	92	91
Musvoto *et.al.*, (1992)	MUCT (NDBEPR)	20°C	106	105
Musvoto *et.al.*, (1992)	MUCT (NDBEPR)	20°C	107	98
Pilson *et.al.*, (1995)	MUCT (NDBEPR)	20°C	99	84
Pilson *et.al.*, (1995)	MUCT (NDBEPR)	12°C	94	84
Sneyders *et.al.*, (1997)	UCT (EXP) (NDBEPR)	20°C	92	90
Sneyders *et.al.*, (1997)	UCT (CTL) (NDBEPR)	20°C	92	88
Kaschula *et.al.*, (1993)	MUCT (NDBEPR)	20°C	84	89
Ubisi *et.al.*, (1996) 7	MLE (ND)	20°C	88	94
Arkley *et.al.*, (1981)	MLE (ND)	20°C	91-77*	98
Arkley *et.al.*, (1981)	Wuhrman (ND)	20°C	89-80*	96
Arkley *et.al.*, (1981)	Aerobic	20°C	93	101
This investigation	UCT (NDBEPR)	30°C	92	82
This investigation	MLE (ND)	30°C	94	80

* COD balance decreased progressively as anoxic mass fraction increased from 0.10 50%, 60% and 70%.

2) Nitrogen in the influent, present in South African sewage virtually all as TKN (nitrate/nitrite usually is negligible). The TKN exists in similar fractions to those of COD except that a fraction in ammonia form will be present.
3) Total phosphorus, present principally as orthophosphate and a lesser fraction as organic phosphorus.

It is not possible to measure all these fractions directly, some fractions are always small and estimated empirically from observation in past investigations, for example unbiodegradable soluble TKN. Some fractions are estimated from the system response to the specific influent sewage; in this regard the UPCOD is of particular importance.

Total COD (TCOD)

The total influent COD of each sewage batch is listed in Table 3.3. In Section 3.2 it was found that for a number of reasons the data needed to be subdivided into 3 periods, designated periods I, II and III. These sets were analysed statistically (Appendix C) and are summarised in Table 3.16. A statistical test (Student's t) of significance showed that mean TCOD's in periods I and II differ significantly at 95% confidence level. Similarly the means of period I and III differ significantly. Because period I shows relatively small data dispersion and extends over 23 batch of sewages (a time period of one year), data from period I forms a suitable set as a steady state input. The distribution of period IV, the total period of investigation, approximates normality but the distribution gives indication of sampling from two populations.

Readily biodegradable COD (RBCOD)

An important input parameter for the BEPR model is the influent RBCOD - its magnitude has a major influence on the proportion of the biodegradable COD utilized by the PAOs and hence their VSS mass and BEP removal. The influent RBCOD was not measured in this investigation but was obtained from other investigations on this influent sewage:

1) Ubisi *et al.*, (1997), conducted batch tests to measure the active organism concentration in the same Mitchell's Plain influent wastewater which was the same as the influent used in this investigation. By following the procedure of Wentzel *et al.*, (1995) the influent RBCOD also could be calculated from the batch test results. From 88 batch tests conducted over a period of 15 months, during which time sewage batches 11 to 28 (this investigation) corresponded to Ubisi's sewage batches 12 to 27. A mean influent RBCOD concentration of 79mgCOD/*l* was obtained for a mean influent total COD concentration of 465mgCOD/*l*. Hence the average fraction of RBCOD with respect to the total COD (f_{ts}) was 17.1%.

2) Mbewe *et al.*, (1995), also measured the influent RBCOD fraction on the same Mitchell's Plain wastewater by three different methods viz. (a) the continuous square wave short sludge age system method (WRC, 1984), (b) batch test method by Wentzel *et al.*, (1995) and (c) the flocculation-filtration method of Mamais *et*

al., (1993) using glassfiber filters and 0.45μm filter membranes. The first two methods are direct biological methods; the third method an indirect physical one where the RBCOD is identified in the filtrate by subtracting the USCOD. On 23 sewage batches obtained from 12/7/1993 to 3/11/1994, during which time 200 square tests, 172 batch tests, 160 flocculation - glassfiber filtration tests and 176 flocculation - 0.45μm filter membrane tests were conducted the RBCOD fraction with respect to total COD was 19.5+/-2.2%, 19.9+/-3.6%, 18.9+/-2.6% and 19.0+/-2.9% respectively. These results indicate that the physical methods gave virtually the same results as the biological method. The overall average f_{ts} fraction was 19.7% for the biological methods, and 19.0% for the physical method.

3) Sneyders *et al.*, (1997), who operated, the parallel UCT system at 20°C on Mitchell's Plain wastewater, using the flocculation filtration method obtained an average f_{ts} fraction of 17.1%.

From Mbewe's, Ubisi's and Sneyders' RBCOD measurements on the Mitchell's Plain wastewater the RBCOD fraction is about 18% of total COD. Taking account of the unbiodegradable COD fractions (f_{us} and f_{up}) found in this investigation (i.e. 0.05 and 0.154 (see Chapter 4) respectively the RBCOD fraction with respect to the biodegradable COD (BCOD), f_{bs} = $f_{ts}/(1-f_{us}-f_{up})$ = 0.18/(1-0.05-0.154) = 0.226, approx. 0.23. Therefore for this investigation the RBCOD fraction was accepted at 23% of the influent biodegradable COD concentration, except where there was evidence indicating a deviation from this value.

In Section 3.2 it was noted that the influent apparently changed qualitatively from about sewage batch 24 to batch 33 suggesting that the data needed to be analysed separately over 3 long term periods: period I, sewage batches 1 to 23; period II, sewage batches 24 to 33; and period III, sewage batches 34 to 41. Experimental confirmation of this deviatory behaviour is indicated in Ubisi's RBCOD investigation. He determined experimentally that the mean RBCOD was 97mgCOD/*l* for sewage batches 12 and 17 to 23 in period I, and 69mgCOD/*l* in period II i.e. the RBCOD was considerably lower in long term period II than in period I.

It is of interest to note that the "default" value accepted in design of ND and NDBEPR system in South Africa (WRC 1984) are f_{bs} = 0.24. The fraction of RBCOD/BCOD for this sewage therefore approximated to the default value accepted in South Africa.

Unbiodegradable soluble COD (USCOD)

The filtered effluent COD concentration from the system is generally accepted as a measure of USCOD because the value tends to be constant and independent of the sludge age and the process system. From Table 3.3 the mean filtered effluent COD concentrations from the MLE and UCT systems at 30°C for period IV are closely the same viz. 36.4 and 38.5 mgCOD/*l* respectively and the dispersion around the mean is small. This gives average (USCOD/TCOD) fraction (f_{us}) for the wastewater of 37.5/726 = 0.051.

Unbiodegradable particulate COD (UPCOD)

No direct method has been yet derived as for measuring the UPCOD. Its value inferred from the kinetic and stoichiometric response of the system. The UPCOD will be determined in Chapter 4, where UPCOD/TCOD, f_{up} fraction is evaluated at 0.154mgUPCOD/mgTCOD. For completeness f_{up} is listed in Table 3.16.

TKN

From Table 3.4 the means of the TKN and their 95% confidence intervals for period I, II and III were determined statistically (see Appendix C); for period IV the mean values only were calculated numerically, Table 3.4. These values are summarised in Table 3.16.

Total P

From Table 3.7 the means of the P and their 95% confidence intervals for period I, II and III were determined statistically (see Appendix C); for period IV the mean values only were calculated numerically, Table 3.7. These values are summarised in Table 3.16.

3.5.1 Influent characteristics summary

Mean concentrations of diluted influent sewage (Mitchells Plain WWTP) for both the MLE and UCT systems

Table 3.16 Influent characteristics Mitchells Plain sewage.

Parameter	Label	Period I	Period II	Period III	Period IV
COD	mg/*l*	751 +/- 11	681 +/- 15	701 +/-47	727 +/-16
f_{bs}		0.23**	-	-	-
f_{us}		0.051			
$f_{up\ MLE}$		0.154***	0.202***	0.095***	0.155+/-0.02
$f_{up\ UCT}$		0.14* +/-0.02	0.18* +/-0.04	0.12* +/-0.02	0.149+/-0.02
TKN	mgN/*l*	65 +/- 3	74 +/- 7	68 +/-5	69
Total P	mgP/*l*	15.1 +/- 0.5	14.0 +/-0.7	14.1 +/- 1.1	14.8

The +/- defines 95% confidence interval of the mean value.

*Based on batch f_{up} values, see Chapter 4.

** ~~Historic value.~~ See Section 3.5 for details

*** Based on mean period input values, see Chapter 4.

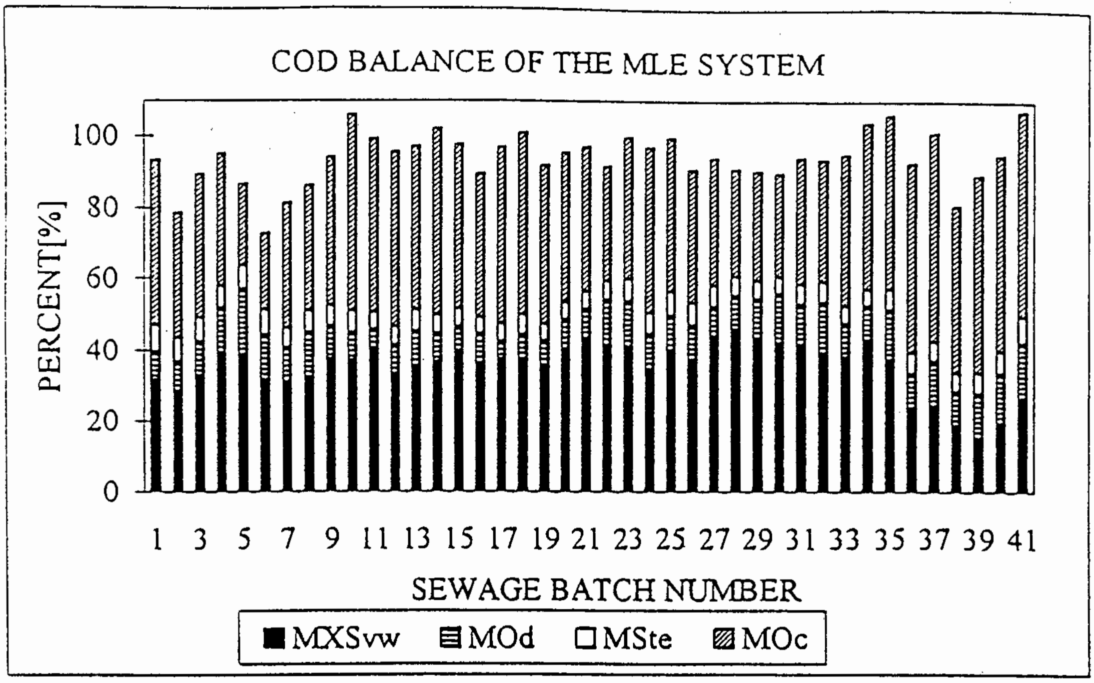


Fig 3.9 COD mass balance of MLE system for 41 batches of sewage. Percentages are also shown for: Unfiltered effluent COD (MSte), COD of waste sludge (MXSvw), 'Oxygen' demand for anoxic growth of heterotrops (MOd), and Oxygen demand for aerobic groth of heterotrops (MOc).

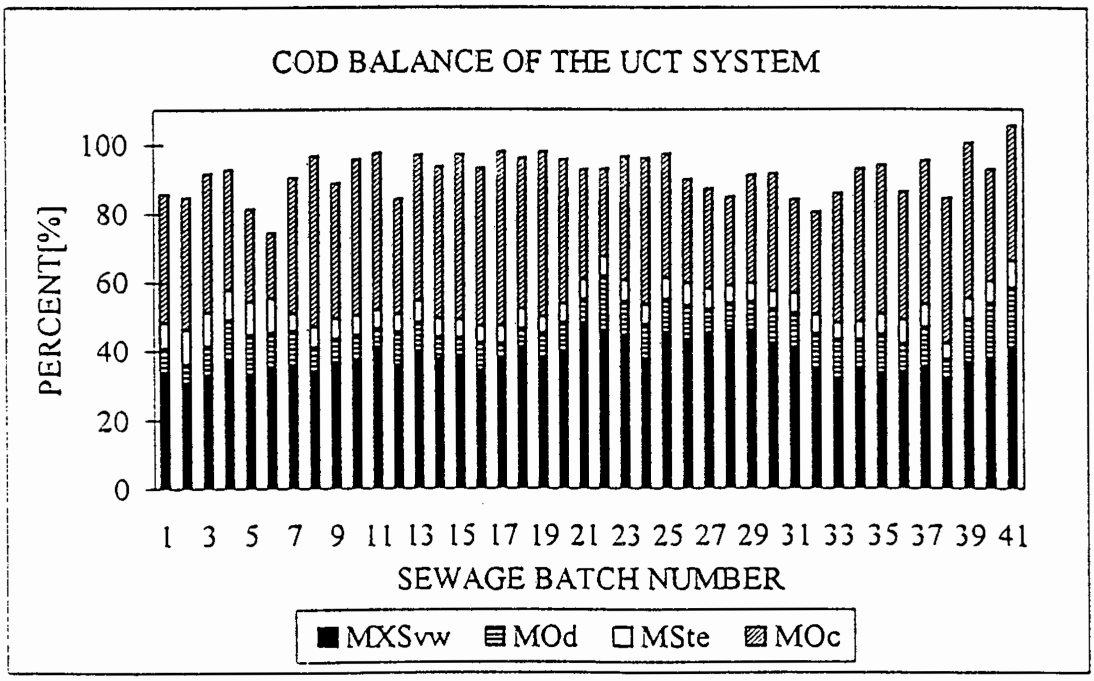


Fig 3.10 COD mass balance of UCT system for 41 batches of sewage. Percentages are also shown for: Unfiltered effluent COD (MSte), COD of waste sludge (MXSvw), 'Oxygen' demand for anoxic growth of heterotrops (MOd), and Oxygen demand for aerobic groth of heterotrops (MOc).

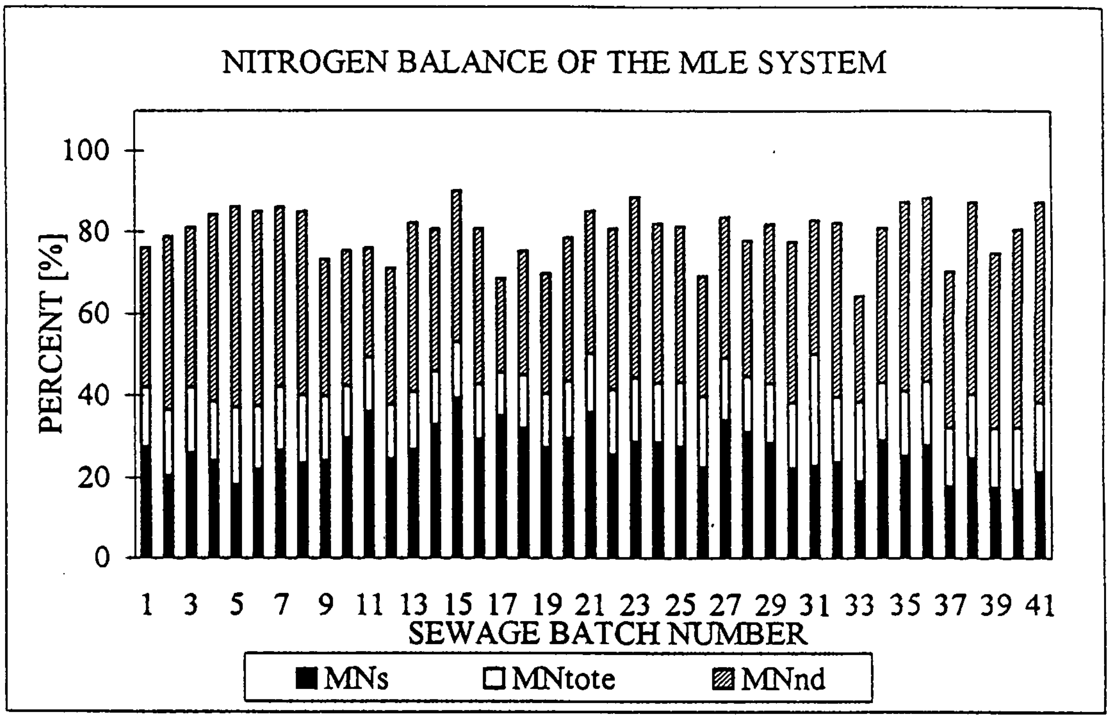


Fig 3.11 Nitrogen mass balance of MLE system for 41 batches of sewage. Percentages are also shown for Nitrogen in Effluent (TKN plus Nitrate) (MNtote), Nitrogen for sludge production (MNs), and Nitrogen denitrified (MNnd).

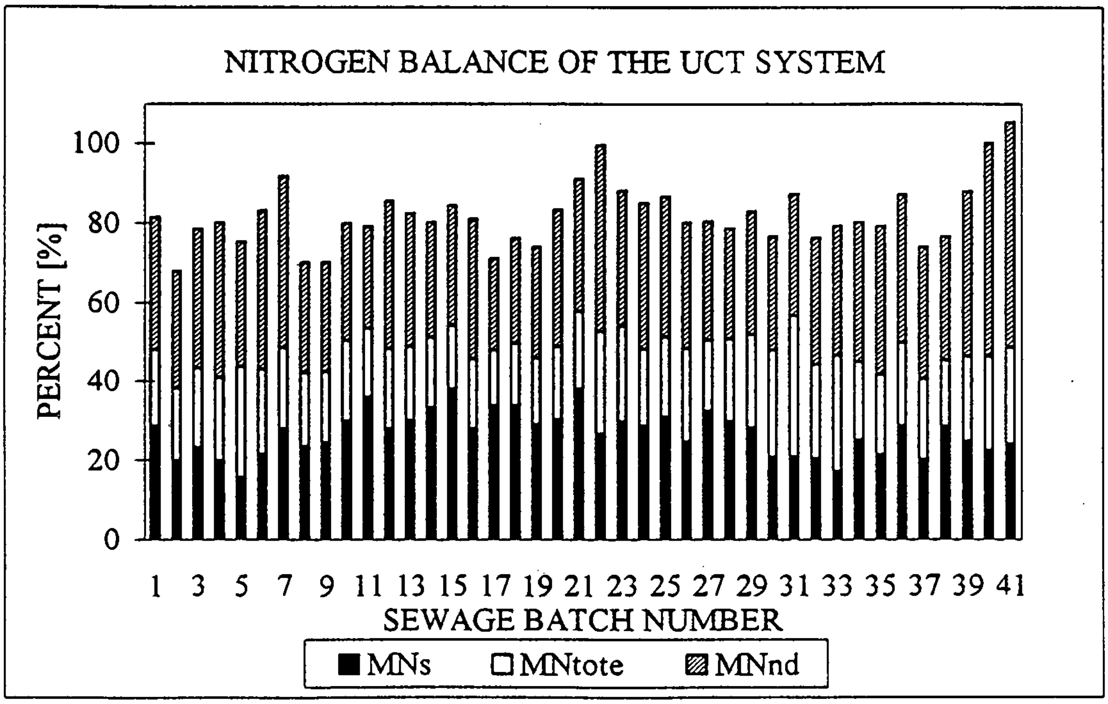


Fig 3.12 Nitrogen mass balance of UCT system for 41 batches of sewage. Percentages are also shown for Nitrogen in Effluent (TKN plus Nitrate) (MNtote), Nitrogen for sludge production (MNs), and Nitrogen denitrified (MNnd).

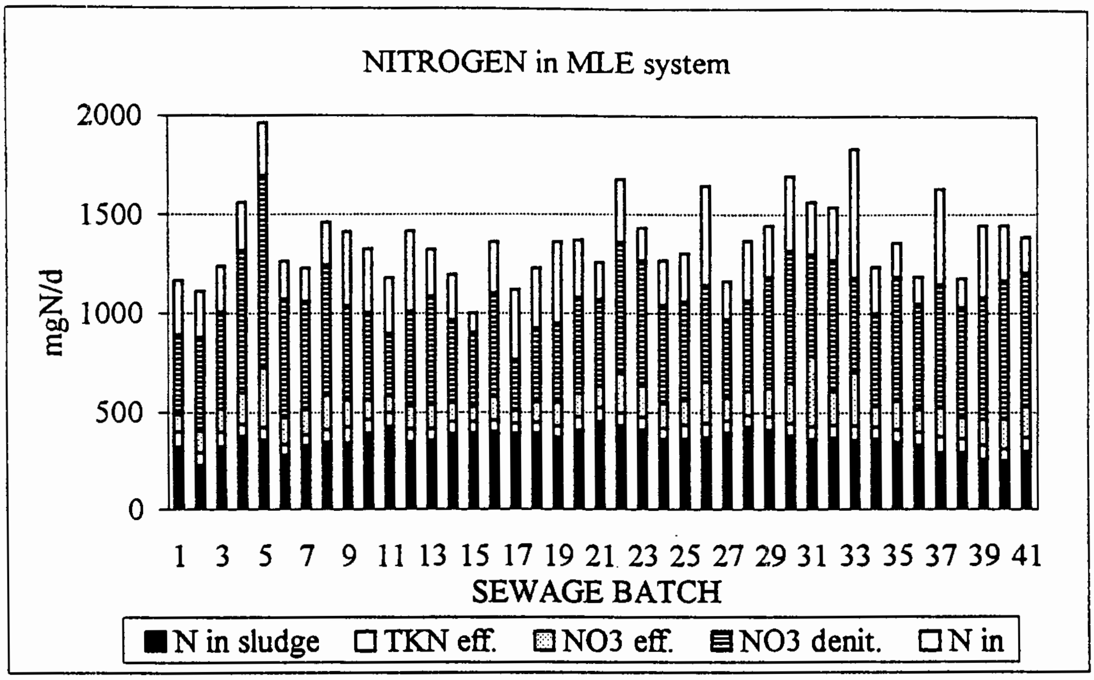


Fig 3.13 Masses of Nitrogen in influent, wasted sludge, in effluent (TKN plus NOx) and NOx denitrified per day in MLE system.

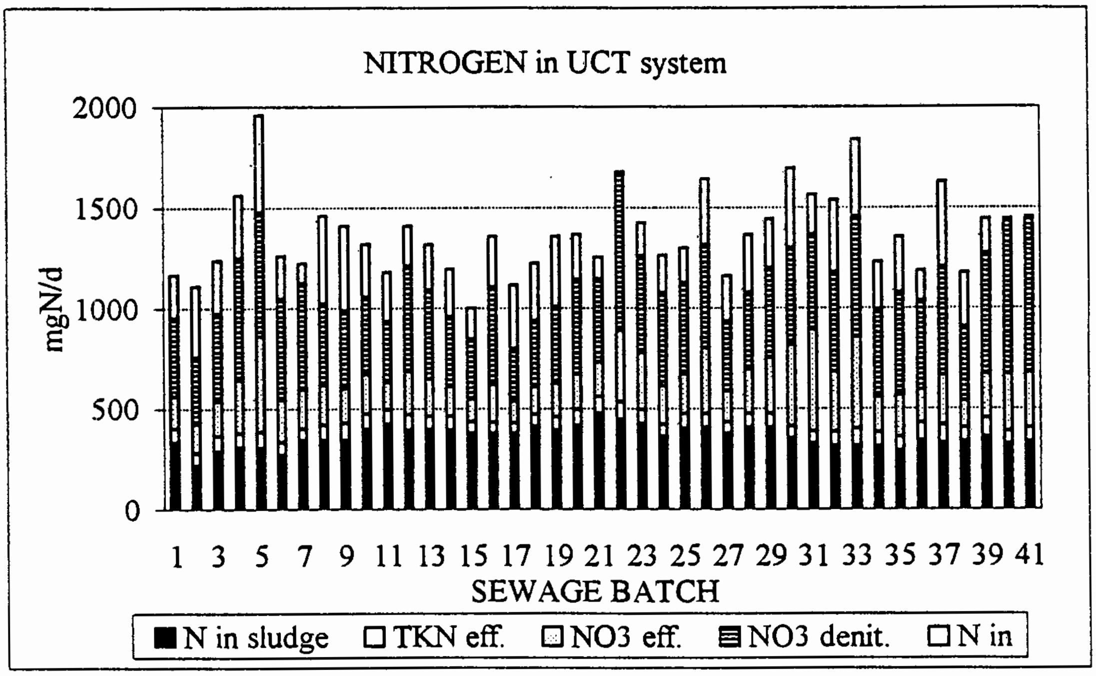


Fig 3.14 Masses of Nitrogen in influent, wasted sludge, in effluent (TKN plus NOx) and NOx denitrified per day in UCT system.

3.6 EXPERIMENTAL SYSTEM PERFORMANCE

3.6.1 Average COD and nitrogen removal performance

To gain an overall impression of the experimental system performance the mass balances for each of the 41 batches of sewage listed in Tables 3.3 to 3.7 can be usefully employed.

Graphical presentations of the magnitudes of the different components of the COD and nitrogen recoveries are given in Figs 3.9 and 3.10 (COD) and 3.11 and 3.12 (nitrogen) for the MLE and UCT systems respectively. Stack bar representations of the COD and nitrogen balances for each of the 41 sewage batches are shown. The percentage component contributions of COD and nitrogen leaving the systems are indicated by the percentage stacked bar for each sewage batch. Using the numerical data from Tables 3.3 to 3.7 the percentage components of COD and N leaving the system were calculated. From the overall average results (means of the 41 sewage batch means), for each 100 COD entering to system, the following percentages COD passed out of the system via different routs:

> <u>MLE system</u>: Of 100% influent COD, 5.7% leaves in unfiltered effluent, 36.0% in daily wasted sludge, 10.4% in nitrate denitrified, 41.9% in oxygen utilized with 6.0% unaccounted for.
>
> <u>UCT system</u>: Of 100% influent COD, 6.2% leaves in unfiltered effluent, 37.8% in daily wasted sludge, 9.2% in nitrate denitrified, 38.8% in oxygen utilized with 8.0% unaccounted for.

3.6.2 Average nitrogen removal performance

> <u>MLE system</u>: Of 100% influent TKN, 10.5% and 4.2% leaves in the effluent as nitrate and filtered TKN respectively, 25.8% in daily wasted sludge, 39.5% via denitrification with 20.0% unaccounted for (see Table 3.11).
>
> <u>UCT system</u>: Of 100% influent TKN, 16.5% and 4.3% leaves in the effluent as nitrate and filtered TKN respectively, 26.1% in daily wasted sludge, 35.1% via denitrification wih 18.0% unaccounted for (see Table 3.12).

Filtered effluent nitrogen

At 30°C of the 2.9mgN/*l* filtered effluent TKN concentration from the MLE system, 2.2mgN/*l* is free and saline ammonia, so that 0.7mgN/*l* is soluble organic nitrogen N_{us}. For the UCT system the organic nitrogen is 3.0-2.3=0.7mgN/*l*, the same as for the MLE system. These organic nitrogen concentrations probably are unbiodegradable.

By conducting nitrate and nitrite (NO_x) mass balances around the aerobic and anoxic reactors of the MLE and UCT systems, the concentrations (per *l* influent) of nitrate generated by nitrification in the aerobic reactor and that denitrified in the anoxic reactor was calculated for the 41 steady state periods. The results are listed in Table

3.13. The nitrate generated (known as the nitrification capacity, WRC, 1984) in the MLE and UCT systems are closely the same viz. 33.5mgN/*l* in the MLE and 35.1mgN/*l* in the UCT systems. The nitrate concentration denitrified are also quite close viz. 26.3mgN/*l* in the MLE system and 23.5mgN/*l* in the MLE system. Because the denitrification is higher in the MLE system than in the UCT system, the overall average effluent nitrate concentration is lower in the MLE system (7.3mgN/*l*) than in the UCT system (11.1mgN/*l*). The differences in denitrification will be assessed in greater detail via the simulation models in Chapter 4.

With regard to the nitrogen mass balances for the MLE and UCT systems, in Figs 3.11 and 3.12 the percentage of influent N leaving the system in the wasted sludge, the effluent total N (NO_x+TKN) and the nitrate denitrified are shown as stacked bars. For both systems about 20% of influent N leaves the system in the solid phase (wasted sludge), 15% in the liquid phase (effluent) and about 36% in the gas phase (denitrified). In contrast to the COD mass balance, in the nitrogen mass balance a major fraction (36%) of nitrogen leaves via denitrification. Consequently an error in denitrification determination will have a disproportionally large effect on the nitrogen mass balance. This effect is illustrated perhaps more clearly by stack bar presentation of the mean masses of N (mgN/d) entering and leaving the systems in the 41 sewage batches Figs 3.13 and 3.14 (see also Tables 3.11 and 3.12).

From Figs 3.13 and 3.14, the incorporation of the anaerobic zone ahead of the MLE system, to convert it to a UCT system, did not significantly reduce the mass denitrification in the anoxic zone. In the MLE system 38,4% (26,3mgN/l) of the influent N was denitrified and in the UCT system 34.1% (23,43mgN/l). Even though the anoxic reactor in the UCT system did not receive influent RBCOD for denitrification (due to RBCOD conversion to VFA, and sequestration and storage of VFA by the the PAO in the anaerobic zone) the nitrate denitrified remains nearly the same as in the anoxic reactor of the MLE system, which does receive influent RBCOD for denitrification. This behaviour supports the findings of Clayton *et al.*, (1991) and Musvoto *et al.*, (1992), that the presence of an anaerobic zone apparently increases the specific denitrification rate due to the SBCOD in the primary anoxic zone, thereby compensating for the reduction in denitrification due to removal of RBCOD in the upstream anaerobic zone.

3.6.3 Average biological excess phosphorus removal (BEPR) performance

The daily results of the influent and effluent total P (TP) concentrations, as well as those in the anaerobic, anoxic and aerobic reactors of the MLE and UCT systems are listed in Appendix A and plotted in Figs A.41-A.48 in Appendix A. Accepting the same 41 sewage batches of periods as earlier for the COD and N removal performance evaluations, the average influent, reactor and effluent TP concentrations for both systems were calculated and are given in Table 3.7.

By conducting a total phosphorus balance over each reactor in the MLE and UCT systems, (noting that the reactor P concentrations were filtered and those in the influent and effluent unfiltered) the net P uptake or release in each reactor and settling tank effluent was calculated (see Tables 3.14 and 3.15 in which; a positive value

Table 3.11 Masses of nitrogen in influent, wasted sludge, in effluent (TKN plus NO_3) and denitrified per day in MLE system.

SEWAGE BATCH No:	N in mgN/d	N in sludge mgN/d	TKN eff. mgN/d	NO_3 eff. mgN/d	NO_3 denit. mgN/d	Total Nout mgN/d	Balance %
1	1166	319	78	92	-400	888	76
2	1109	225	66	114	-469	874	79
3	1237	319	78	121	-485	1003	81
4	1560	373	63	164	-713	1313	84
5	1959	356	64	305	-966	1690	86
6	1261	276	56	140	-599	1071	85
7	1226	325	55	136	-540	1055	86
8	1460	341	67	176	-656	1241	85
9	1412	339	84	136	-474	1034	73
10	1324	391	72	96	-438	997	75
11	1178	424	73	85	-313	895	76
12	1414	345	69	117	-474	1005	71
13	1320	352	62	124	-546	1084	82
14	1194	389	62	97	-414	961	81
15	998	390	60	78	-370	898	90
16	1359	396	60	123	-517	1096	81
17	1116	389	51	69	-256	765	69
18	1225	390	56	104	-372	922	75
19	1359	368	59	121	-398	945	70
20	1368	403	72	121	-479	1075	79
21	1256	449	74	109	-434	1066	85
22	1678	429	69	197	-660	1355	81
23	1429	407	67	159	-629	1263	88
24	1265	359	57	128	-493	1037	82
25	1300	357	74	130	-496	1057	81
26	1644	367	76	209	-485	1137	69
27	1160	392	63	116	-397	969	83
28	1364	424	60	125	-454	1063	78
29	1444	407	70	143	-562	1182	82
30	1696	377	66	202	-669	1314	78
31	1565	358	67	359	-512	1296	83
32	1539	363	69	177	-656	1265	82
33	1835	351	78	273	-476	1179	64
34	1232	357	67	107	-465	996	81
35	1355	341	68	148	-625	1181	87
36	1185	329	69	116	-530	1044	88
37	1628	290	80	153	-619	1143	70
38	1175	290	70	113	-550	1023	87
39	1444	253	74	134	-614	1075	74
40	1443	246	63	154	-698	1160	80
41	1381	297	72	157	-675	1201	87
AVERAGE	1372	355	67	145	-526	1093	80

+ ve = net production - ve = net reduction

Table 3.12 Masses of nitrogen in influent, wasted sludge, effluent (TKN plus NO_3)and denitrifie per day in UCT system.

SEWAGE BATCH No:	N in mgN/d	N in sludge mgN/d	TKN eff. mgN/d	NO_3 eff. mgN/d	NO_3 denit. mgN/d	Total Nout mgN/d	Balance %
1	1166	333	69	158	-392	951	82
2	1109	219	59	144	-330	752	68
3	1237	284	78	173	-436	971	78
4	1560	308	68	262	-611	1248	80
5	1959	303	78	474	-620	1475	75
6	1261	268	64	208	-507	1047	83
7	1226	340	57	198	-529	1124	92
8	1460	341	77	198	-406	1022	70
9	1412	341	84	172	-389	987	70
10	1324	395	75	196	-390	1057	80
11	1178	420	72	137	-302	932	79
12	1414	393	74	217	-526	1210	86
13	1320	395	64	186	-444	1089	82
14	1194	393	66	152	-346	957	80
15	998	377	55	111	-300	843	84
16	1359	376	55	189	-481	1101	81
17	1116	376	52	106	-259	793	71
18	1225	412	57	139	-327	935	76
19	1359	392	65	166	-383	1006	74
20	1368	413	79	176	-473	1140	83
21	1256	475	81	170	-419	1145	91
22	1678	444	88	352	-787	1671	100
23	1429	424	69	280	-486	1259	88
24	1265	361	60	188	-466	1075	85
25	1300	399	71	197	-459	1126	87
26	1644	404	66	325	-523	1317	80
27	1160	374	57	154	-347	932	80
28	1364	405	66	221	-382	1073	79
29	1444	404	68	277	-448	1197	83
30	1696	349	62	400	-490	1301	77
31	1565	325	61	501	-479	1365	87
32	1539	313	70	297	-494	1175	76
33	1835	314	84	455	-600	1453	79
34	1232	308	71	173	-436	988	80
35	1355	288	70	206	-511	1074	79
36	1185	338	90	163	-442	1033	87
37	1628	326	90	243	-546	1205	74
38	1175	334	69	131	-368	901	77
39	1444	356	92	221	-601	1270	88
40	1443	322	64	281	-777	1444	100
41	1381	331	71	271	-782	1455	105
AVERAGE	1372	358	70	226	-471	1124	82

+ ve = net production   - ve = net reduction

Table 3.13 Nitrate plus nitrite (NOx) per *l* influent, produced or reduced in the aero and anoxic reactors obtained from NOx balances around the aerobic and anoxic reactors and the NOx concentrations in effluent.

MLE and UCT System (units- mgN/l, influent)						
SEWAGE BATCH No:	NITRIFICATION (aerobic reactor) NO_3+NO_2		DENITRIFICATION (anoxic reactor) NO_3+NO_2		EFFLUENT NO_3+NO_2	
	MLE	UCT	MLE	UCT	MLE	UCT
1	24.6	27.5	-20.0	-19.6	4.6	7.9
2	29.1	23.7	-23.5	-16.5	5.7	7.2
3	30.3	30.4	-24.3	-21.8	6.0	8.6
4	43.8	43.6	-35.6	-30.5	8.2	13.1
5	63.5	54.7	-48.3	-31.0	15.2	23.7
6	37.0	35.7	-30.0	-25.3	7.0	10.4
7	33.8	36.3	-27.0	-26.4	6.8	9.9
8	41.6	30.2	-32.8	-20.3	8.8	9.9
9	30.5	28.1	-23.7	-19.5	6.8	8.6
10	26.7	29.3	-21.9	-19.5	4.8	9.8
11	19.9	22.0	-15.6	-15.1	4.3	6.9
12	29.6	37.1	-23.7	-26.3	5.9	10.9
13	33.5	31.5	-27.3	-22.2	6.2	9.3
14	25.6	24.9	-20.7	-17.3	4.9	7.6
15	22.4	20.6	-18.5	-15.0	3.9	5.5
16	32.0	33.5	-25.9	-24.1	6.1	9.4
17	16.2	18.3	-12.8	-12.9	3.4	5.3
18	23.8	23.3	-18.6	-16.4	5.2	6.9
19	25.9	27.5	-19.9	-19.2	6.0	8.3
20	30.0	32.4	-24.0	-23.6	6.0	8.8
21	27.2	29.4	-21.7	-20.9	5.4	8.5
22	42.8	56.9	-33.0	-39.3	9.8	17.6
23	39.4	38.3	-31.4	-24.3	8.0	14.0
24	31.1	32.7	-24.6	-23.3	6.4	9.4
25	31.3	32.8	-24.8	-22.9	6.5	9.8
26	34.7	42.4	-24.2	-26.1	10.4	16.3
27	25.7	25.0	-19.9	-17.4	5.8	7.7
28	29.0	30.1	-22.7	-19.1	6.2	11.0
29	35.3	36.2	-28.1	-22.4	7.2	13.8
30	43.6	44.5	-33.4	-24.5	10.1	20.0
31	43.5	49.0	-25.6	-23.9	17.9	25.0
32	41.7	39.6	-32.8	-24.7	8.9	14.8
33	37.5	52.8	-23.8	-30.0	13.7	22.8
34	28.6	30.5	-23.3	-21.8	5.3	8.7
35	38.6	35.8	-31.2	-25.5	7.4	10.3
36	32.3	30.3	-26.5	-22.1	5.8	8.2
37	38.6	39.4	-31.0	-27.3	7.6	12.2
38	33.2	25.0	-27.5	-18.4	5.7	6.6
39	37.4	41.1	-30.7	-30.1	6.7	11.0
40	42.6	52.9	-34.9	-38.8	7.7	14.0
41	41.6	52.7	-33.8	-39.1	7.9	13.6
AVERAG	33.5 +/ 8.5	34.8 +/-9.8	-26.3 +/-6.5	-23.5 +/-6.2	7.2 +/-2.9	11.3 +/-5.1

+ ve = net production - ve = net reduction

Table 3.14 P release or uptake for each reactor and net P removal for the 41 sewage batches in the MLE system.

SEWAGE BATCH	ANOXIC [mgP/*l*]	AEROBIC [mgP/*l*]	SETTLER [mgP/*l*]	REMOVAL [mgP/*l*]
1	-4.0	-1.1	-0.3	-5.4
2	1.7	-7.3	-1.0	-6.6
3	5.7	-11.1	-1.2	-6.6
4	2.2	-6.2	-1.6	-5.5
5	4.6	-9.9	-2.0	-7.2
6	-0.1	-3.7	-0.8	-4.6
7	0.9	-4.6	-2.7	-6.4
8	-4.0	-1.2	-0.9	-6.1
9	-3.3	-2.4	0.4	-5.3
10	-6.2	0.3	-1.4	-7.4
11	-6.2	0.9	-1.9	-7.2
12	-4.7	-0.8	-1.5	-7.0
13	-4.7	0.5	-1.9	-6.1
14	-3.6	-2.6	-0.8	-6.9
15	0.0	-7.3	0.3	-7.0
16	-2.4	-5.2	0.2	-7.4
17	4.2	-12.3	-0.6	-8.7
18	-1.5	-2.4	-3.5	-7.5
19	-4.0	-1.7	-0.9	-6.6
20	-5.2	-0.2	-1.8	-7.2
21	-4.9	-0.1	-2.7	-7.7
22	-8.3	6.7	-4.6	-6.1
23	-3.3	0.0	-1.1	-4.4
24	-7.5	5.0	-2.7	-5.2
25	-3.1	0.3	-0.2	-3.1
26	-6.2	2.6	-0.9	-4.5
27	-4.5	1.4	-0.8	-3.9
28	-5.3	2.2	-1.4	-4.5
29	-3.8	0.5	-1.0	-4.3
30	-3.4	-0.5	-1.0	-4.9
31	-3.4	-0.3	0.3	-3.4
32	-4.5	0.9	-1.0	-4.6
33	-3.6	-1.0	-0.6	-5.2
34	-4.8	1.3	-1.1	-4.7
35	-4.5	0.4	0.1	-4.0
36	-3.3	-2.2	0.7	-4.8
37	-4.2	3.9	-2.7	-3.0
38	-2.1	-2.1	-0.5	-4.7
39	-2.4	-1.1	-1.4	-5.0
40	-3.4	-0.5	-0.2	-4.1
41	1.4	-3.5	-0.1	-2.1
AVERAGE	-2.8	-1.6	-1.1	-5.5

+ ve = net production - ve = net reduction

Table 3.15 P release or uptake for each reactor and net P removal for the 41 sewage in batches the UCT system.

SEWAGE BATCH	ANAEROBIC [mgP/*l*]	ANOXIC [mgP/*l*]	AEROBIC [mgP/*l*]	SETTLER [mgP/*l*]	REMOVAL [mgP/*l*]
1	15.0	-4.1	-20.7	-1.3	-11.1
2	18.8	-9.2	-18.4	-1.9	-10.8
3	22.0	-10.9	-21.1	-2.1	-12.1
4	21.2	-10.0	-19.4	-2.3	-10.4
5	8.2	-2.0	-16.9	-0.2	-10.9
6	20.4	-14.1	-15.4	-1.7	-10.8
7	22.6	-1.0	-24.6	-8.8	-11.8
8	18.6	-10.8	-18.3	-2.1	-12.6
9	17.4	-16.0	-14.3	1.9	-11.0
10	25.3	-18.8	-19.5	-2.7	-15.7
11	22.9	-20.4	-17.9	1.6	-13.7
12	33.3	-22.1	-26.7	-0.4	-15.9
13	24.0	-16.0	-20.8	-0.3	-13.1
14	31.3	-17.3	-27.2	-0.8	-13.9
15	19.6	1.5	-33.9	-1.2	-14.1
16	19.4	0.5	-32.3	-1.0	-13.3
17	24.5	-3.3	-34.4	-1.2	-14.4
18	25.4	-3.6	-35.6	0.2	-13.6
19	10.5	2.1	-26.5	0.5	-13.5
20	32.4	-12.4	-33.0	-0.8	-13.8
21	21.0	-9.4	-20.8	-4.9	-14.0
22	22.5	-6.8	-28.7	0.1	-12.9
23	16.9	-4.7	-22.1	0.6	-9.2
24	18.3	-2.5	-26.4	0.1	-10.5
25	18.5	-6.3	-20.8	0.0	-8.6
26	10.8	-7.7	-11.8	0.4	-8.2
27	11.3	-6.4	-14.0	0.4	-8.7
28	15.5	-9.8	-14.2	0.1	-8.4
29	15.1	-11.5	-13.7	-0.1	-10.2
30	7.6	-6.1	-8.1	-1.2	-7.9
31	1.2	-4.0	-0.7	0.0	-3.6
32	11.3	-8.4	-12.1	0.0	-9.2
33	5.2	-4.0	-9.7	0.2	-8.4
34	17.0	-5.4	-23.2	0.4	-11.2
35	21.6	-7.3	-25.0	0.0	-10.7
36	26.2	-2.0	-34.9	-2.6	-13.3
37	24.3	-12.8	-18.3	-2.4	-9.3
38	26.8	-7.6	-29.9	0.9	-9.7
39	23.5	-14.2	-23.5	0.2	-14.0
40	29.3	-12.6	-28.1	-0.9	-12.2
41	30.8	-11.1	-26.7	-1.5	-8.6
AVERAGE	19.7	-8.5	-21.7	-0.8	-11.4

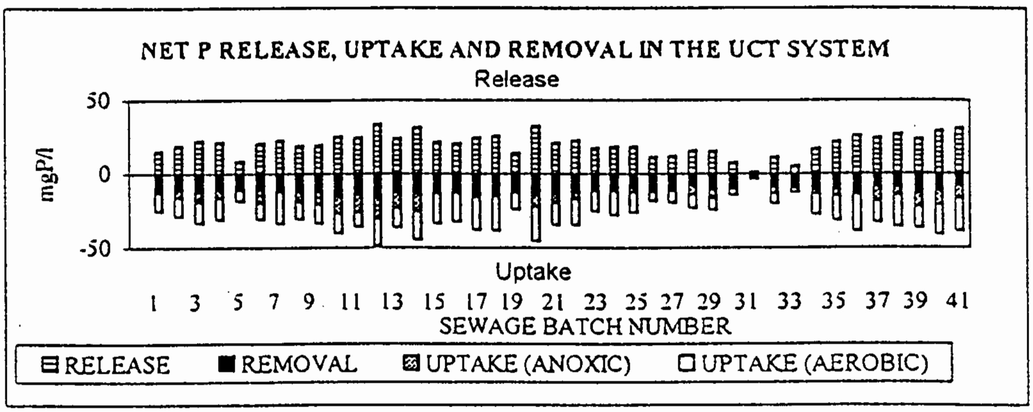


Fig 3.15 Net P release (+), uptake (-) and removal (-) in each of the reactors.

indicates P release and a negative value indicates P uptake). Adding the uptake and release for a steady state period gives the system P removal which is equal to influent P minus effluent P concentration. The last column in Tables 3.14 and 3.15 shows the system P removal for the MLE and UCT respectively. Clearly no P release and BEPR took place in the MLE system - the mean P removal was 5.5 mgP/*l* which is P taken up for normal sludge production. The average mass of VSS wasted per day is given by VSS times waste flow per day (i.e. 1778mgVSS/*l**2*l*/d) = 3556mgVSS/d. The mass of P removal is 5.5mgP/*l**20*l*/d = 110mgP/d. Hence the mean P content of the VSS is 110/3556 = 0.0309mgP/mgVSS or 3.1%. For the UCT system this is much higher, i.e. (11.4mgP/*l**20*l*/d)/ (1894mgVSS/*l**2*l*/d)= 0.062mgP/mgVSS or 6.2%. These values demonstrate that biological excess phosphorus removal took place in the UCT system at 30°C.

Graphical representation of P removal, P release and P uptake under anoxic and aerobic conditions in the UCT system is given in Fig 3.15 (below Table 3.15). For the first 23 sewage batches (period I), although the magnitude of P uptake in the anoxic zone varied, P release and uptake was relatively steady. From sewage batch 24 to 33 (period II), the P release, uptake and removal declined significantly confirming earlier findings that in period II there was a qualitative change in the influent characteristics. From sewage batch 34 to 41 (period III) P removal approached that in period I supporting earlier findings that the influent characteristics reverted to that in period I.

3.7 PERIOD ND AND NDBEPR PERFORMANCES

It was noted repeatedly in this Chapter that there was a qualitative change in the influent between sewage batches 24 to 33 and this suggested that the performance should be reported over 4 periods, period I sewage batches 1 to 23, period II sewage batches 24 to 33, period III batches 34 to 41 and period IV batches 1 to 41. The mean sewage input values for the sewage (Appendix C) for periods I, II and III are listed in Table 3.16. For period IV the mean sewage input values are listed at the bottom of Tables 3.3 to 3.7. These mean values has been and summarised in Table 3.16. The system performance for each period, for MLE and UCT systems (Appendix C, for period I, II and III and Tables 3.3. to 3.7 for period IV) are summarised in Table 3.17 and 3.18.

3.7.1 MLE System (Fig 3.1a)

System operational parameters:

Sludge age 10 days, temperature 30°C, influent flow 20*l*/d, a- recycle ratio 4:1, s- recycle ratio 1:1, sludge waste flow 2*l*/d, anoxic reactor volume 10*l*, aerobic reactor volume 10*l*,.

System performance:

Table 3.17 Performance of MLE system.

Parameter	Label	Period I	Period II	Period III	Period IV
Anoxic reactor					
NO_3	mgN/*l*	0.6 +/- 0.1	3.4 +/- 2.4	0.6 +/- 0.2	1.1
Total P	mgP/*l*	9.8 +/-0.4	9.9 +/- 0.6	10.7 +/- 0.9	10.1
Aerobic reactor					
VSS	mg/*l*	1892 +/- 94	1829 +/- 84	1430 +/- 117	1778
OUR	mgO_2/*l*	38.3 +/-1.6	33.8 +/-2.0	41.8 +/-2.7	38
NO_3	mgN/*l*	5.5 +/- 0.6	8.1 +/- 2.2	6.5 +/- 0.7	6.4
COD/VSS	mgCOD/mgVSS	1.45 +/- 0.02	1.53 +/- 0.05	1.23 +/- 0.18	1.42
TKN/VSS	mgTKN/mgVSS	0.096 +/- 0.003	0.105 +/- 0.002	0.105 +/- 0.005	0.100
Total P	mgP/*l*	9.3 +/-0.4	10.1 +/- 0.6	10.6 +/- 1.1	9.8
Filtered effluent					
TKN	mgN/*l*	(3.3)* +/- 0.2	(3.4)* +/- 0.2	(3.3)* +/- 0.2	(3.4)*
FSA	mgN/*l*	2.1 +/- 0.1	2.6 +/- 0.1	2.5 +/- 0.2	2.2
COD (unfiltered)	mg/*l*	(43)* +/- 0.2	(37)* +/- 2.7	(40)* +/- 2.9	41
COD filtered	mg/*l*	38 +/- 2.4	35 +/- 2.6	35 +/- 2.3	36
NO_3	mgN/*l*	6.0 +/- 0.7	10.1 +/- 2.8	6.5 +/- 0.8	7.2
Total P	mgP/*l*	8.6 +/-0.4	9.6 +/- 0.5	10.3 +/- 1.0	9.3
Total P removal	mgP/*l*	5.4	3.9	3.5	5.5

The +/- defines 95% confidence interval of the mean value

*( ) Unfiltered effluent

3.7.2 **UCT System** (Fig 3.1b)

System operational parameters:

Sludge age 10 days, temperature 30°C, influent flow 20*l*/d, a- recycle ratio 2:1, r- recycle ratio 1:1, s- recycle ratio 1:1, sludge waste flow 2*l*/d, anaerobic reactor volume 6*l*, anoxic reactor volume 7*l*, aerobic reactor volume 10*l*.

System performance:

Table 3.18 Performance of UCT system.

Parameter	Label	Period I	Period II	Period III	Period
Anaerobic reactor					
NO_3	mgN/*l*	0.2 +/- 0.0	0.6 +/- 0.2	0.2 +/- 0.1	0.3
Total P	mgP/*l*	23.1 +/- 1.3	17.2 +/- 2.0	24.7 +/- 1.8	21.9
Anoxic reactor					
NO_3	mgN/*l*	0.7 +/- 0.1	5.1 +/- 2.3	0.5 +/- 0.2	2.0
Total P	mgP/*l*	9.2 +/- 0.8	8.9 +/- 0.8	10.1 +/- 1.1	9.3
Aerobic reactor					
VSS	mg/*l*	1959 +/- 106	1843 +/- 129	1739 +/- 87	1894
OUR	mgO_2/l	37.8 +/- 1.3	33.2 +/- 3.2	38.6 +/- 1.3	37
NO_3	mgN/*l*	7.6 +/- 0.9	13.6 +/- 3.3	9.9 +/- 1.9	10.1
COD/VSS	mgCOD/mgVSS	1.42 +/- 0.03	1.48 +/- 0.03	1.42 +/- 0.05	1.45
TKN/VSS	mgTKN/mgVSS	0.094 +/- 0.002	0.102 +/- 0.001	0.094 +/- 0.003	0.095
Total P	mgP/*l*	3.0 +/- 0.7	5.7 +/- 1.0	3.6 +/- 1.0	3.9
Filtered effluent					
TKN	mgN/*l*	(3.4)* +/- 0.2	(3.2)* +/- 0.2	(3.5)* +/- 0.4	3.5*
FSA	mgN/*l*	2.3 +/- 0.2	2.5 +/- 0.1	2.6 +/- 0.2	2.3
COD (unfiltered)	mg/*l*	(49)* +/- 5.2	(39)* +/- 2.4	(43)* +/- 4.8	45
COD filtered	mg/*l*	40 +/- 2.4	36 +/- 2.5	37 +/- 5.0	39
NO_3	mgN/*l*	8.4 +/- 0.7	16.7 +/- 3.8	10.6 +/-1.8	11.3
Total P	mgP/*l*	2.2 +/- 0.5	5.8 +/- 1.0	6.0 +/- 1.1	3.5
Total P removal	mgP/*l*	12.9	8.3	10.3	11.4

The +/- defines 95% confidence interval of the mean value

*( ) Unfiltered effluent

3.8 BULKING

Virtually daily the diluted sludge volume index (DSVI) was measured using the mixed liquor drawn from the aerobic reactors of the MLE and UCT systems. From day 250 to the end of the investigation, approximately once per month the dominant filament organisms were identified either by microbiologists at the Johannesburg or Cape Town waste water treatment laboratories. The filament identifications are listed in Appendix J. In Appendix A Figs A.49 to A.52 the DSVIs for the MLE and UCT systems are shown plotted for the whole period of the investigation. The DSVI ranged from 150 to about 300m*l*/g indicating mild to severe bulking. The dominant filaments organisms associated with these bulking situations always included 0092, a filament closely associated with bulking in ND and NDBEPR systems.

4a,b

An hypothesis has been proposed by Casey *et al.*, (1993) to explain the causes that give rise to this type of bulking, called anoxic-aerobic (AA) bulking. From this hypothesis one important conclusion is that AA bulking is promoted by the presence of nitrite in the effluent from the anoxic zone, and, that bulking can be controlled to low DSVI values if the nitrite concentration leaving the anoxic zone is kept low. In this investigation, because of the excess of volume of the anoxic reactors available at 30°C there was always a low NO_2-N in the effluent from the anoxic zone. Whereas there is persuasive evidence that a low NO_2-N concentration in the anoxic effluent leads to low DSVI at 20°C, the data in this investigation would indicate that additional factors come into play that need to be considered in anoxic-aerobic bulking at 30°C. In this regard the following comment might merit attention: Over the temperature range the system has to operate, say from 20°C to 30°C, the critical temperature is the lower one, for both nitrification and denitrification. If satisfactory performance is accommodated at the lower temperature, the system is in fact overdesigned for nitrification and denitrification at the higher temperature. In particular, the anoxic mass fraction for denitrification is so large that NO_2 and NO_3 in the outflow from the anoxic reactor certainly will be zero. One may propose the hypothesis that where the anoxic zone is greatly in excess of that just sufficient to reduce the nitrate to zero in anoxic zone, the redox potential in the zone will be lowered and could give rise to a different micro-organisms assembly and growth characteristics which may result in some advantage for filament growth. If this hypothesis has any validity then it may be necessary to design the system with flexibility to change the anoxic mass fraction between winter and summer.

3.9 DISCUSSION

3.9.1 Data acquisition

It was noted earlier that examination of the response data indicated that the there was a period II extending from the 24th to 33rd sewage batches in which a qualitative change had taken place in the influent characteristics. As a consequence the data set was subdivided into 3 periods, designated I, II and III. Period II was identified by the significant reduction in phosphorus removal compared to those in periods I and III. The cause was identified to be due to sludge recycled to the sewer upstream of the sewage collection point for the laboratory. The main effect of the sludge 'contamination' on the influent characteristics almost certainly was a reduction of RBCOD in the influent. The difficulties thus encountered in analysing the P response are indicative of the need for early identification of changes in sewage characteristics in research.

A further difficulty was that the variability of the diluted COD feed differed between the first and second half of the investigation. The projected influent mean was 750mgCOD/*l*. In the first 23 sewage batches (period I), the mean equalled 751mgCOD/*l* with a 95% confidence interval of +/- 11mg/*l*. This, from past experience in the laboratory indicated reasonable control in making up the influent feed. Passing over period II, in period III the mean and its 95% confidence interval were 701 +/- 47mgCOD/*l* which indicate poor control of the influent COD feed, so much so that there was little merit in combining this period data with that of the period I even though the sewage quality had reverted to that of period I. Period II gave a mean of 681 +/- 15mgCOD/*l*, a mean value that deviates significantly from the intended concentration of 750mgCOD/*l*. This deviation coupled with the qualitative change that had taken place in the sewage during period II, a change which principally affected the RBCOD, further caused that the data in this period are very inadequate for testing the UCTPHO model predictions. In period I the lack of RBCOD data also was severe. The sewage apparently was 'normal'. Accordingly in order to perform an analysis it was necessary to accept historical RBCOD values with some measurements made at the same time as this investigation; this introduced an unquantifiable uncertainty. Past studies with this sewage as influent indicated a fairly constant ratio of RBCOD/(total COD) of 0.18 to 0.19 or RBCOD/BCOD of about 0.23. These ratios necessarily had to be accepted in any further analyses.

From the discussion above the conclusion is that, period I contains influent data with the greatest consistency and, with the acceptance of the historical RBCOD/BCOD value discussed above, provides the most reliable information for analyses involving the basic transformation processes in the system (in Chapter 4). Data from periods II and III have marked differences and do not merit acceptance as sources in further analyses of the systems.

3.9.2 ND and NDBEPR process performance

The first objective of this study was to determine if the ND and NDBEPR processes do operate at 30°C; this we will now examine. From remarks made above, we shall examine only period I.

With regard to the nitrification-denitrification in both the MLE and UCT systems the ammonia was nitrified in the aerobic zones and all the nitrate recycled to the anoxic zones was denitrified. Therefore the nitrification-denitrification processes operated in both systems at 30°C.

With regard to biological excess phosphorus removal, this was evaluated this by comparing the P concentrations in the MLE system with that in the UCT system. The MLE system utilises P only for normal metabolic needs; this is indicated by the sameness of the P concentration in all the zones where it was measured and relatively high values with to the influent P, Table 3.14. In the UCT system the P concentration shows an increase in the anaerobic zone and a significant decrease in the aerobic/ anoxic zones to a value significantly lower than that in the influent, Table 3.15; these are features that demonstrate BEPR. In period I the MLE system removed 5.4mgP/*l* giving a P/VSS ratio for the mixed liquor of 0.025 which corresponds to normal metabolic requirements. In period I the UCT system removed 12.1mgP/*l* (gives a P/VSS ratio of 0.05) which implies that this system removed (12.1 - 5.4) = 6.7mgP/*l* in excess over that in the MLE system. This further demonstrates that the excess P removal processes operated at 30°C.

3.10 CONCLUSION

The experimental performance data has demonstrated unequivobly that nitrification-denitrification (ND) and biological excess phosphorus removal (BEPR) processes do operate at 30°C. In this regard the experimental enquiry has given a positive answer to a principal objective set for this investigation i.e. to investigate whether ND and BEPR processes operate at 30°C.

Although the experimental data has demonstrated that the ND and NDBEPR processes do operate at 30°C, the data do not give direct information on the efficiency with which these operate. To obtain information of this kind demands an enquiry in the kinetic behaviour of the system. This behaviour centres around the kinetics of the biological processes involving COD, nitrogen and phosphorus transformations in the system and have been integrated in general kinetic models, UCTOLD and UCTPHO. In Chapter 4 steady state kinetic evaluation is undertaken of the systems, subject to the constraints imposed on the experimental systems.

CHAPTER 4

KINETIC STATE EVALUATION OF ND AND NDBEPR SYSTEMS

4.1 INTRODUCTION

In this Chapter, activated sludge models will be employed to confirm some influent characteristics and to evaluate the measure in which the experimental data from the steady state ND and NDBEPR systems reported in the Chapter 3, fits with the predictions of models. Further, results from the batch tests on sludge harvested from the steady state systems to determine the kinetic rates will be reported and eveluated against the models and the historical results.

4.1.1 Activated sludge models

In order to appreciate the application of the activated sludge models it is useful to highlight certain aspects of these models that impact on the analysis of the experimental data from the two systems.

Modelling of the kinetic responses of ND and NDBEPR systems have been developed to a marked degree over the past two decades and today general mathematical kinetic models are available. The mathematical models are general in that for any temporal input of flow and load, a temporal output is generated. Two general models have been programmed by the Water Research Group at University of Cape Town for execution on computers, designated UCTOLD for ND systems (Dold *et al.*,1991), and UCTPHO for NDBEPR systems (Wentzel *et al.* 1992). These two model programs are not completely general; they require a fixed daily input pattern (called daily cyclic) and the program, by iteration, generates a fixed daily cyclic response pattern. That is, a fixed daily cyclic input will give rise to a fixed daily cyclic output, designated as giving a dynamic steady state solution. If the input is constant with time, accordingly the output also will be constant with time. This particular case is designated as giving a stationary steady state solution, sometimes shortened to steady state solution.

A general model comprises a set of differential equations defining the kinetic behaviour of the reactants and products in the various processes acting within the system in each reactor of a set of reactors. The reactor configuration is in-series with inter-reactor recycle flows; each reactor is completely mixed and is either aerated or non-aerated; provision is made for sludge wastage from the aerobic reactor preceeding the settling tank to give a specified sludge age. Reactor volumes, magnitudes of daily flow and load input patterns and recycle flows are specified.

It should be noted in particular that, to apply the general model the reactor volumes, aeration states, reactor configuration, recycle flows, and system sludge age need to be specified in order to obtain a solution. But these parameters are indeed the ones to be determined in a design. In effect, if the general model is used for design, the design necessarily must proceed by trial and error. Furthermore, the solution generated by general model is very much that of a "black box" in that only output is provided, the user gains very little insight into the internal behaviour of the processes.

General activated sludge models are the final products from investigations into activated sludge behaviour extending over the past 20 years (see Chapter 2). During this period "watershed" changes in concepts on activated sludge behaviour were introduced and different models of behaviour were proposed of increasing complexity. Initially only systems receiving constant flow and load were investigated, yielding stationary steady state solutions. Differential relationships linking the significant output parameters with the input were developed and most importantly, many of the parameters could be expressed explicitly. These stationary steady state models are relatively simple and graphic to the mind and provide simple structures for design and analysis. Most of the important parameters could be expressed explicitly terms of input and process parameters.

The stationary steady models were developed first for aerobic-nitrification systems (Marais and Ekama, 1976), and later for anoxic/aerobic ND systems (van Haandel *et al.*, 1982; WRC, 1984). In the ND model, denitrification was modelled explicitly by linking the denitrification rate to the active heterotrophic mass by $dNO_3\text{-}N/dt = K.X_{B,H}$ with denitrification constants K_1 and K_2 in the primary anoxic reactor and K_3 in the secondary anoxic reactor. Experimentally these constants were found to remain essentially constant in value for sludge ages between 10 and 20 days at 20°C (Van Haandel *et al.*, 1981; WRC, 1984).

The differential equations derived in the stationary steady state models above were found to be inapplicable if cyclic flow and load conditions were applied to the system. To predict output under cyclic input conditions required incorporation of a number of new processes. In this fashion eventually general models for aerobic-nitrification (Dold *et al.*, 1980), nitrification-denitrification (ND) systems (van Haandel *et al.*, 1981- UCTOLD) and nitrification-denitrification-biological-excess-phosphorus-removal (NDBEPR) systems (Wentzel *et al.*, 1992 - UCTPHO) were developed. These models contained many processes some with strong interaction. Explicit solutions for stationary steady state no longer were possible. However, van Haandel *et al.* (1981), WRC (1984) and Wentzel *et al.* (1990) showed that under stationary steady state many reactions were virtually complete and hence reactants and products became stoichiometrically related, so that kinetic relationships between reactants and products no longer were required. In others, one process dominated in a series of processes by having the slowest rate and hence became the limiting rate in the series, so that only this process was significant in the system kinetics. By these considerations, the number of processes to be considered in stationary steady state description was greatly reduced and the remainder could be expressed explicitly. In this fashion the stationary steady state models were developed. This approach also gave substance to empirical relationships derived experimentally. For example, in ND system, van Haandel *et al.* (1981) showed that the K_1, K_2 and K_3 denitrification rate constants could be derived from the general model, and the denitrification rate could be modelled in terms of $X_{B,H}$ with the K values virtually constant and independent of sludge age between 10 and 20 days. However, the K values are temperature dependent. These considerations produced the stationary steady state WRC

(1984) model for ND systems, and Wentzel *et al.* (1990) model for the NDBEPR systems. Today there are 4 models available:

ND system:	Stationary steady state (WRC model, WRC, 1984)
	Dynamic steady state (UCTOLD model, Dold *et al.*, 1991)
NDBEPR system:	Stationary steady state (Wentzel model, Wentzel *et al.*, 1990)
	Dynamic steady state (UCTPHO model, Wentzel *et al.*, 1992)

The areas of application of these models can be briefly stated as follows:

A dynamic state model can simulate output for specified daily cyclic inputs, any specified reactor configuration, including reactors that are aerated and unaerated, for specified recycles and sludge age to give a dynamic steady state solution. If the input is constant over the day the output will also exhibit constancy, to give a stationary steady state solution. A stationary steady state model accepts as basis that the input is constant over the day and a stationary steady state solution is generated. A stationary steady state model cannot describe behaviour under cyclic load and flow. Furthermore there is a restriction to the system configuration of the steady state ND model - only one reactor per zone is allowed in a system (aerobic, primary and/or secondary anoxic).

In applying these models experience indicates that the general models under constant flow and load conditions give substantially the same stationary state solutions as the stationary state models within the normal design range of BNR plants in South Africa. An example of this equivalence in given in the closing Section 4.4 of this chapter (Table 4.18). In analysing experimental systems receiving constant flow and load, one may use either a stationary steady state or dynamic steady state model but preferably the latter because it is not subject to the imposed approximations of the former.

4.1.2 Model application to steady state systems

In developing the experimental protocol, Chapter 2, it was decided to operate the system only under steady state (constant flow and load conditions) and to choose the system mass fractions, recycles, process configurations, and sludge ages of the MLE and UCT systems such that (1) synthesis of biological mass from influent biodegradable carbonaceous material (BCOD), (2) nitrification of influent biodegradable TKN in the aerobic reactor, (3) denitrification of nitrate/nitrite entering the anoxic reactor, were all effectively complete, and, (4) conversion and uptake of readily biodegradable COD in the anaerobic reactor and P uptake in the aerobic reactor were as nearly complete as possible. By so doing the steady state concentrations in the system became virtually independent of the kinetic rates of the various processes. The only processes that cannot go to completion are the endogenous mass losses of the ordinary heterotrophic organisms (OHO), polyP accumulating heterotrophic organisms (PAO), and the nitrifying autotrophs - these endogenous processes continue to operate irrespective of whether the other biological processes have gone to completion or not.

The kinetic rates of the processes are all temperature dependent to different degrees. For most processes the rates increase with increase in temperature. As a consequence, the critical temperature for determining the anaerobic, anoxic and aerobic mass fractions is the minimum for the yearly temperature cycle. Hence, if the processes are designed to go to completion at a lower temperature then, very likely, they will do so at a higher temperature.

There remain three important problems that require resolution before analysis of the experimental systems can be attempted:

1. The biological heterotrophic processes operate only on the biodegradable fraction of the influent COD (BCOD), which consists of two fractions, readily biodegradable (RBCOD) and slowly biodegradable (SBCOD). There are two unbiodegradable influent COD fractions, unbiodegradable soluble COD (USCOD) and unbiodegradable particulate COD (UPCOD); these are unaffected by biological action. All these influent fractions must be known in order to calculate the active and endogenous VSS masses, associated heterotrophic oxygen demands of the OHOs and PAOs, and the inert VSS mass derived from the UPCOD in the influent. All the fractions of COD, with the exception of UPCOD, are estimated either directly by batch experiment or from the system effluent. UPCOD cannot be measured directly and must be estimated from the kinetic response of the system. In Chapter 3 the influent TCOD, RBCOD and USCOD are listed as determined from experimental measurements. In this Chapter estimation of UPCOD is set out.

2. Although the nitrification process will go to virtual completion, there is always some ammonia present in the aerobic reactor and hence in the effluent, arising from the Monod kinetic behaviour in the transformation of ammonia to nitrate. The nitrification kinetic constants μ_{nmT} and K_{nT} in the mathematical nitrification kinetic relationship are very temperature dependent, but these dependencies are not well established in the temperature range above 20°C. Interactive effects between these constants makes the theoretical estimation of the effluent ammonia concentration uncertain in the high temperature range.

3. There is uncertainty in regard to the effects of temperature on processes involving the PAOs - there is no information on the temperature sensitivity of the PAOs processes in the high temperature range, 20-30°C.

In this Chapter we will address these three problems. We will use the dynamic simulation ND and NDBEPR models (UCTOLD and UCTPHO respectively) operated under constant flow and load conditions, or their simplified stationary steady state versions, WRC (1984) and Wentzel *et al.* (1990), to determine in what degree one can develop solutions at 30°C in systems designed such that all the processes except the endogenous ones go to virtual completion at 20°C. In attempting to resolve problems (1) and (2) above, it is preferable to do so on systems that do not include possible confounding affects of (3) so that the MLE system should form the basis for assessing (1) and (2) and thereafter information thus obtained can assist in resolving (3) in the UCT system.

4.1.3 Kinetic Behaviour

As noted above, it is very likely that most of the processes in the steady state systems will go to completion at 30°C, thus the steady state systems themselves will not provide useful information on the kintic rates of the biological processes at 30°C but only on the stoichiometric behaviour. To obtain information on the kinetics, a number of aerobic, anoxic and anaerobic batch tests were conducted on sludge harvested from the steady state systems. Kinetic rates determined from these batch test will be evaluated and compared with 20°C rates from this and earlier investigations to generate temperature sensitivity coefficients for some of the kinetic constants.

4.2 BEHAVIOUR OF MLE SYSTEM AT 30°C

4.2.1 Estimation of unbiodegradable particulate COD fraction, f_{up}, in influent

In Chapter 2 the selection of the anoxic and aerobic mass fractions of the MLE system was discussed. The basis for selection was that using UCTOLD, simulations at 20°C for the selected configuration, sludge mass fractions, sludge age and operational parameters (Table 3.1), and experimental influent characteristics COD, TKN and P (Table 3.16), with default estimates of RBCOD and USCOD and UPCOD, the carbonaceous growth and nitrification processes in the aerobic reactor and denitrification in the anoxic reactor would be virtually complete; the only processes not complete were those of endogenous mass loss.

Differences in the responses of the heterotrophs at 30°C compared with those at 20°C, would arise only from the effects of temperature on endogenous mass loss. If one can accept that the specific yield of the heterotrophs remains unchanged, that the aerobic synthesis process is effectively complete and that nitrate entering the anoxic reactor is completely denitrified, the actual values of the rates are not of consequence in the simulation studies using ND dynamic model (UCTOLD) or steady state model WRC (1984). These rates only need to be higher than a certain minimum value for a specific system configuration to ensure synthesis and denitrification are complete. As these rates most likely will be higher at 30°C relative to their values at 20°C, and as the design at 20°C using well established values for the rates was such that it ensured the complete reaction of these processes at 20°C, the simulation model which incorporates the temperature effects on the processes should predict complete process action at 30°C. However, endogenous processes, we have seen, continue to operate. Hence simulations of the behaviour at 30°C under the above conditions would differ from those at 20°C to the degree in which endogenous processes are influenced by temperature.

In regard to the endogenous mass loss phenomenon in activated sludge modelling, the earlier approach was a "black box" one of net effects. Marais and Ekama (1976) showed that from aerobic batch digestion studies on mixed liquor from aerobic systems the rates of active mass loss, oxygen utilization and endogenous residue generation are first order phenomena with respect to active mass. Later, Dold *et al.* (1980) showed that endogenous mass loss behaviour is constituted of a number of processes, death of live (active) organism, release of SBCOD and endogenous residue to the surroundings and synthesis of new cell mass from the SBCOD that has been released. In this approach, the oxygen demand (endogenous oxygen demand) was due to the oxygen requirement for the resynthesis, true maintenance oxygen requirement was ignored compared to the resynthesis requirement. Dold *et al.* (1980) called this approach death-regeneration. They further showed that the endogenous respiration approach, which considers only a net effect, was linearly related to the death-regeneration one to give identical responses to endogenous oxygen demand for nitrification, endogenous particulate material generation and active mass reduction rates in aerobic digestion of mixed liquor. The death-regeneration approach has had a significant influence in extending the description of activated sludge behaviour to a system with a series of reactors including anaerobic (no dissolved oxygen (DO) and nitrate), anoxic (nitrate but no DO) and aerobic (nitrate and DO) reactors under steady and cyclic flow and load conditions. For our purpose, of importance is that at steady state in completely mixed reactor systems the models give stationary steady state solutions of all the parameters of significance in activated sludge response - OUR, active, endogenous and inert volatile masses, nitrification, denitrification and others. These values can be estimated also by the WRC stationary steady state model for steady state developed on the "net effect approach": In long sludge age systems the net effect approach, if properly calibrated, gives responses that are virtually identical to those given by the general model based on the death-regeneration kinetic approach.

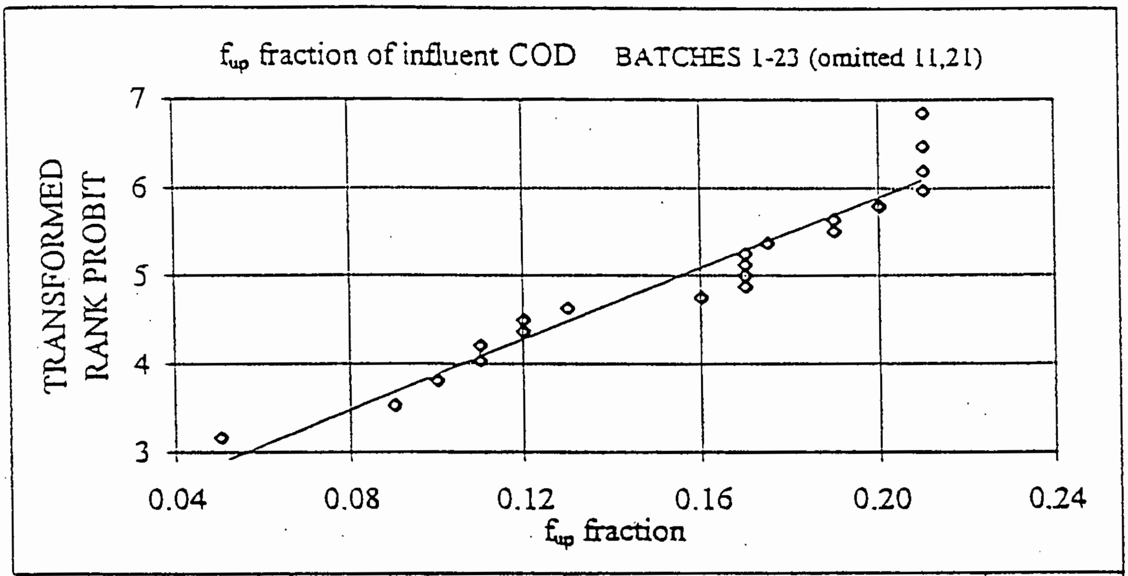
Of the endogenous processes, the one that will have the greatest effect is that associated with the ordinary heterotrophs (OHOs). In this investigation, no aerobic batch digestion tests were performed on the mixed liquor at 30°C, so that there is no information on endogenous mass loss rates at this temperature. Aerobic batch digestion tests in the range 12 to 22°C have indicated that the temperature effect on the endogenous process of the heterotrophs is relatively small (θ_{bH} = 1.029). In the absence of such tests at 30°C, necessarily an assumption must be made that the temperature dependency from 20 to 30°C is approximately the same as that from 12 to 22°C, thereby a value for b_{H30} is determined, viz $b_{H30} = 0.24(1.029)^{10} = 0.32$/d. With this assumption, by simulation it is possible to form estimates of the unbiodegradable particulate COD in the influent, (UPCOD), and hence the fraction of UPCOD in the total influent COD, $f_{up,}$(TCOD), i.e. f_{up} can be determined by using the ND kinetic model (UCTOLD) under constant flow and load conditions, or the stationary steady state model of the WRC (1984). This was done for period I as follows:

> In the UCTOLD model, input the MLE process configuration and operational parameters from Table 3.1; input temperature (30°C) and the mean period influent characteristics from Table 3.16 (pg 3.25) with the RBCOD = 0.23*BCOD (f_{bs} =0.23, see Section 3.5), USCOD = 0.05*TCOD; retain the standard default reference kinetic values at 20°C; input the mean total COD and TKN concentrations in influent. Perform a number of simulation with a series of f_{up} values and select that f_{up} value that gives equivalence between observed and simulated VSS concentrations.

By the procedure above, for long term period I, the value of f_{up} = 0.154 gave equivalence between the observed and simulated VSS, see Table 4.1. The f_{up} value is also recorded for convenience in Table 3.16. Repeating this exercise for long term periods II and III, f_{up} values for the MLE system were determined and are also recorded in Tables 4.1 and 3.16

(pg 3.25); Period IV in Table 4.1 is the average of the whole investigation.

Mbewe *et al.* (1995) and Ubisi *et al.* (1997) also used the above approach to determine f_{up}, except they applied the procedure using the mean influent data for each batch of sewage and the stationary steady state WRC (1984) model to determine the stationary steady state values. They in fact determined an f_{up} value for each sewage batch. This approach was also applied in this investigation to the sewage batches in each period, and the mean f_{up} for each period was found by doing a statistical analysis of the sewage batch f_{up} values. For example, this was done for the 23 sewage batches in period I; the f_{up} values are recorded in Appendix M. The graphical statistical analysis of the 23 batch f_{up} values is shown in Fig 4.1 (see Appendix K for all the graphical statistical plots of the f_{up} values for the 3 long term periods and the whole investigation). The mean f_{up} value for period I is 0.155, a value virtually identical to that found by inputting the mean long term period values.



MEDIAN=	0.170		std dev. of mean =	0.010
MEAN =	0.155		95% conf. of mean = 0.155 +/- 0.020	
s =	0.047			

Fig 4.1: Probability distribution of the unbiodegradable COD fraction (f_{up}) values of sewage batches 1 to 23 (long term period I) in the MLE system from day 1 to day 360 as determined with the WRC (1984) steady state ND model.

One may ask which of the two methods of estimation of f_{up} is preferable? In the individual batch/statistical approach, f_{up} for a batch is found by that value which gives the same simulated VSS as the average VSS measured during the time the sewage batch was used. It should be noted that the steady state simulation using either the WRC model, or, UCTOLD model under constant flow and load, determines the VSS on the basis that the value of the input experimental batch COD concentration is maintained for such a period of time that stationary steady state is attained. In reality the batch input extends only over about 2 weeks, and the experimentally measured VSS is in fact influenced by the previous batches because washout of the unbiodegradable particulate material from a previous batch will continue, with decreasing effect for about 3 sludge ages i.e. 30 days. Furthermore the between-batch COD values show considerable random dispersion, ranging from 692 to 840mg/*l*, see Table 3.3. Experimentally full stationary steady state is not obtained for each batch, whereas the model calculates a full stationary steady state. The consequence is that there is an error introduced with each batch f_{up} determination. The dispersion in between-batch influent COD concentration, arises randomly, with a normal distribution (see Fig CI.1, Appendix C, pg C.1). Hence the error introduced by each batch f_{up} calculation also will be random to give rise to two dispersion factors affecting the f_{up} distribution - a between batch dispersion and a dispersion due to the stationary steady state assumption. The latter named error can be negative or positive but the net effect is to increase the spread of the f_{up} values. A wide dispersion is in fact obtained, from f_{up} = 0.05 to 0.23 for the 23 sewage batches of period I. How does this effect the mean f_{up} value?

The error introduced by the in-batch calculation approach of f_{up} is itself randomly distributed with a normal distribution (deduced from the fact that the final f_{up} distribution is closely normal, Fig 4.1). Hence, it should introduce only small bias when calculating the mean f_{up} and this possibly accounts for the equivalence of the mean period f_{up} values of the two approaches. However, it does increase the spread for the distribution of f_{up} batch determination so that the range of f_{up} values (0.05 to 0.23) is probably excessive and not realistic. The following remarks are pertinent to the f_{up} determination:

> The basis of the theoretical kinetic models is that UPCOD passes unmodified through a system. If this is accepted then the f_{up} should be determined on a system in which uncertainty introduced by other processes is reduced to a minimum. This implies that f_{up} should be determined on an aerobic system, and for greater security be determined at 2 or 3 sludge ages ranging from, say, 3 to 20 days. In this investigation no aerobic system was operated, and the f_{up} necessarily had to be estimated on the MLE ND system at a single sludge age.
>
> Determination of f_{up} from an ND system introduces a number of uncertainties which are not addressed in the general ND model. It is known that the heterotrophic yield with NO_3 as electron acceptor is about 70% of that with oxygen as electron acceptor. In the ND model the effect of NO_3 as electron acceptor has not been considered in detail, and the yield with NO_3 is taken to be the same as with oxygen as electron acceptor. This approach has been accepted because experimental observation of sludge production in the usual ND system showed no significant difference in sludge production from that in an aerobic system with the same sludge age. One possible reason is that in the anoxic zone the 'endogenous' death rate also may be reduced because predators may also have reduced activity under anoxic conditions. Another reason may be that in the usual MLE systems only about 10-15% of the COD mass change is due to nitrate serving as electron acceptor. A further important point to note is when anoxic-aerobic bulking is present it is common to observe a decrease in the sludge concentration with increase in DSVI. Again this may arise because the growth/death rate of the filaments differ from that of the floc formers. None of these effects are considered in the ND model. Consequently, in the estimation of f_{up} value

by equivalence of the theoretical and experimental VSS, one may be consolidating in f_{up} the deviations in VSS due to factors not associated with the f_{up} value.

Despite all these factors influencing the f_{up} value, it is interesting to compare the sewage characteristics values f_{up} (UPCOD) and f_{us} (USCOD) obtained by Mbewe *et al.* (1995) and Ubisi *et al.* (1997) at 20°C with the values for the MLE system of this investigation at 30°C. Mbewe and Ubisi used the same wastewater as was used in this investigation, Mbewe for 18 months immediately before this investigation and Ubisi simultaneously for the first 28 sewage batches (12 months) of this investigation. Mbewe operated a fully aerobic activated sludge system at 12d sludge age and 20°C and the mean f_{up} and f_{us} fractions obtained for the last 11 sewage batches they used was $f_{up} = 0.100$ and $f_{us} = 0.081$. Ubisi operated an MLE system with a 25% anoxic mass fraction at 10d and 20d sludge age at 20°C and the mean f_{up} and f_{us} fractions they obtained at 10d sludge age (spanning 21 sewage batches) were $f_{up} = 0.119$ and $f_{us} = 0.096$ and at 20d sludge age (spanning 7 sewage batches) were $f_{up} = 0.121$ and f_{us} 0.088. The values at 10d and 20d sludge age were very similar (statistically there was no significant difference at the 95% confidence interval) indicating, as one would expect, that the sludge age did not influence the f_{up} and f_{us} values very much. The overall mean f_{up} and f_{us} values determined by Ubisi for both 10d and 20d sludge age (spanning 28 sewage batches) were $f_{up} = 0.120$ and f_{us} 0.094. The f_{up} and f_{us} results obtained by Mbewe and Ubisi at 20°C are compared with the 30°C MLE values obtained in this investigation in Table 4.1.

Table 4.1: Comparison of wastewater characteristics obtained by Mbewe *et al.* (1995) and Ubisi *et al.* (1997) at 20°C with those obtained in this investigation on the 30°C MLE system treating the same Mitchells Plain wastewater.

Parameter	f_{up} (UPCOD)	f_{us} (USCOD)	COD Balance	N Balance	f_{cv} COD/VSS	f_n TKN/VSS
Mbewe	0.100 (±0.045)	0.081 (±0.007)	118%	95%	1.48[1]	0.10[1]
Ubisi						
R_s = 10d	0.119 (±0.042)	0.096 (±0.020)	-	-	1.48 (±0.097)	0.105 (±0.012)
R_s = 20d	0.121 (±0.045)	0.088 (±0.013)	-	-	1.541 (±0.063)	0.109 (±0.005)
Overall	0.120 (±0.042)	0.094 (±0.019)	88%	94%	1.496 (±0.093)	0.106 (±0.011)
MLE						
Period I	0.155[2] (±0.047)	0.050[3] (±0.008)	94%	80%	1.44[4] (±0.06)	0.097[4] (±0.006)
Period II	0.202[2] (±0.045)	0.050[3] (±0.007)	94%	81%	1.51[4] (±0.05)	0.105[4] (±0.003)
Period III	0.095[2] (±0.068)	0.048[3] (±0.006)	97%	82%	1.44[4] (±0.08)	0.103[4] (±0.008)
Period IV	0.155[4] (±0.066)	0.049[4] (±0.008)	94%	80%	1.46[4] (±0.07)	0.100[4] (±0.007)

[1] Assumed the "standard" f_{cv} and f_n values. [2] See Appendix K for details. [3] Calculated from data in Table M.1.
[4] Calculated from sewage batch average data in Appendix A tables.
Values in brackets are standard deviations, not 95% confidence intervals.

Comparing the f_{up} fractions in Table 4.1, it can be seen that compared to Mbewe and Ubisi, who obtained 0.10 and 0.12 at 20°C respectively, the overall value for the MLE system at 30°C is 0.155. This is somewhat higher than at 20°C. If it is accepted that because the same wastewater was feed to the systems, the same f_{up} value should be obtained at 30°C as at 20°C, i.e. around 0.11, then the high f_{up} value obtained at 30°C maybe due to an overestimate in the b_{H30} value. The lower the b_{H30} value, the higher the net sludge production per influent COD mass load. Therefore, in order to reduce the f_{up} value from 0.155 to 0.11, the b_{H30} value would need to be reduced from 0.32 /d to about 0.29/d, i.e. giving a temperature sensitivity coefficient for b_H θ_{bH} of 1.019 instead of the "standard" value of 1.029 for the 20 to 30°C temperature range. However, because the factors that influence the f_{up} estimate of wastewaters in laboratory systems are so numerous as mentioned above, the best approach would appear to be to maintain θ_{bH} at 1.029, but to accept that the sludge production is likely to be underestimated at high temperatures with this value, and therefore to choose a slightly higher f_{up} value for the wastewater to compensate for this in N removal systems.

4.2.2 Nitrification and denitrification rates in MLE system

The MLE system in this investigation was designed on the expectation that it would give complete nitrification in the aerobic zone and complete denitrification in anoxic zone over the range 20°C to 30°C. In terms of the nitrification-denitrification system model, the design was proportioned to satisfy these performance expectations at 20°C because the nitrification and denitrification rates were both expected to increase with increase in temperature in which event the design based on 20°C performance would definitely satisfy the design expectation at 30°C.

The design at 20°C accepted default values for the various constants entering into the process design calculations. These constants were taken from values derived from experimental work done on MLE systems at 20°C in the laboratory, using the same sewage as that in this investigation. Consequently if the performance of the MLE system in this investigation was satisfactory at 30°C it implied that nitrification and denitrification rates were at least as high at 30°C as at 20°C. However, even though the expectation is that the rates should be higher at 30°C than at 20°C, this would have little significant influence on the performance of the system, because the nitrification and denitrification would have reached completion in the system.

The experimental results from the MLE system at 30°C confirmed that in the system nitrification in the aerobic zone was virtually complete and the denitrification in the anoxic zone also was complete and therefore these rates were at least as high at 30°C as at 20°C. Because the nitrification and denitrification rates were complete in the MLE system, the actual rates could not be calculated from the system results. However, because it was of importance to see how these rates changed between 20 and 30°C, a series of aerobic (nitrification) and anoxic (denitrification) batch tests were undertaken on mixed liquor harvested from the aerobic and anoxic reactors of the MLE system respectively. These tests are commonly performed in the laboratory; the procedures, results and calculations of the maximum specific growth rate of nitrifiers, μ_{nm} and specific denitrification rate constants, K_1 and K_2, are presented in Appendix G (procedures), Appendix H (results) and

Appendix L (calculations and statistical analysis) respectively.

4.2.2.1 Aerobic batch tests - maximum specific growth rate of nitrifiers (μ_{nm})

Briefly, the maximum specific growth rate of the nitrifiers μ_{nm} was calculated as follows from the aerobic batch test results in which nitrate and nitrite concentrations were measured at regular intervals. The nitrate and nitrite (where significant) generation rates (mgNO$_x$-N/*l*/h) were obtained from the nitrate and nitrite concentration versus time slopes of the batch test. The slopes were invariably linear because (i) ammonia was in excess in the batch tests i.e. the Monod term $N_a/(K_n+N_a) \approx 1$ so that the nitrifier specific growth rate is at maximum (μ_{nm}) and (ii) the increase in nitrifier concentration small compared to that originally present at the start of the batch tests i.e. $X_n \approx$ constant. Usually the nitrite generation rate was very low because the nitrate was produced as fast as the nitrite with the result that there was very little accumulation of nitrite. The nitrite generation rate therefore was not included in the nitrate generation rate. The μ_{nm} rate (/d) is calculated from the nitrate generation rate viz.

$$\mu_{nm} = [Y_n*(\text{Nitrate generation rate - mgNO}_3\text{-N}/l/\text{h})24]/X_n \quad (/\text{d})$$

where

Y_n = Nitrifier specific yield coefficient = 0.1 mgVSS/mgNO$_3$-N nitrified
X_n = Nitrifier organism VSS concentration in the batch test (mgVSS/*l*)

The X_n concentration in the batch test was calculated from the continuous system sewage batch average results. For example, the first aerobic batch test on the MLE system was done during sewage batch 11. From the N balance calculations for sewage batch 11, it was calculated that an average of 415 mgNO$_3$-N/d was generated by nitrification (see Table L.1 in Appendix L). From this, the average concentration of nitrifiers, X_n, in the MLE system during sewage batch 11 is;

$$X_n = MX_n/V = Y_nR_s(415)]/\{V(1+b_{nT}R_s)\} \quad \text{mgVSS}/l$$

where

R_s = System sludge age (d)
V = System volume (*l*)
MX_n = Mass of nitrifiers in system (mgVSS)
b_{nT} = Endogenous respiration rate of the nitrifiers at T°C
= 0.04/d at 20°C
= $0.04\,(1.029)^{10} = 0.053$/d at 30°C.

Like for the heterotrophic organisms, the temperature sensitivity of the endogenous mass loss rate of the nitrifiers (b_n) was accepted to conform to the 12-22°C range viz. θ_{bn} = 1.029. Hence, b_{n30} = 0.053/d as calculated above. Because undiluted mixed liquor samples were tested in the aerobic batch tests, the system X_n and batch test X_n concentrations are the same. Hence, X_n = 13.6 mgVSS/*l* and μ_{nm30} for the first batch test was

$$\mu_{nm30} = 0.1(7.06)24/13.6 = 1.249\ /d.$$

The above calculation procedure was applied to the 16 aerobic batch tests done on the 30°C MLE system sludge which are listed in Appendix L. Of the 16 batch tests, 13 were done during long term period I and 3 during long term period II. Graphical statistical plots of these μ_{nm30} values are given in Appendix L, Figs L.1 and L.2. The median, mean, standard deviation of the data, standard error of the mean and the 95% confidence intervals are given in Table 4.2.

Two aerobic batch tests were conducted on the parallel 20°C MLE system. Detailed results and calculations of these batch tests are not given in Appendix L, and a graphical statistical plot of the μ_{nm20} values is given in Appendix L, Fig L.3. The results are summarized in Table 4.2.

Table 4.2: The median, mean, standard deviation of the data, standard error of the mean and the 95% confidence interval of the maximum specific growth rate of the nitrifiers (μ_{nm}) measured in the aerobic batch tests at 20 and 30°C.

Test	Median	Mean	SD of data	SE of mean	95% CI	No of tests
30°C MLE system						
BT 1-13	0.976	1.033	0.229	0.064	0.125	13
BT 15-18	0.491	0.510	0.120	0.060	0.117	3
20°C MLE system						
BT 1-2	0.849	0.849	0.021	0.015	0.029	2

The mean obtained for period I is μ_{nm30} = 1.03/d. In the 20°C MLE system μ_{nm20} = 0.849/d which is very high compared with μ_{nm20} values observed in other 20°C systems in the laboratory. These μ_{nm} values at 20 and 30°C give a $\theta_{\mu nm}$ = 1.019 which is much lower than the standard value of 1.123. This aspect is discussed further in Section 4.3.2 where the maximum specific growth rate of the nitrifiers measured in the UCT system of this investigation at 30°C is compared with that measured by Sneyders *et al.* (1997) in the identical UCT system at 20°C.

4.2.2.2 Anoxic batch tests - specific denitrification rates K_1 and K_2.

Altogether 21 anoxic batch tests were done on sludge from the 30°C MLE system and none on the parallel 20°C MLE system. For the anoxic batch tests, 1.5 *l* of sludge was drawn from the aerobic reactor and mixed in the batch reactor with 1.5 *l* of sewage, preheated to 30°C and diluted to the MLE system feed concentration of 750 mgCOD/*l*. Concentrated nitrate solution was added to give an initial nitrate concentration of around 30 mgN/*l*. During the batch test, which lasted about 6 hours, samples were regularly taken and tested for nitrate and nitrite. Details of the test procedure are given in Appendix G, Section G.4. The specific denitrification rates K_1 (due to RBCOD) and K_2 (due to SBCOD) were calculated from the nitrate and nitrite concentration versus time graphs (see Appendix H). The initial fast rate was separated into its K_1 and K_2 rates as described by van Haandel *et al.* (1981) and WRC (1984). The K_1 and K_2 denitrification rates are expressed as specific rates in terms of the active ordinary heterotrophic organisms (OHO) concentration ($X_{B,H}$). This concentration was obtained by halving the measured VSS concentration of the sludge added to the batch test (due the 1:1::sludge:sewage addition to the batch test) times the OHO active fraction of the VSS ($f_{av,OHO}$). The $f_{av,OHO}$ fraction was obtained from the unbiodegradable particulate COD fraction (f_{up}) calculation (see Section 4.2.1 above) with the WRC (1984) steady state model for the MLE system. The calculated $f_{av,OHO}$ fractions for the MLE system at 30°C for the 41 sewage batches are listed in Table M.1 in Appendix M. The calculations for the K_1 and K_2 rates are tabulated in Appendix L, Table L.3 and graphical statistical plots of the calculated K_1 and K_2 denitrification rates are given in Appendix L, Figs L.6 to L.8. The median, mean, standard deviation of the data, standard error of the mean and the 95% confidence interval of the K_1 and K_2 rates are listed in Table 4.3 below. Note that a reliable estimate for K_1 in period II could not be obtained due to the small number of batch tests done during this period.

Table 4.3: The median, mean, standard deviation of the data, standard error of the mean and the 95% confidence interval of the K_1 and K_2 denitrification rates measured in the anoxic batch tests at 30°C on the MLE system.

Test	Median	Mean	SD of data	SE of mean	95% CI	No of tests
K_1 (Period I)	0.775	0.821	0.200	0.053	0.105	14
K_2 (Period I)	0.445	0.430	0.094	0.023	0.044	17
K_2 (Period II)	0.403	0.406	0.072	0.036	0.070	3

The results obtained for period I are K_1 = 0.82 and K_2 = 0.43 (mgNO$_3$-N)/(mgOHOAVSS.d). "Standard" values for N removal systems at 20°C {originally measured by Stern and Marais (1974) and confirmed in subsequent investigations by Wilson and Marais (1976), Marsden and Marais (1977), van Haandel *et al.* (1981) and Warburton *et al.* (1991)}, are K_1 = 0.72 and K_2 = 0.101 mgNO$_3$-N/(mgOHOAVSS.d). The K_1 and K_2 values at 30°C from this investigation and the "standard" values at 20°C indicate temperature sensitivities for denitrification θ_{K1} = 1.03 and θ_{K2} = 1.15. Corresponding "standard" temperature sensitivities in the 12°C to 22°C range are for denitrification θ_{K1} = 1.2 and θ_{K2} = 1.08. From these results, the K_1 and K_2 rates are higher at 30°C than at 20°C. The temperature sensitivity for K_1 is much lower in the high temperature range (20-30°C) than in the low temperature (12-22°C), and that for K_2 substantially higher. Deviation in the temperature sensitivity for K_1, θ_{K1}, from the standard value is not unexpected; K_1 has been linked to the rate of utilization of RBCOD [via μ_H, the maximum specific growth rate of the ordinary heterotrophs (OHOs) on RBCOD (Dold *et al.*, 1991), and this has been found to be system dependent (Still *et al.*, 1996)]. The higher temperature sensitivity for K_2, θ_{K2}, than the standard value means that if the standard value is used, the actual denitrification potential of the system will be higher than calculated, introducing a factor of safety to the design.

4.2.3 Nitrification kinetics for the simulation model

Whether or not nitrification takes place is mainly governed by the maximum specific growth rate of the nitrifiers (μ_{nm}), but the effluent free and saline ammonia (FSA) concentration N_{ae} is governed not only by μ_{nm} but also by the half saturation coefficient for nitrifiers (K_n) and the endogenous mass loss rate of nitrifiers (b_n), all of which are temperature sensitive viz.

$$N_{ae} = \frac{K_{nT}\ (b_{nT}+1/R_s)}{\mu_{nmT}-(b_{nT}+1/R_s)} \qquad \text{mgN}/l$$

where the model standard values for the 12-22°C temperature range are

$K_{nT} = K_{n20}\ (1.123)^{(T-20)}$ mgN/l and $K_{n20} = 1.0$ mgN/l
$b_{nT} = b_{n20}\ (1.029)^{(T-20)}$ /d and $b_{n20} = 0.04$ /d
$\mu_{nmT} = \mu_{nm20}\ (1.123)^{(T-20)}$ /d

Examining the ammonia in the effluents from the MLE and UCT systems at 30°C over the periods I, II and III, significantly all gave concentrations between 2 and 3mgN/l, see Tables 3.17 and 3.18. Using the standard values for the nitrification process, K_{n20} = 1mgN/l, $\mu_{nm20} = 0.4$ and $\theta_{Kn} = \theta_{\mu nm} = 1.123$, simulation of the MLE system at 10 days sludge age gave an effluent ammonia of 2.3mgN/l at 20°C and 1.0mgN/l at 30°C. With $\mu_{nm20} = 0.4$ and $\theta_{\mu nm} = 1.123$, gives a $\mu_{nm30} = 1.27$ /d, which is somewhat higher than the 1.03 /d measured in the batch tests. However, for the purposes of determining the K_{n30} and its temperature sensitivity coefficient θ_{Kn}, the actual value of μ_{nm30} does not influence the outcome very much because the rate is so high. Therefore the model standard μ_{nm20} and θ_{Kn} values were retained. Now an MLE system with the same reactor configuration but a sludge age of 20 days, gives simulated effluent ammonia concentrations of 0.8mgN/l at 20°C and 0.6mgN/l at 30°C. The value at 20°C and 20 days sludge age approximates the historical experimental expectation of 1mgN/l so that it would appear that K_{n20}=1mgN/l is adequate. However, for 10 days sludge age at 20°C the simulated effluent ammonia equals 2.3mgN/l. This higher value arises theoretically due to the short sludge age with K_{n20} = 1mgN/l. (Unfortunately there are no FSA experimental data[1] to verify this higher effluent ammonia value at 10 days sludge age and 20°C). With $\theta_{Kn} = 1.123$ and K_{n20} = 1mgN/l at 10 days sludge age and at 30°C, the simulated effluent ammonia concentration is only 0.8mgN/l. From past simulation experience the effluent ammonia is significantly affected by the K_{nT} value and only to a minor degree by μ_{nmT} provided μ_{nmT} is sufficiently large to ensure near complete nitrification. To obtain an effluent ammonia of between 2 and 3mgN/l as observed experimentally at 30°C and 10 days sludge age in the MLE system, it would appear that K_{n30} must be much larger than the value calculated from the temperature dependency relationship with $\theta_{Kn} = 1.123$. Accordingly by trial the value of θ_{Kn} was increased until the simulated effluent ammonia equalled that observed in period I, i.e. 2.2mgN/l. This required $\theta_{Kn} = 1.215$, that is, in the range 20 to 30°C, K_{nT} is much more sensitive to temperature, increasing at a faster rate in the range 20 to 30°C than in the range 12 to 20°C.

4.2.4 Comparison of simulated and observed MLE performance

For period I, we now have an estimate of $f_{up} = 0.154$ mgCOD/mgTCOD and temperature dependencies of K_{nT}, i.e. $\theta_{Kn} = 1.215$. Inserting these in UCTOLD and the necessary input

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[1] Usually the unfiltered (and filtered) effluent TKN concentration is measured because this is required for the N balance. The effluent FSA concentration is an additional measurement not routinely done, except when the nature of the investigation specifically requires it.

data for the MLE system for period I, the simulated response is listed in Table 4.4 and compared with the experimental response. Except for a lower experimental OUR in the aerobic reactor there is excellent agreement between the simulated and experimental responses. This does not constitute an independent verification, because the data collected over period I was used to determine f_{up} and θ_{Kn}. The lower OUR observed can be explained, at least partially, by noting that the experimental COD and N mass balances were less than 100%, whereas the theoretical models are based on 100% COD and N balance.

There is little merit in simulating and comparing experimental responses for long term periods II and III because experimental data in these periods are not as reliable as period I (see Chapter 3).

Table 4.4 Simulation (UCTOLD) and experimental values of some key parameters in period I in MLE system at 30°C.

Parameter	Label	Simulation	Experimental
Influent			
COD	mg/*l*	751	751
TKN	mgN/*l*	65	65
Total P	mgP/*l*	15.1	15.1
Anoxic reactor			
NO_3	mgN/*l*	0.0	0.6 +/- 0.1
Soluble P	mgP/*l*	- ****	9.8 +/-0.4
Aerobic reactor			
VSS	mg/*l*	1893***	1892*** +/- 94
OUR	mgO_2/l	43.5	38.3 +/-1.6
NO_3	mgN/*l*	6.7	5.5 +/- 0.6
COD/VSS	mgCOD/mgVSS	1.48	1.45 +/- 0.02
TKN/VSS	mgTKN/mgVSS	0.1	0.096 +/- 0.003
Soluble P	mgP/*l*	- ****	9.3 +/-0.4
Filtered effluent			
TKN	mgN/*l*	-	(3.3)* +/- 0.2
FSA	mgN/*l*	2.2	2.1 +/- 0.1
COD (unfiltered)	mg/*l*	-	(43)* +/- 0.2
COD filtered	mg/*l*	37.5	37.9 +/- 2.4
NO_3	mgN/*l*	6.7	6.0 +/- 0.7
Soluble P	mgP/*l*	- ****	8.6 +/-0.4

*( ) Unfiltered effluent. ** The +/- defines 95% confidence interval of the mean value.

*** f_{up} in the simulation model was varied until these two concentrations became equal. Best fit was obtained with $f_{up} = 0.154$.

**** Note that in UCTOLD model there is not soluble P determination.

4.3 BEHAVIOUR OF UCT SYSTEM AT 30°C

4.3.1 Determination of f_{up} for the UCT system at 30°C

Calculation of the wastewater UPCOD (f_{up}) value for the UCT system at 30°C is more complex than that for the MLE system due to the presence of the polyphosphate accumulating organisms (PAOs). These organisms have a different P content ($f_{XBG,P}$), endogenous mass loss rate (b_G) and endogenous residue fraction (f_{EG}) compared with the ordinary heterotrophs (OHOs) viz. $f_{XBG,P}$ (PAO) = 0.38mgP/mgPAOAVSS versus $f_{XBH,P}$ (OHO) = 0.03 mgP/mgOHOAVSS, b_G (PAO) = 0.04/d versus b_H (OHO) = 0.24/d at 20°C and $f_{Ep,G}$ (PAO) = 0.25 versus $f_{Ep,H}$ (OHO) = 0.20 (Wentzel *et al.*, 1990). In fact, it is this much higher P content in the PAOs compared to the OHOs that produces the biological excess P removal. The model of Wentzel *et al.* (1990), which includes the PAOs, was applied calculate UPCOD (f_{up}) of the wastewater and follows the same approach as calculating f_{up} for the MLE system with the WRC (1984) model. The Wentzel *et al.* (1990) model is structured such that the heterotrophic organism mass is divided into two groups; the "ordinary" heterotrophs (OHOs) and the polyP heterotrophs (PAOs), the difference being their stoichiometric and kinetic constants as indicated above. The problem of determining the PAO and OHO active masses in the BEPR system is compounded by the fact that the UPCOD fraction (f_{up}) also is unknown and determines the proportion of the total influent COD which is biodegradable. As a result, the determination of f_{up} and the PAO and OHO active masses is done simultaneously using the measured MLVSS concentrations as the benchmark. The procedure for calculating the 5 constituent components of the VSS including the UPCOD fraction, is shown diagrammatically in Fig 4.2. With the USCOD fraction f_{us} known from the filtered effluent COD concentration (f_{us} = filtered effluent COD / total influent COD), it involves an iterative process where an estimate of the f_{up} is made from which the total biodegradable COD available is calculated by difference. The proportion of the biodegradable COD that the PAOs obtain in the anaerobic reactor then needs to be determined. To do this, the volatile fatty acids (VFA) concentration in the influent needs to be known (for Mitchells Plain wastewater this is negligible and therefore taken to be zero) and also the fraction of the influent RBCOD that is converted to VFA in the anaerobic reactor by the ordinary facultative heterotrophs (OHOs). The PAOs obtain that part of the influent COD which is VFA and the part of the influent RBCOD converted to VFA in the anaerobic reactor; the OHOs obtain the balance of the biodegradable COD i.e. that part of the RBCOD not converted to VFA in the anaerobic reactor and all of the slowly biodegradable COD (SBCOD) - the Wentzel *et al.* (1990) BEPR model does not include SBCOD hydrolysis to RBCOD in the anaerobic reactor. The split of the biodegradable COD between the PAOs and the OHOs is calculated interactively from the measured influent RBCOD concentration and the system design parameters that govern RBCOD conversion and VFA uptake i.e. anaerobic mass fraction and sludge age as demonstrated by Wentzel *et al.* (1990). To to account of temperature, the endogenous mass loss rates of the OHOs and PAOs at 20°C (b_{H20} and b_{G20}) and the OHO RBCOD conversion to VFA rate (K) were adjusted to 30°C with a temperature sensitivity coefficient θ = 1.029 viz. $b_{H30} = 0.24(1.029)^{(T-20)} = 0.32$ /d, $b_{G30} = 0.04(1.029)^{(T-20)} = 0.053$ /d and $K_{30} = 0.06(1.029)^{(T-20)} = 0.08$ /d. With the proportions of the biodegradable COD obtained by the PAOs and OHOs known, the masses of active and endogenous VSS generated by these two groups are calculated. Also from the initial estimate of f_{up}, the inert VSS mass is calculated. By adding the 5 calculated constituent components of the VSS mass (as shown in Fig 4.2), the total VSS mass of the system is known. The correct estimate of the f_{up} is that value which gives the calculated VSS equal to the measured VSS. The active OHO ($X_{B,H}$) and PAO ($X_{B,G}$) concentrations divided by the VSS concentration (X_v) are the active OHO and PAO fractions of the VSS respectively and are designated $f_{av,OHO}$ (= $X_{B,H}$ /X_v) and $f_{av,PAO}$ (= $X_{B,G}$ /X_v) respectively.

<table>
<tr><td colspan="7">Total COD - <i>known</i></td></tr>
<tr><td colspan="5">Total biodegradable COD - <i>unknown</i></td><td colspan="2">Total unbiodegradable COD - <i>unknown</i></td></tr>
<tr><td colspan="3">Measured from influent - <i>known</i></td><td colspan="2"><i>Unknown</i></td><td><i>Unknown</i></td><td>Measured from effluent - <i>known</i></td></tr>
<tr><td colspan="3">RBCOD</td><td colspan="2">SBCOD</td><td>UPCOD</td><td>USCOD</td></tr>
<tr><td colspan="2"></td><td colspan="3"></td><td>f_{up}</td><td>f_{us}</td></tr>
<tr><td colspan="2"><i>Unknown?</i></td><td colspan="3"><i>Unknown?</i></td><td><i>Unknown?</i></td><td>Determined from filtered effluent COD concentration</td></tr>
<tr><td colspan="2">COD obtained by PAOs</td><td colspan="3">COD obtained by OHOs</td><td></td><td rowspan="6"></td></tr>
<tr><td>Active polyP VSS mass</td><td>Endogenous polyP VSS mass</td><td colspan="2">Active ordinary heterotroph VSS mass</td><td>Endogenous ordinary heterotroph VSS mass</td><td>Inert VSS mass</td></tr>
<tr><td>1</td><td>2</td><td colspan="2">3</td><td>4</td><td>5 (Components contributing to Total VSS mass)</td></tr>
<tr><td colspan="6">Total VSS mass (must equal measured value)</td></tr>
<tr><td colspan="2">P_G</td><td colspan="3">P_H</td><td>P_I</td></tr>
<tr><td colspan="6">Total P removal (must equal measured value)</td></tr>
</table>

Fig. 4.2: Diagrammatic representation of the utilisation of the Total influent COD (TCOD) in the BEPR model of Wentzel *et al.* (1990).

With the f_{up} detrermined as above, the P content of the PAO active mass ($f_{XBG,P}$) that produced the observed BEPR is then selected. With the P content of the other 4 constituent fractions of the VSS fixed at 0.03 mgP/mgVSS in terms of the Wentzel *et al.* (1990) model, the total P removal by the system can be calculated for a particular $f_{XBG,P}$. The correct value of $f_{XBG,P}$ is that value for which the calculated P removal is the same as the measured P removal. The f_{up} , $f_{av,OHO}$, $f_{av,PAO}$ and $f_{XBG,P}$ results of the calculations for the 41 sewage batches fed to the 30°C UCT system are listed in Appendix M, Table M.2. Graphical statistical plots of the calculated f_{up} values for the long term periods I, II and III are given in Appendix K, Figs K.4 to K.6. The mean f_{up} with their 95% confidence intervals for the 3 long term periods and the investigation overall (long term period IV), are given in Table 4.5. The mean f_{us} values for the 30°C UCT system are also given in Table 4.5.

Table 4.5 Mean f_{up} and f_{us} values observed in the UCT system at 30°C over long term periods I, II and III and the investigation overall (Period IV).

30°C UCT System	Period I	Period II	Period III	Period IV
f_{up} (UPCOD)	0.141 (±0.024)*	0.179 (±0.038)*	0.118 (±0.023)*	0.149 (±0.020)*
fus (USCOD)	0.053**	0.053**	0.053**	0.053**

* 95% confidence intervals.

** Long term period mean filtered effluent COD concentration divided by the long term period mean influent COD concentration. Identical values are obtained if sewage batch means are averaged over the long term periods and investigation overall. Sewage batch means are given in Appendix M, Table M.2.

Comparing the f_{up} values calculated for the UCT and MLE systems at 30°C (Tables 4.1 and 4.5), it can be seen that relatively similar values are obtained viz. $f_{up} = 0.155$ for the MLE system and $f_{up} = 0.149$ for the UCT system for the investigation overall. The overall investigation f_{us} values are also similar viz. $f_{us} = 0.051$ for the MLE system and $f_{us} = 0.053$ for the UCT system. With f_{up} and f_{us} being wastewater characteristics, this is what one would expect. However, when comparing the f_{up} value obtained in this investigation with f_{up} values obtained in the identical UCT system at 20°C in the parallel investigation of Sneyders *et al.* (1997) and other earlier laboratory scale M/UCT systems fed the same wastewater (Clayton *et al.*, 1989; Musvoto *et al.*, 1992; Kaschula *et al.*, 1993 and Pilson *et al.*, 1995) significantly different results are obtained. The overall mean and standard deviation, and maximum and minimum sewage batch f_{up}, active OHO fraction ($f_{av,OHO}$) and PAO P content ($f_{XBG,P}$) obtained in this and the investigations cited above are listed in Table 4.6.

Table 4.6: Calculated overall investigation mean and standard deviation and sewage batch maximum and minimum f_{up}, $f_{av,OHO}$ and $f_{XBG,P}$ for the MUCT/UCT systems of this (This) and 5 other investigations.

System	Unbio. Part COD frac (f_{up})				OHO active fraction ($f_{av,OHO}$)				PAO P content ($f_{XBG,P}$)			
	Mean	S Dev	Max	Min	Mean	S Dev	Max	Min	Mean	S Dev	Max	Min
Clayton	0.150	-	-	-	0.210	-	-	-	0.388	-	-	-
Musvoto 1	0.287	0.056	0.371	0.163	0.133	0.023	0.192	0.101	0.144	0.067	0.291	0.084
Musvoto 2	0.317	0.074	0.456	0.230	0.122	0.024	0.154	0.079	0.113	0.021	0.143	0.087
Kaschula C	0.191	0.024	0.227	0.161	0.164	0.009	0.181	0.153	0.127	0.063	0.246	0.042
Kaschula E	0.197	0.026	0.252	0.169	0.158	0.017	0.180	0.121	0.143	0.079	0.290	0.035
Pilson 20°C	0.111	0.017	0.26	0.01	0.327	0.011	0.45	0.22	0.136	0.031	0.196	0.085
Pilson 12°C	0.153	0.014	0.26	0.02	0.302	0.008	0.38	0.26	0.098	0.031	0.166	0.041
Sneyders E	0.040	0.055	0.132	-0.042	0.478	0.102	0.678	0.340	0.428[2]	0.070	0.541	0.296
Sneyders C	0.062	0.023	0.107	0.023	0.435	0.042	0.518	0.370	0.428	0.070	0.541	0.296
This LP I	0.141	0.059	0.25	0.03	0.288	0.060	0.42	0.20	0.28	0.05	0.38	0.19
This LP II	0.179	0.054	0.24	0.09	0.260	0.049	0.34	0.21	0.20	0.05	0.27	0.15
This LP III	0.118	0.033	0.17	0.08	0.303	0.033	0.35	0.25	0.26	0.06	0.35	0.15

[2] The $f_{xbg,p}$ of Control (C) system was applied to Experimental (E) system to calculate the % leachate taken up for BEPR.

For the same wastewater source, reasonably consistent f_{up} values are expected. For aerobic and ND systems evaluated above (Table 4.1) this was the case: For the Mitchells Plain unsettled wastewater, f_{up} was found to be around 0.12 for widely differing aerobic and ND systems viz. 0.108±0.052 for aerobic systems (Mbewe *et al.*, 1995), and 0.135±0.060 (Warburton *et al.*, 1991) and 0.12±0.04 (Ubisi *et al.*, 1997b) and 0.155±0.060 in this investigation on the MLE system. However, for NDBEPR M/UCT systems, this was *not* the case (Table 4.6). Not only was f_{up} slightly higher for M/UCT systems fed the Mitchells Plain unsettled wastewater, it also varied widely in the different systems, viz. from 0.04±0.055 (Sneyders *et al.*,1997) to 0.293±0.063 (Musvoto *et al.*, 1994). Because of the method of calculating the f_{up} fraction, the variation in f_{up} changes the $f_{av,OHO}$. This in turn affects the K'_2 (and K'_3 in the secondary anoxic reactor) specific denitrification rates, which are higher for higher f_{up} and lower for lower f_{up} (Table 4.11 and Fig 4.4 below). Clearly, there are factors that affect the sludge production per unit COD load in the NDBEPR system that the models do not recognize. Two such factors appear to be the unaerated sludge mass fraction (f_{xt}) and sludge settleability (DSVI). The higher the f_{xt}, the higher the f_{up}, which could be due to an accumulation of undegraded slowly biodegradable COD (SBCOD) in the system. If this were the only factor, then the method of calculating f_{up} and $f_{av,OHO}$ would be acceptable because undegraded SBCOD in effect is unbiodegradable particulate COD. However, this is not the only factor because systems with the same f_{xt} yield different f_{up} and $f_{av,OHO}$ values depending on the DSVI (Musvoto *et al.*, 1994; Casey *et al.*, 1994a,b). As the DSVI and hence AA (low F/M) filament abundance increased, so the system VSS mass decreased and *vice versa*. The calculated denitrification K' rates varied accordingly (see Table 4.11 below), decreasing as the system VSS mass increased and *vice versa*. No explanation for this variation with DSVI can be advanced.

4.3.2 Aerobic batch tests - maximum specific growth rate of nitrifiers (μ_{nm})

The same procedure as for the 30°C MLE system was applied for the 17 aerobic batch tests conducted on the 30°C UCT system sludge, except that additionally filtered Total P was measured on the samples taken during the tests to observe the progress of aerobic P uptake. Of the 17 batch tests, 14 were conducted during long term period I and 3 during long term period II. The batch test results and calculations are given in Table L.2 and the graphical statistical plots in Figs L.4 and L.5 in Appendix L. The statistical results of the tests conducted during long term periods I and II are summarized in Table 4.7.

Pilson *et al.* (1995) calculated the nitrifier maximum specific growth rate (μ_{nm}) temperature sensitivity coefficient ($\theta_{\mu nm}$) in the temperature range 12 to 20°C (see Table 4.7) using the following equation and obtained a value of $\theta_{\mu nm} = 1.10$ which is close to the standard value often used in design i.e. $\theta_{\mu nm} = 1.123$ (WRC, 1984) viz:

$$\mu_{nm12} = \mu_{nm20}\,\theta_{\mu nm}^{(T-20)}\,; \quad 0.314 = 0.67\,\theta_{\mu nm}^{(-8)}\,; \quad \theta_{\mu nm} = 1.10$$

Sneyders *et al.* (1997) operated an identical UCT system during second half of this investigation, but the system was operated at a temperature of 20°C (see Table 4.8). It was therefore possible to calculate $\theta_{\mu nm}$ in the temperature range 20 to 30°C using the $\mu_{nm30} = 0.81$ /d from this investigation and that measured by Sneyders *et al.* (1997) at

20°C, i.e.

$$\mu_{nm30} = \mu_{nm20}\,\theta_{\mu nm}^{\,(T-20)}\,;\ 0.81 = 0.3002\,\theta_{\mu nm}^{\,(+10)}\,;\ \theta_{\mu nm} = 1.104$$

Table 4.7: The median, mean, standard deviation of the data, standard error of the mean and the 95% confidence interval of the maximum specific growth rate of the nitrifiers (μ_{nm}) measured in the aerobic batch tests on the M/UCT systems at 30 °C in this investigation and in two other investigations at 20°C and 12°C.

Test	Median	Mean	SD of data	SE of mean	95% CI	No of tests
30°C UCT system						
BT 1-14	0.788	0.810	0.202	0.054	0.106	14
BT 14-16	0.423	0.513	0.330	0.191	0.374	3
20°C UCT system (Sneyders *et al.* (1997)						
BT 1-5 EXP	-	0.301	0.044	-	-	5
BT 1-5 CTL	-	0.300	0.027	-	-	5
20°C MUCT system (Pilson *et al.*, 1995)						
BT 1-2	-	0.67	-	-	-	2
12°C MUCT system (Pilson *et al.*, 1995)						
BT 1-2	-	0.314	-	-	-	2

Comparing the $\theta_{\mu nm}$ observed by Pilson *et al.* (1995) with that observed in this and Sneyders *et al.* (1997) investigations, showed that there was no difference in the $\theta_{\mu nm}$. However, a large difference is evident between the μ_{nm20} observed by Sneyders ($\mu_{nm20} = 0.30$ /d) and Pilson ($\mu_{nm20} = 0.67$ /d). Figure 4.3 illustrates the above in that the line representing $\theta_{\mu nm}$ of Pilson *et al.* (1995) and the line representing $\theta_{\mu nm}$ of Sneyders *et al.* (1997) and this investigation, are indeed parallel. The discontinuity in the lines arise because the μ_{nm20} determined by Pilson *et al.* (1995) and Sneyders *et al.* (1997) at 20°C are not the same. This can be ascribed either to changes in the sewage content that was collected from the Mitchells Plain Sewage Treatment Plant (the source sewage for all the investigations) or to adaptation of nitrifiers to system conditions. This latter cause is very plausible. Changes in μ_{nm} have been observed in response to different system conditions, viz:

- Batch Feeding - In intermittently feed fill and draw systems μ_{nm20} was significantly higher than in equivalent continuously fed systems (Still *et al.*, 1996).
- Temperature - A temperature of 12°C and sludge age of 12 days initially stopped nitrification in the Pilson *et al.* (1995) MUCT system but over time, nitrification slowly returned so that towards the end of the 582 day investigation it was again complete.

The μ_{nmT} values measured in the MLE and UCT systems in the different investigations and the corresponding $\theta_{\mu nm}$ values calculated from these are summarized in Table 4.8. Although in the M/UCT system, the μ_{nmT} values measured by Pilson and Sneyders are significantly different, the $\theta_{\mu nm}$ values are similar in the 12-20°C and 20-30°C ranges. That is not the case in the MLE system where a $\theta_{\mu nm} = 1.019$ is found for the 20-30°C range. Examining the μ_{nmT} values in Table 4.8, it seems that the $\mu_{nm20} = 0.849$/d measured in this investigation is very high. This value is based on only two batch tests and doesn't compare well with the μ_{nm30} = 0.51/d in three batch tests at 30°C. If the μ_{nm30} = 1.03 from 13 batch tests is accepted and the M/UCT $\theta_{\mu nm}$ value of 1.10, then the μ_{nm20} is $1.03x(1.10)^{-10}$ = 0.40/d. This is in the range measured in the M/UCT systems by Pilson and Sneyders. The $\theta_{\mu nm}$ = 1.019 therefore probably arises from a spuriously high μ_{nm20} = 0.849/d. Taking the μ_{nm20} values overall, it would appear to be best to accept the $\theta_{\mu nm}$ for the 12-20°C and 20-30°C ranges at the same value of around 1.10 i.e. close to the "standard" value of 1.123. The difficulty therefore is not so much choosing the $\theta_{\mu nm}$ value for the specific wastewater and activated sludge system under consideration for design, but the μ_{nm20} value.

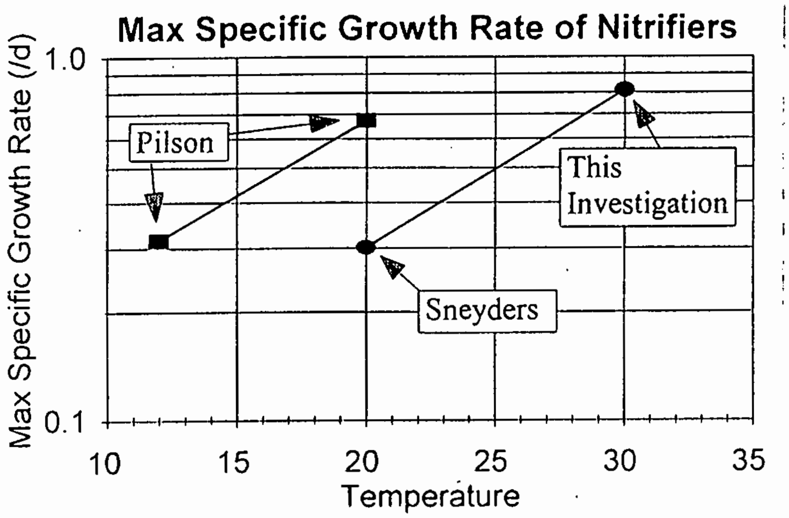

Fig 4.3: Temperature sensitivity ($\theta_{\mu nm}$) of the maximum specific growth rate of the nitrifiers (μ_{nm}). $\theta_{\mu nm}$ is given by the slope of the lines.

Table 4.8: Mean maximum specific growth rates of nitrifiers at 30°C, 20°C and 12°C from this, Sneyders *et al.* (1997) and Pilson *et al.* (1995) investigations in ND (MLE) and NDBEPR (UCT) removal systems

Temperature	30°C	20°C	12°C	Sources
MLE μ_{nmT}	1.033 (13)*	0.849 (2)*		This investigation
	0.510 (3)	-		This investigation
$\theta_{\mu nm}$	1.019*			This investigation
UCT μ_{nmT}	0.810 (14)**			This investigation
	0.513 (3)			This investigation
		0.301(6)**		Sneyders
		0.300(6)**		Sneyders
		0.67 (2)***	0.314 (2)***	Pilson
· $\theta_{\mu nm}$	1.104**	1.100***		

Numbers in ( ) indicate number of batch tests.
Single, double and triple * indicate μ_{nmT} value combinations from which $\theta_{\mu nm}$ was calculated.

4.3.3 Anoxic batch tests - specific denitrification rate K'$_2$

Altogether 27 anoxic batch tests were done on sludge from the 30°C UCT system and 13 on the parallel 20°C UCT system later operated by Sneyders *et al.* (1997). Additionally, Sneyders *et al.* themselves did 6 anoxic batch tests on each of their two 20°C UCT systems, both their systems (CTL and EXP) being identical to the 30°C UCT of this investigation. For the anoxic batch tests of this investigation, 1.5 *l* of sludge was drawn from the aerobic reactor and mixed with 1.5 *l* of sludge from the anaerobic reactor. Sneyders took 1.8 *l* of aerobic reactor sludge and mixed this with 1.2 *l* of anaerobic sludge. Concentrated nitrate solution was added to give an initial nitrate concentration of around 30 mgN/*l*. During the batch test, which lasted about 6 hours, samples were regularly taken and tested for nitrate, nitrite and phosphorus. Details of the test procedure are given in Appendix G, Section G.4. In all the batch tests it was found that there was no initial rapid rate of denitrification (i.e. K_1 due to RBCOD utilization was absent) and the denitrification took place at a single continuous rate. This was expected because the RBCOD would have been mostly converted to volatile fatty acids in the anaerobic reactor and taken up by the PAO organisms. Being due to slowly biodegradable COD utilization, this single denitrification rate was designated K'_2 (Clayton *et al.*, 1991), where the ' indicates the rate in NDBEPR systems to distinguish it from the K_2 rate in ND systems.

Stern and Marais (1974) found that when the batch test nitrate concentration versus time slopes (mgNO_3-N/(*l*.h)) were divided by the VSS concentration to obtain specific denitrification rates (mgNO_3-N/(mgVSS.d)), a decrease in the rate was observed as sludge age increased. However, when the denitrification rates were divided by the Active VSS concentration, they were found to be independent of sludge age (i.e. mgNO_3-N/(mgAVSS.d)). They concluded that this was because the active VSS relates the biological rate of denitrification to the particular component of the VSS mass that is responsible for this rate. This approach has been found to work well for ND systems, because from a modelling perspective, the active mass (AVSS) comprises only one heterotrophic organism group i.e. "ordinary" facultative heterotrophs (OHOs) and these obtain all the influent biodegradable COD. However, for NDBEPR removal plants, the active heterotrophic organism mass comprises two distinct active organism groups viz. (1) the OHOs mentioned above and (2) the polyphosphate accumulating heterotrophs (PAOs) which effect the biological excess P removal. Accordingly, for NDBEPR removal systems, the OHO and PAO active masses need to be "separated" and the denitrification linked to the organism group(s) and mass(es) that perform(s) the denitrification process. The VSS "fractionation" was done in Section 4.3.1 above (see Table 4.6). When anoxic P uptake does *not* take place, the PAOs are considered *not* to contribute to denitrification (Wentzel *et al.*, 1990; Ekama and Wentzel, 1997) and the denitrification rate K'_2 therefore can be specified in terms of the OHO active concentration only (i.e. mgNO_3-N/ (mgOHOAVSS.d)). When anoxic P uptake *does* take place, by implicatuion the PAOs contribute to the denitrification so that the denitrification rate K'_2 should be specified in terms of both the OHOs and PAOs active concentrations in some fashion. However, with the information available at present, it is not possible to quantify the relative contribution of the PAOs to the K'_2 denitrification rate because anoxic P uptake is unpredictable and variable. Accordingly, even though anoxic P uptake did take place in the UCT system of this investigation (see Table 4.15), it was decided to specify the K'_2 rate in terms of the OHO active concentration only. This was done by dividing the observed batch test nitrate concentration versus time slopes (mgNO_3-N/(*l* .h) by the product of the batch test VSS concentration and the OHO active fraction $f_{av,OHO}$ calculated from the sewage batch mean values of the sewage batch during which the anoxic batch tests were carried out. The calculated $f_{av,OHO}$ fractions for the UCT system at 30°C for the 41 sewage batches are listed in Table M.2 in Appendix M. The calculations for the K'_2 rates for the 30 °C and 20°C UCT systems are tabulated in Appendix L, Table L.4. Note that the 20°C UCT system batch tests conducted in this investigation are not the same batch tests Sneyders *et al.* (1997) did on the same 20°C UCT system; Sneyders' batch tests were done about 9 months later than those of this investigation. The graphical statistical plots of the calculated K'_2 denitrification rates are given in Appendix L, Figs L.9 to L.11. The median, mean, standard deviation of the data, standard deviation of the mean and the 95% confidence interval of the mean of the K_2' rates are listed in Table 4.9 below.

From Table 4.9 it can be seen that for period II the mean K'_2 rate at 30°C (K'_{230}) was lower than those for periods I and III and virtually the same as the mean rate for period II at 20°C i.e. K'_{220}. Hence for period II the $\theta_{K'2}$ value is 1.00. Taking period I at 30°C and period II at 20°C gives the highest $\theta_{K'2}$ value viz. 1.035. The K'_{220} rates determined by Sneyders *et al.* (1997) cannot be applied to determine a $\theta_{K'2}$ value because these values do not conform to the 20°C K'_2 rates determined in this investigation. For the period Sneyders operated this 20°C UCT system he obtained an average f_{up} value of 0.062, whereas the f_{up} value for the same system in this investigation was 0.151. This higher f_{up} value decreases the $f_{av\,OHO}$, which in turn increases the K'_2 rate in relation to a lower f_{up} value (see Table 4.6 and Fig 4.4). Because of the variability that the variation in f_{up} causes on the K'_2 rates, the best $\theta_{K'2}$ estimate that can be made for the 20°C to 30°C range is that determined above viz. 1.035. The $\theta_{K'2}$ value for the temperature range 12 to 20°C from the investigation of Pilson *et al.* (1995) is 1.018 (see Table 4.10 for their K'_2 rates at 12°C and 20°C). It therefore appears that the temperature sensitivity of the K'_2 rate is much lower in NDBEPR systems than that for the equivalent rate (K_2) in ND systems viz. from Section 4.3.2 above θ_{K2} was found to be 1.15 for the 20°C to 30°C range and the 'standard' value applied for the 12°C to 20°C is 1.08 (WRC, 1984). These results are summarized in Table 4.10.

Table 4.9: The median, mean, standard deviation of the data, standard error of the mean and the 95% confidence interval of the mean of the K'_2 denitrification rate measured in the anoxic batch tests conducted in this investigation on 30°C and 20°C UCT systems. The values of the anoxic batch tests done later by Sneyders *et al.* (1997) are also shown.

Test	Median	Mean	SD of data	SE of mean	95% CI	No of tests
30°C UCT system						
Period I	0.250	0.254	0.068	0.018	0.035	15
Period II	0.187	0.182	0.052	0.018	0.035	9
Period III	0.232	0.225	0.017	0.010	0.019	3
20°C UCT system (Same as Sneyders' system but test done as part of this investigation)						
Period II	0.176	0.181	0.051	0.016	0.031	10
Period III	0.215	0.218	0.006	0.003	0.007	3
20°C UCT system (Tests done by Sneyders *et al.*, 1997)						
BT 1-5 EXP	-	0.0845	0.0165	-	-	6
BT 1-5 CTL	-	0.0711	0.0132	-	-	6

Interestingly, despite the effect of f_{up} variation in the K'_2 rate, the K'_2 rate obtained in this investigation at 20°C is the same as that obtained by Pilson *et al.* (1995) at 20°C. From

Table 4.10 a consistant pattern can be seen i.e. increased value for the K_2 and K'_2 rates in the higher temperature range and in the both cases their % increase per °C temperature rise in the higher temperature range is double that of the lower range. An overview of the K'_2 rates measured in the investigations of Clayton *et al.* (1989), Musvoto *et al.* (1992), Pilson *et al.* (1995), Sneyders *et al.* (1997) and this one is given in Table 4.11. Where the nitrite denitrification rate was measured, this is also given in Table 4.11.

Table 4.10: Denitrification rates attributable to utilization of SBCOD in NDBEPR (K'_2) and ND (K_2) systems (mg NO_3-N/(mgOHOAVSS*d)) at 30°C, 20°C and 12°C and their temperature sensitivity constants .

SBCOD		30°C	20°C	12°C	Sources
MLE	K_2	0.430	Not determined		This investigation
	K_2		0.101	0.072	"Standard" values
	θ_{K2}	1.15		1.08	
MUCT	K'_2	0.254	0.181		This investigation
	K'_2		0.181	0.157	Pilson *et al.* (1995)
	$\theta_{K'2}$	1.035		1.018	

Table 4.11: Nitrate and nitrite denitrification rates attributable to OHOs only as mgNO_x-N/(mgOHOAVSS.d) observed in the primary anoxic reactor of M/UCT NDBEPR systems operated in five investigations.

System	Nitrate denitrification rate - K'_2				Nitrite denitrification rate				Active ($f_{av,OHO}$)	No of tests**
	Mean	S Dev	Max	Min	Mean	S Dev	Max	Min		
Clayton 20°C	0.255	0.041*	-	-	-	-	-	-	0.210	48/ 0
Musvoto 20°C	0.335	0.113	0.517	0.193	0.291	0.093	0.453	0.190	0.130	11/ 7
Pilson 20°C	0.181	0.0076	0.300	0.111	0.181	0.004	0.197	0.164	0.327	34 / 2
Pilson 12°C	0.157	0.0069	0.248	0.085	0.133	0.011	0.241	0.085	0.302	34 / 5
Sneyders CTL 20°C	0.071	0.013	0.088	0.050	-	-	-	-	0.435	6/0
Sneyders EXP 20°C	0.085	0.016	0.115	0.070	-	-	-	-	0.478	6/0
This 30°C (I)	0.254	0.068	0.41	0.15	-	-	-	-	0.288	15/0
This 30°C (II)	0.182	0.053	0.27	0.08	-	-	-	-	0.260	9/0
This 30°C (III)	0.225	0.017	0.238	0.205	-	-	-	-	0.303	3/0
This 20°C (II)	0.181	0.051	0.275	0.107	-	-	-	-	0.398	10/0
This 20°C (III)	0.216	0.006	0.224	0.214	-	-	-	-	0.487	3/0
* Calculated by multiplying 0.036 Std Dev by 1.14 (see text); **Number of nitrate / nitrite tests										

From Table 4.11, the mean K'_2 rates observed in the different investigations vary widely; from 0.071 to 0.335 mgNO_3-N/(mgOHOAVSS.d), both at 20°C. The single most significant factor influencing the K'_2 rate was the estimate of the $f_{av,OHO}$ fraction - as already mentioned above (see Figs 4.4a and 4.4b below). From Fig 4.4a, it can be seen that as the OHO active fraction increases so the specific denitrification rate K'_2 decreases in almost a linear fashion. From Fig 4.4b, the same applies to the relationship between the unbiodegradable particulate COD fraction f_{up} and the OHO active fraction, i.e. as f_{up} increases so $f_{av,OHO}$ decreases. Therefore K'_2 increases almost linearly with increase in f_{up}.

As mentioned above the reasons for this are not clear. However, the fact that there is a consistent pattern means that there must be a consistent underlying cause. From Fig 4.4a it would appear as though there is a constant concentration of OHOs mediating the denitrification process. Multiplying the K'$_2$ rates by the $f_{av,OHO}$ fraction gives the denitrification rates in terms of mgNO$_3$-N/(mgVSS.d) and for the different investigations the following results are obtained: Clayton - 0.0536; Musvoto - 0.0446; Pilson 20°C - 0.0592 and 12°C - 0.0474; Sneyders EXP - 0.0339 and CTL - 0.0370; Kaschula EXP - 0.0131 and CTL - 0.0128, This invetigation at 30°C, I - 0.0732, II - 0.073, III - 0.0682, and at 20°C I - 0.0452 and II - 0.0624 mgNO$_3$-N/(mgVSS.d). There is not a consistent pattern in these rates expressed as per VSS. Although some probable causes for the variation in denitrification rates in the NDBEPR systems have been identified, as mentioned in Section 4.4.1 above, no satifactory explanation can be advanced for this at this stage.

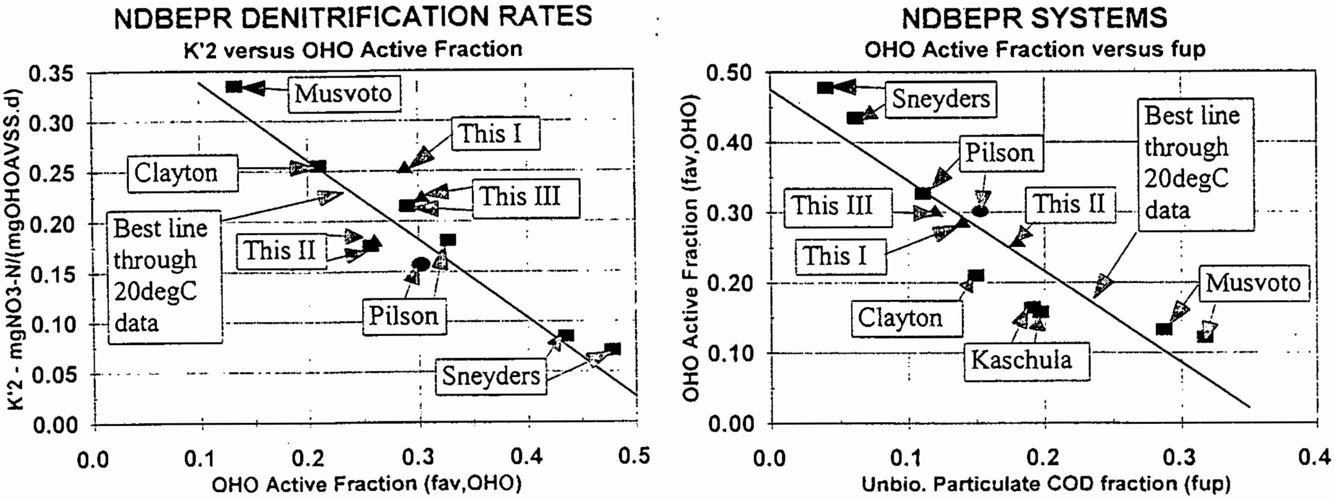

Fig 4.4: Specific denitrification rate K'$_2$ [in mgNO$_3$-N/(mgOHOAVSS.d)] versus ordinary heterotroph active fraction of the VSS ($f_{av,OHO}$) from Table 4.11 (Fig 4.4a, left) and $f_{av,OHO}$ versus influent unbiodegradable particulate COD fraction (f_{up}) from Table 4.6 (Fig 4.4b, right) in M/UCT NDBEPR systems at 12°C (●), 20°C (■) and 30°C (▲).

Initially when Clayton *et al.* (1989) observed the higher K'$_2$ rate in the M/UCT system (0.225mgNO$_3$-N/(mgOHOAVSS.d)) compared with the K $_2$in ND removal system (0.101mgNO$_3$-N/(mgOHOAVSS.d)), they concluded that this (i) was not due to PAO contribution to denitrification because no P uptake was observed in the anoxic reactors and (ii) was not due to SBCOD pretreatment in the anaerobic reactor making it more easily degradable under anoxic conditions because M/UCT system sludge exposed to SBCOD that had not passed through the anaerobic reactor produced the same high K'$_2$ rate. They concluded that the increased K'$_2$ rate was due to an increased adsorbed SBCOD hydrolysis-utilization rate by the OHOs in NDBEPR systems compared with ND systems. The observation of higher K'$_2$ rate in NDBEPR systems at 20°C compared to the 'standard' K$_2$ rate in ND systems was also made in the subsequent investigations of Musvoto *et al.* (1992) and Pilson *et al.* (1995). Also, the K'$_2$ rate observed in the 20°C UCT system of this investigation is higher than the 'standard' K$_2$ rate in ND systems at 20°C (see Table 4.11). This increase in K'$_2$ rate in NDBEPR systems is dealt with in the general simulation models, such as UCTPHO (Wentzel *et al.*, 1992) and IAWQ ASM No 2 (Henze *et al.*, 1995), by increasing the factor which accounts for the reduction in the SBCOD hydrolysis-utilization rate under anoxic conditions η_G from 0.33 for ND systems to 0.60 for NDBEPR systems. What cannot be explained in this investigation at 30 °C is the very high K_2 rate observed in the MLE system, viz. 0.430mgNO_3-N/(mgOHOAVSS.d), which is 1.7 times higher than the K'_2 rate in the NDBEPR system (0.254mgNO_3-N/(mgOHOAVSS.d)) (see Tables 4.10 and 4.11). This is contrary to the observations at 20 °C where K'_2 was significantly higher than K_2. This high K_2 rate at 30 °C also results in the very high θ_{K2} of 1.15 in the 20 °C to 30 °C temperature range for the MLE system (see Table 4.10). It is unlikely that the K_2 rate at 30 °C is spuriously high because it is the mean of 17 batch tests (seeTable 4.3).

4.3.4 Different biological P release, uptake and removal behaviour

The NDBEPR models; both steady state (e.g. Wentzel *et al.*, 1990) and dynamic simulation eg. IAWQ ASM No 2 (Henze *et al.*, 1995) are extensions of their predecessors; WRC, 1984; IAWQ ASM No 1 (Henze *et al.*, 1987) by including the kinetics of BEPR. Relatively few interactions between the ND and BEPR processes take place in these models, the main ones being that (1) the reduction factor for the SBCOD hydrolysis/utilization rate, η_G, is increased from 0.33 to 0.60 to account for the increased K'_2 (and K'_3) rates as mentioned above and (2) the volatile fatty acids for the PAOs are generated by the OHOs in the anaerobic zone from the influent RBCOD. Insofar as the BEPR kinetics are concerned, P release and uptake occur exclusively in the anaerobic and aerobic reactors respectively, in conformity with observations such as those of Siebritz *et al.* (1983), Wentzel *et al.* (1985, 1989, 1990), Clayton *et al.* (1991) and Sneyders *et al.* (1997). Therefore, for the Clayton and Sneyders results, given the correct input f_{up} (see Table 4.6) and η_G values, the NDBEPR simulation models will satisfactorily predict the performance of the M/UCT systems. However, in 3 investigations discussed above, viz. Musvoto *et al.* (1992), Kaschula *et al.* (1993) and Pilson *et al.* (1995) and in this investigation, the P release, uptake and removal behaviour was different to that observed on which the kinetic models are based. Not only was the excess P removal lower at about ⅔rds of that expected from the model of Wentzel *et al.* (1990), but also the P release to removal ratio was decreased (see Table 4.12). With the lower P removal, significant P uptake took place in the second anoxic reactors of the MUCT systems of Musvoto and Pilson and in the anoxic reactor of the UCT system of this investigation (Table 4.12). This was confirmed in the anoxic batch tests; whereas in the tests of Clayton *et al.* (1991) and Sneyders *et al.* (1997), negligible P uptake took place under anoxic conditions, in the anoxic batch tests of this investigation, significant (up to 40%) P uptake took place (see Fig 4.5, and Appendix H). It is possible that different species of PAOs find a niche in the systems that can accomplish anoxic P uptake, but which have lower RBCOD to P release, P release to P removal and $f_{XBG,P}$ ratios (Tables 4.6 and 4.12). Biochemical assays have indicated that some PAOs can denitrify (Lötter, 1985; Lötter *et al.*, 1986). Also, laboratory anaerobic-anoxic BEPR systems have been operated successfully (Kuba *et al.*, 1993) and in other studies significant anoxic P uptake has been observed e.g. Kerrn-Jespersen and Henze (1993), Bortone *et al.* (1996), Sorm *et al.* (1996) and Kuba *et al.*

Table 4.12: Overall COD and N balance results and P release, uptake and removal performance of the M/UCT systems from 5 different investigations at UCT.

Parameter	Clayton	Musvoto		Pilson		This	Sneyders	
	1989	1992		1995		1996	CTL	EXP
Temperature (C)	20	20	20	12	20	30	20	20
N Balance (%)	91	105	98	94	99	82	88	90
COD Balance (%)	92	106	107	84	84	92	92	92
Total P removal (mgP/*l*)	21.0	12.2	11.3	12.0	10.9	11.4	13.1	16.8
Total P release (mgP/*l*)	63.0	32.0	32.1	15.0	14.6	19.9	22.8	40.8
% Release in anaerobic	95	64	64	47	15	98	99	95
% Release in 1st anoxic/anoxic	5	36	36	48	56	1	0	5
% Release in settling tank	0	0	0	5	29	1	1	0
Total P uptake (mgP/*l*)	84.0	44.2	43.4	26.9	26.4	31.0	35.9	57.9
% Uptake in 2nd anoxic/anoxic	5	27	47	47	16	29	0	0
% Uptake in aerobic	95	73	53	53	84	68	99	100
P release/P removal ratio	3.3:1	2.44:1	2.70:1	1.34:1	1.24:1	1.75:1	2.42:1	2.74:1
P rem/infl RBCOD ratio	0.105	0.063	0.060	0.069	0.063	0.082	0.116	0.116[2]
P rem/Total infl COD ratio	0.0210	0.0123	0.0118	0.0121	0.0110	0.0156	0.023	0.024
Remarks[1]	(1)	(2)	(2)	(2)	(2)	(2)	(1)	(1)

[1] Total P removal *does* (1;$f_{XBG,P} \approx 0.38$) and *does not* (2;1; $f_{XBG,P} \ll 0.38$) conform to Wentzel *et al.* (1990) BEPR model.

[2] Used same value as CTL system to calculate the VFA and RBCOD available for BEPR in leachate.

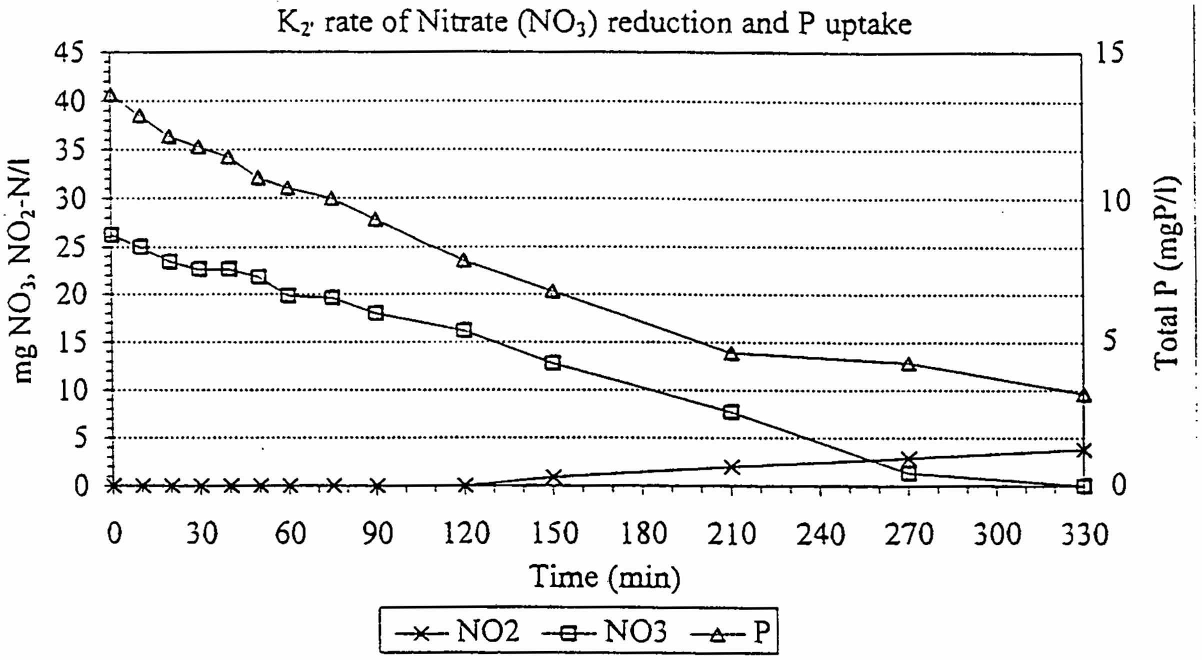

Fig 4.5: Nitrate, nitrite and total P concentrations versus time in a typical anoxic batch test (No12 done on 14/12/95, see Appendix H) on anoxic reactor sludge harvested from the UCT system at 30°C. Note the significant P uptake taking place concomitantly with nitrate reduction.

(1996). Denitrification by PAOs is included in the biochemical model of Wentzel *et al.* (1986, 1991) but is not included in the current NDBEPR simulation models (e.g. IAWQ ASM No2 - Henze *et al.*, 1995 and UCTPHO - Wentzel *et al.*, 1992). Therefore anoxic P uptake behaviour cannot be simulated with current NDBEPR models and this may significantly effect the comparison between the UCTPHO model predictions and the observed experiment results of this investigation at 30°C where significant anoxic P uptake was observed - see Section 4.3.7 below. Proposals to include PAO denitrification into the simulation models have been made (Mino *et al.*, 1995; Barker and Dold, 1997) and it would be interesting to compare the anoxic/aerobic P uptake BEPR behaviour in Table 4.12 with that observed in the DEPHANOX system, which is designed to maximize anoxic P uptake (Bortone *et al.*, 1996; Sorm *et al.*, 1996) to see if the BEPR in these systems also is lower.

4.3.5 Comparison of measured and calculated P Removal.

In order to match the calculated P removal to that measured, the PAO P content ($f_{XBG,P}$) in the Wentzel *et al.* (1990) BEPR model was varied from its "standard" value of 0.38 mgP/mgPAOAVSS. The average $f_{XBG,P}$ values obtained in earlier investigations and in this investigation at 30°C are given in Table 4.6. The mean values for the three long term periods I, II and III of this investigation are 0.28, 0.20 and 0.26 respectively, clearly significantly lower than the "standard" 0.38 mgP/mgPAOAVSS. The effect that this reduced $f_{XBG,P}$ has on the overall system P removal is not as much as the ratio 0.28 to 0.38 would indicate because the OHOAVSS and inert VSS components, which make up a substantial part of the VSS mass, also contribute to the P removal (see Fig 4.2). Had $f_{XBG,P}$ been equal to the "standard" value of 0.38, then the mean P removals for the long term periods I, II and III would have been 15.5, 12.3 and 14.7 mgP/*l* compared with 12.9, 8.3 and 10.3 mgP/*l* observed. This indicates that when simulating the 30°C UCT system BEPR performance with the UCTPHO simulation model, which is based on aerobic P uptake and a $f_{XBG,P} = 0.38$ mgP/mgPAOAVSS, the difference between the predicted and measured P removals and effluent P concentrations will not be as large as the differences in $f_{XBG,P}$ values appear to indicate. This applies in particular to long term period I, the mean results of which are simulated with UCTPHO in the next section below, because this long term period has the closest $f_{XBG,P}$ value to the "standard" model value of 0.38, i.e. 0.28 mgP/mgPAOVSS.

4.3.7 Simulated behaviour of the UCT system at 30°C

A NDBEPR kinetic model has been presented by Wentzel *et al.* (1992) and is available in computerised form (UCTPHO). Default values for the stoichiometric and kinetic constants with associated temperature dependencies of the kinetic constants are included in the model. These values were obtained from experimental systems operated over the temperature range 12 to 20°C. In the UCTPHO model the constants relating to OHO and nitrifier (autotrophs) processes are the same as those in the UCTOLD model except η_G relating to denitrification which is increased from 0.33 to 0.60.

No information is available on the temperature dependencies of the kinetic constants in the temperature range 20 to 30°C for the UCT system. The principal reason for this is that in the past interest was focused virtually totally on the temperature behaviour of plants over summer to winter wastewater temperatures which, in South Africa, ranges from 20 to 12°C respectively. In all the designs incorporating nitrification-denitrification the critical temperature for the design is the low winter temperature. At the low temperature in South Africa (12°C) the sludge age required for ND and NDBEPR plants ranges around 20 days. At 20°C the sludge age for effective operation could in fact be much lower, 10 days or less. This means in effect that the plant designed for winter temperature is overdesigned for summer temperature. In order always to satisfy expected winter conditions, research on the system behaviour even at 20°C, is usually done on sludge ages of 20 days, satisfactory at 12°C.

In the proposed combined treatment systems at Kajaani (Finland) the expected wastewater temperature will range between 20 and 30°C. For the lowest temperature the system sludge age probably need not exceed 10 days so that a plant designed for 20°C at 10d sludge age will be overdesigned at 30°C, provided the temperature dependencies follow the same trend in 20-30°C range as that in the 12-20°C range.

In the absence of information on the temperature dependencies of the kinetic constants (other than those developed above for μ_{nm20} and K'_{220} in this investigation), the default values for the temperature dependencies must be accepted as equal to those in the 12 to 20°C range, as was done when investigating the MLE system. However, for the MLE system in this investigation it was found that the temperature dependency of the half saturation constant for the ammonia-nitrification process had to be modified, $\theta_{Kn} = 1.215$ instead of 1.123. Other parameters of importance in BEPR are the concentrations of USCOD, UPCOD and RBCOD. Of these, the first was obtained from the experimental analysis of UCT system, the second from the experimental analysis of MLE system and the third was measured on the wastewater and confirmed with historical data obtained from previous investigations using the same raw sewage as influent (see Chapter 3, Section 3.5) to give $f_{us} = 0.053$, $f_{up} = 0.155$ and $f_{bs} = 0.23$. The reason for using the MLE system period I f_{up} value was because it was argued that as f_{up} is a wastewater characteristic, it should be independent of the the type of activated sludge system. However, while in this investigation this seems to be the case i.e. similar f_{up} values were obtained in the MLE (0.155) and UCT systems (0.149), this has not always been so (see Section 4.3.1).

To gain an impression of the behaviour of the UCT system, simulations with the UCTPHO model were done at 10 and 20 days sludge age (R_s) and at 20 and 30°C for each sludge age. The system configuration and operational parameters were taken from Table 3.2 and the influent characteristics from Table 3.16. A complete computer printout for the UCT system with $R_s = 10$d, T = 30°C is given in Appendix D. In Table 4.13 are shown the principal output parameters from the four simulations.

In comparing these simulations the following general points of interest are: (1) There are high concentrations of P in the anaerobic reactors, (2) the total P removed is greater at 10 days sludge age than at 20 days sludge age, (3) with the operational recycles specified all the nitrate entering the anoxic reactors is denitrified, (4) the effluent ammonia is about 1mg/*l* at 20 days sludge age and 20°C as observed historically in NDBEPR systems in the laboratory; at 10 days sludge age the effluent ammonia generally is higher, between 2 and 3mg/*l* for both 20 and 30°C.

In Table 4.14 the simulated and experimental values obtained on the UCT system are compared for the long term period I results and sludge age 10 days and temperature 30°C. With regard to ammonia, nitrate and VSS, the simulated and observed responses are in close accord; had the UCT system period I f_{up} value of 0.149 been given as input, the VSS concentrations would have been vitually identical. Close correspondence for these parameters is expected because, in a large measure, the sewage characteristics and kinetic constants were calibrated to reflect the observed response. The experimental OUR is, as in the MLE system, again lower than that simulated, by about 8 percent. Again a part of this difference could be ascribed to the less than 100 percent experimental COD and N balances in the mass balances of the UCT system as noted earlier also with the MLE system.

Table 4.13 Simulation* (UCTPHO) of UCT system at 20°C and 30°C with sludge ages of 10 and 20 days for long term period I.

Influent: COD total 751 mg/*l*, TKN 65 mg/*l*, Total P 15.1 mg/*l*

Sludge age	d	10	10	20	20
Temperature	C	20	30	20	30
Anaerobic reactor					
NO$_3$	mgN/*l*	0.0	0.0	0.0	0.0
Total P	mgP/*l*	43.2	44.6	47.6	48.9
Anoxic reactor					
NO3	mgN/*l*	0.0	0.0	0.1	0.0
Soluble P	mgP/*l*	19.2	20.1	23.2	24.8
Aerobic reactor					
VSS	mg/*l*	2267	2039	3845	3618
OUR carbonaceous	mgO$_2$/*l*	24.5	27.1	28.2	29.5
OUR autotrophs	mgO$_2$/*l*	13.4	14.0	15.1	15.2
OUR total	mgO$_2$/*l*	37.9	41.1	43.3	44.7
NO$_3$	mgN/*l*	9.1	9.5	10.2	10.3
COD/VSS	mgCOD/mgVSS	1.48	1.48	1.48	1.48
TKN/VSS	mgTKN/mgVSS	0.1	0.1	0.1	0.1
Soluble P	mgP/*l*	0.7	0.8	2.9	4.4
Filtered effluent					
TKN	mgN/*l*	-	-	-	
FSA	mgN/*l*	2.4	2.2	0.8	1.4
COD (unfiltered)	mg/*l*	-	-	-	-
COD filtered	mg/*l*	42	42	44	41
NO$_3$	mgN/*l*	9.1	9.5	10.2	10.3
Soluble P	mgP/l	0.7	0.8	2.9	4.4
Total P removal	mgP/*l*	14.4	14.3	12.2	10.7

*Based on $\mu_{nm20} = 0.4$, $\theta_{KnT} = 1.215$, $f_{up} = 0.154$, $f_{bs} = 0.23$

With regard to the P concentrations, the experimental system removal is about 1.4mgP/*l* less than that simulated (Experimental removal = 12.9mgP/*l*, Simulated removal = 14.3mgP/*l*). However, in the anaerobic and anoxic reactors the experimental and simulated soluble P concentrations differ markedly due to the anoxic/aerobic P uptake behaviour of the UCT system and the aerobic P uptake kinetics of the UCTPHO model. These differences are highlighted in Table 4.15, which gives the experimental and simulated influent and effluent P concentrations, the P removal and the anaerobic, anoxic and aerobic reactor P release (-ve) and uptake (+ve) concentrations with respect to the influent flow calculated from P mass balances on the different reactors.

Table 4.14: Simulation (UCTPHO) and experimental values of some key parameters in period I in UCT system at 30°C.

Parameter	Label	Simulation	Experimental
Influent			
COD	mg/*l*	751	751
TKN	mgN/*l*	65	65
Total P	mgP/*l*	15.1	15.1
Anaerobic reactor			
NO_3	mgN/*l*	0.0	0.2 +/- 0.0
Soluble P	mgP/*l*	44.6	23.1 +/- 1.3
Anoxic reactor			
NO_3	mgN/*l*	0.0	0.7 +/- 0.1
Soluble P	mgP/*l*	20.1	9.2 +/- 0.8
Aerobic reactor			
VSS	mg/*l*	2039	1959 +/- 106
OUR carbonaceous	mgO_2/*l*	27.1	-
OUR autotrophs	mgO_2/*l*	14.0	-
OUR total	mgO_2/*l*	41.1	37.8 +/- 1.3
NO_3	mgN/*l*	9.5	7.6 +/- 0.9
COD/VSS	mgCOD/mgVSS	1.48	1.42 +/- 0.03
TKN/VSS	mgTKN/mgVSS	0.1	0.094 +/- 0.002
Soluble P	mgP/*l*	0.8	3.0 +/- 0.7
Filtered effluent			
TKN	mgN/l	-	(3.4)* +/- 0.2
FSA	mgN/*l*	2.2	2.3 +/- 0.2
COD (unfiltered)	mg/*l*	-	(49)* +/- 5.2
COD filtered	mg/*l*	42	40 +/- 2.4
NO_3	mgN/*l*	9.5	8.4 +/- 0.7
Soluble P	mgP/l	0.8	2.2 +/- 0.5
Total *P* removal	mgP/*l*	14.3	12.9

*( )= Unfiltered effluent;
**The +/- defines 95% confidence interval of the mean value.

Table 4.15: Comparison of experimental and simulated influent, effluent and removal, and anaerobic, anoxic and aerobic P release (-ve) and uptake (+ve) P concentrations.

mgP/*l*	Influent	Anaerobic	Anoxic	Aerobic	Effluent	Removal
Experimntl	15.1	-23.5	+6.8	+28.0	2.2	12.9
Simulated	15.1	-55.6	-8.9	+77.2	0.8	14.3

With the exception of P concentrations, the experimental behaviour of the other parameters are in reasonable accord with that simulated. Because the system was designed to give complete nitrification and denitrification at 20°C, the fact that this is so also at 30°C does not necessarily verify the temperature dependencies of the process rates, only that the rates at least did not decline below their values at 20°C. With regard to the BEPR processes there appear to be different behaviour patterns between the experimental and simulated. This aspect was discussed above but will be elaborated on in the next section.

4.3.8 Phosphorus behaviour in the UCT system at 30°C

4.3.8.1 Background

In BEPR systems, the mass of phosphorus incorporated in the sludge is increased from the 'normal' value of 0.02-0.03mgP/mgVSS to a value around 0.06-0.15mgP/mgVSS. This is achieved by the growth of PAOs that take up large quantities of P and store it internally. From Fig 4.2, the more PAOs that can be stimulated to grow in the system, the greater will be the P removal. To stimulate the growth of PAOs, two conditions are required: (1) An anaerobic and anoxic/aerobic sequence of zones, and (2) the presence of short chain fatty acids (also called volatile fatty acid, VFA) in the anaerobic zone.

In many systems treating normal municipal wastewaters, the concentration of VFA in the influent is very low. Yet in these systems the P removal can be substantial. This removal has been linked to the influent RBCOD concentration. In the anaerobic zone, the OHOs take up the RBCOD and acid-ferment it to VFA. However, they are unable to utilize the VFA due to the absence of an external electron acceptor (oxygen or nitrate). The VFAs are therefore rejected to the bulk liquid by the OHOs where they become available to the PAOs. The PAOs are able to take up the VFAs in the anaerobic zone and store these internally. This process requires energy, which they obtain by breaking down the energy-rich polyphosphate chains to orthophosphate. The orthophosphate is released to the bulk liquid increasing the soluble P concentration in the anaerobic reactor, called P release. The P release process is therefore the PAO substrate uptake process. With the internally stored substrate (in the form of polyhydroxyalkanoates such as polyhydroxybutyrate, PHB), the PAOs now are able to grow in the mixed culture system without competition for substrate against the OHOs when electron acceptors nitrate or oxygen become available in the anoxic or aerobic zones. The PAOs therefore thrive in the NDBEPR system through a process of metabolic selection. In the aerobic (and anoxic) zones the PAOs utilize their internally stored substrate to form new PAO mass and replenish their polyphosphate chains. The new PAO mass that forms also makes polyphosphate chains and results in the P uptake being greater than the P release. At steady state, a balance (equality) between the new PAO mass formed and PAO mass harvested from the system via the sludge wastage is established and gives rise to the excess P removal. Nitrate recycled to the anaerobic reactor has an adverse effect on P removal. This is because the OHOs utilize RBCOD with nitrate as electron acceptor; only after the nitrate is depleted would they commence to reject the VFAs. In this way, there is less VFA generation from the influent RBCOD, and the greater the mass of nitrate recycled, the lower the VFA production and the lower the P removal.

From a review of kinetics of BEPR (Wentzel *et al.*, 1985, 1992), the general behavioural characteristics of this phenomena are as follows:

1. P release under anaerobic conditions must be take place in order to give rise to P uptake subsequently under aerobic (or anoxic) conditions, which results in a net P removal for the system.
2. For any fixed process configuration the magnitude of the excess P removal is linked directly to the magnitude of the RBCOD concentration in the influent wastewater; higher the RBCOD the higher the P release, uptake and removal.
3. The greater the fraction of total sludge mass in the anaerobic reactor, f_{xa}, the greater the proportion of the influent RBCOD converted to VFA and hence from (2) above the greater the expected P removal.
4. The more nitrate recycled to the anaerobic zone, the more RBCOD utilized for denitrification and the lower the VFA generation.

The steady state BEPR model of Wentzel *et al.* (1990) is based on the general BEPR behaviour described above. However, while comparison of the steady state and the kinetic simulation BEPR model predicted and experimental results is helpful, this gives little information on the degree of completion of the P release and uptake processes. With nitrification /denitrification there was acceptance that these processes were essentially complete, but no such assumption can be made in regard to the BEPR processes. To find greater insight on the degree of completeness of the BEPR processes, a number of anaerobic, anoxic and aerobic batch tests were undertaken to monitor the progress of the P release in the anaerobic zone and the P uptake in the anoxic and aerobic zones.

4.3.8.2 Batch P release theory

In a BEPR system, P release in the anaerobic reactor is due to uptake of VFA by PAOs, the VFA being produced by the OHOs from the influent RBCOD concentration. Past research has established that for the RBCOD in municipal wastewater, the P release reaction is first order with respect to anaerobic reactor OHO and RBCOD concentrations. The OHO concentration remains essentially constant in the anaerobic reactor so that the rate of release at any time is proportional to the concentration of RBCOD present at that time. While the progress of RBCOD conversion can be monitored by measuring the changes in soluble COD concentrations in the anaerobic reactor, VFA uptake by PAOs is monitored more easily by measuring the change in soluble P concentration. Accordingly the P release anaerobic batch test protocol is to add a volume of wastewater to a sample of mixed liquor drawn from the anoxic reactor (because the system was a UCT system), their respective volumes proportional to their inflow to the anaerobic reactor and then trace the P concentration with time.

Theoretically, in conformity with the first order kinetics described above, the P release with the time has been formulated according to the Eq (4.1) from Wentzel *et al.* (1985):

$$P_t = P_{max}[1-\{(P_{max}-P_o)/P_{max}\}e^{-Ct}] \qquad (4.1)$$

where

P_o = the initial P concentration
P_{max} = maximum P concentration
P_t = P concentration at time t
P_o = P concentration at time zero
$(P_{max} - P_o)$ = maximum release of P possible
C = first order rate constant

Graphically the P concentration versus time in the batch test is illustrated in Fig 4.6a. In a batch test the soluble P concentration (P_t) is determined with time over a test period of 5-6 hours. The value of P_{max} is determined as follows: Select a P_{max} by trial, calculate (P_{max} - P_t) and plot log(P_{max} - P_t) versus time. Adjust the value of P_{max} until the log(P_{max} - P_t)plot is linear. Fig 4.6b. The intersection point of the log(P_{max} - P_t) line on the vertical log(P_{max} - P_t) axis equals P_{max}; the straight line also validates the first order basis of the P release reaction Eq (4.1).

Wentzel *et al.* (1985) showed that the P released, ΔP, by this mechanism is proportional to RBCOD converted to VFA and taken up by the PAOs in the ratio $\Delta P/\Delta RBCOD \approx 0.5$. That is, the PAOs in order to take up 2 mg RBCOD require release of 1mg P from its polyP pool.

The kinetics above describe the behaviour of an anaerobic batch test with municipal wastewater. If instead of wastewater with RBCOD, VFA were added to the anaerobic batch test, the VFA is taken up directly by the PAOs and the P release is proportional to the VFA taken up. The rate of VFA uptake is rapid and constant and the P release kinetic reaction therefore is zero order. That is, the observed P release is linear with time and continues until all the VFA has been taken up by the PAOs or the reservoir of polyP stored in the PAOs has all been released. In contrast, with RBCOD the P release rate is limited to the relatively slow rate of conversion of RBCOD to VFA.

4.3.8.3 P release batch test results

A total 15 batch tests with addition of raw sewage were carried out on the UCT system at 30°C during this investigation, 10 of which were done during long term period I (details of the experimental batch test procedure with sewage (and acetate) as substrate are given in Appendix G.5 and G.6). For each test the value of P_{max} was determined. An example of one such a determination is shown in Fig 4.6. The value for the influent RBCOD fraction (f_{bs}) accepted for the wastewater was $f_{bs} = 0.23$ (see Section 3.5). With this f_{bs} value and $f_{us} = 0.053$, $f_{up} = 0.154$ for the UCT system at 30°C, for each test the value of the RBCOD concentration added to the batch test was calculated and then ratio P_{max} / RBCOD concentration added was calculated. The 10 ratios from the 10 period I batch tests were analysed statistically (see Appendix L, Fig L.14) and give a mean ratio of 0.40mgP/mgRBCOD. That is, in these 10 tests at 30°C, 0.4 mgP were released per

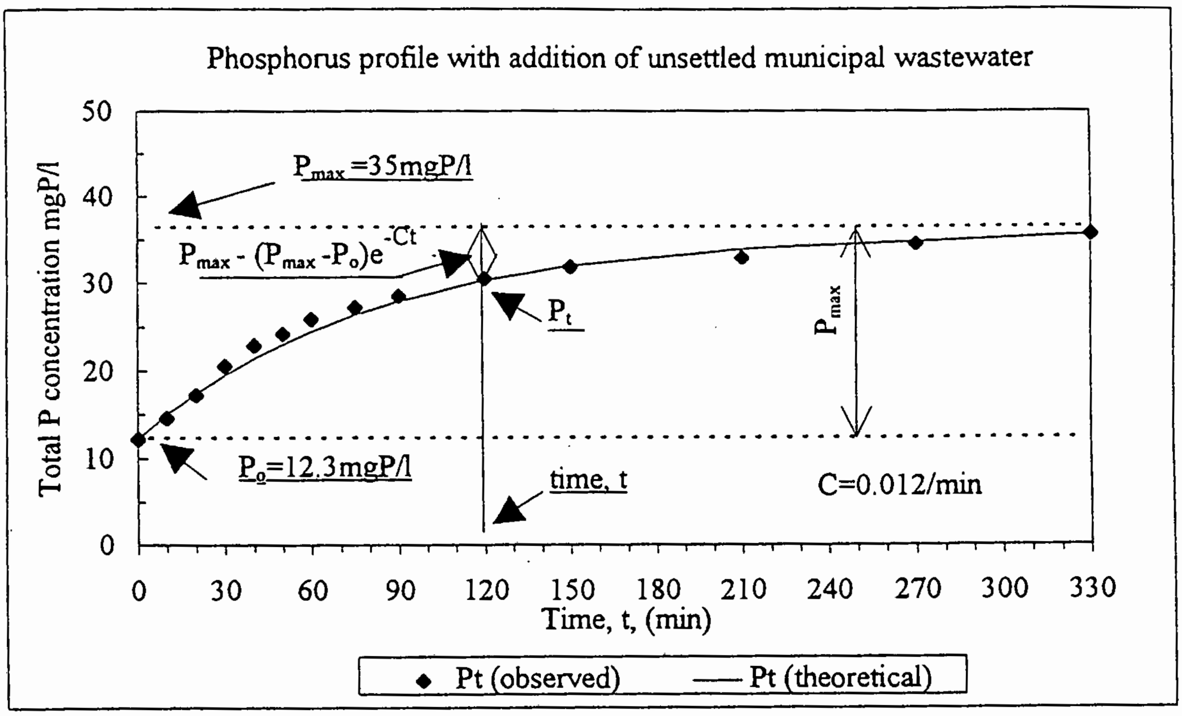

Fig 4.6a: Typical P release versus time profile for anaerobic batch tests on anoxic reactor sludge to which sewage is added. (Test 14 done on 20/11/96, see Appendix H, page H.68).

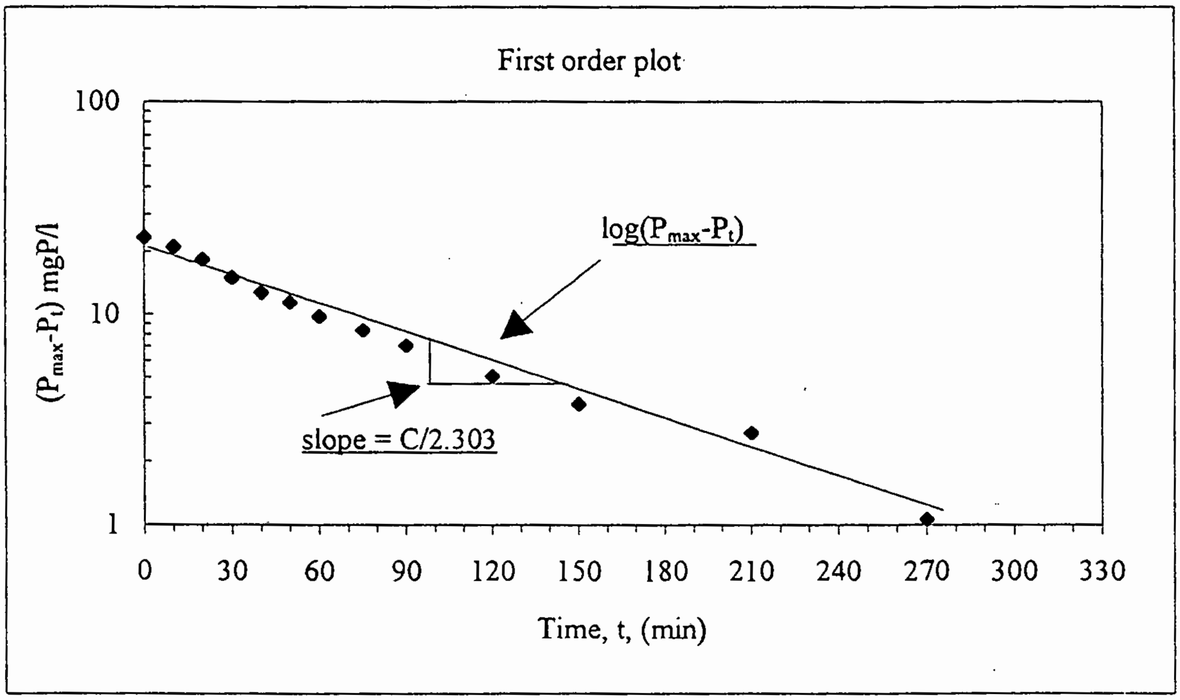

Fig 4.6b: Determination of P_{max} by trial and error; the P_{max} value which gives a linear plot for log[P_{max} - P_t (observed)] is the correct value. (Test 14 done on 20/11/96, see Appendix H, page H.68).

mgRBCOD taken up. Therefore on average, for the total influent COD of 751mg/*l* with an f_{bs} fraction of 0.23, or equivalently f_{ts} = 0.19, the P release should have been 0.4x0.19x751 = 57mgP/*l*.

Batch tests were undertaken also with acetate instead of sewage addition with the acetate concentration at about the same concentration as the RBCOD in the influent wastewater. Nine anaerobic batch tests were done during long term period I. These tests results are reported in Appendix H.43 to H.52, but they serve principally as support of the P release hypothesis and do not contribute to explain the deviant system P release uptake and removal behaviour from that expected from the kinetic models. These batch tests are therefore not of direct interest and not discussed further.

The slope of the log(P_{max}-P_t) versus time plot (Fig 4.6b) gives the P release rate denoted C in Fig 4.6b. For the batch test results in Fig 4.6, the C rate in Eq(4.1) is 0.012 /min. The P release rate C is directly proportional to the RBCOD conversion rate K in Wentzel *et al.* (1985, 1990) steady state BEPR model. In this model K is defined as

$$dS_{bs}/dt = -K\ X_{B,H}\ S_{bs} \qquad [\text{mgCOD}/(l.\text{d})]$$

where S_{bs} = RBCOD concentration (mgCOD/*l*) and
$X_{B,H}$ = OHO active VSS concentration (mgOHOAVSS/*l*)

and therefore after rearranging to allow intergration by parts yields

$$dS_{bs}/S_{bs} = -K\ X_{B,H}\ dt.$$

The basic equation from which Eq (4.1) is derived is

$$dP_t/dt = C.(P_{max} - P_t)$$

and after rearranging to allow integration by parts to obtain Eq (4.1) is

$$dP_t/(P_{max} - P_t) = C\ dt$$

Now as outlined above, the rates of P release and RBCOD conversion to VFA are equal i.e.

$$\frac{dS_{bs}}{S_{bs}} = \frac{dP}{(P_{\max}-P_t)}$$ and hence, sustituting above equations

$$K = C\ .\ \frac{1440}{X_{B,H}} \qquad l/(\text{mgOHOAVSS.d})$$

where C = P release rate determined in the batch tests in /min and
$X_{B,H}$ = active OHO concentration in the batch test mgOHOAVSS/*l*.

In the Wentzel *et al.* (1985, 1990) model the ΔP/ΔRBCOD ratio ≈ 0.5 mgP/mgRBCOD and in this investigation at 30°C this ratio was determined above to be about 0.4 mgP/mgRBCOD. The $X_{B,H}$ concentration was obtained from the measured VSS concentration in the anaerobic batch test (see Appendix H, pages H55 to H69) and the calculated OHO active fraction for the sewage batch during which the batch tests were conducted (see Appendix M). The results for the 15 anaerobic batch tests done in this investigation are summarized in Table 4.16. The overall mean, standard deviation, standard error of the mean, 95% condidence interval and the means of the long term periods I, II and III batch tests of the K values are summarized in Table 4.17.

Table 4.16: Anaerobic batch test data giving the P release rate (C in /min) and RBCOD conversion rate K in *l*/(mgOHOAVSS.d)

Period	Date	C (/min)	Sewage Batch	VSS Conc*	f_{avOHO}	K (/d)
Period I	05-Dec-95	0.011	13	2042	0.256	0.061
Period I	12-Dec-95	0.014	14	1962	0.294	0.070
Period I	20-Dec-95	0.012	14	1962	0.294	0.060
Period I	28-Dec-95	0.014	15	2064	0.269	0.073
Period I	02-Jan-96	0.017	15	2064	0.269	0.088
Period I	09-Jan-96	0.016	15	2064	0.269	0.083
Period I	17-Jan-96	0.013	16	2166	0.289	0.060
Period I	23-Jan-96	0.015	16	2166	0.289	0.069
Period I	30-Jan-96	0.013	17	2162	0.252	0.069
Period I	20-Feb-96	0.010	18	2205	0.229	0.057
Period II	14-May-96	0.011	25	2011	0.208	0.076
Period II	05-Jul-96	0.012	29	2081	0.219	0.076
Period II	08-Jul-96	0.013	29	2081	0.219	0.082
Period III	20-Nov-96	0.012	40	1790	0.282	0.068
Period III	21-Nov-96	0.011	40	1790	0.282	0.063

*This system VSS cancentration is divided by 2 to get the batch test VSS concentration due to the 1:1 dilution by the added influent wastewater.

Table 4.17: RBCOD conversion rate [K, *l*/(mgOHOAVSS.d)] overall mean, standard deviation, standard error of the mean, 95% condidence interval and the means of the long term periods I, II and III anaerobic batch tests.

Overall Mean	Standard Deviation	Std Error of Mean	95% Conf Inetrval	Mean Period I	Mean Period II	Mean Period III
0.070	0.0093	0.0024	0.0048	0.069	0.078	0.066

Taking the 20°C RBCOD conversion rate K determined by Wentzel *et al.* (1985, 1990) and included in the BEPR models of 0.060 *l*/(mgOHOAVSS.d), and the overall mean value determined at 30°C in this investigation of 0.070 *l*/(mgOHOAVSS.d) gives a θ_K = 1.016. Clearly the conversion rate increases as temperature increases, as one would expect, and the increase is reasonable in relation to other temperature sensitivity constants relating to the OHOs. However, it should be noted that this θ_K = 1.016 is based on the $f_{av,OHO}$ estimate, which in turn is based on an assumed θ_K = 1.029 and for which there was no experimental basis (see Section 4.3.1 above). Also, the accuracy of this θ_K = 1.016

depends entirely on the accuracy of the $f_{av,OHO}$ estimate. As was seen above, this fraction caused some problems in the determination of the specific denitrification rate constant K'_2. Despite this, it would seem that reasonable results are obtained for the θ_K value for anaerobic RBCOD conversion rate.

4.3.8.4 Batch test versus UCT system P release

The batch tests were done on blended samples of anoxic reactor sludge and influent wastewater, with the volumes in proportion to their respective flow rates to the anaerobic reactor. Also, the batch test time was at least as long as the anaerobic reactor actual retention time. Therefore, the P release process in the batch test and anaerobic reactor should have been virtually complete and the magnitude of the P release should have been closely the same i.e. in the anaerobic reactor the P release should be closely equal to the batch release P_{max}. Comparing the batch test and a UCT system P release behaviour:

1. Average experimental batch test P release = 57.0mgP/*l*
2. Simulated anaerobic reactor P release in UCT system = 55.6mgP/*l* influent
3. Experimental anaerobic P release in UCT system = 28.0mgP/*l* influent

This exposes a number of contradictory BEPR behavioural patterns:

1. The experimental batch P release conforms to the hypothesised kinetic behaviour and its P_{max} is closely equal to the anaerobic reactor P release from the simulated model, (Exp. batch: simulated P release = 57.0: 55.6).
2. The experimental P release in the anaerobic reactor 28.0mgP/*l* is only about half that predicted by the simulation model or the experimental batch release (55.6; 57.0mgP/*l*).
3. The P removal is dependent on the P release. The simulated P release and removal are 55.6mgP/*l* and 14.3mgP/*l* respectively and that observed experimentally are 23.5mgP/*l* and 12.9mgP/*l* respectively. That is, the simulated and observed P removal are approximately in agreement but simulated and observed P release in the anaerobic reactor are in total disagreement, yet simulated P release is in agreement with the observed batch release.

Despite careful review of the experimental analyses of the data, the conflicting behaviour found above could not be reconciled.

4.3.8.5 P uptake in the anoxic and aerobic reactors

The P mass balance over the anoxic reactor of the UCT system (see Table 4.15) indicated significant P uptake in the anoxic reactor, a behavioural pattern deviant from that 'normally' observed in the NDBEPR system. That anoxic P uptake indeed took place was confirmed by the anoxic batch tests. A typical example of an anoxic batch test response is shown in Fig 4.5 done during period I. A reduction of P took place, approximately linear, at a slow rate while nitrate was present. Nitrate was similarly reduced. However, it is not possible to link the reduction of nitrate to the P uptake because nitrate reduction took place also due to denitrification by the OHOs. Incorporating anoxic P uptake into the BEPR kinetic models like UCTPHO falls outside the scope of this investigation.

Phosphorus uptake in the aerobic reactor was also confirmed by the aerobic batch tests in which the nitrifier maximum specific growth rate was determined (see Section 4.3.2). A typical example of a batch test response done during period I is shown in Fig 4.7. The aerobic P uptake is very rapid initially and of much greater magnitude in mgP/(*l*.h) in the aerobic batch tests than in the anoxic batch tests. It can therefore be inferred that anoxic P uptake in the anoxic reactor of the system also is much slower than the aerobic P uptake in the aerobic reactor of the system.

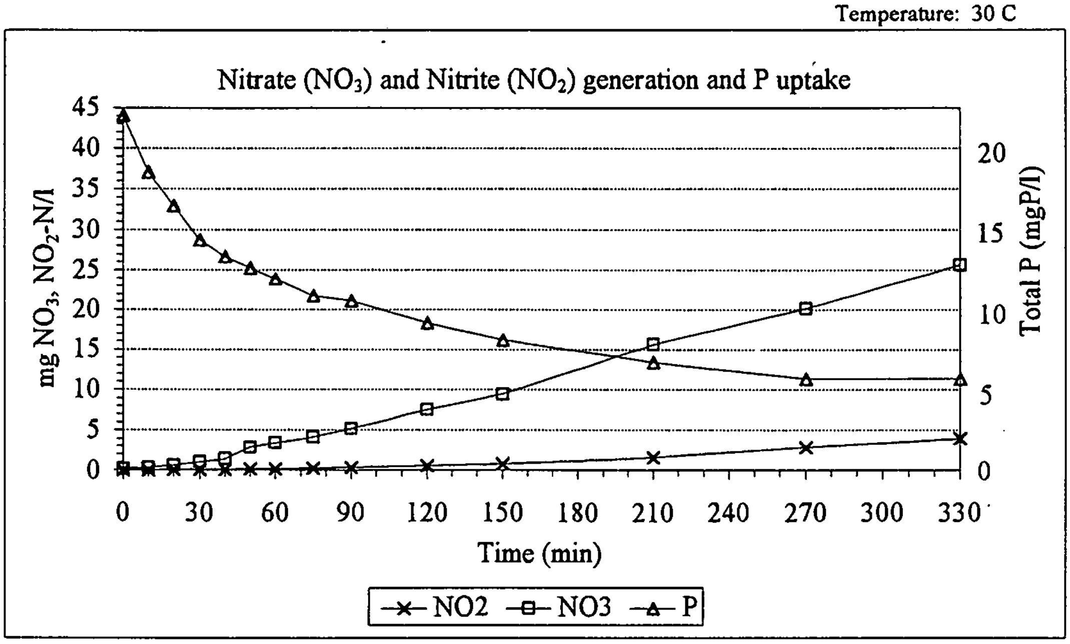

Fig 4.7: Typical aerobic batch test time profiles for nitrate and nitrite concentrations upon ammonia addition from which nitrifier growth rates were calculated. Note the rapid P uptake under aerobic conditions, much faster than under anoxic conditions (see Fig 4.5).

4.3.8.6 Comments on the P release, uptake and removal behaviour

Analysis of the experimental P response data from the UCT system showed that P release, P uptake, and P removal took place by the BEPR process. However, the process showed a behavioural pattern deviant from that expected from the current BEPR models. The models predict P uptake only in the aerobic reactor, whereas experimentally significant P uptake in the anoxic reactor was observed, with the remainder taken up in the aerobic reactor. This deviant behaviour has been observed in other investigations and must be accepted as indicative of a deficiency in the current BEPR models. From the data obtained in this investigation, the total P removal did not appear to be severely affected by this deviant behaviour, but this conclusion cannot be stated with a high degree of certainty. Curiously, the identical UCT system at 20°C operated by Sneyders *et al.* (1997) at the same time as the 30°C UCT system of this investigation, did not show any significant anoxic P uptake and its BEPR behaviour, both qualitatively and quantitatively, was in accordance with the current BEPR models. However, this is not to say that it is the temperature difference that stimulated the anoxic P uptake: There have been two earlier investigations with M/UCT type NDBEPR systems at 20°C where significant anoxic P uptake also has been observed (see Table 4.12). At this stage it's not possible to define the conditions which stimulate significant anoxic P uptake. However, it can concluded that at 30°C a NDBEPR system has the propensity to remove P by the BEPR mechanism and that this P removal can be predicted in some degree by the current BEPR models but that the uptake may take place partially in the anoxic and partially in the aerobic reactors. This proviso applies also for 20°C. Because deviant BEPR behaviour was observed in the 30°C system, it is difficult to assess the magnitude of the temperature effect on the BEPR. Nevertheless, from the observed differences in the anoxic/aerobic and aerobic only P uptake BEPR at 20°C, it can be stated that the effect of anoxic P uptake has a far greater reducing effect on the BEPR than the temperature.

4.3.9 Sludge settleability and filament identification

During the second half of the investigation (day 308 to 582) samples were taken from the MLE and UCT systems approximately every four weeks for filament identification. The results of the identifications are given in Appendix J. The filament most commonly dominant in both the MLE and UCT systems were, in descending order, type 0092, *Microthrix parvicella* and type 1851. Type 021N and *Haliscomenobacter hydrossis* were also frequently observed but not at dominant levels. Apart from type 021N, these filaments are classified as typical of the low F/M category (Jenkins *et al.*, 1984) and are almost always observed in laboratory (Ekama *et al.*, 1996) and full scale (Blackbeard *et al.*, 1986, 1988) ND and NDBEPR systems. Type 021N, being classified as septic sewage filament (Jenkins *et al.*, 1984), probably grew in the systems as a result of the aging of the sewage batch during storage up to two to three weeks.

With laboratory systems Ekama *et al.* (1996) found that once nitrification-denitrification (ND) conditions were included in the activated sludge systems, selector reactors, whether aerobic, anoxic or anaerobic, were not effective for controlling low F/M filament proliferation and bulking. Investigating the ND conditions as a stimulus for proliferation of low F/M filaments, Casey *et al.* (1994) proposed a hypothesis for low F/M filament bulking and renamed this filament category anoxic-aerobic (AA) as more descriptive of the conditions that cause their proliferation. This hypothesis, which is based on the electron transport and enzyme pathways and the inhibition of the oxygen transfer enzyme cytochrome o by the denitrification intermediate nitric oxide (NO), describes how a bulking arises in an ND or NDBEPR system. Stated briefly but not completely because the aerobic mass fraction also plays a role, AA filament bulking is the result of the nitrate and nitrite concentration (NO_x) leakage from the anoxic reactor to the aerobic reactor. If these concentrations are high (> 1 mgN/ℓ) in conjunction with a low aerobic mass fraction (<0.70), then a bulking sludge with a DSVI > 150 mℓ/g would prevail.

A graph of the mean sewage batch DSVI and anoxic reactor nitrate plus nitrite concentration (NO_x, mgN/ℓ) for the MLE and UCT systems is given in Fig 4.8.

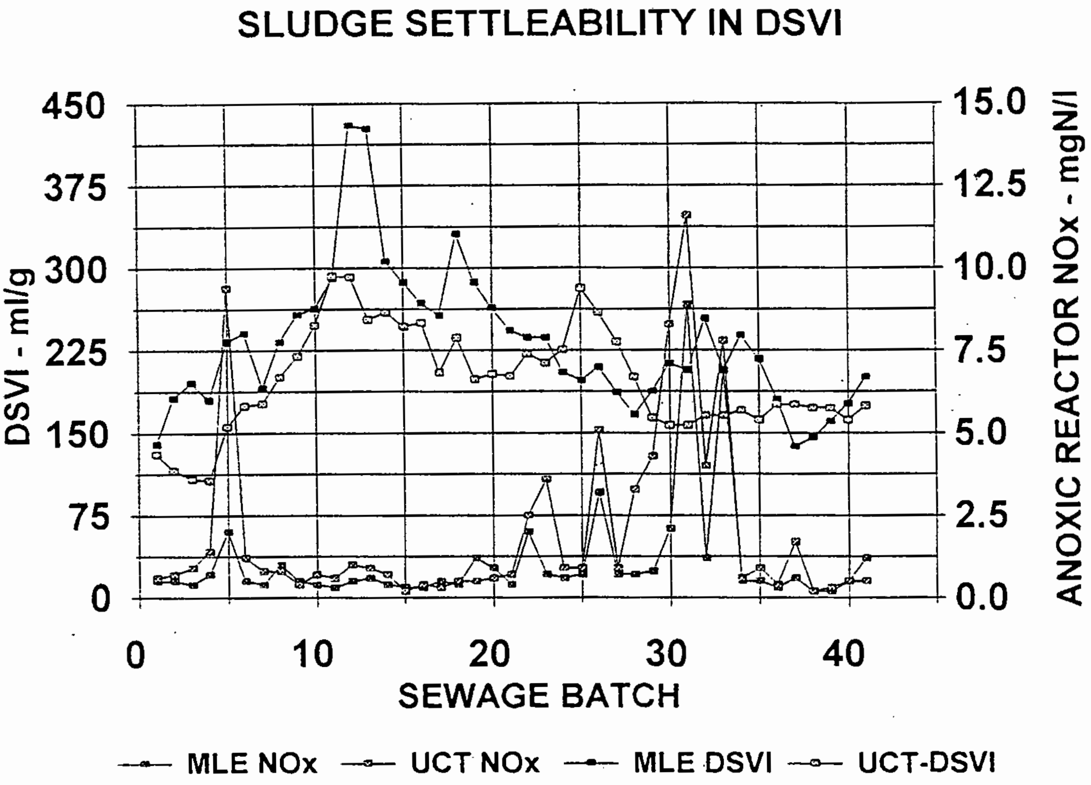

Fig 4.8: Sewage batch mean DSVI and anoxic reactor nitrate plus nitrite concentration (NO_x, mgN/ℓ) observed in the MLE and UCT systems during the 582 day investigation during which 41 sewage batches, each lasting about two weeks, were fed to the systems.

From Fig 4.8 it can be seen that:

1) The DSVI was generally higher in the MLE system than in the UCT system except for sewage batches 24 to 28, which includes the first half of long term period II which showed the very poor BEPR performance in the UCT system.

2) During the first 12 sewage batches, the DSVI increased in both systems from about 150 mℓ/g to over 300 mℓ/g. During this time the anoxic NO_x concentration was generally low (< 1 mgN/ℓ) except for sewage batch 5 which had a very high TKN concentration (98 mgN/ℓ, see Table 3.4) resulting in high nitrate concentrations in the systems and higher nitrate loads on the anoxic reactors than these reactors were able to denitrify. The MLE system coped better with this high nitrate load (lower NO_x than the UCT system) because it's anoxic reactor was larger than that of the UCT system (see Table 3.1).

3) After sewage Batch 12, the DSVI in both systems decreased to about 220 mℓ/g to sewage batch 22.

4) From sewage batch 22 to 33, high NO_x concentrations appeared in the anoxic reactors of both systems. These were generally caused by high influent TKN concentrations; 7 of the 12 sewage batches had very high TKN concentrations (71-85 mgN/ℓ, see Table 3.4) while the remaining 5 sewage batches were "normal" in the 60 to 70 mgN/ℓ range. Sewage batches 24 to 33 constituted long term period II which showed the poor BEPR in the UCT system. Clearly this was caused mainly by high nitrate concentrations recycled to the anaerobic reactor from the anoxic reactor.

5) During the high anoxic NO_x concentration period of sewage batches 22 to 25, the DSVI in the UCT system increased from 220 to 275 mℓ/g but thereafter decreased steadily to 160 mℓ/g by sewage batch 30. The DSVI in the UCT system remained at around 160 mℓ/g until the end of the investigation.

6) During the high anoxic NO_x concentration period of sewage batches 22 to 28, the DSVI in the MLE system continued to decrease from 240 mℓ/g to 160 mℓ/g. Thereafter the DSVI increased to 230 mℓ/g at sewage batch 33. After sewage batch 33, when the NO_x concentration decreased below 1 mgN/ℓ, the DSVI decreased rom 230 to 140 mℓ/g but from sewage batch 37 to 41, while the NO_x concentration still was low, the DSVI increased from 140 to 190 mℓ/g at the end of the investigation.

7) During the changes in DSVI in the MLE and UCT systems, the filament types did not change significantly and therefore the different DSVIs were caused by essentially the same filament types at different levels of abundance.

8) While some periods during the investigation show decreasing DSVI with low anoxic NO_x concentrations in the MLE and UCT systems, e.g. from sewage batch 13 to 22, and would therefore support the AA filament hypothesis, other periods are in conflict with this, e.g. decreasing DSVI with high anoxic NO_x concentrations. The results from this investigation therefore do not give unequivocal support for the AA filament bulking hypothesis of Casey *et al.* (1994).

4.4 CLOSURE

In this chapter, the experimental results obtained from the MLE and UCT systems at 30°C, and the aerobic, anoxic and anaerobic batch tests conducted on sludges harvested from these systems, were evaluated in detail. The results were compared with ND and NDBEPR system results obtained in this and other investigations at 20°C to develop temperature sensitivity coefficients for some of the important kinetic rates in the 20 to 30°C range. Conclusions form this evaluation and comparison are set out in Chapter 5.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 SCOPE AND OBJECTIVES OF INVESTIGATION

The main objective of this investigation was to evaluate activated sludge biological nutrient removal (BNR) performance at elevated temperatures for possible application of nitrification denitrification (ND) and ND biological excess phosphorus removal (NDBEPR) systems to municipal wastewater treatment in the equatorial and tropical regions or to combined treatment of municipal and anaerobically (thermophilic) pretreated paper and pulp industry wastewaters in the very cold northern forested regions. To accomplish this objective a ND Modified Ludzack Ettinger (MLE) system and a NDBEPR University of Cape Town (UCT) system were operated at 30°C and 10 days sludge age for a period of 582 days. During the investigation 41 sewage batches, each lasting about two weeks, of real sewage from the Mitchells Plain municipal wastewater treatment plant (Western Cape, South Africa) were fed to the systems. The two systems were sampled and tested almost daily for Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Free and Saline Ammonia (FSA), nitrate, nitrite, Total Phosphorus, Volatile Settleable Solids (VSS), Total Settleable Solids (TSS), pH, Oxygen Utilization Rate (OUR) and diluted sludge volume index (DSVI) in the influent, anaerobic, anoxic and aerobic reactors and effluent as appropriate. Microscopic analysis of the sludge mixd liquor was undertaken every four weeks during the latter half of the investigation to identify the filamentous organisms. Also, in order to determine the kinetic rates of nitrification, denitrification and readily biodegradable COD (RBCOD) conversion to Volatile Fatty Acids (VFA), aerobic, anoxic and anaerobic batch tests were conducted at 30°C on sludge harvested from the two systems. These kinetic rates at 30°C were then compared with equivalent process rates measured in 20°C ND and NDBEPR systems operated in parallel as part of this investigation or in separate investigations before and after this one. From the 20°C and 30°C process rates, the temperature sensitivity coefficients θ of some of the biological kinetic processes were determined for the 20 to 30°C range and compared with those determined in earlier investigations in the 12 to 20°C range.

Examining the average experimental results of each of the 41 sewage batches, it was noticed that during the winter months (May to June) the UCT sytem showed a very poor P removal performance. The data were therefore divided into 3 long term periods with long term period I including sewage batches 1 to 23 (360 days), long term period II including sewage batches 24 to 33 (130 days) and long term period III including sewage batches 34 to 41 (92 days). The poor P removal performance occurred during period II, with periods of good (though not "normal", see 16 below) P removal during periods I and III. The UCT system BEPR performance was therefore evaluated with the aid of steady state and dynamic simulation models for period I only. These and the other results from this investigation are summarized in Sections 5.2 to 5.9 below.

5.2 SYSTEM COD AND N REMOVAL PERFORMANCE (see Table 5.1)

1. Over the 582 day investigation the average COD balance in the MLE and UCT systems were 94 and 92% respectively, and the average N balance 80% and 82% respectively. Although considerably lower than 100%, these are acceptable and similar to COD and N balances observed in other investigations on nutrient removal systems (see Table 4.12).

Table 5.1: Comparison of MLE and UCT system performance at 30°C and 20°C receiving the wastewater from the same source (Mitchells Plain, Western Cape, South Africa).

Parameter	MLE	MLE*	UCT	UCT**
Temperature	30°C	20°C	30°C	20°C
Sludge age (days)	10	12	10	10
%COD balance	94	91	92	92
%N Balance	80	90	82	88
%COD removal	94.3	89.9	93.8	94.1
%COD in unfiltered effluent	5.7	10.1	6.2	6.9
%COD in waste sludge	36.0	32.7	37.8	37.4
%COD in denitrification	10.4	10.1	9.2	12.8
%COD in oxygen utilized	41.9	8.1	38.8	34.3
%COD unaccounted for	6.0	9.0	8.0	8.6
%N removal	85.3	72.7	79.2	77.6
%TKN in unfiltered effluent	4.2	7.6	4.3	4.2
%Nitrate in effluent	10.5	19.8	16.5	18.2
%N in waste sludge	25.8	24.7	26.1	21.7
%N in denitrification	39.5	37.8	35.1	44.6
%N unaccounted for	20.0	10.1	18.0	11.3
Filtered effluent COD concentration (mgCOD/*l*)	36.4	-	38.5	46.4
Unbiodegradable soluble COD fraction (f_{us})	0.050	0.094	0.054	0.058
Unfiltered effluent COD concentration (mgCOD/*l*)	41.2	54.4	44.2	-
COD of effluent suspended solids (mgCOD/*l*)	4.8	-	5.7	-
Filtered effluent TKN concentration (mgN/*l*)	2.86	-	3.05	2.21
Effluent FSA concentration (mgN/*l*)	2.2	-	2.3	-
Unbiodegradable soluble Organic N concentration	0.7	-	0.7	-
Unbiodegradable soluble Organic N fraction (fnu)	0.010	-	0.010	0.033
Unfiltered effluent TKN concentration (mgN/*l*)	3.36	3.48	3.50	-
TKN of effluent suspended solids (mgN/*l*)	0.5	-	0.45	-
Mass TSS wasted (mgTSS wasted/d)/(mgCOD load/d)	0.278	0.258	0.316	0.327
Mass TSS in system (mgTSS in system)/(mgCOD load/d)	2.78	3.09	3.16	3.27
Mass VSS wasted (mgVSS wasted/d)/(mgCOD load/d)	0.245	0.226	0.260	0.266
Mass VSS in system (mgVSS in system)/(mgCOD load/d)	2.45	2.72	2.60	2.66
Unbiodegradable particulate COD fraction (f_{up})	0.155	0.114	0.149	0.062
COD/VSS ratio (f_{cv})	1.460	1.449	1.442	1.48
TKN/VSS ratio (f_n)	0.100	0.102	0.095	0.10
VSS/TSS ratio (f_i)	0.873	0.876	0.824	0.812
P Removal (mgP/*l*)	5.5	-	11.3	19.6

* Data from Ubisi *et al.* (1997) from a MLE ND system at 12 days sludge age and 25% anoxic mass fraction, which also was system (recycle, 2:1) denitrification limited.

** Data from Sneyders *et al.* (1997) from identical UCT NDBEPR system.

2. The percentage COD removal in the MLE system was 94.3%. Of the 100% influent COD, 5.7% passed out of the system via the unfiltered effluent, 36.0% via the waste sludge, 10.4% via nitrate denitrified and 41.9% via oxygen utilized with 6.0% unaccounted for. The percent COD removal in the UCT system was 93.8%. Of the 100% influent COD, 6.2% passed out of the system via the unfiltered effluent, 37.8% via the waste sludge, 9.2% via nitrate denitrified and 38.8% via oxygen utilized with 8.0% unaccounted for.

3. The overall average 0.45 μm membrane filtered effluent COD concentrations from the MLE and UCT systems were 36.4 and 38.5 mgCOD/ℓ respectfully, giving unbiodegradable soluble COD fractions (f_{us}) of 0.050 and 0.054 respectively. The overall average unfiltered effluent COD concentration from the MLE and UCT systems were 41.2 and 44.2 mgCOD/*l* respectively. The difference between the unfiltered and filtered COD concentrations was therefore 5 mgCOD/ℓ from both systems and is the COD of the suspended solids in the effluent. These results at 30°C are very simliar to those typically obtained at 20°C.

4. The percentage N removal in the MLE system was 85.3%. Of the 100% influent TKN, 10.5%, 4.2 % and 3.3% passed out of the system via the unfiltered effluent as nitrate, TKN and FSA respectively, 25.8% via the waste sludge and 39.5% as N_2 gas via denitrification with 20.0% unaccounted for. The percentage N removal in the UCT system was 79.2%. Of the 100 % influent TKN, 16.5%, 4.3% and 3.3% passed out of the system via the unfiltered effluent as nitrate, TKN and FSA respectively, 26.1% via the waste sludge and 35.1% as N_2 gas via denitrification with 18.0% unaccounted for. The higher % N removal in the MLE system compared with that in the UCT system arises because the MLE system anoxic mass fraction and mixed liquor recycle ratio (i.e. 50% and 4:1) were higher than those of the UCT system (i.e. 35% and 2:1). Denitrification kinetics details are given in Section 5.4 and 5.5 below.

5. The overall average 0.45 μm membrane filtered effluent TKN concentrations from the MLE and UCT systems were 2.86 and 3.05 mgN/ℓ of which 2.2 and 2.3 mgN/*l* is FSA respectively. Hence, the unbiodegradable soluble organic N concentrations (N_{ousi}) from both systems was 0.7 mgN/*l* giving an unbiodegradable soluble TKN fraction (f_{nu}) of 0.010. The overall average unfiltered effluent TKN concentrations from the MLE and UCT systems were 3.36 and 3.50 mgN/*l* respectively. The difference between the unfiltered and filtered TKN concentrations was therefore 0.5 mgN/ℓ from both systems and is the TKN of the suspended solids in the effluent (see 4 above). While the TKN results at 30°C are very simliar to those typically obtained at 20°C, the FSA is considerably higher and the organic N considerably lower than at 20°C (see 12 and 13 below).

6. The masses of COD, TKN and TP fed to both systems daily as well as the system volumes were the same. Hence the TSS and VSS sludge production and reactor masses are directly comparable. In the UCT system, the TSS and VSS sludge production and reactor masses [i.e. 0.316 (mgTSS/d)/(mgCOD/d), 0.260 (mgVSS/d)/(mgCOD/d), 3.16 mgTSS/(mgCOD/d), 2.60 mgVSS/(mgCOD/d) respectively] were 12.6% and 6.5% higher compared with those in the MLE system [i.e. 0.278 (mgTSS/d)/(mgCOD/d), 0.245 (mgVSS/d)/(mgCOD/d), 2.78

mgTSS/(mgCOD/d), 2.45 mgVSS/(mgCOD/d) respectively]. The higher TSS and VSS in the UCT system is due to BEPR - the polyphosphate accumulating organisms (PAOs) generate more VSS per COD utilized than the ordinary heterotrophs (OHOs) and also have a much higher inorganic content due to the presence of internally accumulated P (Wentzel *et al.*, 1990). For the same wastewater characteristics at 10 days sludge age and 20°C (temperature does not influence this result very much), the BEPR model of Wentzel *et al.* (1990) predicts a 23.6% TSS and 8.3% VSS increase due to BEPR compared to ND systems (no BEPR). A VSS/TSS ratio of PAOs (f_{iG}) of 0.69 instead of the "standard" Wentzel *et al.* (1990) BEPR model value of 0.46 mgVSS/mgTSS gives the observed 12.6 %TSS increase over the MLE system. This higher value of $f_{iG} = 0.69$ confirms at least qualitatively that the PAOs in the UCT system of this investigation contained less P per mgVSS ($f_{XBG,P}$) than those in the enhanced PAO cultures of Wentzel *et al.* (1989) (see 16 below).

7. To determine the unbiodegradable particulate COD fraction (f_{up}) of the sewage fed to the MLE system, the appropriate f_{up} value was selected so that the system VSS mass calculated with the ND model of WRC (1984) was equal to that measured using the measured influent characteristics of the sewage (f_{us}, S_{ti}) and the system parameters as input. To do this the endogenous mass loss rate of the OHOs at 20°C (b_{H20}) was adjusted to 30°C with $b_{H30} = 0.24(1.029)^{(T-20)} = 0.32$ /d. Because the model assumes all the biodegradable COD is utilized, this procedure fractionates the VSS mass into its hypothetical constitutive components viz. active OHOs, endogenous residue of OHOs and unbiodegradable particulate VSS (X_i). This fractionation is also required to determine the specific denitrification rates K_1 and K_2 in terms of mgNO$_3$-N/(mgOHOAVSS.d) (see 14 below). An overall average f_{up} value of 0.155 was found for the MLE system. This value is reasonably close to other f_{up} values obtained at 10 and 20 days sludge age and 20°C in previous (Warburton *et al.*, 1991; Mbewe *et al.*, 1995) and concurrent (Ubisi *et al.*, 1995) investigations using the same wastewater viz 0.135, 0.11 and 0.12 respectively. Also, the 30°C COD/VSS (f_{cv}) and TKN/VSS (f_n) ratios of the mixed liquor were similar to the 20°C values viz. $f_{cv} = 1.46$ mgCOD/mgVSS and $f_n = 0.095$ at 30°C mgN/mgVSS compared with 1.48 and 0.10 at 20°C (WRC, 1984). These results indicate that the WRC (1984) ND model is consistent in the temperature range 20-30°C and can be used for estimating sludge production and oxygen demand at 30°C with reasonable confidence. The ND aspects of the WRC (1984) models are given in Sections 5.3 and 5.4 below.

8. To determine the unbiodegradable particulate COD fraction (f_{up}) of the sewage fed to the UCT system, the appropriate f_{up} value was selected so that the system VSS mass calculated with the BEPR model of Wentzel *et al.* (1990) was equal to that measured using the measured readily biodegradable (RB) COD concentration and influent characteristics of the sewage (f_{us}, S_{ti}) and the system parameters as input. To do this the endogenous mass loss rates of the OHOs and PAOs at 20°C (b_{H20} and b_{G20}) and the OHO RBCOD conversion to VFA rate (K) were adjusted to 30°C with $b_{H30} = 0.24(1.029)^{(T-20)} = 0.32$ /d and $b_{G30} = 0.04(1.029)^{(T-20)} = 0.053$ /d and $K_{30} = 0.06(1.029)^{(T-20)} = 0.08$ /d (see Table 5.4 below). This procedure fractionated the VSS mass into its hypothetical constitutive components viz. OHOs, PAOs, endogenous residue of OHOs and PAOs and unbiodegradable particulate VSS (X_i).

This fractionation also is required to evaluate the P removal (see 16 below) and to check the specific denitrification and RBCOD conversion to VFA rates in the UCT system (see 17 below). An overall average f_{up} value of 0.149 was found for the UCT system, which is similar to that found for the MLE system. After reconciling the calculated VSS mass in the UCT system with that measured, the calculated P removal for the standard PAO P content ($f_{XBG,P}$) of 0.38 mgP/mgPAOAVSS was higher than that measured (14.3 versus 12.9 mgP/ℓ) for long term period I. One of two Wentzel *et al.* (1990) model parameters could be decreased to decrease the calculated P removal; either (1) the conversion rate (K) of RBCOD to VFA, which decreases the proportion of the RBCOD obtained by the PAOs and hence decreases their mass in the system, or (2) the P content of the PAOs, $f_{XBG,P}$. Approach 2 does not affect the calculated VSS mass and fractionation. Approach 1 decreases the calculated VSS mass and results in a higher f_{up} and OHO concentration, which in turn affects the measured specific denitrification rates (see 15 below). Because the RBCOD conversion rate was measured to be close to the BEPR model value of 0.07/d (see 17 below) and the f_{up} value similar to that found for the MLE system, it was decided to accept approach 2. This approach is also the most appropriate for design because in design situations the active PAO mass will be calculated using the Wentzel *et al.* (1990) model from the influent RBCOD concentration with the "standard" conversion rate of K=0.06 ℓ/(mgOHOAVSS.d) at 20°C. An overall average $f_{XBG,P}$ value of 0.280 mgP/mgPAOAVSS set the calculated P removal equal to that measured in the UCT system (12.9 mgP/ℓ). In contrast, the overall average P removal in the MLE system was 5.5 mgP/*l*.

9. Comparing the f_{up} = 0.149 found for the UCT system at 30°C with f_{up}values obtained in other investigations on NDBEPR systems with the same wastewater at 20°C, a wide range in f_{up} values from 0.04 to 0.32 was found. Because reasonably consistent f_{up} values for the same wastewater are expected, and indeed found to be so for the MLE systems, there must be factors that influence sludge production in NDBEPR systems that are not taken account of in the steady state and dynamic simulation models. One such factor appears to be the sludge settleablity. It has been found in earlier investigations (Musvoto *et al.*, 1992, 1994; Casey *et al.*, 1994 a,b) that as the DSVI, and hence the AA (low F/M) filament abundance, increased so the VSS mass in the NDBEPR system decreased and *visa versa*. The peculiar aspect of this phenomenon is that the MLE system, which had an overall higher DSVI than that of the UCT system (see 26 below), did not exhibit this variation in VSS mass with DSVI. No explanation for this unusual behaviour in the UCT system can be advanced (see 15 below).

5.3 NITRIFICATION IN THE MLE AND UCT SYSTEMS AT 30°C

10. Accepting that the endogenous respiration rate of nitrifiers b_A at 30°C is given by $b_{A30} = 0.04(1.029)^{(T-20)} = 0.053$ /d, an average maximum specific growth rate of nitrifiers μ_{nm} at 30°C μ_{nm30} of 1.03 /d was determined from the 13 aerobic batch tests on the MLE system. The μ_{nm30} rate determined for the parallel 20°C MLE system of this investigation from 2 batch tests was 0.85 /d. This 20°C rate far exceeds any earlier μ_{nm20} rate measured at 20°C in the UCT Water Research Laboratory and because it was obtained from only 2 batch tests, this very high μ_{nm20} rate was not taken into account in the further evaluation.

11. From the 14 aerobic batch tests conducted on the UCT system at 30°C, an average μ_{nm30} rate of 0.81 /d was determined. From the 6 aerobic batch tests conducted on the parallel and identical UCT system at 20°C operated by Sneyders *et al.* (1997), a μ_{nm20} of 0.30 /d was obtained. These μ_{nm30} and μ_{nm20} rates give a temperature sensitivity coefficient $\theta_{\mu nm} = 1.10$, which is close to the "standard" value of 1.123. Although Pilson *et al.* (1995) measured different μ_{nm} rates in their MUCT systems at 12°C and 20°C (i.e. $\mu_{nm12} = 0.31$ /d and $\mu_{nm20} = 0.67$ /d), they obtained the same $\theta_{\mu nm}$ coefficient of 1.10. The temperature sensitivity for the μ_{nm} and b_A rates of nitrifiers therefore can be seen to be the same in the 20 to 30°C range as in the 12 to 20°C range. Hence in nitrification design, the difficulty remains to establish the μ_{nm20} rate for the particular wastewater and system under consideration because this rate, which governs the required minimum sludge age of the system (R_{sm}) to ensure nitrification, varies from wastewater to wastewater and to some extent for different systems.

12. Both MLE and UCT systems had a sludge age (R_s = 10d,) about 4 times longer than the minimum required for nitrification (R_{sm}) viz. $R_{sm30} = 1/[(1-f_{xt})\mu_{nm30} - b_{A30}] = 1/[(1-0.5)0.81 - 0.053] = 2.8$d where f_{xt} is the total unaerated mass fraction of the systems (i.e. 0.50). Hence nitrification can be considered to be as complete as possible from a kinetic point of view. The effluent FSA concentration of 2.2 mgN/*l* is therefore not a consequence of poor nitrification but a consequence of the nitrification kinetic response to the higher temperature. The minimum effluent FSA concentration is govermed by the half saturation coefficient of the nitrifiers (K_{nT}) - the higher the K_{nT}, the higher the effluent FSA concentration. At 20°C, $K_{n20} \approx 1.0$ mgN/*l* and the effluent FSA is usually < 1.0 mgN/*l*. At 30°C, K_{n30} seems to be much higher at about 7 mgN/*l* to give an effluent FSA concentration of around 2.2 mgN/*l* (see 13 below).

13. The half saturation coefficient for nitrification K_n at 30°C, K_{n30}, was determined from simulation studies with the ND UCTOLD and NDBEPR UCTPHO activated sludge dynamic simulation models. The effluent FSA concentration from the 30°C MLE and UCT systems were 2.2 and 2.3 mgN/*l* respectively (see 5 above). The model default temperature sensitivity coefficint for K_n , θ_{Kn} , in the temperature range 12 to 22°C (i.e. 1.123) was found to be too low for the simulation models to predict 2.2 and 2.3 mgFSA-N/*l* and needed to be increased to 1.215. Hence, while the θ values for the μ_{nm} and b_A rates are similar in the 12 to 22°C and 20 to 30°C ranges, that for K_n is significantly increased in the 20 to 30°C range from 1.123 to 1.215. The K_{nT} coefficient affects only the effluent FSA concentration; it does not significantly affect the minimum sludge age for nitrification, the nitrate concentration generated by nitrification and the nitrification oxygen demand.

5.4 DENITRIFICATION IN THE MLE SYSTEM

14. The anoxic reactor of the MLE system was generally underloaded with nitrate throughout the investigation (see 26 below). Therefore the system denitrification was recycle limited and the system denitrification rate [27.3 mgN/*l* influent giving a system dentrification rate of 0.088 mgNO$_3$-N/(mgOHOAVSS.d)], was so much lower than the biological denitrification rates (K). The biological rates K_1 (due to utilization of influent RBCOD) and K_2 (due to utilization of SBCOD) at 30°C were determined in anoxic batch tests on sludge harvested from the MLE system. The

mean K_1 and K_2 rates at 30°C from 17 anoxic batch tests were 0.821 and 0.430 $mgNO_3$-N/(mgOHOAVSS.d) respectively. The "standard" K_1 and K_2 rates at 20°C and their temperature sensitivity coefficients θ_{K1} and θ_{K2} in the 12 to 20°C range determined in previous investigations were 0.720 and 0.101 $mgNO_3$-N/(mgOHOAVSS.d) and $\theta_{K1} = 1.20$ and $\theta_{K2} = 1.080$. These "standard" values give 30°C K_{130} and K_{230} rates of 4.46 and 0.218 $mgNO_3$N/(mgOHOAVSS.d) respectively. The measured K_{130} rate is much lower than 4.46 (i.e. 0.821) and the measured K_{230} rate is much higher than 0.218 (i.e. 0.43). From the measured K_{130} and "standard" K_{120} rates, a θ_{K1} of 1.03 is obtained. The actual K_1 rate and θ_{K1} coefficient usually are not important in the design of ND systems (except for design of anoxic selectors) because the influent RBCOD usually is utilized in a very short time (< 1h) and so would be completely utilized in a normal anoxic reactor. The θ_{K2} coefficient based on the measured K_{230} and "standard" K_{220} is 1.15 which is very high. It is difficult to reconcile the very fast K_{230} rate with the earlier K_{220} and θ_{K2} measurements. Even though the very high measured K_{230} rate is based on 17 batch tests, because the K_{220} rate and its θ_{K2} coefficient are so important in ND system design, it is recommended that the standard K_{220} rate and its θ_{K2} coefficient are accepted until the very high K_{230} rate of 0.43 $mgNO_3$-N/(mgOHOAVSS.d) can be confirmed with additional tests.

5.5 DENITRIFICATION IN THE UCT SYSTEM AT 30°C

15. The anoxic reactor of the UCT system also was underloaded with nitrate with the result that the system nitrate removal [24.2 mgN/*l* influent giving a system denitrification rate of 0.133 $mgNO_3$-N/(mgOHOAVSS.d)] also was much lower than the biological denitrification rate K'_2. The biological denitrification rate at 30°C due to utilization of SBCOD, K'_{230}, was determined in 15 anoxic batch tests on sludge harvested from the UCT system. The K_1 rate attributable to utilization of influent RBCOD was absent in the UCT system due to RBCOD conversion to VFA and VFA uptake by PAOs in the preceding anaerobic reactor. Also the K'_{230} rate is expressed in terms of the OHOs only i.e. $f_{av,OHO}$ x Measured VSS concentration where the $f_{av,OHO}$ is the OHO active fraction of the VSS and is a result obtained from the integrated f_{up} determination for the sewage batch during which the anoxic batch tests were done (see 8 above). The mean K'_{230} rate at 30°C was 0.254 $mgNO_3$-N/(mgOHOAVSS.d). The K'_{220} rate determined from 10 batch tests on the parallel UCT system at 20°C as part of this investigation was 0.181 $mgNO_3$-N/(mgOHOAVSS.d). Later Sneyders *et al.* (1997) determined a K'_{220} rate at 20°C of 0.071 $mgNO_3$-N/(mgOHOAVSS.d) on the same 20°C UCT system which is less than half of the rate measured earlier at 20°C in this investigation. Comparing the K'_{2T} rates obtained in this and in 5 other investigations, it was concluded that (see Table 4.11, Fig 4.4) the K'_2 rate is inversely proportional to the $f_{av,OHO}$, which in turn is itself inversely proportional to f_{up}. No explanation for this consistent but wide variation in the K'_{2T} rate observed in NDBEPR systems can be advanced (see 9 above). The variation in f_{up}, which appears to be the basic varying parameter on which the variation in $f_{av,OHO}$ and K'_2 depend, causes the K'_2 rate to vary much more than temperature because the K'_{212} and K'_{230} rates determined by Pilson *et al.* (1995) at 12°C and in this investigation at 30°C, fall close to the K'_2 - $f_{av,OHO}$ and $f_{av,OHO}$ - f_{up} trend lines for 20°C. It would appear therefore that the temperature sensitivity coefficient for K'_2, $\theta_{K'2}$, is very small, around 1.035 in the 12 to 20°C

range and even smaller at 1.018 in the 20 to 30°C range.

5.6 BEPR IN THE UCT SYTEM AT 30°C

16. Accepting that the endogenous respiration rates of the OHOs and PAOs (b_H and b_A) and the RBCOD conversion to VFA (K) rates have temperature sensitivity coefficients of 1.029 each (see 8 above), the theoretically predicted BEPR by the Wentzel *et al.* (1990) BEPR model at 30°C was found to be significantly higher than that observed for long term period I viz. 14.3 mgP/*l* compared with 12.9 mgP/*l*. In order to match the predicted BEPR to that observed, the P content of the PAOs ($f_{XBG,P}$) was reduced from the "standard" model value of 0.38 mgP/mgPAOAVSS to 0.28. Lower than expected BEPR has also been observed in a number of earlier investigations at 20°C viz. Musvoto *et al.* (1992), Kaschula *et al.* (1993) and Pilson *et al.* (1995) and appears to be associated with significant P uptake in the anoxic reactor. Significant P uptake under anoxic conditions was confirmed in this investigation in the anoxic batch tests (see Fig 4.4). In investigations where P uptake took place mainly (>95%) in the aerobic reactor viz. Wentzel *et al.* (1985, 1989), Clayton *et al.* (1991) and Sneyders *et al.* (1997), the BEPR was found to be "normal" i.e. $f_{XBG,P} = 0.38$ mgP/mgPAOAVSS. It appears that for reasons not clear yet at this stage that denitrifying PAOs, which have a P content lower than their aerobic counter parts or grow less biomass from the same VFA taken up in the anaerobic reactor, find a niche in the NDBEPR system. Biochemical assays have indicated that some PAOs can denitrify (Lötter, 1985; Lötter *et al.*, 1986). Also, laboratory anaerobic-anoxic BEPR systems have been operated successfully (Kuba *et al.*, 1993) and in other studies significant anoxic P uptake has been observed in NDBEPR systems at laboratory scale (Kerrn-Jespersen and Henze, 1993), pilot scale (Bortone *et al.*, 1996; Sorm *et al.*, 1996) and full scale (Kuba *et al.*, 1996). Denitrification by PAOs is included in the biochemical model of Wentzel *et al.* (1986, 1991) but is not included in the current NDBEPR simulation models such as IAWQ ASM No2 (Henze *et al.*, 1995) and UCTPHO (Wentzel *et al.*, 1992). *Therefore anoxic P uptake behaviour cannot be realistically simulated with current NDBEPR models and this will significantly effect the comparison between the UCTPHO model predictions and the observed experiment results of this investigation at 30 °C where significant anoxic P uptake was observed (see 19 below).* Proposals to include PAO denitrification into the simulation models have been made (Mino *et al.*, 1995; Barker and Dold, 1997) and it would be interesting to compare the anoxic/aerobic P uptake BEPR behaviour in "conventional" NDBEPR systems with that observed in the DEPHANOX system, which is designed to maximize anoxic P uptake (Bortone *et al.*, 1996; Sorm *et al.*, 1996) to see if the BEPR in these latter systems also is lower.

17. The RBCOD to VFA conversion rate by the OHOs in the anaerobic reactor K was determined with anaerobic batch tests on sludge harvested from the UCT system. From 15 such batch tests a mean K rate = 0.070 *l*/(mgOHOAVSS.d) was determined. Accepting the 20°C rate of 0.060 *l*/(mgOHOAVSS.d) measured by Wentzel *et al.* (1985) gives a temperature sensitivity coefficient θ_K of 1.016. This is a low value and indicates that the RBCOD to VFA conversion K rate is not very sensitive to temperature. Interestingly, a similarly low θ value is obtained for the K'_2 denitrification rate, which also is mediated by the OHOs (see 14 above). [The OHO

active fraction $f_{av,OHO}$ to calculate the specific K rate was based on a θ_K of 1.029 (see 8 above) making K_{30} = 0.08 *l*/(mgOHOAVSS.d). However, a lower value of 0.07 was actually found. The RBCOD conversion to VFA was therefore somewhat overpredicted, but the difference between a K_{30} rate of 0.08 or 0.07 *l*/(mgOHOAVSS.d) is so small that the VSS fractionation based on a K_{30} = 0.07 was not recalculated.]

5.7 SIMULATION OF MLE AND UCT SYSTEM PERFORMANCE AT 30°C

18. The wastewater characteristics determined either from direct measurement or with the aid of the steady state ND model (WRC, 1984) and the MLE system operating conditions (Table 3.1) were given as input to the UCTOLD dynamic simulation model. The model default stoichiometric and kinetic constants and temperature coefficients were retained except for the two Monod constants associated with nitrification. The measured maximum specific growth rate of nitrifiers at 30°C (μ_{nm30}) was standardized to 20°C with the standard $\theta_{\mu nm}$ = 1.123 and given as input to the model; K_{n20} = 1.0 mgN/*l* was retained but its θ value, θ_{Kn}, was increased from 1.123 to 1.215 (see 13 above, and Section 5.9 below). The predicted MLE system response was then compared with that observed. A very good correlation was found for all the measured parameters, except for the aerobic reactor oxygen utilization rate (OUR), which was predicted to be 43.5 mgO/(*l*.h) whereas that measured was 38.3 mgO/(*l*.h). The reason for the higher predicted OUR is that the model is based on a 100% COD and N balance, whereas experimentally 92% COD and 80% N balance was obtained (see 1 above). Because the influent unbiodegradable particulate COD fraction (f_{up}) was calculated from the measured VSS mass in the system with the aid of the WRC (1984) ND model (which is essentially a simplified subset of the UCTOLD dynamic ND simulation model see Section 5.9 below), the lower than 100% observed COD and N balances will reflect in the OUR. In this respect, a good correlation between predicted and measured response is expected because to a large extent the simulation model was calibrated to the observed results because some wastewater characteristics and kinetic constants were calculated from the measured results.

19. The measured and predicted VSS concentrations were 1893 and 1893 mgVSS/*l*, the (i) anoxic, (ii) aerobic and (iii) effluent nitrate and nitrite concentrations were (i) 0.6 and 0.0 mgN/*l*, (ii) 5.5 and 6.7 and (iii) 6.0 and 6.7 mgN/*l* respectively, and the measured and predicted FSA concentration were 2.1 and 2.2 mgN/*l* respectively. The UCTOLD ND simulation model therefore predicts the MLE system observed results at 30°C very well provided the appropriate sewage charateristics and kinetics constants are given as input. However, it must be remembered that the anoxic reactor was underloaded with nitrate. Predicting the nitrate concentrations in the various reactors is therefore not a test of the denitrification kinetics in the model; provided the kinetic rates are fast enough, these concentrations are governed mainly by the recycle ratio for underloaded reactors.

20. As for the MLE system, the wastewater characteristics determined either from direct measurement or with the aid of the steady state BEPR model of Wentzel *et al.* (1990) and the UCT system operating conditions (Table 3.1) were given as input to the UCTPHO NDBEPR dynamic simulation model. Also, the model default

stoichiometric and kinetic constants and temperature coefficients were retained except for the μ_{nm20} and θ_{Kn} like for the MLE system (see 18 above and Table 5.4 below). It should be noted that in the UCTPHO model, the P content of the PAOs ($f_{XBG,P}$) is not an input stoichiometric constant - it arises from the process rates of P release and uptake and PAO organism growth, which, when go to completion, result in a net PAO content of 0.38 mgP/mgPAOAVSS. As for the MLE system, a very good correlation was obtained for all the measured parameters relating to COD and N removal, except for the aerobic reactor OUR. Because the f_{up} was calculated from the measured VSS mass in the system with the aid of the BEPR model of Wentzel *et al.* (1990) (which is essentially a simplified subset of the UCTPHO dynamic ND simulation model see Table 5.4 below), the lower than 100% observed COD and N balances result in the significantly higher predicted OUR than observed viz. 41.1 versus 37.8 mgO/(*l*.h). It should be noted that because the VSS sludge production per mass COD load is higher for the UCT system than the MLE system due to BEPR, the OUR is lower in the UCT system compared with that in the MLE system. This is apparent both theoretically (Wentzel and Ekama, 1997) and experimentally - the MLE and UCT predicted OUR is 43.5 and 41.1 mgO/(*l*.h) respectively and the MLE and UCT system measured OUR is 38.3 and 37.8 mgO/(*l*.h).

21. The measured and predicted VSS concentrations were 1959 and 2039 mgVSS/*l*, the (i) anaerobic (ii) anoxic, (iii) aerobic and (iv) effluent nitrate and nitrite concentrations were (i) 0.2 and 0.0 mgN/*l*, (ii) 0.7 and 0.0 mgN/*l* (iii) 7.6 and 9.5 and (iv) 8.4 and 9.5 mgN/*l* respectively. As for the MLE system, because the anoxic reactor was underloaded with nitrate, this good correlation between predicted and observed results is mainly the consequence of the recycle ratio and therefore not a test of the denitrification kinetics in the model. Because of the calibration of the nitrification kinetic constants (μ_{nm20} and θ_{Kn}) the predicted and observed FSA concentrations were very close at 2.2 and 2.3 mgN/*l* respectively. The COD and ND components of the UCTPHO BEPR simulation model therefore predicted the UCT system results at 30°C very well provided the appropriate sewage charateristics and kinetics constants were given as input.

22. For any wastewater, the wastewater characteristics, including the μ_{nm20} rate, applicable to it have to be given as input to the UCTOLD and UCTPHO models - these models cannot be expected to give a good correlation between experimental and predicted results if this is not done. Therefore, the measure of reliabilty of the models is the measure whereby the values of the kinetic and stoichiometric constants have to be adjusted to achieve a good correlation. In this investigation very few kinetic constants and their temperature sensitivity coefficients needed to be adjusted - only θ_{Kn} was changed from 1.123 to 1.215 to correctly predict the effluent FSA concentration for both the MLE and UCT systems. The default values for all the other kinetic and stoichiometric constants and their θ coefficients (except θ_{Kn}) relating to COD removal and ND were not required to be changed to obtain a good correlation between experimental and observed results. It is mainly in the BEPR component of UCTPHO that a poor correlation between experimental and predicted results is obtained.

23. Although the difference between the predicted and observed BEPR is relatively small i.e. 14.3 and 12.9 mgP/*l* respectively for long term period I, the BEPR component of UCTPHO model predicts completely different P concentrations to those observed for the reactors (see Table 4.15). As mentioned above (see 16 above), the steady state and dynamic state BEPR models are based on experimental BEPR performance associated with predominantly aerobic P uptake, whereas in the UCT system, significant anoxic P uptake took place. This therefore makes a comparison between predicted and experimental BEPR performance invalid. Comparison of the BEPR behaviour of the UCTPHO model is therefore confined to experimental results which manifest the same predominantly (>90%) aerobic P uptake behaviour.

5.8 SLUDGE SETTLEABILITY AND FILAMENT IDENTIFICATION

24. The filament most frequently dominant in both the MLE and UCT systems were, in descending order, type 0092, *Microthrix parvicella* and type 1851. Type 021N and *Haliscomenobacter hydrossis* were also frequently observed but not at dominant levels. Apart from type 021N, these filaments are classified as typical of the low F/M category (Jenkins *et al.*, 1984) and are almost always observed in laboratory (Ekama *et al.*, 1996) and full scale (Blackbeard *et al.*, 1986, 1988) ND and NDBEPR systems. During the changes in DSVI in the MLE and UCT systems, the filament types did not change significantly and therefore the different DSVIs were caused by essentially the same filament types at different levels of abundance.

25. The AA (low F/M) filament bulking hypothesis of Casey *et al.* (1994a,b) describes how an AA filament bulking sludge may be the result of nitrate and nitrite "leakage" from the anoxic to the aerobic reactor of ND and NDBEPR systems. If these concentrations are high (> 1 mgN/*l*) in conjunction with a low aerobic mass fraction (<0.70), then a bulking sludge with a high DSVI (> 150 m*l*/g) would prevail.

26. The nitrate plus nitrite concentrations (NO_x, mgN/*l*) in the anoxic reactor of the MLE and UCT were generally low (< 1.0 mgN/l) because the anoxic reactors were underloaded with nitrate, except for the sewage batches with high TKN/COD ratios (>0.10 mgN/mgCOD) which occurred mostly during long term period II. The overall mean DSVI in the MLE and UCT systems were 235 and 201 ml/g (see Table 5.2).

Table 5.2: Mean DSVI and anoxic reactor nitrate plus nitrite (NO_x) concentrations in the MLE and UCT systems at 30°C during long term periods I, II, III and IV (overall).

System	Parameter	Overall (IV)	Period I	Period II	Period III
MLE	DSVI (m*l*/g)	235	270	204	183
	No_x (mgN/*l*)	1.13	0.68	2.58	0.50
UCT	DSVI (m*l*/g)	201	213	201	171
	No_x (mgN/*l*)	2.06	1.34	4.71	0.64

27. While some periods during the investigation show decreasing DSVI with low anoxic NO_x concentrations in the MLE and UCT systems, e.g. from sewage batch 13 to 22, and would therefore support the AA filament hypothesis, other periods are in

conflict with this, e.g. decreasing DSVI with high anoxic NO_x concentrations. The results from this investigation therefore do not give unequivocal support for the AA filament bulking hypothesis of Casey *et al.* (1994a,b).

5.9 CLOSURE

In this investigation an inquiry into the kinetic behaviour of the MLE and UCT systems at 30°C has been undertaken. This inqiry was facilitated by application of both the steady state and dynamic simulation models (i) to laboratory scale steady state MLE and UCT activated sludge systems and (ii) in the interpretation of the data collected from an extensive series of anaerobic, anoxic and aerobic batch tests conducted on sludges harvested from the two systems both at 20 and 30°C. The models provided a defined structure within which the data could be consistently evaluated, and enabled the results to be compared on the same basis with similar results collected from systems operated in earlier investigations in the laboratory.

In application of the models to the steady state systems, one question that arose was whether the steady state models could be applied without significant error: In the steady state models it is assumed that a number of biological processes have essentially progressed to completion so that the kinetic relationships can be replaced with more simple stoichiometric ones. In particular, it is assumd that the organism synthesis processes on biodegradable COD are complete (both for OHOs and PAOs), so that the kinetics of synthesis are excluded in the steady state models. To asses this assumption, accepting the same wastewater characteristics (derived from the experimental data) the appropriate steady state and dynamic models were applied to the laboratory MLE and UCT system results for long term period I. Both models provide estimations for the active organism (OHO and PAO where appropriate) and VSS masses that are remarkably simliar (see Table 5.3). This confirmed that the simplified steady state models could be applied to evaluate the experimental data.

From the data and model application, it is evident that:

1) Stoichiometric constants obtained from experimental work in the temperature range 12 to 22°C e.g. sludge production and oxygen demand (with underlying organism yield, endogenous residue and influent unbiodgradable particulate COD fraction) remain valid for the temperature range 20 to 30°C.

2) All kinetic processes proceed more rapidly at 30°C than at 20°C.

The above implies that for systems operated over a temperature range 20 to 30°C, the systems can be designed at 20°C with the models and constants which are well established for 20°C and the system performance (in terms of effluent quality) will not be poorer at 30°C. To asses the expected performance at 30°C, it would appear that the structure of the models remains valid. Some information was developed on the tempertature sensitivity of the kinetic constants of key processes such as nitrification, denitrification and RBCOD conversion to VFA in BEPR. A detailed comparison of the temperature sensitivity coefficients in the 20 to 30°C range with coefficients determined in earlier investigations in the 12 to 20°C range was presented in Chapter 4 and was summerized above and is given in Table 5.4 below.

Table 5.4: Kinetic and stoichiometric constants, and their temperature sensitivity coefficients, for the steady state WRC (1984) ND and Wentzel *et al.* (1990) NDBEPR models.

Steady State Model (WRC, 1984)							
Kinetic and Stoichiometric Constants		Value at 20oC	Units	Temp Sensitivity Coefficient			Notes
Symbol	Name			Symbol	12-22oC	20-30oC	
Organic Material Degradation	Ordinary Heterotrophic Organisms		Aerobic and Anoxic				
	Aerobic						
YH	Yield Coefficient of OHOs in terms of VSS	0.450	mgVSS/mgCOD		1.000	1.000	a
bH	Endogenous respiration rate of OHOs	0.240	/d	ObH	1.029	1.029	a
fE	Endogenous residue fraction of OHOs	0.200	-		1.000	1.000	a
fcv	COD/VSS ratio of all VSS components	1.480	mgCOD/mgVSS		1.000	1.000	a
fn	N fraction of all VSS components	0.100	mgN/mgVSS		1.000	1.000	a
fp	P content of all VSS components	0.030	mgP/mgVSS		1.000	1.000	a
Kv	Substrate utilization rate	0.070	l/(mgVSS.d)	OKv	1.035	1.035	e
	Anoxic Conditions in ND systems						
K1	Denitrification with RBCOD	0.720	mgNO3-N/(mgOHOAVSS.d)	OK1	1.200	1.030	b, j
K2	Denitrification with SBCOD	0.101	mgNO3-N/(mgOHOAVSS.d)	OK2	1.080	1.150	b, f
K3	Denitrification with SBCOD	0.072	mgNO3-N/(mgOHOAVSS.d)	OK3	1.029	1.019	c, g
	Anoxic Conditions in NDBEPR systems						
K'1	Denitrification with RBCOD	0.720	mgNO3-N/(mgOHOAVSS.d)	OK'1	1.200	1.030	b
K'2	Denitrification with SBCOD	0.250	mgNO3-N/(mgOHOAVSS.d)	OK'2	1.080	1.035	b
K'3	Denitrification with SBCOD	0.100	mgNO3-N/(mgOHOAVSS.d)	OK'3	1.029	1.029	c
Nitrification	Autothophic Organisms	Aerobic					
unm	Maximum specific growth rate	0.400	/d	Ounm	1.100	1.100	b
Yn	Yield Coefficient	0.100	mgVSS/mgN	-	1.000	1.000	a
bn	Endogenous respiration rate	0.040	/d	Obn	1.029	1.029	c
Kn	Half saturation coefficient	1.000	mgN/l	Okn	1.123	1.215	d
Biological Excess Phosphorus Removal - Polyphosphate Accumulating Organisms				Aerobic P uptake only			
YG	Yield Coefficient of PAOs in terms of VSS	0.450	mgVSS/mgCOD	-	1.000	1.000	a
bG	Endogenous respiration rate of PAOs	0.040	/d	ObG	1.029	1.029	a
fEp,G	Endogenous residue fraction of PAOs	0.250	-	-	1.000	1.000	a
fXBG,P	P content of active PAO VSS	0.380	mgP/mgPAOAVSS	-	1.000	1.000	h
fXEG,P	P content of PAO endogenous residue	0.030	mgP/mgVSS	-	1.000	1.000	a
Csp	P release to CFA COD uptake ratio of PA	0.500	mgP/mgCOD	-	1.000	1.000	a
K	RBCOD to VFA conversion rate by OHOs	0.060	l/(mgOHOAVSS.d)	OK	1.029	1.016	b, i

Comments

a	Approximate values indirectly confirmed in this investigation through goodness of fit between predicted and measured VSS concs.
b	Measured in this investigation
c	Not determined - estimated from OHO endogenous process
d	Determined from simulation of the effluent FSA concentration
e	Usually not required; assume all biodegradable COD utilized.
f	Recommend using 12-20oC value (1.080) until this high value (1.15) is confirmed in further research at 30oC
g	Difference between using 1.029 or 1.016 is very small; recocmmend using normal endogenous process value 1.029.
h	Value applicable for aerobic P uptake only; is lower for anoxic/aerobic P uptake as was observed in this investigation.
i	Calculation of 1.016 is based on initial assumption of 1.029; difference between using 1.016 or 1.029 is small
j	Actual value not important (except for aerobic/anoxic selector design) because RBCOD is completely utilized in primary anoxic.

Table 5.4 (cont): Kinetic and stoichiometric constants, and their temperature sensitivity coefficients, for the dynamic simulation UCTOLD ND (Dold *et al.*,1990) and UCTPHO NDBEPR (Wentzel *et al.*, 1992) models.

Dynamic Simulation Model - Wentzel et al. (1992)							
Kinetic and Stoichiometric Constants		Value	Units	Temp Sensitivity Coefficient			Notes
Symbol	Name	at 20oC		Symbol	12-20oC	20-30oC	
Organic Material Degradation	Ordinary Heterotrophic Organisms		Aerobic and Anoxic				
Aerobic							
YZH	Yield Coefficient of OHOs in terms of COD	0.666	mgOHOCOD/mgCOD	-	1.000	1.000	a
bH	Death-regeneration rate of OHOs	0.620	/d	ObH	1.029	1.029	a
fE	Unbiodegradable fraction of Active OHOs	0.200	-	-	1.000	1.000	a
fcv	COD/VSS ratio of all VSS components	1.480	mgCOD/mgVSS	-	1.000	1.000	a
fZB,N	N fraction of Active OHOs	0.068	mgN/mgOHOCOD	-	1.000	1.000	a
fZE,N	N fraction of unbio fraction of OHOs	0.068	mgN/mgCOD				a
fXBH,P	P fraction of Active OHOs	0.020	mgP/mgOHOCOD	-	1.000	1.000	a
fXEH,P	P fraction of unbio fraction of OHOs	0.020	mgP/mgCOD	-	1.000	1.000	a
fXI,P	P fraction of unbiodegrad. particulate COD	0.014	mgP/mgCOD	-	1.000	1.000	a
uH	Maximum RBCOD utilization rate	2.500	/d	OuH	1.200	1.030	b
KSH	Half saturation coefficient for RBCOD	5.000	mgCOD/l	OKSH	1.000	1.000	c
KA	Adsorption rate of SBCOD	0.170	mgCOD/(mgCOD.d)	OKA	1.029	1.029	c
fMA	Maximum SBCOD to Active OHO conc rati	1.000	mgCOD/mgCOD	-	1.000	1.000	c
KMP	Maximum SBCOD utilization rate	1.350	mgCOD/(mgCOD.d)	OKMP	1.080	1.150	d
KSP	SBCOD to Active OHO conc ratio	0.027	mgCOD mgCOD	OKSP	0.910	0.910	b
Kr	Ammonification rate by OHOs	0.032	l/(mgCOD OHO.d)	OKr	1.029	1.029	b
Anoxic Conditions in ND systems							
nG	Reduction factor for anoxic SBCOD utilizati	0.330	-		1.000	1.000	c
Anoxic Co							
nG	Reduction factor for anoxic SBCOD utilizati	0.600	-		1.000	1.000	c
Nitrification	Autothophic Organisms	Aerobic					
unm	Maximum specific growth rate	0.400	/d	Ounm	1.100	1.100	b
Yn	Yield Coefficient	0.100	mgVSS/mgN	-	1.000	1.000	c
bn	Endogenous respiration rate	0.040	/d	Obn	1.029	1.029	c
Kn	Half saturation coefficient	1.000		Okn	1.123	1.215	e
Biological Excess Phosphorus Removal - Polyphosphate Accumulating Organisms				Aerobic P uptake only			
YZG	Yield Coefficient of PAOs in terms of COD	0.666	mgPAOCOD/mgCOD	-	1.000	1.000	a
bG	Endogenous respiration rate of PAOs	0.040	/d	ObG	1.029	1.029	a
fEp,G	Endogenous residue fraction of PAOs	0.250	-	-	1.000	1.000	a
							f
fXBG,N	N content of PAO active organisms (COD)	0.068	mgN/mgPAOCOD	-	1.000	1.000	a
fXEG,N	N content of PAO endog. residue (COD)	0.068	mgN/mgCOD	-	1.000	1.000	a
fXBG,P	P content of PAO active organisms (COD)	0.020	mgP/mgPAOCOD	-	1.000	1.000	a
fXEG,P	P content of PAO endog. residue (COD)	0.020	mgP/mgCOD	-	1.000	1.000	a
Csp	P release to COD uptake ratio of PAOs	0.500	mgP/mgCOD	-	1.000	1.000	c
KC	RBCOD to VFA conversion rate by OHOs	0.040	l/(mgOHOACOD.d)	OKC	1.029	1.016	b, g
uG1	u of PAOs on PHAs with no P limitation	1.200	/d	OuG1	1.080	1.080	h
KSG1	Half saturation coefficient for uG1	0.180	mgCOD/l	-	1.000	1.000	a
uG2	u of PAOs on PHAs with P limitation	0.420	/d	OuG2	1.080	1.080	h
KSG2	Half saturation coefficient for uG2	0.180	mgCOD/l	-	1.000	1.000	a
bpp	P release rate for cell maintenance	0.030	mgP/(mgPAOACOD.d)	Obpp	1.029	1.029	i
Kp	VFA uptake rate by PAOs	6.000	mgCOD/(mgPAOACOD.d)	OKp	1.029	1.029	j

Comments

a	Approximate values indirectly confirmed in this investigation through goodness of fit between predicted and measured VSS concs.
b	Measured in this investigation
c	Default UCTOLD and UCTPHO values
d	Linked K2 and K'2 (with ng) measured in this investigation
e	Determined from simulation of the effluent FSA concentration
f	P content of PAOs is the result of PAO growth and P uptake processes
g	Calculation of 1.016 is based on initial assumption of 1.029; difference between using 1.016 or 1.029 is small
h	Not determined - estimated from Ok2
i	Not determined - estimated from OHO endogenous process
j	No experimental basis for this value

Table 5.3: Comparison of steady (or stationary) state solutions for OHO and PAO active organism and VSS concentrations predicted by the WRC (1984) steady state and UCTOLD (Dold *et al.*, 1991) dynamic simulation ND models and the Wentzel *et al.* (1990) steady state and UCTPHO (Wentzel *et al.*, 1992) dynamic simulation NDBEPR models with experimental VSS concentrations measured during long term period I in the MLE and UCT systems operated in this investigation at 30°C.

Wastewater characteristic input data:
Influent COD (S_{ti}) concentration = 751 mgCOD/*l*
Unbiodegradable soluble COD fraction of influent (f_{us}) = 0.050
Unbiodegradable particulate COD fraction of influent (f_{up}) = 0.154

Model	VSS mgVSS/l	OHO Active Concentrations			PAO Active Concentrations		
		f_{avOHO}	mgCOD/*l*	mgAVSS/*l*	f_{avPAO}	mgCOD/*l*	mgAVSS/*l*
ND System response: MLE System							
WRC (1984)	1849	0.347	950	642	-	-	-
UCTOLD	1893	0.345	968	654	-	-	-
Measured	1892	-	-	-	-	-	-
NDBEPR System response: UCT System							
Wentzel *et al.* (1990)	2004[1]	0.267	792	535	0.145	431	291
UCTPHO	2039[1]	0.273	824	577	0.146	439	297
Measured	1959	-	-	-	-	-	-

[1] The reason for the higher predicted VSS concentrations than measured is because the MLE system f_{up} fraction (0.154) was given as input to the NDBEPR models instead of the UCT system f_{up} fraction (0.149) for long term period I; had the UCT system f_{up} fraction been given as input, the predicted VSS concentration would have been as close as measure as for the ND system.

If the system design has been set for 20°C, it is evident from this study that all the principal kinetic processes will be essentially complete at 30°C except the endogeous respiration ones, e.g. heterothophic COD degradation and autotrophic nitrification, and in essence the system will be overdesigned for 30°C. If the design is to be done at 30°C, then, for the MLE ND system, the models with the temperature sensitivities validated or determined in this investigation can be used for the design with reasonable surity (see Table 5.4). However, for the UCT NDBEPR system, the same surity could not be established, but this is not due to a lack of confidence in the temperature sensitivity coefficients (see Table 5.4). Rather, there is considerable uncertainty surrounding the specific denitrification rate K'_2. This uncertainty is not unique to this investigation at 30°C; it has been noted in several other investigations with NDBEPR systems at 20°C also and is an aspect that needs to urgent attention.

REFERENCES

Allison P. (1998). The Baltic Sea progress report. *World Water*, **21**(2), 10-16.

Arkley M.J. and Marais G.vR. (1981). The effect of the anoxic zone on sludge settleability in the activated sludge process. Research Report W38, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Barker P.S. and Dold P.L. (1997) General model for biological nutrient removal activated - sludge systems: Model presentation, *Water Environment Research*, **69**(5), 969- 984.

Blackbeard J.R., Ekama G.A. and Marais G.vR. (1986). A survey of filamentous bulking and foaming in activated sludge plants in South Africa. *Water Pollut. Control*, **85**(1), 90-100.

Blackbeard J.R., Gabb D.M.D., Ekama G.A. and Marais G.vR. (1988). Identification of filamentous organisms in nutrient removal activated sludge plants in South Africa. *Water SA*, **14**(1), 29-34.

Bortone G., Saltarelli R., Alonso V., Sorm R., Wanner J. and Tilche A. (1996) Biological anoxic phosphorus removal - The DEPHANOX process. *Water Sci. Technol.*, **34**(½), 119-128.

Burke R.A., Dold P. L. and Marais G.vR. (1985). Biological excess P removal in short sludge age activated sludge systems. Research Report W58, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Casey T.G., Wentzel M.C., Ekama G.A., Loewenthal R.E. and Marais G.v.R. (1994a). An hypothesis for the cause and control of anoxic-aerobic (AA) filament bulking in nutrient removal activated sludge systems. *Water Sci. Technol.*, **29**(7), 203-212.

Casey T.G., Wentzel M.C., Ekama G.A., Lakay M.T. and Marais G.vR. (1994b). Causes and control of anoxic-aerobic (AA) filament bulking in biological N and N & P removal systems. Final report to Water Research Commission on 4 year (1989 - 1992) research contract K5/286. WRC 286/2/93, P O Box 824, Pretoria, 0001.

Clayton J.A., Ekama G.A., Wentzel M.C. and Marais G.vR. (1989). Denitrification kinetics in biological nitrogen and phosphorus removal activated sludge systems. Research Report W63, Dept. Of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Clayton J.A., Ekama G.A., Wentzel M.C. and Marais G.v.R. (1991). Denitrification kinetics in biological nitrogen and phosphorus removal systems treating municipal wastewaters. *Water Sci. Technol.*, **23**(4/6-2), 1025-1035.

Dold P.L., Ekama G.A. and Marais G.vR. (1980). A general model for the activated sludge process. *Prog.Wat.Tech.*, **12**, Tor 47-77.

Dold P.L., Wentzel M.C., Billing A.E., Ekama G.A. and Marais G.vR. (1991). *Activated sludge simulation programs: Nitrification and nitrification/ denitrification systems (Version 1.0).* Water Research Commission, P O Box 824, Pretoria, South Africa. TT 52/91, ISBN 0 947447 199.

Ekama G.A., Wentzel M.C., Casey T.G. and Marais G.vR. (1996) Filamentous organism bulking in nutrient removal activated sludge systems. Paper 6: Review, evaluation and consolidation of results. *Water SA*, **22**(2), 147-152.

Ekama G.A. and Wentzel M.C. (1997) Denitrification kinetics in biological N&P removal activated sludge systems treating municipal wastewaters. *Procs. 3rd AWWA/IAWQ BNR Conference*, 30 Nov-3 Dec, Brisbane, Aus.

Henze M., Grady C.P.L. (Jr), Gujer W., Marais G.v.R and Matsuo T. (1987). *Activated Sludge Model No.1.* IAWQ Scientific and Technical Report No.1, IAWQ, London. 33pp.

Henze M., Gujer W., Mino T., Matsuo T., Wentzel M.C. and Marais G.v.R. (1995). *Activated sludge model No.2*, IAWQ Scientific and Technical Report No. 3, IAWQ, London. 32pp.

Jahren S.J. and Rintala J.A. (1997). The closure of water circuits by internal thermophilic (55 and 70°C) anaerobic treatment in the thermomechanical pulping process. *Water Sci. Technol.*, **35**(2/3), 49-56.

Jenkins D., Richard M.G. and Daigger G.T. (1984) *Manual on the causes and control of activated sludge bulking and foaming.* Water Research Commission, PO Box 824, Pretoria, 0001, South Africa.

Kaschula W.A., Ekama G.A., Palmer S.H., Wentzel M.C. and Birch R.R. (1993). The effect of alternative detergent builders on the nutrient removal activated sludge sewage treatment process. Research Report W78, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Kerrn-Jespersen J.P. and Henze M. (1993) Biological phosphorus uptake under anoxic and oxic condition. *Water Research*, **27**(4), 617-624.

Kuba T., Smolders G.J.F., van Loosdrecht M.C.M. and Heinen J.J. (1993) Biological phosphorus removal from wastewater by anaerobic-anoxic sequencing batch reactor. *Water Sci. Technol.*, **27**(5/6), 241-252.

Kuba T., Murnleitner E., van Loosdrecht M.C.M. and Heinen J.J. (1996) A metabolic model for the biological phosphorus removal by denitrifying organisms. *Biotech. Bioeng.*, **52**, 685-695.

Kuba T., van Loosdrecht M.C.M., Brandse F.A. and Heinen J.J. (1997) Occurrence of denitrifying phosphorus removing bacteria in modified UCT-type wastewater treatment plants. *Water Research*, **31**(4), 777-786.

Laubsher N.F. (undated). Testing outlying observations. National physical research laboratory, CSIR, PO Box 395, Pretoria, 0001, South Africa.

Lötter L.H. (1985). The role of bacterial phosphate metabolism in enhanced phosphorus removal from the activated sludge process. *Water Sci. Technol.*, **17**(11/12), 127-139.

Lötter L.H., Wentzel M.C., Ekama G.A. and Marais G.v.R. (1986). A study of selected characteristics of *Acinetobacter* spp. isolated from activated sludge in anaerobic/anoxic/aerobic and aerobic systems. *Water SA*, **12**(4), 203-208.

Mamais D., Jenkins D. and Pitt P. (1993). A rapid physical-chemical method for the determination of readily biodegradable COD in municipal wastewaters. *Water Research*, **27**(1), 195-197.

Marais G.vR. and Ekama G.A. (1976) The activated sludge process, Part 1- Steady state behaviour. *Water SA*, **2**(4), 163-200.

Marsden M.G. and Marais G.vR. (1976). The role of the primary anoxic reactor in denitrification and biological phosphorus removal. Research Report W19, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Mbewe A., Wentzel M.C. and Ekama G.A. (1995). Characterization of the carbonaceous material in municipal wastewaters. Research Report W84, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Mellin H.K.O., Rintala J., Karsisto S., Viitasaari M., Wentzel M.C., Ekama G.A. and Marais G.vR. (1995). Integrated treatment of a cold municipal wastewater and a thermophilically pretreated effluent from a paper mill. Presented at 5th IAWQ symposium on forestry industry wastewater, Vancouver, June.

Mino T., Liu W.T., Kurisu F. and Matsuo T. (1995) Modelling glycogen storage and denitrification capability of microorganisms in enhanced biological phosphate removal processes. *Water Sci. Technol.*, **31**(2), 25-34.

Musvoto E.V., Casey T.G., Ekama G.A., Wentzel M.C. and Marais G.VR. (1992). The effect of a large anoxic mass fraction and concentrations of nitrate and nitrite in the primary anoxic zone on low F/M filament bulking in nutrient removal activated sludge systems. Research Report W77, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Musvoto E.V., Casey T.G., Ekama G.A., Wentzel M.C. and Marais G.v.R. (1994) The effect of incomplete denitrification on anoxic-aerobic (low F/M) filament bulking in nutrient removal activated sludge systems. *Water Sci. Technol.*, **29**(7), 295-299.

Pilson R.A., Wentzel M.C. and Ekama G.A. (1995). The effect of temperature on denitrification kinetics and biological excess phosphorus removal in nutrient removal activated sludge plants in temperate climates (12°C - 20°C). Research Report W86, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Randall E.W., Wilkinson A. and Ekama G.A. (1991). An instrument for direct determination of oxygen utilization rate. *Water SA*, **17**(1), 11-18.

Siebritz I.P., Ekama G.A. and Marais G.v.R. (1983) A parametric model for biological excess phosphorus removal. *Water Sci. Technol.*, **15**(3/4), 127-152.

Sneyders M.J., Wentzel M.C. and Ekama G.A. (1997) Treatability of unstabilized landfill leachate in a nutrient removal activated sludge system. Research Report W95, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Sorm R., Bortone G., Saltarelli R., Jenicek P., Wanner J. and Tilche A. (1996) Phosphate uptake under anoxic conditions and fixed film nitrification in nutrient removal activated sludge system. *Water Research*, **30**(7), 1573-1584.

Standard Methods (1985). *Standard methods for the examination of water and wastewater*. (16th Edition), APHA, AWWA, WEF, Washington DC, USA.

Stern L.B. and Marais G.vR. (1974). Sewage as the electron donor in biological denitrification. Research Report W7, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Still D.A., Ekama G.A., Wentzel M.C., Casey T.G. and Marais G.v.R. (1996) Filamentous organism bulking in nutrient removal activated sludge systems. Paper 2: Stimulation of the selector effect under aerobic conditions. *Water SA*, **22**(2), 97-118.

Ubisi M.F., Wenzel M.C. and Ekama G.A. (1997). Organic and inorganic components of activated sludge mixed liquor. Research Report W94, Dept of Civil Eng., Univ of Cape Town, Rondebosch, 7701, Cape, South Africa.

van Haandel A.C., Ekama G.A. and Marais G.v.R. (1981). The activated sludge process 3 - Single sludge denitrification. *Water Research*, **15**(10), 1135-1152.

van Haandel A.C., Dold P.L. and Marais G.vR. (1982). Optimization of nitrogen removal in the single sludge activated sludge process. *Water Sci. Technol.*, **14**(Cape Town), 443-461.

Warburton C.A., Lakay M.T., Casey T.G., Ekama G.A., Wentzel M.C. and Marais G.vR. (1991). The effect of sludge age and aerobic mass fraction on low F/M filament bulking in intermittent aeration nitrogen removal systems. Research Report W65, Dept. of Civil Eng., Univ. of Cape Town, Rondebosch, 7701, Cape, South Africa.

Wentzel M.C., Dold P.L., Ekama G.A. and Marais G.v.R. (1985) Kinetics of biological phosphorus release. *Water Sci. Technol.*, **17**(11/12), 57-71.

Wentzel M.C., Lötter L.H., Loewenthal R.E. and Marais G.v.R. (1986) Metabolic behaviour of *Acinetobacter* spp. in enhanced biological phosphorus removal - A biochemical model. *Water SA*, **12**(4), 209-224.

Wentzel M.C., Ekama G.A., Loewenthal R.E., Dold P.L. and Marais G.v.R. (1989) Enhanced polyphosphate organism cultures in activated sludge systems. Part II: Experimental behaviour. *Water SA*, **15**(2), 71-88.

Wentzel M.C., Dold P.L., Ekama G.A. and Marais G.v.R. (1990) Biological excess phosphorus removal - Steady state process design. *Water SA*, **16**(1), 29-48.

Wentzel M.C., Lötter L.H., Ekama G.A., Loewenthal R.E. and Marais G.v.R. (1991) Evaluation of biochemical models for biological excess phosphorus removal. *Water Sci. Technol.*, **23**(4/6-2), 567-576.

Wentzel M.C., Ekama G.A. and Marais G.v.R. (1992) Processes and modelling of nitrification denitrification biological excess phosphorus removal systems - A review. *Water Sci. Technol.*, **25**(6), 59-82

Wentzel M.C., Mbewe A. and Ekama G.A. (1995). Batch test measurement of readily biodegradable COD and active organism concentrations in municipal wastewaters. *Water SA*, **21**(2), 117-124.

Wentzel MC and Ekama GA (1997) Principles in the design of single sludge activated sludge systems for the biological removal of carbon, nitrogen and phosphorus. *Water Environment Research,* **69**(7),1222-1231.

Wilson D.E. and Marais G.vR. (1976). Adsorption phase in biological denitrification. Research Report W11, Dept. of Civil Eng., Univ. of Cape Town.

WRC (1984). *Theory, design and operation of nutrient removal activated sludge processes.* Water Research Commission, PO Box 824, Pretoria 0001, South Africa. ISBN 0908356137.

APPENDIX A

In the day to day results, the means for each sewage batches.

Sewage batches	From day to day	From page to page
1 to 41	1 to 582	A.1 to A.83

Description of data	From page to page
Influent COD concentration,. UFE, FE, aerobic reactor COD concentration in MLE system. UFE, FE, aerobic reactor COD concentration in UCT system.	A.1 to A.11
Influent TKN concentration,. UFE, FE, aerobic reactor TKN concentration and OUR in MLE system. UFE, FE, aerobic reactor TKN concentration and OUR in UCT system.	A.12 to A:21
Influent FSA concentration, FE FSA conc. in MLE and UCT systems. NO_3 plus NO_2 conc. of anoxic, aerobic and effluent in MLE system. NO_3 plus NO_2 conc. of anaerobic, anoxic, aerobic and effluent in UCT system.	A.22 to A.32
TSS, VSS, DSVI and pH values in MLE system. TSS, VSS, DSVI and pH values in UCT system.	A.33 to A.43
Influent Total P concentration. Tot. P conc. of anoxic, aerobic reactors and effluent in MLE system. Tot. P conc. of anaerobic, anoxic, aerobic reactors and effluent in UCT system.	A.44 to
Table A.1 Summary og graphical plots of the day to day results	A.55 to A.83

APPENDIX A

Daily measured COD concentrations in influent, and unfiltered (UFE) and filtered (FE) effluents and COD concentrations in the aerobic reactors of the MLE and UCT systems at 30 C.

BATCH OF SEWAGE	*YEAR* MONTH / DAY	DAY NO	*INFLUENT* [mgCOD/*l*]	MLE SYSTEM		UCT SYSTEM		AEROB.REACTORS	
				UFE [mgCOD/*l*]	FE [mgCOD/*l*]	UFE [mgCOD/*l*]	FE [mgCOD/*l*]	MLE [mgCOD/*l*]	UCT [mgCOD/*l*]
	1995								
1	May 1	1	865¤	106.1¤	53.0	53.0	53.0	-	-
	May 2	2	885¤	65.3	77.5¤	57.1	69.4¤	-	-
	May 3	3	864¤	53.0	61.2	85.7	61.2	-	-
	May 4	4	836	51.0	46.9	95.9¤	55.1	-	-
	May 5	5	763	81.6	61.2	44.9	44.9	-	-
	May 6	6	747	57.1	53.0	89.8	49.0	-	-
	May 7	7	775	93.8	61.2	49.0	49.0	-	-
	May 8	8	744	54.3	54.3	74.4	54.3	-	-
	May 9	9	696	106.6¤	54.3	38.2	38.2	-	-
	May 10	10	728	48.3	48.3	76.5	40.2	-	-
	May 11	11	748	74.4	58.3	38.2	34.2	-	-
	May 12	12	732	48.3	48.3	36.2	36.2	-	-
	May 13	13	785	50.3	50.3	74.4	46.3	-	-
	May 14	14	728	36.2	36.2	64.4	36.2	-	-
	May 15	15	748	72.4	56.3	24.1	28.2	-	-
	May 16	16	672	42.3	34.2¤	38.2	34.2	-	-
	May 17	17	716	40.2	36.2	40.2	28.2	-	-
	May 18	18	704	56.3	48.3	44.3	36.2	-	-
	May 19	19	773	36.2	32.2¤	76.5	52.3	-	-
	AVERAGE		744	**56.5**	**51.7**	**55.8**	**43.2**		
2	May 20	20	676¤	72.4	72.4¤	92.6	72.4¤	-	-
	May 21	21	741	45.1	45.1	102.4	36.9	-	-
	May 22	22	745	49.2	32.8	57.3	20.5¤	-	-
	May 23	23	705	45.1	36.9	57.3	36.9	-	-
	May 24	24	721	53.2	49.2	53.2	45.1	-	-
	May 25	25	721	38.9	38.9	38.9¤	38.9	-	-
	May 26	26	688	30.7	30.7	100.4	38.9	-	-
	May 27	27	750	43.0	43.0	79.9	47.1	-	-
	May 28	28	737	57.3	57.3	77.8	45.1	-	-
	May 29	29	807	65.5	49.2	131.1¤	69.6	-	-
	May 30	30	795	57.3	53.2	122.9¤	65.5	-	-
	May 31	31	676¤	81.9	49.2	49.2	45.1	-	-
	June 1	32	700	30.7	26.6¤	71.7	30.7	-	-
	June 2	33	786	45.1	41.0	77.8	69.6	-	-
	June 3	34	757	111.3¤	62.7	50.6	46.6	-	-
	June 4	35	765	131.6¤	70.8	62.7	54.6	-	-
	June 5	36	761	44.5	40.5	89.1	36.4	-	-
	June 6	37	749	52.6	44.5	68.8	56.7	-	-
	June 7	38	765	46.6	62.7	91.1	58.7	-	-
	June 8	39	826¤	54.6	46.6	70.8	54.6	-	-
	AVERAGE		747	**50.8**	**47.5**	**73.7**	**48.7**		
	June 9	40	769	36.4	24.3¤	48.6	36.4	-	-
	June 10	41	765	52.6	48.6	105.2	52.6	-	-
	June 11	42	749	50.6	50.6	123.5¤	50.6	-	-
	June 12	43	745	58.7	46.6	91.1	50.6	-	-
	June 13	44	765	56.7	48.6	56.7	48.6	-	-
	June 14	45	749	56.7	32.4	36.4	32.4	1984	1943
	June 15	46	769	30.4	30.4	99.2	42.5	2409	2004

¤ Data rejected as outliers at 10% level of significance.

3	June 16	47	688	42.5	42.5	99.2	30.4	2328	2206
	June 17	48	721	46.6	46.6	87.0	58.7	2530	2409
	June 18	49	708	105.2¤	24.3¤	24.3¤	24.3¤	2388	2429
	June 19	50	805¤	40.9	40.9	76.9	45.0	2105	2226
	June 20	51	760	126.7¤	65.4¤	45.0	45.0	2739	2984
	June 21	52	744	61.3	49.1	69.5	40.9	2575	2167
	June 22	53	756	36.8	36.8	77.7	57.2	2453	2862
	June 23	54	752	55.2	63.4¤	96.1	71.5	2351	3086
	June 24	55	752	40.9	40.9	65.4	61.3	2208	3025
	June 25	56	679	73.6	49.1	77.7	77.7¤	2616	2003
	June 26	57	719	30.7	22.4¤	30.7	30.7	1942¤	1615
	June 27	58	646¤	61.3	49.1	45.0	36.8	2494	3066
	June 28	59	680	40.5	40.5	64.8	56.7	2793¤	1943
	AVERAGE		737	**48.5**	**43.5**	**70.7**	**47.1**	**2433**	**2430**
4	June 29	60	793	36.4	36.4	76.9	52.6	1903¤	2672
	June 30	61	712	46.6	26.3	46.6	30.4¤	2651	3299
	July 1	62	708	76.9¤	36.4	48.6	44.5	3076	1984¤
	July 2	63	716	42.5	38.5	54.6	42.5	3259	2813
	July 3	64	749	64.8	60.7¤	48.6	44.5	3400	2024
	July 4	65	793	81.0¤	56.7	52.6	36.4	2550	2469
	July 5	66	874¤	44.5	40.5	60.7	48.6	2388	2307
	July 6	67	778	52.9	40.7	105.9¤	57.0	2443	2891
	July 7	68	790	36.6	36.6	48.9	44.8	2565	3054
	July 8	69	-	-	-	-	-	-	-
	July 9	70	778	36.6	36.6	61.1	52.9	1873¤	2606
	July 10	71	823	63.1	34.6	50.9	42.8	3115	3767
	July 11	72	-	-	-	-	-	-	-
	July 12	73	782	36.6	36.6	77.4	57.0	3787¤	4031¤
	July 13	74	802	73.3	69.2¤	89.6	48.9	3828	3583
	July 14	75	802	57.0	44.8	85.5	57.0	3583	3380
	July 15	76	829	48.8	32.5	89.4	61.0¤	2804	2560
	July 16	77	732	40.6	28.4	69.1	44.7	2885	3129
	July 17	78	752	44.7	28.4	69.1	44.7	2642	3373
	July 18	79	772	50.8	42.7	67.1	46.7	3475	2987
	July 19	80	752	54.9	50.8	87.4	58.9	2824	3068
	July 20	81	711	38.6	38.6	67.1	34.5	2946	2743
	July 21	82	675¤	32.5	20.3¤	56.9	40.6	2642	2235
	AVERAGE		767	**47.5**	**38.1**	**65.4**	**47.4**	**2949**	**2893**
5	July 22	83	723	54.9	54.9	95.5	71.1	2784	3597¤
	July 23	84	675	48.8	24.4¤	81.3	44.7	2885	2520
	July 24	85	688	53.2	36.9	45.1	32.8	2662¤	2376
	July 25	86	-	-	-	-	-	-	-
	July 26	87	-	-	-	-	-	-	-
	July 27	88	-	-	-	-	-	-	-
	July 28	89	823	51.2	47.1	79.9	47.1	2847	2355
	July 29	90	786	55.3	51.2	55.3	51.2	3052	2232
	July 30	91	774	51.2	47.1	43.0	43.0	2970	2273
	July 31	92	836	51.2	51.2	104.4	59.4	3011	3133
	Aug 1	93	774	40.7	40.7	85.5	73.3¤	3095	2850
	Aug 2	94	818	48.9	44.8	52.9	40.7	3095	2525
	Aug 3	95	741	93.7¤	52.9	69.2	57.0	2973	2362
	Aug 4	96	713	52.9	48.9	109.9	52.9	2728	2280
	AVERAGE		759	**50.8**	**47.6**	**74.7**	**50.0**	**2944**	**2491**
	Aug 5	97	802	59.0	46.8	42.8	34.6¤	1893¤	2097
	Aug 6	98	761	46.8	46.8	87.5	50.9	1975	2016
	Aug 7	99	806	40.7	40.7	175.1¤	65.2	2117	2240
	Aug 8	100	823	38.7	38.7	67.2	55.0	2179	2504
	Aug 9	101	684	46.6	42.5	46.6	46.6	2287	2287
	Aug 10	102	644	54.6	50.6	66.8	46.6	2247	2611

¤ Data rejected as outliers at 10% level of significance.

6	Aug 11	103	660	52.6	32.4	105.2	64.8	2145	2550
	Aug 12	104	660	38.5	34.4	58.7	46.6	1882¤	2287
	Aug 13	105	729	76.9¤	48.6	60.7	56.7	2226	1862¤
	Aug 14	106	636	89.1¤	56.7¤	68.8	52.6	2186	3117¤
	Aug 15	107	765	58.7	58.6¤	78.9	70.8	2247	2247
	Aug 16	108	765	52.6	48.6	76.9	76.9¤	2348	2226
	Aug 17	109	645	49.0	40.8	89.8	49.0	2448	2244
	Aug 18	110	612	44.9	40.8	73.4	53.0	2122	2815
	Aug 19	111	632	61.2	32.6	106.1	61.2	1958	3182¤
	Aug 20	112	636	55.1	42.8	59.2	38.8	2550¤	2591
	Aug 21	113	612	30.6¤	30.6	51.0	46.9	2142	2346
	Aug 22	114	583	44.9	24.5¤	53.0	53.0	2285	2815
	AVERAGE		**692**	**49.6**	**41.2**	**70.2**	**53.6**	**2194**	**2392**
7	Aug 23	115	792	36.7	28.6	77.5¤	69.4¤	2448	2815
	Aug 24	116	812	57.1	44.9	44.9	40.8	2489	2734
	Aug 25	117	744	32.7	16.4	28.6	24.5	2248	2535
	Aug 26	118	748	28.6	24.5	32.7	28.6	2494	2698
	Aug 27	119	650¤	16.4¤	12.3	24.5	24.5	2371	2657
	Aug 28	120	752	16.4¤	16.4	12.3¤	12.3¤	2330	3025
	Aug 29	121	801	28.6	16.4	36.8	36.8	2616	3229,5¤
	Aug 30	122	785	49.1	40.9	57.2	53.1	2616	3066
	Aug 31	123	805	51.1	30.7	42.9	38.8	2310	2473
	Sept 1	124	764	34.7	26.6	34.7	22.5	2473	2800
	Sept 2	125	764	49.1	40.9	45.0	45.0	2984¤	2821
	Sept 3	126	763	49.0	44.9	53.0	36.7	2611	3060
	Sept 4	127	669¤	44.9	44.9	32.6	32.6	2122	2693
	Sept 5	128	714	40.8	36.7	49.0	32.6	2162	2530
	Sept 6	129	869¤	40.8	32.6	40.8	36.7	2203	2897
	Sept 7	130	840	44.9	40.8	36.7	32.6	2244	2938
	AVERAGE		**776**	**42.0**	**31.1**	**40.0**	**34.7**	**2383**	**2783**
8	Sept 8	131	665	38.8	38.8	38.8	38.8	2468	2632
	Sept 9	132	641	49.0	49.0	97.9¤	49.0	2448	2530
	Sept 10	133	726	32.6	16.3¤	36.7	36.7	2693	2285
	Sept 11	134	635	14.3¤	22.4	22.4¤	14.3¤	2016	2179
	Sept 12	135	668	48.9	40.7	57.0	52.9¤	2240	2565
	Sept 13	136	770	44.8	44.8	44.8	40.72	2240	2565
	Sept 14	137	818	38.7	26.5	46.8	38.7	2016	1812¤
	Sept 15	138	814	44.8	36.6	44.8	32.6	2402	2525
	Sept 16	139	782	81.4¤	44.8	52.9	36.6	2240	2280
	Sept 17	140	733	42.8	42.8	46.8	42.8	2626	2382
	Sept 18	141	711	58.9	46.7	42.7	42.7	2337	2662
	Sept 19	142	817	54.9	46.7	58.9	42.7	2865	2865¤
	Sept 20	143	589¤	40.6	32.5	36.6	36.6	2357	2235
	Sept 21	144	821	44.7	32.5	32.5	32.5	3048¤	2357
	AVERAGE		**739**	**44.9**	**38.8**	**44.9**	**39.2**	**2381**	**2433**
9	Sept 22	145	776	44.7	36.6	44.7	36.6	2520	2479
	Sept 23	146	825	52.8	48.8	48.8	44.7	2642	2845
	Sept 24	147	891¤	42.5	38.5	99.2¤	50.6	2409	3299¤
	Sept 25	148	680	56.7	52.6	56.7	52.6	2631	2672
	Sept 26	149	749	22.3	22.3	34.4	18.2	2530	2490
	Sept 27	150	793	52.6	48.6	48.6	44.5	3157	2793
	Sept 28	151	704	36.4	32.4	32.4	20.2	2915	2672
	Sept 29	152	644	30.4	26.3	34.4	34.4	3178	2732
	Sept 30	153	696	40.5	32.4	52.6	44.5	2591	2510
	Oct 1	154	715	37.0	32.9	45.2	32.9	2920	2591
	Oct 2	155	691	82.2¤	69.9¤	61.7	53.5	3043	3660¤
	Oct 3	156	843	57.6	49.3	37.0	37.0	2673	2549
	Oct 4	157	518¤	16.4¤	16.4	24.7	16.4¤	2714	2755
	AVERAGE		**738**	**43.0**	**36.4**	**43.4**	**39.1**	**2763**	**2644**

¤ Data rejected as outliers at 10% level of significance.

10	Oct 5	158	998¤	22.4¤	22.4¤	26.5¤	26.5¤	3034	3074
	Oct 6	159	806	46.8	46.8	42.8	34.6	3115	2952
	Oct 7	160	798	44.8	44.8	44.8	44.8	2647¤	2932
	Oct 8	161	818	55.0	38.7	46.8	42.8	2911	2993
	Oct 9	162	754	57.3	53.2	53.2	53.2	3441¤	3277
	Oct 10	163	786	32.8	24.5¤	41.0	32.8	2990	3973¤
	Oct 11	164	766	47.1	43.0	47.1	47.1	2888	3297
	Oct 12	165	844	61.4	49.2	69.6¤	53.2	2990	3195
	Oct 13	166	803	56.8	28.4	60.8	40.6	3204	2920
	Oct 14	167	827	40.6	40.6	36.5	36.5	2880	3001
	Oct 15	168	840	60.8	48.7	32.4	32.4	3123	2961
	Oct 16	169	844	54.8	46.6	62.9	50.7	2981	2819
	Oct 17	170	794	45.2	41.1	41.1	41.1	2796	2920
	AVERAGE		**807**	**50.3**	**43.7**	**46.3**	**42.5**	**2992**	**3028**
11	Oct 18	171	794	35.0	30.8	35.0	26.7	2858	3228
	Oct 19	172	818	28.8	24.7	49.3	41.1	3207	3166
	Oct 20	173	781	39.1	39.1	55.5	51.4	2817	3228
	Oct 21	174	724	39.1	39.1	39.1	39.1	2899	3228
	Oct 22	175	806	35.0	30.8	43.2	30.8	3680¤	3228
	Oct 23	176	765	32.9	32.9	32.9	28.8	3248	3248
	Oct 24	177	748	41.1	32.9	41.1	37.0	3125	2878
	Oct 25	178	798	43.2	43.2	43.2	30.8	3228	3228
	Oct 26	179	810	29.1	20.8¤	29.1	29.1	3363	3031
	Oct 27	180	818	47.7	39.4	56.1	56.1	2969	2720¤
	Oct 28	181	793	56.1¤	51.9	47.7	43.6	3301	3384
	Oct 29	182	785	35.3	35.3	47.7	47.7	3135	3259
	Oct 30	183	693	54.0¤	49.8¤	58.1¤	58.1¤	3405	3488¤
	Oct 31	184	645¤	40.8	32.6	32.6	28.6	2938	2978
	AVERAGE		**779**	**37.2**	**36.1**	**42.5**	**37.8**	**3115**	**3174**
12	Nov 1	185	567¤	28.6	28.6	36.7	36.7	2815	2774
	Nov 2	186	694	49.0	40.8	49.0	40.8	2856	2897
	Nov 3	187	702	20.4	20.4	36.7	36.7	2448	1836¤
	Nov 4	188	750	45.1	41.0	45.1	32.8	2662	2867
	Nov 5	189	913¤	38.9	34.8	47.1	30.7	2314	2519
	Nov 6	190	606¤	12.3¤	12.3¤	36.9	12.3¤	2253	2662
	Nov 7	191	811	36.9	36.9	41.0	41.0	2662	2744
	Nov 8	192	766	36.9	36.9	41.0	41.0	2540	2703
	Nov 9	193	795	24.6	16.4	41.0	28.7	2376	2744
	Nov 10	194	754	49.2	49.2	41.0	36.9	2253	2826
	Nov 11	195	815	59.4	51.2	51.2	38.9	2888	3461¤
	Nov 12	196	803	28.7	28.7	45.1	36.9	2785	2826
	Nov 13	197	807	53.2	53.2	32.8	32.8	2417	2867
	Nov 14	198	-	-	-	-	-	-	-
	Nov 15	199	831	49.2	49.2	41.0	41.0	2089¤	2908
	Nov 16	200	836	75.8¤	59.4	63.5¤	51.2¤	2478	3830¤
	AVERAGE		**780**	**40.0**	**39.0**	**41.8**	**36.5**	**2553**	**2778**
13	Nov 17	201	608¤	53.0	44.9	53.0	40.8	2366	3182¤
	Nov 18	202	751	34.7¤	34.7	38.8	26.5	2224¤	2917
	Nov 19	203	718	49.0	40.8	36.7	36.7	2285	3101
	Nov 20	204	698	46.9	46.9	42.8	38.8	2468	3080
	Nov 21	205	889¤	44.9	44.9	44.9	36.7	2448	3101
	Nov 22	206	763	38.8	34.7	42.8	38.8	2428	3080
	Nov 23	207	779	49.0	28.6	40.8	40.8	2530	2938
	Nov 24	208	792	44.9	36.7	44.9	40.8	2856	2856
	Nov 25	209	812	63.2¤	59.2¤	63.2	63.2¤	2672	3121
	Nov 26	210	747	42.8	34.7	38.8	38.8	2550	2917
	Nov 27	211	690	49.0	49.0	57.1	49.0	2774	2856
	Nov 28	212	724	37.0	32.9	45.2	41.1	2632	2961
	Nov 29	213	761	39.1	39.1	39.1	22.6¤	2570	2899

¤ Data rejected as outliers at 10% level of significance.

	Nov 30	214	-	-	-	-	-	-	-
	Dec 1	215	699	45.2	37.0	45.2	37.0	2837	2961
	Dec 2	216	748	47.3	35.0	59.6	35.0	2652	2899
	Dec 3	217	766	36.9	36.9	32.8	24.6¤	2580	2785
	Dec 4	218	754	55.3	34.8	63.5¤	59.4¤	2765	2847
	Dec 5	219	737	49.2	36.9	61.4	45.1	3400¤	2744¤
	AVERAGE		**746**	**45.5**	**38.1**	**46.3**	**39.0**	**2588**	**2957**
14	Dec 6	220	754	32.8	32.8	45.1	41.0	2499	2662
	Dec 7	221	778	32.8	24.6	45.1	36.9	2580	2744
	Dec 8	222	762	26.6	22.5	34.8	34.8	2642	2724
	Dec 9	223	754	49.2	45.1	36.9	32.8	2785	2662
	Dec 10	224	758	34.8	18.4	30.7	30.7	2929	2806
	Dec 11	225	745	20.5	20.5	32.8	20.5¤	2580	2499
	Dec 12	226	750	32.8	24.6	41.0	20.5¤	2458	2703
	Dec 13	227	803	45.1	32.8	36.9	36.9	2867	2949
	Dec 14	228	786	38.9	26.6	43.0	38.9	3174	2765
	Dec 15	229	958¤	28.7	28.7	41.0	41.0	2785	2908
	Dec 16	230	770	53.2	49.2	36.9	36.9	2458	3072
	Dec 17	231	791	57.3	49.2	41.0	36.9	3154	2949
	Dec 18	232	786	57.3	49.2	41.0	36.9	2990	3277¤
	Dec 19	233	811	49.2	45.1	49.2	49.2¤	3113	3154
	Dec 20	234	782	49.2	41.0	45.1	45.1	3154	2949
	Dec 21	235	770	36.9	36.9	45.1	45.1	3072	3113
	Dec 22	236	745	16.4¤	16.4	24.6¤	12.3¤	2662	2417¤
	Dec 23	237	745	49.2	45.1	49.2	36.9	2540	3031
	Dec 24	238	741	40.5	32.4	48.6	36.4	2915	3036
	Dec 25	239	712¤	28.3	24.3	32.4	28.3	3117	3117
	AVERAGE		**768**	**40.2**	**33.2**	**40.8**	**37.2**	**2824**	**2880**
15	Dec 26	240	967¤	56.7	44.5	44.5	40.5	3076	3157
	Dec 27	241	972¤	64.8¤	60.7¤	32.4	32.4	3117	2915
	Dec 28	242	899	64.8¤	28.3	44.5	40.5	2996	2915
	Dec 29	243	874	36.4	36.4	40.5	36.4	3157	3117
	Dec 30	244	806	38.5	38.5	42.5	34.4	3178	3218¤
	Dec 31	245	814	26.3	22.3¤	26.3¤	26.3	3056	3137
	Jan 1 *96*	246	700	34.4	34.4	30.4	30.4	2975	2975
	Jan 2	247	696	42.5	30.4	30.4	26.3	3056	2975
	Jan 3	248	773	30.4	30.4	30.4	22.3¤	3097	2854
	Jan 4	249	769	30.4	26.3	26.3¤	26.3	3097	2813
	Jan 5	250	769	36.4	36.4	36.4	36.4	3117	2915
	Jan 6	251	708	40.5	40.5	40.5	40.5	2996	2996
	Jan 7	252	737	34.4	30.4	34.4	34.4	2975	2894
		253	721	36.4	36.4	36.4	36.4	2915	2793
	Jan 9	254	741	38.5	38.5	34.4	30.4	2732¤	2773
	Jan 10	255	777	54.6	50.6¤	38.5	34.4	2813	2732
	Jan 11	256	742	40.3	40.3	40.3	36.3	2742¤	2540¤
	Jan 12	257	722	38.3	34.3	38.3	34.3	2843	2520¤
	AVERAGE		**765**	**38.4**	**35.1**	**37.2**	**33.9**	**3029**	**2931**
16	Jan 13	258	1157¤	38.3	22.2¤	42.3	38.3	2762	2318¤
	Jan 14	259	1121	36.3	28.2	40.3	32.3	3024	2782
	Jan 15	260	1093	34.3	34.3	42.3	42.3	3165	2762
	Jan 16	261	1097	36.3	36.3	40.3	40.3	3790¤	3347¤
	Jan 17	262	758	36.3	36.3	36.3	36.3	3185	2984
	Jan 18	263	758	28.2¤	28.2	36.3	36.3	3064	2903
	Jan 19	264	766	40.3	40.3	36.3	32.3	3024	2863
	Jan 20	265	764	30.3	26.3	38.4	34.3	2808	2565
	Jan 21	266	760	32.3	32.3	32.3¤	32.3	2990	2990
	Jan 22	267	780	52.5¤	52.5¤	44.4	40.4	2990	2909
	Jan 23	268	743	44.4	40.4	36.4	32.3	2949	3030
	Jan 24	269	772	42.4	38.4	42.4	42.4	3737¤	2848

¤ Data rejected as outliers at 10% level of significance.

	Jan 25	270	747	40.4	36.4	40.4	40.4	2990	2868
	Jan 26	271	764	40.4	32.3	40.4	36.4	2990	2828
	AVERAGE		**840**	**37.7**	**34.1**	**39.7**	**36.9**	**2995**	**2861**
17	Jan 27	272	727	36.4	32.3	36.4	32.3	2788	2707
	Jan 28	273	739	30.3	26.3	38.4	34.3	3010	2646
	Jan 29	274	792	52.5	32.3	40.4	36.4	2909	2788
	Jan 30	275	788	40.6	40.6	40.6	40.6	2926	3007
	Jan 31	276	711	71.1¤	34.5	58.9¤	38.6	3068	3068
	Feb 1	277	736	38.6	34.5	38.6	38.6	2865	2865
	Feb 2	278	740	40.6	12.2¤	24.4¤	16.3	2764	2642
	Feb 3	279	801	30.5	30.5	30.5	30.5	2743	2377¤
	Feb 4	280	719	32.5	28.4	32.5	28.4	2642	2845
	Feb 5	281	675	24.4¤	16.3¤	32.5	16.3	2682	2479
	Feb 6	282	695	45.0	28.6	57.2¤	28.6	2698	2657
	Feb 7	283	834	45.0	28.6	36.8	20.4	2698	2902
	Feb 8	284	879	36.8	36.8	36.8	20.4	2780	2821
	Feb 9	285	924¤	36.8	36.8	49.1	36.8	3066	3107
	AVERAGE		757	**38.8**	**32.5**	**37.5**	**29.9**	**2831**	**2810**
18	Feb 10	286	826¤	38.8	34.7	51.1	42.9	2841	3127
	Feb 11	287	752	22.5¤	22.5¤	38.8	30.7	2637	2841
	Feb 12	288	711	40.9	32.7	40.9	40.9	2739	3107
	Feb 13	289	666¤	36.8	28.6	36.8	20.4¤	2616	3025
	Feb 14	290	741	55.3	38.9	59.4¤	51.2	2847	3215
	Feb 15	291	762	49.2	41.0	53.2	53.2	2744	3031
	Feb 16	292	758	38.9	26.6	51.2	51.2	2929	3092
	Feb 17	293	791	36.9	32.8	36.9	32.8	2621	2580¤
	Feb 18	294	745	41.0	41.0	41.0	36.9	2580	2826
	Feb 19	295	778	63.5¤	38.9	43.0	43.0	3011	2970
	Feb 20	296	714	49.2	49.2¤	41.0	36.9	2011¤	2873
	Feb 21	297	706	36.9	28.7	41.0	24.6	2134¤	2668
	AVERAGE		746	**42.4**	**34.4**	**43.2**	**40.4**	2757	**2980**
19	Feb 22	298	714	32.8	24.6	36.9	32.8	2339	2750
	Feb 23	299	735	26.7	22.6	26.7	22.6	2483	2770
	Feb 24	300	714	36.9	36.9	41.0	41.0	2586	2873
	Feb 25	301	694	43.1	39.0	43.1	39.0	2483	2770
	Feb 26	302	759	45.1	24.6	41.0	36.9	2544	2914
	Feb 27	303	745	24.6	20.5	24.6	20.5	2540	2662
	Feb 28	304	778	41.0	41.0	53.2	36.9	2826	2949
	Feb 29	305	827¤	22.5	18.4	26.6	26.6	2519	2765
	March 1	306	754	32.8	28.7	32.8	28.7	2744	3113¤
	March 2	307	774	24.6	24.6	24.6	24.6	2826	2785
	March 3	308	762	24.6	24.6	24.6	24.6	2867	3031
	March 4	309	783	20.4¤	20.4	40.8	40.8	2774	2897
	March 5	310	816	36.7	20.4	36.7	28.6	2815	2856
	March 6	311	792	51.0	38.8	46.9	42.8	2917	2999
	March 7	312	669¤	42.8	42.8	51.0	46.9	2468	2550¤
	AVERAGE		755	**34.7**	**28.5**	**36.7**	**32.9**	**2649**	**2848**
20	March 8	313	763	38.8	26.5	18.4¤	14.3¤	2795	2876
	March 9	314	677¤	22.4	22.4	26.5	18.4	2713	2713
	March 10	315	743	40.8	32.6	36.7	36.7	2774	2774
	March 11	316	763	32.6	32.6	32.6	28.6	2978	3223
	March 12	317	785	20.8	16.6¤	33.2	29.1	3031	3156
	March 13	318	760	37.4	33.2	41.5	41.5	3072	3571¤
	March 14	319	747	56.1¤	43.6	47.7	47.7	2969	3135
	March 15	320	710	45.7	29.1	33.2	29.1	2616¤	3031
	March 16	321	747	45.7	41.5	41.5	41.5	3072	2616
	March 17	322	735	30.8	30.8	43.1	30.8	2975	2852
	March 18	323	739	32.8	32.8	53.4	49.2	3119	3037
	March 19	324	780	28.7	28.7	53.4	45.1	3201	2709

¤ Data rejected as outliers at 10% level of significance.

	March 20	325	833¤	45.1	45.1¤	49.2	49.2	2873	3201
	AVERAGE		**752**	**35.1**	**32.2**	**41.0**	**37.2**	**2964**	**2944**
21	March 21	326	788	24.6	24.6	36.9	36.9	3201	3[illegible]83
	March 22	327	739	53.4	49.2¤	28.7	24.6	3201	3488
	March 23	328	804	32.8	28.7	45.1	45.1	3201	3242¤
	March 24	329	759	45.1	41.0	45.1	45.1	3570	3570
	March 25	330	780	39.0	30.8	47.2	47.2	3304	3837
	March 26	331	806	24.4	24.4	48.9	36.6	3420	3502
	March 27	332	831¤	48.9	40.7	61.1	44.8	3706¤	3868
	March 28	333	802	40.7	40.7	52.9	40.7	3502	3828
	March 29	334	741	50.9	38.7	50.9	38.7	3563	3848
	March 30	335	709¤	28.5	28.5	52.9	32.6	3176	3624
	March 31	336	753	30.5	30.5	42.8	42.8	3319	3522
	April 1	337	761	30.5	30.5	30.5	30.5	3319	3441
	April 2	338	763	40.6	40.6	36.5	36.5	3326	3569
	April 3	339	710	26.4	26.4	14.2¤	14.2¤	3062	3427
	AVERAGE		**767**	**36.9**	**32.8**	**44.6**	**38.6**	**3320**	**3601**
22	April 4	340	698	42.6	34.5	50.7	50.7	3225	3711
	April 5	341	771¤	60.8¤	60.8¤	85.2¤	81.1¤	3285	3853¤
	April 6	342	698	30.4	30.4	46.6	46.6	3062	3508
	April 7	343	673	36.5	36.5	48.7	44.6	2920	3326
	April 8	344	688	34.6	34.6	30.5	30.5	2708	2871
	April 9	345	709	28.5	28.5	24.4	24.4	2688	3135
	April 10	346	749	34.6	34.6	46.8	38.7	2586	3156
	April 11	347	717	50.9	46.8	34.6	34.6	2626	3074
	April 12	348	745	38.7	38.7	50.9	50.9	2871	3115
	AVERAGE		**710**	**37.1**	**35.6**	**41.7**	**40.1**	**2886**	**3237**
23	April 13	349	680	28.5¤	28.5	28.5	28.5	3054	3013
	April 14	350	684	38.5	34.4	34.4	34.4	2813	3016
	April 15	351	676	46.6	46.6	46.6	42.5	3056	3259
	April 16	352	733	52.6	48.6	36.4	36.4	2834	3157
	April 17	353	724	33.1	33.1	62.0	62.0¤	2771	3309¤
	April 18	354	728	53.8	53.8	57.9	57.9¤	2854	3102
	April 19	355	711	45.5	45.5	41.4	41.4	2854	3143
	April 20	356	682	49.6	49.6	41.4	41.4	2854	3143
	April 21	357	670	33.1	33.1	41.4	41.4	2647	3019
	April 22	358	724	43.4	39.3	31.0	31.0	2709	2916
	April 23	359	640	41.0	28.7	41.0	20.5¤	2339¤	2668¤
	April 24	360	575¤	39.0	30.8	67.7¤	47.2	2606	3057
	AVERAGE		**696**	**43.3**	**39.3**	**42.0**	**38.2**	**2823**	**3083**
24	April 25	361	792	43.1	43.1	51.3	51.3	2565	3099¤
	April 26	362	767	39.0	39.0	55.4	51.3	2647¤	2934
	April 27	363	747	36.9	36.9	45.1	45.1	2421	2791
	April 28	364	672	22.1¤	22.1¤	30.2	30.2	2475	2636
	April 29	365	688	38.2	34.2	42.3	22.1	2435	2756
	April 30	366	668	48.3	40.2	40.2	28.2	2253	2455
	May 1	367	736	40.2	32.2	36.2	32.2	2455	2535
	May 2	368	765	48.3	48.3¤	52.3	40.2	2414	2736
	May 3	369	710	38.5	38.5	34.5	34.5	2373	2535
	May 4	370	625	40.6	28.4	40.6	36.5	2434	2596
	May 5	371	621	42.6	38.5	50.7	42.6	2170	2454
	May 6	372	637	24.3¤	24.3	32.4	32.4	2069¤	2474
	May 7	373	608	36.7	36.7	40.8	24.5	2203	2530
	AVERAGE		**695**	**41.1**	**35.7**	**42.5**	**36.2**	**2382**	**2619**
	May 8	374	975¤	38.8	38.8	34.7	34.7	2387	2713
	May 9	375	1004¤	44.9	44.9	53.0	53.0	2734	3305
	May 10	376	971¤	40.8	40.8	44.9	44.9	2652	3305
	May 11	377	702	49.0	49.0	49.0	49.0	2978¤	3427
	May 12	378	714	46.9	46.9	42.8	42.8	2672	3896¤

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25	May 13	379	710	42.8	42.8	38.8	38.8	2836	3488
	May 14	380	714	44.6	44.6	44.6	44.6	2718	3042
	May 15	381	645	34.5	34.5	38.5	38.5	2981¤	2859
	May 16	382	657	58.8¤	58.8¤	50.7	46.6	2373¤	3062
	May 17	383	694	44.6	44.6	32.4	32.4	2515	2920
	May 18	384	617	28.4¤	28.4¤	20.3¤	20.3¤	2677	2839
	May 19	385	649	28.4¤	28.4¤	40.6	40.6	2515	2799
	May 20	386	662	54.9	46.7	67.1¤	63.0¤	2784	2784
	AVERAGE		**676**	**44.2**	**43.4**	**42.7**	**42.4**	**2649**	**3045**
26	May 21	387	878¤	38.6	26.4	38.6	38.6	2621	2824
	May 22	388	715	48.8	36.6	40.6	36.6	2723	3048
	May 23	389	744	61.0	61.0¤	61.0	56.9	2682	3251
	May 24	390	688	53.2	53.2	49.2	49.2	3072¤	3195
	May 25	391	684	38.9	38.9	47.1	47.1	2806	3133
	May 26	392	664	34.8	30.7	47.1	43.0	2314	2806
	May 27	393	733	65.5¤	53.2	61.4	53.2	2621	2949
	May 28	394	733	36.9	36.9	36.9	32.8	2417	3031
	May 29	395	714	48.7	44.6	56.8	52.7	2474	2920
	May 30	396	665	40.6	40.6	32.4	32.4	2920	3772¤
	May 31	397	702	32.4	32.4	36.5	32.4	2434	2677
	AVERAGE		**704**	**43.4**	**39.4**	**46.1**	**43.2**	**2601**	**2984**
27	June 1	398	779¤	32.4	28.4	52.7	48.7	2920	2961
	June 2	399	612	22.3	22.3	34.5	34.5	2981	2941
	June 3	400	635	20.5¤	20.5	41.0	28.7	2990	2458¤
	June 4	401	627	38.9	38.9	26.6	26.6	3420¤	2888
	June 5	402	737	28.7	28.7	32.8	28.7	2867	2990
	June 6	403	684	45.1	45.1	32.8	32.8	3318¤	3031
	June 7	404	676	49.2	49.2	53.2	49.2	2867	3031
	June 8	405	611	49.2	49.2	45.1	45.1	3119	3119
	June 9	406	747	39.0	39.0	39.0	39.0	2524	2647
	June 10	407	632	30.8	30.8	39.0	39.0	2770	2852
	June 11	408	611	45.1	24.6	49.2	45.1	2709	2709
	June 12	409	620	39.0	34.9	30.8	30.8	2688	2770
	June 13	410	648	45.1	28.7	32.8	28.7	2627	2750
	AVERAGE		**653**	**38.7**	**33.9**	**39.2**	**36.7**	**2824**	**2891**
28	June 14	411	556¤	28.6	12.3¤	28.6	20.4	2616¤	2862
	June 15	412	683	36.8	36.8	40.9	40.9	2902	3393
	June 16	413	634	32.7	32.7	36.8	36.8	3025	2862
	June 17	414	560¤	28.6	28.6	28.6	28.6	2780	2821
	June 18	415	756	26.6	22.5	18.4	18.3¤	3332	2514¤
	June 19	416	801¤	34.7	34.7	30.7	42.9	2882	3250
	June 20	417	658	69.9¤	65.8¤	69.9¤	69.9¤	3207	3248
	June 21	418	674	32.9	32.9	41.1	41.1	3125	3125
	June 22	419	662	32.9	32.9	28.8	28.8	3619	3002
	June 23	420	-	-	-	-	-	-	-
	June 24	421	711	45.2	41.1	82.2¤	45.2	4071¤	3084
	June 25	422	670	26.7	26.7	35.0	35.0	3146	3228
	June 26	423	703	47.3	47.3	43.2	39.1	3146	3187
	June 27	424	669	53.4	49.2	49.2	41.0	3119	3283
	AVERAGE		**682**	**35.5**	**35.0**	**34.7**	**36.3**	**3117**	**3112**
29	June 28	425	747	34.9	26.7	26.7	22.6	3263	3386
	June 29	426	648	36.9	32.8	41.0	32.8	2750	3201
	June 30	427	677	43.1	30.8	55.4¤	34.9	2647	3057
	July 1	428	550¤	24.6	24.6	21,0¤	20.5¤	2257¤	3488
	July 2	429	763¤	39.0	30.8	39.0	39.0	2893	3057
	July 3	430	714	24.6	24.6	36.9	36.9	2873	2996
	July 4	431	685	45.1	45.1	45.1	45.1	2914	3488
	July 5	432	702	26.7	26.7	39.0	26.7	2975	3263
	July 6	433	676	26.3	26.3	34.4	34.4	2813	2449¤

¤ Data rejected as outliers at 10% level of significance.

	July 7	434	623	28.3	24.3	32.4	28.3	2510	2631
	July 8	435	721	44.5	44.5	32.4	32.4	2429	2915
	July 9	436	644	36.4	36.4	40.5	40.5	2712	2388
	July 10	437	692	38.5	38.5	42.5	42.5	3340	2773
	July 11	438	704	54.6¤	50.6¤	46.6	46.6¤	3218	3016
	July 12	439	631	28.7	20.5	28.7	24.6	3195	2990
	AVERAGE		**682**	**34.1**	**30.9**	**37.3**	**33.9**	**2895**	**3046**
30	July 13	440	672	32.8	32.8	41.0	41.0	2785	2949
	July 14	441	713	32.8	32.8	41.0	36.9	3072	2744
	July 15	442	791¤	24.6	24.6	24.6	24.6	3523¤	3236
	July 16	443	672	28.7	16.4¤	20.5¤	20.5¤	3072	3113
	July 17	444	725	53.2¤	41.0¤	41.0	41.0	3072	3031
	July 18	445	-	-	-	-	-	-	-
	July 19	446	696	30.7	30.7	34.8	34.8	2765	2724
	July 20	447	758	30.7	30.7	47.1	34.8	2888	2724
	July 21	448	639	30.7	30.7	71.7¤	55.3¤	2765	2232¤
	July 22	449	623¤	49.2¤	36.9	41.0	41.0	2990	3031
	July 23	450	692	31.6	31.6	27.7	27.7	2806	2569
	July 24	451	672	35.6	31.6	35.6	27.7	2845	2687
	July 25	452	684	23.7	23.7	35.6	31.6	2411¤	2095¤
	AVERAGE		**692**	**30.2**	**30.6**	**36.9**	**34.1**	**2906**	**2881**
31	July 26	453	680	37.5	33.6	45.4	45.4	2984	2786
	July 27	454	652	39.5	39.5	39.5	39.5	2529	2450
	July 28	455	583	40.8	40.8	57.1¤	57.1¤	3264	3223¤
	July 29	456	588	20.4¤	20.4¤	20.4	20.4	2366	2570
	July 30	457	612	36.7	36.7	44.9	44.9	2652	2489
	July 31	458	778¤	33.1	29.0	41.4	24.8	2771	2895
	Aug 1	459	682	29.0	29.0	41.4	37.2	2771	2275
	Aug 2	460	637	20.7¤	20.7¤	33.1	33.1	2606	2647
	Aug 3	461	678	33.1	33.1	41.4	29.0	2233	2978
	Aug 4	462	786¤	41.4	33.1	57.9¤	45.5	2275	2275
	Aug 5	463	534¤	31.0	31.0	26.9	26.9	2461	2213
	Aug 6	464	-	-	-	-	-	-	-
	AVERAGE		**639**	**35.8**	**34.0**	**37.1**	**34.7**	**2628**	**2558**
32	Aug 7	465	676	28.3	28.3	32.4	32.4	2631	2348
	Aug 8	466	684	40.5	28.3	36.4	36.4	2550	2388
	Aug 9	467	644	38.5	38.5	42.5	42.5	2328	2287
	Aug 10	468	664	32.4	32.4	36.4	36.4	2226¤	2186
	Aug 11	469	644	52.6¤	40.5	44.5	40.5	2267¤	2226
	Aug 12	470	644	36.4	36.4	28.3	28.3	2510	2226
	Aug 13	471	664	32.8	32.8	32.8	32.8	2580	2253
	Aug 14	472	729¤	49.2	49.2¤	57.3¤	53.2¤	2744	2458
	Aug 15	473	680	41.0	36.9	36.9	36.9	2662	2335
	Aug 16	474	676	49.2	36.9	28.7	28.7	2703	2089
	Aug 17	475	692	30.7	26.6	38.9	38.9	2601	1946¤
	Aug 18	476	602¤	43.0	34.8	22.5¤	22.6	2724	2109
	Aug 19	477	644	28.3	28.3	48.6	44.5	2591	2712¤
	AVERAGE		**665**	**37.5**	**33.4**	**36.9**	**35.1**	**2602**	**2264**
33	Aug 20	478	797	50.6¤	42.5	30.4	30.4	1963	2085
	Aug 21	479	631	32.4	32.4	16.2¤	16.2¤	2267	2064
	Aug 22	480	692	36.4	24.3	32.4	20.2	2186	2226
	Aug 23	481	700	32.4	24.3	36.4	32.4	2348	2469¤
	Aug 24	482	684	28.3	20.2	36.4	28.3	2348	1943¤
	Aug 25	483	1046¤	28.4	28.4	24.3	24.3	2190	2231
	Aug 26	484	811	36.5	36.5	48.7¤	48.7¤	3083	2231
	Aug 27	485	771	32.4	28.4	36.5	28.4	3366	2231
	Aug 28	486	758	20.3¤	12.2¤	36.5	36.5	2961	2231
	Aug 29	487	641	44.6	44.6¤	40.6	40.6	2515	2190
	Aug 30	488	726	42.6	30.4	38.5	26.4	3103	2373

¤ Data rejected as outliers at 10% level of significance.

	Aug 31	489	-	-	-	-	-	-	-
	Sept 1	490	-	-	-	-	-	-	-
	AVERAGE		**721**	**34.9**	**29.7**	**34.7**	**29.7**	**2575**	**2207**
34	Sept 2	491	657	12.2¤	12.2¤	36.7	20.4	2734	2530
	Sept 3	492	665	32.6	32.6	20.4¤	20.4	2162	2081
	Sept 4	493	649	28.6	16.3	28.6	28.6	2407	2203
	Sept 5	494	620	57.1¤	40.8¤	40.8	36.7	2693	2081
	Sept 6	495	641	53.0¤	36.7	36.7	36.7	3264	2407
	Sept 7	496	669	30.6	30.6	30.6	38.8	2224	2224
	Sept 8	497	830¤	32.6	28.5	32.6	32.6	2728	2240
	Sept 9	498	676	28.5	28.5	36.6	28.5	2484	2240
	Sept 10	499	668	40.7	32.6	28.5	24.4	2484	2199
	Sept 11	500	770	34.6	22.4	34.6	34.6	3156	2585¤
	Sept 12	501	700	30.5	26.5	34.6	34.6	3156	2301
	AVERAGE		**671**	**32.3**	**28.3**	**34.0**	**30.6**	**2681**	**2250**
35	Sept 13	502	623	42.8	38.7	38.7	38.7	2545	2138
	Sept 14	503	802¤	22.4¤	18.3	42.8	34.6	2871	2138
	Sept 15	504	773¤	40.7	24.4	44.8	44.8	2565	2443
	Sept 16	505	709	36.6	28.5	28.5	20.4	2728	2077
	Sept 17	506	696	36.4	40.5	44.5	40.5	2267	2226
	Sept 18	507	607	40.5	32.4	40.5	40.5	2186	2064
	Sept 19	508	664	44.5	40.5	40.5	20.2	3036	2064
	Sept 20	509	672	40.5	40.5	48.6	32.4	1984	2226
	Sept 21	510	607	40.5	32.4	44.5	28.3	1984	3197¤
	Sept 22	511	676	32.4	20.2	24.3	20.2	3521¤	1822
	Sept 23	512	640	28.3	28.3	28.3	28.3	1822	2105
	Sept 24	513	575	28.3	28.3	28.3	24.3	1660	1741
	Sept 25	514	-	-	-	-	-	-	-
	AVERAGE		**647**	**37.4**	**31.1**	**37.9**	**31.1**	**2331**	**2095**
36	Sept 26	515	808	37.7	37.7	58.6	41.8	1590	2301
	Sept 27	516	824	58.6	25.1	121.3¤	62.8	2929	3347¤
	Sept 28	517	799	46.0	33.5	41.8	41.8	2176	2469
	Sept 29	518	-	-	-	-	-	-	-
	Sept 30	519	820	23.0¤	14.6¤	60.7	43.9	1987	2197
	Oct 1	520	690¤	45.5	29.0	70.3	45.5	2192	2482
	Oct 2	521	699	66.2¤	66.2¤	70.3	66.2¤	3391¤	2730
	Oct 3	522	-	-	-	-	-	-	-
	Oct 4	523	757	43.4	43.4	31.0	26.9¤	2337	2750
	Oct 5	524	761	43.4	39.3	60.0	51.7	2420	2668
	Oct 6	525	-	-	-	-	-	-	-
	Oct 7	526	798	37.2	37.2	41.4	37.2	1820	2771
	AVERAGE		**783**	**44.5**	**35.0**	**54.3**	**46.4**	**2181**	**2546**
37	Oct 8	527	720	45.5	41.4	49.6	49.6	2109	2564
	Oct 9	528	-	-	-	-	-	-	-
	Oct 10	529	683	40.6	36.6	73.2¤	44.7	2195	2642
	Oct 11	530	-	-	-	-	-	-	-
	Oct 12	531	769¤	58.5¤	58.7¤	50.6	46.6	1801	3420¤
	Oct 13	532	-	-	-	-	-	-	-
	Oct 14	533	761	54.6	46.6	50.6	50.6	2125	2530
	Oct 15	534	692	24.3	24.3	44.5	44.5	1862	2307
	Oct 16	535	700	40.5	40.5	36.4¤	32.4¤	2024	2267
	Oct 17	536	676	26.3	26.3	42.5	42.5	1761	2328
	Oct 18	537	650	37.0	37.0	49.3	49.3	2467¤	2015
	Oct 19	538	691	35.0	35.0	47.3	30.8¤	2118	2118
	Oct 20	539	-	-	-	-	-	-	-
	Oct 21	540	-	-	-	-	-	-	-
	AVERAGE		**697**	**38.0**	**35.9**	**47.8**	**46.8**	**1999**	**2346**
	Oct 22	541	1040	35.0	35.0	47.3	35.0	1706	1542¤
	Oct 23	542	-	-	-	-	-	-	-

¤ Data rejected as outliers at 10% level of significance.

38	Oct 24	543	711	63.7	55.5	39.1	39.1	2200	2817
	Oct 25	544	662	20.6	20.6	16.4	16.4¤	2097	2591
	Oct 26	545	946	49.3	45.2	49.3	41.1	2097	2961
	Oct 27	546	-	-	-	-	-	-	-
	Oct 28	547	743	42.2	38.2	30.1	30.1	1827	2390
	Oct 29	548	-	-	-	-	-	-	-
	AVERAGE		**820**	**42.2**	**38.9**	**36.5**	**36.3**	**1986**	**2689**
39	Oct 30	549	610	36.1	32.1	28.1	16.1	1446	2570
	Oct 31	550	783	46.2	34.1	42.2	38.2	1386	2590
	Nov 1	551	608	39.3	39.3	39.3	31.0	1634	2502
	Nov 2	552	786	33.1	33.1	24.8	20.7	1903	2564
	Nov 3	553	-	-	-	-	-	-	-
	Nov 4	554	736	99.3¤	33.1	70.3¤	37.2	1530	2564
	Nov 5	555	546¤	41.7	33.3	50.0	45.8	1584	2251
	Nov 6	556	700	60.4	52.1¤	60.4	56.3¤	1980	2980¤
	Nov 7	557	650	29.2	20.8¤	33.3	20.8	1751	2209
	Nov 8	558	646	29.2	20.8¤	37.5	12.5	958¤	2584
	Nov 9	559	671	33.3	29.2	37.5	25.0	1334	2334
	Nov 10	560	-	-	-	-	-	-	-
	Nov 11	561	654	49.1	40.9	49.1	45.0	2166¤	2616
	AVERAGE		**685**	**39.8**	**34.4**	**40.2**	**29.2**	**1616**	**2479**
40	Nov 12	562	748	47.0	42.9	47.0	30.7	1533	2351
	Nov 13	563	-	-	-	-	-	-	-
	Nov 14	564	728	47.0	30.7	59.3	34.7	2187	2923
	Nov 15	565	724	34.7	34.7	30.7	26.6	1860	3005
	Nov 16	566	613	45.0	32.7	36.8	28.6	2003	2657
	Nov 17	567	646	36.8	32.7	45.0	28.6	1635	2412
	Nov 18	568	-	-	-	-	-	-	-
	Nov 19	569	735	39.4	39.4	47.7	31.1	1931	2553
	Nov 20	570	698	54.0	53.9¤	49.8	33.2	1868	2574
	Nov 21	571	727	60.2¤	51.9	110.0¤	97.6¤	1307¤	2886
	Nov 22	572	652	45.7	29.1	37.4	37.4	1785	2367
	Nov 23	573	635	37.4	33.2	37.4	37.4	1993	2284
	Nov 24	574	-	-	-	-	-	-	-
	Nov 25	575	-	-	-	-	-	-	-
	AVERAGE		**690**	**43.0**	**36.4**	**43.4**	**32.0**	**1866**	**2601**
41	Nov 26	576	677	49.8	41.5	49.8	33.2	1910	2408¤
	Nov 27	577	619	41.5	41.5	41.5	41.5	1827	2491
	Nov 28	578	673	76.8¤	64.4¤	51.9	51.9	2304¤	2512
	Nov 29	579	-	-	-	-	-	-	-
	Nov 30	580	536	49.8	24.9	29.1¤	29.1	1827	2533
	Dec 1	581	-	-	-	-	-	-	-
	Dec 2	582	581	37.4	37.4	49.8	49.8	1951	2533
	AVERAGE		**617**	**44.6**	**36.3**	**48.3**	**41.1**	**1879**	**2517**

¤ Data rejected as outliers at 10% level of significance.

APPENDIX A

Daily measured TKN concentrations in influent, and unfiltered (UFE) and filtered effluents (FE) and TKN concentrations in the aerobic reactors and Oxygen Utilization Rate (OUR) of the aerobic reactors of the MLE and UCT systems at 30 C.

			TKN CONCENTRATIONS							OUR OF AEROB.REACTORS	
BATCH OF SEWAGE	*YEAR* MONTH / DAY	DAY NO	*INFLUENT* [mgN/*l*]	MLE SYSTEM UFE [mgN/*l*]	MLE SYSTEM FE [mgN/*l*]	UCT SYSTEM UFE [mgN/*l*]	UCT SYSTEM FE [mgN/*l*]	AEROB.REACTORS MLE [mgN/*l*]	AEROB.REACTORS UCT [mgN/*l*]	MLE [mgO/*l*/h]	UCT [mgO/*l*/h]
	1995										
1	May 1	1	63	3.5	2.7	0.7○	0.7○	-	-	38.0	41.0○
	May 2	2	67 ○	4.9	3.9	4.8	4.9○	-	-	39.6	41.3○
	May 3	3	62	3.4	3.4	2.0	1.8	-	-	40.3	38.9
	May 4	4	62	2.9	3.5	2.9	3.6	-	-	37.3	35.0
	May 5	5	58	6.0	3.5	9.5○	2.5	-	-	37.0	35.0
	May 6	6	69 ○	3.6	2.5	5.3	3.8	-	-	37.0	30.6
	May 7	7	58	4.5	3.5	3.1	2.8	-	-	38.0	22.9○
	May 8	8	58	2.7	3.1	3.5	2.1	-	-	37.6	30.0
	May 9	9	55	2.4	1.9○	2.7	3.4	-	-	36.4	29.0
	May 10	10	58	5.9○	3.6	3.6	3.5	-	-	32.3○	34.8
	May 11	11	56	2.5	2.5	2.7	1.4	-	-	39.6	31.6
	May 12	12	58	5.5	3.9	2.8	2.8	-	-	39.6	33.3
	May 13	13	55	4.2	3.1	3.1	2.9	-	-	31.9○	33.6
	May 14	14	58	2.7	2.7	2.9	2.2	-	-	37.0	35.6
	May 15	15	60	4.5	3.4	3.5	3.2	-	-	39.8	34.7
	May 16	16	58	3.6	3.4	3.8	2.8	-	-	36.2	33.3
	May 17	17	63	4.1	3.6	3.8	2.8	-	-	40.9	35.9
	May 18	18	54	4.9	4.7○	4.2	4.1	-	-	37.9	34.8
	May 19	19	55	4.2	4.1	4.1	3.9	-	-	35.0	27.0○
	AVERAGE		58	3.9	3.3	3.5	2.9			38.0	33.7
2	May 20	20	52	2.2	2.2	2.9	2.1	-	-	34.0	29.0
	May 21	21	50	4.3	2.5	3.6	3.1	-	-	34.6	30.9
	May 22	22	53	3.8	3.8	3.9	3.9○	-	-	32.0	30.9
	May 23	23	51	3.4	3.1	3.6	2.5	-	-	30.9	33.8
	May 24	24	53	3.1	2.5	2.8	2.4	-	-	33.1	31.6
	May 25	25	52	2.7	2.2	2.1	2.0	-	-	29.9	31.1
	May 26	26	54	2.9	2.8	4.1○	2.4	-	-	31.8	29.1
	May 27	27	53	3.6	2.9	1.7	1.5○	-	-	28.1	33.1
	May 28	28	53	4.9	4.9	3.1	2.9	-	-	28.2	34.5
	May 29	29	60	6.7○	6.7○	3.1	2.5	127	109	41.8○	32.5
	May 30	30	56	2.8	2.5	2.9	2.8	127	111	36.3	30.0
	May 31	31	55	2.9	2.4	3.1	2.8	116	120○	38.9	33.1
	June 1	32	53	2.5	1.7	2.2	1.8	122	116	32.6	34.3
	June 2	33	61	2.5	2.7	2.8	2.5	106	109	32.1	35.2
	June 3	34	59	3.9	2.4	3.5	2.7	107	112	33.3	38.7
	June 4	35	58	3.8	3.4	3.2	3.1	109	107	41.0○	39.5
	June 5	36	61	1.7○	1.7	2.4	2.2	105	94○	37.4	43.5○
	June 6	37	60	3.6	3.9	3.5	3.2	104	101	31.5	36.4
	June 7	38	57	4.2	3.6	2.9	2.0	95	108	37.0	25.2○
	June 8	39	58	2.1	1.7	2.7	2.7	119	113	26.9○	24.2○
	AVERAGE		55	3.3	2.8	3.0	2.5	112	110	33.0	33.2
3	June 9	40	59	2.4	2.2	2.5	2.2	101○	109	29.4	21.5○
	June 10	41	59	2.9	1.5	2.9	1.8○	120	118○	30.5	33.4
	June 11	42	59	3.2	2.2	2.9	2.4	146	132	28.8	35.9
	June 12	43	63	3.9	2.7	3.6	2.9	120	117	37.2	35.4
	June 13	44	61	3.9	3.1	4.5	3.6	169	146	39.5	29.9
	June 14	45	53○	3.4	3.5	2.4	3.5	148	146	39.0	29.8
	June 15	46	62	3.1	2.8	3.4	3.4	160	137	26.8	33.5
	June 16	47	59	3.1	2.8	3.2	2.9	139	148	41.8	31.5
	June 17	48	60	2.9	2.2	3.2	2.5	160	137	42.8	33.1
	June 18	49	60	4.5	2.5	4.1	2.9	181	163	45.4	33.2
	June 19	50	67○	3.5	2.5	4.5	3.2	156	146	58.7○	35.6
	June 20	51	67	15.1○	12.6○	4.5	3.5	194	155	42.8	36.2
	June 21	52	66	5.2	4.9	3.4	3.1	162	150	34.4	36.0

○ Data rejected as outliers at 10% level of significance.

	June 22	53	63	4.1	3.8	4.9	4.2	179	148	49.5	42.5
	June 23	54	63	5.0	4.6	4.9	3.9	167	139	38.9	39.8
	June 24	55	64	5.3	4.5	5.0	3.8	170	162	35.2	43.4
	June 25	56	62	10.9○	9.5○	4.6	4.6○	189	148	34.0	46.1
	June 26	57	64	5.9	3.8	5.3	4.2	205○	169○	32.6	47.8○
	June 27	58	59	5.6	4.8	4.6	4.6○	164	133	32.3	40.1
	June 28	59	64	2.1	2.0	3.1	2.4	146	144	31.4	43.0
	AVERAGE		**62**	**3.9**	**3.1**	**3.9**	**3.2**	**159**	**142**	**36.4**	**36.6**
4	June 29	60	74	2.0	2.0	2.1	2.0	128○	144	41.3	42.6
	June 30	61	74	2.1	1.7	2.2	1.8	181	132	40.8	44.1
	July 1	62	77	2.4	2.2	3.5	3.1	189	124	34.5	43.3
	July 2	63	74	1.8	1.4○	3.1	2.5	192	155	43.0	45.0
	July 3	64	70○	4.3	2.8	4.5	3.2	166	123○	42.7	44.1
	July 4	65	75	15.7○	15.1○	2.8	2.5	170	127	46.5	33.5
	July 5	66	79	6.4	5,5○	2.7	1.7	172	148	45.0	35.2
	July 6	67	81	3.4	2.7	4.9	4.8	174	147	53.9○	37.4
	July 7	68	81	2.5	2.2	3.2	2.9	196	153	44.2	39.7
	July 8	69	-	-	-	-	-	-	-	-	-
	July 9	70	82	3.2	2.7	2.9	2.8	207	158	46.5	36.1
	July 10	71	84○	3.8	3.5	3.1	3.1	200	176	37.1	33.7
	July 11	72	-	-	-	-	-	-	-	-	-
	July 12	73	80	2.5	2.2	3.9	3.6	220	186○	44.0	33.3
	July 13	74	79	9.1○	8.0○	4.2	3.6	237○	176	38.7	34.5
	July 14	75	79	3.2	2.9	4.5	3.4	200	168	38.6	31.4
	July 15	76	80	3.8	2.2	3.9	3.6	207	183	37.0	28.6○
	July 16	77	79	4.2	4.2	3.8	3.6	186	155	35.5	40.9
	July 17	78	81	4.5	3.9	4.9	4.2	169	169	37.5	39.0
	July 18	79	81	3.4	3.1	3.5	2.9	190	175	39.8	41.1
	July 19	80	77	2.5	2.0	2.5	2.4	177	156	36.9	44.2
	July 20	81	76	2.1	2.1	2.0	2.0	186	153	39.1	43.7
	July 21	82	73	1.7	1.3○	1.5○	1.4	167	124	40.7	40.6
	AVERAGE		**78**	**3.1**	**2.7**	**3.4**	**2.9**	**187**	**154**	**40.5**	**39.2**
5	July 22	83	83○	1.8	1.8	2.1	1.7	168	147	40.7	33.0
	July 23	84	91	1.7	1.4	2.0	2.0	161	102○	40.3	35.8
	July 24	85	91	1.5	0.8	1.3	1.0	171	153	38.3	42.3
	July 25	86	-	-	-	-	-	-	-	-	-
	July 26	87	-	-	-	-	-	-	-	-	-
	July 27	88	-	-	-	-	-	-	-	-	-
	July 28	89	94	2.2	2.1	2.8	2.4	181	134	51.9○	39.6
	July 29	90	98	3.4	2.8	3.5	2.8	170	139	38.3	40.4
	July 30	91	99	6.4○	1.8	6.9	3.6	187	146	38.8	37.9
	July 31	92	104	4.1	3.9	5.9	5.5	216○	170	39.5	39.6
	Aug 1	93	102	4.3	3.8	5.7	5.0	188	183○	27.5○	27.5○
	Aug 2	94	102	3.9	3.6	3.4	3.1	184	165	37.7	34.3
	Aug 3	95	99	4.2	3.5	5.0	4.3	189	155	35.4	38.3
	Aug 4	96	98	4.9	4.6	4.5	4.5	180	155	39.2	38.9
	AVERAGE		**98**	**3.2**	**2.7**	**3.9**	**3.3**	**178**	**152**	**38.7**	**38.0**
6	Aug 5	97	72	4.5	3.9	3.2	3.2	128	143	33.1	31.5
	Aug 6	98	71	4.3	3.2	7.4○	4.5	141	153	33.0	29.5
	Aug 7	99	69	3.9	3.6	4.5	4.2	163	144	21.5	27.2
	Aug 8	100	69	3.5	3.1	4.3	3.8	149	153	26.1	25.6
	Aug 9	101	64	5.7○	3.2	4.9	3.9	153	154	23.1	32.6○
	Aug 10	102	63	3.5	3.1	5.5	2.4	151	144	19.1	28.1
	Aug 11	103	62	3.5	2.5	4.1	2.9	143	145	44.6	24.8
	Aug 12	104	65	2.9	2.7	3.4	0.7	123	149	44.7○	23.8
	Aug 13	105	65	2.7	2.2	3.6	3.1	165	127	34.3	28.2
	Aug 14	106	68	4.5	2.1	3.5	2.8	148	129	31.2	25.1
	Aug 15	107	71	3.1	2.8	5.0	2.2	183○	142	47.1○	23.3
	Aug 16	108	71	3.6	3.1	9.7○	8.1○	187○	121	21.5	24.3
	Aug 17	109	55	2.7	2.4	2.5	2.4	117	119	19.9	23.3
	Aug 18	110	57	1.0	0.7	1.4	0.8	126	122	22.7	20.6
	Aug 19	111	54	1.0	0.7	1.4	0.8	115	127	16.4	17.7
	Aug 20	112	55	1.0	0.7	1.4	1.1	103○	118	22.5	14.2○
	Aug 21	113	54	1.0	0.7	1.3	0.8	111	112	22.3	17.6
	Aug 22	114	51	1.0	0.7	1.4	0.8	135	111	33.0	15.7○
	AVERAGE		**63**	**2.8**	**2.3**	**3.2**	**2.4**	**138**	**134**	**26.5**	**24.7**

○ Data rejected as outliers at 10% level of significance.

7	Aug 23	115	57	2.5	1.8	2.4	2.1	113○	136○	30.6	34.8
	Aug 24	116	42○	1.0○	0.7○	1.4○	0.8○	147	151	31.6	36.8
	Aug 25	117	62	2.1	2.0	2.7	1.8	167	161	34.6	41.1
	Aug 26	118	60	3.1	2.4	3.1	2.8	172	179	37.0	41.4
	Aug 27	119	63	2.0	1.7	1.7	1.8	154	174	39.9	40.3
	Aug 28	120	62	2.4	2.0	2.4	2.1	160	176	39.4	34.3
	Aug 29	121	61	2.5	2.4	3.1	2.8	189○	127○	37.0	42.2
	Aug 30	122	61	3.2	2.9	2.9	2.4	181	160	44.2○	40.1
	Aug 31	123	62	3.1	2.7	3.8	3.2	176	174	28.4	41.8
	Sept 1	124	64	3.1	2.8	2.8	2.5	173	176	35.5	40.9
	Sept 2	125	61	3.4	2.2	3.9	3.4	165	169	39.6	41.0
	Sept 3	126	65	3.1	2.8	5.0○	2.9	176	197○	39.7	39.3
	Sept 4	127	60	3.2	2.5	2.9	2.8	151	185	38.3	26.2○
	Sept 5	128	60	2.8	2.7	3.2	2.5	155	158	33.2	41.1
	Sept 6	129	74○	2.9	2.9	3.6	3.4	158	190	35.7	31.9
	Sept 7	130	52○	1.7	1.1	1.7	1.4	141	158	35.9	46.0
	AVERAGE		**61**	**2.7**	**2.3**	**2.9**	**2.5**	**163**	**170**	**35.8**	**39.5**
8	Sept 8	131	64	2.7	2.5	3.5	3.2	169	155	25.4	40.2
	Sept 9	132	60○	3.6	2.9	3.5	3.1	160	156	28.8	42.1
	Sept 10	133	77	3.2	3.2	3.6	3.9	174	177	28.5	43.6
	Sept 11	134	67	2.8	2.2○	4.3	3.9	175	176	31.4	41.9
	Sept 12	135	67	4.1	3.5	3.6	3.4	172	174	42.0	40.6
	Sept 13	136	69	3.4	3.2	4.3	3.9	163	190	38.2	41.6
	Sept 14	137	79	3.5	3.2	4.5	4.1	161	151	31.5	49.7
	Sept 15	138	73	3.2	2.7	3.9	3.6	158	176	33.4	40.1
	Sept 16	139	73	2.9	2.8	3.6	3.4	161	152	43.3	44.6
	Sept 17	140	74	2.9	2.8	3.8	3.6	180	162	47.0	38.7
	Sept 18	141	75	4.5	2.4	4.9○	2.5○	192	195	49.5	41.6
	Sept 19	142	76	3.6	3.4	3.9	2.9	174	169	48.4	41.7
	Sept 20	143	76	3.2	2.8	3.5	3.4	181	182	34.7	41.4
	Sept 21	144	79	5.7○	3.4	2,9○	2.9	239○	204○	44.2	53.3○
	AVERAGE		**73**	**3.4**	**3.0**	**3.9**	**3.5**	**171**	**170**	**37.6**	**42.1**
9	Sept 22	145	66	4.9	4.2	5.2	4.3	186	176	47.1	42.7
	Sept 23	146	66	4.8	4.1	4.5	3.9	160	172	53.0○	42.6
	Sept 24	147	80	4.8	3.4	7.7○	5.3○	166	159	45.1	40.7
	Sept 25	148	66	5.0	4.1	4.9	4.1	158	148	36.6	30.0
	Sept 26	149	69	3.5	3.2	4.5	4.1	209○	200	32.9	31.1
	Sept 27	150	67	4.5	3.9	4.1	3.4	202○	180	46.4	36.4
	Sept 28	151	67	3.2	2.9	4.1	4.1	181	186	37.2	35.8
	Sept 29	152	77	4.1	3.5	3.2	2.9	157	147	34.1	32.2
	Sept 30	153	77	3.4	2.7	4.9	4.3	153	155	34.1	42.2
	Oct 1	154	63	4.3	3.8	3.6	3.1	174	179	34.0	36.7
	Oct 2	155	74	13.3○	14.0○	3.5	2.9	165	153	31.5	27.2
	Oct 3	156	77	15.5○	13.6○	2.7○	4.2	182	170	42.0	28.2
	Oct 4	157	69	3.9	2.2	3.9	3.8	185	193	27.6	28.1
	AVERAGE		**71**	**4.2**	**3.4**	**4.2**	**3.8**	**170**	**171**	**37.4**	**34.9**
10	Oct 5	158	78○	3.2	2.8	3.2	2.9	194	186○	49.2	45.3
	Oct 6	159	67	3.1	2.9	2.8	2.5	192	190	43.6	41.5
	Oct 7	160	64	3.5	3.2	3.9	3.4	175○	179	43.8	38.6
	Oct 8	161	68	4.3	3.5	5.7○	5.0○	197	195	49.8	41.7
	Oct 9	162	58○	3.6	2.2○	3.2	2.9	193	198	44.3	40.0
	Oct 10	163	66	3.6	2.7	3.5	3.2	209	223○	49.7	41.7
	Oct 11	164	65	2.9	2.9	3.2	2.7	200	209	48.1	38.3
	Oct 12	165	66	3.8	3.1	4.5	3.5	205	204	47.5	44.6
	Oct 13	166	71	4.5○	3.6○	3.9	3.4	213○	206	46.7	47.4○
	Oct 14	167	69	3.6	3.4	3.9	3.4	183	193	49.8	42.8
	Oct 15	168	65	3.8	2.9	4.9	4.2	186	202	47.2	44.6
	Oct 16	169	64	2.8○	2.5	3.2	2.7	190	195	44.1	40.6
	Oct 17	170	65	4.1	2.8	4.9	3.2	202	200	48.5	41.8
	AVERAGE		**66**	**3.6**	**3.0**	**3.8**	**3.2**	**195**	**197**	**47.1**	**41.8**
	Oct 18	171	58	4.3	2.9	3.2	2.9	207	203	45.2	38.4
	Oct 19	172	61	3.9	3.4	3.6	3.4	215	210	48.1	42.7○
	Oct 20	173	58	7.6○	5.7○	3.6	3.4	204	220	30.5	41.0
	Oct 21	174	55○	3.6	3.6	3.6	3.4	202	208	37.8	39.9
	Oct 22	175	60	4.6	3.1	3.5	3.5	223	228	44.7	38.9
	Oct 23	176	57	3.1	2.4	2.2○	2.1○	228	207	46.3	38.0

11

○ Data rejected as outliers at 10% level of significance.

11	Oct 24	177	60	2.9	2.5	3.8	3.5	219	192	44.6	40.5
	Oct 25	178	61	3.4	2.5	3.5	2.8	226	216	32.3	33.4
	Oct 26	179	59	3.4	2.9	3.2	2.9	207	217	40.8	37.4
	Oct 27	180	59	2.8	2.5	2.9	2.7	209	178□	40.8	37.7
	Oct 28	181	57	4.2	2.4	3.5	2.4	194	204	42.3	27.3□
	Oct 29	182	60	4.2	2.9	3.9	2.8	221	202	24.5□	42.5
	Oct 30	183	65□	3.4	2.5	4.1	3.8	198	230□	26.2	33.3
	Oct 31	184	58	6.4□	4.2	4.2	4.2□	247□	215	31.3	36.6
	AVERAGE		**59**	**3.7**	**2.9**	**3.6**	**3.1**	**212**	**210**	**39.3**	**38.1**
12	Nov 1	185	54□	3.4	2.9	3.2	3.2	197	204	21.8□	30.3
	Nov 2	186	75	3.9	2.8	3.8	3.4	219□	202	31.0□	41.5
	Nov 3	187	68	3.4	3.4	9.2□	9,1□	181	150□	38.6	33.8
	Nov 4	188	69	3.4	2.9	3.9	3.9	176	186	41.9	42.3
	Nov 5	189	77□	4.8	3.2	4.1	3.5	174	193	42.7	31.9
	Nov 6	190	70	5.4□	5.2□	6.9□	6.4□	174	211	40.6	33.7
	Nov 7	191	62□	2.8	3.5	3.6	2.7	164	170	49.1	37.6
	Nov 8	192	73	3.8	3.2	5.2	4.5	180	190	43.0	33.2
	Nov 9	193	69	3.4	2.2	3.6	2.8	174	183	42.2	37.4
	Nov 10	194	69	3.2	2.7	3.6	2.9	157	197	41.6	32.2
	Nov 11	195	72	3.5	2.4	3.1	2.5	173	202	44.8	29.7
	Nov 12	196	71	2.8	2.5	3.2	2.7	172	193	49.4	40.8
	Nov 13	197	71	3.4	3.1	3.1	2.8	162	206	47.3	47.1□
	Nov 14	198	-	-	-	-	-	-	-	-	-
	Nov 15	199	71	5.7□	5.5□	4.5	4.1	146□	200	44.4	34.2
	Nov 16	200	70	3.2	2.9	3.1	2.9	162	211	36.0	45.2
	AVERAGE		**71**	**3.4**	**2.9**	**3.7**	**3.2**	**173**	**196**	**43.2**	**36.0**
13	Nov 17	201	52□	2.8	2.5	2.1	2.1	156□	208	27.9□	30.7
	Nov 18	202	65	5.3□	2.7	2.0	2.0	160□	193	34.5	40.9
	Nov 19	203	65	3.8	3.1	4.1	3.6	207□	179□	37.5	43.4
	Nov 20	204	63	3.6	3.1	3.4	2.9	168	201	38.4	39.5
	Nov 21	205	66	3.9	3.6□	2.9	2.7	179	199	49.9□	48.5□
	Nov 22	206	69	2.7	2.7	3.2	2.2	186	211□	44.2	43.8
	Nov 23	207	68	2.2	2.5	2.9	2.5	173	189	45.7	45.6
	Nov 24	208	66	2.2	1.7□	2.4	2.2	173	207	42.2	40.0
	Nov 25	209	67	4.1	3.2	4.2	3.6	183	195	41.0	40.5
	Nov 26	210	68	2.7	2.2	2.8	2.5	179	198	42.8	35.2
	Nov 27	211	66	2.5	1.4□	2.8	2.2	181	195	40.8	32.9
	Nov 28	212	67	3.4	2.4	3.1	2.5	172	195	40.6	36.9
	Nov 29	213	65	2.2	2.1	2.4	2.2	173	204	44.5	37.8
	Nov 30	214	-	-	-	-	-	-	-	-	-
	Dec 1	215	66	2.8	2.2	2.8	2.2	178	191	34.5	34.7
	Dec 2	216	66	4.1	3.1	4.1	4.1□	174	188	40.2	36.3
	Dec 3	217	62	2.8	2.7	3.6	2.9	196□	201	44.3	38.1
	Dec 4	218	70□	2.9	2.7	3.9	3.2	181	178□	44.3	29.3□
	Dec 5	219	68	3.9	3.4	4.9	3.8	166	177□	44.5	40.2
	AVERAGE		**66**	**3.1**	**2.7**	**3.2**	**2.7**	**176**	**197**	**41.3**	**38.5**
14	Dec 6	220	58	2.7	2.4	2.9	2.2	174	178	44.7	37.2
	Dec 7	221	56	2.7	2.2	2.8	2.2	155□	165□	47.8	36.0
	Dec 8	222	57	3.5	2.5	3.6	3.5□	193	204	45.7	36.2
	Dec 9	223	56	4.1	2.7	4.2□	3.1	188	190	42.0	36.6
	Dec 10	224	59	3.8	2.9	3.6	2.5	192	202	39.9	38.0
	Dec 11	225	60	3.4	2.5	3.5	2.8	187	190	36.5	34.4
	Dec 12	226	60	2.9	2.7	3.6	3.4	188	181	39.8	36.4
	Dec 13	227	61	3.1	2.7	3.4	2.9	215	192	45.8	36.8
	Dec 14	228	60	3.1	2.5	3.1	2.8	203	194	46.3	39.4
	Dec 15	229	62	3.2	2.5	2.9	2.9	193	197	48.7	33.9
	Dec 16	230	54□	8.5□	7.7□	3.8	3.2	169	188	43.6	36.0
	Dec 17	231	57	6.2□	4.3□	3.2	2.7	194	192	33.9□	36.3
	Dec 18	232	60	2.8	2.4	3.4	2.8	194	214	38.6	48.0□
	Dec 19	233	59	2.9	2.2	3.2	2.5	234□	213	42.9	44.5
	Dec 20	234	62	3.5	3.2	3.4	3.4	237□	239□	40.8	45.8
	Dec 21	235	63	2.7	2.2	2.9	2.4	218	221	44.4	48.2□
	Dec 22	236	63	2.4	2.0	2.4□	2.0□	188	219	44.7	45.1
	Dec 23	237	61	2.8	2.4	2.9	2.5	201	183	44.6	36.2
	Dec 24	238	60	6.0□	3.4	3.5	3.2	204	189	41.5	37.5
	Dec 25	239	61	2.9	2.1	3.2	2.7	202	191	30.9□	36.6

□ Data rejected as outliers at 10% level of significance.

	AVERAGE		60	3.1	2.5	3.3	2.8	194	196	43.2	37.9
15	Dec 26	240	67○	3.9	2.0	2.8	2.8○	201	194	38.2	45.5
	Dec 27	241	67○	3.5	2.1	3.6○	2.4	206	200	52.0○	49.1
	Dec 28	242	60	3.5	2.5	3.2	2.5	193	185	45.9	517○
	Dec 29	243	58	2.7	2.1	2.9	2.4	212○	197	44.2	50.0○
	Dec 30	244	50	3.1	2.4	2.9	2.1	199	202	43.4	46.4
	Dec 31	245	50	2.7	2.7	2.7	2.4	204	191	44.9	37.9
	Jan 1 96	246	46	2.5	1.7	2.2	1.8	196	191	32.3	38.2
	Jan 2	247	44	2.4	1.8	2.1	1.7○	197	194	32.9	36.4
	Jan 3	248	48	3.2	2.8	2.4	2.2	193	185	37.3	36.6
	Jan 4	249	48	2.2	1.7	2.8	2.1	200	189	39.0	39.1
	Jan 5	250	49	2.5	1.7	2.1	2.1	200	183	40.4	39.7
	Jan 6	251	49	3.4	2.0	2.9	2.7	196	204○	36.4	33.2
	Jan 7	252	49	2.4	2.2	2.5	2.4	184	187	40.0	33.1
	Jan 8	253	48	2.2	1.7	2.1	2.0	185	184	33.1	29.8
	Jan 9	254	49	4.6	4.3	2.9	2.4	188	187	35.7	27.1○
	Jan 10	255	50	12.3○	10.5○	2.9	2.7	187	178	32.5	27○
	Jan 11	256	51	8.4○	8.1○	3.8	2.1	189	178	35.8	38.1
	Jan 12	257	50	3.5	2.2	2.9	2.4	194	182	34.9	38.2
	AVERAGE		50	3.0	2.2	2.7	2.3	195	189	38.0	38.7
16	Jan 13	258	88	3.6	3.1	2.9	2.9○	195	186	53.5	58.5
	Jan 14	259	85	2.9	2.2	2.2	2.1	202	198○	62.4	57.2
	Jan 15	260	93	3.5	2.7	3.5○	2.9○	204	186	65.3○	56.5
	Jan 16	261	96○	2.7	1.8	2.7	1.8	204	188	68.0○	58.9
	Jan 17	262	65	2.8	2.5	2.7	2.0	203	195	40.7	35.7
	Jan 18	263	62	2.5	2.5	2.9	2.2	204	183	37.9	42.6
	Jan 19	264	63	2.8	2.5	2.7	2.7	198	197	36.9	43.5
	Jan 20	265	61	3.1	2.5	2.8	2.4	192	181	34.3	45.3
	Jan 21	266	60	2.8	2.2	2.8	2.1	193	195	33.0	37.5
	Jan 22	267	59	8.5○	8.4○	2.9	2.1	195	188	39.8	37.8
	Jan 23	268	64	3.9	3.6	2.8	2.1	192	185	39.9	40.6
	Jan 24	269	63	2.8	2.2	2.8	2.0	202	186	36.2	40.6
	Jan 25	270	61	3.2	1.8	2.1○	2.1	197	189	37.8	41.4
	Jan 26	271	60	2.4	2.2	2.8	2.4	195	185	36.8	36.4
	AVERAGE		68	3.0	2.5	2.8	2.2	198	188	40.8	45.2
17	Jan 27	272	50	2.5	1.8	2.5	2.0	197	183	37.6	25.5○
	Jan 28	273	53	2.9	2.5	2.9	2.4	186	189	37.4	31.9
	Jan 29	274	58	3.9○	2.9○	3.1	2.7	206	188	38.0	38.2
	Jan 30	275	53	2.5	1.8	2.4	2.1	195	188	36.3	44.5
	Jan 31	276	52	2.2	2.0	2.4	2.1	195	193	30.8○	39.3
	Feb 1	277	53	2.8	1.8	2.5	1.8	188	183	36.4	34.3
	Feb 2	278	60	3.8○	2.4	3.4○	2.7	217○	218○	38.1	34.5
	Feb 3	279	51	2.1	2.0	2.2	2.0	190	179	37.7	42.9
	Feb 4	280	53	2.2	2.1	2.2	2.1	176○	184	35.5	42.2
	Feb 5	281	52	2.8	2.2	2.8	2.2	188	183	36.3	42.1
	Feb 6	282	60	2.7	2.4	3.1	2.9	195	188	38.5	41.2
	Feb 7	283	62	2.8	2.1	2.8	2.2	195	189	40.1	45.5
	Feb 8	284	62	2.7	2.2	2.2	2.0	227○	218○	47.3○	32.8
	Feb 9	285	62	2.5	2.4	2.7	2.5	205	207	46.9○	37.6
	AVERAGE		56	2.6	2.1	2.6	2.3	194	188	37.4	39.0
18	Feb 10	286	63	2.7	2.2	2.4	2.2	189	205	44.6	33.7
	Feb 11	287	59	2.8	1.8○	2.4	2.0	186	200	40.8	38.7
	Feb 12	288	60	2.8	2.5	2.9	2.8	202	194	36.6	32.5
	Feb 13	289	61	3.4	2.8	3.8○	3.5○	214	218	28.5○	33.3
	Feb 14	290	60	2.5	2.5	3.4	2.4	225○	218	34.0	30.6
	Feb 15	291	63	2.7	2.5	2.2	2.0	211	214	36.1	28.4
	Feb 16	292	64	2.9	2.8	3.5	2.9	203	216	37.7	25.9
	Feb 17	293	61	2.8	2.5	2.5	2.4	183	174○	46.6	41.1
	Feb 18	294	60	2.7	2.4	2.7	2.5	186	193	43.8	42.4
	Feb 19	295	64	2.7	2.4	3.1	2.4	197	214	44.3	42.5
	Feb 20	296	62	5.6○	3.1○	3.2	2.8	196	210	41.6	42.9
	Feb 21	297	58	2.8	2.4	2.9	2.5	177	183	43.6	42.4
	AVERAGE		61	2.8	2.5	2.8	2.4	195	206	40.9	36.2
	Feb 22	298	68	2.7	2.4	2.2○	2.2	169	189	42.3	38.5
	Feb 23	299	67	3.2	2.8	4.3○	4.2○	174	189	43.0	39.7
	Feb 24	300	67	3.4	3.1	3.5	3.1	178	190	42.5	41.1

○ Data rejected as outliers at 10% level of significance.

19	Feb 25	301	66	3.1	2.8	3.1	2.8	179	193	39.1	39.7
	Feb 26	302	68	2.9	2.5	3.1	2.9	180	205	35.3	42.2
	Feb 27	303	69	2.8	2.5	2.8	2.8	199	193	25.1○	43.0
	Feb 28	304	69	3.4	2.9	3.9	3.1	192	200	35.0	44.6
	Feb 29	305	70	2.4	2.1	2.7	2.4	191	195	36.4	44.2
	March 1	306	69	2.4	2.2	2.5	2.2	190	204	28.2○	41.2
	March 2	307	67	3.1	2.4	3.2	2.2	185	193	39.2	41.9
	March 3	308	65	2.5	2.0○	3.6	2.5	191	195	38.2	41.3
	March 4	309	68	2.8	2.7	2.9	2.8	187	193	38.9	42.3
	March 5	310	69	3.1	2.5	3.6	3.1	149○	195	34.7	37.4
	March 6	311	69	3.1	2.8	3.6	3.1	180	204	36.3	37.2
	March 7	312	62○	3.2	2.9	3.5	2.2	156○	172○	34.1	37.3
	AVERAGE		**68**	**2.9**	**2.6**	**3.2**	**2.7**	**184**	**196**	**38.1**	**40.8**
20	March 8	313	69	5.2	4.2	4.1	3.6	193	198	37.2	40.1
	March 9	314	66	2.5	2.4	3.4	2.5	179○	179○	38.3	37.2
	March 10	315	68	2.8	2.7	3.5	3.1	182	186	38.0	38.1
	March 11	316	73	2.8	2.8	3.4	3.4	200	207	38.2	41.7
	March 12	317	70	3.8	3.1	4.2	4.2	230○	221	37.8	39.8
	March 13	318	73○	4.6	4.5	4.2	4.2	211	214	40.8	38.2
	March 14	319	69	5.5○	4.5	4.1	3.6	197	209	37.7	39.8
	March 15	320	68	3.1	3.1	3.8	3.2	203	199	37.3	35.4
	March 16	321	69	3.8	4.1	4.5	4.3	212	202	35.4	37.0
	March 17	322	68	3.9	3.2	4.2	3.6	216	215	42.9○	39.7
	March 18	323	67	3.5	2.9	7.3○	7.3○	206	213	38.9	34.9○
	March 19	324	67	2.8	2.5	2.9	2.7	196	195	37.3	38.6
	March 20	325	73○	4.3	3.2	5.2	3.9	199	218	45.8○	43.1○
	AVERAGE		**68**	**3.6**	**3.3**	**3.9**	**3.5**	**201**	**206**	**37.9**	**38.7**
21	March 21	326	62	4.1	3.8	4.3	3.9	228	229	38.3○	39.1
	March 22	327	60	4.8	3.9	5.5	4.8	216	221	36.2	35.7
	March 23	328	63	3.6	3.4	3.4	2.8	217	227	37.5	29.7
	March 24	329	60	3.2	3.2	3.5	3.1	235	230	37.1	26.8
	March 25	330	62	3.2	2.9	5.6	5.3	228	252	36.7	28.8
	March 26	331	70	7.6○	6,.6○	9.7○	7.8○	237	249	36.4	41.2
	March 27	332	64	3.9	3.6	9.5○	9.2○	245	262	36.8	42.9○
	March 28	333	63	3.6	3.1	4.1	3.9	214	246	36.5	35.1
	March 29	334	63	6.9○	4.2	2.9	2.7	221	238	35.5	28.1
	March 30	335	63	3.6	3.4	4.3	3.9	244	246	36.6	28.2
	March 31	336	63	3.6	3.4	3.9	3.5	214	267○	35.8	29.3
	April 1	337	62	3.5	2.9	3.5	3.2	218	231	36.1	30.1
	April 2	338	59○	3.2	3.2	3.6	3.5	206	221	35.8	30.3
	April 3	339	-	-	-	-	-	-	-	-	-
	AVERAGE		**63**	**3.7**	**3.4**	**4.1**	**3.7**	**225**	**238**	**36.4**	**31.8**
22	April 4	340	74○	2.8	2.5	10.2	10.2	226	237	34.5	34.7
	April 5	341	75	18.5○	17.6○	17.8○	16.2○	223	228	35.4	36.7
	April 6	342	84	3.6	3.6	4.5	4.5	214	214	35.0	34.4
	April 7	343	86	3.6	3.1	3.8	3.8	226	233	35.2	33.4
	April 8	344	81	3.6	3.5	3.6	3.4	209	218	34.8	33.5
	April 9	345	86	2.9	2.5	2.7	2.4	192○	206	37.6○	42.5
	April 10	346	88	4.1	3.5	3.8	3.5	202	214	36.2	33.3
	April 11	347	88	3.2	2.7	3.4	3.2	203	197○	38.5○	41.5
	April 12	348	95○	3.6	3.6	3.4	3.2	214	225	37.3	42.1
	AVERAGE		**84**	**3.4**	**3.1**	**4.4**	**4.3**	**215**	**222**	**35.5**	**36.9**
23	April 13	349	69	4.5○	3.6	4.9	3.6	209	219	37.7	34.9
	April 14	350	69	3.9	3.6	3.9	3.1	189	239	40.8	33.6
	April 15	351	70	2.9	2.9	2.4	2.4	204	218	39.0	33.2
	April 16	352	69	2.4	2.2	3.5	3.1	207	217	41.7	35.1
	April 17	353	69	2.9	2.5	6.4○	6.3○	216	200	40.6	39.8
	April 18	354	74	3.1	3.1	2.9	2.9	203	197	40.0	35.6
	April 19	355	78○	3.6	3.2	3.1	3.1	202	210	40.0	35.0
	April 20	356	74	3.9	3.2	3.6	2.7	207	224	32.5	36.7
	April 21	357	75	3.5	2.5	3.4	3.4	203	221	35.4	32.9
	April 22	358	76	4.1	3.4	4.3	3.5	195	202	41.4	37.9
	April 23	359	72	2.2○	2.1	2.9	2.9	170○	139○	31.3	36.7
	April 24	360	69	3.4	2.5	2.9	2.4	172○	184	30.0○	22.1○
	AVERAGE		**71**	**3.4**	**2.9**	**3.4**	**3.0**	**203**	**212**	**38.2**	**35.6**
	April 25	361	67	3.6	3.2	3.4	2.4	186	176	45.5	41.0

○ Data rejected as outliers at 10% level of significance.

24	April 26	362	64	2.4	2.2	2.9	2.9	183	160○	44.0	40.9
	April 27	363	63	2.4	2.0	2.4	2.4	175	188	44.2	40.6
	April 28	364	61	2.9	2.8	3.9	3.1	163	181	36.0	35.1
	April 29	365	57○	3.1	2.8	2.5	2.2	193	188	35.8	37.8
	April 30	366	61	3.1	3.1	3.2	2.9	188	181	31.8	32.0
	May 1	367	62	3.1	2.8	2.8	2.7	193	190	42.6	38.4
	May 2	368	67	2.4	2.0	5.2○	2.8	196	176	41.6	38.2
	May 3	369	65	3.2	3.1	2.9	2.7	163	197○	42.5	40.2
	May 4	370	63	2.5	2.2	2.9	2.8	176	185	31.7	29.1○
	May 5	371	64	3.6○	3.5○	3.6	3.5○	174	177	37.3	27.7
	May 6	372	64	2.8	2.4	2.4	2.2	162	172	34.5	37.5
	May 7	373	60	2.7	2.7	2.8	2.2	149○	174	35.8	36.8
	AVERAGE		**63**	**2.8**	**2.6**	**3.0**	**2.6**	**179**	**181**	**38.7**	**37.2**
25	May 8	374	91○	3.8	2.7	2.9	2.2	176	176○	42.2	44.9
	May 9	375	87	3.4	2.5	3.9	3.6	165	204	42.2	46.6○
	May 10	376	89○	4.5	3.6	4.5○	3.9○	200○	210	40.5	48.1○
	May 11	377	65	4.5	3.8○	3.9	3.4	183	209	39.6	35.9
	May 12	378	63	4.1	3.2	3.9	3.2	175	203	38.3	35.3
	May 13	379	64	3.9	2.5	3.9	3.5	177	200	37.4	32.4
	May 14	380	60	2.2○	2.0○	2.1○	2.1○	174	194	37.7	31.8
	May 15	381	62	3.5	2.5	3.8	3.4	191	197	33.3	31.5
	May 16	382	65	4.2	3.5	3.4	2.9	176	192	31.3	29.9
	May 17	383	63	2.8	2.8	3.6	2.8	196	214○	34.2	30.7
	May 18	384	63	3.4	2.7	3.1	2.9	165	194	30.7	28.9
	May 19	385	65	3.1	2.8	3.2	2.9	175	201	29.6	29.9
	May 20	386	58	3.4	2.5	3.5	2.9	191	192	34.7	31.0
	AVERAGE		**65**	**3.7**	**2.9**	**3.6**	**3.1**	**179**	**200**	**36.3**	**32.9**
26	May 21	387	84	2.2○	2.0○	2.7	2.5	181	190	36.1	33.9
	May 22	388	74○	3.8	2.7	2.9	2.1	195	200	40.8○	35.0
	May 23	389	81	3.2	2.8	3.6	3.5	183	212	39.4	34.1
	May 24	390	83	4.3	2.9	4.5	3.9	204	210	34.0	34.3
	May 25	391	72○	3.9	3.4	5.0○	3.1	204	217	34.8	30.9○
	May 26	392	79	3.9	2.8	2.4	2.4	184	201	33.3	32.3
	May 27	393	84	4.2	2.9	3.8	2.8	190	207	30.4○	33.8
	May 28	394	81	3.9	2.5	2.4	2.4	166	190	33.0	33.7
	May 29	395	82	3.9	3.5○	3.4	2.9	171	191	34.0	34.9
	May 30	396	81	4.9○	2.8	2.9	4.8○	170	213	36.2	35.2
	May 31	397	84	3.1	3.5○	4.2	3.8	172	190	37.5	32.3
	AVERAGE		**82**	**3.8**	**2.9**	**3.3**	**2.9**	**184**	**202**	**35.4**	**34.0**
27	June 1	398	60	3.9	3.1	3.9○	3.6○	207	213○	32.8○	32.7○
	June 2	399	64○	3.4	2.5	3.2	2.5	184	195	31.4	22.8
	June 3	400	60	2.9	2.8	2.9	2.4	169○	166○	29.0	24.3
	June 4	401	58	3.2	2.5	2.9	2.7	209	201	29.3	24.8
	June 5	402	57	3.6	2.5	2.9	2.8	209	187	29.9	26.9
	June 6	403	58	1.8○	1.8○	2.4	2.0	207	179	30.6	27.7
	June 7	404	56	2.8	2.4	3.2	2.9	170	179	29.3	26.7
	June 8	405	60	2.5	2.7	2.8	2.4	202	189	29.8	26.7
	June 9	406	57	2.9	2.7	2.9	2.5	181	177	29.2	26.9
	June 10	407	56	2.8	2.5	2.7	2.7	196	187	27.2	23.9
	June 11	408	58	3.5	3.5○	4.5○	3.9○	205	192	23.7○	24.3
	June 12	409	60	2.8	2.5	2.2	2.2	187	177	28.0	25.4
	June 13	410	58	3.6	2.5	3.2	3.1	195	192	30.0	25.8
	AVERAGE		**58**	**3.2**	**2.6**	**2.9**	**2.6**	**196**	**187**	**29.4**	**25.5**
28	June 14	411	67	2.8	2.7	2.9	2.9	206	198	24.7	27.5
	June 15	412	67	2.5	2.8	3.6	2.8	197	196	33.8○	28.0
	June 16	413	67	2.8	2.4	3.2	2.7	203	189	29.0	23.7
	June 17	414	67	3.5	2.8	3.6	3.6	214	219	28.5	24.0
	June 18	415	70	2.9	2.5	2.8	2.8	220	177○	28.8	25.2
	June 19	416	73	2.4	1.8○	2.0○	2.0○	200	193	30.4	26.2
	June 20	417	68	3.2	2.9	3.5	3.4	209	206	29.9	26.3
	June 21	418	61○	3.1	3.4	4.1	3.9	232	202	29.0	25.2
	June 22	419	67	3.5	3.2	4.1	3.9	240○	209	28.0	25.1
	June 23	420	-	-	-	-	-	-	-	-	-
	June 24	421	74○	3.2	3.1	2.8	2.8	198	213	28.7	27.9
	June 25	422	70	3.6	3.5	2.5	2.9	218	203	28.0	28.3
	June 26	423	69	2.5	2.5	2.8	2.8	184○	197	28.0	26.5

○ Data rejected as outliers at 10% level of significance.

	June 27	424	67	4.2○	4.1○	3.6	3.6	235	225○	26.8	28.4
	AVERAGE		**68**	**3.0**	**2.9**	**3.3**	**3.2**	**212**	**202**	**28.3**	**26.3**
29	June 28	425	74	3.1	2.4	3.4	3.2	246○	225	30.8	28.3
	June 29	426	68	3.4	2.9	2.8	2.7	196	234○	28.1	28.3
	June 30	427	73	2.9	2.9	3.4	3.2	180	202	28.5	29.5
	July 1	428	56○	3.6	2.9	3.4	3.4	169○	211	29.1	22.1○
	July 2	429	76	4.1	3.1	3.4	3.2	200	203	37.1○	33.8
	July 3	430	80○	5.5○	4.8○	3.8	3.6	218	225	36.2○	33.7
	July 4	431	78	3.8	3.6	4.5○	3.4	209	197	33.0	31.3
	July 5	432	74	2.0○	1.8○	3.5	3.4	197	207	32.2	31.1
	July 6	433	73	3.1	2.5	2.8	2.7	195	192	29.7	28.4
	July 7	434	73	3.8	3.8	4.1	3.6	204	191	31.6	32.8
	July 8	435	72	2.7	2.5	3.6	2.5○	190	204	31.4	34.6
	July 9	436	74	3.8	2.7	3.1	2.8	220	192	32.9	34.2
	July 10	437	69	3.6	2.9	4.5○	4.2○	219	190	33.4	35.0
	July 11	438	69	3.6	3.6	3.4	3.1	197	175○	32.2	34.1
	July 12	439	66	3.8	3.1	4.1	3.8	220	187	30.5	29.8
	AVERAGE		**72**	**3.5**	**3.0**	**3.4**	**3.2**	**203**	**202**	**31.0**	**31.8**
30	July 13	440	83	3.8	3.4	2.7	2.5	179	176	34.3	32.8○
	July 14	441	87	2.1	1.9○	2.2	2.2	206	192	35.1	35.6
	July 15	442	102○	3.6	3.4	3.4	2.5	219○	188	34.9	36.4
	July 16	443	84	4.5	3.9○	3.1	2.5	196	208○	35.0	39.0
	July 17	444	90	4.2	3.1	4.1	3.5	193	185	34.5	38.0
	July 18	445	-	-	-	-	-	-	-	-	-
	July 19	446	81	4.5	2.9	2.5	2.4	178	162	33.3	38.8
	July 20	447	80	2.9	2.5	2.7	2.5	181	172	34.2	35.4
	July 21	448	80	2.8	3.2	2.8	2.9	185	172	29.0	36.0
	July 22	449	80	5.3○	3.2	5.9○	4.8○	197	168	28.9○	36.1
	July 23	450	89	3.1	2.8	4.5	3.6	180	158	31.1	33.2
	July 24	451	93	2.2	2.2	2.4	2.4	191	174	34.1	37.6
	July 25	452	86	2.7	2.2	3.9	2.8	146○	148○	34.1	38.6
	AVERAGE		**85**	**3.3**	**2.9**	**3.1**	**2.7**	**189**	**175**	**33.6**	**36.8**
31	July 26	453	78	3.1	2.8	2.5	2.4	188	173	33.9	33.6
	July 27	454	74	3.9	3.6	3.6	3.5	197	155	35.3	33.6
	July 28	455	80	2.5	2.2	3.5	3.4	184	151	34.6	32.0
	July 29	456	81	3.5	3.5	4.5○	3.9○	167	164	34.6	34.1
	July 30	457	77	5.0○	3.8	3.4	3.1	183	169	36.0	33.1
	July 31	458	82	2.2○	2.2	2.7	2.2	187	186	36.6	33.1
	Aug 1	459	76	4.2	3.1	2.8	2.5	162	160	35.3	32.3
	Aug 2	460	79	2.7	2.5	2.2	2.2	181	176	35.8	35.1
	Aug 3	461	77	3.5	2.8	3.5	2.9	124○	193○	36.3	32.8
	Aug 4	462	92○	3.4	3.4	2.9	2.9	169	141	41.3○	28.7○
	Aug 5	463	78	3.5	2.8	3.5	3.1	171	150	38.7	38.5○
	Aug 6	464	-	-	-	-	-	-	-	-	-
	AVERAGE		**78**	**3.4**	**3.0**	**3.1**	**2.8**	**179**	**162**	**35.7**	**33.3**
32	Aug 7	465	78	4.2	3.4	3.9	3.8	188	158	41.2	32.5
	Aug 8	466	86○	2.5	2.1○	3.9	2.2	197	193○	29.6	32.8
	Aug 9	467	77	3.2	2.9	3.2	3.1	196	167	30.8	33.0
	Aug 10	468	75	2.8	2.5	2.8	2.7	168	150	31.5	32.8
	Aug 11	469	78	3.2	2.8	3.1	2.7	155	156	35.5	33.4
	Aug 12	470	81	3.6	3.2	2.5	2.5	160	151	33.9	33.5
	Aug 13	471	75	5.0○	2.7	4.1	2.5	182	172	32.6	32.4
	Aug 14	472	79	3.6	2.9	4.1	3.5	196	164	29.2	29.9
	Aug 15	473	78	2.8	2.7	2.9	2.5	184	146	31.8	29.7
	Aug 16	474	85○	4.3	2.8	3.5	3.4	194	169	42.8	29.5
	Aug 17	475	76	3.6	3.4	4.2	3.9	200	135	40.3	28.9
	Aug 18	476	74	3.2	2.2	3.1	2.8	162	133○	40.2	32.3
	Aug 19	477	75	4.2	3.6○	4.5	4.5○	176	155	35.5	27.9○
	AVERAGE		**77**	**3.5**	**2.9**	**3.5**	**3.0**	**181**	**157**	**35.0**	**31.7**
33	Aug 20	478	87	3.2	2.8	3.1	2.2	126○	151	30.8	39.4
	Aug 21	479	86	3.1	2.8	5.3	5.0○	157	167	34.1	35.3
	Aug 22	480	88	4.5	2.1	3.4	3.4	160	167	30.2	38.6
	Aug 23	481	89	4.5	4.1	4.1	3.6	161	148	34.6	39.5
	Aug 24	482	89	3.6	3.4	3.2	2.5	190	141	29.6	40.5
	Aug 25	483	106	4.9	3.8	4.6	4.3	188	144	49.5○	49.3
	Aug 26	484	101	5.0	4.2	3.2	3.4	185	150	41.8	44.0

○ Data rejected as outliers at 10% level of significance.

	Aug 27	485	81	2.8	2.4	2.9	2.2	189	158	40.0	49.5
	Aug 28	486	90	2.7	2.4	2.5	2.2	183	145	37.2	44.1
	Aug 29	487	100	4.6	4.2	4.8	4.6	173	144	34.7	45.5
	Aug 30	488	94	4.1	3.2	9.1	3.9	192	173	34.7	45.8
	Aug 31	489	-	-	-	-	-	-	-	-	-
	Sept 1	490	-	-	-	-	-	-	-	-	-
	AVERAGE		92	3.9	3.2	4.2	3.2	178	153	34.8	42.9
34	Sept 2	491	62	2.7	2.5	4.2	3.8	188	170○	33.1	28.5○
	Sept 3	492	60	3.5	2.8	4.8	3.2	183	139	33.9	32.0
	Sept 4	493	63	2.9	2.5	3.2	2.4	174	159	35.6	35.3
	Sept 5	494	61	12.7○	12.0○	2.7	2.4	190	150	28.9	36.4
	Sept 6	495	60	6.3	4.5	4.2	3.6	166	149	27.0○	27.3○
	Sept 7	496	59	3.1	2.5	2.2	2.2	169	151	38.1	34.8
	Sept 8	497	64	2.9	2.0	2.7	2.2	158○	160	38.5	37.7
	Sept 9	498	59	3.9	3.1	3.4	3.4	177	145	36.5	40.1
	Sept 10	499	63	3.1	2.5	3.6	3.1	183	156	36.1	35.1
	Sept 11	500	63	2.5	2.5	3.5	3.4	173	154	42.1○	39.9
	Sept 12	501	64	2.4	2.1	4.3	3.8	183	161	35.1	38.3
	AVERAGE		62	3.3	2.7	3.5	3.0	179	152	35.1	36.6
35	Sept 13	502	59	2.2	2.1	3.4	3.2	168	99○	34.1	37.1
	Sept 14	503	69	2.9	2.4	2.8	2.8	176	143	41.1	38.1
	Sept 15	504	71	4.3	3.5	3.6	3.5	150	151	41.8	39.6
	Sept 16	505	70	2.9	2.7	2.8	2.5	176	151	41.9	37.1
	Sept 17	506	62	4.3	3.9○	3.9	2.5	162	115	40.2	33.5
	Sept 18	507	75	2.1○	2.1	3.5	3.4	174	197○	40.3	33.7
	Sept 19	508	70	3.4	2.5	3.6	3.5	176	139	30.4○	42.7○
	Sept 20	509	68	2.9	2.4	4.1	3.4	178	172	36.9	42.2
	Sept 21	510	65	3.4	2.5	2.8	2.5	155	121	35.9	34.4
	Sept 22	511	67	3.5	2.2	3.8	3.5	150	127	33.5	36.3
	Sept 23	512	70	3.4	3.1	3.9	3.8	149	149	39.1	38.5
	Sept 24	513	54○	4.1	2.7	3.9	2.7	170	139	37.6	31.4○
	Sept 25	514	-	-	-	-	-	-	-	-	-
	AVERAGE		68	3.4	2.6	3.5	3.1	165	141	38.4	37.1
36	Sept 26	515	58	4.1	4.1	6.3	3.9	158	171	57.1○	34.3
	Sept 27	516	68○	4.1	3.6	3.8	3.5	167	169	48.1	30.5
	Sept 28	517	53	1.8○	1.7○	2.2	2.0○	111○	108○	49.1	32.9
	Sept 29	518	-	-	-	-	-	-	-	-	-
	Sept 30	519	62	2.9	2.7	3.6	3.5	141	151	42.9	36.5
	Oct 1	520	58	2.8	2.8	6.7	4.8	168	135	42.4	30.6
	Oct 2	521	50○	3.6	3.5	5.3	4.2	172	169	39.2	36.7
	Oct 3	522	-	-	-	-	-	-	-	-	-
	Oct 4	523	60	3.5	3.1	2.9	2.9	179	218	45.1	40.2
	Oct 5	524	63	3.1	2.9	4.1	3.8	189	211	44.2	40.9
	Oct 6	525	-	-	-	-	-	-	-	-	-
	Oct 7	526	62	5.0○	3.5	5.3	4.5	132	193	48.9	41.2
	AVERAGE		59	3.4	3.3	4.5	3.9	163	177	45.0	36.0
37	Oct 8	527	82	4.1	3.6	4.2	4.2	164○	186	46.6	42.3
	Oct 9	528	-	-	-	-	-	-	-	-	-
	Oct 10	529	84	4.9	3.8	4.3	3.2	144	176	42.0○	30.2○
	Oct 11	530	-	-	-	-	-	-	-	-	-
	Oct 12	531	68	1.8○	1.6○	1.7○	1.4○	137	172	47.2	39.4
	Oct 13	532	-	-	-	-	-	-	-	-	-
	Oct 14	533	71	5.0	2.9	3.9	2.9	124	160	47.4	39.1
	Oct 15	534	87	4.5	4.1	5.3	4.9	151	181	48.4	39.1
	Oct 16	535	82	3.8	3.1	4.2	3.8	137	168	45.0	39.5
	Oct 17	536	88	3.6	3.6	4.9	4.1	124	144	45.5	37.3
	Oct 18	537	84	3.1	2.9	8.7○	5.2	140	156	42.5	39.8
	Oct 19	538	87	3.1	2.7	4.8	3.8	147	128○	45.0	38.3
	Oct 20	539	-	-	-	-	-	-	-	-	-
	Oct 21	540	-	-	-	-	-	-	-	-	-
	AVERAGE		81	4.0	3.3	4.5	4.0	138	168	46.0	39.4
38	Oct 22	541	67	4.1	3.2	3.5	2.9	127	98	46.3○	58.3○
	Oct 23	542	-	-	-	-	-	-	-	-	-
	Oct 24	543	51	2.4	2.4	2.7	2.4	99	144	42.3	39.3
	Oct 25	544	56	4.1	3.6	3.9	3.6	171	193	42.8	35.9
	Oct 26	545	62	3.5	3.2	3.6	3.6	142	180	42.7	38.1

○ Data rejected as outliers at 10% level of significance.

	Oct 27	546	-	-	-	-	-	-	-	-	-
	Oct 28	547	59	5.7○	4.6○	4.9○	4.5	165	193	43.0	41.2
	Oct 29	548	-	-	-	-	-	-	-	-	-
	AVERAGE		**59**	**3.5**	**3.1**	**3.4**	**3.4**	**141**	**161**	**42.7**	**38.6**
39	Oct 30	549	65	3.5	3.6	3.8	3.5	118	157○	45.7	34.5○
	Oct 31	550	79	4.5○	2.1○	3.1	2.7	141	181	47.5	45.6
	Nov 1	551	63	3.8	2.9	2.5	2.4	124	175	37.5○	41.9
	Nov 2	552	76	4.2	3.4	3.9	3.4	125	184	45.4	45.0
	Nov 3	553	-	-	-	-	-	-	-	-	-
	Nov 4	554	79	3.6	3.6	25.0○	23.8○	108	201○	43.8	43.6
	Nov 5	555	69	4.1	3.1	10.9	9.2	113	170	41.4	35.7
	Nov 6	556	70	4.1	3.6	4.8	3.1	135	186	43.8	41.2
	Nov 7	557	70	3.5	3.2	4.5	3.4	144	176	39.8	41.1
	Nov 8	558	69	3.5	2.8	3.5	2.9	130	181	39.2	35.8
	Nov 9	559	77	3.6	2.9	4.2	3.2	143	176	45.2	45.1
	Nov 10	560	-	-	-	-	-	-	-	-	-
	Nov 11	561	77	3.4	2.9	4.6	2.8	149	181	42.9	40.1
	AVERAGE		**72**	**3.7**	**3.2**	**4.6**	**3.7**	**130**	**179**	**43.5**	**41.5**
40	Nov 12	562	76	3.2	3.1	4.2	3.4	127	171	46.9	47.1○
	Nov 13	563	-	-	-	-	-	-	-	-	-
	Nov 14	564	75	3.1	3.1	3.4	3.1	152	193○	43.2	37.3
	Nov 15	565	78	4.2	3.4	4.3	3.9	159	172	43.0	37.8
	Nov 16	566	79	3.5	3.1	3.2	3.2	128	167	42.6	39.2
	Nov 17	567	65	2.7	2.4	2.5	2.2	92	138	41.2	37.5
	Nov 18	568	-	-	-	-	-	-	-	-	-
	Nov 19	569	65	1.8○	1.7○	2.0	2.0	87	132○	46.8	40.1
	Nov 20	570	71	2.9	2.5	2.5	2.2	107	162	47.3	40.7
	Nov 21	571	70	2.7	2.4	2.5	2.4	99	158	45.9	39.1
	Nov 22	572	76	2.8	2.5	2.9	2.5	116	162	48.1	38.7
	Nov 23	573	67	4.5○	4.2○	4.3	3.6	139	155	46.2	40.3
	Nov 24	574	-	-	-	-	-	-	-	-	-
	Nov 25	575	-	-	-	-	-	-	-	-	-
	AVERAGE		**72**	**3.1**	**2.8**	**3.2**	**2.9**	**120**	**161**	**45.1**	**39.0**
41	Nov 26	576	69	3.8	3.5	3.4	3.1	130	135○	46.3	42.7
	Nov 27	577	69	3.1	2.7	3.2	3.1	139	182	45.1	41.8
	Nov 28	578	69	15.1○	14.7○	3.6	3.4	171○	161	42.9	41.3
	Nov 29	579	-	-	-	-	-	-	-	-	-
	Nov 30	580	69	4.5	3.2	3.9	3.5	148	173	40.3	38.6
	Dec 1	581	-	-	-	-	-	-	-	-	-
	Dec 2	582	68	3.1	2.9	18.3○	18.3○	142	183	39.1	37.1
	AVERAGE		**69**	**3.6**	**3.1**	**3.5**	**3.3**	**140**	**175**	**42.7**	**40.3**

○ Data rejected as outliers at 10% level of significance.

APPENDIX A

Daily measured Free and Saline Ammonia (FSA) in influent and filtered effluents (FE) and Nitrate (NO_3-N) plus Nitrate (NO_2-N) concentrations in filtered mixed liquor of each reactors and filtered effluents of the MLE and UCT systems at 30 C.

			FSA CONCENTRATIONS			REACTORS NO_3-N plus NO_2-N CONCENTRATIONS						
				MLE	UCT	MLE SYSTEM			UCT SYSTEM			
BATCH OF SEWAGE	YEAR MONTH / DAY	DAY NO	*INFLUENT* [mgN/*l*]	FE [mgN/*l*]	FE [mgN/*l*]	ANOXIC [mgN/*l*]	AEROB [mgN/*l*]	EFFLUENT [mgN/*l*]	ANAEROB [mgN/*l*]	ANOXIC [mgN/*l*]	AEROB [mgN/*l*]	EFFLUENT [mgN/*l*]
1	*1995*											
	May 1	1	46	0.00¤	0.00¤	1.20¤	5.4	7.00¤	0.40¤	1.0	7.2	9.6
	May 2	2	43	0.7	0.4	1.2	7.20¤	6.80¤	0.4	1.2	8.8	9.6
	May 3	3	45	2.5	0.4	0.8	5.8	6.60¤	0.1	1.3	9.20¤	10.60¤
	May 4	4	47	0.00¤	0.00¤	0.2	5.2	4.8	0.2	0.4	1.00¤	8.0
	May 5	5	43	6.70¤	0.00¤	0.1	4.6	4.6	0.2	0.5	8.0	8.0
	May 6	6	56¤	4.80¤	5.90¤	0.2	4.2	4.0	0.1	0.5	7.4	8.0
	May 7	7	42	2.3	2.0	0.1	3.4	4.0	0.1	0.9	6.4	7.6
	May 8	8	41	1.1	0.00¤	0.00¤	3.4	4.6	0.1	0.6	6.0	7.0
	May 9	9	42	1.1	1.4	0.1	3.6	4.0	0.1	0.9	6.6	6.8
	May 10	10	40	1.2	1.9	0.9	4.4	4.6	0.60¤	0.2	8.6	7.2
	May 11	11	41	0.7	1.3	0.7	5.0	4.4	0.1	0.3	7.2	7.2
	May 12	12	46	1.8	1.6	0.7	4.0	4.4	0.1	0.2	7.0	7.8
	May 13	13	43	0.6	1.3	0.7	5.4	4.2	0.1	0.2	7.0	7.8
	May 14	14	44	1.5	1.8	0.8	4.4	5.0	0.1	0.5	6.2	7.2
	May 15	15	46	2.3	2.5	0.6	5.2	5.0	0.1	0.9	5.8	8.0
	May 16	16	46	2.2	2.5	0.2	4.4	4.2	0.1	0.9	6.0	7.2
	May 17	17	46	3.0	2.4	0.2	4.2	4.6	0.2	0.8	6.8	8.2
	May 18	18	48	3.9	3.2	0.7	5.4	5.4	0.3	2.60¤	8.2	8.8
	May 19	19	39¤	3.5	3.3	0.6	4.6	5.8	0.3	1.90¤	8.0	9.80¤
	AVERAGE		**44**	**1.9**	**1.8**	**0.5**	**4.6**	**4.6**	**0.2**	**0.6**	**7.1**	**7.9**
2	May 20	20	39	2.0	1.6	0.3	2.80¤	5.4	0.3	0.5	4.4	7.4
	May 21	21	37	1.8	1.7	0.6	4.6	5.8	0.2	0.5	4.7	6.0
	May 22	22	41	2.2	1.8	0.7	5.3	5.7	0.3	0.6	5.0	6.7
	May 23	23	38	2.9	2.4	0.6	5.0	5.3	0.3	1.0	5.7	7.1
	May 24	24	40	2.2	2.4	0.5	5.3	5.5	0.2	0.5	6.8	7.9
	May 25	25	39	1.5	1.10¤	0.2	5.7	6.3	0.2	0.6	6.0	8.9
	May 26	26	36¤	1.3	1.8	0.8	5.6	5.9	0.3	0.1	5.3	6.4
	May 27	27	35¤	4.10¤	2.0	0.8	5.5	6.5	0.4	0.1	5.0	6.8
	May 28	28	39	1.8	1.2	0.90¤	13.00¤	5.2	0.1	0.1	6.8	6.8
	May 29	29	39	5.20¤	2.0	0.2	5.2	6.0	0.2	0.8	7.9	7.5
	May 30	30	40	2.2	1.8	0.6	4.9	5.3	0.1	0.8	6.4	7.1
	May 31	31	41	2.0	1.8	0.6	4.9	5.8	0.1	0.9	6.3	6.9
	June 1	32	40	1.4	1.5	0.20¤	5.2	5.3	0.3	1.60¤	7.7	8.3
	June 2	33	42	1.8	1.8	0.3	5.6	6.0	0.5	2.0	9.50¤	8.8
	June 3	34	41	1.7	1.5	0.7	5.7	6.3	0.1	0.9	9.80¤	9.90¤
	June 4	35	42	2.8	1.5	0.6	5.4	5.8	0.60¤	0.8	5.7	9.40¤
	June 5	36	45¤	1.5	2.2	0.6	6.3	7.30¤	0.80¤	0.7	5.9	5.8
	June 6	37	45¤	3.2	2.8	0.3	3.8	4.70¤	0.2	0.7	5.7	7.4
	June 7	38	41	2.7	2.2	0.7	5.1	5.0	0.3	1.2	7.1	6.3
	June 8	39	44	1.5	1.5	0.6	5.2	5.1	0.1	0.8	7.0	7.4
	AVERAGE		**40**	**2.0**	**1.9**	**0.5**	**5.2**	**5.7**	**0.2**	**0.7**	**6.1**	**7.2**
3	June 9	40	44	1.7	2.1	0.7	4.6	5.7	0.2	1.0	8.0	9.1
	June 10	41	42	1.7	1.8	0.8	4.6	5.1	0.50¤	0.10¤	7.5	7.6
	June 11	42	41	2.0	2.0	0.6	4.6	5.3	0.0	0.3	7.2	7.6
	June 12	43	46	2.2	2.0	0.7	4.6	5.3	0.1	0.6	8.4	8.4
	June 13	44	45	2.2	3.0	0.8	6.3	6.5	0.3	1.4	9.8	7.0
	June 14	45	42	1.8	2.0	0.6	6.0	7.6	0.3	1.4	9.5	8.2
	June 15	46	46	2.0	2.6	0.3	6.2	8.60¤	0.3	2.1	9.9	11.60¤
	June 16	47	41	2.7	1.9	0.9	6.3	6.7	0.4	1.0	8.7	10.7
	June 17	48	42	2.0	1.9	0.8	5.7	6.1	0.2	0.8	6.30¤	8.7
	June 18	49	42	1.8	2.0	0.3	6.1	8.0	0.2	0.1	6.6	5.70¤
	June 19	50	47	2.5	2.7	0.1	5.6	8.2	0.2	0.6	8.2	8.2

¤ Data rejected as outliers at 10% level of significance.

	June 20	51	45	10.00¤	2.1	0.2	1.6¤	2.4¤	0.2	1.0	7.6	8.2
	June 21	52	45	4.1	1.8	0.2	3.7	6.4	0.1	0.5	7.8	8.8
	June 22	53	45	2.5	2.2	0.2	2.3¤	6.0	0.1	1.0	8.2	8.7
	June 23	54	46	2.5	2.4	0.2	4.7	6.1	0.1	0.8	8.7	9.2
	June 24	55	49	2.8	2.7	0.4	4.4	4.2	0.1	0.6	7.0	9.0
	June 25	56	50	8.1¤	3.5	0.0	5.0	3.0¤	0.1	0.6	6.3¤	9.2
	June 26	57	49	3.4	3.2	0.6	5.0	6.4	0.1	0.9	8.8	8.7
	June 27	58	50	3.3	3.5¤	0.2	4.5	4.5	0.1	0.9	9.6	13.2¤
	June 28	59	48	1.5	1.8	0.2	5.8	4.7	0.1	1.1	11.2¤	9.5
	AVERAGE		**45**	**2.4**	**2.3**	**0.4**	**5.2**	**6.0**	**0.2**	**0.9**	**8.3**	**8.6**
4	June 29	60	51¤	0.9	1.1	0.7	5.3	6.1	0.2	1.4	10.9	12.2
	June 30	61	56	2.1	1.5	0.2	6.8	4.4¤	0.2	1.3	13.3	12.5
	July 1	62	55	1.5	1.8	0.8	6.2	8.3	0.2	1.0	10.8	10.7¤
	July 2	63	53	1.3	1.4	0.2	7.1	6.0	0.2	1.1	11.3	12.4
	July 3	64	57	1.1	1.3	0.7	7.8	9.3	0.2	1.3	12.4	11.1
	July 4	65	57	10.9¤	1.6	0.2	1.6¤	3.0¤	0.2	1.6	11.8	13.5
	July 5	66	56	3.6	1.1	1.3	8.3	9.0	0.2	1.4	10.0	13.5
	July 6	67	52	2.4	2.7	0.9	8.9	8.8	0.2	1.0	10.1	13.1
	July 7	68	62	2.1	2.8	0.7	5.9	5.9	0.2	1.3	12.8	13.4
	July 8	69	-	-	-	-	-	-	-	-	-	-
	July 9	70	61	2.4	2.4	0.9	9.8	6.8	0.2	0.9	11.9	14.2
	July 10	71	65	1.5	1.8	0.9	8.0	7.2	0.2	1.6	13.9	14.3
	July 11	72	-	-	-	-	-	-	-	-	-	-
	July 12	73	62	2.1	2.0	0.2	9.1	7.7	0.3	2.0	14.5	15.4
	July 13	74	61	5.0¤	2.0	0.1	9.3	9.3	0.3	1.6	9.2	13.6
	July 14	75	62	1.5	2.3	1.2	7.3	8.4	0.2	0.3	9.9	12.2
	July 15	76	62	1.7	2.1	1.2	7.6	9.1	0.2	1.5	9.9	11.3
	July 16	77	62	2.9	2.4	1.2	8.9	9.1	0.2	0.7	8.5¤	10.7¤
	July 17	78	60	3.1	2.2	0.2	7.5	9.3	0.2	1.0	10.2	12.1
	July 18	79	60	2.5	2.7	0.8	7.6	9.2	0.3	2.5	12.7	13.2
	July 19	80	59	1.4	1.3	0.9	9.2	9.2	0.5¤	2.5	11.7	13.7
	July 20	81	57	1.5	1.4	0.8	8.2	9.3	0.3	2.5	12.9	13.7
	July 21	82	54	1.0	0.7¤	0.1	8.8	12.8¤	1.1¤	7.5¤	15.0¤	17.4¤
	AVERAGE		**59**	**1.9**	**1.9**	**0.7**	**7.9**	**8.2**	**0.2**	**1.4**	**11.6**	**13.1**
5	July 22	83	61	1.1	1.3	1.5	8.9	13.8	1.0	8.7	21.4	16.6¤
	July 23	84	66	1.0	1.1	2.0	9.5	15.3	0.9	4.8	18.6	20.0
	July 24	85	65	1.0	1.0	1.8	9.7	15.0	0.9	9.8	22.8	24.0
	July 25	86	-	-	-	-	-	-	-	-	-	-
	July 26	87	-	-	-	-	-	-	-	-	-	-
	July 27	88	-	-	-	-	-	-	-	-	-	-
	July 28	89	71	1.8	1.2	2.9	11.9	14.0	0.5¤	3.6¤	17.2¤	21.0
	July 29	90	77	2.2	1.8	2.3	10.4	10.8¤	1.4¤	5.4	19.8	21.4
	July 30	91	72	1.8	2.0	1.1	10.8	14.5	1.2	7.4	22.4	23.4
	July 31	92	79	2.7	3.5	2.0	12.0	15.2	0.9	11.0	25.2	25.4
	Aug 1	93	86	3.4¤	3.6	1.7	12.0	14.2	1.1	12.3	27.6¤	26.4
	Aug 2	94	81	2.1	2.5	2.7	14.2	17.3	0.8	13.8	24.8	28.2¤
	Aug 3	95	81	2.1	2.9	2.0	12.6	16.3	0.8	11.0	23.6	26.4
	Aug 4	96	80	2.8	2.9	4.2¤	14.8¤	16.8	1.3	9.5	23.0	25.2
	AVERAGE		**74**	**1.8**	**2.2**	**2.0**	**11.2**	**15.2**	**1.0**	**9.4**	**22.4**	**23.7**
6	Aug 5	97	54	3.4¤	2.9	0.9	14.4¤	18.0¤	0.1	1.2	13.2¤	21.6¤
	Aug 6	98	56	2.2	2.6	0.5	7.8	6.8	0.1	0.5¤	8.6	8.4
	Aug 7	99	51	3.5¤	3.2	0.3	6.4	6.1	0.2	1.1	9.6	10.4
	Aug 8	100	55	2.4	2.5	0.4	6.4	6.2	0.2	1.1	9.2	10.4
	Aug 9	101	51	2.7	2.9	0.7	8.0	5.8	0.1	0.8	6.8¤	10.0
	Aug 10	102	52	2.5	2.9	0.2	6.8	7.1	0.1	1.3	10.4	10.4
	Aug 11	103	41	1.8	1.7	0.4	6.4	7.5	0.2	1.5	11.0	11.0
	Aug 12	104	47	2.2	2.6	0.2	5.0	7.3	0.2	0.0¤	8.2	11.8
	Aug 13	105	52	2.0	2.1	0.6	9.0	5.2	0.0¤	1.3	10.0	10.6
	Aug 14	106	53	1.4	2.0	0.8	6.8	6.1	0.2	0.8	11.4	11.0
	Aug 15	107	55	1.7	2.3	0.7	7.2	5.0	0.2	1.8¤	11.4	8.2
	Aug 16	108	55	2.9	6.8¤	0.9	7.2	10.2	0.4¤	1.6	10.4	6.4¤
	Aug 17	109	48	2.1	2.2	0.4	6.6	6.2	0.2	1.4	11.0	9.4
	Aug 18	110	42	0.0¤	0.0¤	0.3	4.6	7.7	0.3	1.4	8.4	11.1

¤ Data rejected as outliers at 10% level of significance.

	Aug 19	111	40	1.4	1.4	1.6¤	3.9	8.6	0.3	1.3	9.1	10.3
	Aug 20	112	39	0.7	0.7¤	0.6	5.8	8.0	0.3	0.9	8.3	11.1
	Aug 21	113	39	1.4	2.1	0.2	5.3	8.2	0.2	1.1	10.3	10.7
	Aug 22	114	40	1.4	2.1	0.1	2.7¤	7.0	0.1	1.0	9.6	11.5
	AVERAGE		**48**	**1.9**	**2.4**	**0.5**	**6.5**	**7.0**	**0.2**	**1.2**	**9.8**	**10.4**
7	Aug 23	115	39	1.5	2.7	0.1	6.0	7.3	0.3	0.8	10.4	5.9¤
	Aug 24	116	32¤	1.2	1.8	0.1	6.3	7.3	0.1¤	0.8	9.1	9.2
	Aug 25	117	47	0.8	1.3	0.2	5.7	7.4	0.1¤	0.8	10.6	10.2
	Aug 26	118	44	1.8	2.1	0.6	6.0	6.6	0.2	0.7	9.5	10.8
	Aug 27	119	44	1.1	1.1	0.6	6.0	6.3	0.3	0.8	10.0	10.5
	Aug 28	120	44	1.5	1.7	0.5	6.8¤	8.5¤	0.3	0.6	9.1	9.8
	Aug 29	121	46	1.9	2.0	0.1	4.3¤	7.0	0.3	0.9	8.5	9.3
	Aug 30	122	44	2.9¤	2.0	0.5	5.2	6.5	0.3	0.9	11.0	10.1
	Aug 31	123	47	2.0	2.8	0.4	5.0	6.9	0.4	0.7	13.1¤	9.9
	Sept 1	124	46	1.3	1.5	0.2	5.5	6.6	0.3	0.6	8.9	10.1
	Sept 2	125	46	1.3	4.0¤	0.1	5.6	6.1	0.4¤	0.1¤	9.9	7.5¤
	Sept 3	126	48	2.5	2.6	0.6	5.6	6.9	0.2	0.4	9.9	9.3
	Sept 4	127	46	1.8	1.8	0.4	4.9	6.2	0.4	0.5	9.2	9.6
	Sept 5	128	43	2.4	2.1	3.8¤	4.0¤	5.2¤	0.4	0.9	8.4	9.7
	Sept 6	129	54¤	2.7	2.5	0.7	5.3	6.3	0.3	0.9	12.3	12.4¤
	Sept 7	130	30¤	0.0¤	0.0¤	0.7	6.3	7.5	0.3	0.9	12.7¤	10.2
	AVERAGE		**45**	**1.7**	**2.0**	**0.4**	**5.6**	**6.8**	**0.3**	**0.8**	**9.8**	**9.9**
8	Sept 8	131	46	2.4	2.2	0.6	5.8	7.8	0.3	0.9	12.5¤	10.0
	Sept 9	132	45	2.6	3.0	4.1¤	7.0	7.0	0.1	0.7	8.4	11.4
	Sept 10	133	53	3.2¤	2.4	4.2¤	7.1	9.0	0.3	1.0	13.4¤	9.8
	Sept 11	134	48	2.4	3.4¤	4.3¤	5.5	8.3	0.2	1.0	10.4	9.3
	Sept 12	135	52	3.2¤	2.9	0.9	8.6	8.8	0.2	0.9	9.6	7.6¤
	Sept 13	136	52	2.5	2.8	1.0	6.0	6.6¤	0.3	0.9	6.8	11.6
	Sept 14	137	57	2.4	2.6	0.7	7.0	7.7	0.4	0.9	7.2	8.4
	Sept 15	138	54	2.4	2.5	1.0	11.3¤	8.8	0.1	0.5	6.8	12.0¤
	Sept 16	139	56	2.2	2.7	1.0	7.7	9.4	0.4	0.7	4.2	9.8
	Sept 17	140	54	2.2	2.5	1.2	8.2	11.4¤	0.3	0.9	5.0	8.4
	Sept 18	141	57	2.3	2.4	0.3	9.2	10.1	0.7	0.2	5.6	9.7
	Sept 19	142	56	2.2	2.0	1.3	9.2	9.6	0.2	1.1	5.8	10.6
	Sept 20	143	54	1.9¤	2.7	1.3	8.0	9.9	0.2	1.1	6.2	10.0
	Sept 21	144	59	2.1	1.6¤	1.4	7.3	9.2	0.2	0.8	6.0	9.8
	AVERAGE		**53**	**2.3**	**2.6**	**1.0**	**7.4**	**8.8**	**0.3**	**0.8**	**6.8**	**9.9**
9	Sept 22	145	45¤	2.7	2.5	1.1	6.3	7.6	0.1	0.1	7.4	8.7
	Sept 23	146	44¤	2.9	2.2	0.7	4.2	7.6	0.4	0.1	5.5	9.2
	Sept 24	147	55	1.8	2.0	0.2	5.5	6.7	0.1	0.5	5.0	8.2
	Sept 25	148	51	2.4	2.8	1.5¤	1.8¤	5.0	0.1	0.1	3.4¤	8.0
	Sept 26	149	58¤	2.7	2.5	1.2	5.9	7.1	0.2	0.8	7.8	8.5
	Sept 27	150	52	3.4	2.9	0.1	4.0	7.2	0.2	0.4	5.7	8.2
	Sept 28	151	49	2.7	3.4	0.8	4.3	6.5	0.4	0.2	6.3	8.5
	Sept 29	152	50	2.8	2.3	1.0	7.1¤	7.2	0.1	0.7	7.1	8.9
	Sept 30	153	49	3.2	3.4	0.1	4.7	7.6	0.1	0.5	4.6	9.5¤
	Oct 1	154	52	3.6	3.2	0.5	5.3	6.7	0.1	0.7	5.6	8.4
	Oct 2	155	53	11.9¤	2.3	0.1	1.4¤	1.8¤	0.4	0.9	8.0	8.6
	Oct 3	156	55	13.9¤	2.8	0.2	5.5	6.3	0.2	1.3¤	8.7¤	8.8
	Oct 4	157	55	2.3	1.8	0.5	4.3	6.3	0.5¤	0.3	6.1	9.1
	AVERAGE		**52**	**2.8**	**2.6**	**0.5**	**5.0**	**6.8**	**0.2**	**0.4**	**6.3**	**8.6**
10	Oct 5	158	59¤	2.2	1.8¤	0.6	4.8	4.4	0.1	0.7	4.8	4.9¤
	Oct 6	159	47	2.4	2.4	0.4	4.3	4.3	0.1	0.6	3.9	9.2
	Oct 7	160	49	1.4¤	2.2	0.5	4.3	4.3	0.6¤	0.1¤	5.6	8.5
	Oct 8	161	50	2.2	2.4	0.1	4.2	4.2	0.1	0.6	6.1	11.8
	Oct 9	162	45¤	1.8	1.8¤	0.4	4.6	4.6	0.1	0.6	6.1	8.9
	Oct 10	163	53	1.8	2.4	0.7	5.0	5.3	0.1	0.7	5.0	7.6
	Oct 11	164	50	1.8	2.4	0.4	5.0	5.0	0.1	0.7	7.3	10.1
	Oct 12	165	55	2.5	2.9¤	0.5	5.3	5.3	0.1	0.9	9.5¤	11.2
	Oct 13	166	57	2.9¤	2.2	0.7¤	5.2	5.2	0.1	0.8	8.7	11.3
	Oct 14	167	53	2.1	2.2	0.1	3.5¤	3.5¤	0.6¤	0.1¤	6.9	9.7
	Oct 15	168	51	2.7	2.6	0.1	5.1	5.1	0.1	0.6	5.2	10.6
	Oct 16	169	48	1.8	2.2	0.4	5.2	5.2	0.1	0.8	6.8	8.2

¤ Data rejected as outliers at 10% level of significance.

	Oct 17	170	49	2.5	2.9¤	0.3	4.8	4.6	0.1	0.6	7.8	10.7
	AVERAGE		**51**	**2.2**	**2.3**	**0.4**	**4.8**	**4.8**	**0.1**	**0.7**	**6.2**	**9.8**
11	Oct 18	171	42	2.4	2.7	0.3	2.3	4.5	0.1¤	0.5	4.3	7.7
	Oct 19	172	41	2.4	2.7	0.2	1.7	4.9	0.1	0.7	7.1¤	8.8¤
	Oct 20	173	42	5.0¤	2.2	0.6	6.8¤	3.8	0.2	0.7	5.4	6.7
	Oct 21	174	42	3.4	2.0	0.6	4.8	5.1	0.1	0.1¤	5.5	6.9
	Oct 22	175	45	2.9	2.8	0.2	1.1¤	4.8	0.1	0.5	4.6	6.7
	Oct 23	176	40	1.8	1.8	0.5	3.8	5.0	0.1	0.8	6.9	6.6
	Oct 24	177	44	2.0	2.6	0.4	4.3	4.3	0.2	0.5	4.5	6.7
	Oct 25	178	44	2.0	2.1	0.1	1.0¤	4.5	0.1	0.7	6.2	6.6
	Oct 26	179	42	2.2	1.9	0.1	3.7	3.8	0.1	0.7	6.0	7.2
	Oct 27	180	49¤	1.8	2.2	0.1	3.1	4.0	0.1	0.7	6.2	7.4
	Oct 28	181	41	2.7	1.8	0.3	3.2	3.2	0.2	0.6	4.8	6.6
	Oct 29	182	47	1.8	2.4	0.3	1.9	4.2	0.2¤	0.6	4.6	7.4
	Oct 30	183	48	1.8	2.5	0.6	3.6	3.5	0.1	0.6	5.6	6.6
	Oct 31	184	48	3.2	3.1¤	0.5	4.2	4.2	0.1	0.6	5.6	6.1
	AVERAGE		**44**	**2.3**	**2.3**	**0.3**	**3.3**	**4.3**	**0.1**	**0.6**	**5.4**	**6.9**
12	Nov 1	185	40	2.1	1.8	0.6	4.9	4.8	1.8¤	0.4	5.3	8.1
	Nov 2	186	57	2.2	2.1	0.6	3.3	5.5	0.2	1.4	9.0	6.3
	Nov 3	187	51	2.3	8.1¤	0.6	4.9	5.8	0.1	0.2	1.6¤	5.9¤
	Nov 4	188	49	1.5	2.1	0.7	5.0	6.2	1.0¤	0.1¤	8.1	10.2
	Nov 5	189	58	2.2	3.3	0.2¤	1.1¤	6.5	0.2	0.9	8.5	12.7
	Nov 6	190	59	4.3¤	4.8	0.1	5.0	5.8	0.2	1.5	10.6	10.0
	Nov 7	191	56	2.3	2.7	0.6	5.8	7.3	0.1	1.0	9.0	12.4
	Nov 8	192	56	2.4	3.6	0.6	5.8	6.5	0.2	1.3	12.6	12.4
	Nov 9	193	50	1.8	1.8	0.7	6.5	7.7	0.2	1.1	13.2	12.7
	Nov 10	194	54	2.0	2.0	1,1¤	6.3	7.8	0.2	1.1	9.7	11.2
	Nov 11	195	56	2.2	2.4	0.2	4.8	6.9	0.4	1.2	11.0	12.5
	Nov 12	196	58	2.0	2.0	0.6	5.0	5.0	0.4	1.1	11.5	12.1
	Nov 13	197	54	2.5	2.4	0.1	4.9	3.1	0.3	1.0	10.7	12.0
	Nov 14	198	-	-	-	-	-	-	-	-	-	-
	Nov 15	199	54	3.8¤	2.4	0.2¤	4.5	3.1	0.3	0.8	9.0	9.5
	Nov 16	200	55	2.2	2.0	0.7	6.4	1.7¤	0.2	0.7	7.0	10.0
	AVERAGE		**54**	**2.1**	**2.5**	**0.5**	**5.2**	**5.9**	**0.2**	**1.0**	**9.7**	**10.9**
13	Nov 17	201	38¤	2.2	1.8	0.5	4.9¤	4.1	0.3	0.7	6.6¤	6.3¤
	Nov 18	202	48	2.2	1.5	0.3	5.5	3.1¤	0.3	0.9	8.3	8.5
	Nov 19	203	46	2.4	2.6	0.7	5.7	3.5¤	0.3	0.8	8.7	9.1
	Nov 20	204	48	2.5	2.2	0.6	5.6	3.7	0.3	0.8	8.8	9.3
	Nov 21	205	50	2.9¤	2.4	0.2	6.3	4.3	0.3	0.9	11.2¤	9.0
	Nov 22	206	52	2.4	1.5	0.8	6.6	6.8	0.3	1.0	7.8	10.0
	Nov 23	207	54¤	1.8	1.8	0.7	6.6	6.7	0.2	0.9	8.5	9.0
	Nov 24	208	48	1.6	2.0	0.3	6.2	6.4	0.2	1.0	8.2	9.4
	Nov 25	209	52	2.2	2.5	0.2	6.3	6.3	0.1¤	0.9	7.7	8.6
	Nov 26	210	51	1.8	1.8	0.7	6.4	6.4	0.2	0.9	8.3	9.9
	Nov 27	211	52	2.1	1.8	0.7	6.6	6.8	0.2	1.0	7.8	9.9
	Nov 28	212	50	1.8	1.8	0.7	6.1	6.4	0.2	1.1	8.7	9.8
	Nov 29	213	51	1.6	1.3	0.2	6.0	6.1	0.2	0.2¤	9.3	9.6
	Nov 30	214	-	-	-	-	-	-	-	-	-	-
	Dec 1	215	50	1.7	1.9	1.1	6.1	6.5	0.3	1.1	8.7	9.2
	Dec 2	216	51	2.1	2.2	1.1	6.2	7.2	0.7¤	0.4¤	7.0	8.4
	Dec 3	217	51	1.6	1.5	1.4¤	6.8	7.4	0.3	1.1	9.0	9.6
	Dec 4	218	47	1.8	1.8	1.1	6.5	6.9	0.3	0.7	7.1	9.6
	Dec 5	219	49	2.8¤	2.9¤	1.0	6.5	7.1	0.3	0.9	8.7	9.1
	AVERAGE		**50**	**2.0**	**1.9**	**0.6**	**6.2**	**6.2**	**0.3**	**0.9**	**8.3**	**9.3**
	Dec 6	220	44	1.7	1.5	0.9¤	7.2¤	6.5¤	0.3	0.8	5.6	7.5
	Dec 7	221	43	1.8	1.8	0.3	3.8	5.5	0.3	0.7	5.5	7.3
	Dec 8	222	45	2.1	2.3	0.6	4.5	5.1	0.2	0.7	5.5	7.6
	Dec 9	223	45	1.9	1.7	0.6	5.0	5.1	0.1	0.1¤	6.1	7.8
	Dec 10	224	48	2.2	2.3	0.6	3.8	5.0	0.3	0.9	6.6	8.0
	Dec 11	225	45	1.4	1.5	0.2	4.2	5.0	0.5¤	0.8	5.9	8.3
	Dec 12	226	52	2.5	2.6	0.6	4.8	5.5	0.3	0.9	6.7	7.8
	Dec 13	227	49	2.0	1.7	0.6	4.8	5.1	0.2	0.8	7.1	8.0
	Dec 14	228	48	2.5	2.0	0.7	4.8	5.1	0.4	0.8	7.5	8.4

¤ Data rejected as outliers at 10% level of significance.

14	Dec 15	229	47	2.5	2.3	0.8	5.6	4.2	0.7¤	0.4	7.7¤	8.3
	Dec 16	230	44	6.2¤	2.0	0.1	4.3	4.3	0.4	0.7	5.1	5.8¤
	Dec 17	231	45	3.3	2.1	0.4	5.0	5.5	0.2	0.1¤	6.1	6.4
	Dec 18	232	46	1.4	1.8	0.4	4.3	4.6	0.2	0.7	6.0	6.9
	Dec 19	233	49	1.7	1.9	0.3	5.3	4.2	0.2	0.7	6.7	8.0
	Dec 20	234	54¤	2.7	3.1¤	0.4	4.4	5.0	0.1	0.7	6.3	7.2
	Dec 21	235	50	1.8	1.5	0.4	4.5	4.8	0.2	0.7	7.3	7.5
	Dec 22	236	53¤	1.7	1.5	0.1	4.5	5.1	0.1	0.7	6.9	7.5
	Dec 23	237	48	1.8	1.8	0.5	5.1	4.2	0.1	0.5	6.3	7.4
	Dec 24	238	47	1.5	1.4	0.1	4.3	4.6	0.1	0.1¤	6.1	7.1
	Dec 25	239	47	1.4	1.6	0.2	4.3	4.4	0.2	0.6	5.8	7.8
	AVERAGE		47	2.0	1.9	0.4	4.6	4.9	0.2	0.7	6.3	7.6
15	Dec 26	240	46	1.5	2.1	0.7¤	3.9	4.6	0.1	0.6¤	6.1	7.1¤
	Dec 27	241	50¤	1.7	2.2	0.3	4.0	3.8	0.5	0.2	6.0	7.1¤
	Dec 28	242	43	1.9	1.8	0.6	4.1	4.2	0.5	0.2	5.5	7.0¤
	Dec 29	243	40	1.8	2.4¤	0.3	4.1	3.9	0.5	0.1	6.2¤	6.3
	Dec 30	244	37	1.4	1.4	0.5	4.1	4.1	0.1	0.1	5.4	5.9
	Dec 31	245	35	1.1	1.1	0.1	3.5¤	4.3	0.3	0.1	5.4	5.6
	Jan 1 *96*	246	46¤	1.1	1.3	0.3	4.3	4.5	0.1	0.1	4.5	5.8
	Jan 2	247	33	1.1	1.3	0.4	4.2	3.9	0.1	0.2	4.5	5.8
	Jan 3	248	36	1.4	1.2	0.4	4.2	3.8	0.1	0.7¤	5.0	5.5
	Jan 4	249	33	1.2	1.3	0.1	4.1	3.6	0.4	0.5	5.0	5.8
	Jan 5	250	36	1.1	1.3	0.4	4.7	3.6	0.4	0.1	4.3	5.4
	Jan 6	251	35	1.6	2.2	0.4	4.0	3.3	0.1	0.1	4.7	4.7¤
	Jan 7	252	36	1.0	1.1	0.3	4.2	3.6	0.4	0.3	5.0	4.7
	Jan 8	253	35	0.9	1.5	0.1	3.9	3.5	0.4	0.1	5.5	5.0
	Jan 9	254	35	2.2	1.8	0.6	4.0	2.5¤	0.2	0.1	5.7	5.3
	Jan 10	255	35	7.9¤	2.1	0.1	4.4	3.9	0.2	0.3	4.1¤	5.8
	Jan 11	256	39	6.2¤	1.6	0.4	4.3	2.5¤	0.1	0.1	5.1	5.5
	Jan 12	257	36	1.6	1.5	0.1	5.5¤	4.0	0.1	0.5	5.1	5.4
	AVERAGE		37	1.4	1.6	0.3	4.1	3.9	0.3	0.2	5.1	5.5
16	Jan 13	258	70	1.4	1.5	0.1	4.3	7.0	0.1	0.3	7.1	6.5¤
	Jan 14	259	71	1.5	1.5	0.4	6.4	5.4	0.1	0.5	9.3	9.3
	Jan 15	260	74¤	1.3	1.3	1.1¤	6.2	6.5	0.2	0.7	10.6	12.0¤
	Jan 16	261	73¤	1.4	1.3	0.1	7.0	7.5¤	1.0¤	0.2	12.1¤	10.7
	Jan 17	262	49	1.2	1.3	0.5	5.3	5.8	0.2	0.6	8.5	10.7
	Jan 18	263	47	1.4	1.3	0.9	5.5	6.0	0.2	0.2	9.2	9.7
	Jan 19	264	45	1.1	1.0¤	0.2	5.5	6.0	0.2	0.6	8.6	9.3
	Jan 20	265	46	1.2	1.1	0.5	5.4	6.0	0.2	0.2	6.6	8.5
	Jan 21	266	48	1.5	1.3	0.1	5.2	6.6	0.2	0.4	7.4	8.9
	Jan 22	267	48	6.5¤	1.4	0.2	5.3	3.4¤	0.8	0.7	7.8	8.8
	Jan 23	268	46	3.0	1.0¤	0.1	4.1¤	6.8	0.2	0.5	8.3	8.9
	Jan 24	269	51	2.3	1.3	0.4	4.8	5.4	0.3	0.8¤	7.4	9.0
	Jan 25	270	49	1.3	1.2	0.7	4.9	6.1	0.1	0.5	7.2	8.3
	Jan 26	271	49	1.3	1.5	0.1	5.1	6.1	1.3¤	0.1	11.7¤	11.3
	AVERAGE		51	1.5	1.3	0.3	5.4	6.1	0.2	0.4	8.1	9.4
17	Jan 27	272	36	1.5	0.9	0.5	3.6	5.0¤	0.1	0.2	8.3¤	9.9¤
	Jan 28	273	33	1.1	1.3	0.6	3.9	4.7¤	0.1	0.2	5.4	7.2
	Jan 29	274	36	2.1	2.1	0.7	3.4	4.0	0.2	0.4	5.1	6.2
	Jan 30	275	35	1.3	1.5	0.6	4.2¤	3.9	0.1	0.2	4.5	6.0
	Jan 31	276	34	1.3	1.5	0.5	3.8	3.9	0.2	0.6	4.6	5.4
	Feb 1	277	34	1.5	1.6	0.1¤	3.0	3.4	0.2	0.5	3.5	4.9
	Feb 2	278	43¤	2.0	2.2	0.6	3.0	3.1	0.5¤	0.2	4.1	4.8
	Feb 3	279	32	1.3	1.3	0.5	3.3	3.3	0.1	0.1	4.3	5.2
	Feb 4	280	33	0.8¤	0.8	0.1¤	2.4	3.0	0.2	0.4	4.1	4.8
	Feb 5	281	34	1.2	1.1	0.4	3.0	3.3	0.4	0.1	4.4	4.8
	Feb 6	282	35	2.3¤	2.2	0.4	2.5	3.5	0.2	0.5	4.3	5.3
	Feb 7	283	36	1.6	1.8	0.4	2.7	3.6	0.1	0.1	4.5	5.5
	Feb 8	284	43¤	1.8	1.5	0.4	2.6	3.5	0.2	0.4	4.3	4.6
	Feb 9	285	43¤	2.0	2.1	0.4	2.7	3.0	0.4	0.2	4.5	4.4
	AVERAGE		34	1.6	1.6	0.5	3.1	3.4	0.2	0.3	4.4	5.3
	Feb 10	286	44	1.4	1.5	0.1	3.3¤	5.5	0.5	0.1¤	4.3¤	5.2¤
	Feb 11	287	43	1.3	1.3¤	0.7	3.7	6.4¤	0.1	0.4	4.5	6.4

¤ Data rejected as outliers at 10% level of significance.

18	Feb 12	288	45	2.2	2.4	0.5	3.6	5.3	0.1	0.5	5.1	7.0
	Feb 13	289	44	2.0	2.1	0.6	4.0	5.7	0.2	0.5	5.6	7.0
	Feb 14	290	45	2.0	1.9	0.2	3.8	5.0	0.2	0.5	5.7	7.1
	Feb 15	291	48¤	2.1	1.8	0.6	4.4	5.3	0.1	0.5	5.8	7.2
	Feb 16	292	46	2.0	2.2	0.4	4.1	5.5	0.1	0.4	6.2	7.4
	Feb 17	293	43	1.9	2.3	0.4	4.7¤	4.9	0.1	0.5	6.0	7.6
	Feb 18	294	41	1.5	1.5	0.1¤	4.0	5.1	0.1	0.4	6.4	6.4
	Feb 19	295	43	2.2	2.0	0.4	4.2	5.1	0.1	0.5	6.1	6.7
	Feb 20	296	49¤	2.7¤	2.1	0.4	3.7	3.6¤	0.1	0.4	5.2	7.0
	Feb 21	297	41	1.4	1.8	0.5	4.5	4.7	0.1	0.1¤	5.3	6.4
	AVERAGE		**43**	**1.8**	**2.0**	**0.4**	**4.0**	**5.2**	**0.1**	**0.5**	**5.6**	**6.9**
19	Feb 22	298	45	2.0	1.8	0.5	4.5	5.8	0.1	0.6	6.7	6.4¤
	Feb 23	299	49	2.4	2.5	0.5	4.5	6.5	0.2	0.6	7.9	8.3
	Feb 24	300	46	1.3¤	1.5	0.5	6.0	6.7	0.1	0.1	7.0	8.9
	Feb 25	301	43	1.3¤	1.3¤	0.7	5.8	6.4	0.1	0.1	7.4	8.5
	Feb 26	302	49	2.5	2.4	0.5	5.0	7.2	0.2	0.6	6.9	8.6
	Feb 27	303	48	2.3	2.5	3.7	4.7	5.3	0.3	1.0	5.7	8.2
	Feb 28	304	52	2.2	2.6	3.8¤	5.3	4.9	0.3	0.9	5.8	8.6
	Feb 29	305	47	2.1	2.1	1.0	5.8	8.5¤	0.3	0.7	5.7	8.6
	March 1	306	46	1.8	2.1	3.1	5.6	4.7¤	0.3	0.8	5.8	8.5
	March 2	307	48	1.8	2.2	1.0	5.3	6.1	0.2	0.1	4.9	8.9
	March 3	308	48	1.5	1.7	1.2	5.8	6.1	0.3	0.1	5.0	7.8
	March 4	309	51	2.2	2.1	3.8¤	6.8¤	6.1	0.5¤	0.8	4.9	7.9
	March 5	310	47	2.2	2.1	0.9	5.6	6.4	0.2	0.6	7.6	7.6
	March 6	311	51	2.6	2.9¤	1.5	5.2	5.9	0.2	0.4	7.7	7.8
	March 7	312	38¤	2.0	2.5	1.2	5.5	5.2	0.2	0.2	7.7	7.9
	AVERAGE		**48**	**2.1**	**2.2**	**1.2**	**5.3**	**6.0**	**0.2**	**0.5**	**6.4**	**8.3**
20	March 8	313	51	2.4	2.8	0.9	5.8	5.5	0.2	0.2	7.3	7.8¤
	March 9	314	46¤	2.1	1.7	1.1	5.7	6.3	0.2	0.0	8.1	8.2
	March 10	315	50	1.7¤	2.0	0.1¤	5.5	6.0	0.1	0.1	8.5	8.7
	March 11	316	55	2.2	2.7	0.1¤	5.7	5.9	0.1	0.1	8.6	8.8
	March 12	317	52	2.5	2.5	0.1	6.0	5.7	0.1	0.1	9.5	9.7
	March 13	318	56	2.7	3.6	1.0	5.8	6.1	0.2	1.0	7.7	8.7
	March 14	319	57	3.4¤	3.1	1.1	5.5	5.0¤	0.2	1.0	7.5	8.9
	March 15	320	56	2.7	3.1	1.0	6.2	5.9	0.2	1.1	9.1	8.7
	March 16	321	54	2.7	2.5	1.1	5.6	6.1	0.2	1.0	9.4	9.0
	March 17	322	54	2.5	2.4	1.0	5.9	6.1	0.2	1.0	8.9	8.1
	March 18	323	59¤	2.4	4.6¤	0.9	6.2	6.4	0.1	0.2	8.7	8.8
	March 19	324	56	1.7¤	2.0	1.0	6.8¤	7.1¤	0.3¤	0.8	7.7	10.0¤
	March 20	325	55	2.4	2.9	1.1	6.5	6.6	0.2	1.1	9.8	9.4
	AVERAGE		**54**	**2.5**	**2.6**	**0.9**	**5.9**	**6.0**	**0.1**	**0.6**	**8.5**	**8.8**
21	March 21	326	41	2.1	2.2	0.3	4.3	4.9	0.1	0.7	5.2¤	8.2
	March 22	327	40	3.5	3.6	0.5	5.1	4.9	0.1	0.2	6.9	8.6
	March 23	328	43	2.0	2.7	0.1	4.3	5.6	0.2	0.9	6.7	8.1
	March 24	329	41	2.6	2.5	0.2	4.6	5.4	0.1	0.9	7.6	8.2
	March 25	330	43	2.7	4.6	0.5	4.3	5.4	0.1	0.2	7.9	5.6¤
	March 26	331	42	3.9¤	4.1	0.1	4.3	5.3	0.1	0.7	7.2	9.0
	March 27	332	44	3.5	8.7¤	0.6	4.8	6.0	0.1	0.1¤	7.7	9.2
	March 28	333	46	2.6	3.5	0.6	4.9	5.7	0.2	0.7	7.5	10.0¤
	March 29	334	44	2.4	2.7	0.6	5.0	5.6	0.1	0.8	7.6	8.4
	March 30	335	48¤	2.7	3.3	0.2	4.9	5.6	0.2	0.9	8.1	8.4
	March 31	336	44	2.4	2.7	0.7	4.8	5.8	0.2	0.9	8.5	8.3
	April 1	337	44	2.7	2.2	0.6	5.1	5.6	0.1	0.8	8.1	8.3
	April 2	338	38¤	2.9	3.1	0.7	4.8	4.9	0.2	0.8	7.8	8.6
	April 3	339	-	-	-	-	-	-	-	-	-	-
	AVERAGE		**43**	**2.7**	**3.1**	**0.4**	**4.7**	**5.4**	**0.1**	**0.7**	**7.6**	**8.5**
22	April 4	340	60¤	2.6	8.5	2.4	8.5	8.0¤	0.1¤	0.1¤	7.6¤	8.4¤
	April 5	341	66	3.1	13.9¤	1.9	8.2	9.4	0.4	2.5	13.5	13.8
	April 6	342	79¤	3.8¤	3.2	1.6	8.6	9.3	0.9	2.1	14.3	17.1
	April 7	343	68	2.3	2.6	1.2	8.5	9.9	0.7	2.6	16.1	17.6
	April 8	344	68	2.2	2.2	1.7	8.7	9.4	0.7	2.6	17.1	17.7
	April 9	345	68	2.2	2.0	1.5	8.5	9.6	0.5	2.6	17.4	17.9
	April 10	346	74	2.8	1.9	2.6	9.2	10.3	0.8	2.7	15.6	18.0

¤ Data rejected as outliers at 10% level of significance.

	April 11	347	74	2.3	2.4	2.6	9.1	10.5	0.8	2.7	15.7	18.6
	April 12	348	71	2.5	2.4	2.1	9.3	10.2	0.8	2.7	18.0	20.1
	AVERAGE		**70**	**2.5**	**3.2**	**2.0**	**8.7**	**9.8**	**0.7**	**2.5**	**16.0**	**17.6**
23	April 13	349	52	2.3	2.5	0.5	6.6	7.8	0.4	2.7	12.8	17.7¤
	April 14	350	53	3.0	1.7	0.6	6.9	7.8	0.4	2.2	11.5	13.1
	April 15	351	56	2.0	1.6	0.8	6.8	7.5	0.3	1.8	9.4¤	12.5
	April 16	352	59	1.9	2.2	0.9	6.8	7.5	0.5	3.3	10.5	12.7
	April 17	353	57	1.9	4.6¤	1.1	6.9	7.6	0.2¤	0.5¤	12.2	9.7¤
	April 18	354	57	1.8	3.6	0.3	6.9	7.9	0.5	3.9	12.7	14.1
	April 19	355	60	2.9	2.5	0.9	7.2	8.0	0.6	4.1	11.6	14.0
	April 20	356	61	2.4	2.4	1.0	7.2	8.4	0.6	4.7	11.0	14.4
	April 21	357	63	2.2	2.2	0.3	7.2	8.1	0.6	4.8	13.5	14.8
	April 22	358	62	2.9	2.6	0.3	7.2	8.3	0.5	5.5	13.3	16.0
	April 23	359	54	2.0	2.4	0.8	5.9¤	8.2	0.9	7.7¤	13.7	11.7
	April 24	360	56	1.8	1.9	0.9	6.5	8.5	0.8	7.9¤	14.0	16.7
	AVERAGE		**57**	**2.3**	**2.3**	**0.7**	**6.9**	**8.0**	**0.5**	**3.6**	**12.4**	**14.0**
24	April 25	361	51	2.5	3.1¤	0.7	5.1	8.2¤	0.3	3.3¤	10.1	15.9¤
	April 26	362	51	1.7	1.9	0.7	5.3	7.9¤	0.2	1.0	9.0	10.7
	April 27	363	49	1.5	2.0	0.8	5.4	6.6	0.2	1.1	9.4	9.5
	April 28	364	46	2.2	2.4	0.6	5.1	6.3	0.2	0.9	8.1	8.8
	April 29	365	47	2.3	2.0	0.6	5.4	6.3	0.2	0.9	7.5	8.8
	April 30	366	49	2.4	2.0	0.6	5.4	6.2	0.2	0.9	7.1¤	8.6
	May 1	367	48	2.0	2.2	0.7	5.9	6.8	0.2	0.2	9.1	10.1
	May 2	368	54	1.8	2.2	0.7	6.0	6.8	0.2	0.9	8.2	9.4
	May 3	369	54	2.5	1.7	0.6	5.9	6.7	0.2	0.9	8.6	10.3
	May 4	370	53	1.6	2.2	0.6	6.0	6.8	0.2	0.8	9.3	9.9
	May 5	371	53	2.6	2.6	0.4¤	6.2	6.3	0.5¤	0.5	8.2	9.4
	May 6	372	55	1.4	1.8	1.2¤	5.1	6.1	0.3	1.4	7.9	8.1
	May 7	373	49	1.5	1.6	0.7	5.1	5.7	0.2	1.3	9.5	9.4
	AVERAGE		**51**	**2.0**	**2.0**	**0.6**	**5.5**	**6.4**	**0.2**	**0.9**	**8.7**	**9.4**
25	May 8	374	74¤	2.2	2.0	0.7	6.4	6.7	0.1	0.5	7.5	10.0
	May 9	375	65	2.0	2.9¤	0.1¤	6.4	6.9	0.1	0.8	10.3¤	9.3
	May 10	376	63	2.7¤	2.9¤	0.7	5.1	7.4	0.1	1.0	11.3¤	11.7¤
	May 11	377	48	3.0¤	2.2	0.5	4.9	6.6	0.1	0.7	8.2	8.9
	May 12	378	47	2.1	2.2	0.5	5.1	5.7	0.2	1.0	8.9	8.6¤
	May 13	379	48	2.1	2.2	0.5	4.9	5.7	0.1	0.9	8.6	9.4
	May 14	380	49	1.8¤	1.8	0.9	5.9	6.3	0.3	1.2	8.6	10.4
	May 15	381	42	2.2	2.0	0.2¤	6.1	6.1	0.2	0.1	8.8	10.1
	May 16	382	51	2.4	2.6	0.6	5.8	6.8	0.1	0.8	8.2	10.2
	May 17	383	49	2.0	2.2	0.7	5.2	6.4	0.2	1.0	8.0	9.8
	May 18	384	51	2.2	2.5	0.7	5.8	6.4	0.2	1.2	8.9	10.2
	May 19	385	52	2.2	2.4	1.0	5.8	6.6	0.2	0.9	7.9	10.2
	May 20	386	48	2.2	2.4	0.9	5.6	6.7	0.2	0.9	7.3	9.6
	AVERAGE		**51**	**2.2**	**2.2**	**0.7**	**5.6**	**6.5**	**0.2**	**0.9**	**8.3**	**9.8**
26	May 21	387	62	1.8¤	1.7	1.6	7.5	8.0¤	0.3¤	0.6¤	10.3¤	10.0¤
	May 22	388	58	2.3	1.7	1.0	6.5	9.5	0.6	4.7	11.6	14.3
	May 23	389	59	2.4	2.7	1.8	7.2	8.4	0.7	5.5	13.7	14.6
	May 24	390	59	2.4	3.6¤	4.2	8.2	11.4	0.8	6.1	13.6	15.0
	May 25	391	59	2.3	2.8	4.4	9.0	11.8	0.7	5.5	12.6	16.0
	May 26	392	60	2.5	2.2	2.5	8.1	10.6	0.7	5.9	16.0	16.3
	May 27	393	61	2.4	2.3	3.9	8.3	10.3	0.8	7.2	16.7	16.3
	May 28	394	61	2.2	2.1	4.5	8.6	10.5	0.8	6.0	16.5	18.3
	May 29	395	61	2.3	2.5	5.0	9.8	10.7	0.6	7.1	16.5	17.6
	May 30	396	56¤	2.3	2.8	5.9	10.0	10.7	0.8	1.6	16.5	17.5
	May 31	397	56	2.6¤	3.2	1.1	12.7¤	12.8¤	0.3¤	1.1	16.7	16.8
	AVERAGE		**60**	**2.3**	**2.4**	**3.2**	**8.3**	**10.4**	**0.7**	**5.1**	**15.0**	**16.3**
27	June 1	398	42	2.2	3.1¤	0.7	4.7	8.5	0.2	1.1	6.9	13.5¤
	June 2	399	39	2.3	2.4	0.7	4.7	5.4	0.2	1.3	6.6	7.7
	June 3	400	38¤	2.3	2.0	0.7	4.7	6.0	0.2	0.9	6.5	7.9
	June 4	401	40	2.1	2.3	0.7	4.4	5.4	0.2	0.9	6.1	8.2
	June 5	402	43	2.3	2.3	0.8	4.5	5.2	0.2	0.9	6.1	7.7
	June 6	403	43	1.5¤	1.8¤	0.7	10.6¤	15.5¤	0.2	0.8	6.2	7.7
	June 7	404	41	1.8	2.4	0.5	4.4	5.2	0.2	0.8	6.2	7.5

¤ Data rejected as outliers at 10% level of significance.

27	June 8	405	43	2.1	2.0	0.2□	4.7	5.1	0.2	0.8	6.9	7.1
	June 9	406	45	2.4	2.3	0.6	4.5	5.4	0.2	0.8	7.0	7.5
	June 10	407	41	2.2	2.3	0.5	3.9	4.7	0.2	0.8	7.1	6.9
	June 11	408	41	2.4	2.5	0.3□	4.5	5.4	0.2	1.0	7.2	7.8
	June 12	409	44	2.0	2.2	1.1□	10.9□	7.8	0.2	2.2□	6.5	8.2
	June 13	410	43	2.3	2.7	0.7	4.5	5.4	0.3□	1.0	7.3	8.1
	AVERAGE		**42**	**2.2**	**2.3**	**0.7**	**4.5**	**5.8**	**0.2**	**0.9**	**6.7**	**7.7**
28	June 14	411	51	2.2	2.7	0.6	5.0	6.1	0.2□	1.0□	9.5	8.9
	June 15	412	48	2.2	2.5	2.0□	6.4□	6.1	0.6	3.9	9.4	10.4
	June 16	413	46	2.2	2.5	0.6	5.6	6.1	0.5	2.9	10.5	11.7
	June 17	414	47	2.4	2.6	0.9	5.6	7.0	0.6	4.1	12.5	12.0
	June 18	415	50	2.0	2.4	0.6	5.4	6.6	0.5	2.5	11.3	12.8
	June 19	416	53□	2.3	2.7	0.9	5.5	6.5	0.6	2.8	12.3	11.8
	June 20	417	45	2.3	2.7	0.4	4.8	5.6	0.7	3.3	10.5	20.5□
	June 21	418	48	2.4	3.1□	0.9	4.8	5.6	0.4	2.7	10.9	10.2
	June 22	419	47	2.9	2.9	0.6	5.0	5.6	0.6	3.7	10.3	10.5
	June 23	420	-	-	-	-	-	-	-	-	-	-
	June 24	421	47	2.0	2.0□	0.8	5.0	6.6	0.5	3.8	11.0	10.4
	June 25	422	48	3.2□	2.4	0.4	4.8	5.9	0.3	2.5	9.4	12.2
	June 26	423	49	2.0	2.2	1.3	5.9	7.9□	0.9□	4.2	9.8	10.8
	June 27	424	47	3.4□	3.0	0.9	5.3	7.2	0.6	5.5□	13□	10.8
	AVERAGE		**48**	**2.3**	**2.6**	**0.7**	**5.2**	**6.2**	**0.5**	**3.3**	**10.6**	**11.0**
29	June 28	425	53	1.8	2.9	1.3	6.6	7.5	0.4	4.2	11.0	13.2
	June 29	426	52	2.2	2.5	1.1	5.8	7.5	0.3	2.5□	10.3□	11.1
	June 30	427	52	2.3	2.5	1.0	6.3	7.9	0.5	3.4	12.6	12.4
	July 1	428	41□	2.2	2.5	1.0	5.4□	5.8	0.3	3.5	12.8	13.5
	July 2	429	60□	2.6	2.2	0.3	6.7	5.5□	0.3	3.9	13.1	14.6
	July 3	430	62□	4.4□	1.9□	0.9	7.4□	8.5□	0.5	3.7	13.7	14.6
	July 4	431	54	2.3	3.2□	1.4□	6.4	6.4	0.6	5.1	14.1	15.6
	July 5	432	57	1.5□	2.9	0.8	6.4	6.8	0.5	4.8	14.0	15.4
	July 6	433	53	2.2	2.2	0.6	6.1	6.5	0.5	5.2	13.5	15.2
	July 7	434	53	2.3	2.5	0.4	6.8	7.2	0.6	6.1□	13.9	15.3
	July 8	435	50	2.2	2.3	0.9	7.0	8.3	0.6	5.4	14.2	15.1
	July 9	436	51	2.3	2.9	0.3	6.2	7.7	0.5	4.2	13.2	15.0
	July 10	437	51	2.7	3.1	0.9	6.4	7.1	0.3	2.3□	10.7	12.7
	July 11	438	52	2.2	2.5	0.5	6.2	7.1	0.4	3.9	11.2	11.1
	July 12	439	51	2.1	2.4	0.9	6.2	7.3	0.4	4.2	11.3	12.6
	AVERAGE		**52**	**2.3**	**2.6**	**0.8**	**6.4**	**7.2**	**0.4**	**4.3**	**12.8**	**13.8**
30	July 13	440	66	2.9	2.4	4.7□	10.6	8.5	0.8	7.7	16.7	15.4
	July 14	441	67	1.8	2.1	5.1□	11.5□	13.1	1.0	9.7	20.4	19.5
	July 15	442	65	3.2□	2.1	4.1	10.3	13.1	1.1	9.9	22.6	22.6
	July 16	443	59	2.9	2.2	2.4	9.0	11.8	1.2	8.9	19.4	20.8
	July 17	444	63	2.2	2.5	2.0	9.6	18.8□	0.9	8.3	17.7	20.0
	July 18	445	-	-	-	-	-	-	-	-	-	-
	July 19	446	61	2.6	2.2	1.0	8.1	9.0	1.3	4.7	16.7	18.7
	July 20	447	59	2.0	2.3	1.7	10.4	9.8	1.0	8.0	17.9	20.1
	July 21	448	59	2.4	2.4	2.2	9.1	9.0	0.6	0.3□	10.3□	12.3□
	July 22	449	51□	2.5	3.2□	1.1	7.0	9.4	0.8	7.8	17.3	19.3
	July 23	450	64	2.4	2.7	1.4	7.7	9.4	0.9	8.6	18.7	19.2
	July 24	451	62	1.6□	1.6□	2.6	8.1	9.4	1.7□	12.5□	24.0□	24.2
	July 25	452	57	2.0	2.2	2.6	8.6	8.8	0.9	9.9	21.8	25.0□
	AVERAGE		**62**	**2.4**	**2.3**	**2.1**	**9.0**	**10.1**	**0.9**	**8.3**	**18.9**	**20.0**
31	July 26	453	59	2.5	2.2	4.6	11.4	12.0□	1.4	10.5	22.0	24.0
	July 27	454	59	2.2	2.5	8.5	15.6	14.5	1.2	11.5	22.4	21.2
	July 28	455	50□	2.0	2.2	10.1	18.8	17.5	1.4	13.6	25.0	25.6
	July 29	456	60	2.7	2.7	13.0	18.8	19.8	1.3	16.0	27.4□	26.6
	July 30	457	65□	3.2□	2.8	14.5□	19.6□	21.8	1.6	17.2□	27.2□	27.2
	July 31	458	62	1.7	1.8	13.2	17.6	23.4□	1.8□	11.7	24.2	26.6
	Aug 1	459	57	2.1	2.1	9.6	13.4	19.6	1.2	10.3	23.2	28.2
	Aug 2	460	56	2.1	1.8	7.4	13.8	18.6	1.2	10.2	22.2	28.0
	Aug 3	461	57	2.2	2.2	6.9	13.8	15.6	1.2	9.8	20.4	22.4
	Aug 4	462	64	3.2□	2.5	9.3	15.6	16.4	1.2	10.7	21.4	23.0
	Aug 5	463	57	2.3	2.2	6.8	14.4	17.6	1.3	11.7	23.0	22.6

□ Data rejected as outliers at 10% level of significance.

	Aug 6	464	-	-	-	-	-	-	-	-	-	-
	AVERAGE		59	2.2	2.3	8.9	15.3	17.9	1.3	11.6	22.6	25.0
32	Aug 7	465	58	2.4	2.5	6.4¤	9.6¤	13.8¤	1.1¤	8.2¤	21.0¤	21.6¤
	Aug 8	466	58	2.0	2.0	3.1	7.4	8.9	0.9	5.7	15.1	16.8
	Aug 9	467	57	2.1	2.2	0.8	8.9	8.4	0.7	4.5	13.1	15.7
	Aug 10	468	58	2.1	2.3	1.1	7.2	8.1	0.4	3.1	13.1	14.9
	Aug 11	469	58	2.3	2.5	2.1	7.8	8.5	0.5	4.1	11.7	14.9
	Aug 12	470	64¤	2.8¤	2.1	0.5	7.4	8.1	0.7	4.8	13.9	15.2
	Aug 13	471	56	2.0	2.2	1.3	7.0	8.3	0.5	3.8	12.2	14.2
	Aug 14	472	59	2.1	2.1	0.8	6.3	8.6	0.4	2.9	11.5	13.0
	Aug 15	473	61	2.3	2.0	0.4	4.2¤	7.8	0.5	2.9	11.6	12.0¤
	Aug 16	474	63¤	2.4	2.8	1.7	8.7	10.3	1.0¤	5.5	14.0	13.7
	Aug 17	475	60	2.5	2.0	1.0	8.6	10.1	0.5	4.2	13.8	15.4
	Aug 18	476	59	2.0	2.6	1.2	8.1	9.5	0.4	3.9	13.0	15.1
	Aug 19	477	57	2.2	2.7	0.3	7.7	9.8	0.4	2.6	11.3	14.4
	AVERAGE		58	2.2	2.3	1.2	7.7	8.9	0.5	4.0	12.9	14.8
33	Aug 20	478	61	2.3	1.8	1.7¤	10.2	10.0	0.8	7.6	17.4	15.4¤
	Aug 21	479	64	2.1	3.1	1.7¤	9.0	10.5	1.0	8.3	18.5	19.3
	Aug 22	480	60	1.8	2.4	6.3	12.1	8.9	1.1	8.8	18.9	20.9
	Aug 23	481	64	3.1	2.8	5.6	11.5	8.3	1.2	8.8	18.4	21.5
	Aug 24	482	68	2.7	2.2	6.6	10.1	13.8	0.5	7.6	18.5	23.0
	Aug 25	483	79¤	3.4	3.1	9.7¤	18.0	18.6	1.0	7.7	19.7	22.9
	Aug 26	484	69	3.3	2.5	6.7	19.0¤	19.6	0.4	8.0	21.2	24.0
	Aug 27	485	68	2.3	2.0	7.0	14.9	17.5	0.4	7.5	21.0	24.2
	Aug 28	486	63	2.1	2.2	7.4	15.1	15.2	0.3	7.7	19.1	24.2
	Aug 29	487	64	3.2	2.0	7.5	14.8	14.3	0.4	6.5	18.8	23.1
	Aug 30	488	67	2.2	2.9	8.0	12.9	13.6	0.3	4.6¤	20.8	24.4
	Aug 31	489	-	-	-	-	-	-	-	-	-	-
	Sept 1	490	-	-	-	-	-	-	-	-	-	-
	AVERAGE		65	2.6	2.5	6.9	12.9	13.7	0.7	7.8	19.3	22.8
34	Sept 2	491	47	2.0	2.1	0.9¤	4.9	4.6¤	0.3	0.5	5.0¤	8.9
	Sept 3	492	45	2.0	2.3	0.6	5.0	5.1	0.1	0.6	7.0	7.9
	Sept 4	493	46	1.6	1.6	0.7	5.6	5.5	0.1	0.6	9.2¤	8.2
	Sept 5	494	45	9.1¤	1.7	0.3	5.6	5.5	0.2	0.4	8.0	8.3
	Sept 6	495	42¤	3.1	2.5	0.4	5.0	6.2¤	0.2	0.5	8.0	8.2
	Sept 7	496	44	2.1	1.8	0.4	5.1	4.9	0.3	0.6	8.0	8.7
	Sept 8	497	47	1.8	1.8	0.4	5.5	5.2	0.1	0.6	8.0	9.3
	Sept 9	498	46	2.5	2.9	0.4	5.6	5.2	0.3	0.8¤	8.2	8.6
	Sept 10	499	46	2.2	2.4	0.5	4.4	5.2	0.2	0.5	6.9	7.8
	Sept 11	500	45	2.1	2.7	0.3	4.4	5.4	0.4¤	0.3¤	7.1	15.3¤
	Sept 12	501	46	2.1	2.9	0.5	5.7	6.0	0.1	0.6	7.9	10.6
	AVERAGE		46	2.1	2.2	0.5	5.2	5.3	0.2	0.6	7.7	8.7
35	Sept 13	502	44¤	1.6¤	2.2	0.3	5.1¤	6.4	0.2	0.5	8.0	7.8
	Sept 14	503	54	2.0	2.3	0.4	5.7	7.3	0.2	0.6	9.1	8.9
	Sept 15	504	55	2.1	1.8¤	0.3	5.8	6.8	0.2	0.5	9.6	9.5
	Sept 16	505	55	2.2	1.8¤	0.3	6.7	9.3	0.2	1.1	9.8	9.8
	Sept 17	506	53	2.6	2.2	0.3	7.7	6.5	0.1	0.2	5.1¤	9.6
	Sept 18	507	51	2.1	2.2	1.3	6.4	6.6	0.4	1.2	6.5	7.8
	Sept 19	508	54	2.2	2.1	0.3	7.2	7.8	0.2	1.1	10.1	12.7
	Sept 20	509	51	2.0	2.4	0.3	8.0	7.2	0.2	0.8	11.9	12.6
	Sept 21	510	55	2.2	2.2	0.7	7.6	10.4	0.2	0.9	10.9	11.7
	Sept 22	511	54	1.8	2.4	0.6	6.8	14.0¤	0.4¤	0.8	10.1	11.9
	Sept 23	512	54	2.5¤	2.5¤	2.3¤	6.2	7.3	0.3	1.4	11.0	12.2
	Sept 24	513	46¤	2.1	2.5	1.1	6.4	5.6	0.4	1.5	6.1	9.0
	Sept 25	514	-	-	-	-	-	-	-	-	-	-
	AVERAGE		54	2.1	2.3	0.5	6.8	7.4	0.2	0.9	9.4	10.3
36	Sept 26	515	47	2.9	2.8	0.3	6.5	9.3	0.4¤	1.4¤	10.5¤	8.7
	Sept 27	516	46	3.1	2.9	0.4	6.6	10.1¤	0.1	0.4	8.9	9.4¤
	Sept 28	517	41	1.2¤	1.4¤	0.3	5.0	4.8	0.2	0.3	6.7	8.7
	Sept 29	518	-	-	-	-	-	-	-	-	-	-
	Sept 30	519	40	2.1	2.2	0.4	5.0	4.8	0.3	0.5	9.1	8.5
	Oct 1	520	40	2.0	3.0	0.4	6.4	6.5	0.1	0.6	7.0	7.7
	Oct 2	521	38	2.9	2.5	0.1	5.4	5.3	0.1	0.4	6.9	7.4

¤ Data rejected as outliers at 10% level of significance.

	Oct 3	522	-	-	-	-	-	-	-	-	-	-
	Oct 4	523	43	2.0	2.2	0.3	5.2	5.5	0.2	0.2	7.7	8.5
	Oct 5	524	46	2.6	3.2	0.2	5.4	5.1	0.1	0.3	7.7	8.0
	Oct 6	525	-	-	-	-	-	-	-	-	-	-
	Oct 7	526	50	3.4	3.7¤	0.1	5.0	5.1	0.1	0.7	8.8	7.7
	AVERAGE		**43**	**2.6**	**2.7**	**0.3**	**5.6**	**5.8**	**0.2**	**0.4**	**7.9**	**8.2**
37	Oct 8	527	55	2.7	3.7	0.3	7.8	7.1	0.2	1.1	12.6	9.4¤
	Oct 9	528	-	-	-	-	-	-	-	-	-	-
	Oct 10	529	58	3.0	2.7	1.1	7.8	10.2¤	0.2	1.5	12.9	13.0
	Oct 11	530	-	-	-	-	-	-	-	-	-	-
	Oct 12	531	52¤	2.7	2.8	0.4	7.0	8.4	0.3	1.7	9.3	11.1
	Oct 13	532	-	-	-	-	-	-	-	-	-	-
	Oct 14	533	67	2.5	2.3	1.2	6.9	8.2	0.4	2.3	10.1	12.7
	Oct 15	534	63	3.1	3.4	0.3	6.6	7.9	0.4	1.9	10.3	12.3
	Oct 16	535	65	2.6	2.9	0.9	5.9	7.2	0.4	1.5	9.6	12.0
	Oct 17	536	63	3.5¤	3.5	0.7	6.1	7.4	0.3	1.3	10.0	12.7
	Oct 18	537	61	2.6	2.7	0.3	6.2	7.5	0.4	1.3	10.9	12.4
	Oct 19	538	65	2.0¤	2.6	0.5	6.8	7.4	0.2	2.3	12.2	11.0
	Oct 20	539	-	-	-	-	-	-	-	-	-	-
	Oct 21	540	-	-	-	-	-	-	-	-	-	-
	AVERAGE		**62**	**2.7**	**2.9**	**0.6**	**6.8**	**7.6**	**0.3**	**1.7**	**10.9**	**12.2**
38	Oct 22	541	42¤	2.4	2.1	0.2	5.4	5.2	0.1	0.2	6.0	6.5
	Oct 23	542	-	-	-	-	-	-	-	-	-	-
	Oct 24	543	36	2.1	2.2	0.2	5.5	5.2	0.1	0.1¤	6.4	6.9
	Oct 25	544	38	2.8	2.4	0.2	6.1	5.9	0.1	0.2	7.2¤	7.5¤
	Oct 26	545	36	2.7	2.7	0.3	5.9	6.1	0.1	0.2	6.1	6.4
	Oct 27	546	-	-	-	-	-	-	-	-	-	-
	Oct 28	547	39	4.2¤	3.3	0.3	6.2	5.9	0.1	0.2	6.6	6.4
	Oct 29	548	-	-	-	-	-	-	-	-	-	-
	AVERAGE		**37**	**2.5**	**2.5**	**0.2**	**5.8**	**5.7**	**0.1**	**0.2**	**6.3**	**6.6**
39	Oct 30	549	47	2.8	2.5	0.4	6.6	5.6	0.1	0.2	9.3	8.2¤
	Oct 31	550	53	1.8¤	2.4	0.2	7.4	7.4	0.1	0.3	10.9	11.5
	Nov 1	551	48	2.9	3.9	0.2	5.2	5.9	0.1	0.8¤	9.4	10.6
	Nov 2	552	58	2.4	2.4	0.2	6.7	7.0	0.5¤	0.4	9.6	11.3
	Nov 3	553	-	-	-	-	-	-	-	-	-	-
	Nov 4	554	57	3.5¤	20.1¤	0.7¤	6.2	7.2	0.1	0.1	9.5	11.2
	Nov 5	555	54	2.8	6.9	0.2	6.2	7.2	0.1	0.3	10.4	14.6¤
	Nov 6	556	54	2.5	2.2	0.4	6.0	6.7	0.1	0.2	9.2	9.4
	Nov 7	557	52	2.5	2.3	0.3	6.5	6.5	0.2	0.2	10.7	10.0
	Nov 8	558	50	2.2	2.0	0.1	5.1¤	5.2¤	0.3	0.3	9.6	10.0
	Nov 9	559	46	2.3	2.0	0.1	6.1	6.8	0.1	0.6	11.4	12.3
	Nov 10	560	-	-	-	-	-	-	-	-	-	-
	Nov 11	561	52	2.5	2.0	0.1	7.5¤	6.7	0.1	0.3	11.2	13.1
	AVERAGE		**52**	**2.5**	**2.9**	**0.2**	**6.3**	**6.7**	**0.1**	**0.3**	**10.1**	**11.0**
40	Nov 12	562	56	2.7	2.7	0.2	7.1	6.8	0.1	0.4	12.7	11.0¤
	Nov 13	563	-	-	-	-	-	-	-	-	-	-
	Nov 14	564	56	2.5	2.8	0.4	7.3	7.7	0.1	0.7	12.5¤	12.5
	Nov 15	565	63¤	2.5	2.9	0.1	7.8	7.8	0.0	0.3	13.1	13.9
	Nov 16	566	50	2.7	2.5	0.3	7.3	7.9	0.0	0.4	13.2	14.7
	Nov 17	567	50	2.2	1.9	0.5	7.7	8.0	0.1	0.4	13.6	14.6
	Nov 18	568	-	-	-	-	-	-	-	-	-	-
	Nov 19	569	49	1.2¤	1.5	0.5	7.3	8.3	0.3	1.9¤	13.5	14.2
	Nov 20	570	50	1.8	1.3¤	1.2	6.5	7.9	0.3	0.4	13.1	14.7
	Nov 21	571	53	2.3	2.3	1.0	9.2	8.5¤	0.5	0.6	13.4	17.0¤
	Nov 22	572	60	2.4	2.2	0.7	8.2	7.6	0.5	0.5	13.7	14.2
	Nov 23	573	50	3.5¤	3.2	1.7¤	11.9¤	7.2	0.7	0.6	13.7	13.4
	Nov 24	574	-	-	-	-	-	-	-	-	-	-
	Nov 25	575	-	-	-	-	-	-	-	-	-	-
	AVERAGE		**52**	**2.4**	**2.4**	**0.5**	**7.6**	**7.7**	**0.3**	**0.5**	**13.3**	**14.0**
41	Nov 26	576	55	3.1	2.3	1.6¤	7.7	7.2	0.2	0.4	13.3	10.9¤
	Nov 27	577	53	2.5	2.2	1.1	8.5	8.0	0.3	0.5	13.5	13.6
	Nov 28	578	55	11.2¤	3.3	0.8¤	6.8¤	6.2¤	0.5	0.6¤	12.1¤	13.1
	Nov 29	579	-	-	-	-	-	-	-	-	-	-

¤ Data rejected as outliers at 10% level of significance.

	Nov 30	580	59	2.9	3.1	1.2	8.3	7.9	0.5	0.5	13.7	13.0
	Dec 1	581	-	-	-	-	-	-	-	-	-	-
	Dec 2	582	59	2.6	14.9¤	1.2	8.5	8.3	0.3	0.5	14.3	14.5
	AVERAGE		**56**	**2.8**	**2.7**	**1.2**	**8.3**	**7.9**	**0.4**	**0.5**	**13.7**	**13.6**

¤ Data rejected as outliers at 10% level of significance.

APPENDIX A

Daily measured total phosphorus concentrations in influent, filtered mixed liquor in each reactor and filtered effluents of the MLE and UCT systems at 30 C.

BATCH OF SEWAGE	*YEAR* MONTH / DAY	DAY NO		MLE SYSTEM			UCT SYSTEM			
			INFLUENT [mgP/*l*]	ANOXIC [mgP/*l*]	AEROB [mgP/*l*]	EFFLUENT [mgP/*l*]	ANAERO [mgP/*l*]	ANOXIC [mgP/*l*]	AEROB [mgP/*l*]	EFFLUENT [mgP/*l*]
1	*1995*									
	May 1	1	17,1¤	10,6¤	11,3¤	9.8	18.2	11,7¤	4.0	5,5¤
	May 2	2	16.3	9.6	11,0¤	9.6	17.8	8.9	4.3	5.0
	May 3	3	16.0	9.6	10.3	10,7¤	18.1	8.9	6,6¤	5,3¤
	May 4	4	13.6	9.0	8.0	9.0	17.4	9.0	3.5	3.5
	May 5	5	13.6	8.3	8.0	9.0	18.1	8.7	3.1	3.1
	May 6	6	13.9	8.0	8.3	8.7	18.8	9.4	2.8	3.1
	May 7	7	13.6	9.4	9.0	8.3	19.8	8.7	2.8	2.4
	May 8	8	14.7	7,3¤	8.8	8.4	22,4¤	9.2	5.1	2.2
	May 9	9	14.7	8.8	9.5	8.8	21.3	8.1	2.9	2.6
	May 10	10	15.0	8.4	8.4	8.1	20.9	8.1	2.2	2.9
	May 11	11	15.4	9.2	8.8	9.5	20.9	8.1	2.2	2.9
	May 12	12	14.3	9.1	9.1	7.7	19.9	9.8	3.5	2.4
	May 13	13	12.9	8.7	8.0	8.0	20.3	10,8¤	3.5	2.1
	May 14	14	12.9	9.1	8.4	8.0	19.2	8.0	3.5	1.7
	May 15	15	14.0	9.1	8.7	8.4	15.7	8.7	2.4	2.4
	May 16	16	11.9	9.0	8.6	7.9	16.5	7.9	4.7	4.0
	May 17	17	12.6	10,8¤	9.0	8.6	20.8	9.3	5.0	5,4¤
	May 18	18	11,4¤	8.3	8.3	8.3	14,4¤	7,2¤	3.6	3.2
	May 19	19	12.6	9.0	9.0	8.3	16.9	8.6	4.3	2.5
	AVERAGE		**14.0**	**8.9**	**8.7**	**8.6**	**18.9**	**8.7**	**3.5**	**2.9**
2	May 20	20	19.6	10.5	10.1	10.5	27.3	15,0¤	7.7	8.4
	May 21	21	19.6	13.6	13,3¤	14,3¤	26.2	14,7¤	8.7	9,8¤
	May 22	22	18.2	11.2	10.5	10.5	21.3	9.4	4.9	4.2
	May 23	23	13.3	10.5	8.4	7.3	17,1¤	7.0	3.5	3.5
	May 24	24	12.6	9.8	7.0	6.3	17.5	9.8	4.2	4.2
	May 25	25	12.3	10.0	8.1	6.9	20.0	4,6¤	3.1	3.1
	May 26	26	11.6	8.5	6.9	6.9	18.9	4,6¤	3.1	3.1
	May 27	27	11.2	9.2	9.2	8.1	22.4	9.6	1,9¤	1.9
	May 28	28	11.9	13.5	10.4	8.5	22.7	10.0	1,9¤	1.9
	May 29	29	18.4	12.6	11.6	12.6	28.3	13.0	6.5	5.5
	May 30	30	18.4	12.3	11.9	11.3	26.6	13.0	7.2	5.8
	May 31	31	18.4	12.3	13.0	11.6	26.6	13.3	7.8	6.8
	June 1	32	14.5	9.8	8.3	8.3	23.2	10.9	5.4	4.3
	June 2	33	16.3	10.9	9.4	8.3	23.9	11.6	6.9	5.8
	June 3	34	17.4	10.1	8.7	9.4	22.5	10.9	7.2	7.2
	June 4	35	15.9	9.8	8.0	9.4	21.0	10.9	8.7	7.2
	June 5	36	17.0	11.6	9.8	8.7	21.7	12.0	6.2	6.9
	June 6	37	17.5	14,0¤	12.6	10.2	18.9	10.5	7.0	7.0
	June 7	38	16.8	12.6	11.6	11.2	20.3	9.1	5.3	6.0
	June 8	39	16.8	9.8	9.8	9.5	21.0	9.5	5.3	4.2
	AVERAGE		**15.9**	**11.0**	**9.8**	**9.2**	**22.7**	**10.6**	**6.0**	**5.1**
3	June 9	40	16.1	10.2	10.2	8.8	20,0¤	8.4	3.9	3.2
	June 10	41	16.9	10.1	9.4	8.4	21.6	10.1	2.4	2.7
	June 11	42	16.5	10.5	9.4	10.1	20,0¤	7.8	4.4	4.0
	June 12	43	15.5	10.8	10.1	10.5	22.9	9.4	4.7	4.7
	June 13	44	15.8	11.1	10.1	10.8	21.9	10.8	6.1	3.7
	June 14	45	14.2	10.5	10.1	10.1	22.9	10.1	4.0	3.4
	June 15	46	14.8	10.7	9.3	9.3	23.0	10.0	4.4	3.0
	June 16	47	15.2	10.4	9.6	9.3	23.7	13.0	7.8	5,6¤
	June 17	48	14.8	10.4	10.0	9.6	24.1	10.0	3.7	4.8
	June 18	49	15.2	10.7	8.5	7.8	24.8	9.6	4.1	3.7
	June 19	50	15.9	12.2	9.3	9.3	25.6	11.1	3.7	4.1

¤ Data rejected at 95% confidence interval.

	June 20	51	17.0	16.7	15.2	14.4	25.9	11.1	3.7	3.3
	June 21	52	16.2	7.4	6.6	6.3	24.7	9.2	3.7	3.7
	June 22	53	16.2	15.5	6.6	6.3	25.4	10.3	2.9	3.3
	June 23	54	17.7	11.4	7.7	5.5	25.8	9.9	4.0	4.0
	June 24	55	18,8¤	17.3	11.5	15,2¤	24.5	17,3¤	6.5	5.4
	June 25	56	17.3	25,3¤	25,3¤	16,6¤	26.0	17,3¤	7.2	2.9
	June 26	57	16.2	15.2	15.5	13.7	28,1¤	9.4	7.6	3.2
	June 27	58	19,8¤	17.0	14.1	13.0	29,9¤	12.3	9.4	5.4
	June 28	59	14,1¤	6.7	5.9	5.6	23.0	11.1	4.4	5.2
	AVERAGE		**16.0**	**11.8**	**10.0**	**9.4**	**24.1**	**10.2**	**4.9**	**3.9**
4	June 29	60	14.1	7.8	6.3	6.3	24.1	11.1	4.8	4.1
	June 30	61	14.1	12.2	11.1	12.2	23.7	11.1	4.8	4.4
	July 1	62	14.5	6.9	5.9	5.2	22.2	10.7	4.8	4.8
	July 2	63	13.5	9.7	8.3	6.6	22.2	11.1	5.5	5.2
	July 3	64	13.5	9.0	8.7	8.0	21.5	10.4	4.5	5.2
	July 4	65	15.2	16.3	16.3	13.5	20.8	9.0	4.2	3.5
	July 5	66	15.9	5.1	4.3	5.4	21.7	8.3	2.5	2.5
	July 6	67	15.9	6.9	6.9	4.3	22.4	8.7	1,8¤	2.2
	July 7	68	15.9	12.3	9.4	6.5	22.7	8.3	2.2	1.8
	July 8	69	-	-	-	-	-	-	-	-
	July 9	70	14.7	9.1	6.7	7.7	27,7¤	12.6	6.3	2.8
	July 10	71	15.4	14.7	14.0	12.6	30,1¤	14,4¤	7.0	3.9
	July 11	72	-	-	-	-	-	-	-	-
	July 12	73	15.1	14.4	10.9	8.1	27.3	13.7	7.7	6.0
	July 13	74	13.7	20,3¤	17,5¤	12.3	22.1	14,4¤	8.8	6.3
	July 14	75	12.3	9.8	7.0	8.8	23.1	14,4¤	11,2¤	7.4
	July 15	76	14.4	7.0	7.7	4.2	24.5	10.2	9,1¤	6.0
	July 16	77	15.8	8.1	7.0	9.5	24.2	7,0¤	6.0	4.9
	July 17	78	13.6	9.2	8.3	8.9	19.3	7.4	5.0	5.0
	July 18	79	19,6¤	13.9	14.5	12.7	21.9	10.7	5.3	2.4
	July 19	80	19,9¤	14.5	13.6	11.9	24.3	10.4	5.0	1.5
	July 20	81	20,2¤	14.8	14.8	11.9	25.2	10.7	6.2	3.9
	July 21	82	21,0¤	14.8	14.2	12.7	15,7¤	7.4	3.9	2.7
	AVERAGE		**14.6**	**10.8**	**9.8**	**9.0**	**22.9**	**10.1**	**5.3**	**4.1**
5	July 22	83	18.3	14.8	12.1	10,8¤	17.9	11.4	8.4	7.1
	July 23	84	21.0	17.0	13.3	11,1¤	24.4	14.8	9.6	7.4
	July 24	85	18.6	15.8	13.3	11.8	23.5	14.2	8.4	9.3
	July 25	86	-	-	-	-	-	-	-	-
	July 26	87	-	-	-	-	-	-	-	-
	July 27	88	-	-	-	-	-	-	-	-
	July 28	89	21.3	17.0	13.9	12.7	20.4	14.2	9.3	9.6
	July 29	90	22.3	16.1	15.5	12.4	21.3	15.5	8.7	10.8
	July 30	91	21.0	15.5	14.8	12.4	21.3	14.2	8.7	10.8
	July 31	92	23,9¤	18.4	16,4¤	13,7¤	23.6	16.7	10,2¤	12,0¤
	Aug 1	93	18.1	12.6	13.3	12.3	20.8	10.9	7.9	7.2
	Aug 2	94	18.4	12.6	12.6	12.3	16.4	9.9	7,5¤	7.5
	Aug 3	95	18.4	12.6	12.3	12.6	17.8	10.9	8.9	8.2
	Aug 4	96	18.1	12.3	12.3	12.3	16.7	9.9	9.2	8.5
	AVERAGE		**19.6**	**15.0**	**13.3**	**12.3**	**20.4**	**13.0**	**8.8**	**8.6**
6	Aug 5	97	15.4	11.3	10,9¤	12,0¤	19.1	9.9	8.5	8,5¤
	Aug 6	98	16,4¤	10.2	10.2	10.6	20.2	12.6	5.8	6,8¤
	Aug 7	99	15.4	10.2	9.6	9.9	18.8	8.9	5.5	5.5
	Aug 8	100	14.7	10.3	9.2	8.9	20.2	8.2	4.5	4.8
	Aug 9	101	13.7	8.9	8,2¤	8.9	19.5	7.5	3.1	3.4
	Aug 10	102	13.4	9.6	8.9	8.9	19.9	7.2	3.1	2.7
	Aug 11	103	14.0	11.0	9.9	9.2	23.6	7.9	3.1	3.1
	Aug 12	104	14.0	9.9	9.6	9.2	21.6	8.9	3.4	3.8
	Aug 13	105	15.1	9.6	9.6	9.6	23.6	7.5	2.7	1.7
	Aug 14	106	14.7	11.0	9.6	9.2	22.3	6.8	2.1	1.7
	Aug 15	107	14.5	11,7¤	10.0	9.3	25,2¤	7.2	3.1	2.1
	Aug 16	108	14.5	10.0	10.3	9.7	25,2¤	4.1	1.4	5.2

¤ Data rejected at 95% confidence interval.

	Aug 17	109	1770	1984	1560	1604	249	161	7.8	7.7
	Aug 18	110	1712	1958	1582	1632	251	174	7.6	7.6
	Aug 19	111	1572	1990	1376	1608	242	166	8.0	8.1
	Aug 20	112	1696	2040	1454	1664	254	176	7.9	8.3
	Aug 21	113	1630	1938	1526	1684	245	186	8.0	8.0
	Aug 22	114	1708	1846	1572	1636	217	173	8.0	8.1
	AVERAGE		**1682**	**1899**	**1514**	**1631**	**241**	**175**		
7	Aug 23	115	1740	2012	1602	1636¤	195	149	7.9	7.9
	Aug 24	116	1832	2150	1640	1788	207	177	7.8	7.8
	Aug 25	117	1958	2214	1814	1922	174	158	8.0	7.9
	Aug 26	118	1972	2356	1782	1954	172	170	7.9	7.8
	Aug 27	119	1948	2338	1738	1940	185	171	8.0	8.3
	Aug 28	120	2020	2458	1780	2020	168	155	7.9	7.8
	Aug 29	121	1860	2096	1630	1732	194	210	7.9	7.8
	Aug 30	122	1956	2386	1668	1954	158	168	8.0	7.8
	Aug 31	123	1880	2032	1678	1744	170	177	8.0	7.9
	Sept 1	124	2044	2440	1762	1988	186	172	8.1	7.8
	Sept 2	125	2080	2408	1838	2028	173	174	8.1	7.7
	Sept 3	126	2136¤	2492	1949¤	2116	229	185	7.9	8.1
	Sept 4	127	1786	2276	1546	1904	196	189	7.8	7.7
	Sept 5	128	1760	2000	1538	1664	216	200	7.6	7.5
	Sept 6	129	1784	2406	1604	2052	202	175	8.2	7.7
	Sept 7	130	1830	2354	1620	1930	224	200	8.1	7.8
	AVERAGE		**1897**	**2276**	**1683**	**1916**	**191**	**177**		
8	Sept 8	131	1898	2297¤	1542¤	1786	190	191	8.0	8.0
	Sept 9	132	1838	2180	1630	1840	218	197	7.9	7.8
	Sept 10	133	1866	2162	1660	1899¤	241	204	8.0	7.7
	Sept 11	134	1914	2172	1692	1776	240	198	8.0	7.7
	Sept 12	135	1888	2088	1672	1746	233	201	7.9	7.8
	Sept 13	136	1966	2100	1730	1716	203	205	8.0	7.9
	Sept 14	137	1830	1845¤	1598	1533¤	240	206	7.9	7.9
	Sept 15	138	1960	2242	1692	1818	235	205	7.9	7.8
	Sept 16	139	1928	2084	1708	1728	249	211	8.0	7.9
	Sept 17	140	2061¤	2212	1861¤	1840	281	199	7.9	7.9
	Sept 18	141	1964	2202	1702	1786	265	213	7.9	7.8
	Sept 19	142	1960	2140	1772	1760	245	206	7.9	7.9
	Sept 20	143	1896	2062	1728	1788	190	155	7.9	7.8
	Sept 21	144	2053¤	2200	1778	1782	234	218	7.9	7.8
	AVERAGE		**1909**	**2154**	**1697**	**1780**	**233**	**201**		
9	Sept 22	145	2062	2194	1704	1692	247	210	8.0	7.6
	Sept 23	146	2100	2376	1810	1882	233	210	8.0	7.9
	Sept 24	147	1851¤	2060¤	1571¤	1610¤	248	223	8.0	7.9
	Sept 25	148	2130	2342	1754	1808	216	213	7.9	7.5
	Sept 26	149	2254	2380	1940	1926	235	227	7.7	7.5
	Sept 27	150	2186	2474	1994	2145¤	265	210	7.3	7.2
	Sept 28	151	2098	2194	1784	1782	248	205	7.8	8.0
	Sept 29	152	2186	2310	1860	1866	229	208	8.0	7.8
	Sept 30	153	2136	2210	1812	1760	243	226	8.0	7.9
	Oct 1	154	2248	2226	1912	1830	285	234	8.1	8.0
	Oct 2	155	2302	2568¤	1962	2026	261	226	7.8	7.7
	Oct 3	156	2142	2178	1864	1782	317	239	7.9	7.9
	Oct 4	157	2234	2340	2020	2036	322	235	7.8	7.9
	AVERAGE		**2173**	**2293**	**1868**	**1854**	**258**	**220**		
10	Oct 5	158	2378	2548	2068	2122	252	204	7.6	7.6
	Oct 6	159	2364	2594	2068	2180	271	285	7.9	8.0
	Oct 7	160	2069¤	2514	1771¤	2012	251	223	8.0	7.9
	Oct 8	161	2216	2556	1944	2132	280	227	7.8	7.4
	Oct 9	162	2292	2650	1990	2208	233	214	7.8	7.8
	Oct 10	163	2256	2608	1898	2052	236	217	7.7	7.7
	Oct 11	164	2158	2566	1962	2182	247	221	7.8	7.9
	Oct 12	165	2314	2564	1970	2048	303	286	7.9	7.9
	Oct 13	166	2470	2402¤	2102	1831¤	256	250	7.9	7.5

¤ Data rejected as outliers at 10% level of significance.

	Oct 14	167	2258	2440	2038	2036	295	314	7.9	7.7
	Oct 15	168	2214	2410	1954	2022	286	277	7.9	7.8
	Oct 16	169	2336	2717¤	2032	2292¤	278	245	8.1	8.1
	Oct 17	170	2706¤	2516	2323¤	2158	228	265	8.0	8.0
	AVERAGE		**2296**	**2542**	**2002**	**2105**	**263**	**248**		
11	Oct 18	171	2674	2822	2302	2332	268	266	7.9	7.8
	Oct 19	172	2594	2804	2300	2200	257	238	8.0	7.9
	Oct 20	173	2542	2704	2060	2088	262	240	8.0	7.9
	Oct 21	174	2716	2994	2318	2428	270	284	8.1	7.9
	Oct 22	175	2616	2844	2470¤	2612¤	293	305	8.0	8.0
	Oct 23	176	2560	2932	2102	2292	260	284	8.0	8.0
	Oct 24	177	2696	2804	2274	2240	272	297	7.9	7.9
	Oct 25	178	2414	2608	2048	2028	331	332	8.0	7.9
	Oct 26	179	1988¤	2616	1662¤	1976	352	268	8.4	8.2
	Oct 27	180	2460	2481¤	2192	2062	305	403	7.8	7.9
	Oct 28	181	2710	2948	2304	2436	283	305	7.9	7.7
	Oct 29	182	2650	2870	2210	2220	302	290	7.9	7.8
	Oct 30	183	2714	3095¤	2282	2466	282	285	8.0	7.9
	Oct 31	184	2532	2570	2130	2038	329	305	8.0	7.8
	AVERAGE		**2606**	**2793**	**2210**	**2216**	**291**	**293**		
12	Nov 1	185	2432¤	2706	2070¤	2172	322	283	7.8	7.8
	Nov 2	186	2435¤	2604	2138	2142	328	307	-	-
	Nov 3	187	2174	1723¤	1880	1443¤	337	367	-	-
	Nov 4	188	2312	2616	2006	2106	346	293	-	-
	Nov 5	189	2008	2396	1768	2034	332	306	-	-
	Nov 6	190	1928	2472	1730	2048	328	283	-	-
	Nov 7	191	1954	2340	1618	1784	307	285	-	-
	Nov 8	192	2138	2502	1802	1940	327	280	-	-
	Nov 9	193	2054	2562	1860	2158	325	286	-	-
	Nov 10	194	1844	2450	1698	2002	407	299	-	-
	Nov 11	195	2010	2614	1792	2142	564	281	-	-
	Nov 12	196	1914	2530	1648	2034	644	290	-	-
	Nov 13	197	1904	2572	1662	2074	595	285	-	-
	Nov 14	198	-	-	-	-	-	-	-	-
	Nov 15	199	1594¤	2500	1464¤	2008	648	267	-	-
	Nov 16	200	1832	2614	1646	2052	637	268	-	-
	AVERAGE		**2006**	**2534**	**1788**	**2050**	**430**	**292**		
13	Nov 17	201	1788	2572	1570	2106	559	259	-	-
	Nov 18	202	1820	2636	1564	2106	549	253	-	-
	Nov 19	203	1778¤	2616	1558	2116	525	268	-	-
	Nov 20	204	1840	2640	1626	2177¤	498	253	-	-
	Nov 21	205	1888	2717¤	1614	2098	424	245	-	-
	Nov 22	206	1930	2608	1650	2084	449	243	-	-
	Nov 23	207	1970	2514	1752	2000	457	252	-	-
	Nov 24	208	2060	2570	1820	2022	469	233	-	-
	Nov 25	209	2130	2610	1804	2038	430	255	-	-
	Nov 26	210	2090	2582	1764	2006	439	245	-	-
	Nov 27	211	2090	2492	1965¤	2034	415	254	-	-
	Nov 28	212	2052	2484	1836	2052	422	262	-	-
	Nov 29	213	2060	2522	1870	2132	356	238	-	-
	Nov 30	214	-	-	-	-	-	-	-	-
	Dec 1	215	2100	2494	1784	1874¤	349	234	-	-
	Dec 2	216	2178	2508	1814	2094	344	253	-	-
	Dec 3	217	2142	2458	1828	1964	342	258	-	-
	Dec 4	218	2076	2259¤	1820	1914	305	280	-	-
	Dec 5	219	2040	2236¤	1868	1906	359	276	-	-
	AVERAGE		2015	2554	1738	2042	427	253		
	Dec 6	220	2086	2384	1832	1930	336	280	-	-
	Dec 7	221	2102	2324	1780	1838	333	287	-	-
	Dec 8	222	2210	2240	1894	1745¤	287	283	-	-
	Dec 9	223	2340	2416	2000	1914	285	283	-	-
	Dec 10	224	2288	2438	1970	1922	291	280	-	-

¤ Data rejected as outliers at 10% level of significance.

14	Dec 11	225	2236	2404	1938	1940	298	277	-	-
	Dec 12	226	2172	2334	1878	1916	307	286	-	-
	Dec 13	227	2236	2348	1900	1880	298	270	-	-
	Dec 14	228	2330	2392	2008	1924	300	251	-	-
	Dec 15	229	1984	2430	1650¤	1902	336	274	-	-
	Dec 16	230	1794¤	2546	1594¤	2076	334	255	-	-
	Dec 17	231	2490	2712	2168	2204¤	295	252	-	-
	Dec 18	232	2000	2154	1730	1748	375	294	-	-
	Dec 19	233	2292	2472	2064	2078	320	243	-	-
	Dec 20	234	2468	2580	2186	2126	284	226	-	-
	Dec 21	235	2294	2488	1968	1986	291	228	-	-
	Dec 22	236	2256	2406	1950	1920	281	229	7.3	7.4
	Dec 23	237	2472	2674	2066	2102	283	243	7.2	7.4
	Dec 24	238	2448	2784¤	2098	2204¤	293	233	7.3	7.3
	Dec 25	239	2456	2694	2104	2152	299	235	7.3	7.3
	AVERAGE		2272	2444	**1974**	**1962**	**306**	**260**		
15	Dec 26	240	2542	2656	2142	2084	275	226	7.3	7.3
	Dec 27	241	2560	2736	2206	2182	267	231	7.5	7.5
	Dec 28	242	2508	2662	2138	2112	279	238	7.3	7.2
	Dec 29	243	2681¤	2796	2256	2212	261	232	7.3	7.2
	Dec 30	244	2618	2864	2244	2292¤	280	244	7.3	7.3
	Dec 31	245	2669¤	2730	2260	2172	275	232	7.2	7.3
	Jan 1	246	2556	2650	2150	2082	300	252	7.8	8.0
	Jan 2	247	2568	2692	2172	2126	260	223	7.7	7.7
	Jan 3	248	2540	2510	2144	1990	302	252	7.5	7.5
	Jan 4	249	2502	2524	2138	2014	306	251	7.4	7.4
	Jan 5	250	2528	2540	2122	2000	290	236	7.4	7.4
	Jan 6	251	2414	2518	2034	1990	297	252	7.3	7.2
	Jan 7	252	2478	2600	2100	2076	289	244	7.3	7.4
	Jan 8	253	2504	2414	1984	2044	293	276	7.2	7.3
	Jan 9	254	2390	2256	1884¤	1936	286	266	7.4	7.4
	Jan 10	255	2174¤	2256	1916¤	1776¤	307	251	7.2	7.3
	Jan 11	256	2438	2374	2106	1934	287	253	7.5	7.3
	Jan 12	257	2412	2201¤	2024	1735¤	304	272	7.3	7.2
	AVERAGE		**2504**	**2575**	**2139**	**2064**	**287**	**246**		
16	Jan 13	258	2580	2478	2194	1979¤	271	269	7.3	7.3
	Jan 14	259	2674	2688	2282	2148	299	267	7.3	7.4
	Jan 15	260	2750	2556	2352	2072	315	280	7.2	7.2
	Jan 16	261	2811¤	2913¤	2386	2326¤	290	257	7.2	7.2
	Jan 17	262	2830¤	2844	2408¤	2289	271	258	7.2	7.1
	Jan 18	263	2690	2620	2298	2128	273	261	7.1	7.1
	Jan 19	264	2520	2694	2188	2196	238	254	7.0	7.1
	Jan 20	265	2572	2450	2166	1980¤	233	231	8.0	8.0
	Jan 21	266	2556	2722	2148	2196	248	245	7.6	7.7
	Jan 22	267	2606	2700	2260	2214	237	247	7.8	7.3
	Jan 23	268	2666	2764	2250	2240	263	241	7.3	7.2
	Jan 24	269	2606	2554	2204	2070	269	241	7.3	7.3
	Jan 25	270	2594	2658	2186	2148	270	226	7.5	7.5
	Jan 26	271	2606	2540	2278	2130	281	223	7.7	7.7
	AVERAGE		**2618**	**2636**	**2246**	**2166**	**268**	**250**		
17	Jan 27	272	2658	2608	2206	2076	257	217	7.8	7.8
	Jan 28	273	2396	2534	2040	2068	264	224	7.7	7.5
	Jan 29	274	2795¤	2670	2339¤	2130	250	212	7.8	7.8
	Jan 30	275	2604	2816	2198	2282	256	207	7.5	7.5
	Jan 31	276	2652	2748	2230	2250	277	206	7.8	7.7
	Feb 1	277	2440	2662	2112	2186	273	194	7.8	7.6
	Feb 2	278	2484	2674	2032	2146	268	199	7.8	7.9
	Feb 3	279	2458	2450	2038	1941¤	264	204	7.9	7.9
	Feb 4	280	2230¤	2592	1839¤	2058	269	193	7.8	7.9
	Feb 5	281	2580	2652	2202	2170	245	201	7.8	7.8
	Feb 6	282	2378	2448	2000	1954¤	252	191	7.8	7.8
	Feb 7	283	2468	2259¤	2072	2140	243	236	7.6	7.7

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	Feb 8	284	2488	2636	2104	2206	241	183	7.9	7.8
	Feb 9	285	2640	2734	2244	2236	240	195	7.9	7.9
	AVERAGE		**2521**	**2633**	**2123**	**2162**	**257**	**205**		
18	Feb 10	286	2376	2734	1968	2190	267	213	7.9	7.9
	Feb 11	287	2272	2708	1896	2188	308	234	7.9	7.9
	Feb 12	288	2366	2674	1968	2198	296	237	7.9	7.9
	Feb 13	289	2763¤	2784	2360¤	2180	265	227	7.9	7.9
	Feb 14	290	2392	2796	2082	2298	293	238	7.7	7.8
	Feb 15	291	2268	2546	1944	2262	338	249	7.5	7.7
	Feb 16	292	2336	2680	2034	2194	357	236	7.7	7.8
	Feb 17	293	2450	2400¤	2046	1914¤	327	236	7.8	7.8
	Feb 18	294	2338	2592	2032	2148	356	238	7.8	7.8
	Feb 19	295	2212	2718	1906	2254	347	233	7.8	7.8
	Feb 20	296	1340¤	2654	1146¤	2134	398	239	7.8	7.8
	Feb 21	297	1840	2383¤	1520	1989¤	417	259	8.0	7.9
	AVERAGE		**2285**	**2689**	**1940**	**2205**	**331**	**237**		
19	Feb 22	298	2050	2634	1742	2122	374	228	7.8	7.6
	Feb 23	299	2200	2399¤	1890	1941¤	364	222	7.9	7.8
	Feb 24	300	2306	2620	2014	2130	347	216	7.7	7.7
	Feb 25	301	2186	2702	1818	2150	335	210	7.7	7.7
	Feb 26	302	2298	2696	1986	2190	334	198	7.6	7.6
	Feb 27	303	2330	2696	1982	2126	308	210	7.7	7.6
	Feb 28	304	2382	2784	2016	2218	280	186	7.6	7.5
	Feb 29	305	2372	2836	1996	2244	274	188	7.7	7.6
	March 1	306	2426	2852	2052	2270	261	187	7.7	7.7
	March 2	307	2470	2680	2130	2164	256	187	7.5	7.4
	March 3	308	2408	2718	2032	2122	263	190	7.6	7.6
	March 4	309	2410	2724	2072	2170	249	196	7.7	7.6
	March 5	310	1861¤	2852	1590¤	2256	197	187	7.7	7.7
	March 6	311	2164	2802	1890	2244	231	202	7.8	7.8
	March 7	312	2124	2702	1780	2110	235	185	7.8	8.0
	AVERAGE		**2295**	**2736**	**1957**	**2180**	**287**	**199**		
20	March 8	313	2480	2784	2046	2150	228	192	7.7	8.0
	March 9	314	2508	2700	2096	2108	259	191	7.7	8.0
	March 10	315	2436	2710	2044	2222	267	197	7.4	7.5
	March 11	316	2240	2708	2026	2232	238	197	7.8	7.9
	March 12	317	2546	2900¤	2166¤	2342¤	249	190	7.9	8.0
	March 13	318	2396	2726	2000	2166	264	214	7.8	7.9
	March 14	319	2356	2684	2000	2152	283	211	7.7	7.8
	March 15	320	2288	2698	1912	2106	291	204	7.5	7.6
	March 16	321	2270	2364¤	1934	2072	286	226	7.8	7.7
	March 17	322	2312	2410	1970	1972	288	207	7.8	7.9
	March 18	323	2570	2606	2212	2106	246	217	7.8	7.9
	March 19	324	2354	2352¤	2036	1892¤	276	213	7.8	7.9
	March 20	325	2294	2692	1938	2202	254	198	7.7	7.7
	AVERAGE		**2388**	**2672**	**2018**	**2135**	**264**	**204**		
21	March 21	326	2400	2846	2068	2330	243	199	7.6	7.6
	March 22	327	2394	2870	2052	2360	244	203	7.6	7.6
	March 23	328	2408	2914	2088	2368	263	206	7.6	7.6
	March 24	329	2424	2938	2120	2414	261	204	7.6	7.6
	March 25	330	2484	2824	2116	2376	242	207	7.7	7.5
	March 26	331	2500	2948	2180	2472	247	192	7.8	7.7
	March 27	332	2508	2785¤	2160	2384	266	203	7.9	7.8
	March 28	333	2575¤	3020¤	2228	2556¤	246	210	8.2	8.2
	March 29	334	2552	3008	2196	2484	235	199	7.8	7.9
	March 30	335	2460	2920	2124	2440	244	194	7.9	7.9
	March 31	336	2540	2990	2269¤	2542	236	201	7.8	7.8
	April 1	337	2468	2918	2076	2376	230	206	7.8	7.8
	April 2	338	2520	2926	2166	2400	231	205	7.7	7.8
	April 3	339	2492	2936	2116	2386	221	204	7.8	7.8
	AVERAGE		**2473**	**2920**	**2130**	**2410**	**243**	**202**		
	April 4	340	2436¤	2684	2092	2324	226	211	7.7	8.1

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22	April 5	341	2426	2854¤	2088	2380	261	193	7.9	8.0
	April 6	342	2286	2720	1940	2238	233	233	7.8	7.8
	April 7	343	2244	2646	1936	2176	238	233	7.6	7.6
	April 8	344	2200	2684	1874	2148	242	211	7.7	7.7
	April 9	345	2184	2198¤	1812	1650¤	229	265	7.7	7.7
	April 10	346	2186	2658	1972	2160	229	213	7.7	7.7
	April 11	347	2060¤	2568	1776	2074	235	227	7.6	7.7
	April 12	348	2190	2632	1864	2144	244	209	7.6	7.7
	AVERAGE		**2245**	**2656**	**1928**	**2205**	**237**	**222**		
23	April 13	349	2268	2664	1924	2120	235	200	7.6	7.6
	April 14	350	2246	2586	1952	2120	252	206	7.7	7.7
	April 15	351	2094	2564	1780	2048	247	208	7.7	7.7
	April 16	352	2252	2508	1942	2008	237	186	7.7	7.7
	April 17	353	2160	2462	1852	2032	255	217	7.8	7.8
	April 18	354	2144	2462	1838	2004	218	217	7.7	7.7
	April 19	355	2100	2470	1836	2028	238	216	7.7	7.7
	April 20	356	2198	2492	1888	2058	220	214	7.7	7.8
	April 21	357	2152	2430	1818	1946	232	219	7.6	7.6
	April 22	358	2018	2340	1754	1936	248	228	7.6	7.6
	April 23	359	2096	1546¤	1824	1299¤	239	237	7.7	7.7
	April 24	360	2001¤	2318	1721¤	1924	225	216	7.6	7.6
	AVERAGE		**2157**	**2481**	**1855**	**2020**	**237**	**214**		
24	April 25	361	2050	2492¤	1792	2078¤	228	207	7.7	7.7
	April 26	362	2052	2354	1718	1858	227	227	7.8	7.8
	April 27	363	2056	2444	1768	1984	227	218	7.6	7.6
	April 28	364	2088	2332	1822	1906	208	207	7.7	7.7
	April 29	365	2100	2340	1828	1886	206	214	7.7	7.7
	April 30	366	2008	2356	1678	1852	199	212	7.7	7.8
	May 1	367	2066	2190	1792	1738¤	194	228	7.9	7.8
	May 2	368	1876	2268	1644	1902	213	235	7.6	7.8
	May 3	369	1856	2262	1532	1764	207	236	7.7	7.7
	May 4	370	2080	2354	1852	1972	192	227	7.6	7.7
	May 5	371	1744	2244	1534	1838	191	245	7.6	7.6
	May 6	372	1726	2240	1526	1864	193	238	7.5	7.5
	May 7	373	1796	2290	1544	1878	186	247	7.4	7.4
	AVERAGE		**1961**	**2306**	**1695**	**1882**	**205**	**226**		
25	May 8	374	1862	2222	1646	1876	188	255	7.6	7.5
	May 9	375	1614¤	2536	1306¤	2086	207	250	7.6	7.6
	May 10	376	2048	2728¤	1676	2178	187	244	7.5	7.5
	May 11	377	2062	2690	1798	2248¤	186	260	7.3	7.3
	May 12	378	1958	2470	1552	2080	170	310	7.3	7.4
	May 13	379	2052	2408	1818	2004	195	318	7.5	7.5
	May 14	380	2052	2468	1716	1978	211	290	7.7	7.6
	May 15	381	1972	2514	1720	2080	211	285	7.7	7.6
	May 16	382	1497¤	2322	1338	1974	189	309	7.7	7.6
	May 17	383	2060	2380	1840	2000	210	280	7.7	7.7
	May 18	384	1982	2366	1668	1920	210	282	7.7	7.7
	May 19	385	1972	2272	1776	1924	203	308	7.6	7.7
	May 20	386	1900	2428	1644	2028	211	275	7.7	7.7
	AVERAGE		**1993**	**2423**	**1683**	**2011**	**198**	**282**		
26	May 21	387	2086	2432	1804	2030	192	288	7.7	7.7
	May 22	388	2190¤	2546	1938¤	2172	183	262	7.8	7.7
	May 23	389	2092	2480	1854	2134	199	269	7.6	7.6
	May 24	390	2148	2446	1872	2054	202	273	7.5	7.6
	May 25	391	2052	2548	1768	2132	211	262	7.6	7.6
	May 26	392	2048	2540	1778	2120	203	262	7.6	7.5
	May 27	393	2038	2492	1760	2070	213	261	7.8	7.8
	May 28	394	1986	2464	1666¤	1994	210	250	7.6	7.5
	May 29	395	2002	2350	1758	1986	216	270	7.8	7.8
	May 30	396	1885¤	2466	1668	2132	283	257	7.5	7.4
	May 31	397	2102	2249¤	1808	1861¤	198	207	7.5	7.6
	AVERAGE		**2062**	**2476**	**1786**	**2082**	**210**	**260**		

¤ Data rejected as outliers at 10% level of significance.

27	June 1	398	2246	2382	1932	1980	163	238	7.5	7.5
	June 2	399	2178	2300	1936	1982	191	254	7.5	7.5
	June 3	400	2244	2252	1922	1876	193	244	7.6	7.6
	June 4	401	2186	2316	1914	1920	206	245	7.7	7.7
	June 5	402	2319¤	2424	1998¤	2022	172	234	7.7	7.7
	June 6	403	2329¤	2514¤	1986	2068¤	186	225	8.0	7.9
	June 7	404	2250	2390	1924	1982	178	237	7.9	8.0
	June 8	405	2164	2386	1898	1992	185	237	8.0	8.0
	June 9	406	2116	2332	1824	1930	189	229	7.4	7.9
	June 10	407	2196	2354	1862	1924	205	227	7.7	7.8
	June 11	408	2168	2286	1826	1868	200	226	7.6	7.8
	June 12	409	2144	2282	1808	1846	187	219	7.7	7.7
	June 13	410	2132	2298	1852	1922	172	218	7.8	7.8
	AVERAGE		**2184**	**2333**	**1890**	**1937**	**187**	**233**		
28	June 14	411	2230	2272	1916	1880	164	220	7.8	7.9
	June 15	412	2208	2360	1878	1934	181	212	7.7	7.8
	June 16	413	2094¤	2230	1839¤	1868	183	217	7.8	7.8
	June 17	414	2220	2256	1962	1938	165	222	7.8	7.8
	June 18	415	2336	2139¤	2024	1798¤	171	218	7.8	7.7
	June 19	416	2334	2408	2010	2000	163	199	8.1	8.1
	June 20	417	2360	2446	2066	2018	161	196	8.1	8.1
	June 21	418	2426	2428	2088	2016	165	198	8.1	8.1
	June 22	419	2410	2496	2140	2120	166	192	7.8	7.8
	June 23	420	-	-	-	-	-	-	-	-
	June 24	421	2436	2582	2086	2142	168	194	7.8	7.8
	June 25	422	2450	2580	2066	2100	171	190	7.8	7.8
	June 26	423	2516	2564	2152	2120	151	179	7.8	7.8
	June 27	424	2390	2763¤	2076	2323¤	159	181	7.8	7.8
	AVERAGE		**2360**	**2420**	**2039**	**2012**	**167**	**201**		
29	June 28	425	2473¤	2823¤	2159¤	2362	162	177	7.9	7.9
	June 29	426	2112	2626	1878	2274	166	168	7.8	7.8
	June 30	427	2008	2572	1808	2208	189	171	7.7	7.7
	July 1	428	1711¤	2644	1484	2176	181	166	7.9	7.9
	July 2	429	2212	2532	1946	2152	181	174	7.7	7.7
	July 3	430	2124	2552	1866	2172	188	165	7.7	7.7
	July 4	431	2022	2486	1780	2100	188	161	7.7	7.7
	July 5	432	2228	2536	1978	2072	189	166	7.5	7.5
	July 6	433	1934	2284	1748	2016	207	166	7.5	7.5
	July 7	434	1906	2326	1700	1958	189	155	7.7	7.7
	July 8	435	1894	2364	1526¤	2026	201	165	7.7	7.7
	July 9	436	2254	2254	2004	1922	195	160	8.0	7.9
	July 10	437	2396	2140	2020	1727¤	192	150	8.0	7.9
	July 11	438	2258	2198	1986	1824	190	164	7.9	7.9
	July 12	439	2236	2252	1978	1878	197	151	8.3	8.2
	AVERAGE		**2122**	**2412**	**1860**	**2081**	**188**	**164**		
30	July 13	440	1978	2248	1726¤	1876	182	160	8.2	8.1
	July 14	441	2298	2276	2059¤	1956	200	158	8.0	7.9
	July 15	442	2226	2216	2014	1900	207	158	8.0	7.8
	July 16	443	2198	2216	1880	1810	209	162	8.2	8.0
	July 17	444	2294	2306	1966	1894	201	156	8.0	8.0
	July 18	445	-	-	-	-	-	-	-	-
	July 19	446	2238	2288	1918	1892	232	166	7.5	7.3
	July 20	447	2278	2308	1944	1916	224	160	7.6	7.3
	July 21	448	1996	2376	1856	2115¤	235	152	7.7	7.7
	July 22	449	2086	2162	1884	1924	225	157	7.8	7.7
	July 23	450	2218	2156	1904	1776	230	139	7.2	7.2
	July 24	451	2188	2152	1894	1788	219	158	7.6	7.1
	July 25	452	1932¤	1892¤	1680¤	1615¤	197	159	7.7	7.3
	AVERAGE		**2182**	**2246**	**1918**	**1873**	**213**	**157**		
	July 26	453	2030	2038	1818	1726	207	157	7.8	7.9
	July 27	454	2139¤	2094	1907¤	1852	206	153	7.5	7.6
	July 28	455	2038	1882	1782	1612	206	138	7.7	7.6

¤ Data rejected as outliers at 10% level of significance.

31	July 29	456	1990	1906	1724	1618	196	157	7.8	7.7
	July 30	457	2022	1940	1752	1662	198	155	7.8	7.8
	July 31	458	2014	2024	1696	1698	199	158	7.8	7.8
	Aug 1	459	2022	1820	1826	1626	198	165	7.9	7.8
	Aug 2	460	1972	1896	1730	1652	203	158	7.9	7.9
	Aug 3	461	2038	1790	1682	1457¤	211	168	7.8	7.9
	Aug 4	462	1959¤	1830	1788	1634	240	153	7.8	7.7
	Aug 5	463	2054	1806	1800	1598	214	166	7.8	7.8
	Aug 6	464	-	-	-	-	-	-	-	-
	AVERAGE		**2020**	**1911**	**1760**	**1668**	**207**	**157**		
32	Aug 7	465	2098¤	2024¤	1734	1638	234	158	7.7	7.8
	Aug 8	466	2022	1990	1718	1640	267	161	7.9	7.9
	Aug 9	467	1846	1894	1572	1570	282	174	7.9	7.8
	Aug 10	468	1768	1778	1544	1488	305	174	7.8	7.7
	Aug 11	469	1820	1850	1658	1642	319	162	7.7	7.7
	Aug 12	470	1852	1752	1690	1552	292	171	7.7	7.7
	Aug 13	471	1880	1816	1712	1542	277	165	7.7	7.6
	Aug 14	472	1884	1804	1638	1512	308	177	7.8	7.7
	Aug 15	473	2026	1810	1786	1576	237	166	7.8	7.9
	Aug 16	474	1876	1768	1708	1544	229	170	7.7	7.8
	Aug 17	475	1892	1696	1692	1444	185	147	7.7	7.8
	Aug 18	476	1768	1764	1560	1446	187	170	7.7	7.8
	Aug 19	477	1676	1646	1469¤	1466	161	158	7.8	8.0
	AVERAGE		**1859**	**1797**	**1662**	**1535**	**254**	**166**		
33	Aug 20	478	1563	1812	1400	1546	192	177	7.7	7.7
	Aug 21	479	1676	1836	1540	1614	203	174	7.8	7.8
	Aug 22	480	1631	1866	1408	1548	196	161	7.7	7.7
	Aug 23	481	1858	1736	1656	1512	194	156	7.7	7.7
	Aug 24	482	1812	1666	1614	1422¤	210	180	7.7	7.8
	Aug 25	483	1689	1586¤	1512	1407¤	207	189	7.6	7.7
	Aug 26	484	2014	1934	1784	1626	228	165	7.7	7.8
	Aug 27	485	1998	1824	1784	1640	210	154	7.6	7.8
	Aug 28	486	2119	1972	1820	1604	208	162	7.6	7.4
	Aug 29	487	2155	1936	1954	1670	204	155	7.7	7.7
	Aug 30	488	2092	1868	1804	1554	225	150	7.8	7.6
	Aug 31	489	-	-	-	-	-	-	-	-
	Sept 1	490	-	-	-	-	-	-	-	-
	AVERAGE		**1873**	**1845**	**1661**	**1590**	**207**	**166**		
34	Sept 2	491	1972	1926	1820	1692	233	187	7.8	7.7
	Sept 3	492	1910	1938	1740	1732	241	175	7.8	7.7
	Sept 4	493	2044¤	1980	1846	1748¤	225	172	7.7	7.9
	Sept 5	494	1954	1908	1828	1654	230	178	7.7	7.8
	Sept 6	495	1908	1918	1762	1678	241	177	7.6	7.7
	Sept 7	496	1732¤	1930	1550¤	1642	277	166	7.8	8.0
	Sept 8	497	1866	1902	1622	1572	241	174	7.5	7.7
	Sept 9	498	1892	1922	1732	1636	243	172	7.6	7.7
	Sept 10	499	2004	2018¤	1760	1664	230	164	7.6	7.6
	Sept 11	500	1832	1900	1676	1620	229	158	7.5	7.6
	Sept 12	501	1884	1888	1694	1567¤	234	159	7.7	7.8
	AVERAGE		**1914**	**1921**	**1748**	**1654**	**239**	**171**		
35	Sept 13	502	1896	1928	1586	1518	232	156	7.5	7.7
	Sept 14	503	2022	1956	1576	1518	208	158	7.3	7.5
	Sept 15	504	1936	1950	1732	1632	217	154	7.7	7.8
	Sept 16	505	1908	1836	1690	1540	210	163	7.7	7.8
	Sept 17	506	1918	1890	1610	1685¤	209	159	7.7	7.9
	Sept 18	507	1702	1900	1568	1624	247	158	7.7	7.8
	Sept 19	508	1826	1846	1598	1516	214	163	7.8	8.2
	Sept 20	509	1498	1860	1346	1518	267	172	7.9	7.7
	Sept 21	510	1684	1772	1510	1436	202	164	7.9	7.9
	Sept 22	511	1614	1774	1392	1468	211	169	7.8	7.7
	Sept 23	512	1458	1804	1218	1392	178	161	7.9	7.8

¤ Data rejected as outliers at 10% level of significance.

	Sept 24	513	1404	1557¤	1197¤	1193¤	207	167	7.8	7.7
	Sept 25	514	-	-	-	-	-	-	-	-
	AVERAGE		1739	1865	1530	1516	217	162		
36	Sept 26	515	1132¤	1851¤	994¤	1502	186	167	7.8	7.7
	Sept 27	516	1492	1928	1340	1586	201	187	7.8	7.9
	Sept 28	517	1622	2104	1444	1684	191	162	7.9	8.1
	Sept 29	518	-	-	-	-	-	-	-	-
	Sept 30	519	1640	2056	1420	1592	183	175	7.8	7.8
	Oct 1	520	1720	2120	1438	1638	198	189	7.9	7.8
	Oct 2	521	1612	2248	1466	1916	199	178	7.7	7.7
	Oct 3	522	-	-	-	-	-	-	-	-
	Oct 4	523	1592	2300	1420	1878	151	174	7.9	7.8
	Oct 5	524	1698	2350	1446	1892	159	170	8.0	7.8
	Oct 6	525	-	-	-	-	-	-	-	-
	Oct 7	526	1360	2318	1202	1926	162	181	8.1	7.9
	AVERAGE		1592	2178	1397	1735	181	176		
37	Oct 8	527	1652	2326	1440	1860	139	172	8.0	7.9
	Oct 9	528	-	-	-	-	-	-	-	-
	Oct 10	529	1660	2298	1456	1884	133	165	8.0	7.8
	Oct 11	530	-	-	-	-	-	-	-	-
	Oct 12	531	1302¤	2244	1149¤	1848	154	178	7.8	7.8
	Oct 13	532	-	-	-	-	-	-	-	-
	Oct 14	533	1574	2138	1448	1830	140	178	7.8	7.7
	Oct 15	534	1560	2232	1358	1828	141	161	7.7	7.7
	Oct 16	535	1696	2190	1462	1728	142	174	7.9	7.7
	Oct 17	536	1428	1968	1332	1652	140	183	7.7	7.7
	Oct 18	537	1766	2090	1570	1728	113	182	7.9	7.7
	Oct 19	538	1708	1990	1580	1658	141	191	7.7	7.7
	Oct 20	539	-	-	-	-	-	-	-	-
	Oct 21	540	-	-	-	-	-	-	-	-
	AVERAGE		1630	2164	1456	1780	138	176		
38	Oct 22	541	1329¤	1792¤	1225¤	1522¤	135	179	8.0	7.8
	Oct 23	542	-	-	-	-	-	-	-	-
	Oct 24	543	1654	2390	1396	1908	157	167	7.8	7.8
	Oct 25	544	1636	2320	1420	1860	159	172	7.8	7.8
	Oct 26	545	1642	2348	1476	1954	158	179	7.8	7.7
	Oct 27	546	-	-	-	-	-	-	-	-
	Oct 28	547	1682	2518	1482	2058	119	167	7.7	7.7
	Oct 29	548	-	-	-	-	-	-	-	-
	AVERAGE		1653	2394	1443	1945	146	173		
39	Oct 30	549	1346	2304	1196	1886	149	165	7.9	7.9
	Oct 31	550	1388	2389¤	1238	1967¤	137	167	7.9	7.8
	Nov 1	551	1258	2268	1148	1866	127	168	7.9	7.8
	Nov 2	552	1186	2250	1136	1872	169	173	7.9	7.8
	Nov 3	553	-	-	-	-	-	-	-	-
	Nov 4	554	1136	2040	1038	1764	167	186	7.9	7.8
	Nov 5	555	1364	2084	1230	1788	161	182	7.8	7.8
	Nov 6	556	1196	2064	1080	1756	184	184	7.8	7.8
	Nov 7	557	1458	2096	1308	1710	130	172	8.0	7.8
	Nov 8	558	1164	2074	1148	1782	206	174	8.0	7.7
	Nov 9	559	1300	2128	1174	1774	192	169	7.9	7.8
	Nov 10	560	-	-	-	-	-	-	-	-
	Nov 11	561	1704¤	2206	1577¤	1856	153	163	7.8	7.8
	AVERAGE		1280	2151	1170	1805	161	173		
40	Nov 12	562	1364	2058	1204	1680	147	180	7.8	7.8
	Nov 13	563	-	-	-	-	-	-	-	-
	Nov 14	564	1476	2286	1348	1874	163	157	8.1	7.8
	Nov 15	565	1668	2392	1444	1940	156	151	7.9	7.8
	Nov 16	566	1586	2346	1462	1976	177	153	8.0	8.0
	Nov 17	567	1388	2172	1210	1754	216	166	8.0	7.9
	Nov 18	568	-	-	-	-	-	-	-	-
	Nov 19	569	1372	2098	1150	1602	190	167	7.9	7.8

¤ Data rejected as outliers at 10% level of significance.

	Nov 20	570	1452	2188	1234	1718	193	155	7.7	7.7
	Nov 21	571	1063¤	2398	961¤	1930	188	163	7.9	7.8
	Nov 22	572	1394	2306	1170	1740	172	156	7.9	7.8
	Nov 23	573	1604	2140	1380	1688	175	168	7.8	7.7
	Nov 24	574	-	-	-	-	-	-	-	-
	Nov 25	575	-	-	-	-	-	-	-	-
	AVERAGE		**1478**	**2238**	**1289**	**1790**	**177**	**162**		
41	Nov 26	576	1556	2184¤	1372	1781¤	180	183	7.8	7.7
	Nov 27	577	1430¤	2040	1291¤	1680	210	186	7.8	7.8
	Nov 28	578	1638	2052	1452	1656	171	146	7.9	7.8
	Nov 29	579	-	-	-	-	-	-	-	-
	Nov 30	580	1550	2030	1380	1693	219	187	7.9	7.9
	Dec 1	581	-	-	-	-	-	-	-	-
	Dec 2	582	1590	2101	1431	1721	226	171	7.8	7.8
	AVERAGE		**1583**	**2056**	**1409**	**1688**	**201**	**175**		

¤ Data rejected as outliers at 10% level of significance.

APPENDIX A

Daily measured total phosphorus concentrations in influent, filtered mixed liquor in each reactor and filtered effluents of the MLE and UCT systems at 30 C.

BATCH OF SEWAGE	*YEAR* MONTH / DAY	DAY NO	*INFLUENT* [mgP/*l*]	MLE SYSTEM			UCT SYSTEM			
				ANOXIC [mgP/*l*]	AEROB [mgP/*l*]	EFFLUENT [mgP/*l*]	ANAERO [mgP/*l*]	ANOXIC [mgP/*l*]	AEROB [mgP/*l*]	EFFLUENT [mgP/*l*]
	1995									
1	May 1	1	17.1¤	10.6¤	11.3¤	9.8	18.2	11.7¤	4.0	5.5¤
	May 2	2	16.3	9.6	11.0¤	9.6	17.8	8.9	4.3	5.0
	May 3	3	16.0	9.6	10.3	10.7¤	18.1	8.9	6.6¤	5.3¤
	May 4	4	13.6	9.0	8.0	9.0	17.4	9.0	3.5	3.5
	May 5	5	13.6	8.3	8.0	9.0	18.1	8.7	3.1	3.1
	May 6	6	13.9	8.0	8.3	8.7	18.8	9.4	2.8	3.1
	May 7	7	13.6	9.4	9.0	8.3	19.8	8.7	2.8	2.4
	May 8	8	14.7	7.3¤	8.8	8.4	22.4¤	9.2	5.1	2.2
	May 9	9	14.7	8.8	9.5	8.8	21.3	8.1	2.9	2.6
	May 10	10	15.0	8.4	8.4	8.1	20.9	8.1	2.2	2.9
	May 11	11	15.4	9.2	8.8	9.5	20.9	8.1	2.2	2.9
	May 12	12	14.3	9.1	9.1	7.7	19.9	9.8	3.5	2.4
	May 13	13	12.9	8.7	8.0	8.0	20.3	10.8¤	3.5	2.1
	May 14	14	12.9	9.1	8.4	8.0	19.2	8.0	3.5	1.7
	May 15	15	14.0	9.1	8.7	8.4	15.7	8.7	2.4	2.4
	May 16	16	11.9	9.0	8.6	7.9	16.5	7.9	4.7	4.0
	May 17	17	12.6	10.8¤	9.0	8.6	20.8	9.3	5.0	5.4¤
	May 18	18	11.4¤	8.3	8.3	8.3	14.4¤	7.2¤	3.6	3.2
	May 19	19	12.6	9.0	9.0	8.3	16.9	8.6	4.3	2.5
	AVERAGE		**14.0**	**8.9**	**8.7**	**8.6**	**18.9**	**8.7**	**3.5**	**2.9**
2	May 20	20	19.6	10.5	10.1	10.5	27.3	15.0¤	7.7	8.4
	May 21	21	19.6	13.6	13.3¤	14.3¤	26.2	14.7¤	8.7	9.8¤
	May 22	22	18.2	11.2	10.5	10.5	21.3	9.4	4.9	4.2
	May 23	23	13.3	10.5	8.4	7.3	17.1¤	7.0	3.5	3.5
	May 24	24	12.6	9.8	7.0	6.3	17.5	9.8	4.2	4.2
	May 25	25	12.3	10.0	8.1	6.9	20.0	4.6¤	3.1	3.1
	May 26	26	11.6	8.5	6.9	6.9	18.9	4.6¤	3.1	3.1
	May 27	27	11.2	9.2	9.2	8.1	22.4	9.6	1.9¤	1.9
	May 28	28	11.9	13.5	10.4	8.5	22.7	10.0	1.9¤	1.9
	May 29	29	18.4	12.6	11.6	12.6	28.3	13.0	6.5	5.5
	May 30	30	18.4	12.3	11.9	11.3	26.6	13.0	7.2	5.8
	May 31	31	18.4	12.3	13.0	11.6	26.6	13.3	7.8	6.8
	June 1	32	14.5	9.8	8.3	8.3	23.2	10.9	5.4	4.3
	June 2	33	16.3	10.9	9.4	8.3	23.9	11.6	6.9	5.8
	June 3	34	17.4	10.1	8.7	9.4	22.5	10.9	7.2	7.2
	June 4	35	15.9	9.8	8.0	9.4	21.0	10.9	8.7	7.2
	June 5	36	17.0	11.6	9.8	8.7	21.7	12.0	6.2	6.9
	June 6	37	17.5	14.0¤	12.6	10.2	18.9	10.5	7.0	7.0
	June 7	38	16.8	12.6	11.6	11.2	20.3	9.1	5.3	6.0
	June 8	39	16.8	9.8	9.8	9.5	21.0	9.5	5.3	4.2
	AVERAGE		**15.9**	**11.0**	**9.8**	**9.2**	**22.7**	**10.6**	**6.0**	**5.1**
3	June 9	40	16.1	10.2	10.2	8.8	20.0¤	8.4	3.9	3.2
	June 10	41	16.9	10.1	9.4	8.4	21.6	10.1	2.4	2.7
	June 11	42	16.5	10.5	9.4	10.1	20.0¤	7.8	4.4	4.0
	June 12	43	15.5	10.8	10.1	10.5	22.9	9.4	4.7	4.7
	June 13	44	15.8	11.1	10.1	10.8	21.9	10.8	6.1	3.7
	June 14	45	14.2	10.5	10.1	10.1	22.9	10.1	4.0	3.4
	June 15	46	14.8	10.7	9.3	9.3	23.0	10.0	4.4	3.0
	June 16	47	15.2	10.4	9.6	9.3	23.7	13.0	7.8	5.6¤
	June 17	48	14.8	10.4	10.0	9.6	24.1	10.0	3.7	4.8
	June 18	49	15.2	10.7	8.5	7.8	24.8	9.6	4.1	3.7
	June 19	50	15.9	12.2	9.3	9.3	25.6	11.1	3.7	4.1
	June 20	51	17.0	16.7	15.2	14.4	25.9	11.1	3.7	3.3

¤ Data rejected as outliers at 10% level of significance.

	June 21	52	16.2	7.4	6.6	6.3	24.7	9.2	3.7	3.7
	June 22	53	16.2	15.5	6.6	6.3	25.4	10.3	2.9	3.3
	June 23	54	17.7	11.4	7.7	5.5	25.8	9.9	4.0	4.0
	June 24	55	18.8¤	17.3	11.5	15.2¤	24.5	17.3¤	6.5	5.4
	June 25	56	17.3	25.3¤	25.3¤	16.6¤	26.0	17.3¤	7.2	2.9
	June 26	57	16.2	15.2	15.5	13.7	28,1¤	9.4	7.6	3.2
	June 27	58	19.8¤	17.0	14.1	13.0	29.9¤	12.3	9.4	5.4
	June 28	59	14.1¤	6.7	5.9	5.6	23.0	11.1	4.4	5.2
	AVERAGE		**16.0**	**11.8**	**10.0**	**9.4**	**24.1**	**10.2**	**4.9**	**3.9**
4	June 29	60	14.1	7.8	6.3	6.3	24.1	11.1	4.8	4.1
	June 30	61	14.1	12.2	11.1	12.2	23.7	11.1	4.8	4.4
	July 1	62	14.5	6.9	5.9	5.2	22.2	10.7	4.8	4.8
	July 2	63	13.5	9.7	8.3	6.6	22.2	11.1	5.5	5.2
	July 3	64	13.5	9.0	8.7	8.0	21.5	10.4	4.5	5.2
	July 4	65	15.2	16.3	16.3	13.5	20.8	9.0	4.2	3.5
	July 5	66	15.9	5.1	4.3	5.4	21.7	8.3	2.5	2.5
	July 6	67	15.9	6.9	6.9	4.3	22.4	8.7	1.8¤	2.2
	July 7	68	15.9	12.3	9.4	6.5	22.7	8.3	2.2	1.8
	July 8	69	-	-	-	-	-	-	-	-
	July 9	70	14.7	9.1	6.7	7.7	27.7¤	12.6	6.3	2.8
	July 10	71	15.4	14.7	14.0	12.6	30.1¤	14.4¤	7.0	3.9
	July 11	72	-	-	-	-	-	-	-	-
	July 12	73	15.1	14.4	10.9	8.1	27.3	13.7	7.7	6.0
	July 13	74	13.7	20.3¤	17.5¤	12.3	22.1	14.4¤	8.8	6.3
	July 14	75	12.3	9.8	7.0	8.8	23.1	14.4¤	11.2¤	7.4
	July 15	76	14.4	7.0	7.7	4.2	24.5	10.2	9.1¤	6.0
	July 16	77	15.8	8.1	7.0	9.5	24.2	7.0¤	6.0	4.9
	July 17	78	13.6	9.2	8.3	8.9	19.3	7.4	5.0	5.0
	July 18	79	19.6¤	13.9	14.5	12.7	21.9	10.7	5.3	2.4
	July 19	80	19.9¤	14.5	13.6	11.9	24.3	10.4	5.0	1.5
	July 20	81	20.2¤	14.8	14.8	11.9	25.2	10.7	6.2	3.9
	July 21	82	21.0¤	14.8	14.2	12.7	15.7¤	7.4	3.9	2.7
	AVERAGE		**14.6**	**10.8**	**9.8**	**9.0**	**22.9**	**10.1**	**5.3**	**4.1**
5	July 22	83	18.3	14.8	12.1	10.8¤	17.9	11.4	8.4	7.1
	July 23	84	21.0	17.0	13.3	11.1¤	24.4	14.8	9.6	7.4
	July 24	85	18.6	15.8	13.3	11.8	23.5	14.2	8.4	9.3
	July 25	86	-	-	-	-	-	-	-	-
	July 26	87	-	-	-	-	-	-	-	-
	July 27	88	-	-	-	-	-	-	-	-
	July 28	89	21.3	17.0	13.9	12.7	20.4	14.2	9.3	9.6
	July 29	90	22.3	16.1	15.5	12.4	21.3	15.5	8.7	10.8
	July 30	91	21.0	15.5	14.8	12.4	21.3	14.2	8.7	10.8
	July 31	92	23.9¤	18.4	16.4¤	13.7¤	23.6	16.7	10.2¤	12.0¤
	Aug 1	93	18.1	12.6	13.3	12.3	20.8	10.9	7.9	7.2
	Aug 2	94	18.4	12.6	12.6	12.3	16.4	9.9	7.5¤	7.5
	Aug 3	95	18.4	12.6	12.3	12.6	17.8	10.9	8.9	8.2
	Aug 4	96	18.1	12.3	12.3	12.3	16.7	9.9	9.2	8.5
	AVERAGE		**19.6**	**15.0**	**13.3**	**12.3**	**20.4**	**13.0**	**8.8**	**8.6**
6	Aug 5	97	15.4	11.3	10.9¤	12.0¤	19.1	9.9	8.5	8.5¤
	Aug 6	98	16.4¤	10.2	10.2	10.6	20.2	12.6	5.8	6.8¤
	Aug 7	99	15.4	10.2	9.6	9.9	18.8	8.9	5.5	5.5
	Aug 8	100	14.7	10.3	9.2	8.9	20.2	8.2	4.5	4.8
	Aug 9	101	13.7	8.9	8.2¤	8.9	19.5	7.5	3.1	3.4
	Aug 10	102	13.4	9.6	8.9	8.9	19.9	7.2	3.1	2.7
	Aug 11	103	14.0	11.0	9.9	9.2	23.6	7.9	3.1	3.1
	Aug 12	104	14.0	9.9	9.6	9.2	21.6	8.9	3.4	3.8
	Aug 13	105	15.1	9.6	9.6	9.6	23.6	7.5	2.7	1.7
	Aug 14	106	14.7	11.0	9.6	9.2	22.3	6.8	2.1	1.7
	Aug 15	107	14.5	11.7¤	10.0	9.3	25.2¤	7.2	3.1	2.1
	Aug 16	108	14.5	10.0	10.3	9.7	25.2¤	4.1	1.4	5.2
	Aug 17	109	12.4	10.0	9.0	9.0	19.3	4.8	1.7	1.4
	Aug 18	110	12.1	10.0	9.0	8.6	20.7	5.9	3.1	1.7

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	Aug 19	111	12.8	10.3	10.7	2.4¤	19.3	5.9	3.1	2.4
	Aug 20	112	12.8	10.7	9.7	9.7	22.4	13.8¤	9.7¤	3.1
	Aug 21	113	12.4	10.3	9.3	9.0	22.4	10.3	9.7¤	3.1
	Aug 22	114	11.6¤	11.6	10.3	8.9	22.9	15.4¤	7.9	3.1
	AVERAGE		**13.9**	**10.3**	**9.7**	**9.3**	**21.0**	**7.7**	**3.9**	**3.0**
7	Aug 23	115	13.0	10.6	8.9	8.6¤	26.0	12.3	4.1	8.9¤
	Aug 24	116	13.3	9.9	7.9	7.5	23.6	14.0	1.0	1.4
	Aug 25	117	13.0	10.3	7.9	7.2	23.6	14.7	11.0	1.0
	Aug 26	118	13.3	7.9	6.5¤	6.8	23.6	9.2	2.7	1.0
	Aug 27	119	12.3	7.5	8.6	6.8	23.6	13.7	3.4	0.7
	Aug 28	120	13.0	8.2	7.2	6.8	22.6	10.3	7.2	2.1
	Aug 29	121	14.6	10.8	8.7	7.7	23.7	9.4	3.1	3.5
	Aug 30	122	14.6	9.1	8.7	7.3	24.4	10.8	11.5	1.4
	Aug 31	123	13.9	9.4	11.8¤	8.0	25.1	15.7	8.4	2.4
	Sept 1	124	14.3	10.8	9.7	7.3	24.0	11.5	8.0	2.4
	Sept 2	125	13.6	10.1	10.1	7.0	31.0¤	30.6¤	24.7¤	3.5
	Sept 3	126	14.6	9.1	10.1	7.3	23.3	13.6	9.1	2.4
	Sept 4	127	12.9	7.7	7.3	7.3	23.7	11.1	7.7	2.1
	Sept 5	128	12.5	8.7	8.7	6.6	25.6	16.3	6.2	1.0
	Sept 6	129	14.2	9.3	7.6	6.2¤	25.6	10.4	3.8	1.0
	Sept 7	130	14.5	10.0	8.7	7.3	26.3	12.8	6.2	1.7
	AVERAGE		**13.6**	**9.3**	**8.6**	**7.2**	**24.3**	**12.4**	**6.2**	**1.8**
8	Sept 8	131	11.8¤	10.0	9.0	7.6¤	20.4	11.1	8.3	4.5
	Sept 9	132	14.2	9.0	8.7	8.7	17.7	7.3	3.8	3.1
	Sept 10	133	15.9	10.7	11.4	9.3	23.5	12.8	7.6	3.8
	Sept 11	134	15.9	10.7	11.4	9.7	24.9	12.5	5.2	3.5
	Sept 12	135	16.1	10.4	11.1	10.0	23.2	10.4	6.4	3.6
	Sept 13	136	16.1	10.7	11.4	9.6	23.9	11.8	6.1	3.6
	Sept 14	137	18.2	12.1	11.8	10.4	28.2	15.0	6.4	3.9
	Sept 15	138	18.9	11.4	11.8	10.7	21.4	4.6	0.7	2.5
	Sept 16	139	16.1	11.1	11.1	10.7	17.5	4.6	1.8	2.9
	Sept 17	140	16.1	10.7	11.1	10.4	18.6	5.0	2.9	3.9
	Sept 18	141	16.4	11.1	9.6	10.4	24.3	8.6	2.1	3.6
	Sept 19	142	22.5¤	18.9¤	17.9¤	16.4¤	31.4¤	12.9	8.2	6.4¤
	Sept 20	143	15.4	11.8	8.6	11.4	21.8	6.4	3.2	4.6
	Sept 21	144	16.8	11.8	12.1	11.4	22.1	7.9	3.9	4.6
	AVERAGE		**16.3**	**10.9**	**10.7**	**10.2**	**22.1**	**9.3**	**4.8**	**3.7**
9	Sept 22	145	12.1¤	9.3	11.4	10.0	21.8	7.5	2.9	5.0
	Sept 23	146	13.8	8.1	7.4	8.8	19.9	7.4	2.7	3.7
	Sept 24	147	13.8	25.3¤	26.3¤	27.4¤	14.5	3.7	4.7¤	4.1
	Sept 25	148	13.8	26.0¤	25.7¤	26.3¤	16.5	6.8	1.7	3.0
	Sept 26	149	13.5	25.3¤	9.1	8.1	21.6	7.1	2.4	2.0
	Sept 27	150	14.5	9.1	8.1	8.1	18.9	4.1	1.4	1.4
	Sept 28	151	13.5	8.8	9.1	8.8	16.2	15.5¤	2.0	2.7
	Sept 29	152	13.8	8.8	8.8	8.4	25.3¤	20.3¤	3.4	4.1
	Sept 30	153	13.9	9.5	8.2	8.2	17.0	4.4	1.0	3.4
	Oct 1	154	14.3	7.8	7.5	9.2	17.0	6.8	5.1¤	5.1¤
	Oct 2	155	14.6	13.6	13.6	12.6	20.4	5.4	1.0	2.7
	Oct 3	156	14.9¤	7.5	4.8	8.5	18.0	3.1	1.7	1.7
	Oct 4	157	13.6	5.8	4.8	4.4	19.0	4.4	1.4	1.0
	AVERAGE		**13.9**	**8.8**	**8.4**	**8.6**	**18.4**	**5.5**	**2.0**	**2.9**
10	Oct 5	158	16.3	7.1¤	7.5¤	5.8¤	19.7¤	5.4	3.1	1.4
	Oct 6	159	16.5	10.3	10.6	8.6	22.3	6.2	2.1	2.7
	Oct 7	160	16.5	11.0	9.6	9.3	25.1	12.4	2.1	2.7
	Oct 8	161	16.5	10.3	10.3	9.6	21.0	4.5	1.4	2.1
	Oct 9	162	16.8	10.3	10.0	9.3	25.1	5.5	1.4	1.0
	Oct 10	163	16.8	10.6	10.0	8.9	22.7	4.5	1.0	1.0
	Oct 11	164	16.5	10.3	11.0	9.3	24.0	5.8	1.7	1.7
	Oct 12	165	17.5	10.3	10.3	8.9	26.1	5.8	1.7	2.1
	Oct 13	166	17.3	12.2¤	13.2¤	11.2	26.7	12.2	4.1	0.3
	Oct 14	167	18.3	10.2	10.5	11.5	27.4	10.5	4.1	1.0
	Oct 15	168	17.9	12.5¤	11.5	11.5	24.4	8.8	5.4	0.3

¤ Data rejected as outliers at 10% level of significance.

	Oct 16	169	18.6	11.5	11.2	10.5	28.1	10.2	4.7	5.4¤
	Oct 17	170	18.3	10.5	11.5	9.8	28.4	8.8	4.4	5.8¤
	AVERAGE		**17.2**	**10.5**	**10.6**	**9.9**	**25.1**	**7.7**	**2.9**	**1.5**
11	Oct 18	171	19.6¤	10.8	11.2	10.5	22.7	8.1	4.1	5.1¤
	Oct 19	172	18.6¤	11.2	12.2	10.5	26.4	8.5	12.5¤	5.1¤
	Oct 20	173	16.4	23.6¤	5.1¤	9.2	23.6	6.5	2.7	2.7
	Oct 21	174	16.4	7.9	7.2	8.6	22.6	7.5	1.7	2.4
	Oct 22	175	15.7	8.9	10.3	8.2	18.1¤	4.1	1.4	2.4
	Oct 23	176	16.4	9.2	9.6	8.9	26.4	8.2	1.7	2.1
	Oct 24	177	16.8	9.2	9.2	7.9	21.9	5.5	1.0	2.1
	Oct 25	178	16.4	12.3	12.3	8.6	21.9	5.1	1.7	2.4
	Oct 26	179	17.1	10.3	10.3	9.9	20.2	4.8	1.7	3.1
	Oct 27	180	16.6	9.3	9.0	9.3	21.4	7.2	2.4	4.5
	Oct 28	181	16.6	10.0	9.7	8.3	24.8	7.2	1.7	3.1
	Oct 29	182	16.6	10.7	11.4	9.7	19.7	4.8	1.4	2.8
	Oct 30	183	16.2	10.7	11.0	10.3	25.9	7.2	1.4	2.4
	Oct 31	184	15.9	10.0	9.3	9.7	19.3	4.1	1.7	2.8
	AVERAGE		**16.4**	**10.0**	**10.2**	**9.3**	**22.8**	**6.4**	**1.9**	**2.7**
12	Nov 1	185	16.9	11.4	10.3	10.0	21.4	6.2	2.8¤	2.4
	Nov 2	186	16.9	10.3	10.7	10.3	19.3	3.8	1.0	3.1¤
	Nov 3	187	17.2	10.5	8.8	9.8	29.0	1.7	1.7	1.7
	Nov 4	188	18.6¤	10.1	9.8	9.4	20.6	3.7	1.0	1.3
	Nov 5	189	18.6¤	9.8	10.1	9.4	20.6	15.2	2.7	2.0
	Nov 6	190	16.9	11.1	9.1	8.8	39.8	21.6	1.3	3.0¤
	Nov 7	191	17.5	9.8	10.5	8.8	39.8	3.4	1.0	0.7
	Nov 8	192	17.5	11.1	10.5	9.1	40.8	7.1	1.0	0.7
	Nov 9	193	18.2	12.1	12.1	9.8	39.1	7.8	1.3	0.7
	Nov 10	194	16.6	16.2¤	17.2¤	12.1	32.4	11.7	3.4¤	1.7
	Nov 11	195	16.9	15.5¤	14.1	15.2¤	31.0	8.3	1.7	1.0
	Nov 12	196	16.6	12.8	14.1	12.8	35.2	11.7	1.4	1.0
	Nov 13	197	16.9	13.8	11.7	11.4	34.5	11.0	1.7	1.0
	Nov 14	198	-	-	-	-	-	-	-	-
	Nov 15	199	17.6	11.0	10.7	10.7	17.2	4.5	1.4	1.0
	Nov 16	200	152¤	9.0	9.3	9.3	18.3	4.1	1.4	1.0
	AVERAGE		**17.1**	**11.0**	**10.8**	**10.1**	**29.3**	**8.1**	**1.4**	**1.3**
13	Nov 17	201	16.6	9.0	9.3	9.3	17.9¤	4.1¤	1.4	1.0
	Nov 18	202	15.0	9.9	8.2	8.2	20.5	5.8	2.0	1.7
	Nov 19	203	14.3	8.5	9.5	7.8	21.8	6.1	1.4	1.0
	Nov 20	204	14.3	8.5	9.5	9.2	23.9	6.8	1.0	1.4
	Nov 21	205	16.0	10.6	9.5	8.2	22.5	5.8	1.0	1.0
	Nov 22	206	15.3	9.5	8.9	8.5	23.9	5.8	1.4	1.0
	Nov 23	207	15.0	9.9	10.6	8.9	24.6	6.1	1.4	1.0
	Nov 24	208	15.3	10.6	9.5	9.2	20.8	5.1	1.0	1.0
	Nov 25	209	11.9¤	10.1	9.0	10.1¤	20.9	6.8	1.8	1.1
	Nov 26	210	11.9¤	10.1	10.4	9.0	22.0	5.4	1.4	0.7
	Nov 27	211	14.0	9.4	11.2	9.4	29.5¤	6.8	1.4	0.7
	Nov 28	212	14.4	9.7	14.8¤	9.0	25.9	5.8	1.1	1.1
	Nov 29	213	15.1	11.2¤	6.1¤	9.0	25.2	6.5	0.7	0.7
	Nov 30	214	-	-	-	-	-	-	-	-
	Dec 1	215	19.4¤	9.4	14.8¤	9.0	28.4¤	9.7¤	3.6	4.0
	Dec 2	216	13.0	8.7	10.0	7.7	27.0	8.7	3.3	4.0
	Dec 3	217	13.0	8.3	8.0	7.7	20.7	9.3	3.0	3.0
	Dec 4	218	14.7	9.0	9.7	7.7	21.7	9.7	6.3¤	7.0¤
	Dec 5	219	14.0	9.0	9.0	7.7	20.7	9.7	8.0¤	6.3¤
	AVERAGE		**14.7**	**9.4**	**9.5**	**8.6**	**22.8**	**6.9**	**1.7**	**1.5**
	Dec 6	220	12.7	9.0	9.7	8.0	20.3¤	5.0¤	0.3	1.0
	Dec 7	221	13.0	9.3	10.0	8.3	28.7	8.3	0.7	0.3
	Dec 8	222	13.3	9.7	8.0	8.0	28.0	8.0	0.7	0.3
	Dec 9	223	13.2	6.8	5.1	6.4	22.6	7.8	0.3	0.3
	Dec 10	224	12.5	6.4	6.8	5.4	20.6¤	4.7¤	0.3	0.3
	Dec 11	225	13.2	7.1	5.4	5.7	27.7	7.1	0.3	0.3
	Dec 12	226	13.2	7.8	6.8	5.7	27.0	6.8	0.7	0.7

¤ Data rejected as outliers at 10% level of significance.

14	Dec 13	227	12.8	7.8	7.8	6.1	25.3	6.8	0.3	0.3
	Dec 14	228	13.5	7.8	7.8	6.1	25.7	6.4	0.3	0.3
	Dec 15	229	12.8	6.8	6.8	6.1	25.0	6.4	0.3	0.3
	Dec 16	230	15.9	20.4¤	17.0¤	14.2¤	30.1	8.0	1.0	1.0
	Dec 17	231	15.9	6.9	4.8	7.3	27.3	10.0¤	1.7	0.7
	Dec 18	232	15.9	8.0	6.9	9.3	25.3	7.6	1.7	0.7
	Dec 19	233	15.6	9.3	10.4	7.6	26.7	8.3	1.7	1.0
	Dec 20	234	16.3	9.3	8.7	9.3	31.5¤	9.0	2.1	1.0
	Dec 21	235	15.6	10.0	10.7	9.3	26.0	7.6	1.4	1.0
	Dec 22	236	17.0	10.4	11.1	9.7	29.4	8.7	2.1	0.7
	Dec 23	237	17.3	8.7	10.0	9.7	23.5	8.3	2.8	1.0
	Dec 24	238	15.9	9.3	8.0	9.0	28.7	9.3	4.5¤	1.0
	Dec 25	239	15.9	10.7	8.3	8.3	29.8	9.0	1.0	0.7
	AVERAGE		**14.6**	**8.5**	**8.0**	**7.7**	**26.9**	**7.8**	**1.0**	**0.7**
15	Dec 26	240	20.4¤	9.7	8.7	9.3	29.8	13.5	2.1	1.0
	Dec 27	241	21.1¤	10.4	9.3	9.0	34.3¤	16.6¤	2.1	0.7
	Dec 28	242	18.0	9.7	8.7	8.3	34.0¤	14.5	2.1	1.4
	Dec 29	243	17.1	9.7	8.7	8.0	27.9	15.0¤	1.4	0.7
	Dec 30	244	14.7	8.9	8.9	8.2	24.3	10.9	2.0	1.4
	Dec 31	245	14.3	10.6	7.5	8.2	26.0	10.2	1.7	1.4
	Jan 1 96	246	13.7	8.2	6.5	7.5	21.9	10.6	1.0	1.4
	Jan 2	247	13.3	8.9	7.5	7.5	23.9	9.2	3.1¤	1.7
	Jan 3	248	17.1	9.1	7.7	7.7	22.8	10.1	2.0	0.7
	Jan 4	249	17.5	10.1	7.7	7.4	24.2	10.4	3.1¤	1.0
	Jan 5	250	17.5	8.4	7.4	7.4	25.9	10.1	0.7	0.7
	Jan 6	251	13.2	7.3	7.0	7.3	15.7	4.9¤	0.7	0.3
	Jan 7	252	13.2	7.3	7.0	7.3	19.1	6.6	2.1	0.3
	Jan 8	253	13.6	8.4	7.0	7.7	20.5	9.4	1.0	0.3
	Jan 9	254	13.9	13.9¤	15.3¤	9.1	16.0	6.3	1.0	0.3
	Jan 10	255	14.0	13.3¤	13.7¤	12.0¤	13.3¤	5.1¤	1.7	1.4
	Jan 11	256	14.3	3.6¤	1.7¤	5.1¤	18.4	9.6	2.0	1.0
	Jan 12	257	14.3	5.8¤	4.1¤	2.4¤	18.4	8.9	1.0	1.0
	AVERAGE		**15.0**	**9.0**	**7.8**	**8.0**	**22.3**	**10.0**	**1.5**	**0.9**
16	Jan 13	258	17.4	8.5	6.8	6.1	31.8	13.7	2.0	1.4
	Jan 14	259	18.4	11.3¤	7.5	7.9	32.4	12.0	1.0	1.4
	Jan 15	260	18.1	8.2	8.5	8.5	29.4	12.0	1.4	1.0
	Jan 16	261	17.7	7.9	7.9	7.2	32.1	11.1	1.3	0.7
	Jan 17	262	17.4	8.2	6.9	7.2	18.4	9.8	1.6	0.7
	Jan 18	263	11.8	7.2	6.2	7.2	17.4	8.2	0.7	0.7
	Jan 19	264	11.5	6.9	6.9	7.2	15.4	7.5	1.0	1.0
	Jan 20	265	12.5	7.9	7.9	7.2	17.1	9.2	3.3¤	0.7
	Jan 21	266	12.3	7.2	6.8	6.8	15.0	7.2	2.4	1.7¤
	Jan 22	267	12.3	14.3¤	19.8¤	9.9¤	18.1	8.5	1.7	1.0
	Jan 23	268	12.6	3.4¤	3.1¤	3.1¤	19.1	9.2	1.7	0.7
	Jan 24	269	12.8	4.5¤	4.5	2.8¤	16.9	7.9	1.0	1.0
	Jan 25	270	12.8	7.2	5.5	4.5	16.2	7.6	1.4	1.0
	Jan 26	271	12.8	7.2	5.9	5.5	23.4	16.2¤	1.7	1.4
	AVERAGE		**14.3**	**7.6**	**6.8**	**6.9**	**21.6**	**9.5**	**1.5**	**1.0**
17	Jan 27	272	15.2	7.9	7.6	6.9	23.4	8.3	3.8¤	1.4
	Jan 28	273	15.5	7.9	6.9	6.6	25.9	9.7	3.1	1.0
	Jan 29	274	17.6¤	8.3	5.5¤	7.2	26.9	11.0	3.4	1.0
	Jan 30	275	15.9	8.3	5.9	6.6	29.0	13.1	1.7	1.4
	Jan 31	276	15.9	9.0	7.9	6.9	27.9	11.4	1.4	1.0
	Feb 1	277	15.9	10.0	7.2	7.6	23.1	10.0	1.0	0.7¤
	Feb 2	278	15.5	9.3	7.6	7.2	25.9	12.4	1.0	1.4
	Feb 3	279	15.9	9.7	6.9	7.6	23.8	10.3	2.8	1.4
	Feb 4	280	13.8¤	9.7	6.7	6.4	21.5	8.7	0.7	1.0
	Feb 5	281	13.8¤	8.4	6.7	6.4	18.8¤	8.7	1.7	1.3
	Feb 6	282	14.8	10.7	8.1	7.1	24.2	10.1	1.0	1.0
	Feb 7	283	15.4	9.1	5.7	6.7	17.5¤	9.7	1.3	1.0
	Feb 8	284	15.8	10.1	8.4	6.4	24.2	11.1	2.0	0.7¤
	Feb 9	285	15.4	10.1	7.1	6.0	26.5	13.8¤	1.7	1.0

¤ Data rejected as outliers at 10% level of significance.

	AVERAGE		**15.6**	**9.2**	**7.1**	**6.8**	**25.2**	**10.4**	**1.8**	**1.2**
18	Feb 10	286	15.8	8.4¤	6.4¤	5.7¤	29.2	13.4	1.0	0.3
	Feb 11	287	15.8	10.1	9.7	7.1	27.2	10.4	1.3	0.3
	Feb 12	288	15.4	10.7	10.1	7.7	26.2	9.4	0.3	0.3
	Feb 13	289	15.4	10.7	10.1	8.1	24.2	8.7	0.7	0.3
	Feb 14	290	16.9	12.8	11.0	9.0	28.6	12.1	2.8	1.7
	Feb 15	291	14.5¤	11.0	10.3	8.6	28.6	14.1	6.2	4.1
	Feb 16	292	17.2	12.4	12.4	9.7	27.2	14.5	6.6¤	6.2
	Feb 17	293	16.9	12.8	11.4	10.0	26.9	13.1	5.9	5.5
	Feb 18	294	16.2	10.7	10.3	9.7	25.2	11.4	3.4	4.8
	Feb 19	295	16.6	11.0	11.4	9.0	24.8	9.7	3.1	3.8
	Feb 20	296	16.9	10.3	11.4	10.7	21.7¤	10.0	2.4	3.1
	Feb 21	297	16.9	9.0	9.0	8.3	24.8	5.5¤	1.7	2.1
	AVERAGE		**16.4**	**11.1**	**10.6**	**8.9**	**26.6**	**11.5**	**2.6**	**2.7**
19	Feb 22	298	15.5	9.3	10.0	8.3	16.6	6.9	1.7	1.0
	Feb 23	299	14.8	9.3	9.3	8.3	15.2	6.9	1.4	0.7¤
	Feb 24	300	15.9	8.6	8.3	8.6	15.5	7.9	1.0	1.0
	Feb 25	301	15.9	9.0	9.0	8.6	14.8	7.9	2.4¤	1.0
	Feb 26	302	15.5	10.0	10.0	9.0	20.7	9.7	1.4	1.4
	Feb 27	303	14.7	10.0	9.7	9.4¤	22.8	9.0	1.7	2.3
	Feb 28	304	15.1	9.0	8.4	8.4	18.7	8.0	2.0	2.0
	Feb 29	305	15.1	10.4	9.4	7.0¤	20.4	8.4	1.3	2.0
	March 1	306	15.4	9.7	9.4	8.7	17.7	7.4	1.7	2.0
	March 2	307	15.4	9.7	8.7	8.7	18.7	9.0	1.0	2.0
	March 3	308	15.1	9.0	8.4	8.7	16.1	7.7	1.3	1.3
	March 4	309	15.1	8.7	9.4	8.7	13.4	5.7¤	1.3	1.7
	March 5	310	13.3	8.4	8.4	8.1	13.6	5.2¤	1.0	1.9
	March 6	311	13.9¤	7.8¤	8.1	8.1	13.3	5.2¤	0.6¤	1.3
	March 7	312	13.6¤	8.4	8.4	8.7	14.9	7.4	1.3	1.6
	AVERAGE		**15.1**	**9.3**	**9.0**	**8.5**	**16.8**	**8.0**	**1.4**	**1.6**
20	March 8	313	13.9	7.8	8.1	8.1	18.5¤	9.1	2.3	2.9
	March 9	314	13.9	7.1	6.8	7.1	26.2	12.3	2.9	2.9
	March 10	315	14.2	11.7¤	7.4	7.4	33.0	11.3	1.3	1.6
	March 11	316	14.6	11.7¤	7.8	7.1	31.1	10.0	1.6	1.3
	March 12	317	14.6	7.8	7.1	6.8	28.5	9.4	1.6	0.6
	March 13	318	15.7	8.2	8.8	7.8	25.5	8.5	2.0	1.7
	March 14	319	15.3	8.2	8.5	8.2	25.5	6.8	1.4	0.3
	March 15	320	15.7	9.5	9.5	8.2	25.2	8.2	1.4	0.7
	March 16	321	15.7	10.2	10.9	8.5	26.2	9.9	1.4	0.7
	March 17	322	15.7	9.9	10.2	8.8	31.6	11.6	1.4	1.0
	March 18	323	16.0	9.5	9.2	7.5	33.7	20.1¤	12.3¤	6.1¤
	March 19	324	16.0	9.9	10.9	9.5	30.6	12.6	1.7	1.0
	March 20	325	15.7	9.5	9.5	8.2	27.6	9.9	1.7	0.7
	AVERAGE		**15.1**	**8.9**	**8.8**	**7.9**	**28.7**	**10.0**	**1.7**	**1.3**
21	March 21	326	15.7	8.3	8.7	7.3	14.0¤	3.7	2.0	1.3
	March 22	327	15.0	9.0	9.3	8.7	22.3	14.7	10.3	1.7
	March 23	328	15.0	10.0¤	8.3	8.0	24.7	10.0	2.0	0.7
	March 24	329	15.0	9.3	8.0	7.7	23.0	9.3	2.3	0.7
	March 25	330	15.3	9.0	10.3	8.3	30.7	27.3¤	23.0	4.7
	March 26	331	15.0	9.7	8.0	7.7	24.0	10.3	2.0	2.7
	March 27	332	15.7	9.3	12.0	8.3	39.7¤	39.7¤	36.3¤	13.3¤
	March 28	333	15.0	8.0	8.7	7.0	22.0	7.3	0.7	0.7
	March 29	334	15.3	8.0	8.0	6.7	20.7	8.0	0.7	0.7
	March 30	335	15.3	9.3	7.3	7.0	20.0	8.7	1.7	1.0
	March 31	336	15.3	9.0	9.0	7.3	21.3	9.7	1.0	1.3
	April 1	337	16.3¤	9.0	9.3	7.3	23.0	9.7	1.0	0.7
	April 2	338	16.3¤	9.0	9.0	7.0	20.7	8.7	1.0	0.3
	April 3	339	16.0	9.3	9.0	7.7	19.3	7.3	1.0	0.7
	AVERAGE		**15.3**	**8.9**	**8.9**	**7.6**	**22.6**	**8.9**	**3.7**	**1.3**
	April 4	340	13.4	8.5	12.2	8.8	36.0¤	41.4¤	32.6¤	18.6¤
	April 5	341	13.7	8.2	9.8	7.6	20.7	7.6	1.2	2.4
	April 6	342	13.7	8.5	9.4	7.6	21.6	7.6	1.2	0.6

¤ Data rejected as outliers at 10% level of significance.

22	April 7	343	13.7	9.8	8.5	7.0	20.7	7.6	1.2	0.6
	April 8	344	13.7	9.1	9.4	7.9	20.4	7.6	1.2	0.6
	April 9	345	13.7	9.1	10.1	8.2	20.7	7.9	0.9	0.9
	April 10	346	15.7	10.4	11.4	9.1	26.8	11.1	2.6	2.3
	April 11	347	15.7	11.4	11.8	9.5	24.8	9.1	1.3	2.0
	April 12	348	16.0	15.0¤	12.1	10.4¤	26.1	10.1	1.6	2.3
	AVERAGE		**14.4**	**9.4**	**10.5**	**8.2**	**22.7**	**8.6**	**1.4**	**1.5**
23	April 13	349	13.4	10.1	9.5	10.1¤	20.2	7.8	2.0	1.3
	April 14	350	13.7	10.1	9.5	9.5	20.9	8.5	2.3	1.3
	April 15	351	13.7	9.8	10.8	9.5	21.9	8.8	2.3	1.6
	April 16	352	14.0	9.5	10.5	8,8¤	21.4	10.5	3.2	3.9
	April 17	353	14.0	10.2	11.9¤	9.5	29.5¤	26.7¤	17.2¤	8.1
	April 18	354	14.0	10.5	9.8	9.8	20.4	9.1	3.2	4.9
	April 19	355	13.7	9.5	10.5	9.8	20.0	8.8	3.2	3.5
	April 20	356	14.7	9.5	10.9	9.1	20.4	9.5	3.9	4.6
	April 21	357	14.7	10.5	9.8	9.1	19.7	10.5	6.0	5.3
	April 22	358	15.3¤	10.3	9.3	9.0	20.9	11.3	6.0	7.0
	April 23	359	13.0	9.6	9.6	9.6	16.9	12.3	8.0	6.6
	April 24	360	13.0	10.3	9.6	9.6	15.6¤	10.6	7.3	7.0
	AVERAGE		**13.8**	**10.0**	**10.0**	**9.5**	**20.3**	**9.8**	**4.3**	**4.6**
24	April 25	361	16.3	10.3	11.6	9.6	24.2	12.3	6.0	7.3
	April 26	362	15.9	10.6	11.6	10.0	22.3	10.0	3.0	3.7
	April 27	363	15.9	10.6	11.6	10.0	22.3	9.3	2.3	2.3
	April 28	364	14.3	10.0	11.0	9.6	21.9	9.6	2.7	2.3
	April 29	365	14.9	10.0	11.0	9.6	22.9	10.3	3.0	2.7
	April 30	366	14.3	10.7	11.8	10.0	21.8	10.0	3.6	3.2
	May 1	367	15.0	10.7	10.7	10.0	22.9	13.6	5.4	5.0
	May 2	368	17.5¤	11.8¤	11.4	10.7	26.1¤	12.1	5.4	5.7
	May 3	369	15.7	11.1	11.8	12.1¤	23.9	12.1	5.0	5.4
	May 4	370	16.1	10.7	12.1	10.0	22.1	12.5	6.1	5.4
	May 5	371	15.0	11.1	10.4	10.0	20.0	11.8	6.8	6.1
	May 6	372	16.7	11.3	12.3	11.7	19.3¤	11.7	6.7	7.0
	May 7	373	15.0	11.7	13.0	11.7	24.3	14.0	7.7	8.0
	AVERAGE		**15.4**	**10.7**	**11.6**	**10.2**	**22.6**	**11.5**	**4.9**	**4.9**
25	May 8	374	20.0¤	21.3¤	13.0	12.0	25.7	16.0¤	9.7¤	9.7¤
	May 9	375	19.3¤	13.7	12.3	12.7	26.7	14.7	8.3	9.3¤
	May 10	376	19.3¤	13.3	13.7¤	12.0	24.3	12.7	7.7	7.7
	May 11	377	14.3	11.3	11.7	12.3	18.7	8.7	4.7	5.0
	May 12	378	14.0	14.0	11.0	11.0	18.7	9.0	4.7	4.0
	May 13	379	14.3	10.3	11.0	10.3	21.0	13.3	5.0	5.3
	May 14	380	13.7	9.5	10.3	9.1	21.3	9.9	5.3	4.9
	May 15	381	13.3	8.8	11.4	8.8	21.3	10.3	4.9	5.7
	May 16	382	13.7	9.1	9.5	13.3	20.9	9.9	4.6	4.9
	May 17	383	14.5	9.9	10.3	9.1	19.0	9.1	4.6	4.9
	May 18	384	14.1	9.5	9.1	9.5	19.8	9.5	4.6	4.9
	May 19	385	14.1	10.3	10.3	9.5	35.4¤	9.9	3.8	5.3
	May 20	386	12.2	10.3	10.7	10.3	19.0	8.4	4.9	4.9
	AVERAGE		**13.8**	**10.8**	**10.9**	**10.8**	**21.4**	**10.4**	**5.3**	**5.3**
26	May 21	387	16.7¤	9.1	10.3	9.1	19.8¤	9.1	4.9	5.3
	May 22	388	13.9	9.4	10.4	9.4	18.4	9.4	6.3	6.3
	May 23	389	15.6	16.3¤	15.0¤	13.9¤	15.6	8.3	6.3	6.3
	May 24	390	14.3	9.7	10.1	9.7	16.7	9.0	6.3	5.6
	May 25	391	13.9	9.4	10.4	9.4	18.1	9.0	4.9	5.9
	May 26	392	14.3	10.1	10.4	9.7	17.7	9.0	5.9	5.9
	May 27	393	14.3	10.4	10.4	10.4	16.3	8.0	5.2	5.6
	May 28	394	13.9	10.1	10.4	9.7	16.3	8.7	6.3	6.3
	May 29	395	14.8	10.0	10.0	10.0	16.2	9.6	6.6	6.6
	May 30	396	13.6	9.6	10.0	10.3	12.9¤	8.1	5.9	6.3
	May 31	397	14.0	10.0	9.6	9.6	12.9¤	8.1	5.5	6.3
	AVERAGE		**14.3**	**9.8**	**10.2**	**9.7**	**16.9**	**8.8**	**5.8**	**6.0**
	June 1	398	15.5¤	9.2	9.6	9.6	14.8	7.4	5.2¤	6.3¤
	June 2	399	14.8¤	8.9	9.6	8.9	14.8	7.7	4.8	4.4

¤ Data rejected as outliers at 10% level of significance.

27	June 3	400	13.6	9.2	9.6	9.2	16.6	7.7	4.1	4.1
	June 4	401	13.3	9.2	9.6	9.2	15.5	7.4	4.1	4.8
	June 5	402	12.7	8.8	9.4	8.8	15.0	7.5	3.9	4.6
	June 6	403	12.4	9.1	15.6¤	14.0¤	15.0	7.5	4.6	4.6
	June 7	404	12.4	8.8	9.4	8.8	15.6	7.5	3.9	4.6
	June 8	405	12.7	9.8	9.1	9.1	15.6	7.8	4.6	4.6
	June 9	406	12.7	9.4	9.4	8.8	15.6	7.2	3.9	4.2
	June 10	407	13.0	8.8	9.4	9.1	17.6	7.8	3.6	3.6
	June 11	408	13.0	10.1	9.4	9.0	17.7	7.6	3.6	4.7
	June 12	409	13.0	13.0¤	9.0	11.9¤	18.8¤	10.5¤	2.9¤	3.6
	June 13	410	13.4	8.7	9.0	8.3	17.0	5.4¤	3.6	3.6
	AVERAGE		12.9	9.2	9.4	9.0	15.9	7.6	4.1	4.3
28	June 14	411	15.2¤	9.8	10.5	9.0	22.8	10.5	5.1	4.7
	June 15	412	11.2	7.6	8.0	8.3	14.5	6.1	3.6	4.0
	June 16	413	10.8¤	7.6	7.2	7.6	28.9¤	6.9	3.3	2.9
	June 17	414	11.6	6.5	7.2	6.5	17.4	6.9	2.5	2.9
	June 18	415	11.9	6.5	7.2	6.5	16.6	5.8	2.5	2.5
	June 19	416	13.4	7.6	9.0	7.2	17.4	7.2	2.9	2.2
	June 20	417	12.7	10.0	9.4	9.1	18.7	9.1	5.7	5.7
	June 21	418	13.0	9.4	10.0	9.1	17.2	10.0	6.3	6.0
	June 22	419	13.0	9.7	9.4	9.1	16.6	8.8	5.7	6.0
	June 23	420	-	-	-	-	-	-	-	-
	June 24	421	13.9	10.0	10.3	9.4	17.8	9.7	5.7	5.4
	June 25	422	13.3	10.0	9.4	9.4	16.6	8.8	5.4	5.4
	June 26	423	13.0	7.8	8.9	7.5	20.8	6.5	4.4	4.1
	June 27	424	12.6	7.8	8.5	7.2	19.8	5.5	2.0	4.1
	AVERAGE		12.7	8.5	8.8	8.1	18.0	7.8	4.3	4.3
29	June 28	425	14.7	9.2	9.2¤	7.8¤	16.4	6.1	4.4	3.1
	June 29	426	14.3	9.9	10.6	8.9	19.1	7.5	3.1	3.4
	June 30	427	15.3	10.2	10.2	9.5	17.0	6.1	2.4	3.4
	July 1	428	14.7	9.9	11.3	10.2	20.5	7.8	2.7	3.4
	July 2	429	15.7¤	11.6	10.9	9.2	23.5¤	9.5	5.1	4.1
	July 3	430	15.9¤	11.4	12.4¤	10.7	23.8¤	10.3¤	5.2	4.5
	July 4	431	13.8	10.0	9.7	10.7	17.9	7.9	4.8	4.8
	July 5	432	14.1	10.0	11.4	10.3	20.0	8.6	5.2	6.6¤
	July 6	433	14.5	10.3	12.8¤	10.3	20.7	8.6	5.2	5.2
	July 7	434	13.8	10.7	10.0	10.0	16.2	7.6	4.8	5.2
	July 8	435	14.5	11.0	11.0	10.0	19.3	9.0	5.5	5.5
	July 9	436	15.1	11.7	10.6	10.6	19.2	7.5	3.8	5.1
	July 10	437	14.4	14.1¤	10.6	10.3	18.5	6.9	3.8	3.4
	July 11	438	14.1	11.0	10.6	10.3	17.8	6.9	3.4	3.4
	July 12	439	13.7	10.3	10.3	9.9	15.1¤	6.5	3.4	3.4
	AVERAGE		14.4	10.5	10.6	10.1	18.6	7.6	4.2	4.1
30	July 13	440	14.4	9.9	9.9	9.9	12.0	6.2¤	4.1¤	4.5
	July 14	441	15.4	9.9	10.3	9.6	11.3¤	7.5	5.8	5.1
	July 15	442	15.4	10.3	10.3	9.9	15.8	9.9	7.9	7.2
	July 16	443	15.7	11.3	11.9	11.6	17.4	10.9	8.5	9.9
	July 17	444	16.7	10.9	11.3	7.2	18.4	10.6	7.8	8.2
	July 18	445	-	-	-	-	-	-	-	-
	July 19	446	15.7	12.3	11.6	12.3	20.1	10.6	8.5	8.9
	July 20	447	15.7	11.6	11.3	11.6	17.4	12.3	10.2	10.2
	July 21	448	16.0	11.3	10.9	11.3	17.4	11.6	13.3¤	12.6¤
	July 22	449	14.0	10.6	11.3	11.3	14.0	6.1¤	4.1¤	5.5
	July 23	450	16.7	11.9	12.3¤	10.6	18.4	9.5	7.5	5.5
	July 24	451	14.0	9.9	10.2	9.5	13.6	9.2	8.5	8.5
	July 25	452	13.6	11.3	10.2	9.5	24.9¤	8.5	7.5	8.2
	AVERAGE		15.3	10.9	10.8	10.4	16.5	10.1	8.0	7.4
	July 26	453	12.6	8.9	8.5	9.2	11.9	7.8	6.5¤	7.2
	July 27	454	11.6	8.5	8.2	8.5	9.5	7.2¤	6.5¤	6.5¤
	July 28	455	12.6	8.5	8.5	8.5	9.9	8.5	8.2	7.8
	July 29	456	12.6	8.5	8.9	8.5	10.2	8.9	8.5	8.5
	July 30	457	12.6	8.5	8.5	8.5	9.5	8.5	8.5	7.8

¤ Data rejected as outliers at 10% level of significance.

31	July 31	458	12.2	8.5	8.8	9.2	11.9	10.2¤	9.5	9.9
	Aug 1	459	11.9	8.5	9.2¤	9.2	15.3¤	10.2¤	9.5	9.5
	Aug 2	460	11.5	8.8	8.5	8.5	12.6	9.9	8.5	9.9
	Aug 3	461	11.2	8.5	8.5	8.5	11.9	8.8	8.5	8.5
	Aug 4	462	12.9	8.8	8.8	8.8	10.9	8.8	8.2	8.5
	Aug 5	463	11.5	8.8	8.5	8.5	11.9	8.8	7.8	8.2
	Aug 6	464	-	-	-	-	-	-	-	-
	AVERAGE		**12.1**	**8.6**	**8.6**	**8.7**	**11.0**	**8.8**	**8.6**	**8.6**
32	Aug 7	465	12.6¤	9.2	8.8¤	8.5¤	15.3	6.8	5.1	5.8
	Aug 8	466	14.5	9.3	9.7	9.3	14.5	7.3	5.5	5.2
	Aug 9	467	14.2	8.6¤	9.3	9.3	15.6	8.0	4.8	4.5
	Aug 10	468	14.2	9.3	9.7	9.3	15.9	8.7	4.2	4.2
	Aug 11	469	14.5	9.3	9.7	10.0¤	14.9	6.9	4.2	4.2
	Aug 12	470	14.5	10.7¤	10.0	10.0¤	17.3	9.7¤	6.9¤	5.9
	Aug 13	471	14.2	9.7	10.4	9.3	17.3	9.3	6.9¤	7.3¤
	Aug 14	472	13.7	9.6	10.3	9.2	17.1	8.9	6.2	6.2
	Aug 15	473	13.7	10.3	9.9	8.9	17.1	7.2	4.5	4.1
	Aug 16	474	14.0	9.9	9.9	9.2	16.4	6.8	4.5	3.8
	Aug 17	475	13.7	9.9	10.6¤	9.6	18.1	7.9	4.8	4.8
	Aug 18	476	13.4	9.9	10.6¤	9.6	18.1	7.5	4.1	4.1
	Aug 19	477	13.0	10.3	9.6	9.6	18.8¤	7.5	4.1	4.1
	AVERAGE		**14.0**	**9.7**	**9.9**	**9.4**	**16.5**	**7.7**	**4.7**	**4.7**
33	Aug 20	478	14.7	10.6	9.9	9.2	18.5	9.9	7.5	5.1
	Aug 21	479	14.7	10.0	10.0	9.3	11.8	6.0¤	5.0	5.0
	Aug 22	480	14.7	10.0	10.0	9.7	12.9	7.9	6.1	5.4
	Aug 23	481	14.7	9.7	9.7	9.3	13.3	8.6	6.8	7.2
	Aug 24	482	13.3¤	9.3¤	9.3	9.3	12.6	8.6	7.2	7.5
	Aug 25	483	19.0¤	10.4	11.8¤	9.7	17.9	10.8	7.9	8.6
	Aug 26	484	16.5	10.4	10.8	10.4	18.3	10.8	7.5	7.9
	Aug 27	485	15.6	10.8	10.8	10.8	16.2	9.5	7.4	7.8
	Aug 28	486	15.2	10.8	10.8	10.8	14.2	9.1	7.4	7.8
	Aug 29	487	15.2	10.8	10.8	10.8	13.2	8.1	5.4	6.4
	Aug 30	488	15.6	11.2	10.8	10.8	13.9	8.5	5.8	6.4
	Aug 31	489	-	-	-	-	-	-	-	-
	Sept 1	490	-	-	-	-	-	-	-	-
	AVERAGE		**15.2**	**10.5**	**10.3**	**10.0**	**14.8**	**9.2**	**6.7**	**6.8**
34	Sept 2	491	14.6	10.2	10.2	9.8	17.9	9.5	5.4¤	6.7¤
	Sept 3	492	14.6	9.8	9.8	9.8	16.6	8.1	5.7¤	4.4
	Sept 4	493	13.7	9.8	9.8	9.8	17.2	7.3¤	3.5	4.2
	Sept 5	494	14.1	12.6¤	12.0	10.9¤	19.3	7.7	2.8	2.8
	Sept 6	495	13.7	8.7¤	8.4	8.8	19.7	8.4	3.2	2.8
	Sept 7	496	13.7	9.1	8.8	8.4¤	19.7	8.4	2.8	2.8
	Sept 8	497	14.4	9.8	9.8	9.1	20.7	9.5	3.2	3.2
	Sept 9	498	14.4	9.8	9.8	9.5	22.9	8.8	2.8	2.8
	Sept 10	499	14.3	10.0	10.4	9.6	21.8	8.6	2.1	2.5
	Sept 11	500	15.0	10.4	11.4	9.6	21.1	8.9	2.9	2.5
	Sept 12	501	14.6	10.4	11.1	10.0	22.9	8.9	2.9	2.9
	AVERAGE		**14.3**	**9.9**	**10.1**	**9.6**	**20.0**	**8.7**	**2.9**	**3.1**
35	Sept 13	502	13.2¤	10.0	9.6¤	11.1	22.5	8.9	3.6	2.5
	Sept 14	503	15.7	10.4	11.1	11.1	24.3	10.7	4.3	3.9
	Sept 15	504	15.7	10.4	10.4	10.0	23.9	11.1	4.6	4.3
	Sept 16	505	15.4	11.1	10.7	10.4	23.9	11.8	5.7	4.3
	Sept 17	506	14.7	11.8	10.0	12.6	24.4	10.8	10.7¤	6.5
	Sept 18	507	14.7	11.1	11.8	10.8	27.9¤	12.6	7.2	7.8¤
	Sept 19	508	14.3	11.5	11.1	10.8	23.3	12.2	7.5	6.1
	Sept 20	509	14.7	10.8	11.1	11.5	21.9	7.9	2.9	5.7
	Sept 21	510	14.7	10.8	11.1	10.8	23.3	7.9	2.2	2.5
	Sept 22	511	14.0	10.4	11.1	10.4	23.3	10.8	3.2	3.2
	Sept 23	512	14.3	10.8	12.1¤	10.8	23.7	10.0	3.2	3.2
	Sept 24	513	15.8	4.0¤	10.3	4.0¤	14.7¤	4.4¤	1.5	3.7
	Sept 25	514	-	-	-	-	-	-	-	-
	AVERAGE		**14.9**	**10.8**	**10.9**	**10.9**	**23.4**	**10.4**	**4.2**	**4.2**

¤ Data rejected as outliers at 10% level of significance.

36	Sept 26	515	17.3	10.3	11.0	4.0¤	23.5¤	10.3	4.0	3.7
	Sept 27	516	16.6	12.5	10.3	4.7¤	25.8	13.6	4.0	2.6
	Sept 28	517	16.2	11.4	11.0	9.9	27.6	18.7¤	4.4	2.9
	Sept 29	518	-	-	-	-	-	-	-	-
	Sept 30	519	19.5¤	11.4	10.7	10.3	27.6	15.5	4.8	2.9
	Oct 1	520	16.2	10.7	10.7	9.9	26.5	13.6	3.7	0.7
	Oct 2	521	15.8	10.7	11.4	11.0	27.6	11.0	0.7¤	0.7
	Oct 3	522	-	-	-	-	-	-	-	-
	Oct 4	523	13.7¤	10.6	10.3	11.3	27.5	11.7	2.4	2.1
	Oct 5	524	14.8	12.4	19.2¤	12.0	28.1	13.0	4.5	4.5
	Oct 6	525	-	-	-	-	-	-	-	-
	Oct 7	526	15.4	14.0¤	11.7	14.1	29.2	13.0	4.1	4.1
	AVERAGE		**16.0**	**11.2**	**10.9**	**11.2**	**27.5**	**12.7**	**4.0**	**2.7**
37	Oct 8	527	15.4¤	10.2¤	10.2¤	12.7	25.4	9.3	3.1	2.7¤
	Oct 9	528	-	-	-	-	-	-	-	-
	Oct 10	529	13.3¤	11.0	12.4	12.4	24.0	10.0	4.5	3.4
	Oct 11	530	-	-	-	-	-	-	-	-
	Oct 12	531	14.9	12.9	11.8	10.8	25.0	11.1	6.3	5.6
	Oct 13	532	-	-	-	-	-	-	-	-
	Oct 14	533	14.2	11.5	13.6	10.8	24.3	10.8	6.6	5.6
	Oct 15	534	14.2	12.5	11.8	10.8	23.3	9.7	5.2	4.9
	Oct 16	535	14.2	12.2	13.9	10.8	25.4	13.2¤	11.8	4.2
	Oct 17	536	13.9	12.2	13.9	11.5	25.0	12.5	13.2¤	5.9
	Oct 18	537	13.9	12.9	12.2	11.5	25.0	11.8	7.0	5.6
	Oct 19	538	14.6	11.1	11.8	10.8	22.9¤	11.1	5.2	4.9
	Oct 20	539	-	-	-	-	-	-	-	-
	Oct 21	540	-	-	-	-	-	-	-	-
	AVERAGE		**14.3**	**12.0**	**12.7**	**11.3**	**24.7**	**10.8**	**6.2**	**5.0**
38	Oct 22	541	14.6¤	11.1¤	10.0¤	10.4¤	29.1¤	12.5¤	5.2¤	5.2¤
	Oct 23	542	-	-	-	-	-	-	-	-
	Oct 24	543	12.2	8.3	7.0	7.3	25.4	9.7	1.7	2.8
	Oct 25	544	11.5	7.3	7.3	6.6	24.3	8.7	2.1	2.1
	Oct 26	545	12.5	8.0	8.0	7.3	22.9	9.7	1.7	2.1
	Oct 27	546	-	-	-	-	-	-	-	-
	Oct 28	547	11.5	7.6	7.6	7.6	23.3	8.7	1.4	1.7
	Oct 29	548	-	-	-	-	-	-	-	-
	AVERAGE		**11.9**	**7.8**	**7.5**	**7.2**	**24.0**	**9.2**	**1.7**	**2.2**
39	Oct 30	549	12.5¤	9.4	8.6¤	8.6¤	22.6	8.3	3.5	3.1
	Oct 31	550	15.6	11.8	10.8	10.4	28.2	10.1	3.5	3.5
	Nov 1	551	13.2¤	10.8	10.1	10.4	19.5	7.3	4.1¤	2.4
	Nov 2	552	17.0	12.4	11.4	11.0	28.0	10.3	2.1	2.5
	Nov 3	553	-	-	-	-	-	-	-	-
	Nov 4	554	16.7	12.4	12.4	9.9	30.5¤	7.1	1.8	1.8
	Nov 5	555	14.9	12.1	11.7	11.0	20.6	4.6	1.1	2.8
	Nov 6	556	15.3	12.1	11.7	11.7	20.9	6.0	0.7	0.4
	Nov 7	557	15.6	6.7¤	12.4	11.7	22.4	11.7¤	1.1	0.7
	Nov 8	558	15.6	12.4	11.7	11.7	22.7	6.4	0.7	0.4
	Nov 9	559	15.4	11.2	10.5	8.7	23.0	6.6	0.7	0.3
	Nov 10	560	-	-	-	-	-	-	-	-
	Nov 11	561	14.7	11.2	11.2	10.1	25.1	7.7	0.7	0.7
	AVERAGE		**15.6**	**11.6**	**11.4**	**10.7**	**23.3**	**7.4**	**1.6**	**1.7**
40	Nov 12	562	16.4¤	11.5	11.2	10.8	26.9	11.2	4.9	2.8
	Nov 13	563	-	-	-	-	-	-	-	-
	Nov 14	564	15.7	10.8	11.2	11.2	25.8	9.4	2.4	2.1
	Nov 15	565	16.1	11.5	11.5	11.2	27.9	10.8	3.1	2.8
	Nov 16	566	15.4	11.5	11.5	10.8	26.2	10.8	4.2	3.1
	Nov 17	567	15.4	11.5	11.5	11.5	24.4¤	9.8	4.2	3.5
	Nov 18	568	-	-	-	-	-	-	-	-
	Nov 19	569	15.1	14.0¤	11.9¤	12.6¤	28.5	15.1¤	6.3¤	5.2¤
	Nov 20	570	15.1	11.6	11.6	12.0	28.2	10.9	2.8	2.8
	Nov 21	571	15.1	11.6	11.6	11.6	28.2	10.6	2.8	2.8
	Nov 22	572	15.1	11.3	11.3	11.3	28.9	10.9	3.5	3.5

¤ Data rejected as outliers at 10% level of significance.

	Nov 23	573	15.5	12.0	11.3	11.6	28.2	10.9	4.2	4.9
	Nov 24	574	-	-	-	-	-	-	-	-
	Nov 25	575	-	-	-	-	-	-	-	-
	AVERAGE		**15.4**	**11.5**	**11.4**	**11.3**	**27.6**	**10.6**	**3.6**	**3.2**
41	Nov 26	576	11.6	8.8¤	9.2	8.8¤	26.1	14.0¤	6.3	4.2
	Nov 27	577	12.5	10.4	10.7	10.0	27.7	11.8	5.2	4.5
	Nov 28	578	12.1	11.1	10.4	10.4	27.4	10.4	3.5	3.1
	Nov 29	579	-	-	-	-	-	-	-	-
	Nov 30	580	12.1	10.7	10.4	10.0	27.0	10.7	3.1	3.1
	Dec 1	581	-	-	-	-	-	-	-	-
	Dec 2	582	12.5	10.4	9.7	9.7	26.7	11.1	3.5	2.8
	AVERAGE		**12.2**	**10.7**	**10.1**	**10.0**	**27.0**	**11.0**	**4.3**	**3.5**

¤ Data rejected as outliers at 10% level of significance.

Graphical plots of day to day results

Table A.1 Summary of parameters monitored with corresponding Figure numbers.

Test	MLE System		UCT System	
	Days 1 to 297	Days 298 to 582	Days 1 to 297	Days 298 to 582
COD	Fig A.1	Fig A.3	Fig A.2	Fig A.4
TKN	Fig A.5	Fig A.7	Fig A.6	Fig A.8
Ammonia	Fig A.9	Fig A.11	Fig A.10	Fig A.12
NO_3 plus NO_2	Fig A.14	Fig A.15	Fig A.14	Fig A.16
COD (reactor)	Fig A.17	Fig A.19	Fig A.18	Fig A.20
COD/VSS ratio	Fig A.21	Fig A.23	Fig A.22	Fig A.24
TKN/VSS ratio	Fig A.25	Fig A.27	Fig A.26	Fig A.28
Solids	Fig A.29	Fig A.31	Fig A.30	Fig A.32
OUR	Fig A.33	Fig A.35	Fig A.34	Fig A.36
mgO/gVSS*d	Fig A.37	Fig A.39	Fig A.38	Fig A.40
Total P I	Fig A.41	Fig A.43	Fig A.45	Fig A.47
Total P II	Fig A.42	Fig A.44	Fig A.46	Fig A.48
DSVI	Fig A.49	Fig A.51	Fig A.50	Fig A.52
pH	Fig A.53	Fig A.55	Fig A.54	Fig A.56

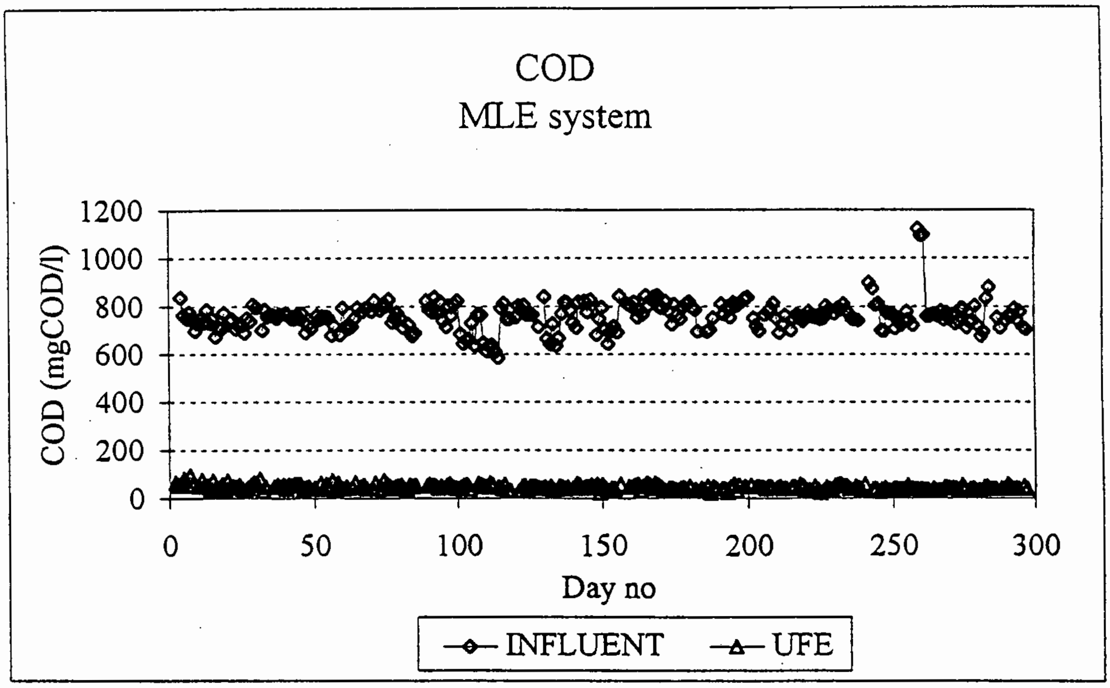


Fig A.1 Daily influent and unfiltered effluent COD concentrations in MLE system from day 1 to day 297.

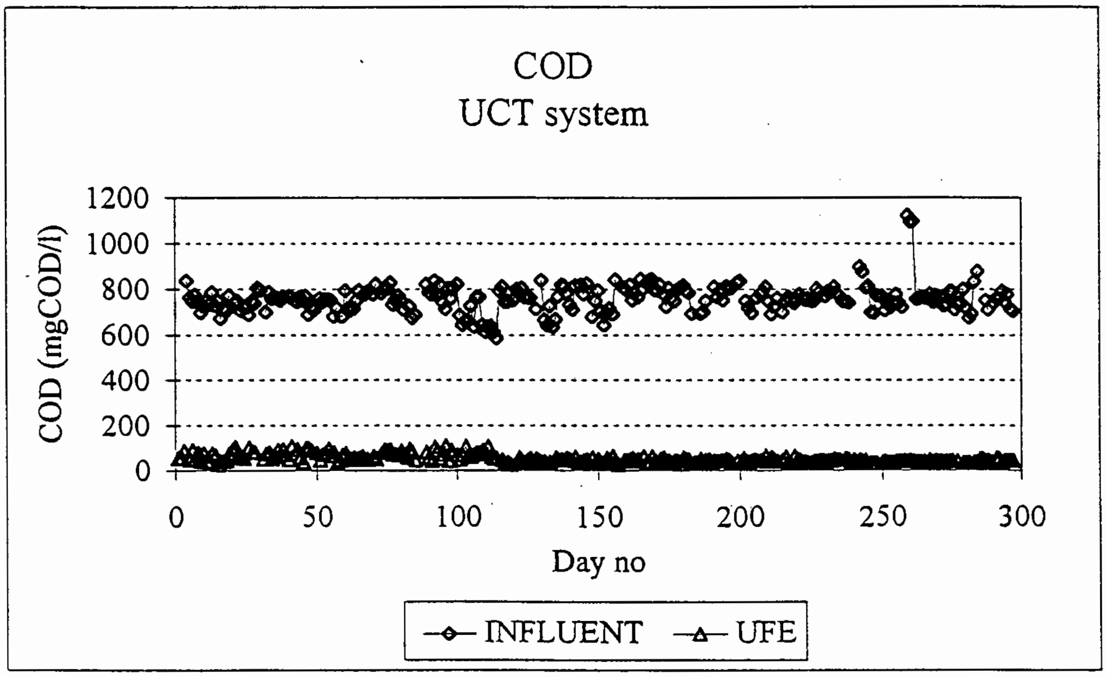


Fig A.2 Daily influent and unfiltered effluent COD concentrations in UCT system from day 1 to day 297.

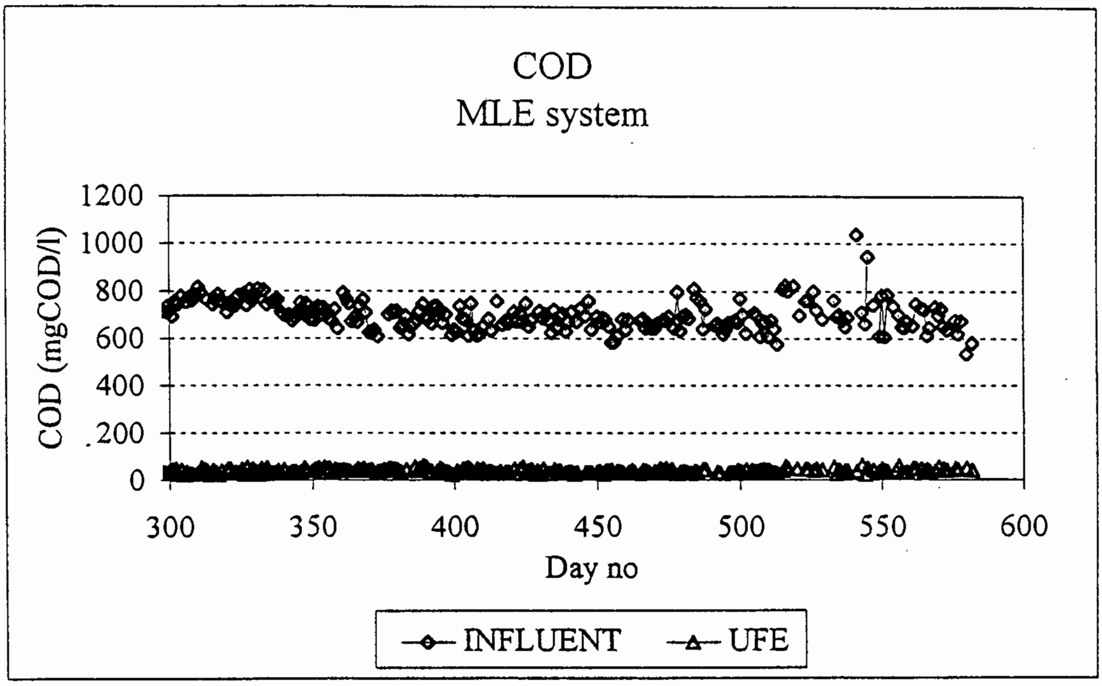


Fig A.3 Daily influent and unfiltered effluent COD concentrations in MLE system from day 298 to day 582.

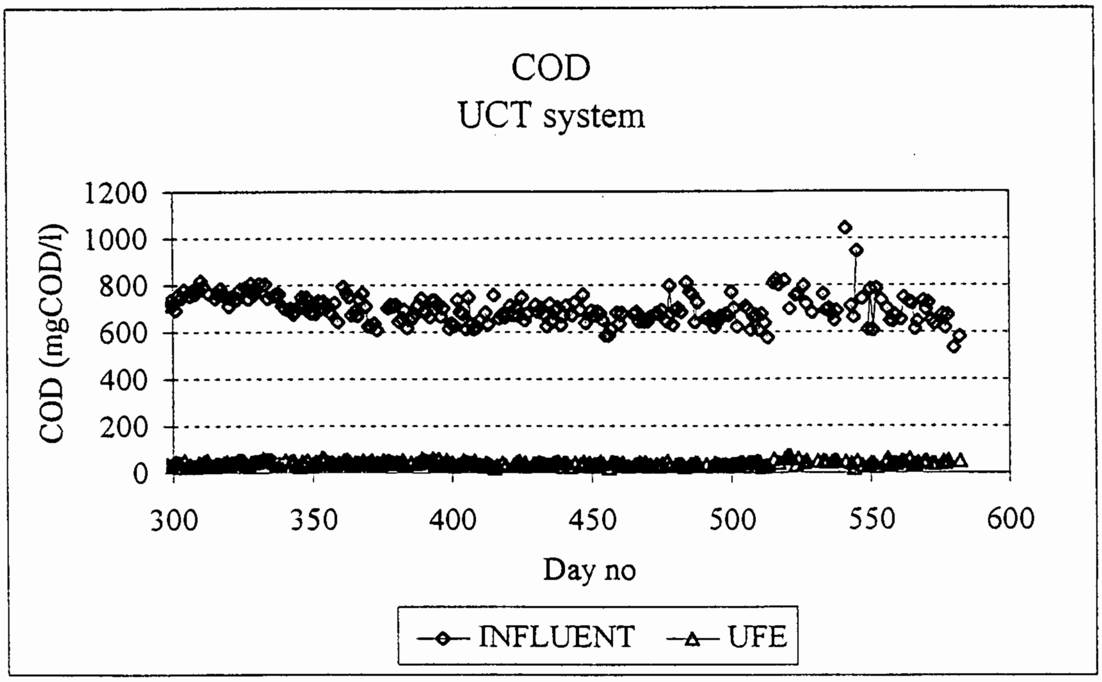


Fig A.4 Daily influent and unfiltered effluent COD concentrations in UCT system from day 298 to day 582.

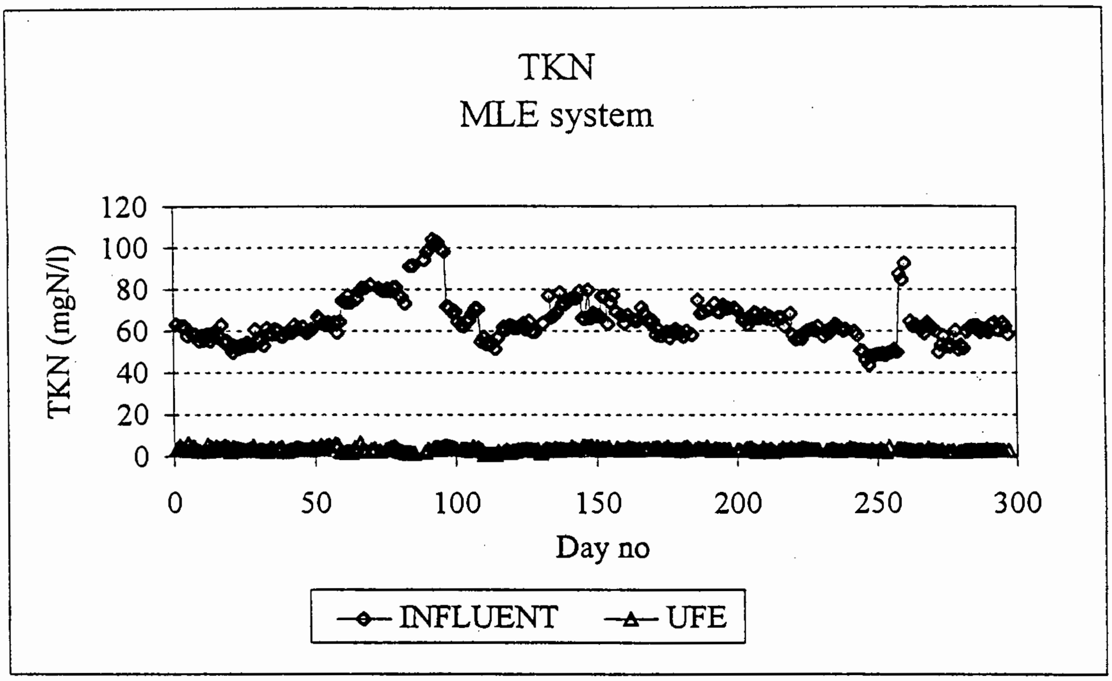


Fig A.5 Daily influent and unfiltered effluent TKN concentrations in MLE system from day 1 to day 297.

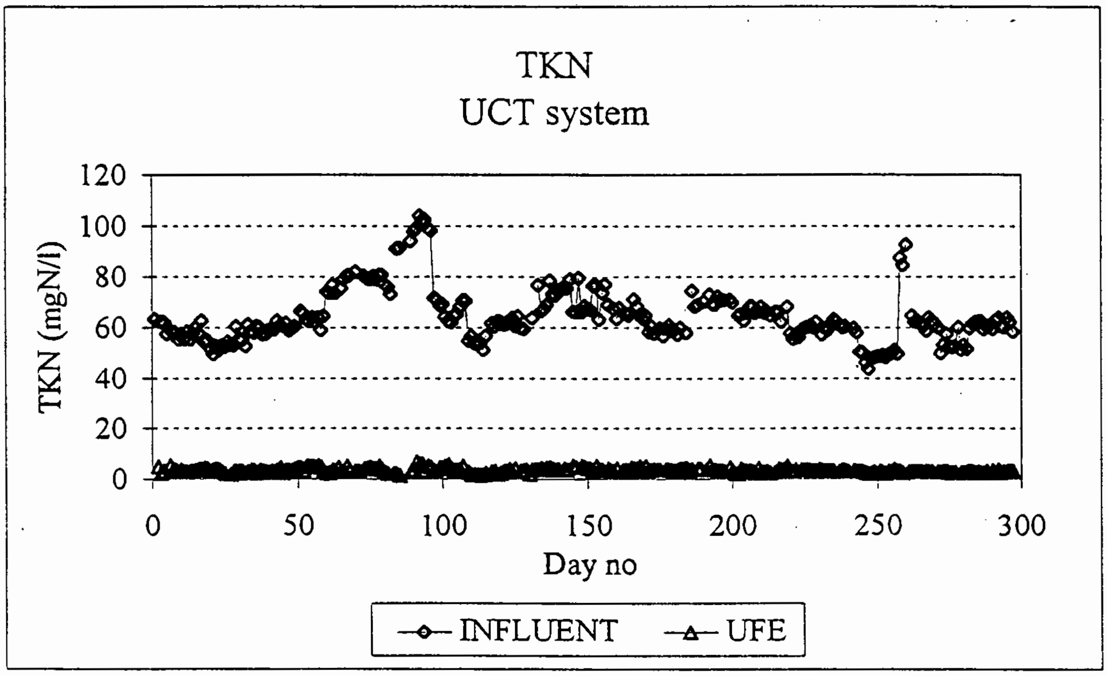


Fig A.6 Daily influent and unfiltered effluent TKN concentrations in UCT system from day 1 to day 297.

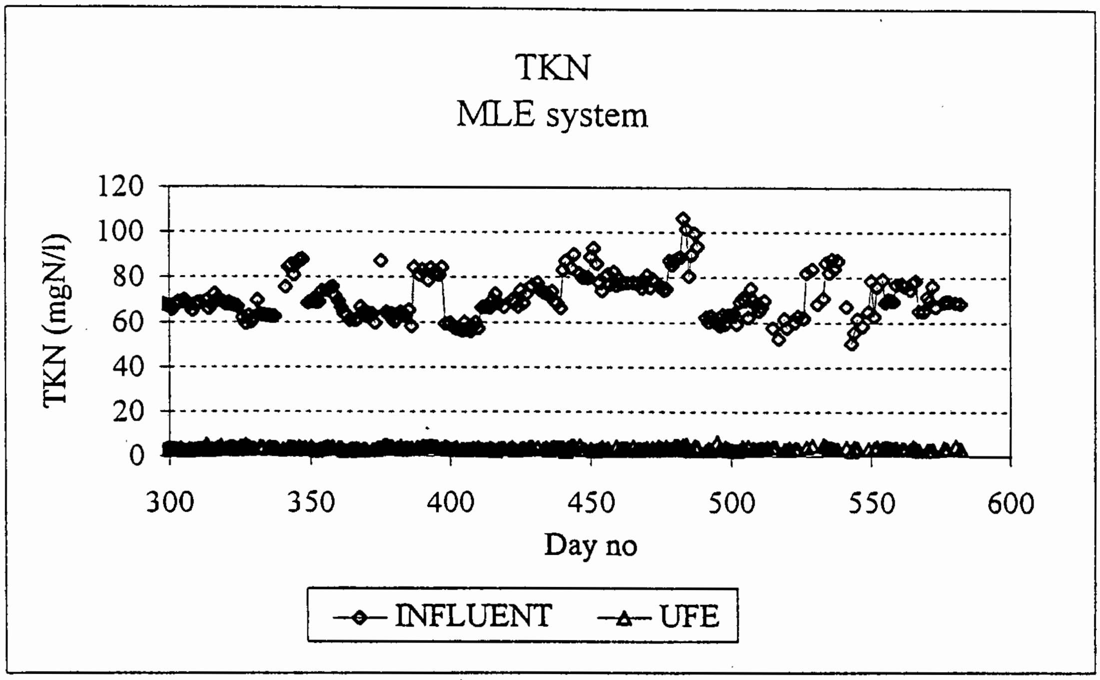


Fig A.7 Daily influent and unfiltered effluent TKN concentrations in MLE system from day 298 to day 582.

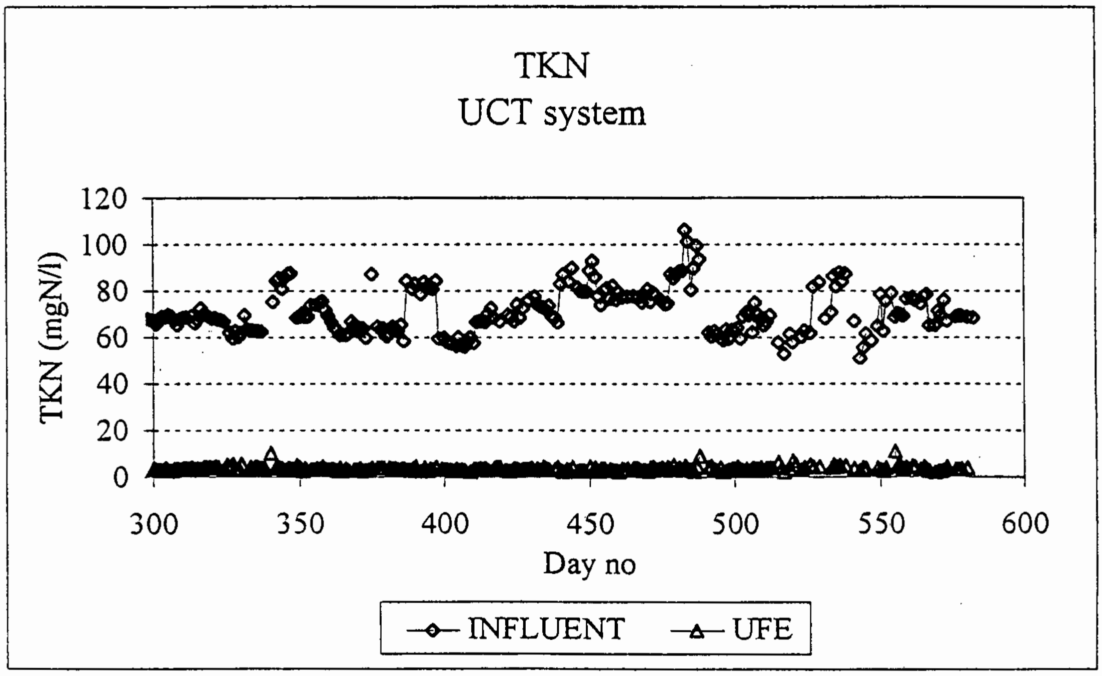


Fig A.8 Daily influent and unfiltered effluent TKN concentrations in UCT system from day 298 to day 582.

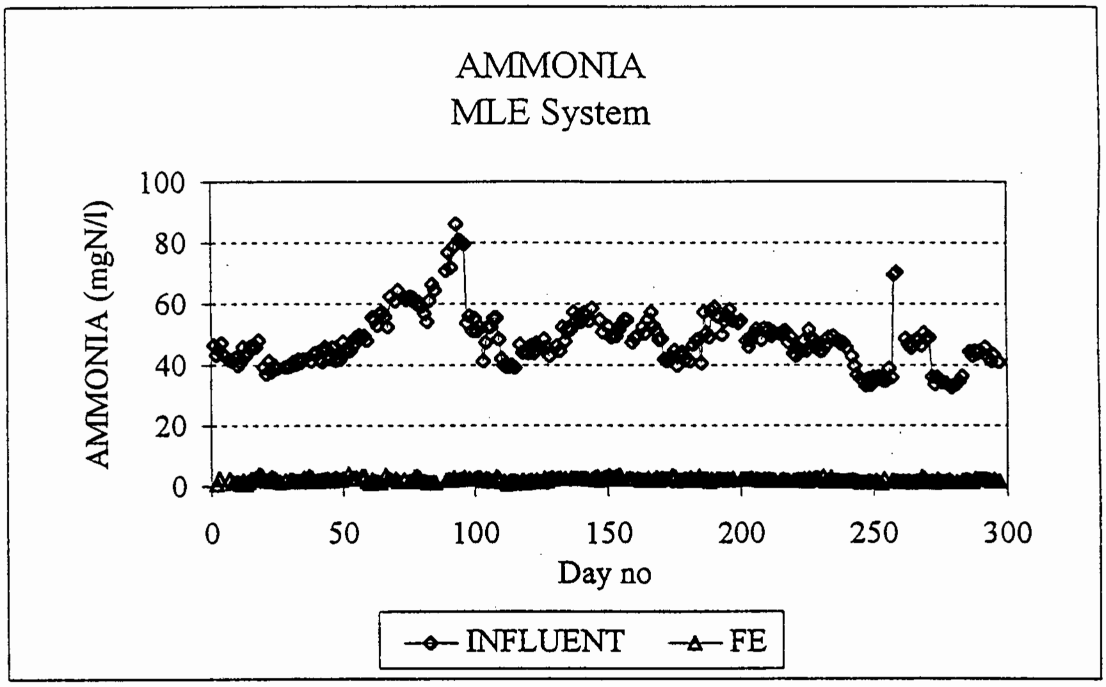


Fig A.9 Daily influent and effluent Ammonia concentrations in MLE system from day 1 to day 297.

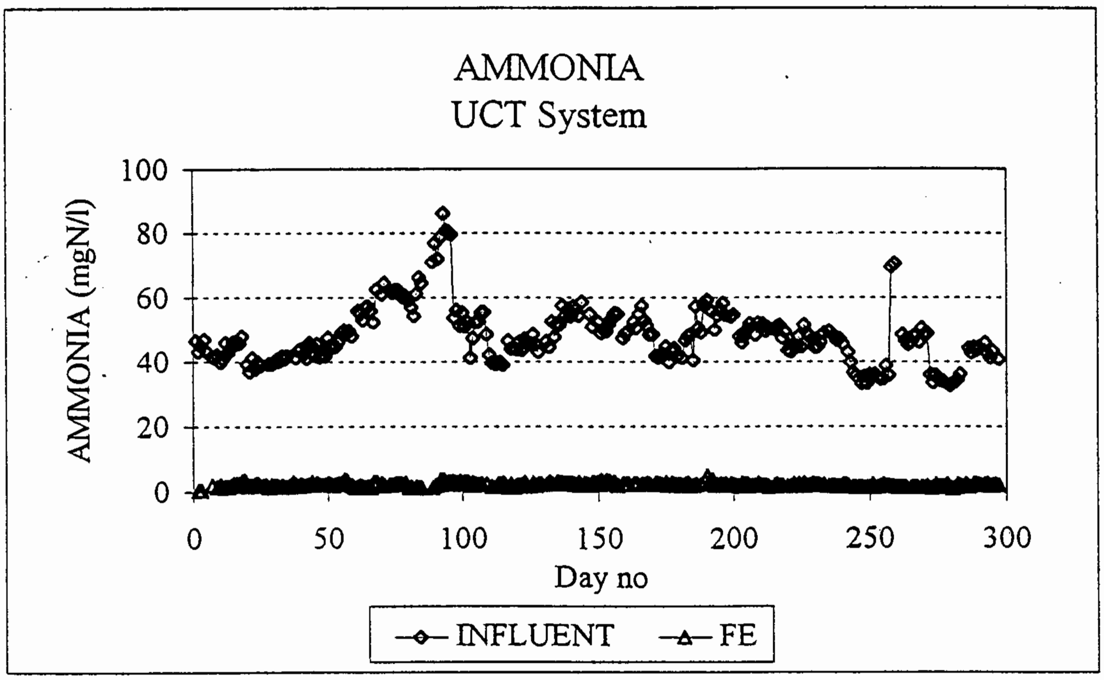


Fig A.10 Daily influent and effluent Ammonia concentrations in UCT system from day 1 to day 297.

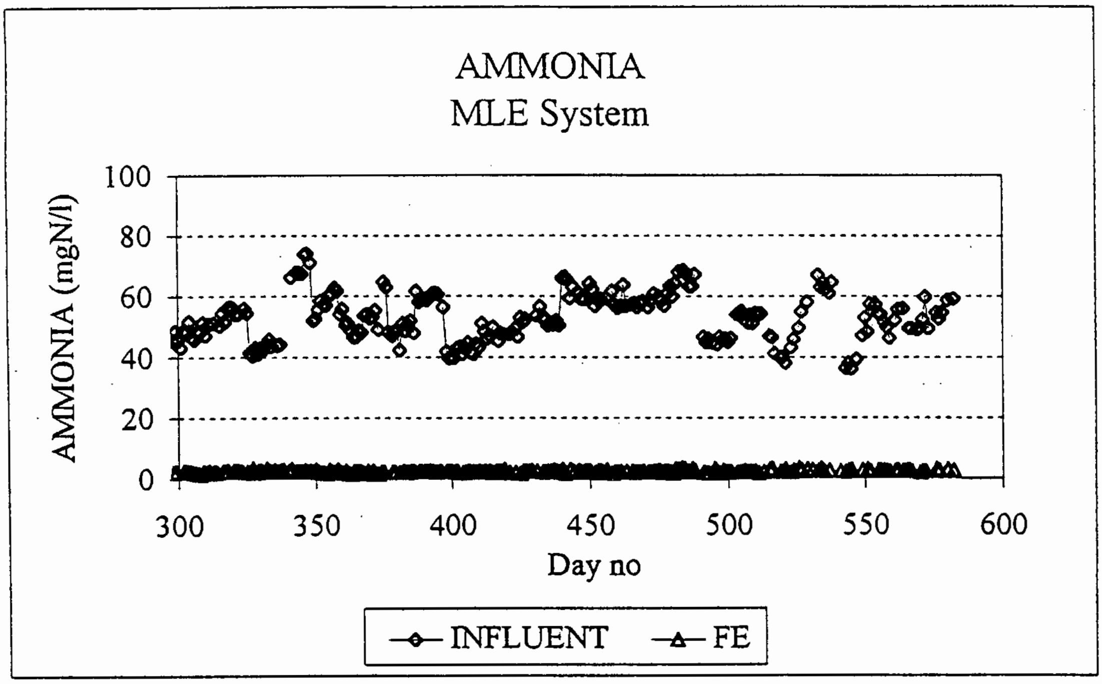


Fig A.11 Daily influent and effluent Ammonia concentrations in MLE system from day 298 to day 582.

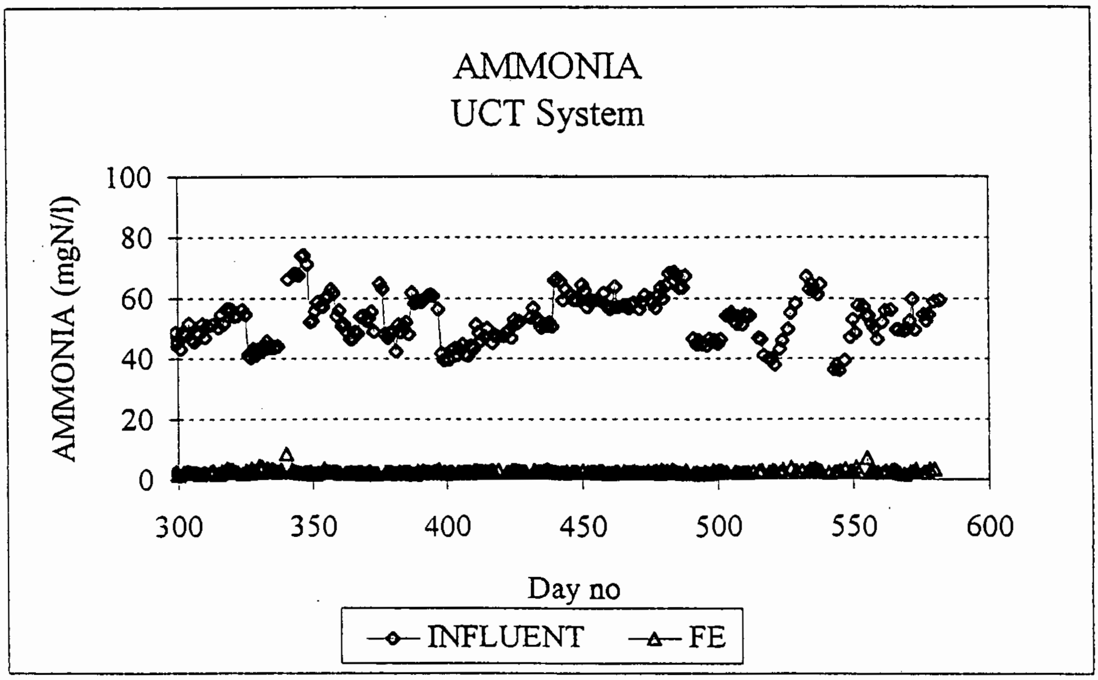


Fig A.12 Daily influent and effluent Ammonia concentrations in UCT system from day 298 to day 582.

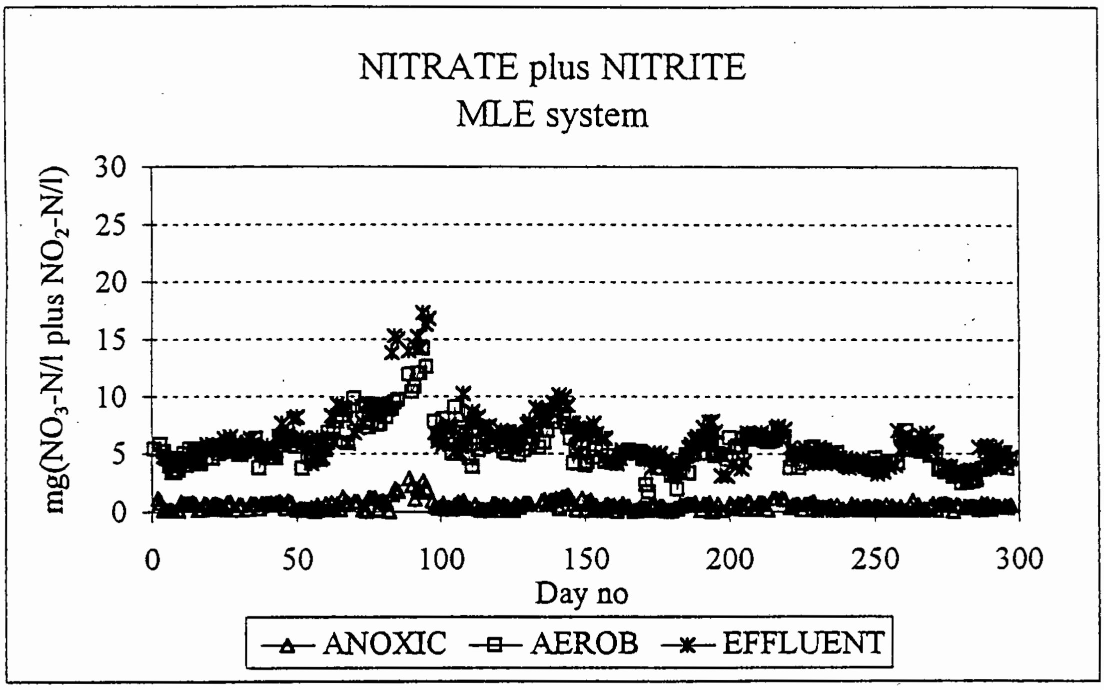


Fig A.13 Daily anoxic, aerobic and effluent Nitrate plus Nitrite concentrations in MLE system from day 1 to day 297.

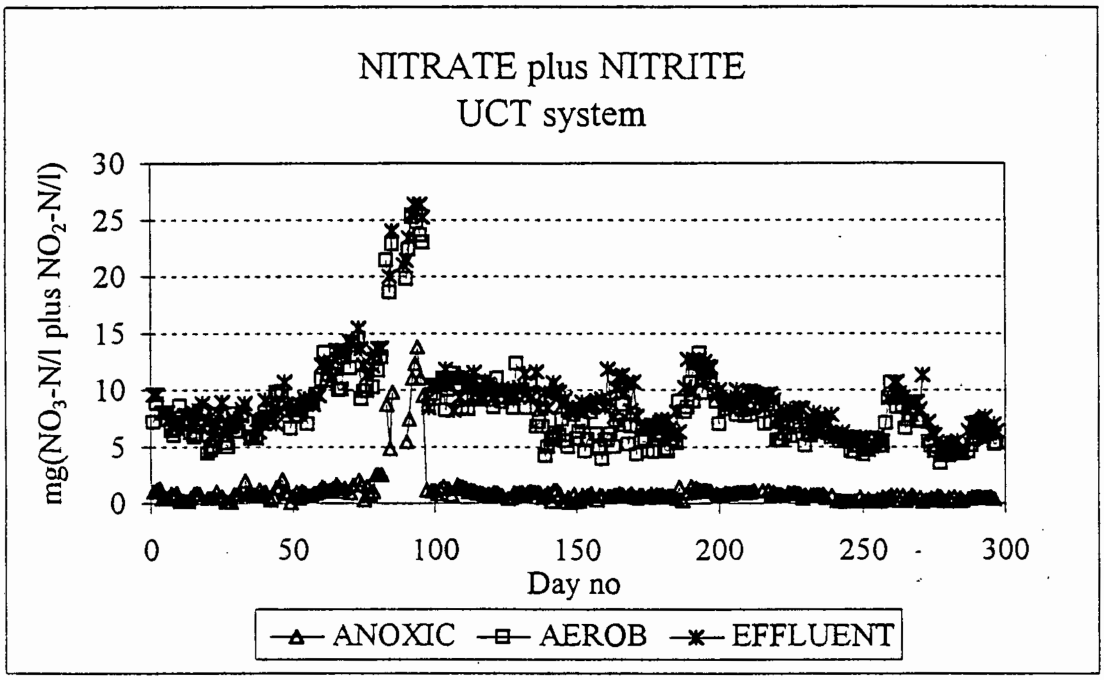


Fig A.14 Daily anoxic, aerobic and effluent Nitrate plus Nitrite concentrations in UCT system from day 1 to day 297.

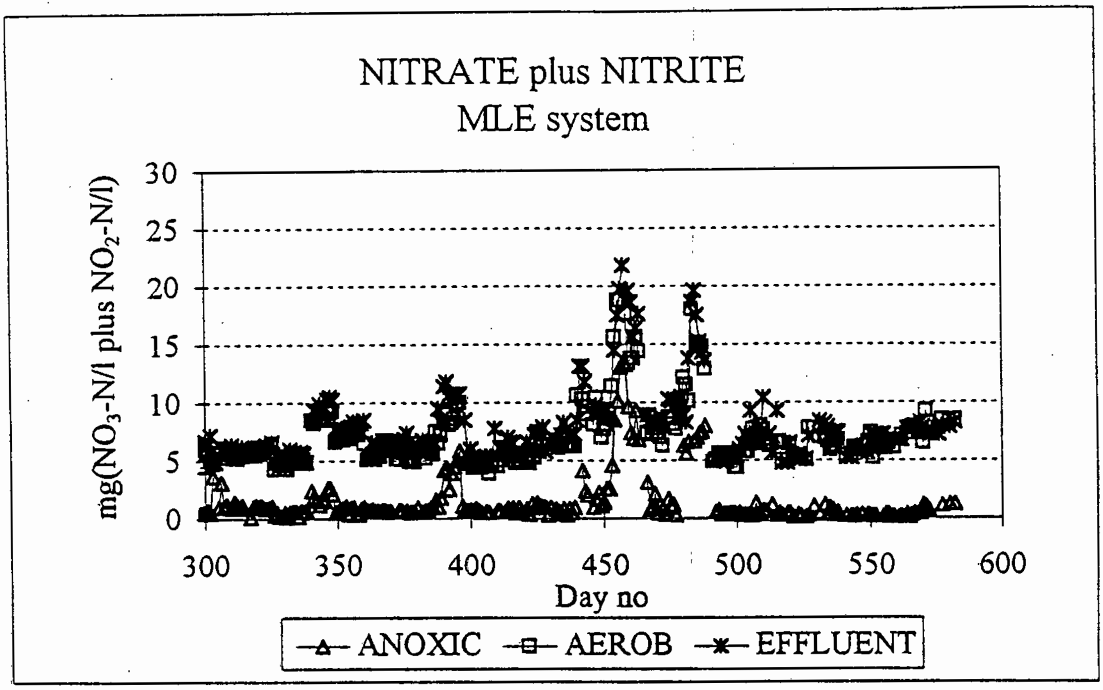


Fig A.15 Daily anoxic, aerobic and effluent Nitrate plus Nitrite concentrations in MLE system from day 298 to day 582.

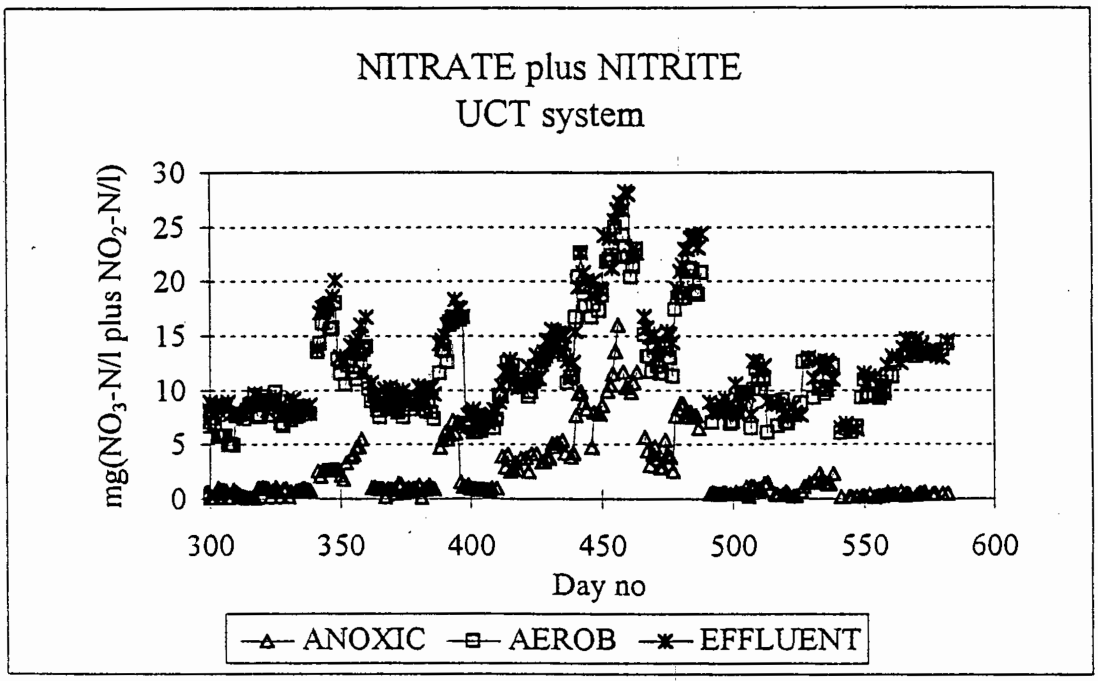


Fig A.16 Daily anoxic, aerobic and effluent Nitrate plus Nitrite concentrations in UCT system from day 298 to day 582.

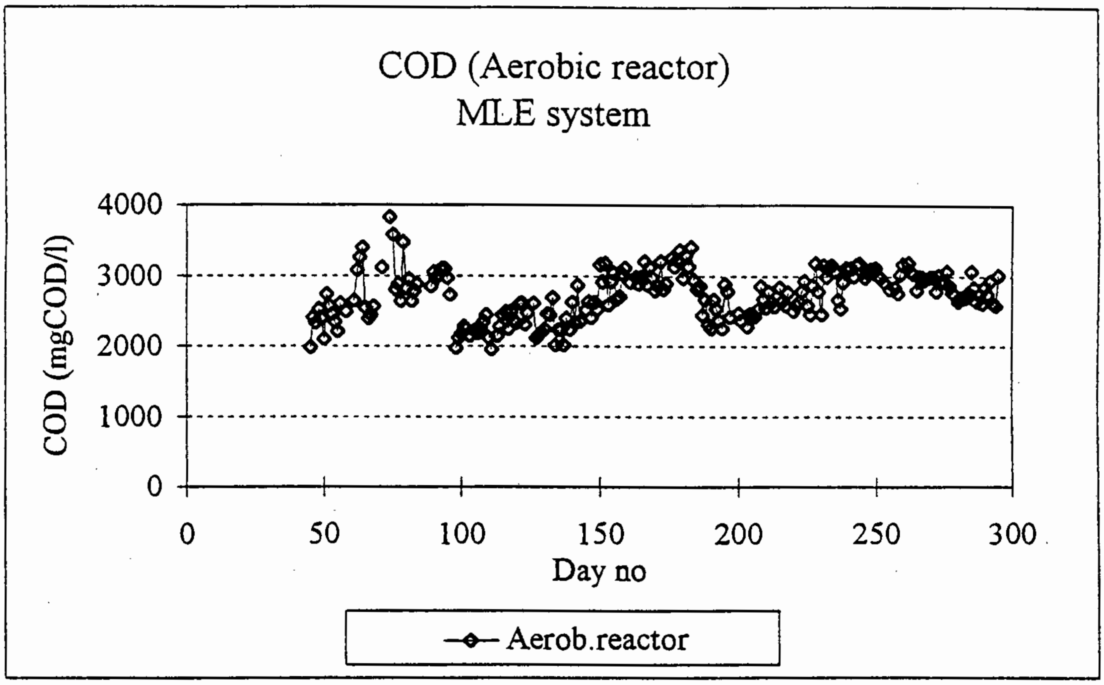


Fig A.17 Daily unfiltered aerobic reactor COD concentrations in MLE system from day 1 to day 297.

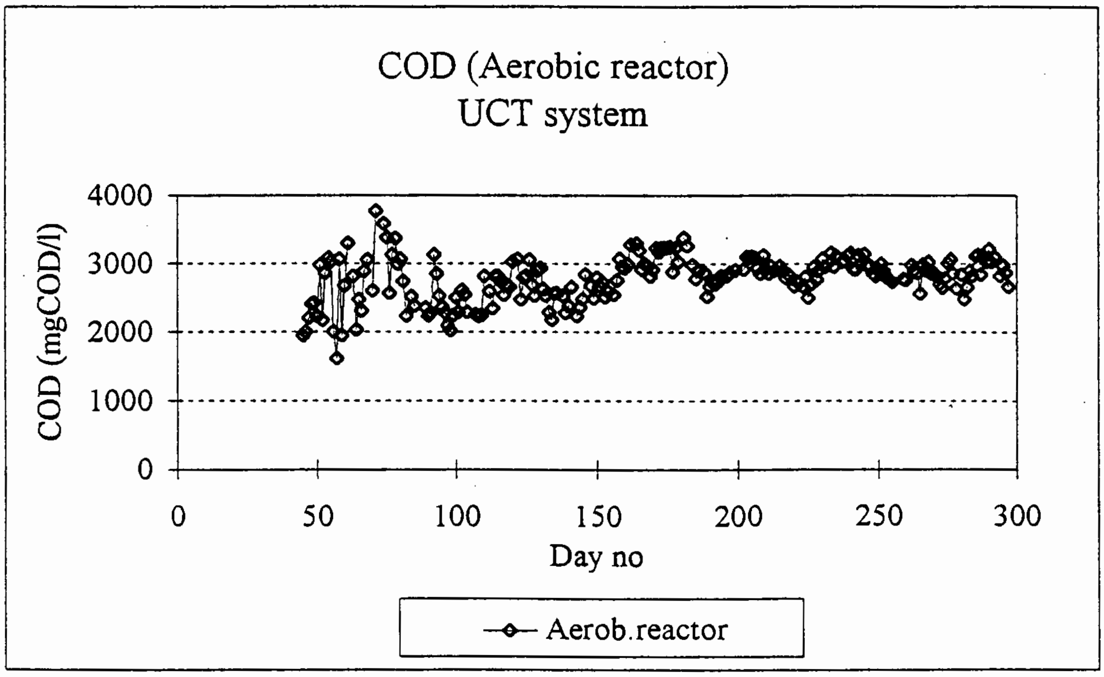


Fig A.18 Daily unfiltered aerobic reactor COD concentrations in UCT system from day 1 to day 297.

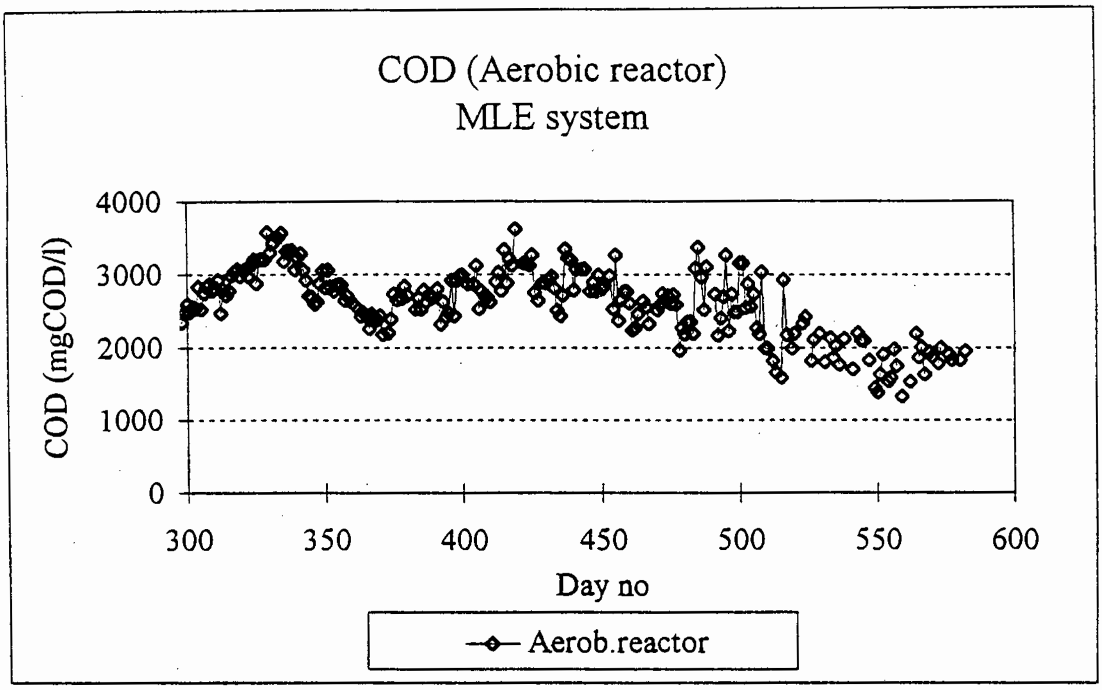


Fig A.19 Daily unfiltered aerobic reactor COD concentrations in MLE system from day 298 to day 582.

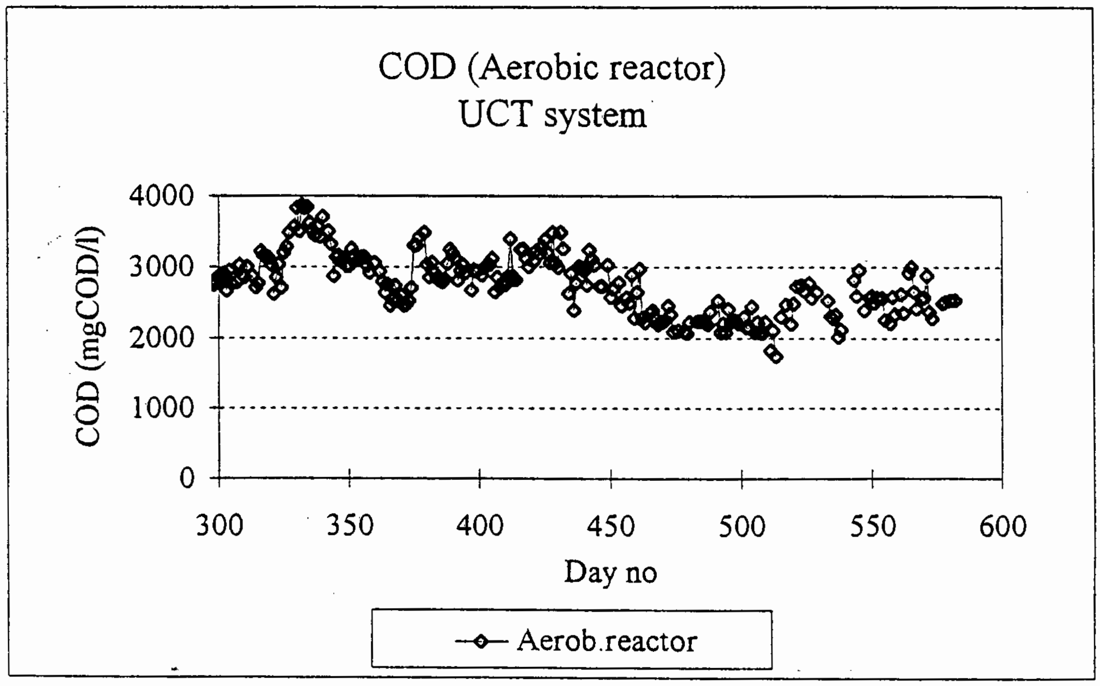


Fig A.20 Daily unfiltered aerobic reactor COD concentrations in UCT system from day 298 to day 582.

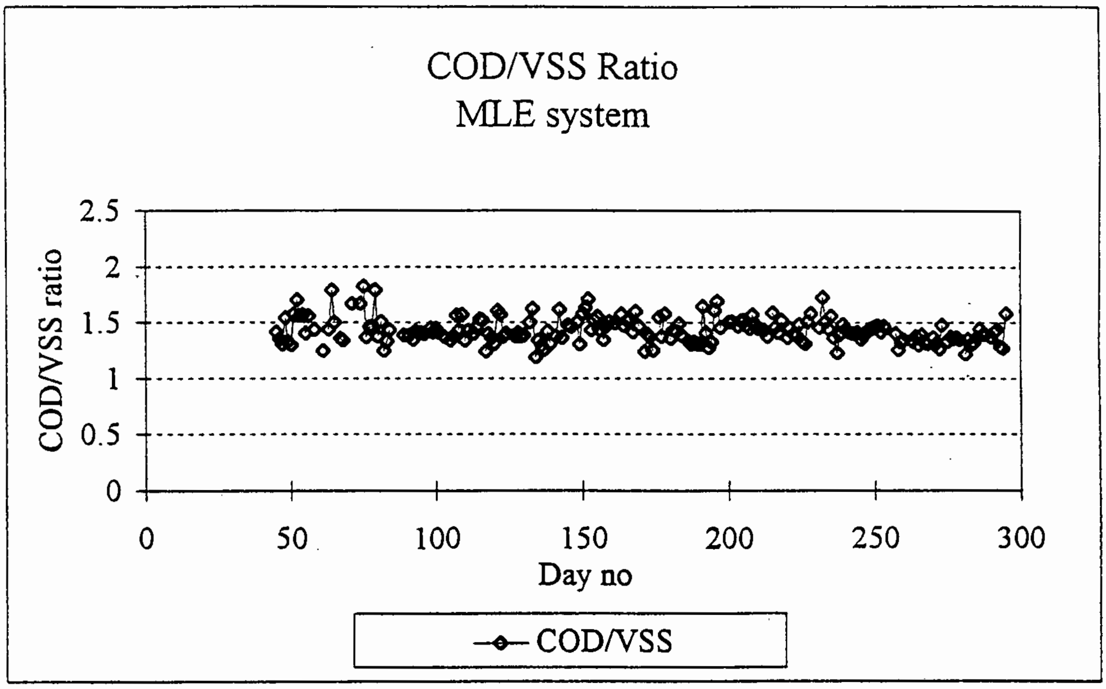


Fig A.21 Daily unfiltered aerobic reactor COD/VSS ratios in MLE system from day 1 to day 297.

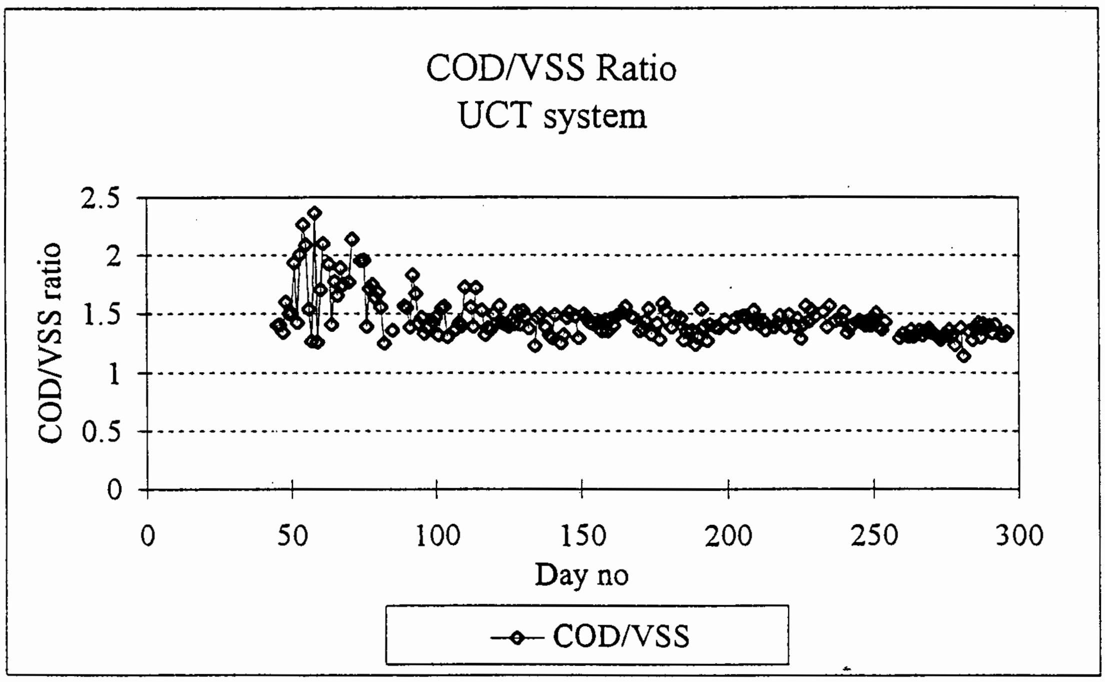


Fig A.22 Daily unfiltered aerobic reactor COD/VSS ratios in UCT system from day 1 to day 297.

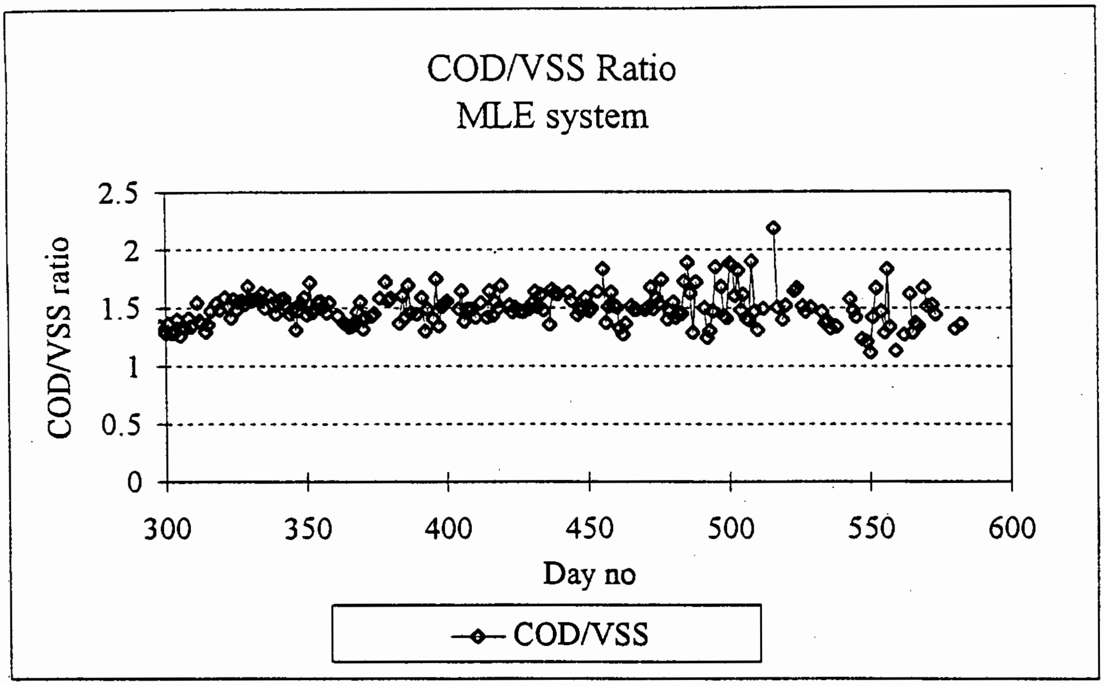


Fig A.23 Daily unfiltered aerobic reactor COD/VSS ratios in MLE system from day 298 to day 582.

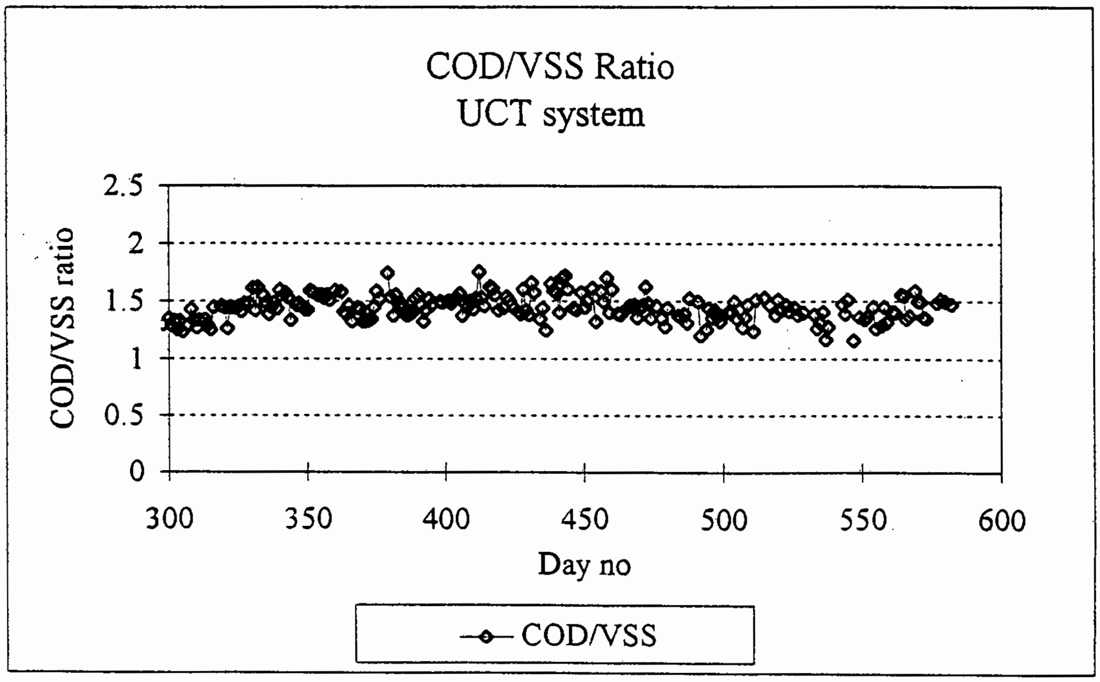


Fig A.24 Daily unfiltered aerobic reactor COD/VSS ratios in UCT system from day 298 to day 582.

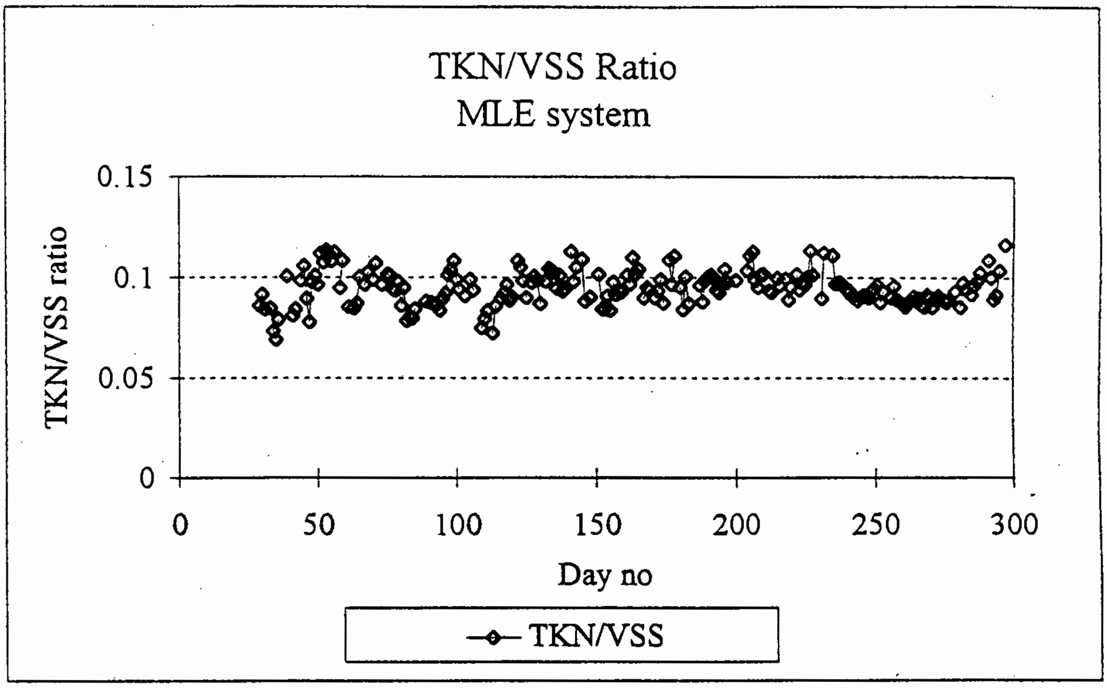


Fig A.25 Daily unfiltered aerobic reactor TKN/VSS ratios in MLE system from day 1 to day 297.

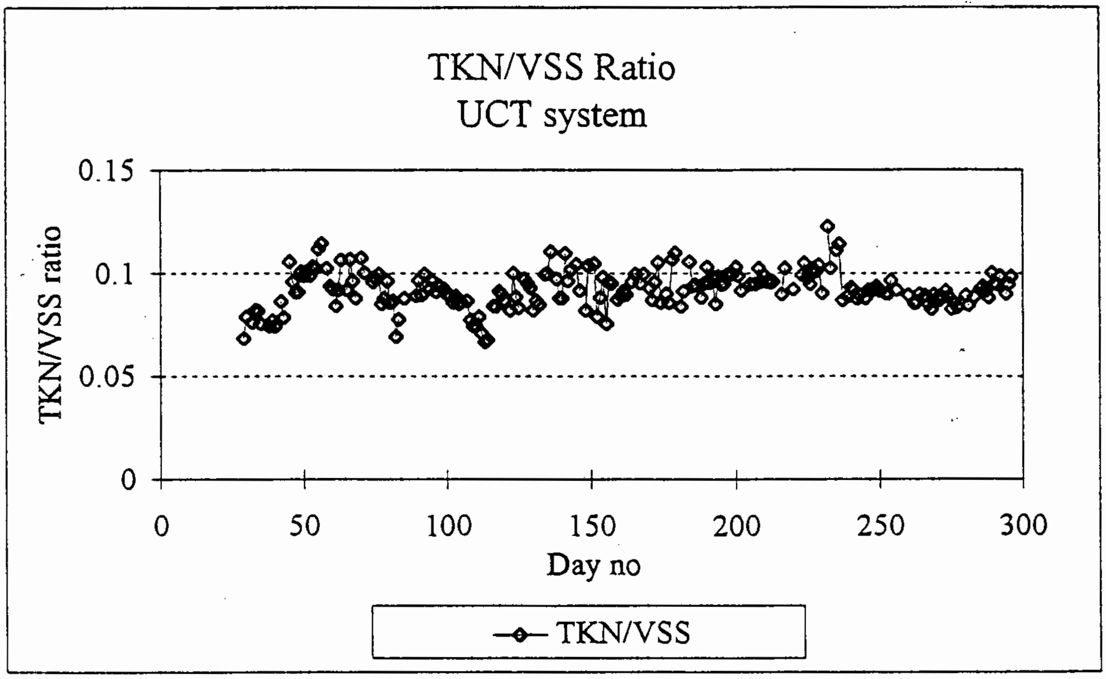


Fig A.26 Daily unfiltered aerobic reactor TKN/VSS ratios in UCT system from day 1 to day 297.

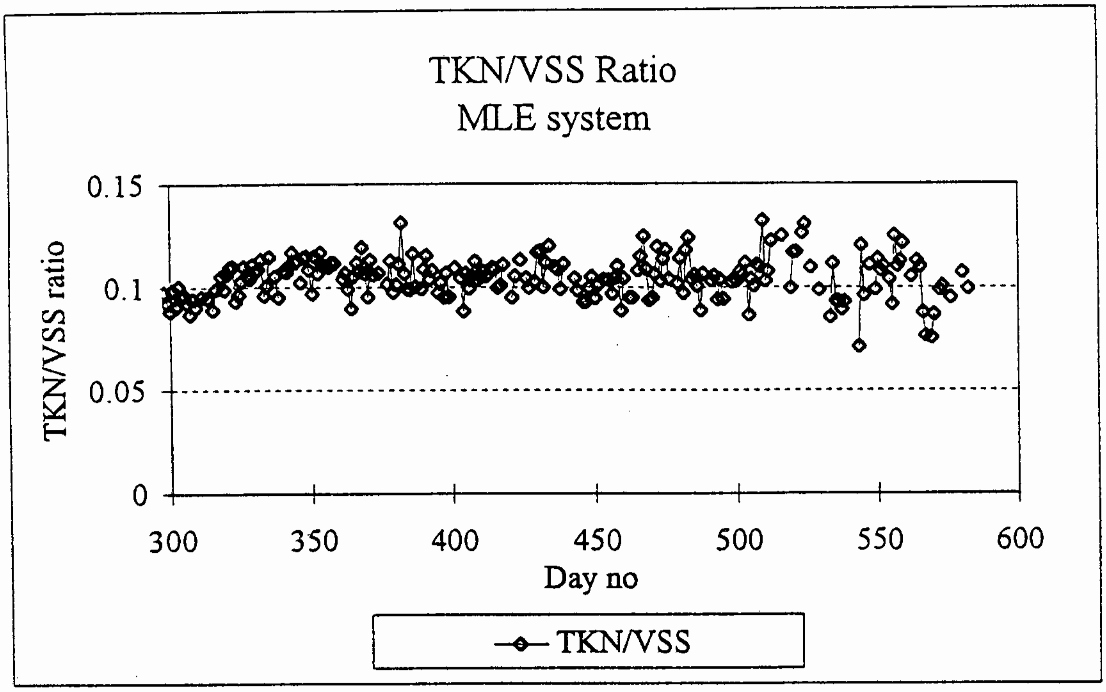


Fig A.27 Daily unfiltered aerobic reactor TKN/VSS ratios in MLE system from day 298 to day 582.

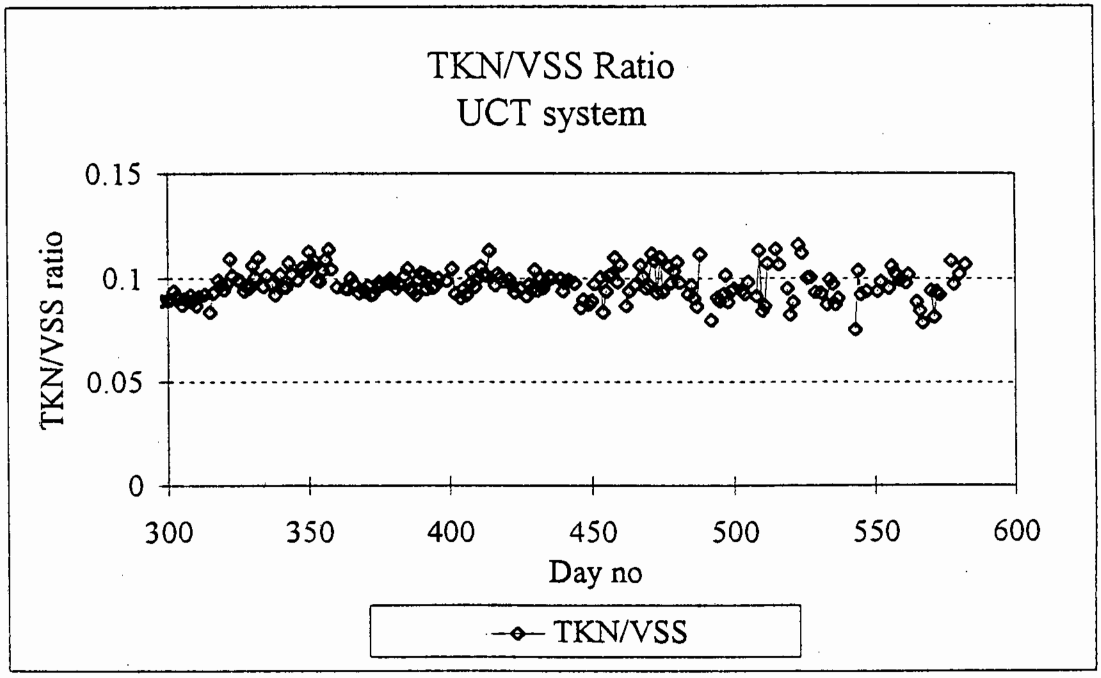


Fig A.28 Daily unfiltered aerobic reactor TKN/VSS ratios in UCT system from day 298 to day 582.

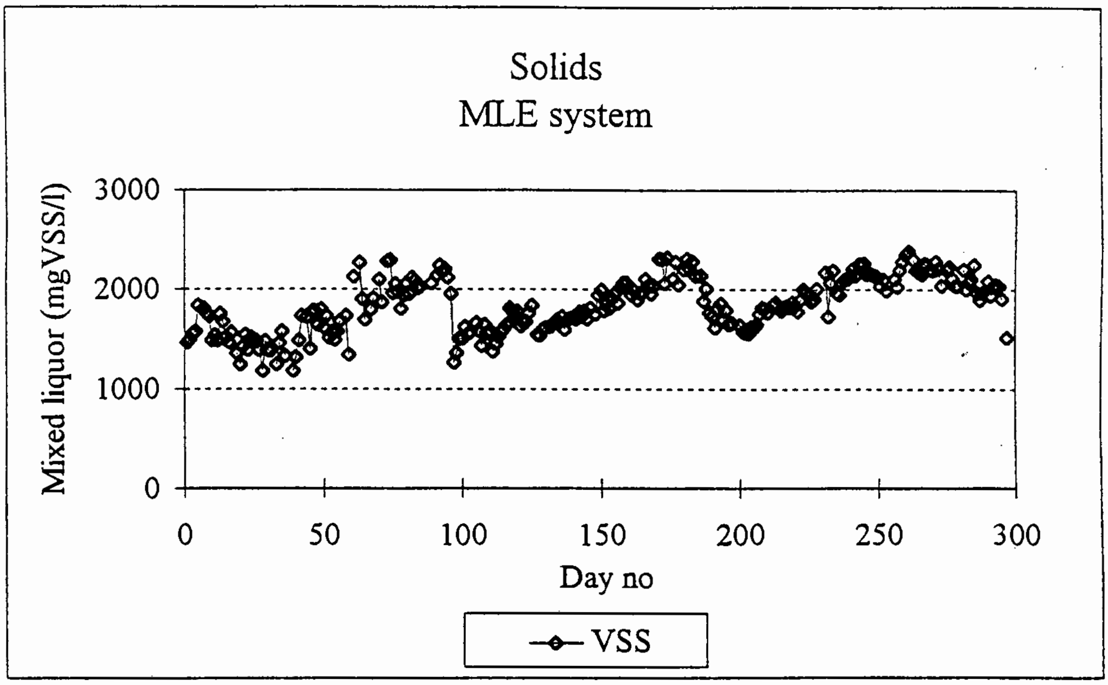


Fig A.29 Daily mixed liquor Volatile Suspended Solids concentrations in MLE system from day 1 to day 297.

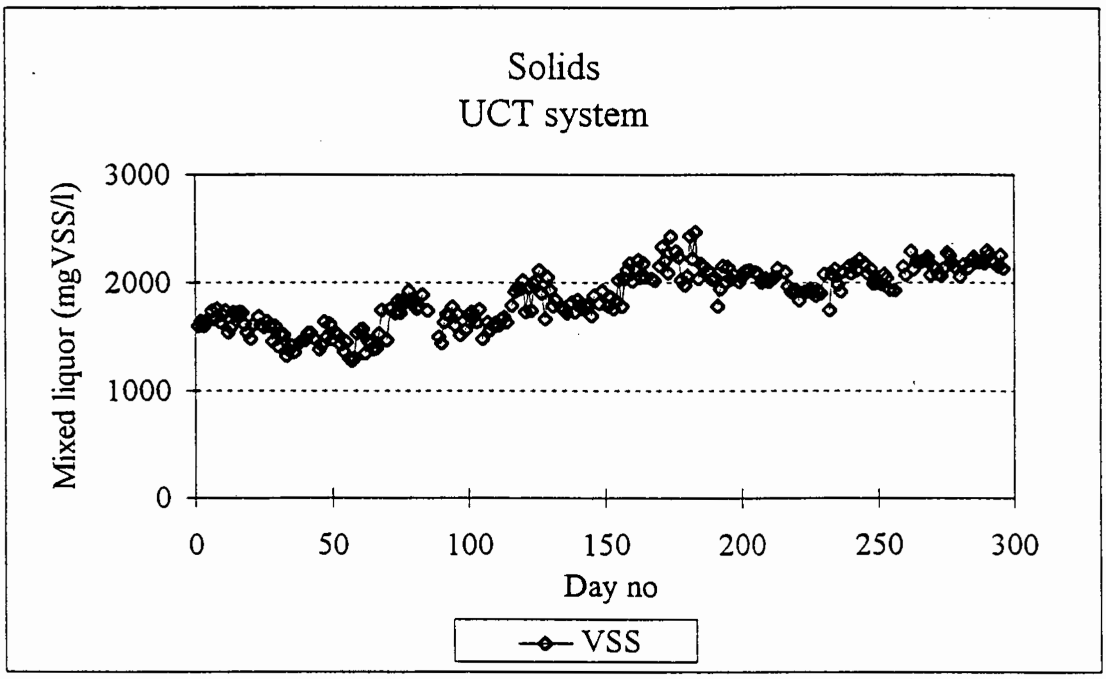


Fig A.30 Daily mixed liquor Volatile Suspended Solids concentrations in UCT system from day 1 to day 297.

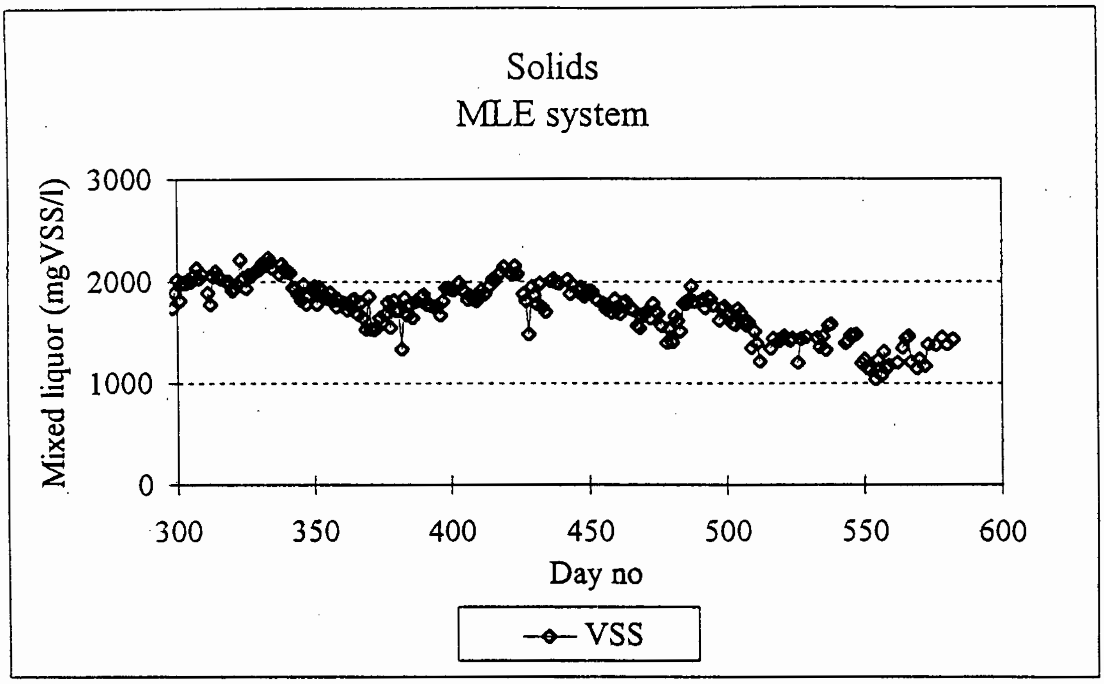


Fig A.31 Daily mixed liquor Volatile Suspended Solids concentrations in MLE system from day 298 to day 582.

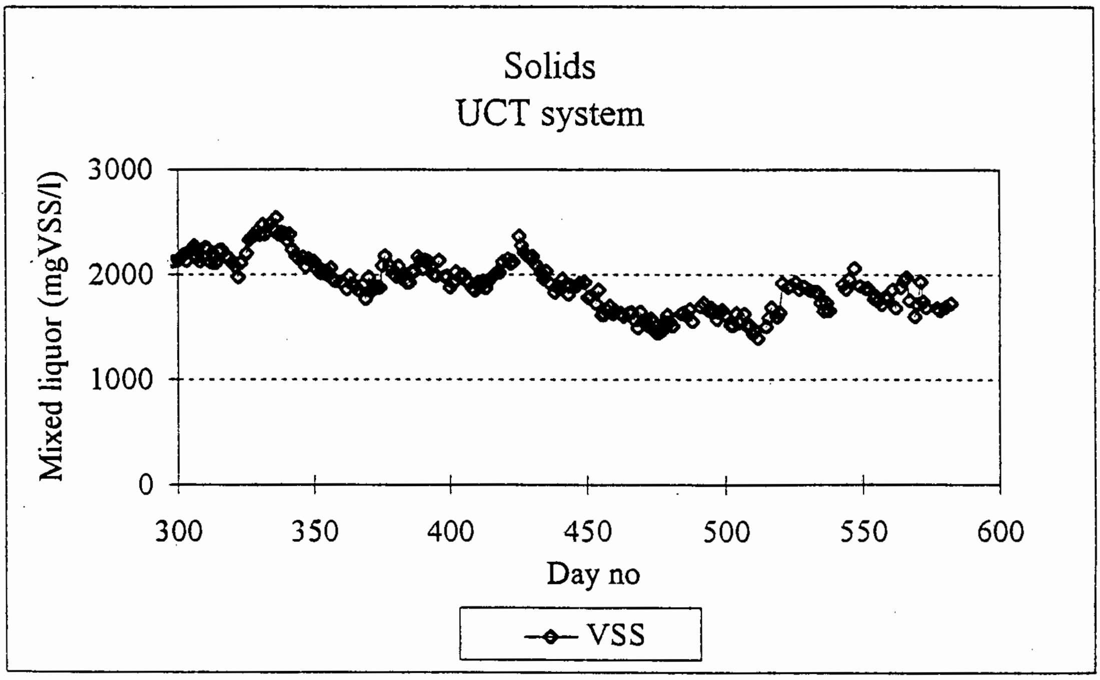


Fig A.32 Daily mixed liquor Volatile Suspended Solids concentrations in UCT system from day 298 to day 582.

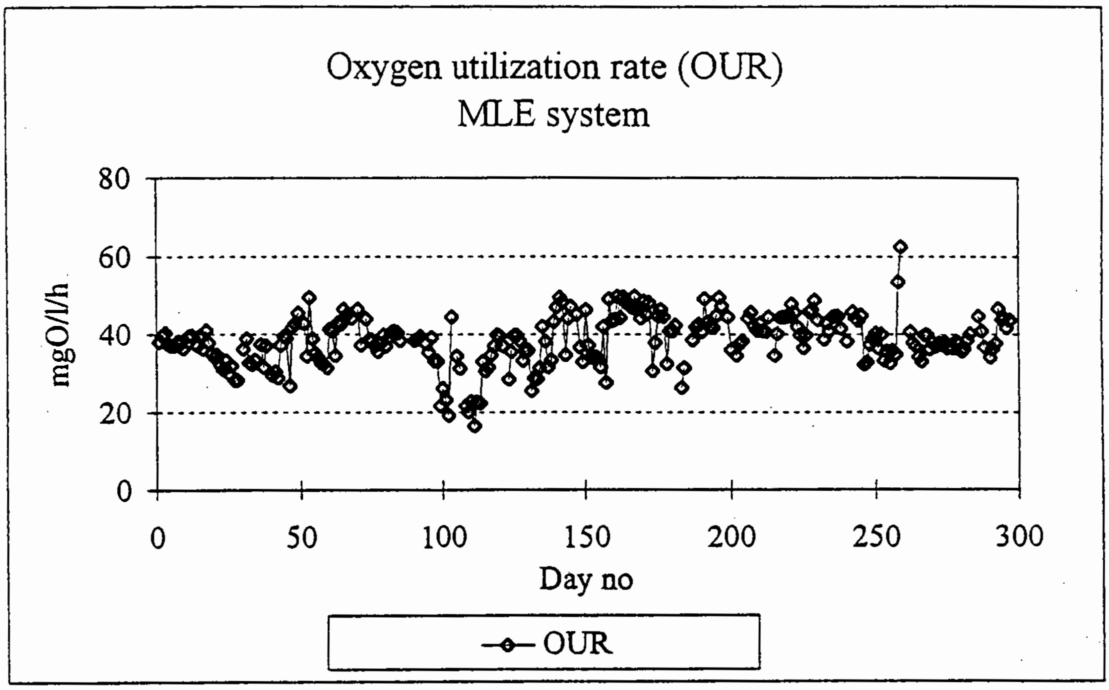


Fig A.33 Daily Oxygen Utilization Rate (mgO/l/h) of aerobic reactor in MLE system from day 1 to day 297.

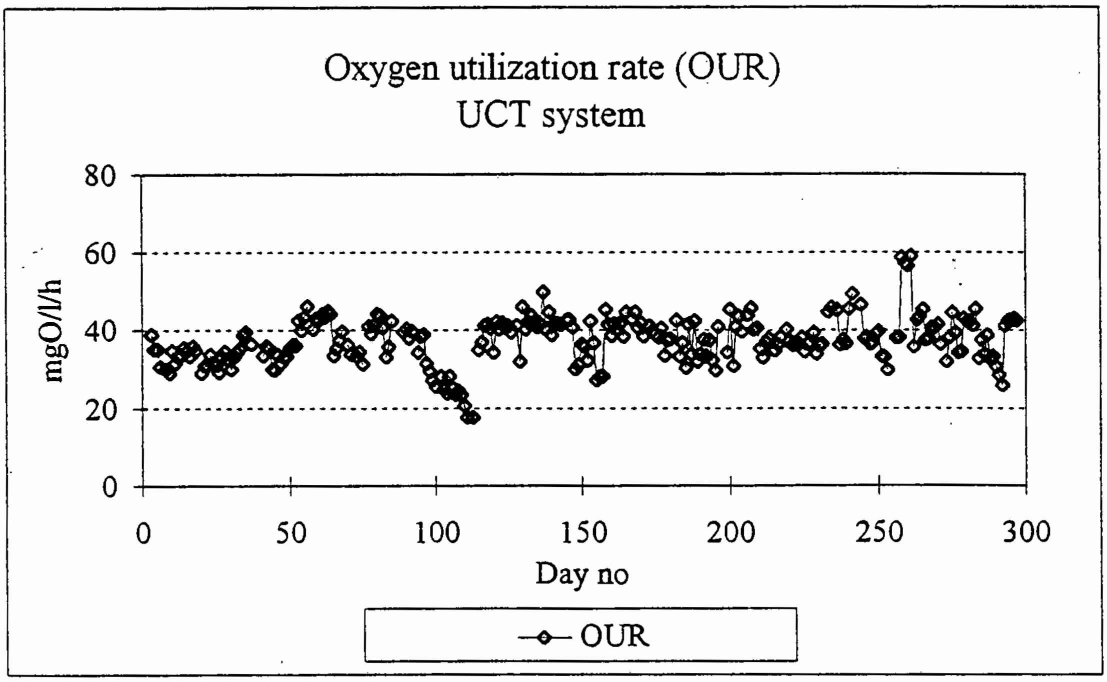


Fig A.34 Daily Oxygen Utilization Rate (mgO/l/h) of aerobic reactor in UCT system from day 1 to day 297.

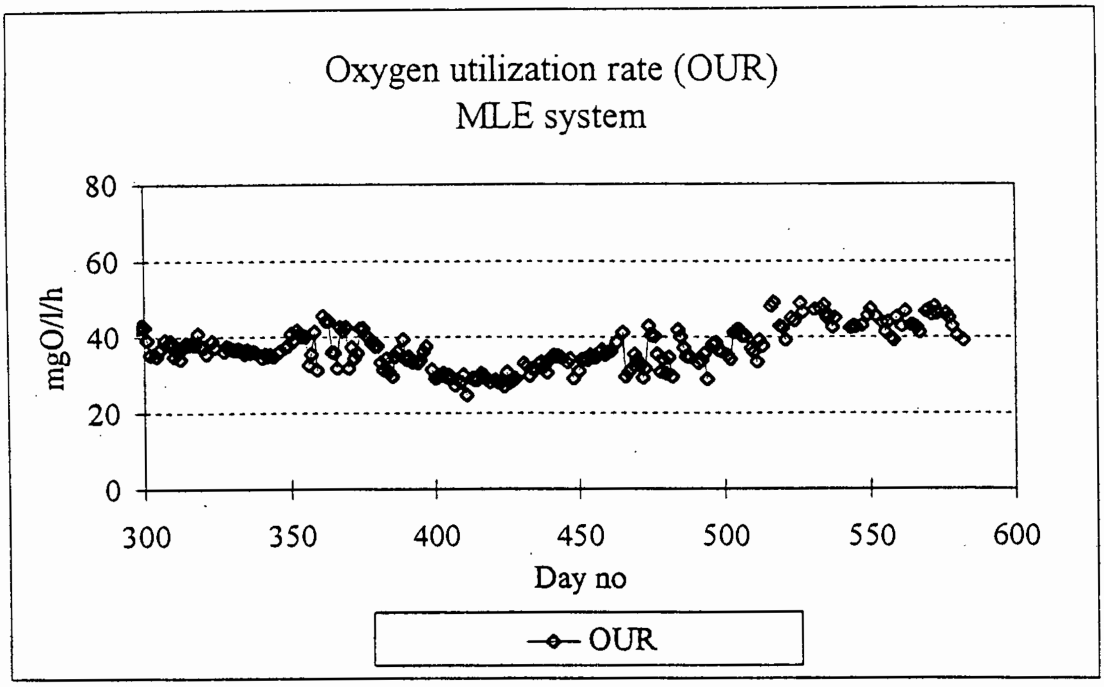


Fig A.35 Daily Oxygen Utilization Rate (mgO/l/h) of aerobic reactor in MLE system from day 298 to day 582.

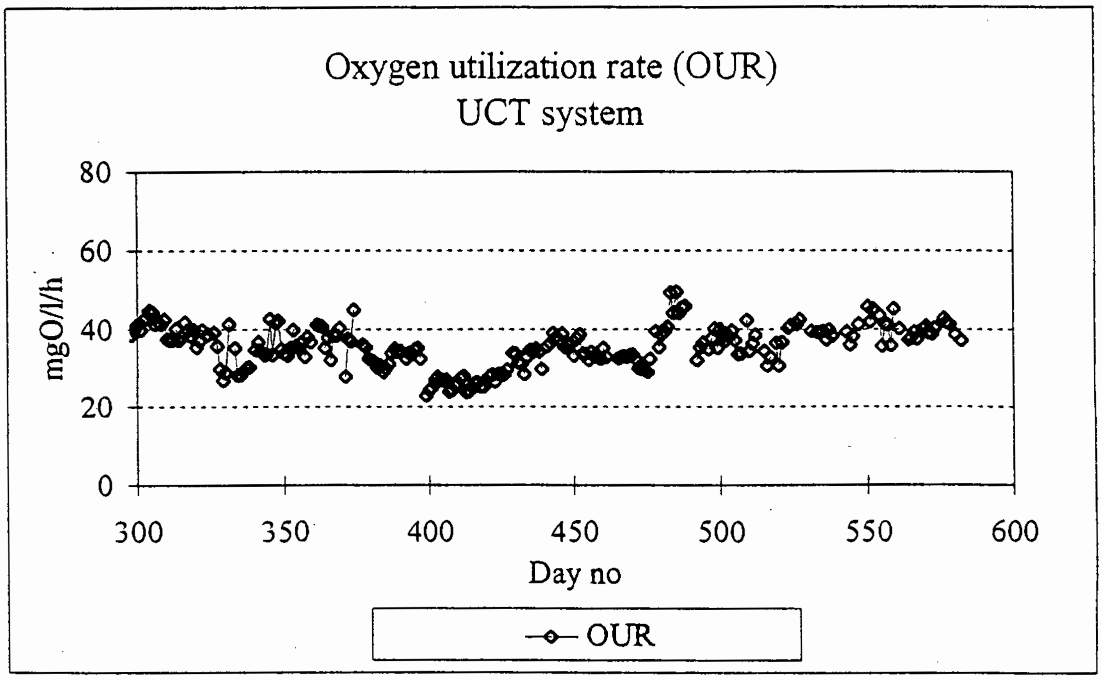


Fig A.36 Daily Oxygen Utilization Rate (mgO/l/h) of aerobic reactor in UCT system from day 298 to day 582.

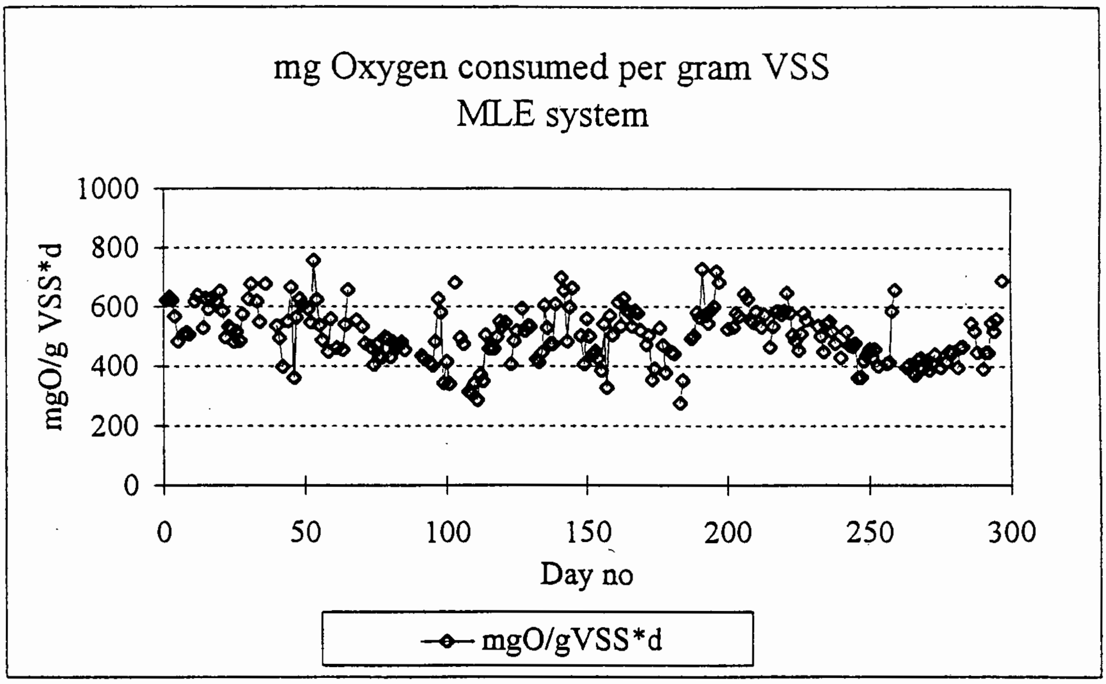


Fig A.37 Daily mass of Oxygen (mg) utilized per gram Volatile Suspended Solids in MLE system from day 1 to day 297.

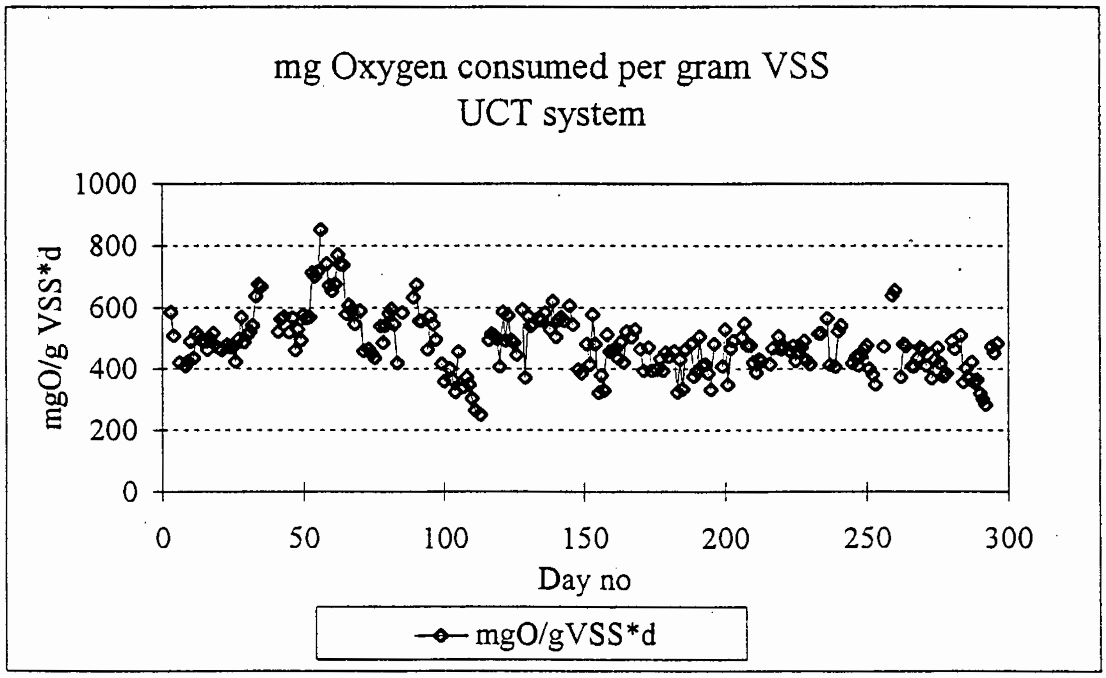


Fig A.38 Daily mass of Oxygen (mg) utilized per gram Volatile Suspended Solids in UCT system from day 1 to day 297.

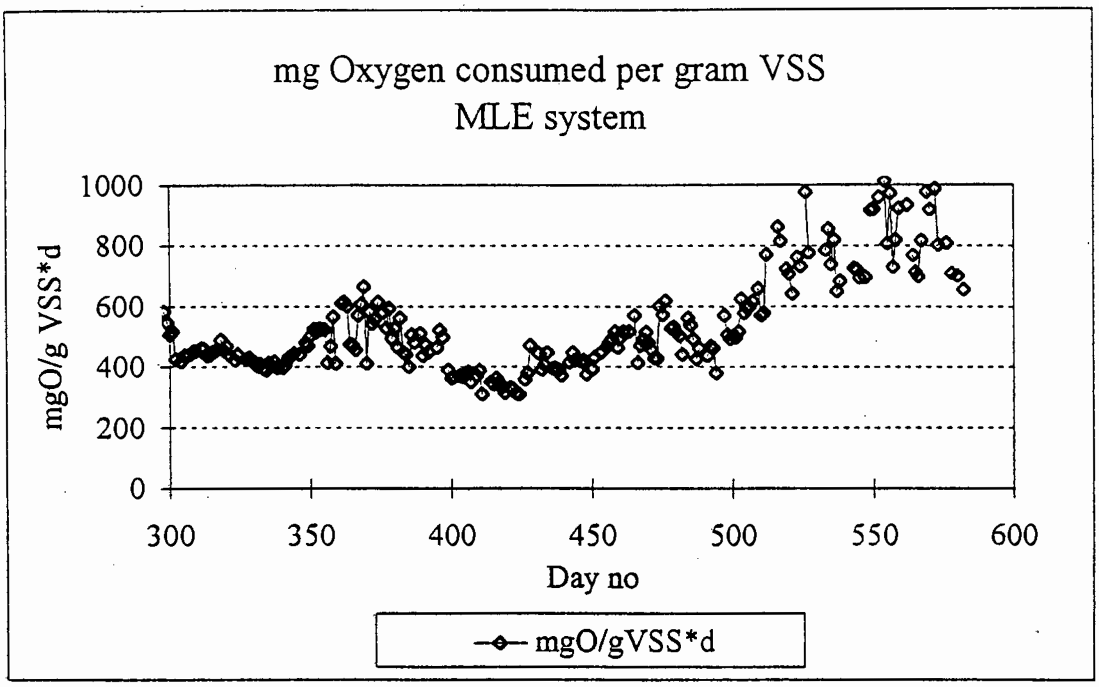


Fig A.39 Daily mass of Oxygen (mg) utilized per gram Volatile Suspended Solids in MLE system from day 298 to day 582.

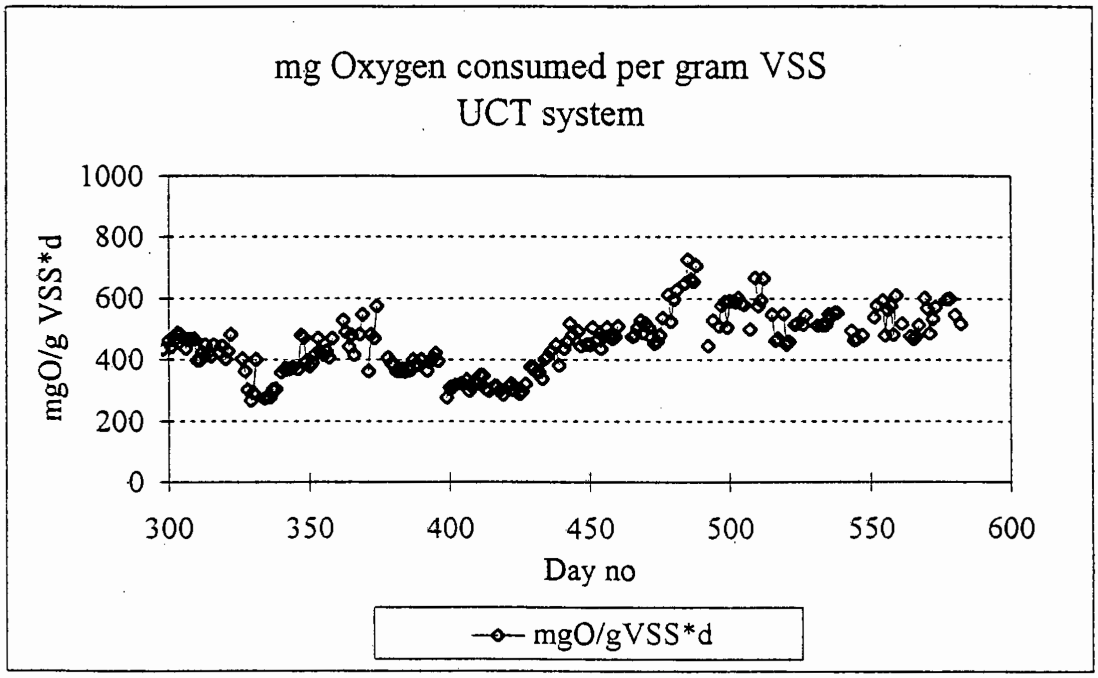


Fig A.40 Daily mass of Oxygen (mg) utilized per gram Volatile Suspended Solids in UCT system from day 298 to day 582.

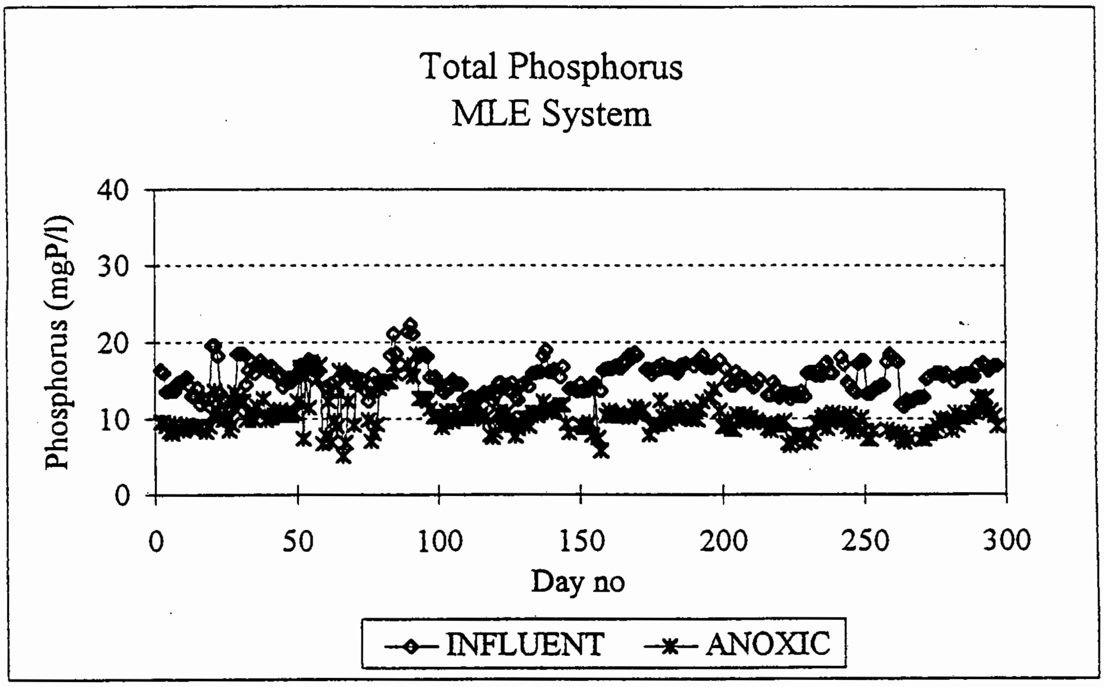


Fig A.41 Daily influent and anoxic Total P concentrations in MLE system from day 1 to day 297.

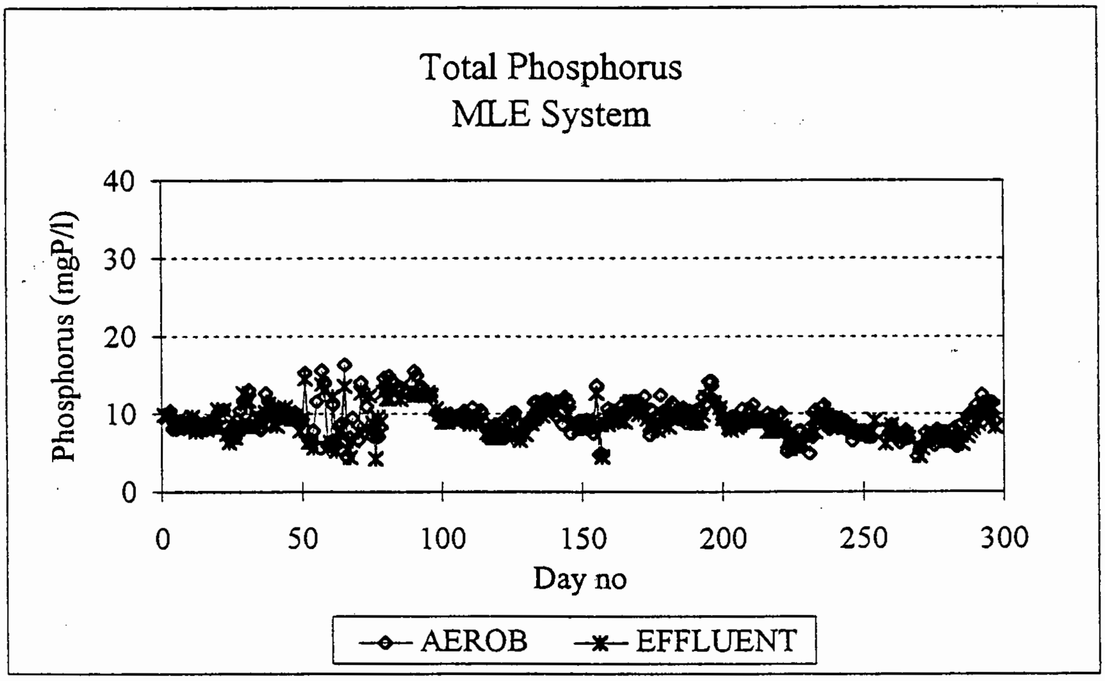


Fig A.42 Daily aerobic and effluent Total P concentrations in MLE system from day 1 to day 297.

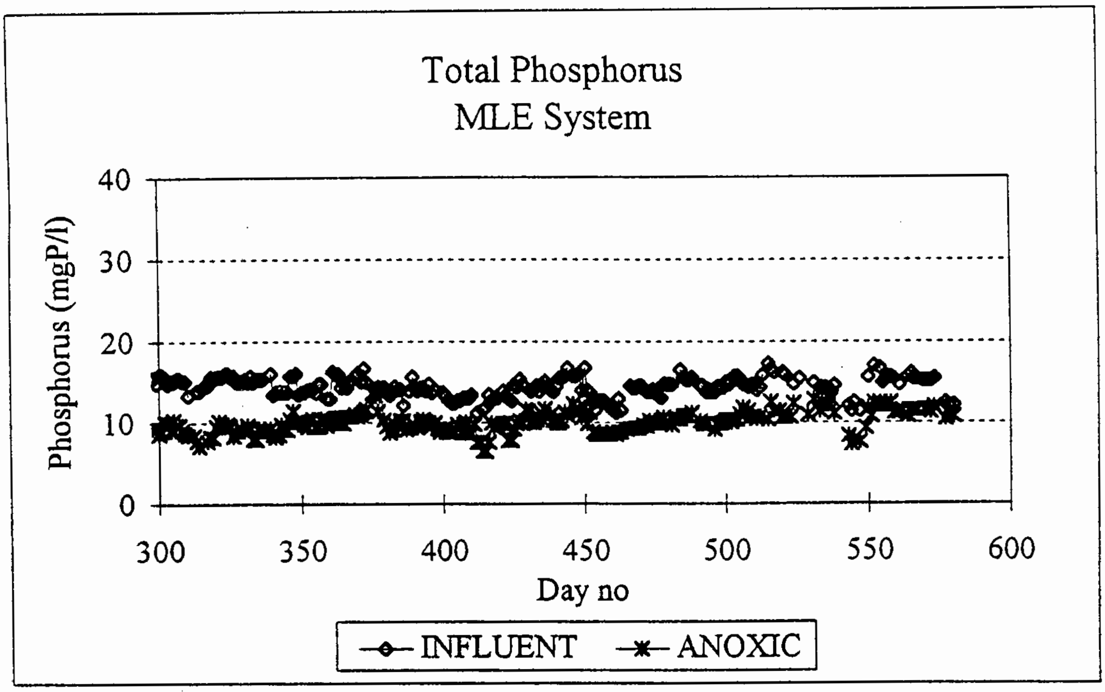


Fig A.43 Daily influent and anoxic Total P concentrations in MLE system from day 298 to day 582.

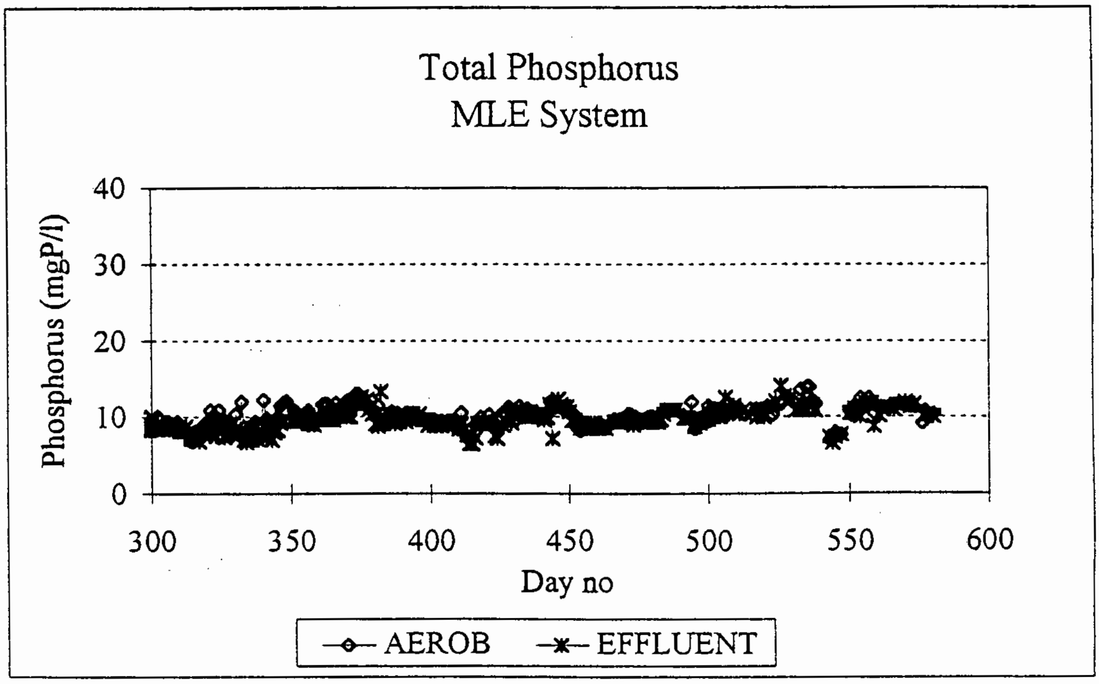


Fig A.44 Daily aerobic and effluent Total P concentrations in MLE system from day 298 to day 582.

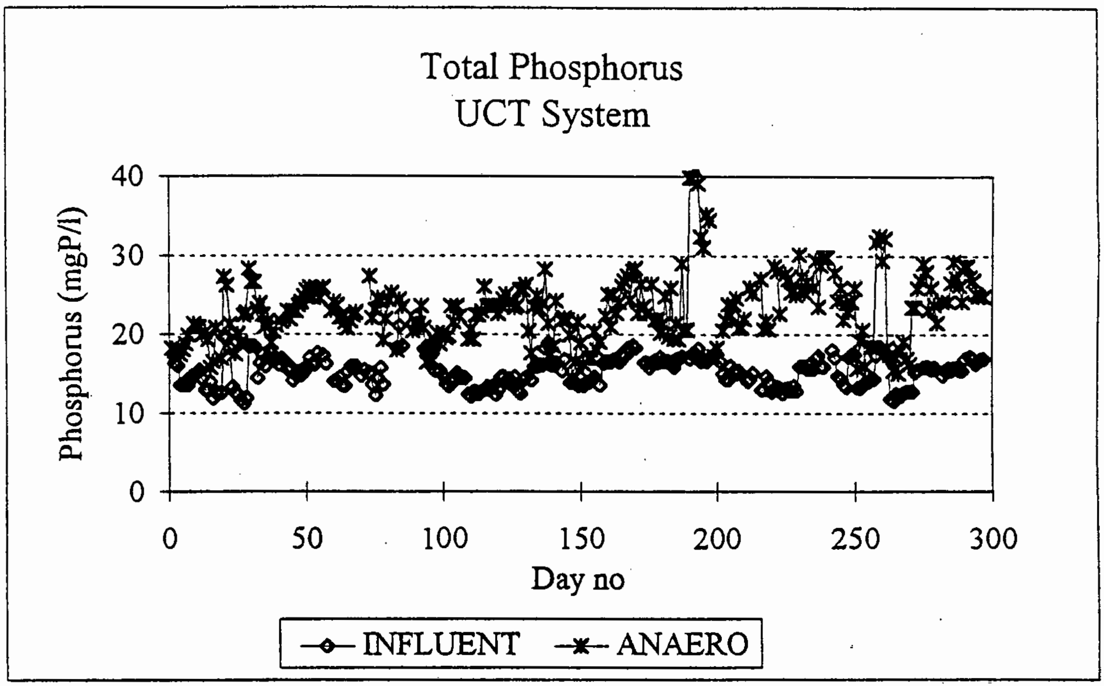


Fig A.45 Daily influent and anaerobic Total P concentrations in UCT system from day 1 to day 297.

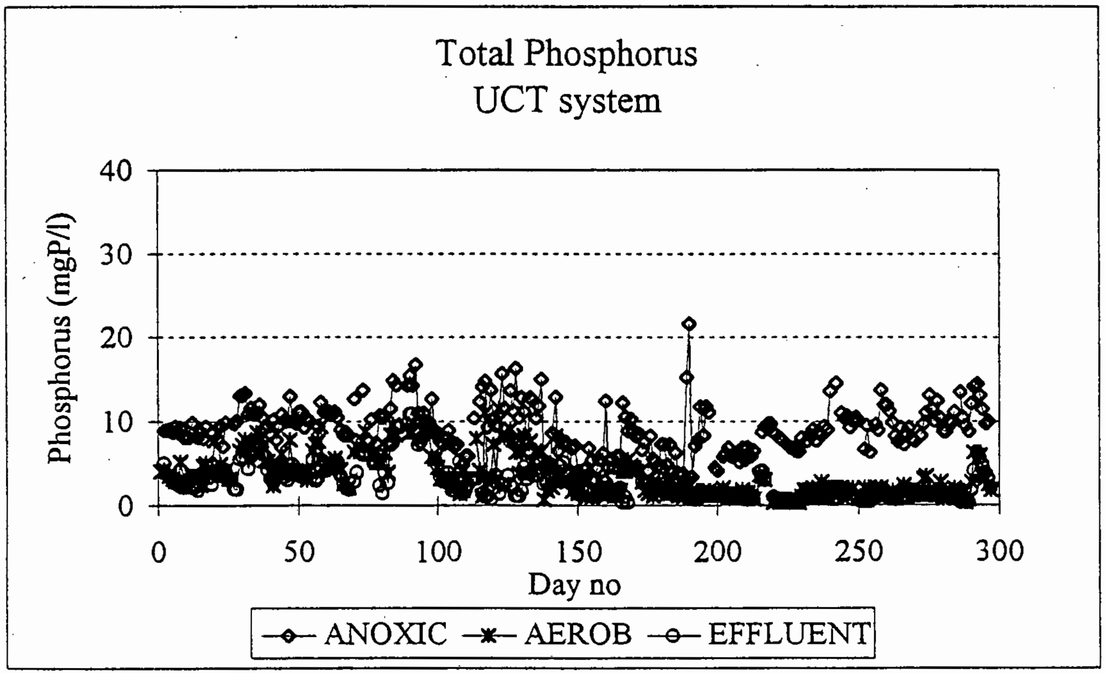


Fig A.46 Daily aerobic, anoxic and effluent Total P concentrations in UCT system from day 1 to day 297.

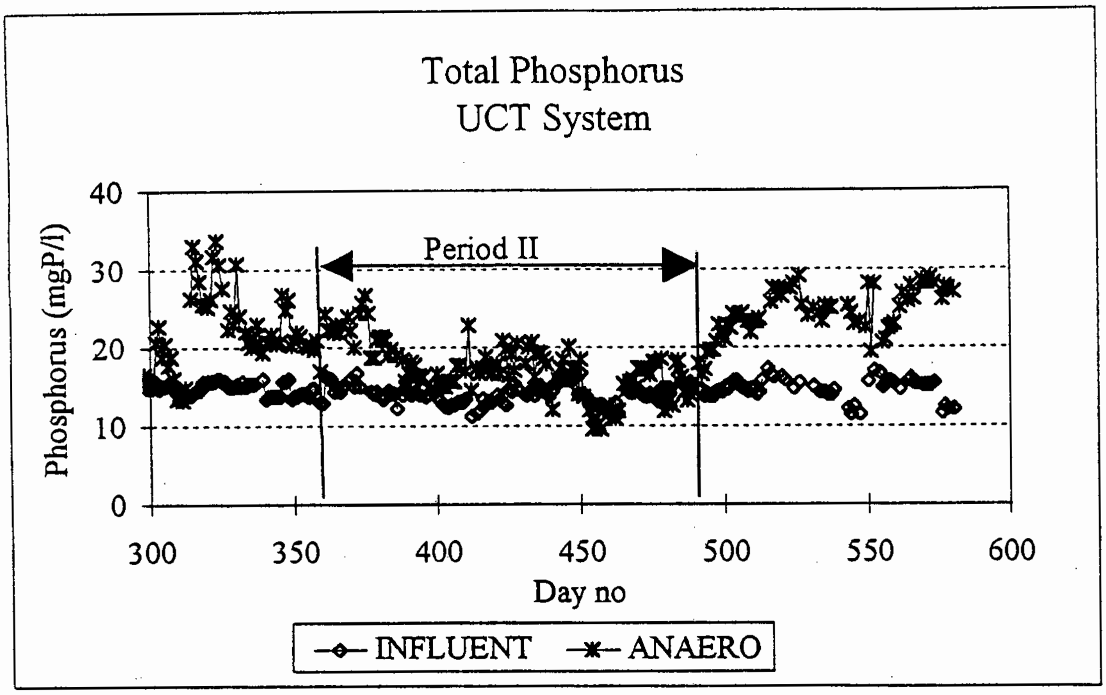


Fig A.47 Daily influent and anaerobic Total P concentrations in UCT system from day 298 to day 582.

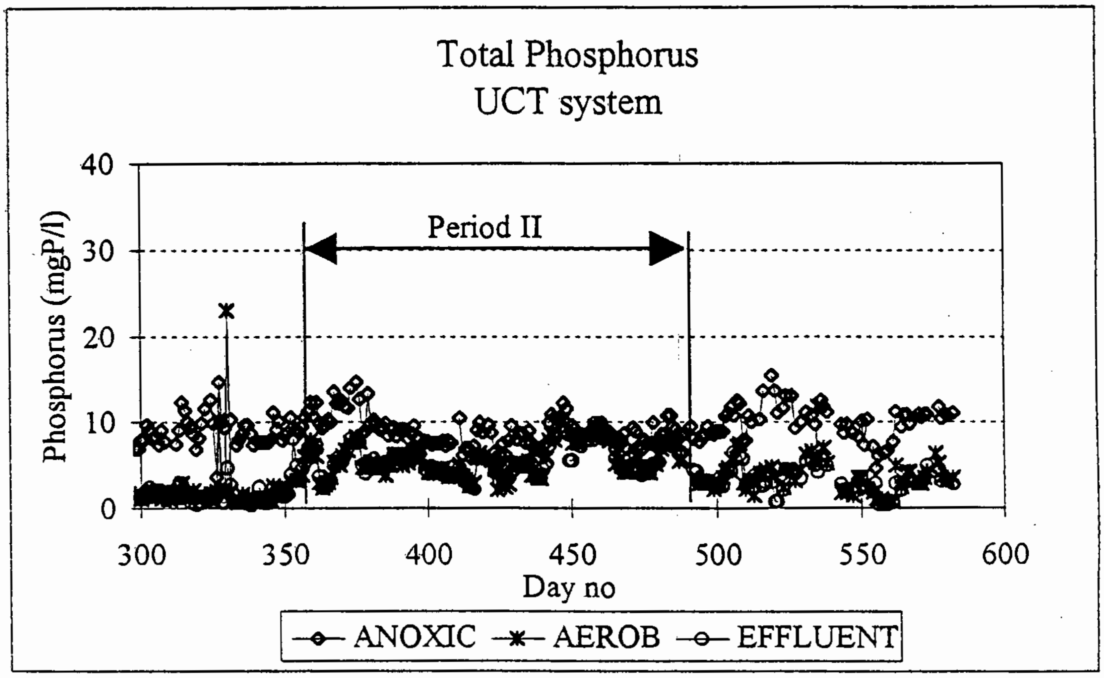


Fig A.48 Daily aerobic, anoxic and effluent Total P concentrations in UCT system from day 298 to day 582.

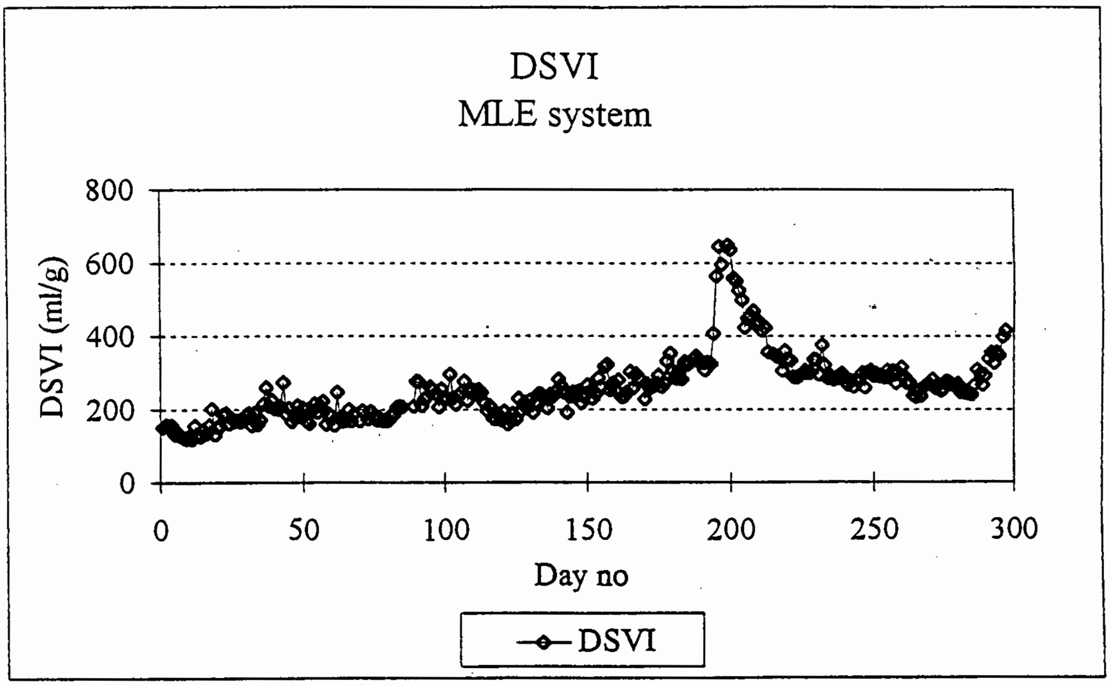


Fig A.49 Daily Diluted Sludge Indices in MLE system from day 1 to day 297

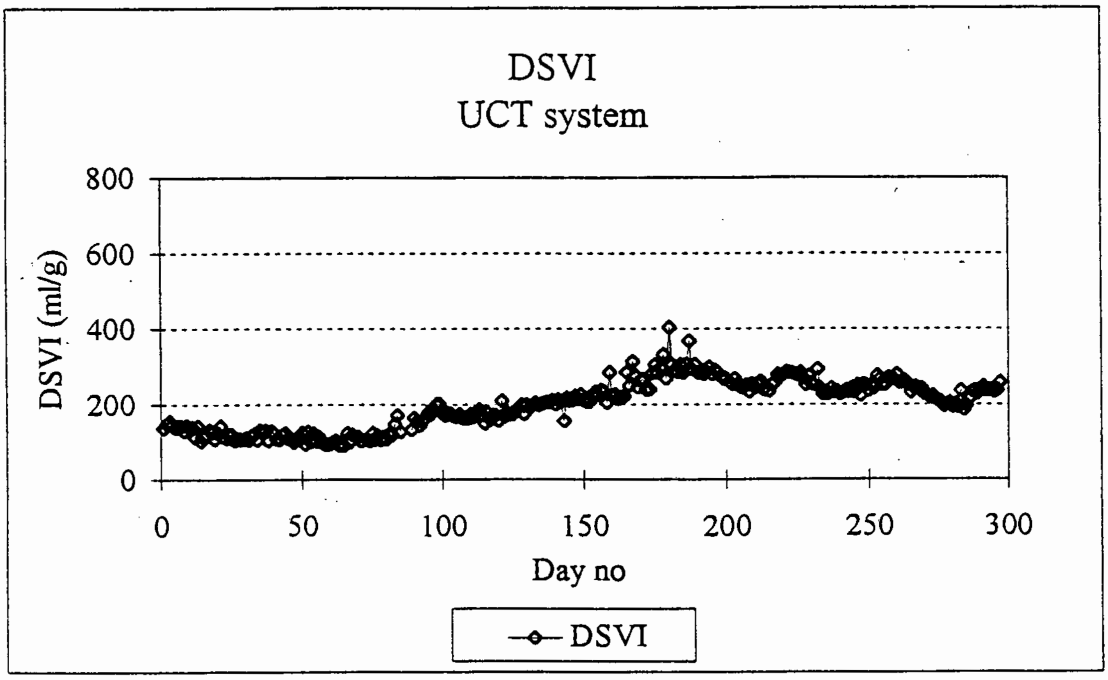


Fig A.50 Fig 3.53 Daily Diluted Sludge Indices in UCT system from day 1 to day 297

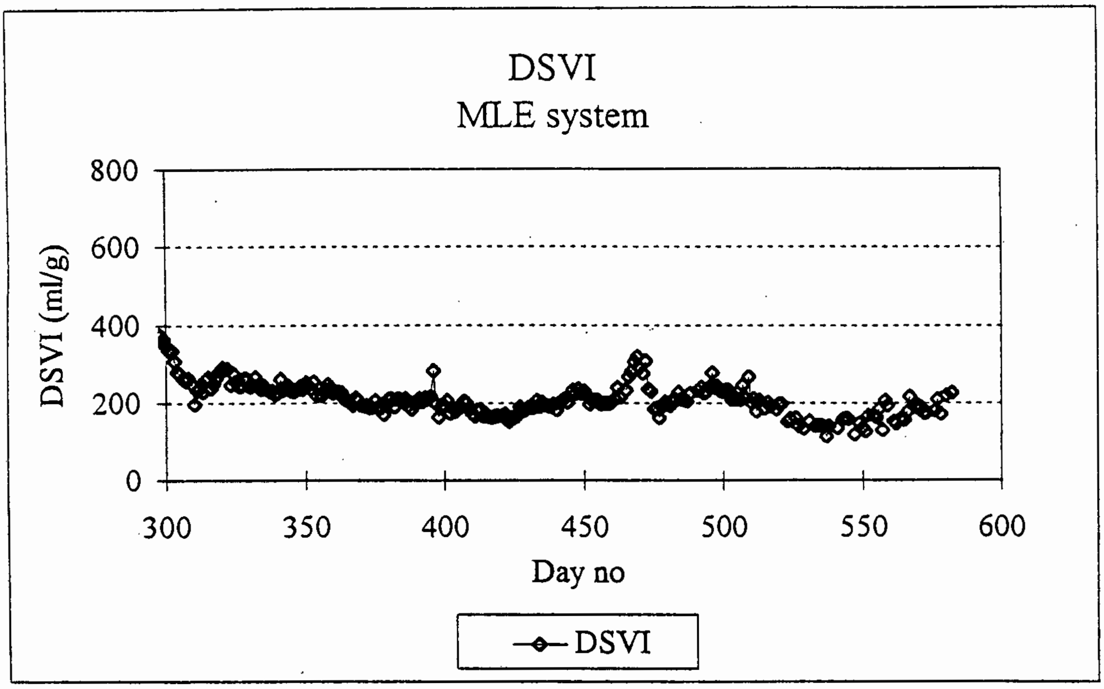


Fig A.51 Daily Diluted Sludge Indices in MLE system from day 298 to day 582

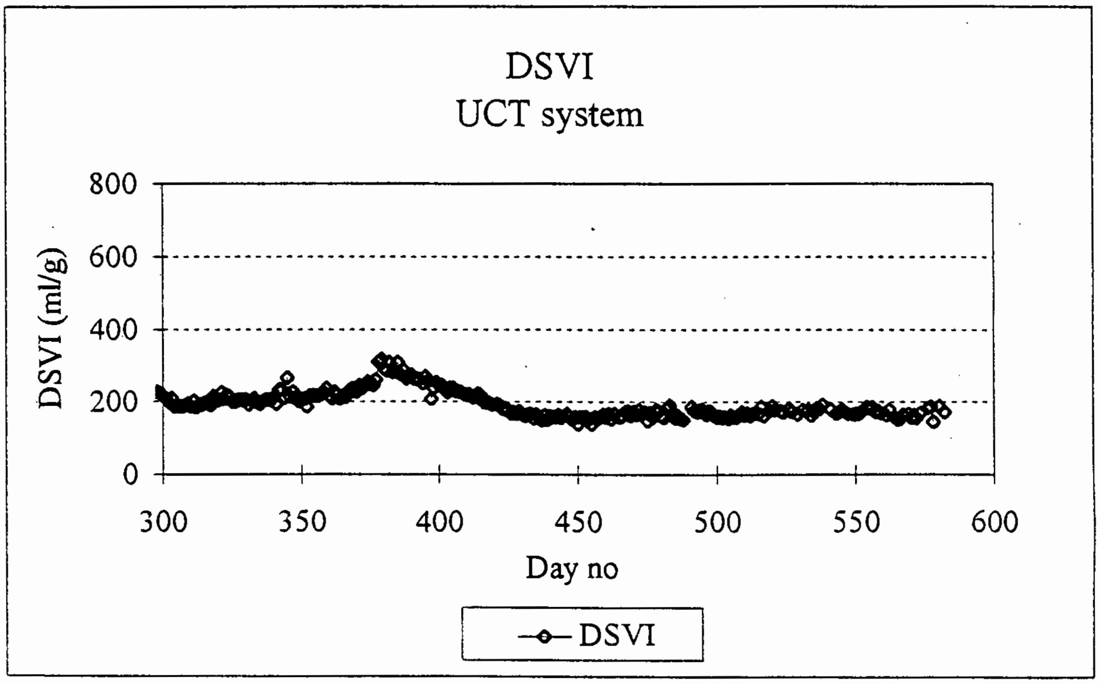


Fig A.52 Fig 3.55 Daily Diluted Sludge Indices in UCT system from day 298 to day 582

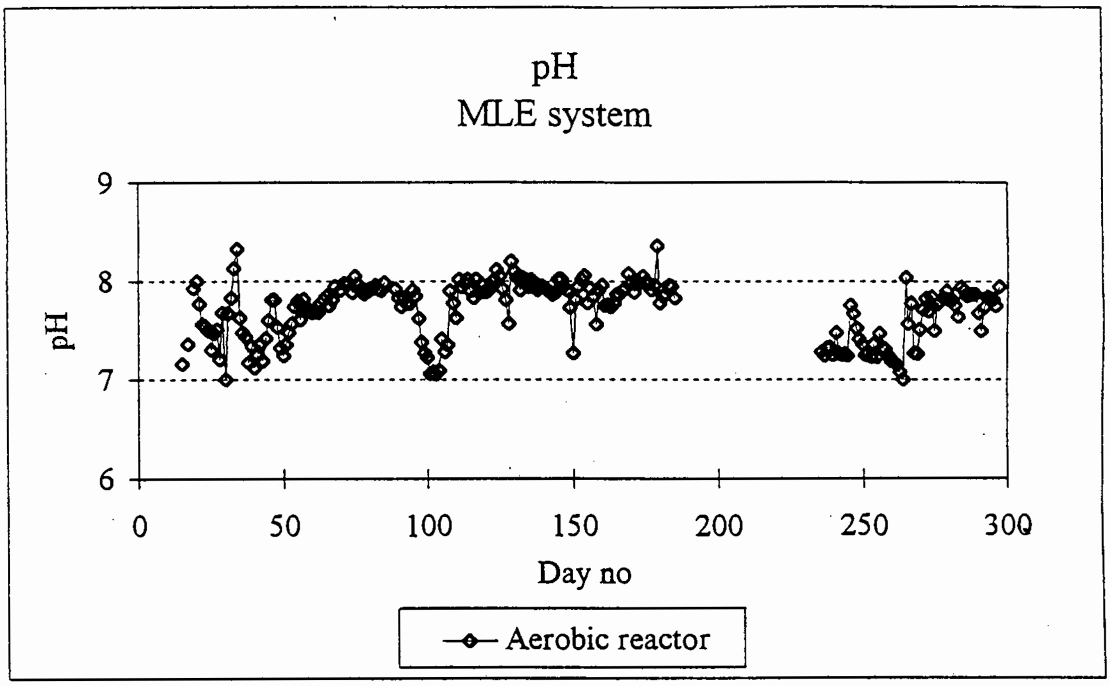


Fig A.53 Daily aerobic pH measurements in MLE system from day 1 to day 297

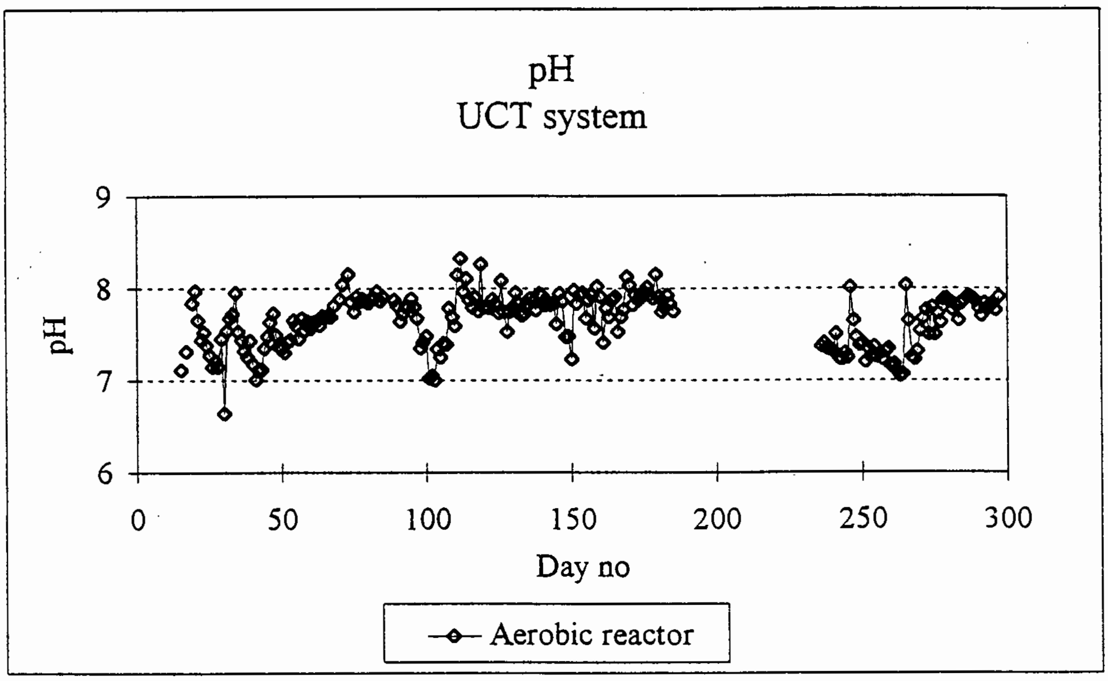


Fig A.54 Daily aerobic pH measurements in UCT system from day 1 to day 297

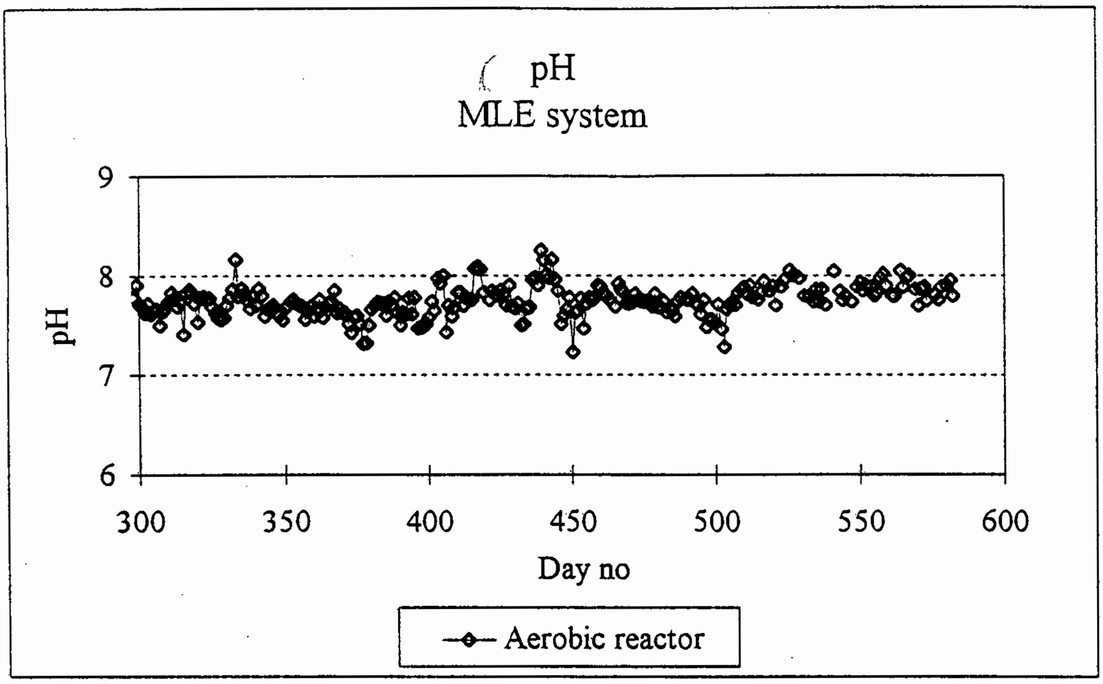


Fig A.55 Daily aerobic pH measurements in MLE system from day 298 to day 582

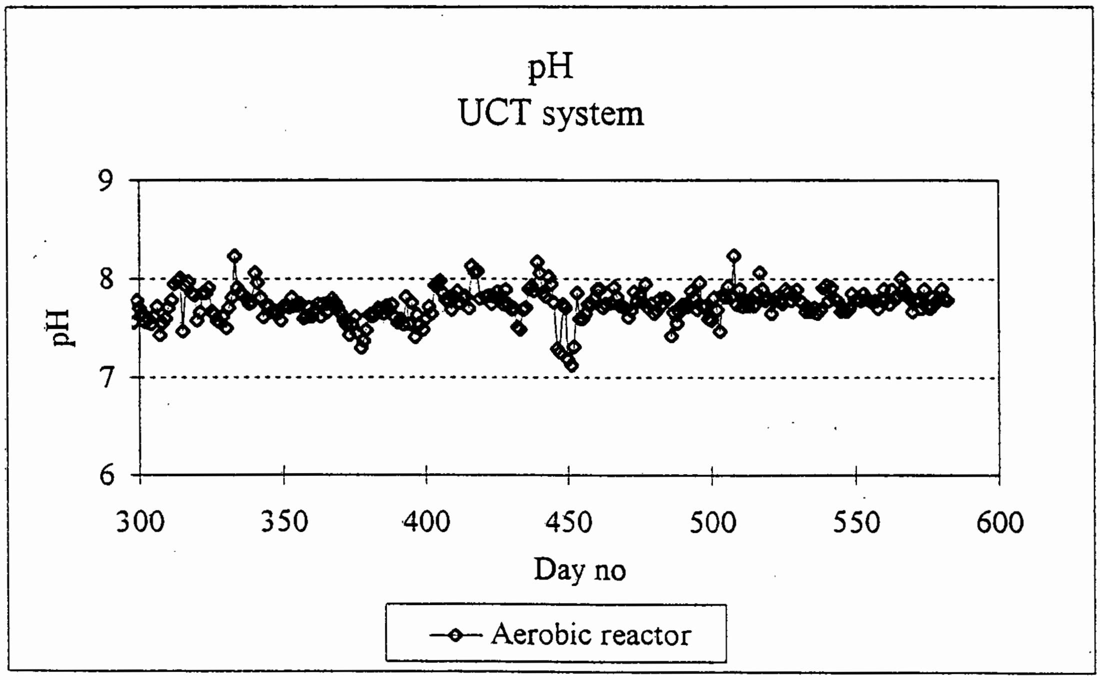


Fig A.56 Daily aerobic pH measurements in UCT system from day 298 to day 582

APPENDIX B

NITROGEN AND COD BALANCES

A good method for testing the accuracy of the measured system response data is to perform nitrogen and COD balances on the both sytem. Both types of balances are discussed below.

B.1 The nitrogen balance

The daily mass of nitrogen that enters the laboratory system in the form of influent TKN (MS_{Nti}) may be accounted for as follows:

(i) Nitrate that is denitrified.
(ii) Nitrogen in the waste sludge.
(iii) TKN in the effluent.
(iv) Nitrate in the effluent.

(i) Mass of nitrate denitrified

This quantity is obtained by a mass balance around the anoxic section of the system. Where significant amounts of nitrite are generated it is necessary to split the nitrate and nitrite to produce an accurate calculation particularly for the COD mass balance.

For the MLE system configuration (see Fig. B.1):

(Mass NO_2-N denitrified) =(Mass NO_2-N into unaerated zone)
-(Mass NO_2-N out of unaerated zone)

$$MNO_{2d} = (a+s)QNO_2\ \text{aer.} - (1+s+a)QNO_2\ \text{unaer.} \qquad (B.1)$$

(Mass NO_3-N denitrified) =(Mass NO_3-N into unaerated zone)
-(Mass NO_3-N out of unaerated zone)

$$MNO_{3d} = (a+s)QNO_3\ \text{aer.} - (1+s+a)QNO_3\ \text{unaer.} \qquad (B.2)$$

For the UCT system configuration (see Fig. B.2):

$$MNO_{2d} = (1+r)QMNO_2\ \text{anaer} + (a+s)QMN_2\ \text{aer.} - (1+s+a)QMNO_2\text{anox} \qquad (B.3)$$

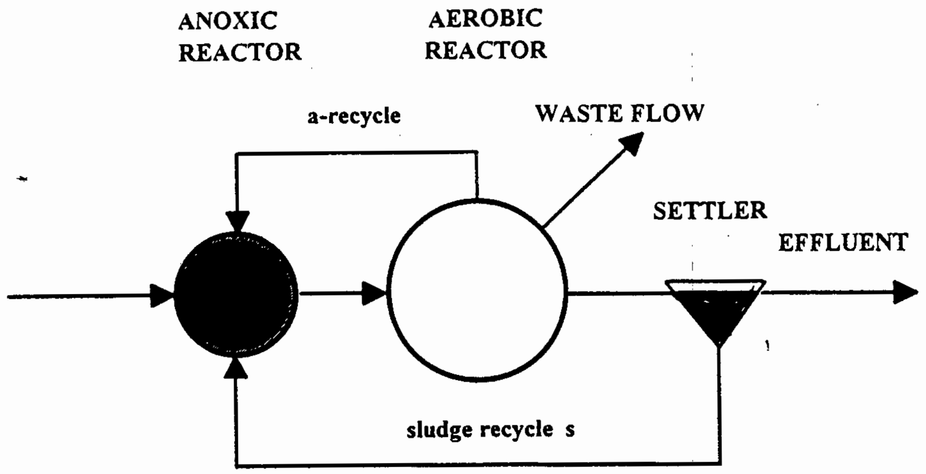


Fig B.1 The MLE system with all the quantities needed for the overall nitrogen and COD balances

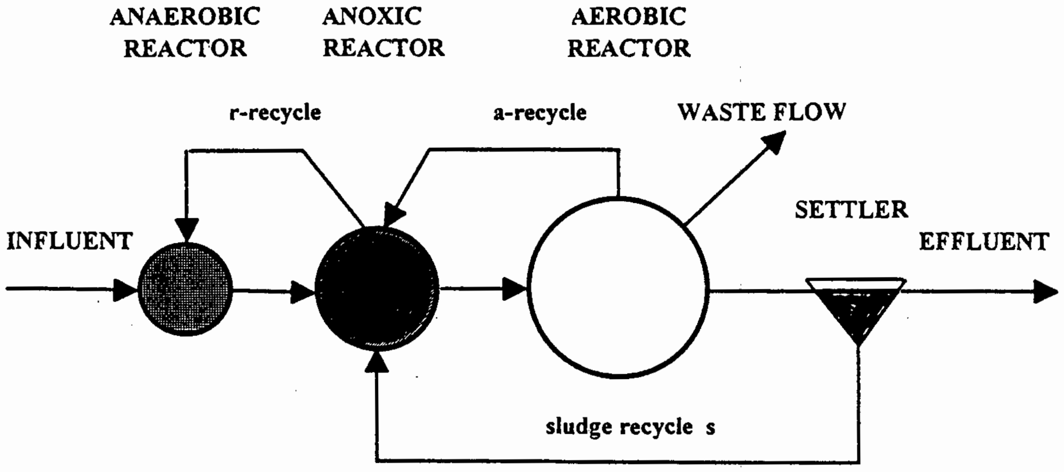


Fig B.2 The UCT system with all the quantities needed for the overall nitrogen and COD balances

MNO_{3d} $= (1+r)QMNO_3\ anaer + (a+s)QMN_3\ aer. -(1+s+a)QMNO_3anox$ (B.4)

where

MNO_2	= mass of nitrite denitrified per day (mgN/d)
MNO_3	= mass of nitrate denitrified per day (mgN/d)
NO_3 anaer	= effluent nitrate concentration from anaerobic reactor (mgN/l)
NO_2 aer	= effluent nitrite concentration from aerobic reactor (mgN/l)
NO_3 aer	= effluent nitrate concentration from aerobic reactor (mgN/l)
NO_2 anox	= effluent nitrite concentration from anoxic reactor (mgN/l)
NO_3 anox	= effluent nitrate concentration from anoxic reactor (mgN/l)
Q	= daily influent flow rate (*l*/d)
a,r,s	= recycled ratios

(ii) Mass N in waste sludge

The mass of N in the waste sludge is given by the TKN/VSS ratio ($f_n = 0.10$mgN/mgVSS) multiplied by the mass of VSS wasted each day:

$MX_N = f_nMX_{vw}$ (mgN/d) (B.5)

(iii) Mass of TKN in effluent

This is simply the effluent TKN concentration multiplied by the daily flow rate:

$MN_e = QN_{te}$ (mgN/d) (B.6)

(iv) Mass of nitrite plus nitrate in effluent

This is given by the nitrite plus nitrate concentration in the effluent multiplied by the daily flow rate:

$MNO_e = Q(NO_{2e}+NO_{3e})$ (mgN/d) (B.7)

The percentage N balance is then given by:

$\%N\ balance = 100*(MNO_d+ MX_N+ MN_{te}+ MNO_e)/MN_{ti}$ (B.8)

B.2 The COD balance

The daily mass of COD (MS_{ti}) that enters the laboratory system in the influent undergoes the following split:

(i) The oxygen required for degradation of carbonaceous material in the aerobic reactor.
(ii) An equivalent oxygen demand of denitrification.
(iii) COD in the waste sludge
(iv) COD in the effluent

(I) Carbonaceous oxygen demand

The total amount of oxygen utilized in the aerobic zone is made up of the nitrification oxygen demand and the carbonaceous oxygen demand. nitrification does not consume any of the influent biodegradable material (the influent COD) and consequently the oxygen demand due to nitrification must be subtracted from the total oxygen demand. Stoichiometrically the oxygen requirements for nitrification of ammonia to nitrite and to nitrate is different being slightly less in the former reacton i.e.(3,43 mgO/mg and 4,57 mgO/mgN generated from ammonia)

The calculation is as follows:

(a) Part of the mass of nitrite plus nitrate generated from nitrification becomes denitrified and the rest passes out in the system effluent, i.e.

$$MNO = MNO_d + MNO_e \quad (mgN/d) \quad (B.9)$$

(b) The nitrification oxygen demand is then given by:

$$MOn = 4{,}75\ MNO_3 + 3{,}43 MNO_2 \quad (mgO/d) \quad (B.10)$$

where

4,57 = mass of oxygen required to form a unit mass of nitrate (mgO/mgN)
3,43 = mass of oxygen required to form a unit mass of nitrite (mgO/mgN

(c) The carbonaceous oxygen demand may now be determined:

$$MO_c = (OUR)*V_a*24*MO_n) \quad (mgO/d) \quad (B.11)$$

where

OUR = oxygen utization rate in the aerobic zone (mgO/*l*/d)
V_a = aerobic reactor volume (*l*)

(ii) Equivalent oxygen demand of denitrification

During denitrification, some influent biodegradable COD is oxidized with nitrate and nitrite. Stochiometrically the equivalent amount of oxygen supplied during denitrification is different for nitrate and nitrite and therefore the equivalent oxygen demand per day for denitrification of nitrate and nitrite is given by:
:

$$MO_d = 2{,}86MNO_3 + 1{,}71\ MNO_2 \qquad (mgO/d) \qquad (B.12)$$

where MNO_d = mass of nitrate denitrified per day (mgN/d)
2,86 = equivalent mass of oxygen for the same amount of oxidation as one unit of nitrate as N ($mgO/mgNO_3$-N)
1,71 = equivalent mass of oxygen for the same amount of oxidation as one unit of nitrite as N ($mgO/mgNO_3$-N)

(iii) COD in waste sludge

The amount of COD that passes out of the system as waste sludge is given by:

$$MX_{SVW} = f_{cv}MX_{VW} \qquad (mgO/d) \qquad (B.13)$$

where f_{cv} = COD/VSS ratio of activated sludge
= 1.48 mgCOD/mgVSS
MX_{VW} = mass of sludge wasted per day (mgVSS/d)

(iv) COD in effluent

COD in the effluent is given by the daily flow rate multiplied by the effluent COD concentration:

$$MS_{te} = QS_{te} \qquad (mgCOD/d) \qquad (B.14)$$

The percentage COD balance is calculated according to:

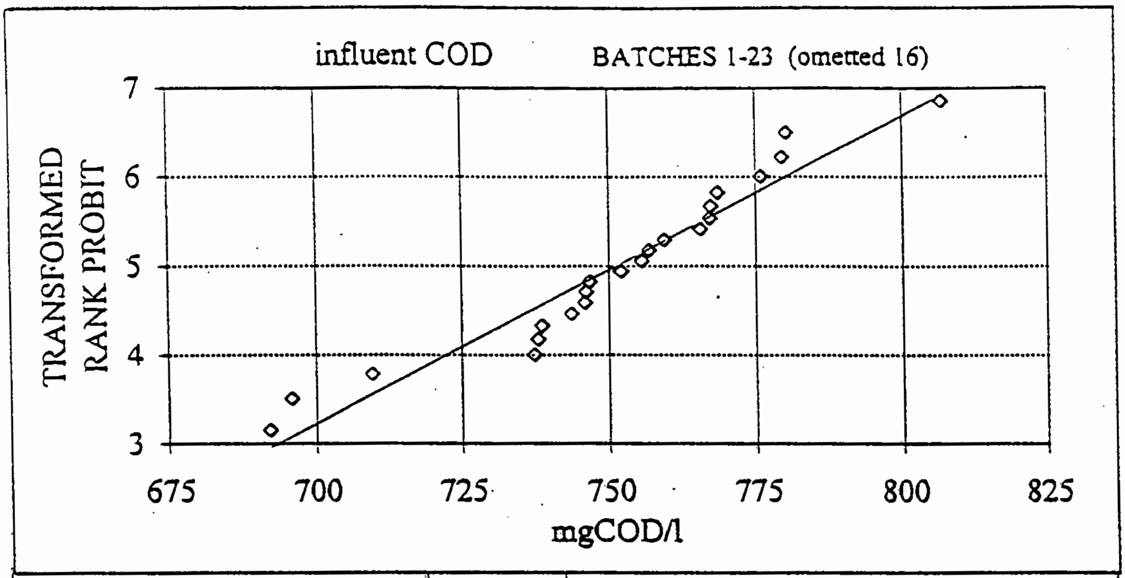
$$\%\ COD\ balance = 100*(\ MO_c + MO_d + MX_{SVW} + MS_{te})/MS_{ti}$$

APPENDIX C

STATISTICAL PLOTS FOR SEWAGE BATCHES OVER THE DIFFERENT PERIODS.

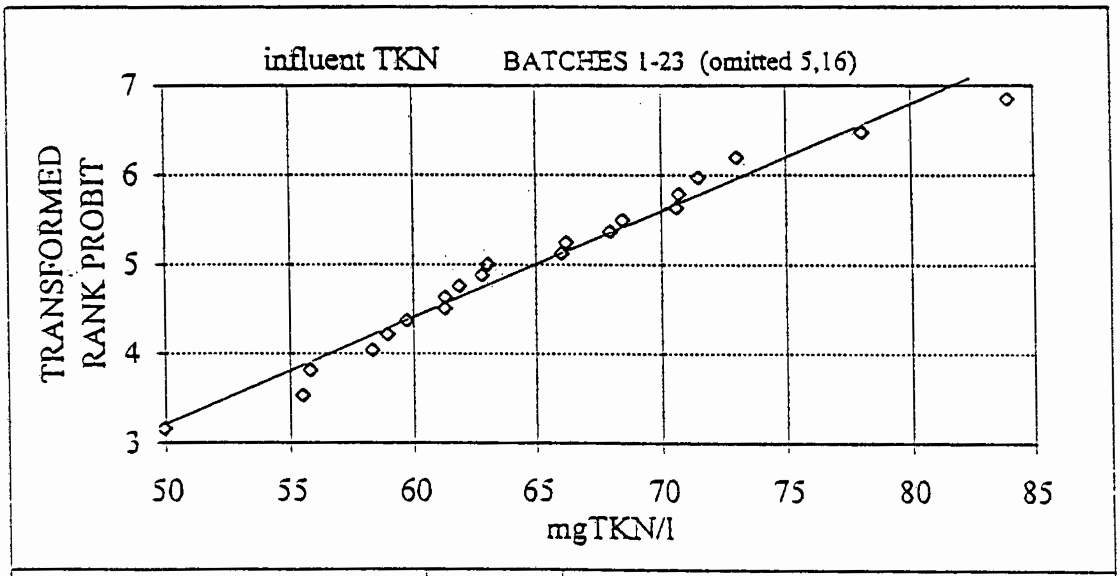
Period	Sewage batches	From day to day	From page to page
CI	1 to 23	1 to 360	C.1 to C.17
CII	24 to 33	361 to 490	C.18 to C.34
CIII	34 to 41	491 to 582	C.35 to C.51

Period CI (sewage batches 1 to 23; days 1 to 360)



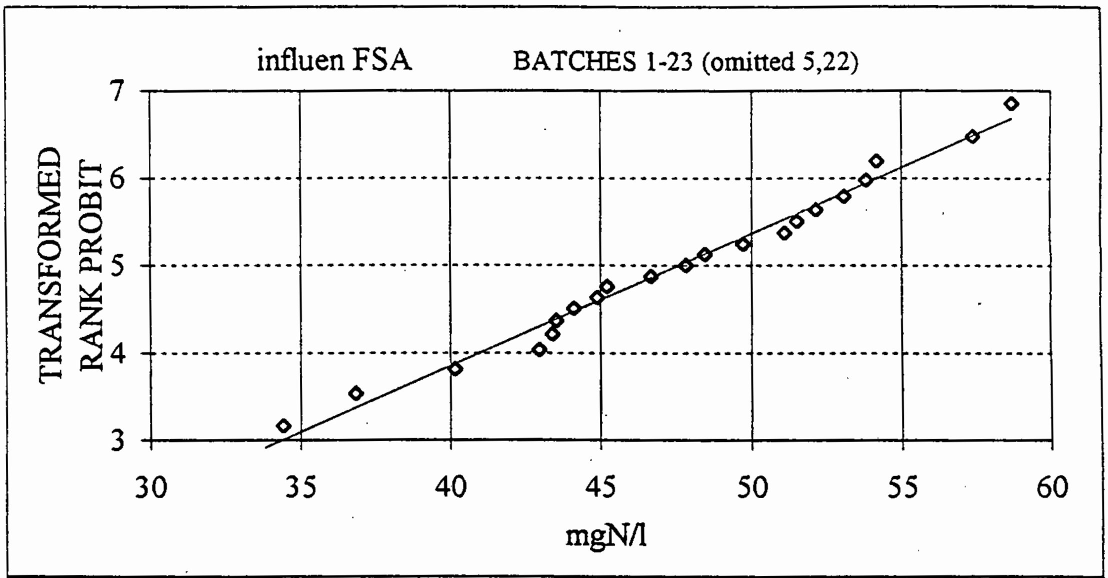
MEDIAN=	754		std dev. of mean =	6
MEAN =	751		95% conf. of mean = 751 +/-	11
s =	27			

Fig CI.1 Probability distribution of the daily influent COD concentration from day 1 to day 360.



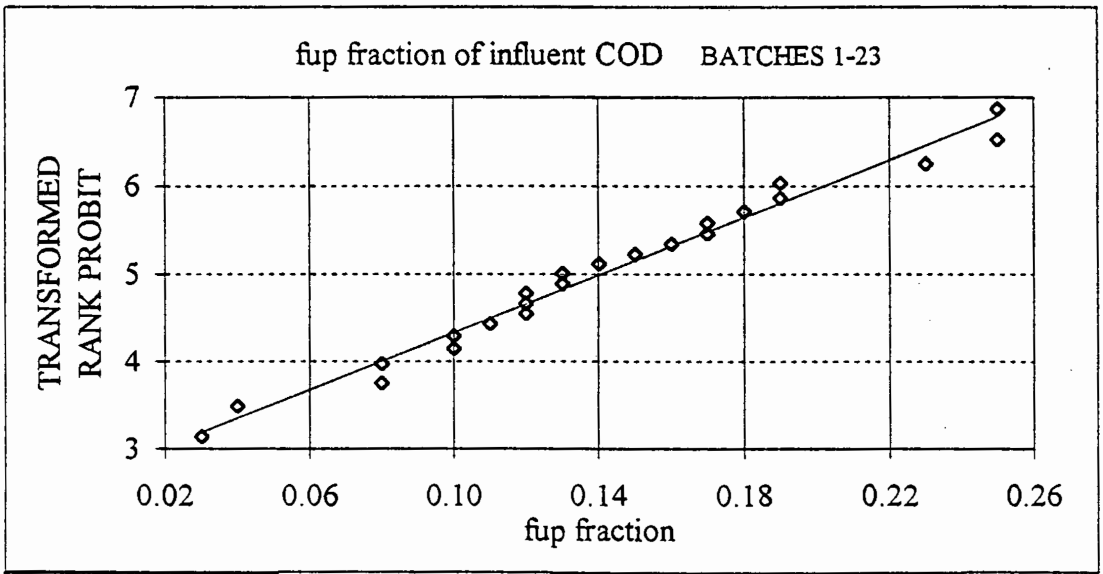
MEDIAN=	63		std dev. of mean =	2
MEAN =	65		95% conf. of mean = 65 +/-	3
s =	8			

Fig CI.2 Probability distribution of the daily influent TKN concentration from day 1 to day 360.



MEDIAN=	47.8		std dev. of mean =	1.4
MEAN =	47.6		95% conf. of mean = 47.6 +/-	2.7
s =	6.4			

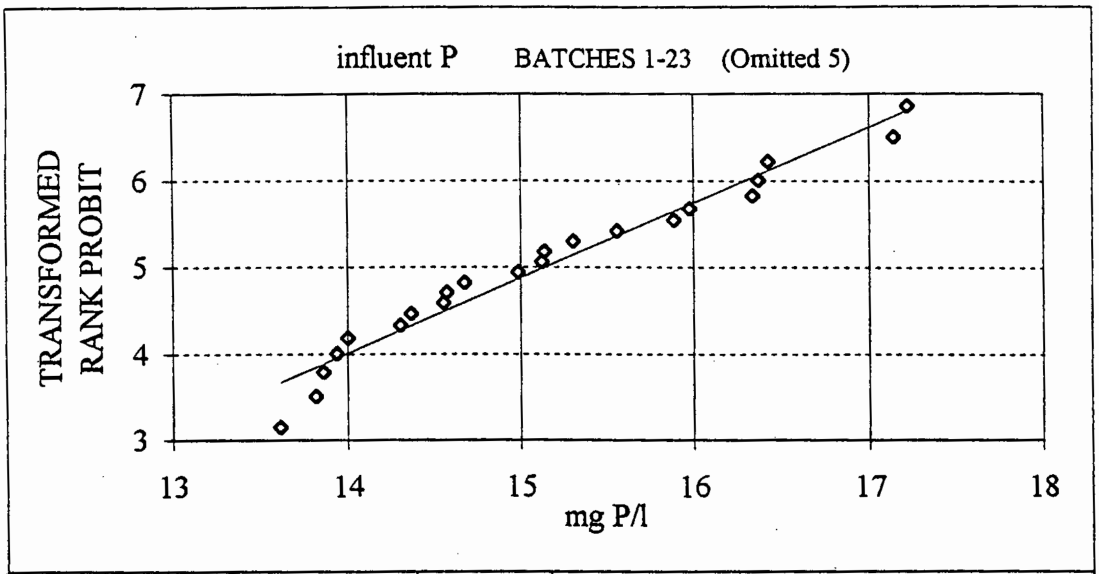
Fig CI.3 Probability distribution of the daily influent Free and Saline Ammonia from day 1 to day 360.



MEDIAN=	0.130		std dev. of mean =	0.012
MEAN =	0.141		95% conf. of mean = 0.141+/-	0.024
s =	0.059			

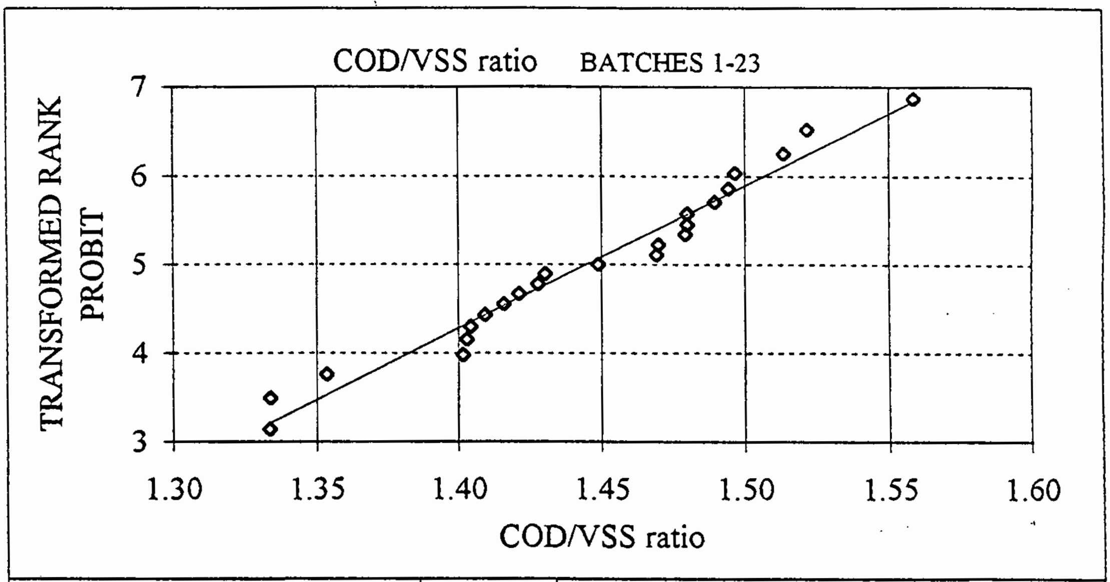
Fig CI.4 Probability distribution of the fup fraction of daily influent COD from day 1 to day 360.

VCT



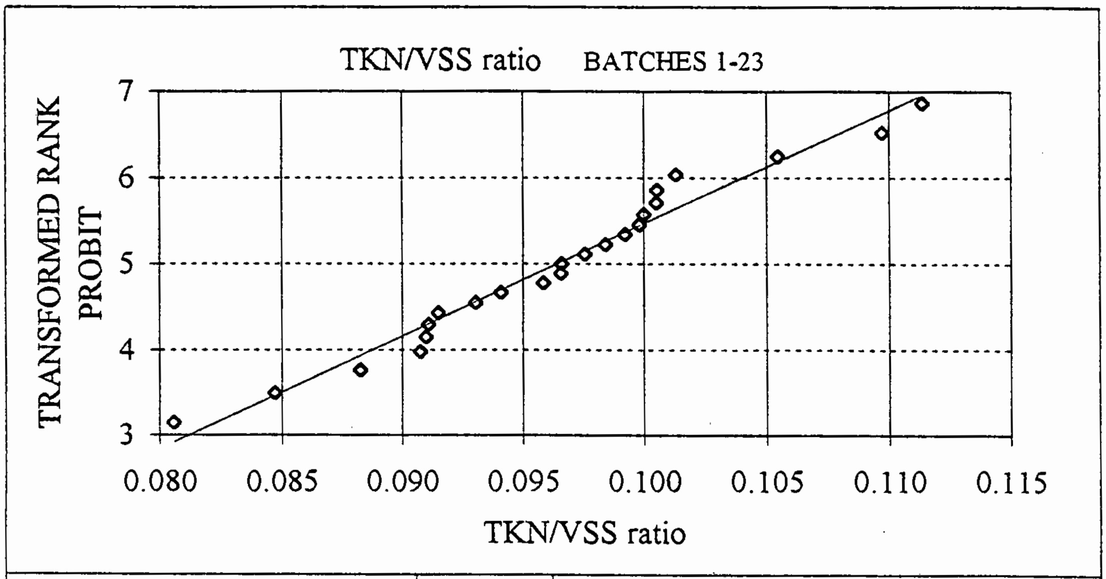
MEDIAN=	15.1		std dev. of mean = 0.2
MEAN =	15.1		95% conf. of mean = 15.1 +/- 0.5
s =	1.1		

Fig CI.5 Probability distribution of the dayly influent P concentration from day 1 to day 360.



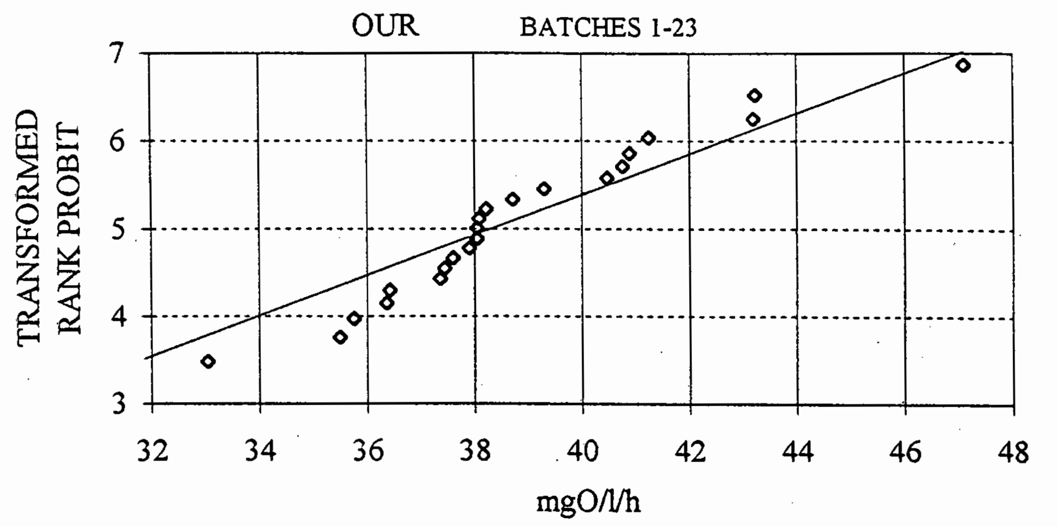
MEDIAN=	1.45		std dev. of mean =	0.01
MEAN =	1.45		95% conf. of mean = 1.45 +/-	0.02
s =	0.06			

Fig CI.6 Probability distribution of the daily COD/VSS ratio in aerobic reactor in MLE system from day 1 to day 360.



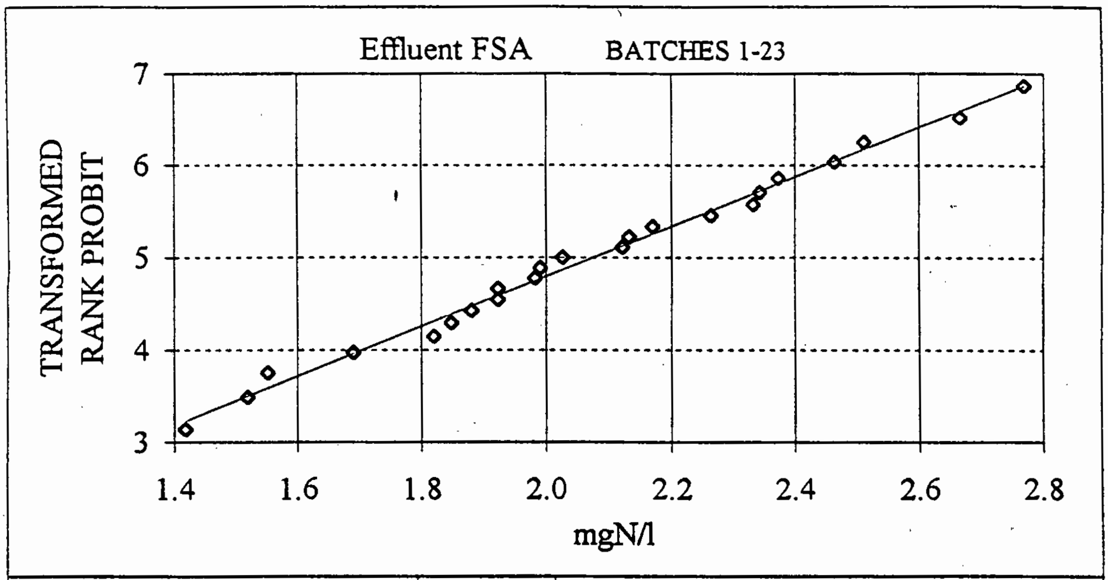
MEDIAN=	0.097		std dev. of mean =	0.002
MEAN =	0.096		95% conf. of mean =0.096 +/-	0.003
s =	0.007			

Fig CI.7 Probability distribution of the daily TKN/VSS ratio in aerobic reactor in MLE system from day 1 to day 360.



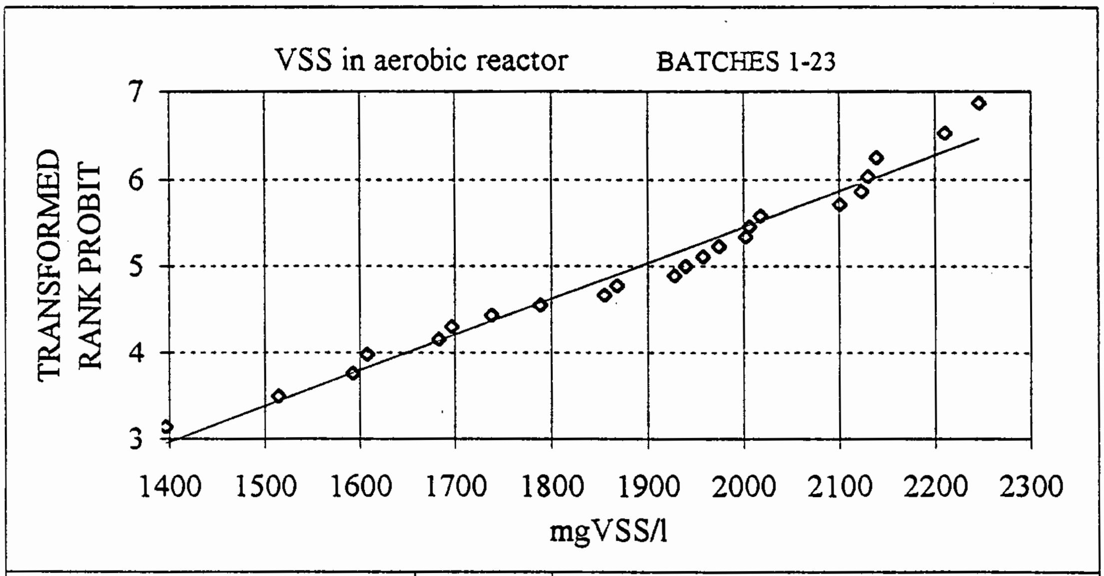
MEDIAN=	38.0		std dev. of mean =	0.8
MEAN =	38.3		95% conf. of mean =	38.3 +/- 1.6
s =	4.0			

Fig CI.8 Probability distribution of the daily Oxygen Utilization Rate in aerobic reactor in MLE system from day 1 to day 360.



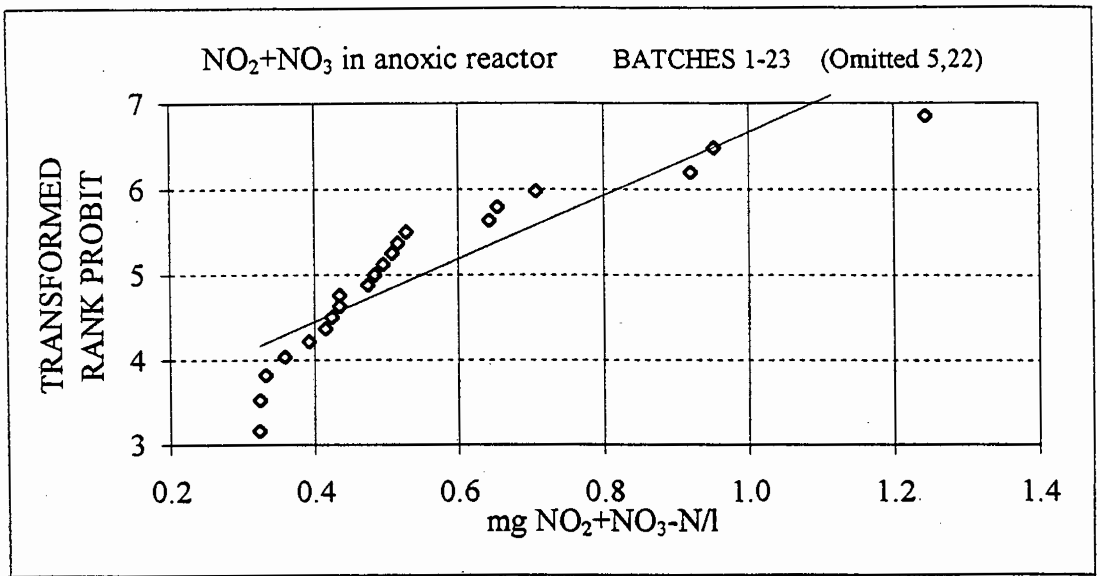
MEDIAN=	2.0		std dev. of mean = 0.1
MEAN =	2.1		95% conf. of mean = 2.1 +/- 0.1
s =	0.4		

Fig CI.9 Probability distribution of the daily effluent FSA concentration in MLE system from day 1 to day 360.



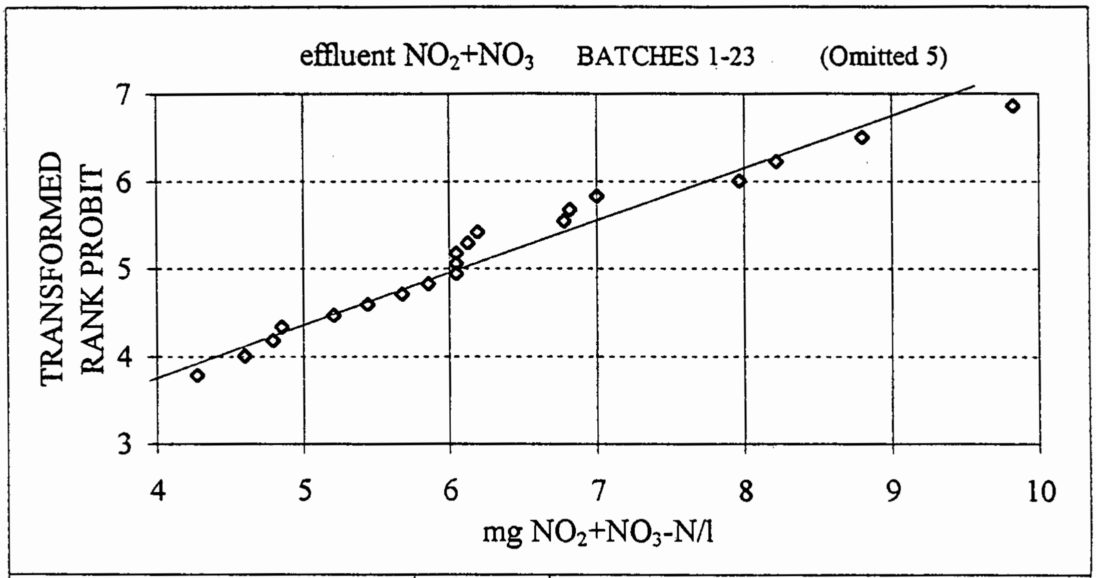
MEDIAN=	1940		std dev. of mean = 48
MEAN =	1892		95% conf. of mean = 1892 +/- 94
s =	231		

Fig CI.10 Probability distribution of the daily VSS concentration in MLE system from day 1 to day 360.



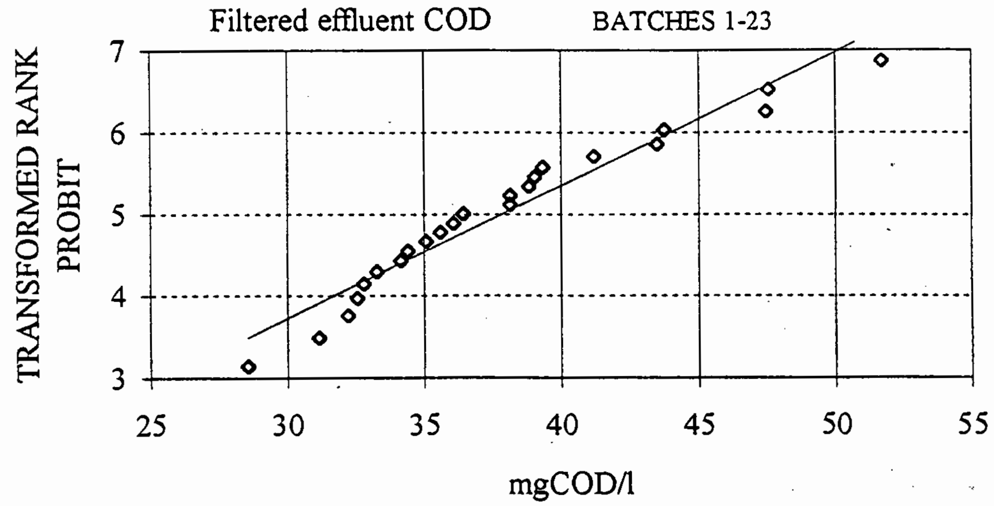
MEDIAN=	0.48		std dev. of mean = 0.05
MEAN =	0.55		95% conf. of mean = 0.55 +/- 0.10
s =	0.24		

Fig CI.11 Probability distribution of the daily NO_3+NO_2 concentration in anoxic reactor in MLE system from day 1 to day 360.



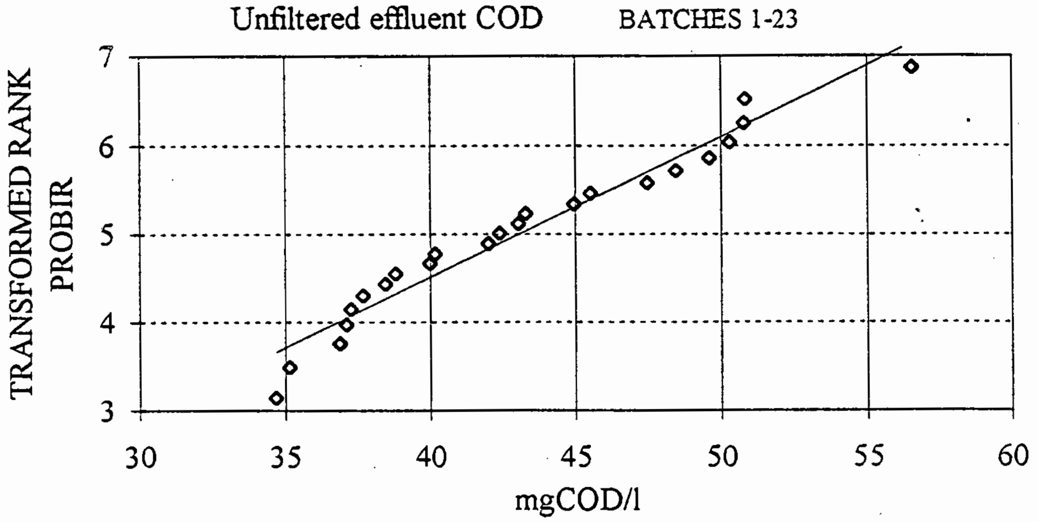
MEDIAN=	6.0		std dev. of mean = 0.3
MEAN =	6.0		95% conf. of mean = 6.0 +/- 0.7
s =	1.6		

Fig CI.12 Probability distribution of the daily effluent NO_3+NO_2 concentration in MLE system from day 1 to day 360.



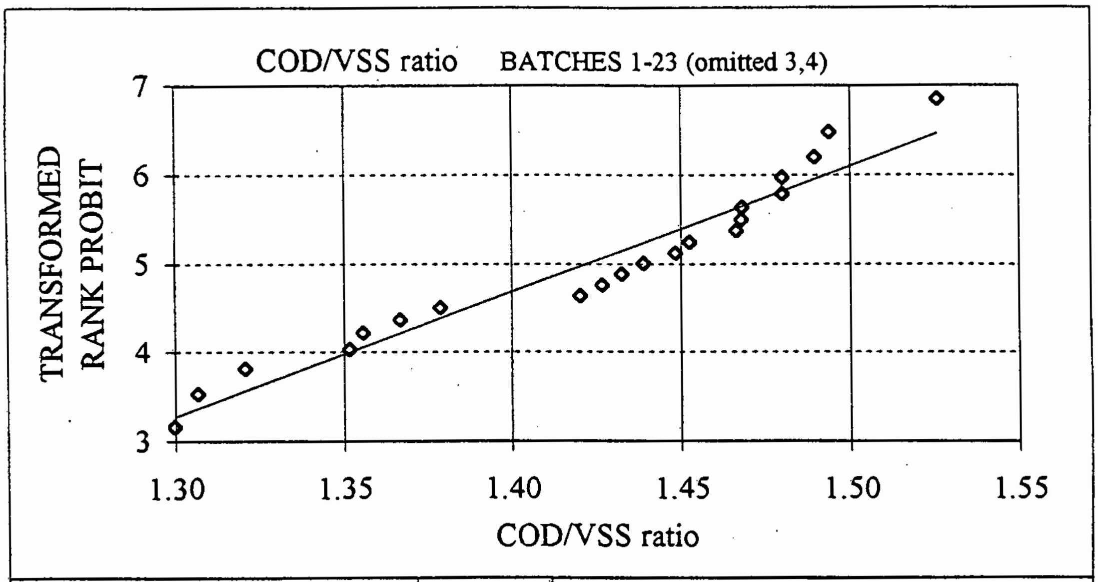
MEDIAN=	36.4		std dev. of mean =	1.2
MEAN =	37.9		95% conf. of mean = 37.9 +/- 2.4	
s =	5.8			

Fig CI.13 Probability distribution of the daily filtered effluent COD concentration in MLE system from day 1 to day 360.



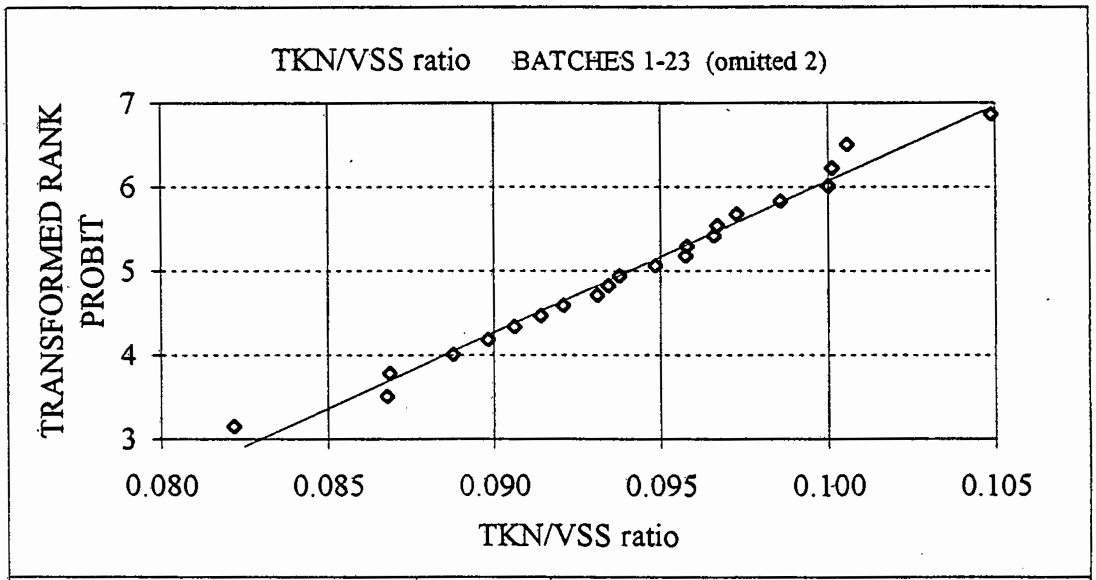
MEDIAN=	42.4		std dev. of mean =	1.2
MEAN =	43.1		95% conf. of mean = 43.1 +/- 2.4	
s =	6.0			

Fig CI.14 Probability distribution of the daily unfiltered effluent COD concentration in MLE system from day 1 to day 360.



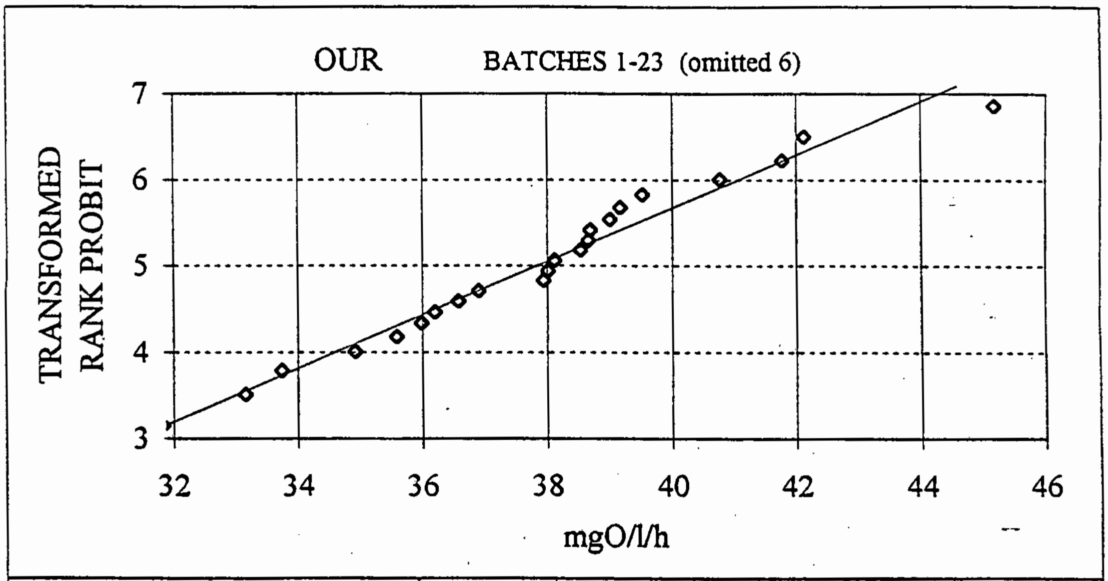
MEDIAN=	1.44		std dev. of mean = 0.01
MEAN =	1.42		95% conf. of mean = 1.42 +/- 0.03
s =	0.07		

Fig CI.15 Probability distribution of the daily COD/VSS ratio in aerobic reactor in UCT system from day 1 to day 360.



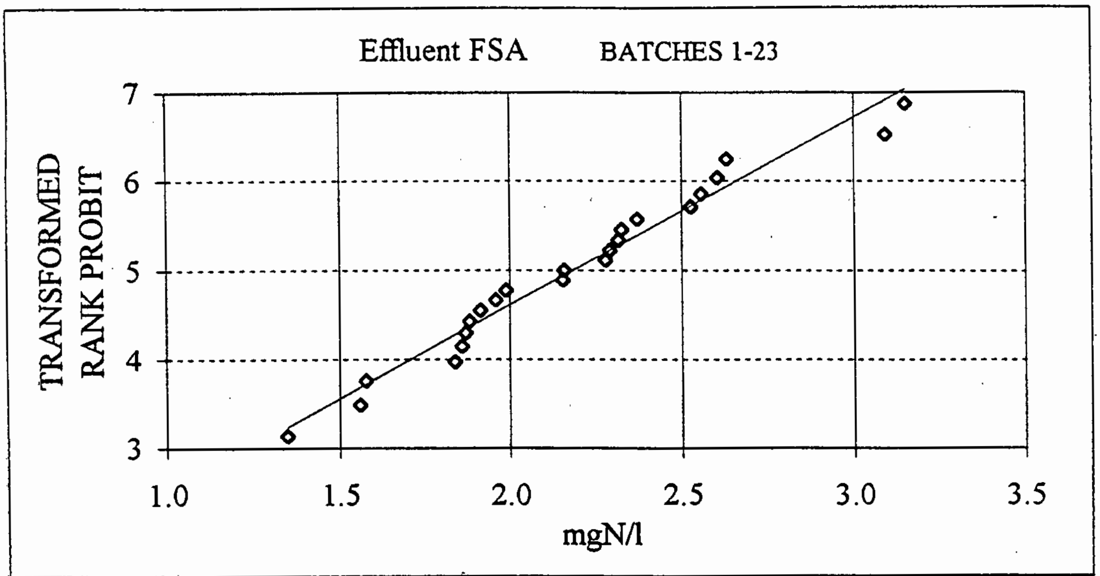
MEDIAN=	0.094		std dev. of mean = 0.001
MEAN =	0.094		95% conf. of mean = 0.094 +/- 0.002
s =	0.005		

Fig CI.16 Probability distribution of the daily TKN/VSS ratio in aerobic reactor in UCT system from day 1 to day 360.



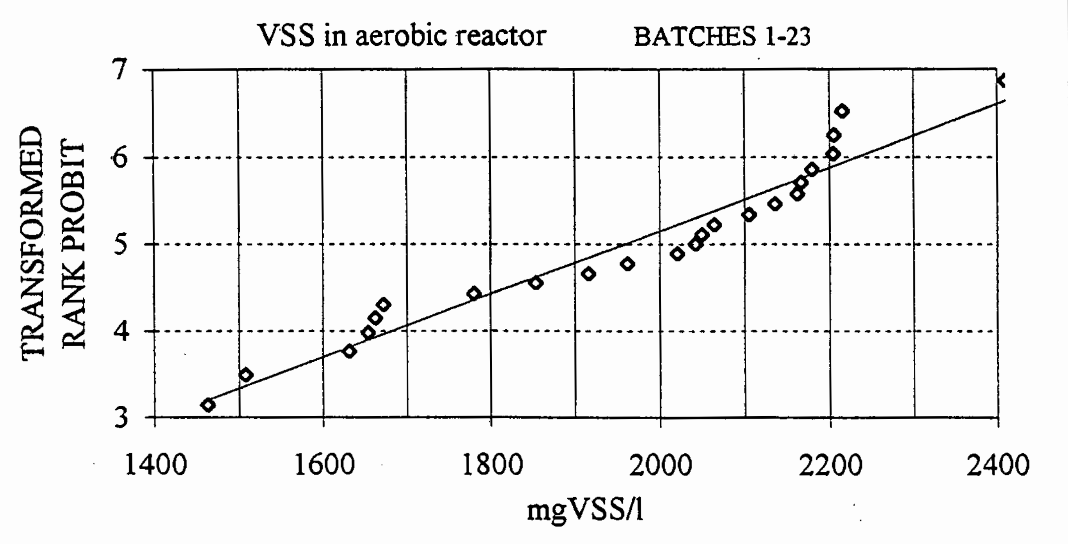
MEDIAN=	38.1		std dev. of mean =	0.7
MEAN =	37.8		95% conf. of mean = 37.8 +/- 1.3	
s =	3.1			

Fig CI.17 Probability distribution of the daily Oxygen Utilization Rate in aerobic reactor in UCT system from day 1 to day 360.



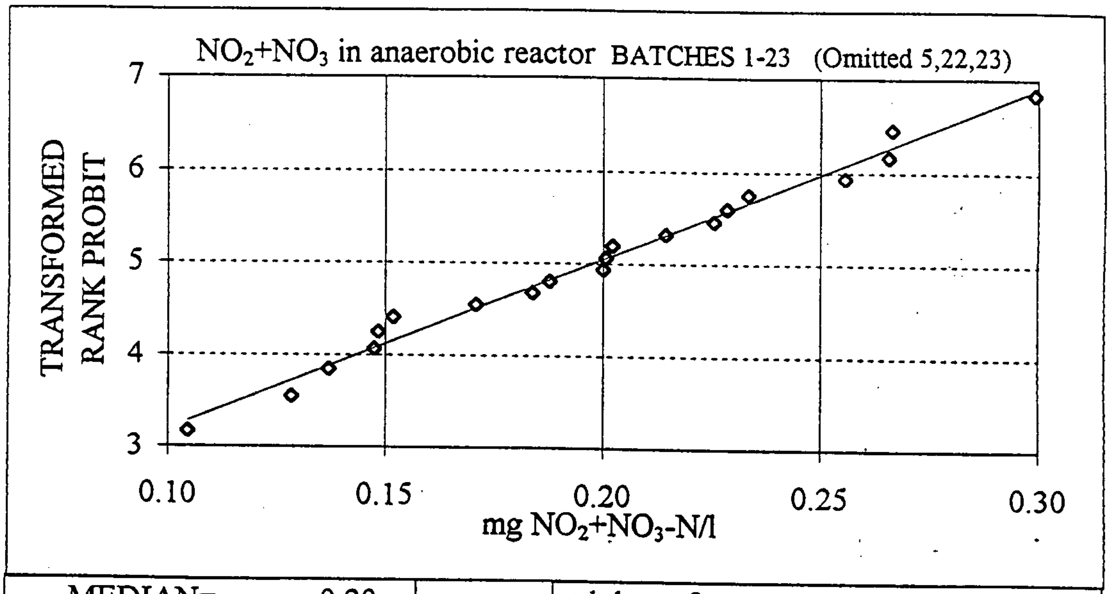
MEDIAN=	2.2		std dev. of mean = 0.1
MEAN =	2.2		95% conf. of mean = 2.3 +/- 0.2
s =	0.5		

Fig CI.18 Probability distribution of the daily effluent FSA concentration in UCT system from day 1 to day 360.



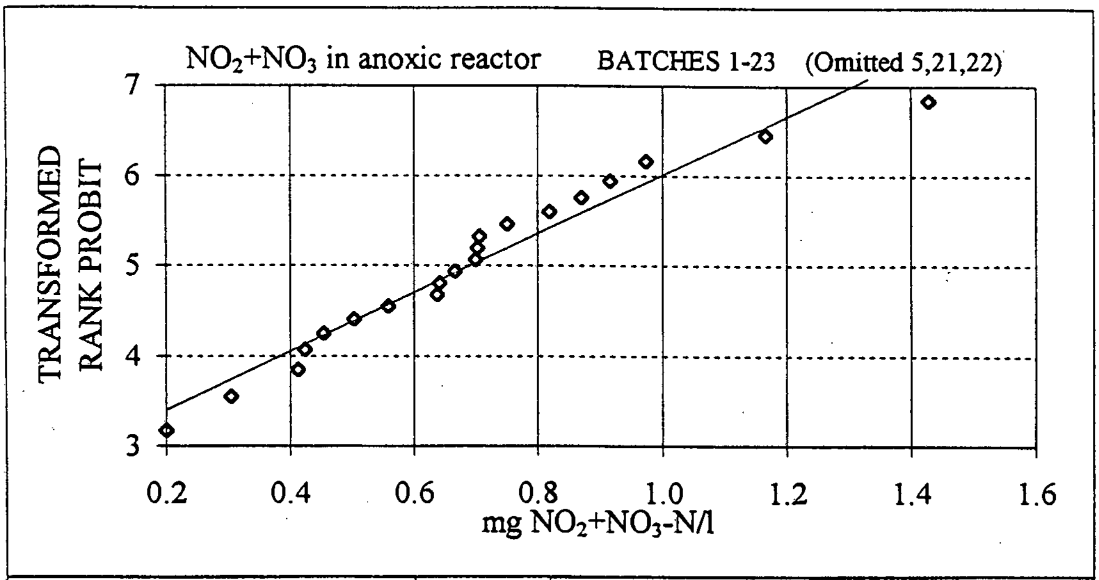
MEDIAN=	2042		std dev. of mean = 54
MEAN =	1959		95% conf. of mean = 1959 +/- 106
s =	259		

Fig CI.19 Probability distribution of the daily VSS concentration in UCT system from day 1 to day 360.



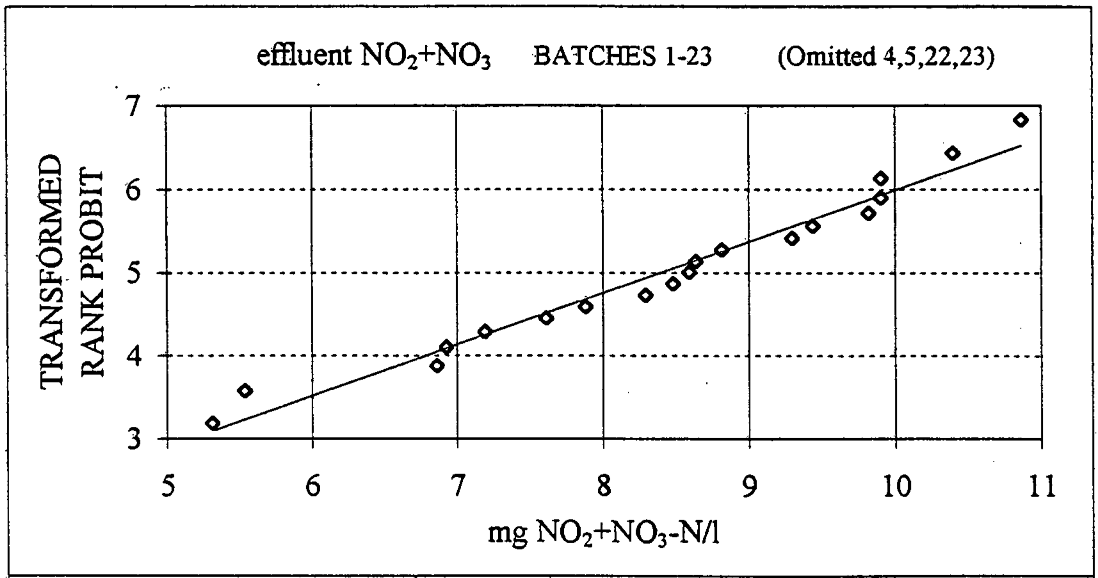
MEDIAN=	0.20		std dev. of mean = 0.01
MEAN =	0.20		95% conf. of mean = 0.20 +/- 0.02
s =	0.05		

Fig CI.20 Probability distribution of the daily NO_2+NO_3 concentration in anaerobic reactor in UCT system from day 1 to day 360.



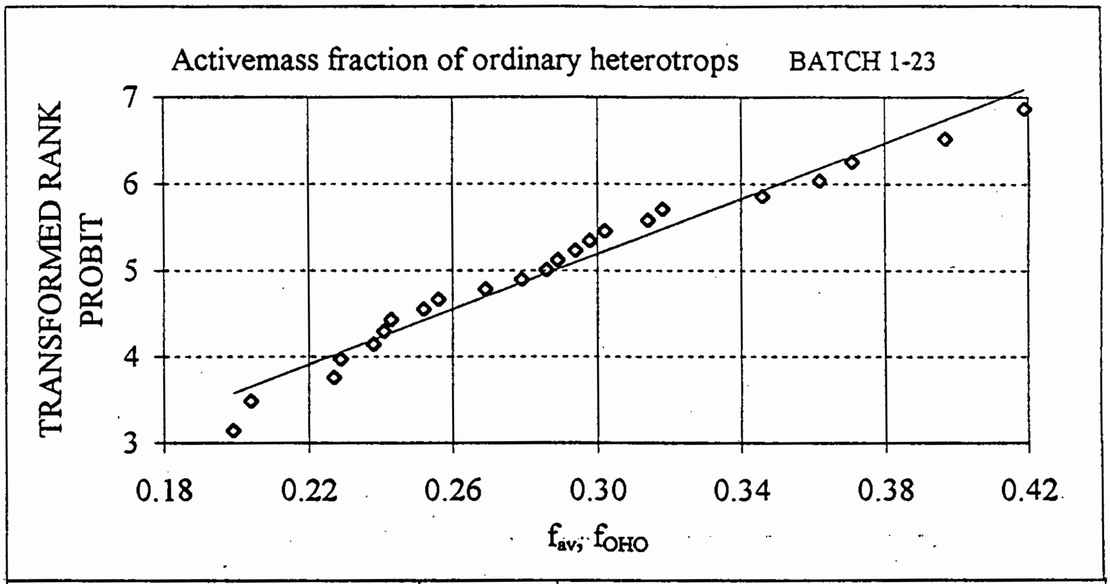
MEDIAN=	0.6		std dev. of mean = 0.1
MEAN =	0.7		95% conf. of mean = 0.7 +/- 0.1
s =	0.3		

Fig CI.21 Probability distribution of the daily NO_3+NO_2 concentration in anoxic reactor in UCT system from day 1 to day 360.



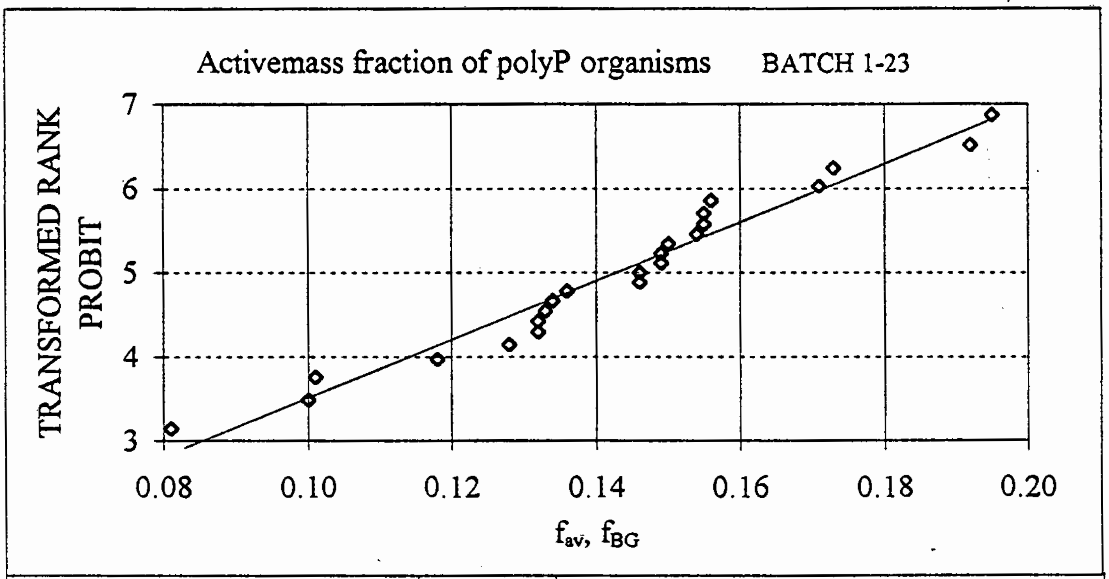
MEDIAN=	8.5		std dev. of mean = 0.4
MEAN =	8.4		95% conf. of mean = 8.4 +/- 0.7
s =	1.6		

Fig CI.22 Probability distribution of the daily effluent NO_3+NO_2 concentration in UCT system from day 1 to day 360.



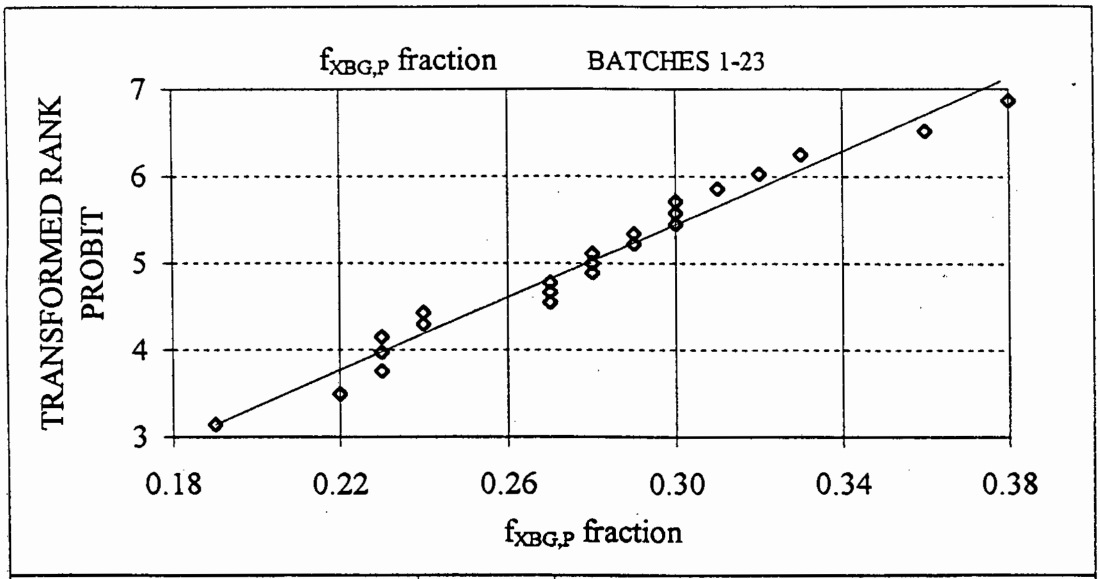
MEDIAN=	0.286		std dev. of mean = 0.012
MEAN =	0.288		95% conf. of mean = 0.288 +/- 0.024
s =	0.060		

Fig CI.23 Probability distribution of the active mass fraction of ordinary heterotrops f_{av}, f_{OHO} in UCT system from day 1 to day 360.



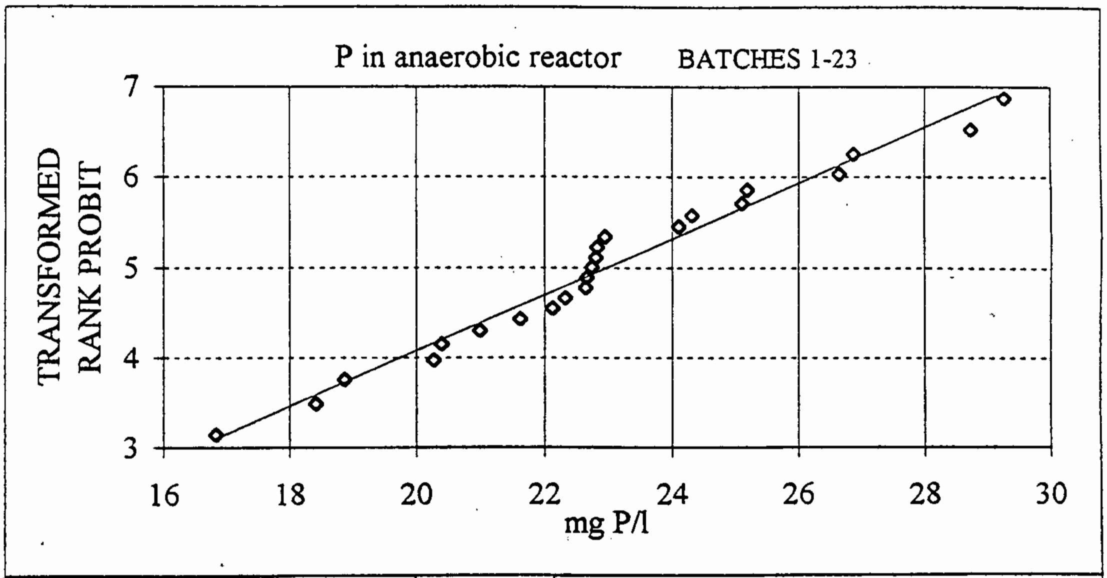
MEDIAN=	0.146		std dev. of mean = 0.006
MEAN =	0.143		95% conf. of mean = 0.143 +/- 0.011
s =	0.027		

Fig CI.24 Probability distribution of the active mass fraction of polyP organisms f_{av}, f_{BG} in UCT system from day 1 to day 360.



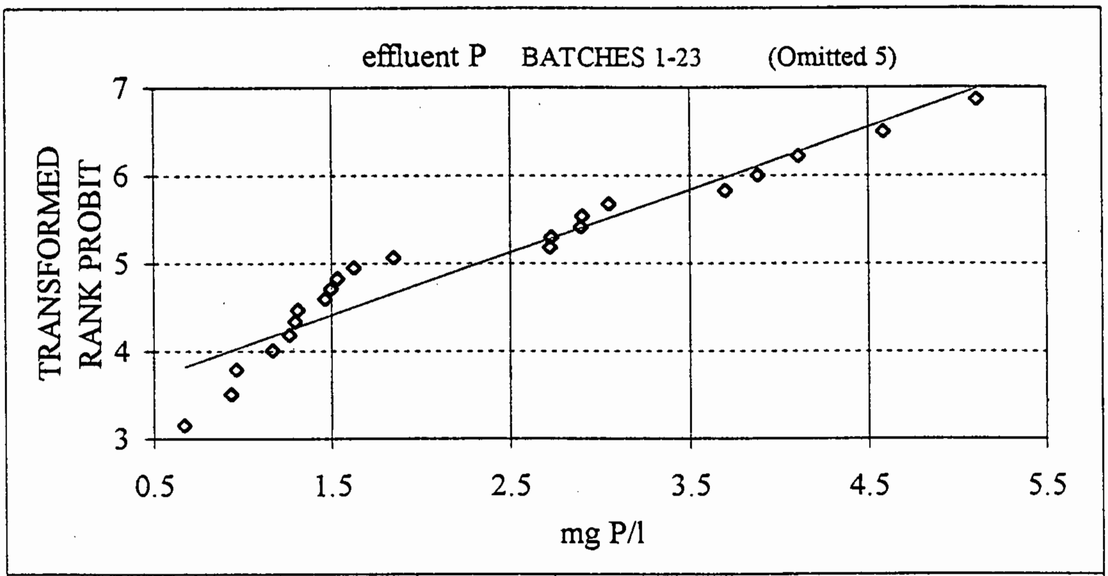
MEDIAN=	0.280		std dev. of mean = 0.009
MEAN =	0.279		95% conf. of mean = 0.279 +/- 0.019
s =	0.045		

Fig CI.25 Probability distribution of the value for fractional P content of polyP organism active mass f_{av}, $f_{XBG,P}$ in UCT system from day 1 to day 360.



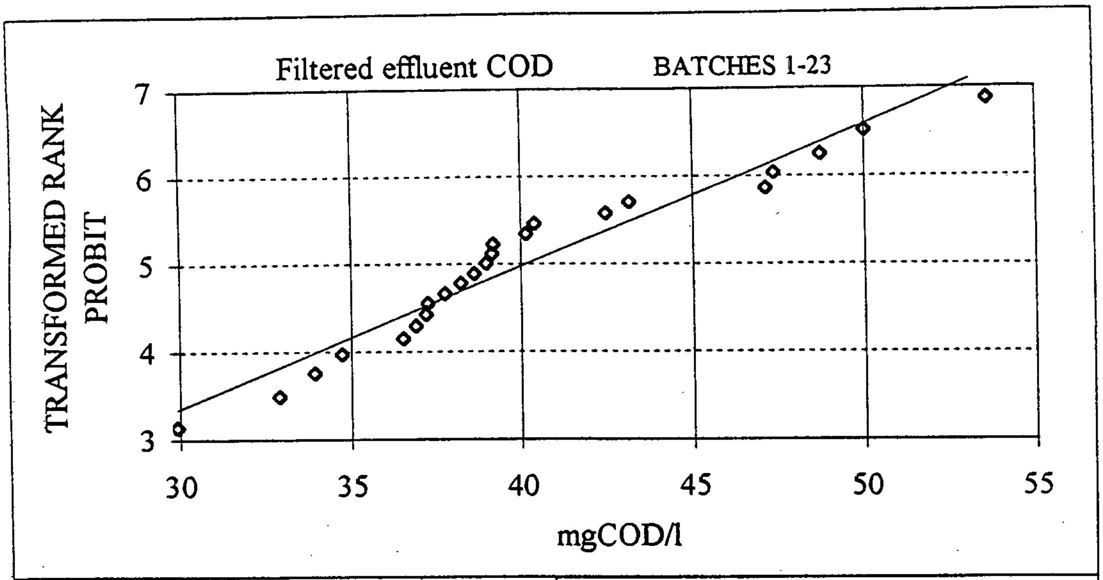
MEDIAN=	22.7		std dev. of mean =	0.6
MEAN =	23.1		95% conf. of mean = 23.1 +/- 1.3	
s =	3.1			

Fig CI.26 Probability distribution of the daily P concentration in anaerobic reactor in UCT system from day 1 to day 360.



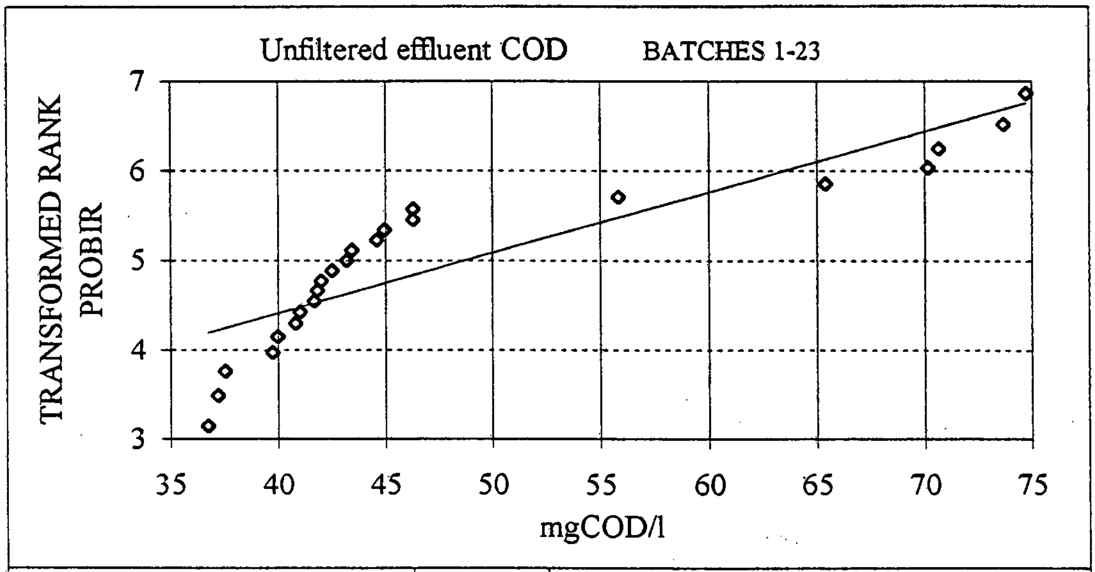
MEDIAN=	1.7		std dev. of mean =	0.3
MEAN =	2.2		95% conf. of mean = 2.2 +/- 0.5	
s =	1.2			

Fig CI.27 Probability distribution of the daily effluent P concentration in UCT system from day 1 to day 360.



MEDIAN=	39.0		std.dev. of mean =	1.2
MEAN =	40.2		95% conf. of mean = 40.2 +/-	2.4
s =	5.8			

Fig CI.28 Probability distribution of the daily filtered effluent COD concentration in UCT system from day 1 to day 360.

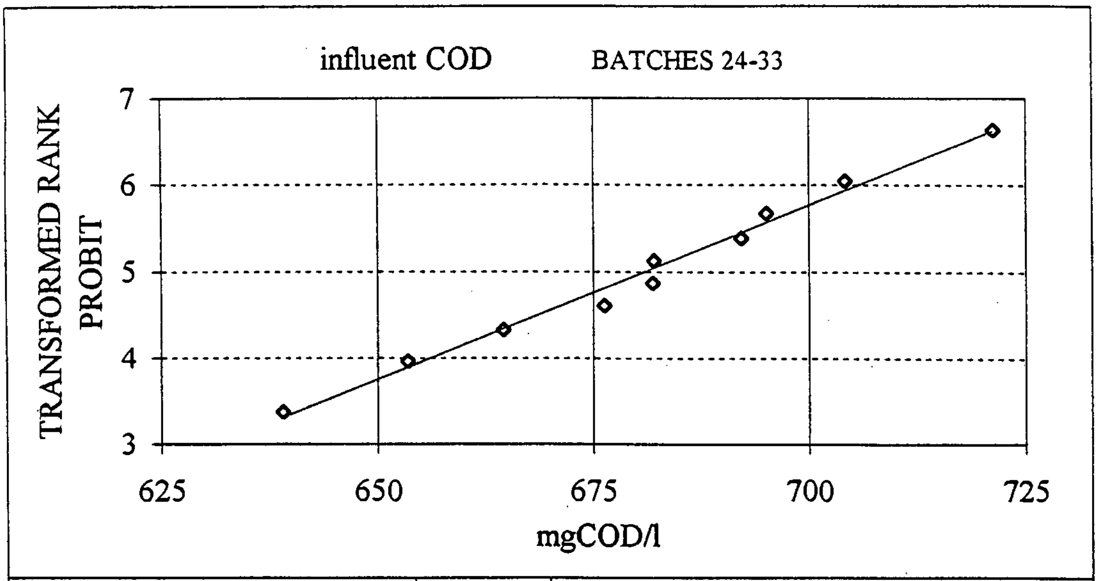


MEDIAN=	43.2		std dev. of mean =	2.6
MEAN =	48.7		95% conf. of mean = 48.7 +/-	5.2
s =	12.7			

Fig CI.29 Probability distribution of the daily unfiltered effluent COD concentration in UCT system from day 1 to day 360.

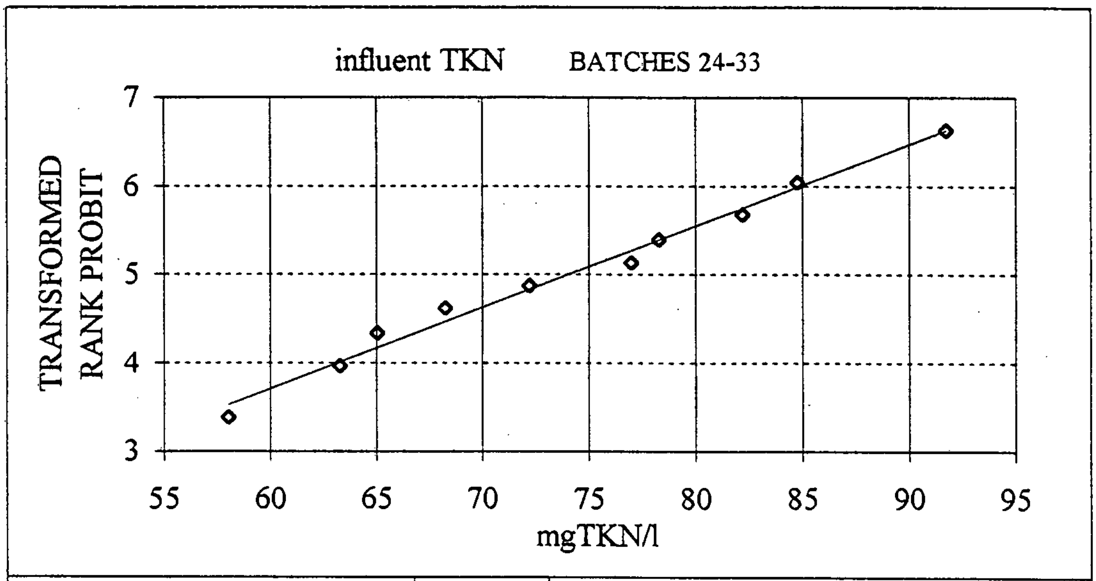
Probability distribution plots for sewage batches over the different periods.

Period CII (sewage batches 24 to 33; days 361 to 490)



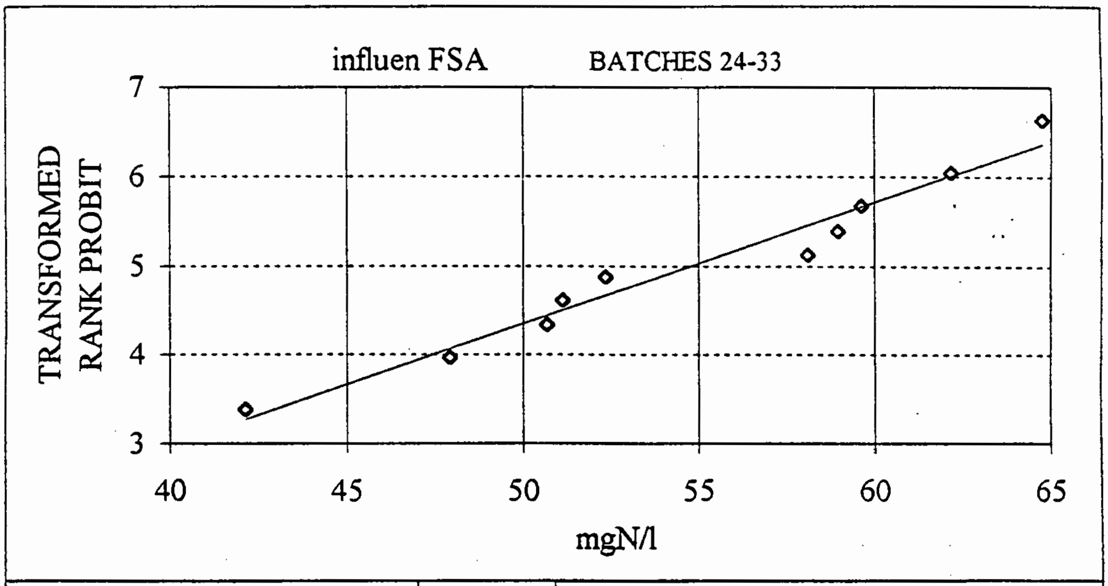
MEDIAN=	682		std dev. of mean = 8
MEAN =	681		95% conf. of mean = 681 +/- 15
s =	24		

Fig CII.1 Probability distribution of the daily influent COD concentration from day 361 to day 490.



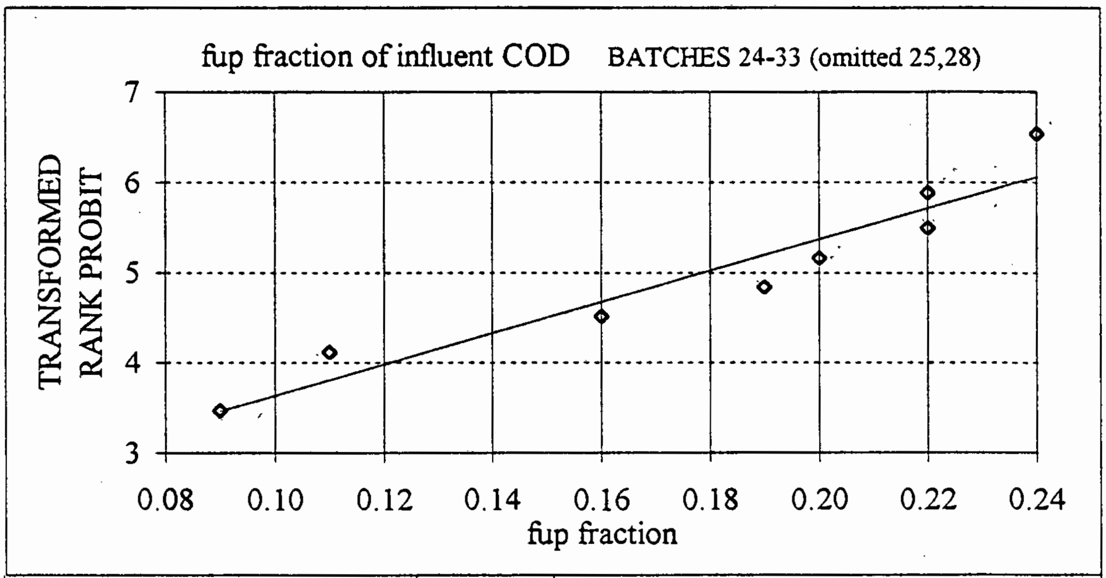
MEDIAN=	75		std dev. of mean = 3
MEAN =	74		95% conf. of mean = 74 +/- 7
s =	11		

Fig CII.2 Probability distribution of the daily influent TKN concentration from day 361 to day 490.



MEDIAN=	55.2		std dev. of mean = 2.2
MEAN =	54.8		95% conf. of mean = 54.8 +/- 4.4
s =	7.1		

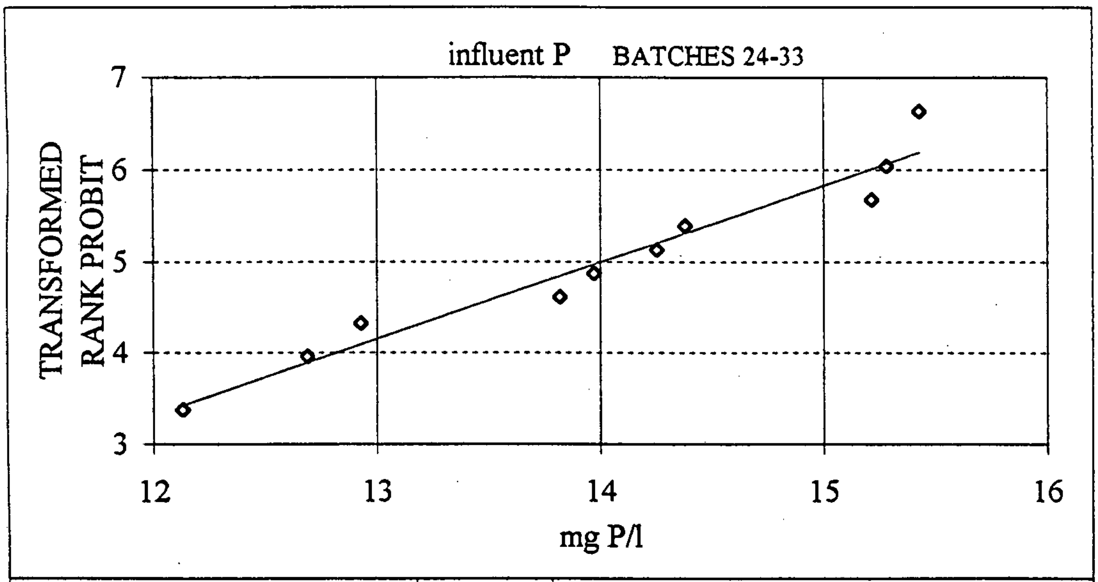
Fig CII.3 Probability distribution of the daily influent Free and Saline Ammonia from day 361 to day 490.



MEDIAN=	0.195		std dev. of mean = 0.019
MEAN =	0.179		95% conf. of mean = 0.179 +/- 0.038
s =	0.054		

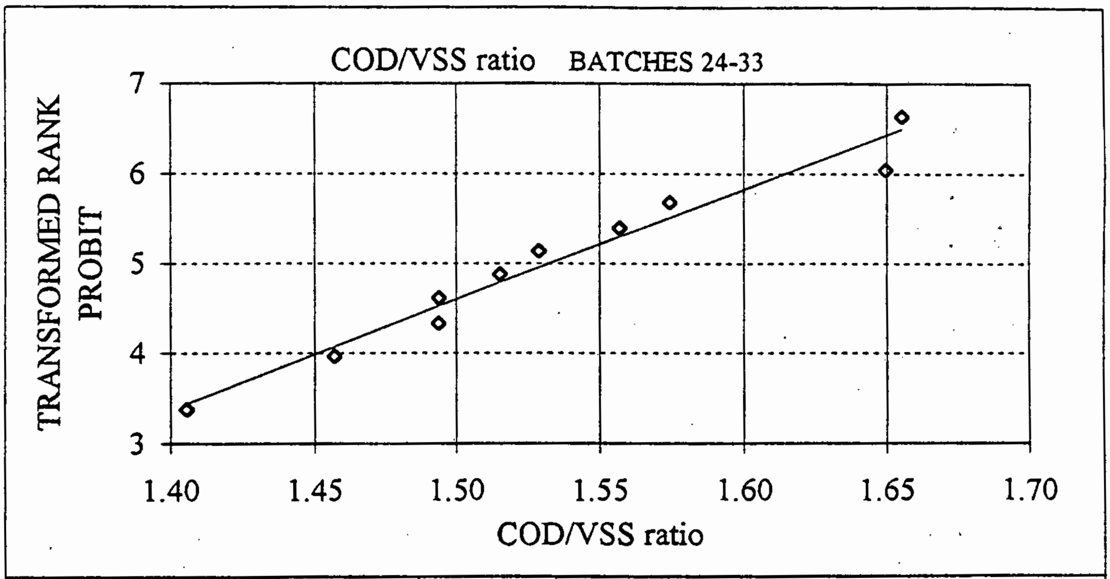
Fig CII.4 Probability distribution of the fup fraction of daily influent COD from day 361 to day 490.

UCT



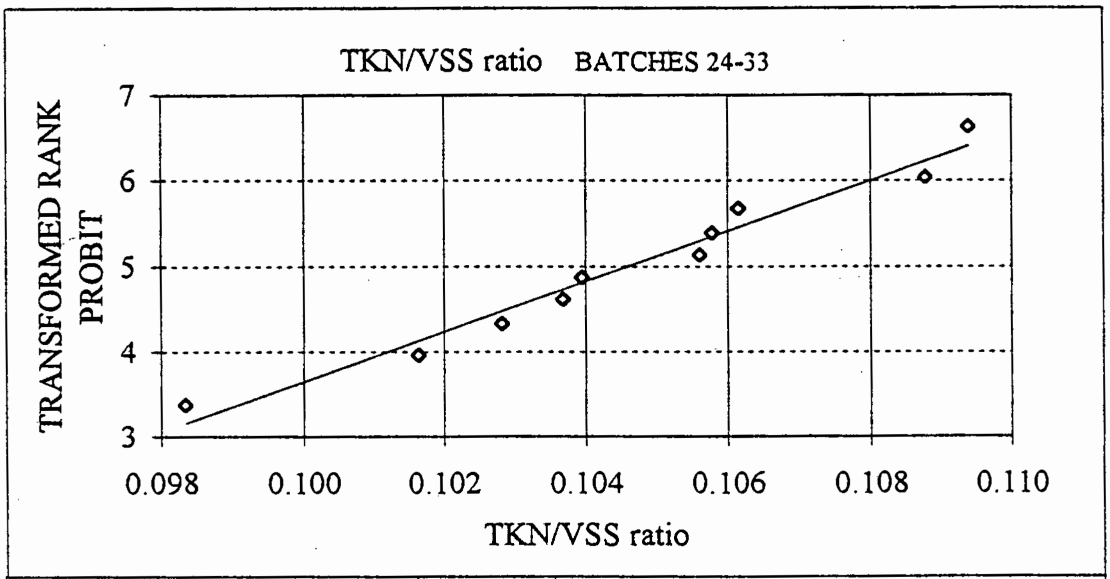
MEDIAN=	14.1		std dev. of mean = 0.4
MEAN =	14.0		95% conf. of mean = 14.0 +/- 0.7
s =	1.1		

Fig CII.5 Probability distribution of the dayly influent P concentration in MLE and in UCT system from day 361 to day 490.



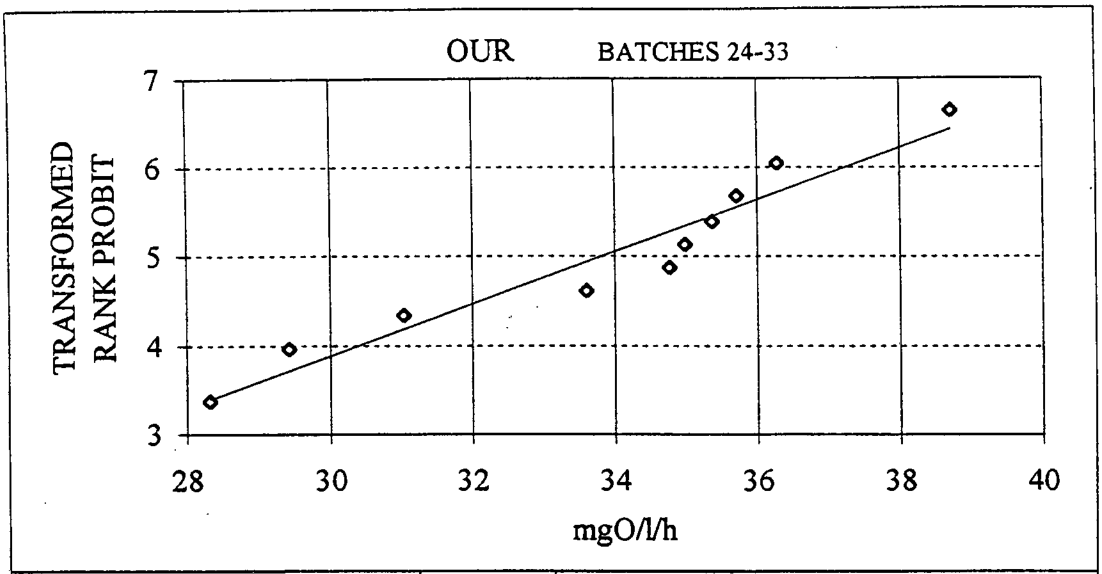
MEDIAN=	1.52		std dev. of mean =	0.03
MEAN =	1.53		95% conf. of mean = 1.53 +/- 0.05	
s =	0.08			

Fig CII.6 Probability distribution of the daily COD/VSS ratio in aerobic reactor in MLE system from day 361 to day 490.



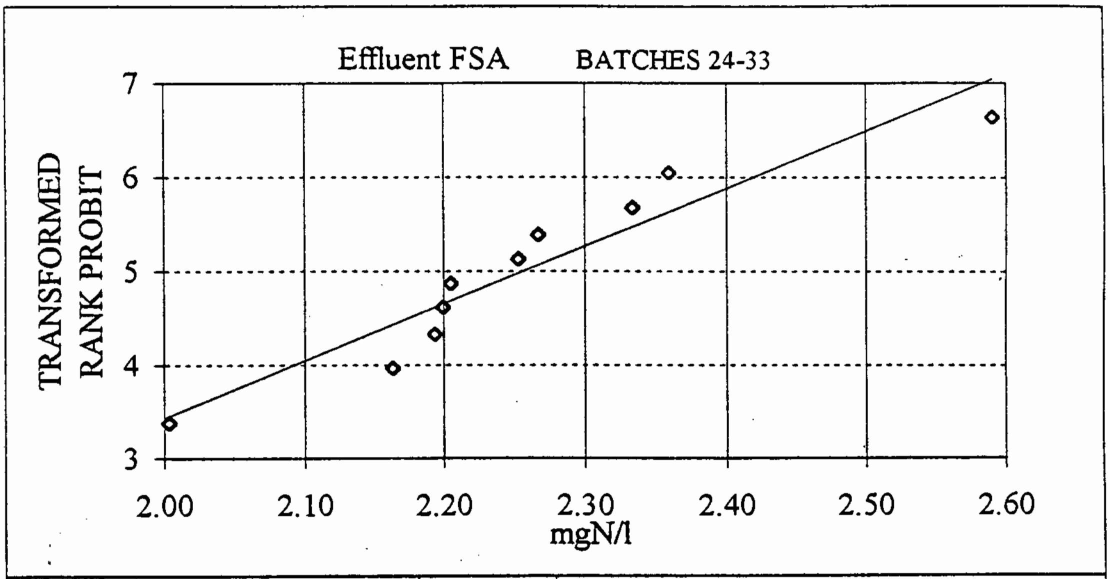
MEDIAN=	0.105		std dev. of mean =	0.001
MEAN =	0.105		95% conf. of mean = 0.105 +/- 0.002	
s =	0.003			

Fig CII.7 Probability distribution of the daily TKN/VSS ratio in aerobic reactor in MLE system from day 361 to day 490.



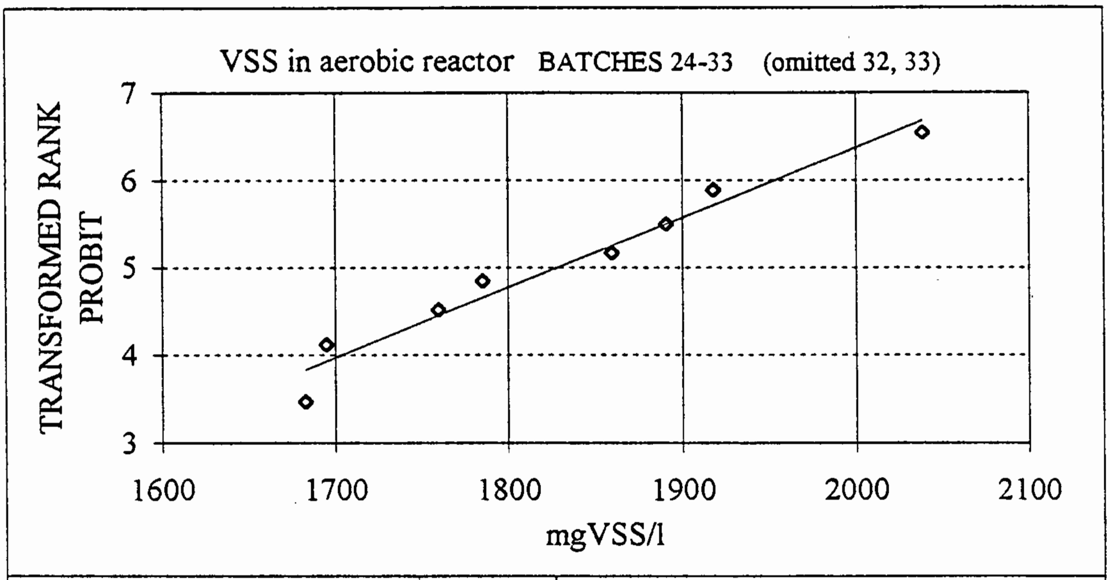
MEDIAN=	34.9		std dev. of mean =	1.0
MEAN =	33.8		95% conf. of mean = 33.8 +/- 2.0	
s =	3.3			

Fig CII.8 Probability distribution of the daily Oxygen Utilization Rate in aerobic reactor in MLE system from day 361 to day 490.



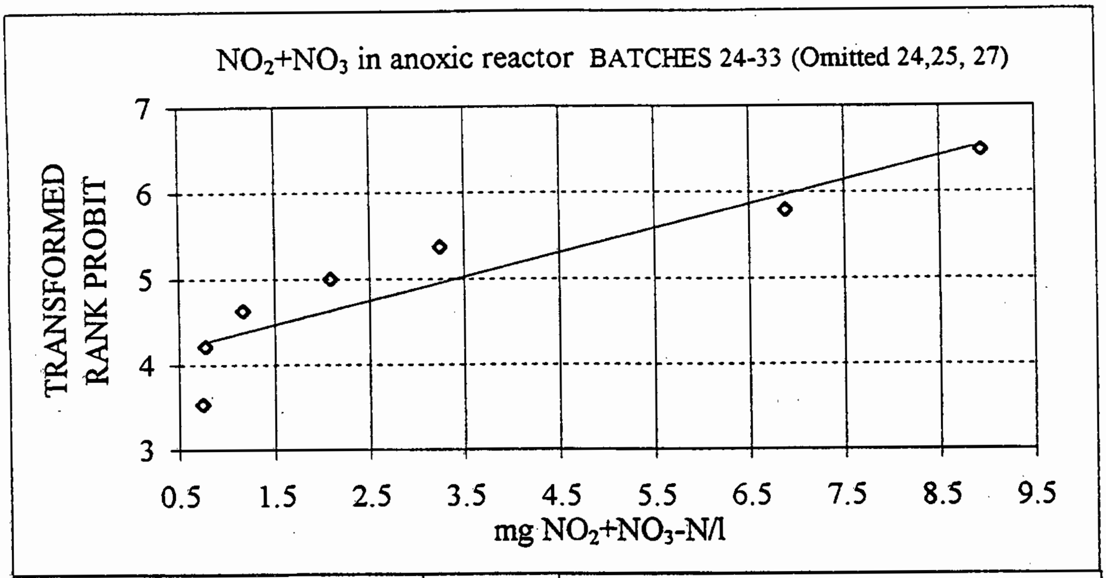
MEDIAN=	2.2		std dev. of mean = 0.0
MEAN =	2.3		95% conf. of mean = 2.6 +/- 0.1
s =	0.2		

Fig DII.9 Probability distribution of the daily effluent FSA concentration in MLE system from day 361 to day 490.



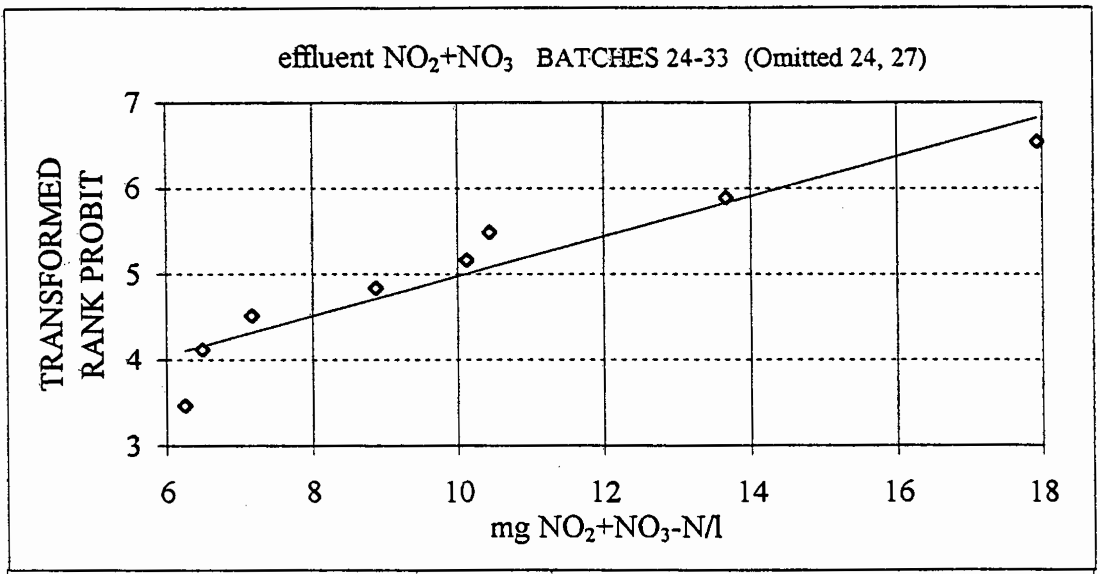
MEDIAN=	1823		std dev. of mean = 43
MEAN =	1829		95% conf. of mean = 1829 +/- 84
s =	121		

Fig DII.10 Probability distribution of the daily VSS concentration in MLE system from day 361 to day 490.



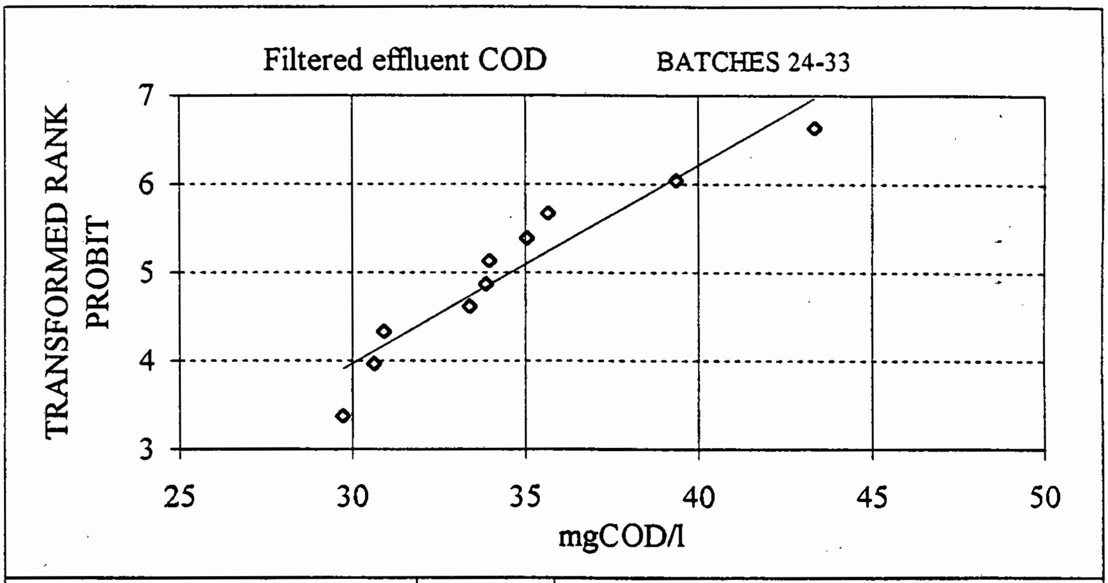
MEDIAN=	2.1		std dev. of mean =	1.2
MEAN =	3.4		95% conf. of mean = 3.4 +/-	2.4
s =	3.3			

Fig CII.11 Probability distribution of the daily NO_3+NO_2 concentration in anoxic reactor from day 361 to day 490.



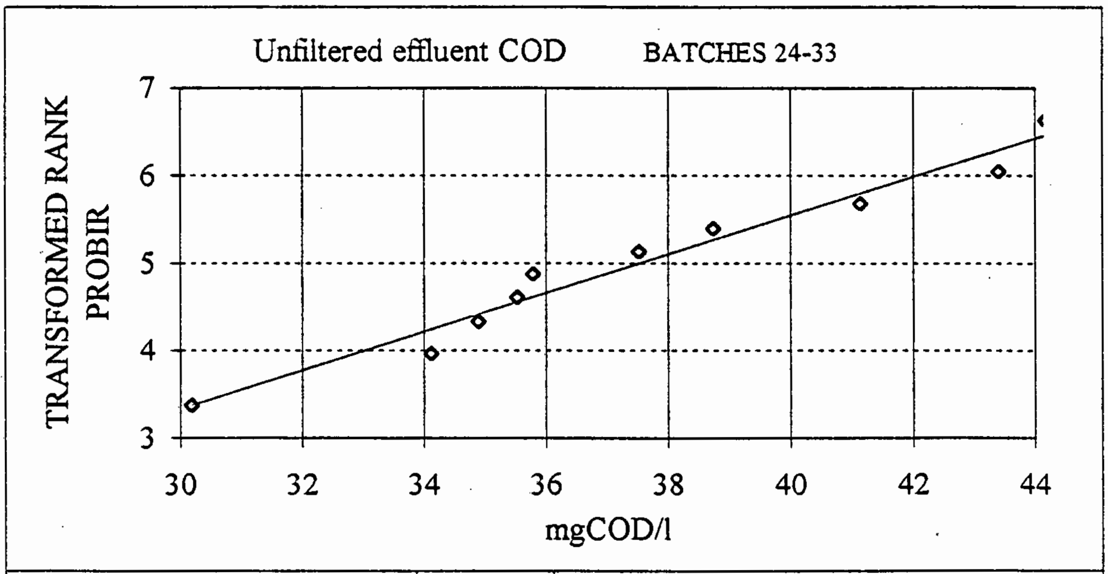
MEDIAN=	9.5		std dev. of mean =	1.4
MEAN =	10.1		95% conf. of mean = 10.1 +/-	2.8
s =	4.0			

Fig CII.12 Probability distribution of the daily effluent NO_3+NO_2 concentration from day 361 to day 490.



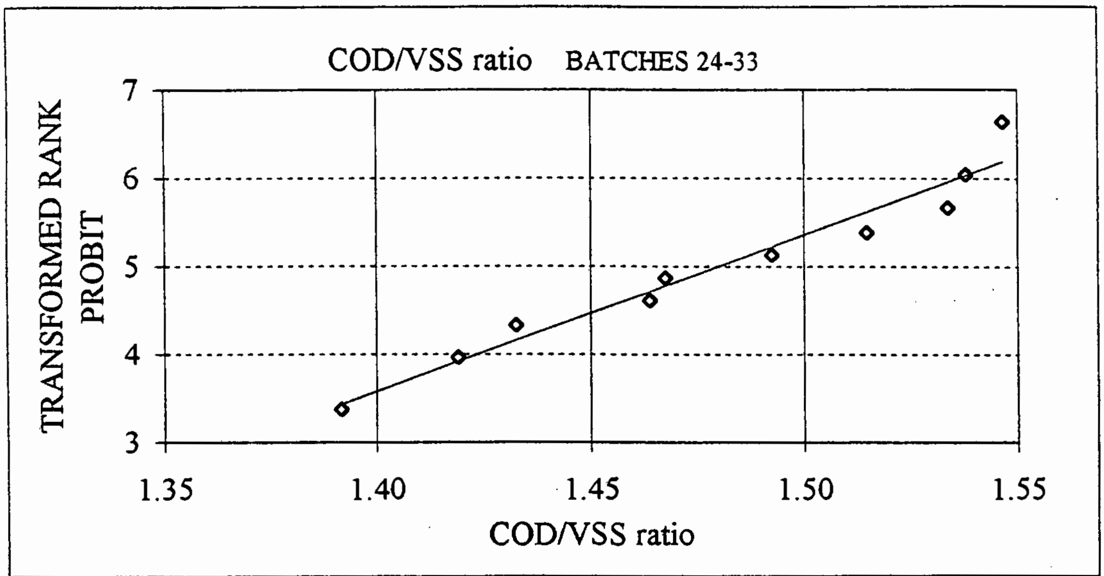
MEDIAN=	33.9		std dev. of mean = 1.3
MEAN =	34.6		95% conf. of mean = 34.6 +/- 2.6
s =	4.2		

Fig CII.13 Probability distribution of the daily filtered effluent COD concentration in MLE system from day 361 to day 490.



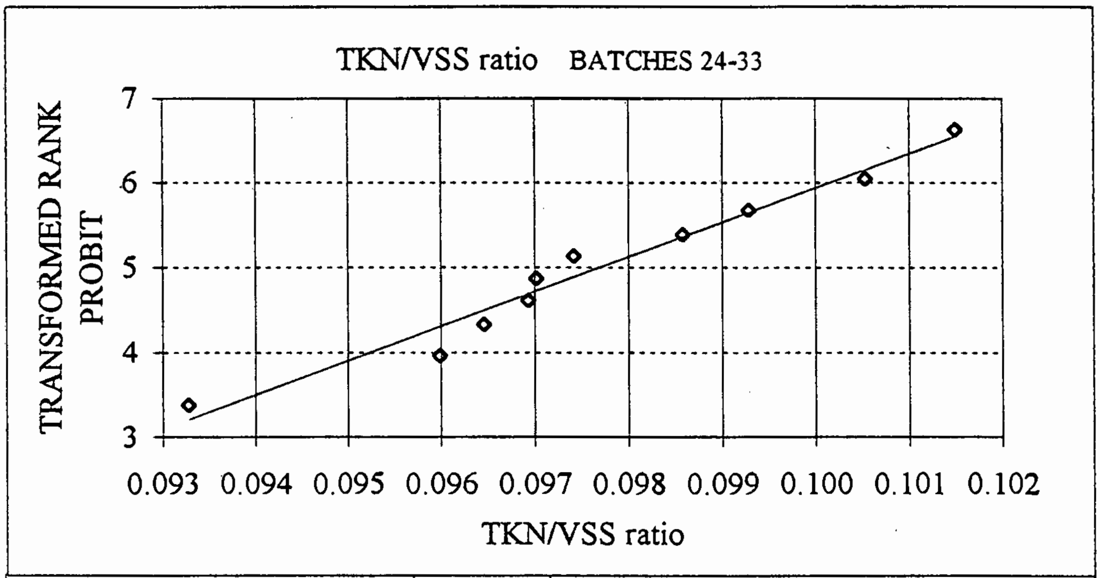
MEDIAN=	36.7		std dev. of mean = 1.4
MEAN =	37.5		95% conf. of mean = 37.5 +/- 2.7
s =	4.4		

Fig CII.14 Probability distribution of the daily unfiltered effluent COD concentration in MLE system from day 361 to day 490.



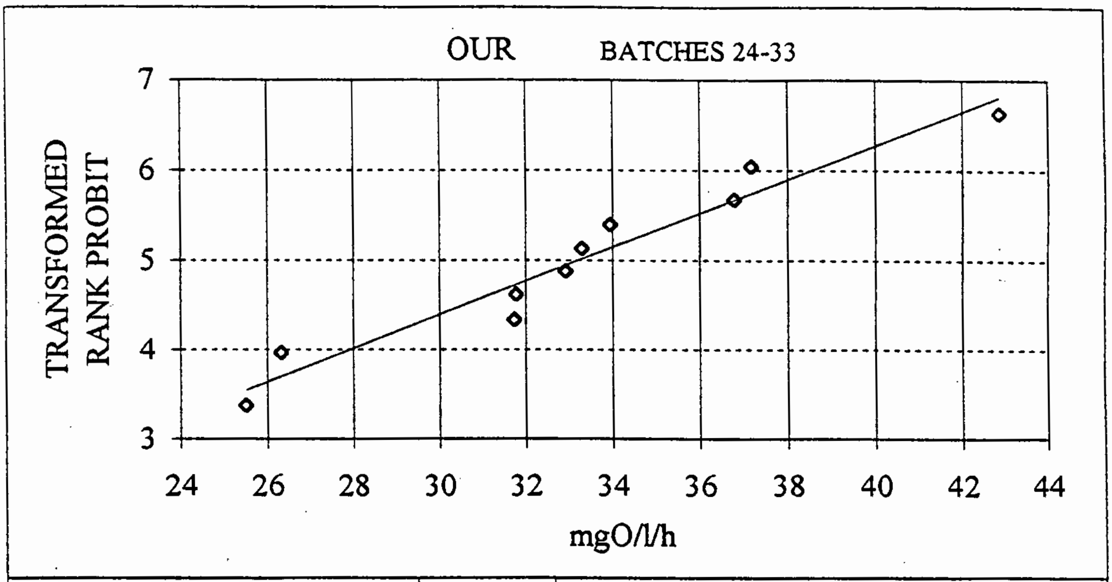
MEDIAN=	1.48		std dev. of mean = 0.02
MEAN =	1.48		95% conf. of mean = 1.48 +/- 0.03
s =	0.05		

Fig CII.15 Probability distribution of the daily COD/VSS ratio in aerobic reactor in UCT syste from day 361 to day 490.



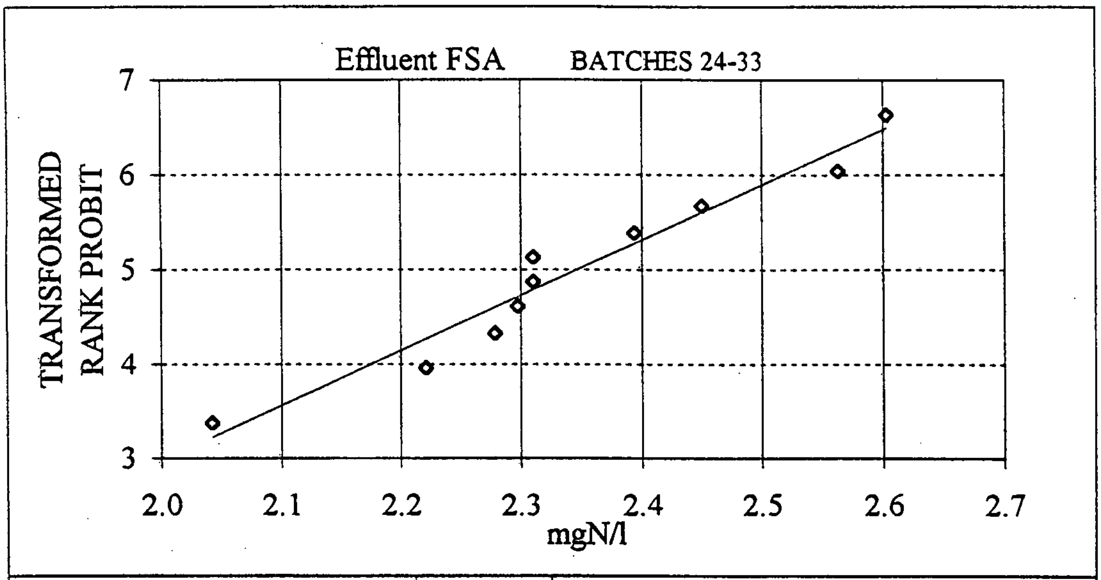
MEDIAN=	0.097		std dev. of mean = 0.001
MEAN =	0.098		95% conf. of mean = 0.098 +/- 0.001
s =	0.002		

Fig CII.16 Probability distribution of the daily TKN/VSS ratio in aerobic reactor in UCT syste from day 361 to day 490.



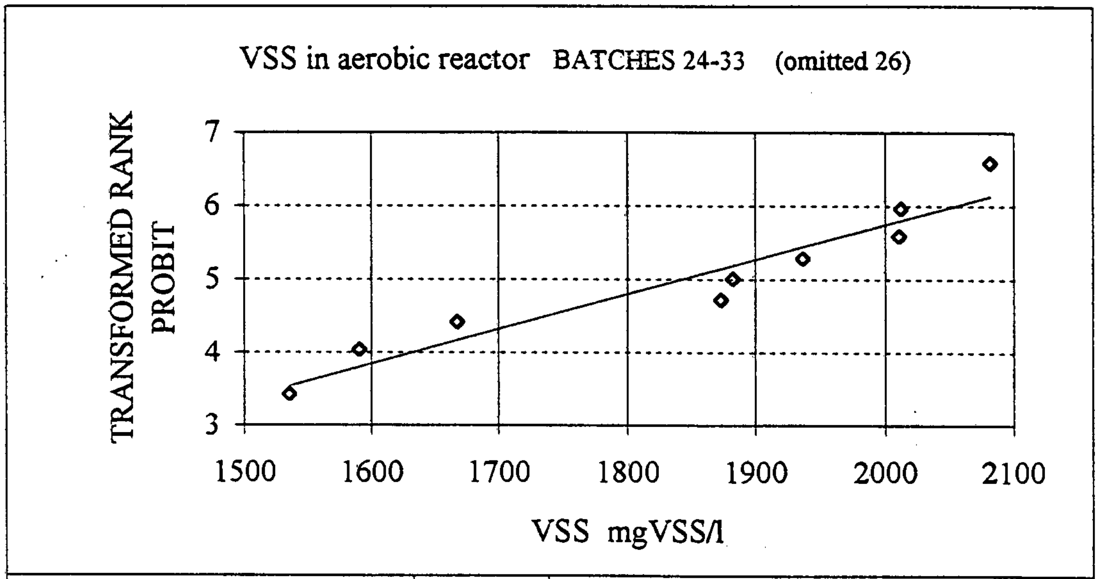
MEDIAN=	33.1		std dev. of mean = 1.6
MEAN =	33.2		95% conf. of mean = 33.2 +/- 3.2
s =	5.1		

Fig CII.17 Probability distribution of the daily Oxygen Utilization Rate in aerobic reactor in UCT system from day 361 to day 490.



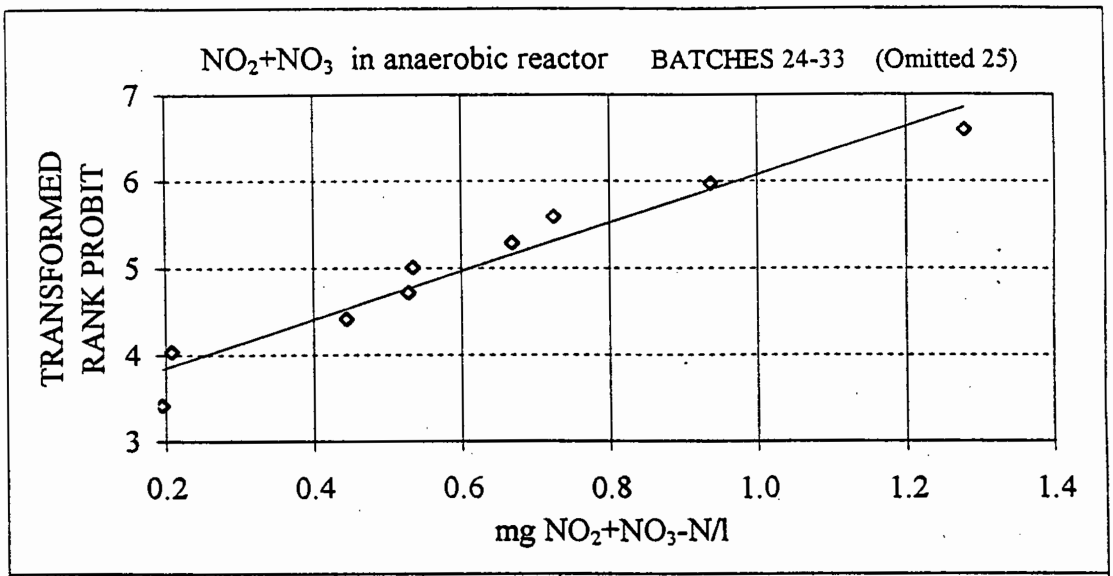
MEDIAN=	2.3		std dev. of mean = 0.1
MEAN =	2.5		95% conf. of mean = 2.5 +/- 0.1
s =	0.2		

Fig CII.18 Probability distribution of the daily effluent FSA concentration in UCT system from day 361 to day 490.



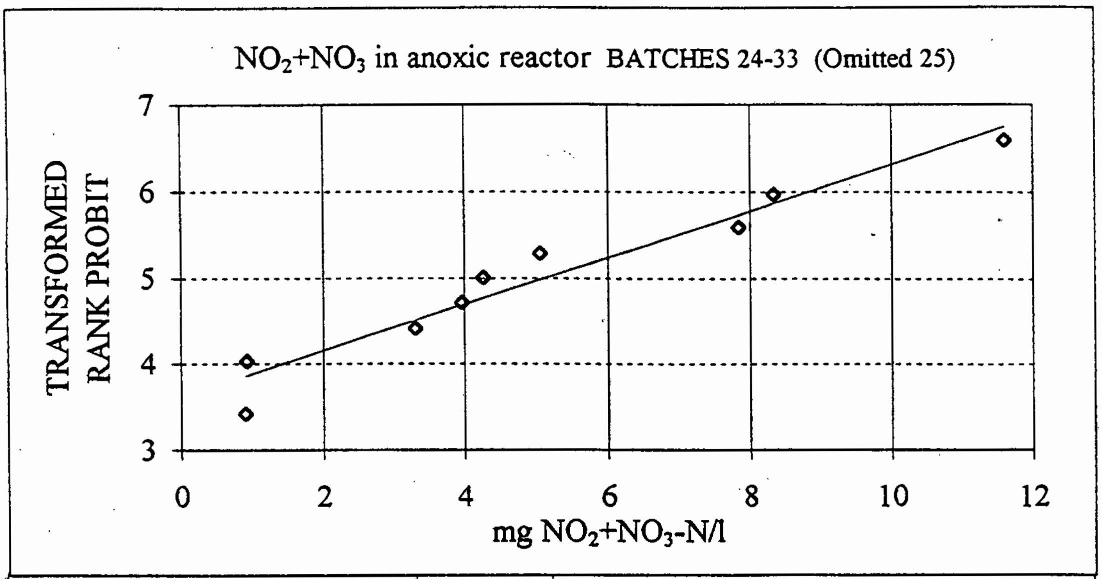
MEDIAN=	1882		std dev. of mean = 66
MEAN =	1843		95% conf. of mean = 1843 +/- 129
s =	198		

Fig CII.19 Probability distribution of the daily VSS concentration in UCT system from day 361 to day 490.



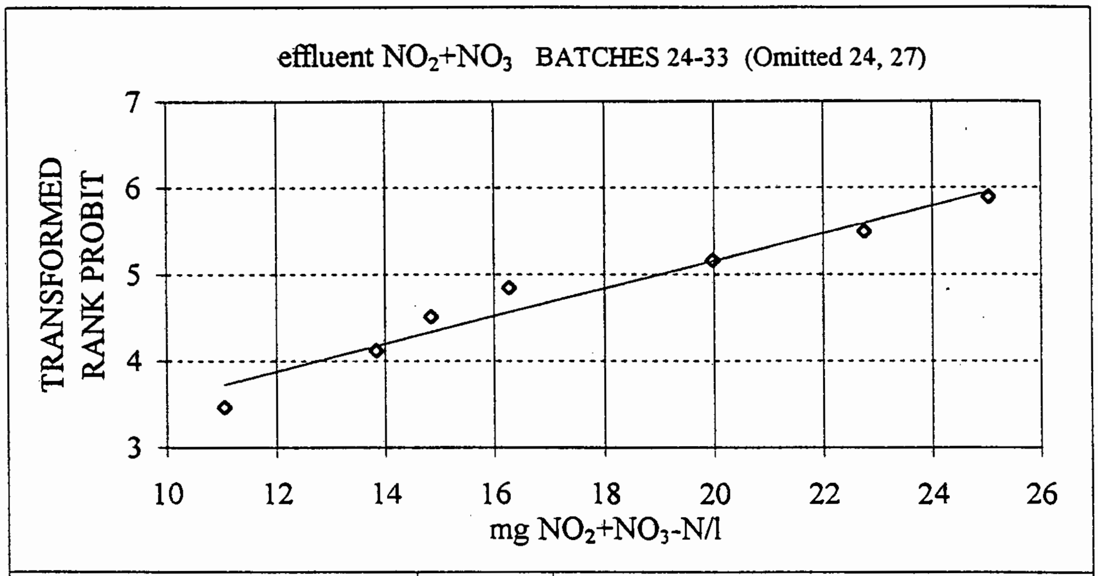
MEDIAN=	0.53		std dev. of mean = 0.11
MEAN =	0.61		95% conf. of mean = 0.61 +/- 0.22
s =	0.34		

Fig CII.20 Probability distribution of the daily NO_2+NO_3 concentration in anaerobic reactor in UCT system from day 361 to day 490.



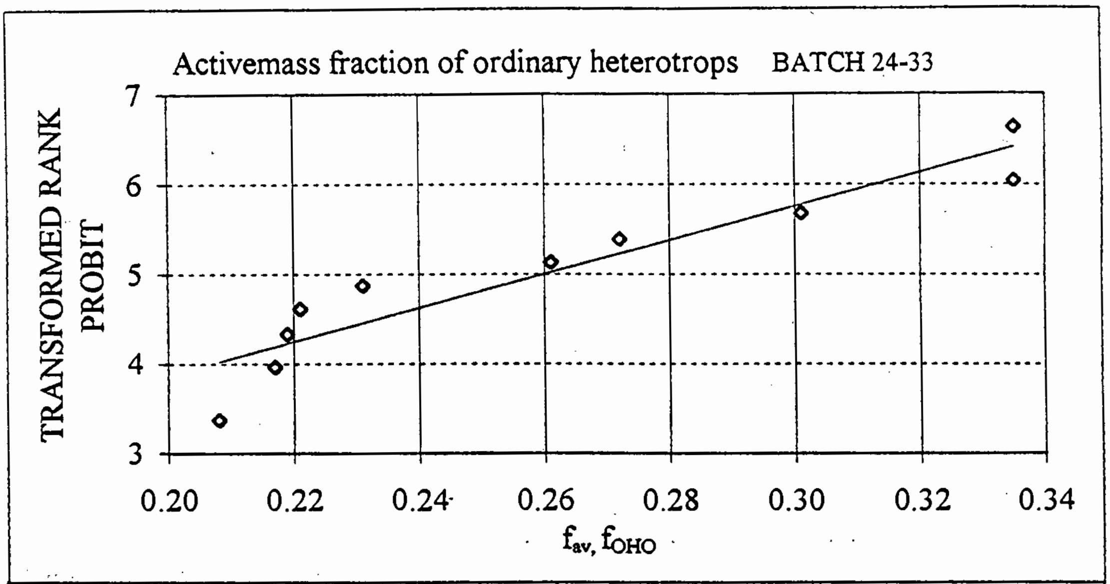
MEDIAN=	4.3		std dev. of mean = 1.2
MEAN =	5.1		95% conf. of mean = 5.1 +/- 2.3
s =	3.5		

Fig CII.21 Probability distribution of the daily NO_3+NO_2 concentration in anoxic reactor in UCT system from day 361 to day 490.



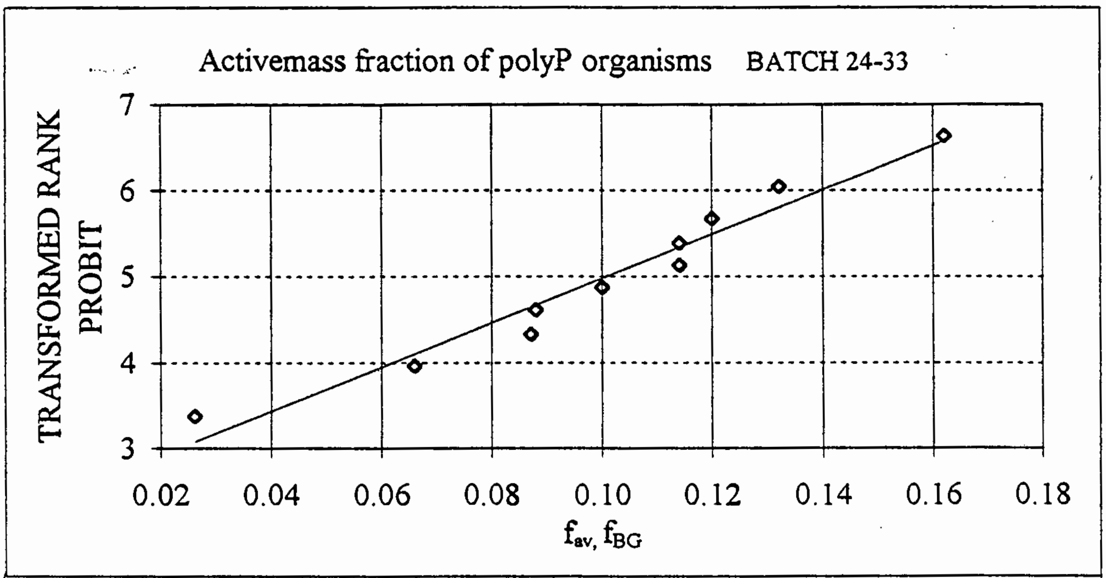
MEDIAN=	15.6		std dev. of mean = 1.9
MEAN =	16.7		95% conf. of mean = 16.7 +/- 3.8
s =	5.5		

Fig CII.22 Probability distribution of the daily effluent NO_3+NO_2 concentration in UCT system from day 361 to day 490.



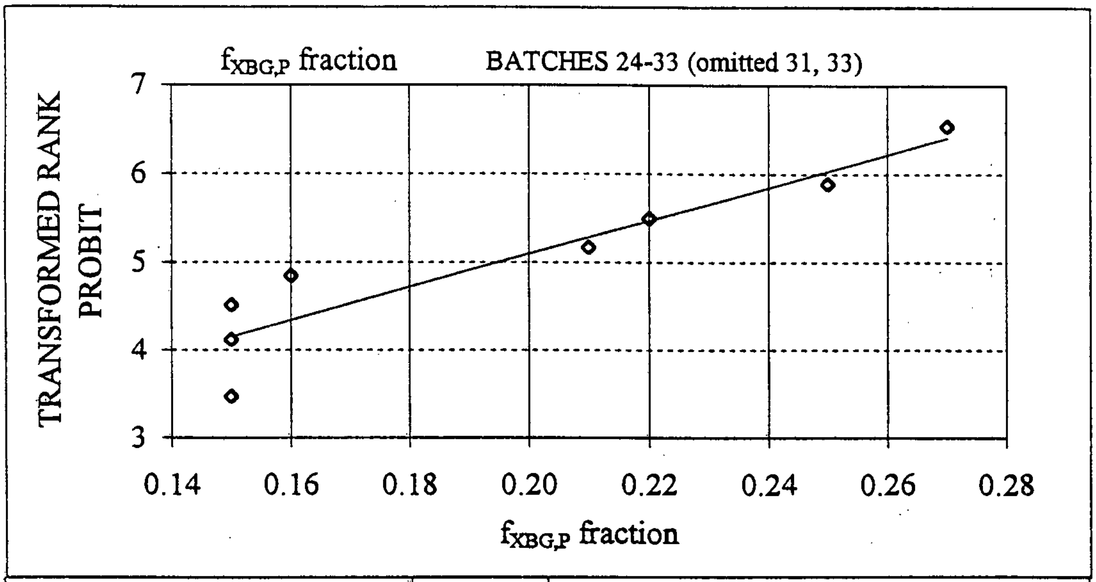
MEDIAN=	0.246		std dev. of mean =	0.016
MEAN =	0.260		95% conf. of mean = 0.260+/- 0.030	
s =	0.049			

Fig CII.23 Probability distribution of the active mass fraction of ordinary heterotrops f_{av}, f_{OHO} in UCT system from day 361 to day 490.



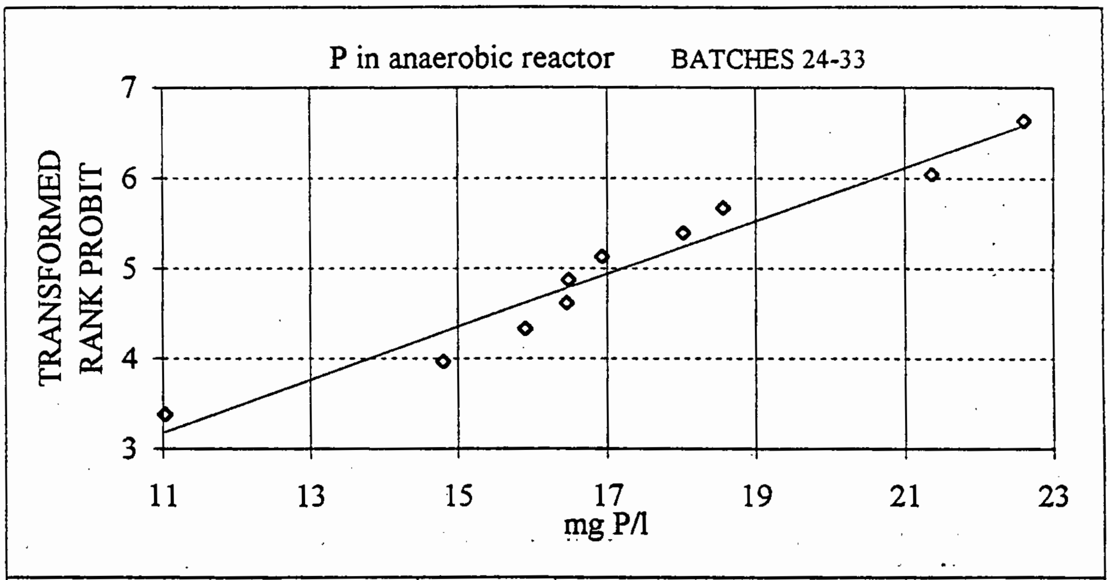
MEDIAN=	0.107		std dev. of mean =	0.012
MEAN =	0.101		95% conf. of mean = 0.101+/- 0.023	
s =	0.037			

Fig CII.24 Probability distribution of the active mass fraction of polyP organisms f_{av}, f_{BG} in UCT system from day 361 to day 490.



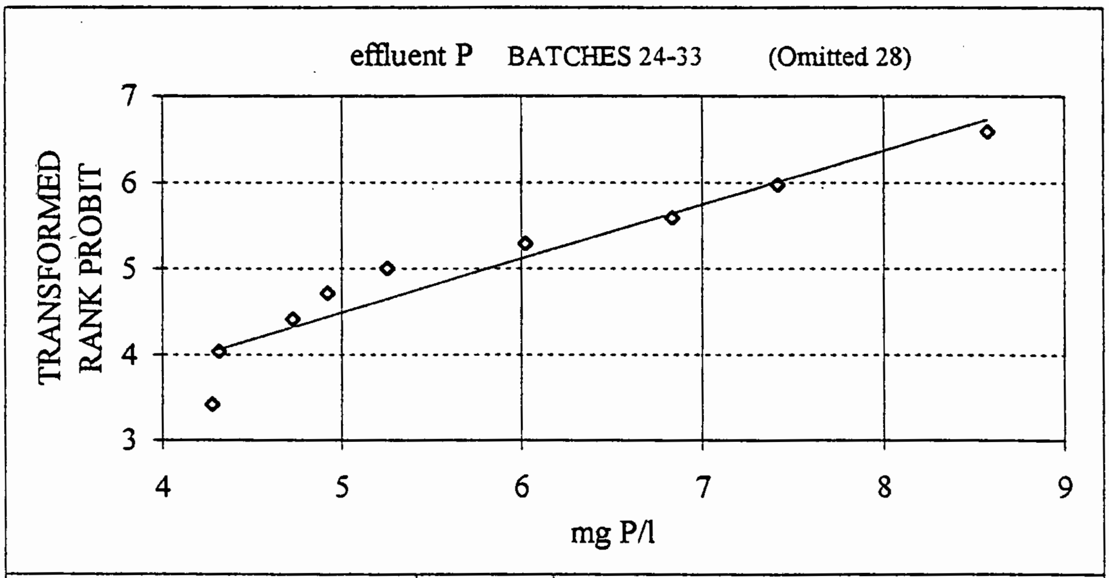
MEDIAN=	0.185		std dev. of mean = 0.017
MEAN =	0.195		95% conf. of mean = 0.195 +/- 0.034
s =	0.049		

Fig CII.25 Probability distribution of the value for fractional P content of polyP organism active mass f_{av}, $f_{XBG,P}$ in UCT system from day 361 to day 490.



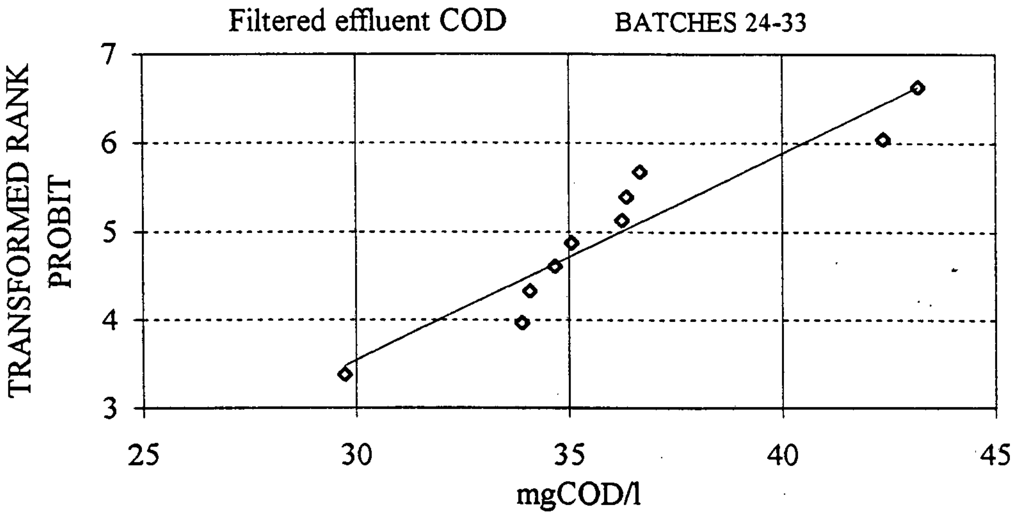
MEDIAN=	16.7		std dev. of mean = 1.0
MEAN =	17.2		95% conf. of mean = 17.2 +/- 2.0
s =	3.3		

Fig CII.26 Probability distribution of the daily P concentration in anaerobic reactor in UCT system from day 361 to day 490.



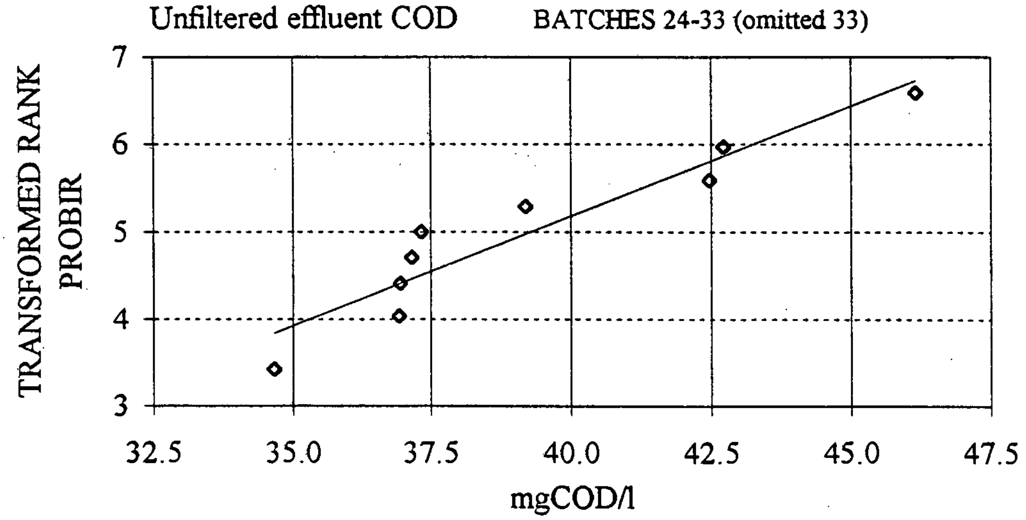
MEDIAN=	5.3		std dev. of mean = 0.5
MEAN =	5.8		95% conf. of mean = 5.8 +/- 1.0
s =	1.5		

Fig CII.27 Probability distribution of the daily effluent P concentration in UCT system from day 361 to day 490.



MEDIAN=	35.7		std dev. of mean = 1.3
MEAN =	36.2		95% conf. of mean = 36.2 +/- 2.5
s =	4.0		

Fig CII.28 Probability distribution of the daily filtered effluent COD concentration in UCT system from day 361 to day 490.

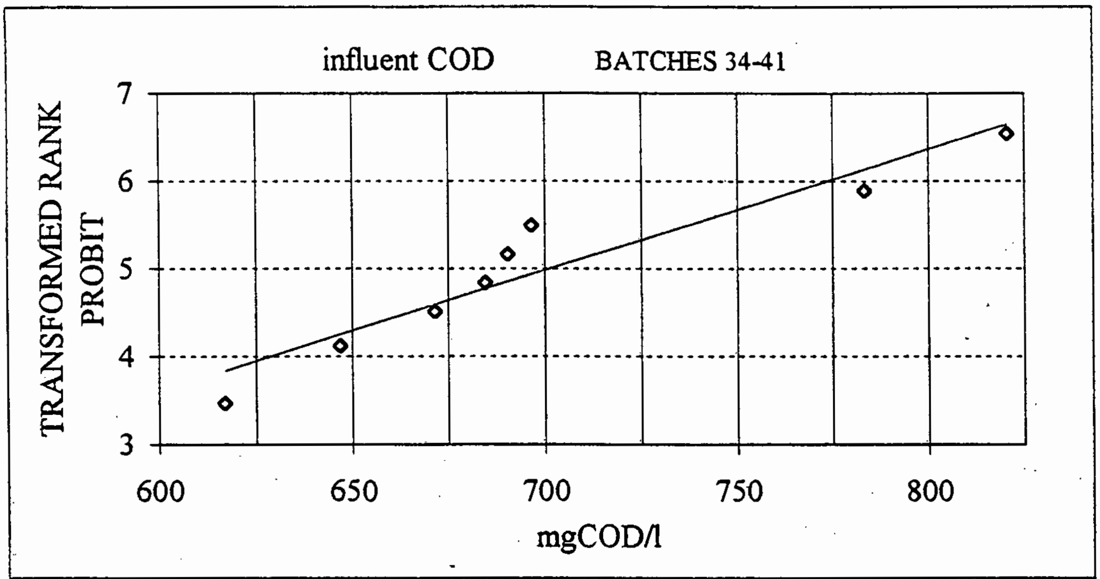


MEDIAN=	37.3		std dev. of mean = 1.2
MEAN =	39.3		95% conf. of mean = 39.3 +/- 2.4
s =	3.7		

Fig CII.29 Probability distribution of the daily unfiltered effluent COD concentration in UCT system from day 361 to day 490.

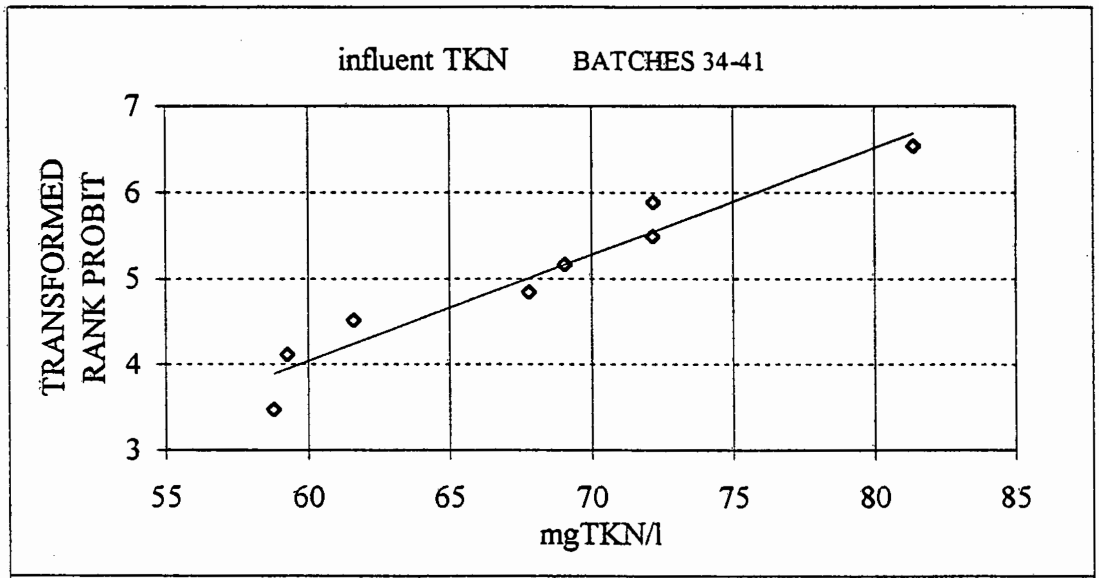
Probability distribution plots for sewage batches over the different periods.

Period CIII (sewage batches 34 to 41; days 491 to 582)



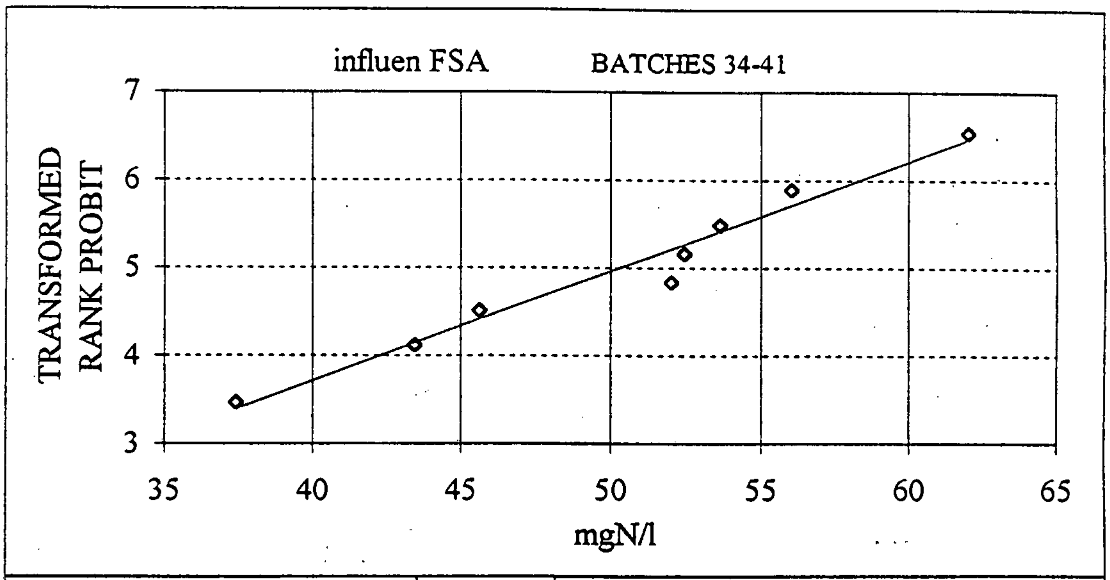
MEDIAN=	687		std dev. of mean = 24.
MEAN =	701		95% conf. of mean = 701 +/- 47
s =	68		

Fig CIII.1 Probability distribution of the daily influent COD concentration from day 491 to day 582.



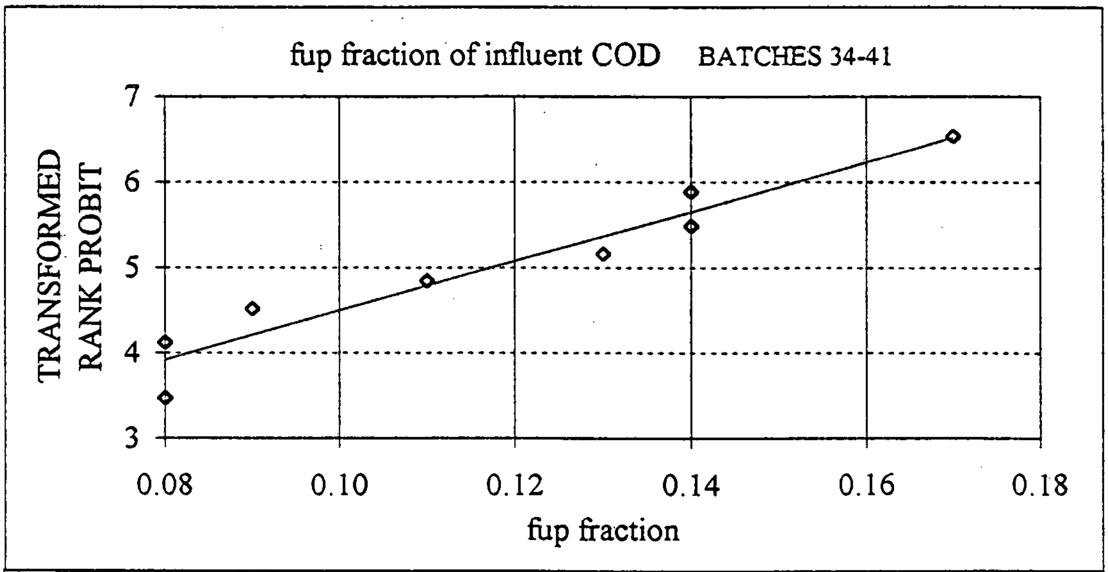
MEDIAN=	68		std dev. of mean = 3
MEAN =	68		95% conf. of mean = 68 +/- 5
s =	8		

Fig CIII.2 Probability distribution of the daily influent TKN concentration from day 491 to day no 582.



MEDIAN=	52.2		std dev. of mean =	2.8
MEAN =	50.3		95% conf. of mean = 50.3 +/-	5.4
s =	7.8			

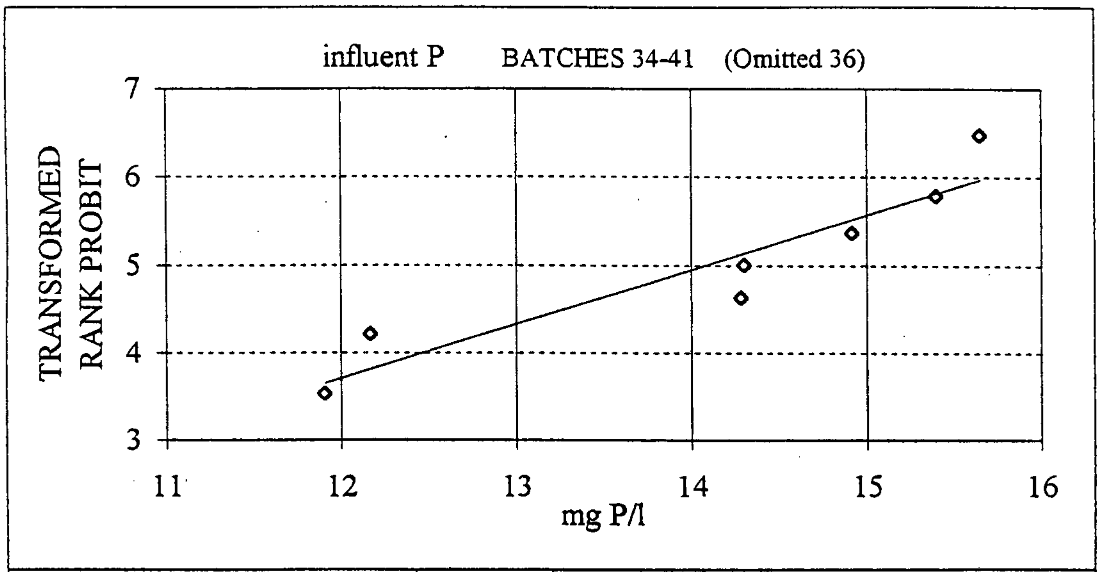
Fig CIII.3 Probability distribution of the daily influent Free and Saline Ammonia from day 491 to day 582.



MEDIAN=	0.120		std dev. of mean =	0.012
MEAN =	0.118		95% conf. of mean = 0.11 +/-	0.023
s =	0.033			

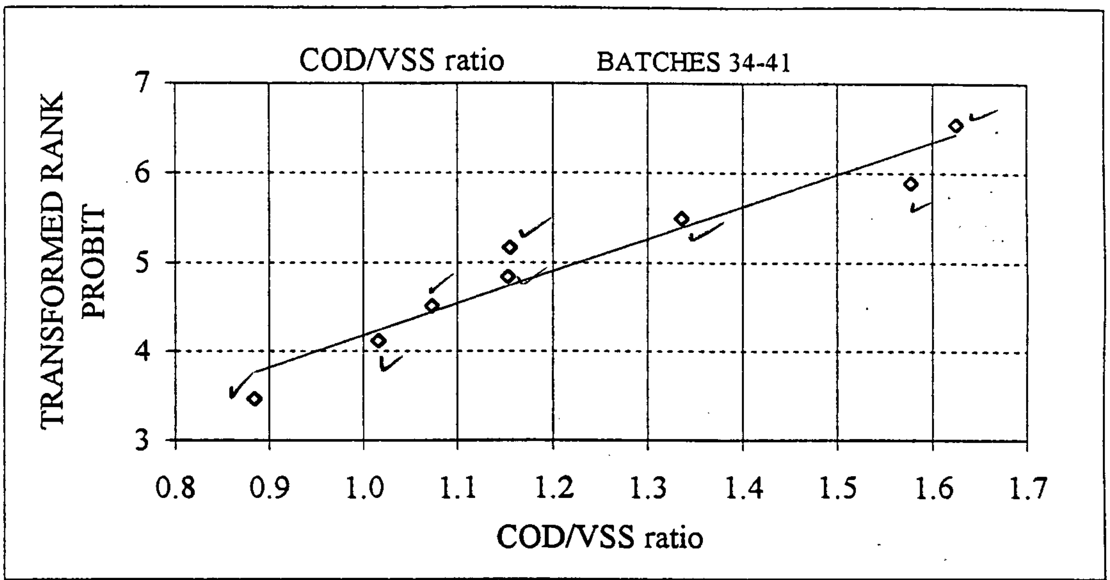
Fig CIII.4 Probability distribution of the fup fraction of daily influent COD from day 491 to day 582.

UCT



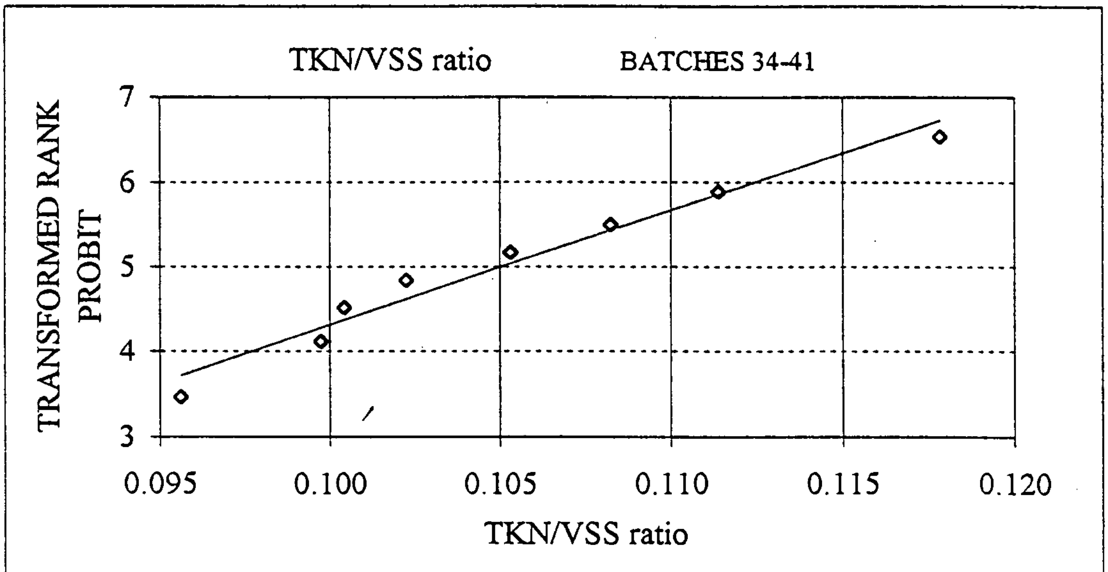
MEDIAN=	14.3		std dev. of mean = 0.6
MEAN =	14.1		95% conf. of mean = 14.1 +/- 1.1
s =	1.5		

Fig CIII.5 Probability distribution of the dayly influent P concentration in MLE and in UCT system from day 491 to day 582.



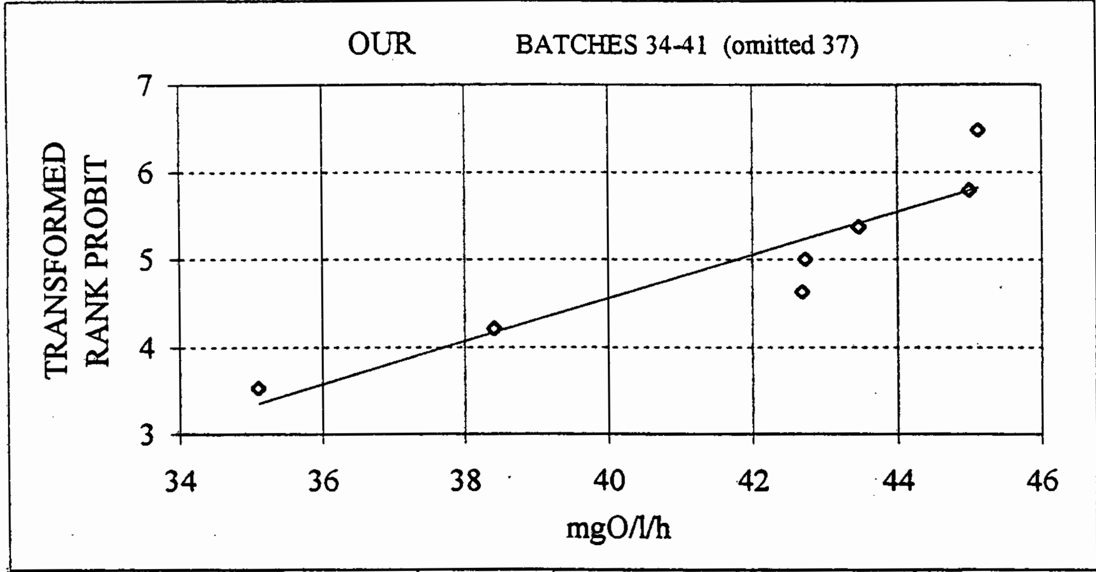
MEDIAN=	1.15		std dev. of mean =	0.09
MEAN =	1.23		95% conf. of mean = 1.23 +/-	0.18
s =	0.26			

Fig CIII.6 Probability distribution of the daily COD/VSS ratio in aerobic reactor in MLE system from day 491 to day 582.



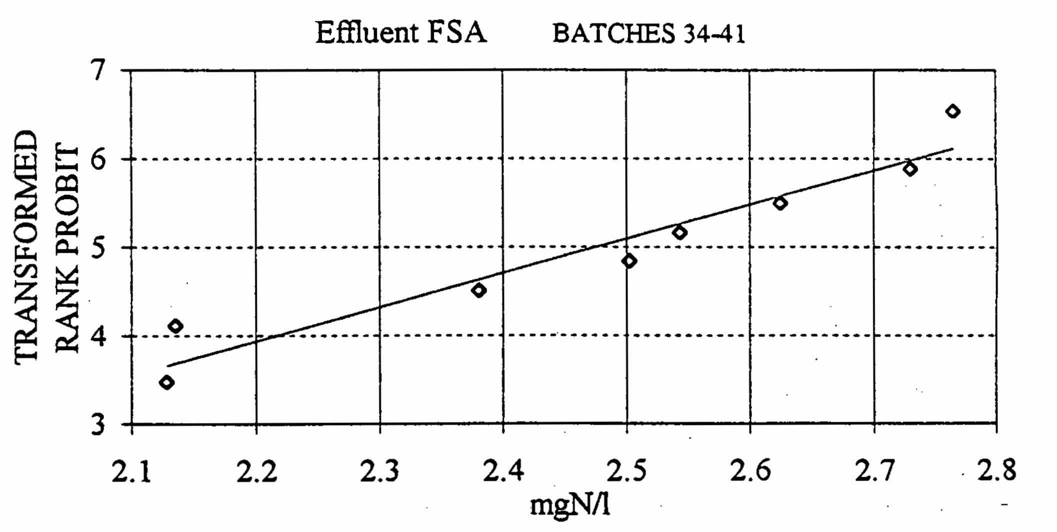
MEDIAN=	0.104		std dev. of mean =	0.003
MEAN =	0.105		95% conf. of mean = 0.105+/- 0.005	
s =	0.007			

Fig CIII.7 Probability distribution of the daily TKN/VSS ratio in aerobic reactor in MLE system from day 491 to day 582.



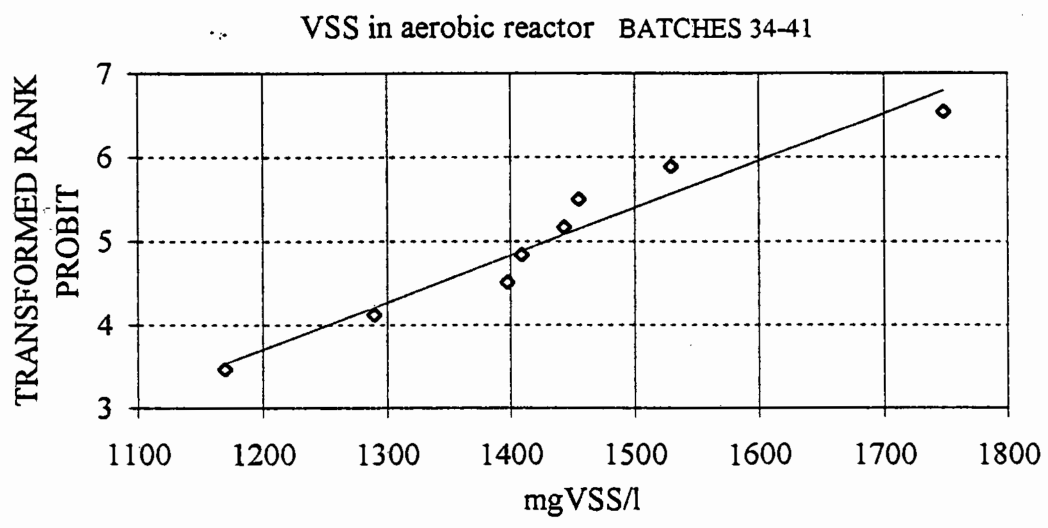
MEDIAN=	42.7		std dev. of mean =	1.4
MEAN =	41.8		95% conf. of mean = 41.8	+/- 2.7
s =	3.7			

Fig CIII.8 Probability distribution of the daily Oxygen Utilization Rate in aerobic reactor in MLE system from day 491 to day 582.



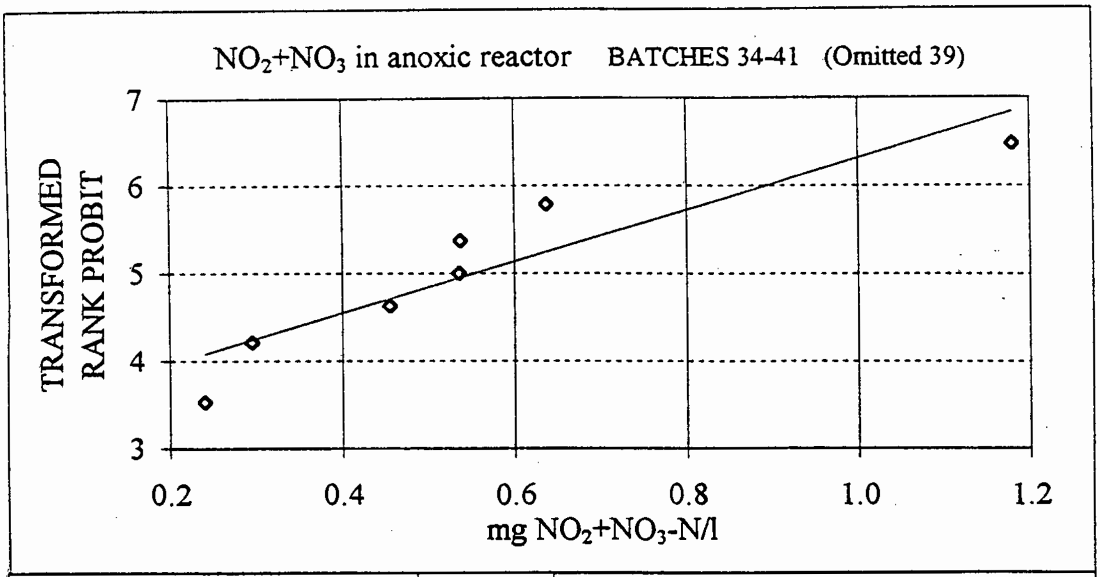
MEDIAN=	2.5		std dev. of mean = 0.1
MEAN =	2.5		95% conf. of mean = 2.5 +/- 0.2
s =	0.2		

Fig CIII.9 Probability distribution of the daily effluent FSA concentration in MLE system from day 491 to day 582.



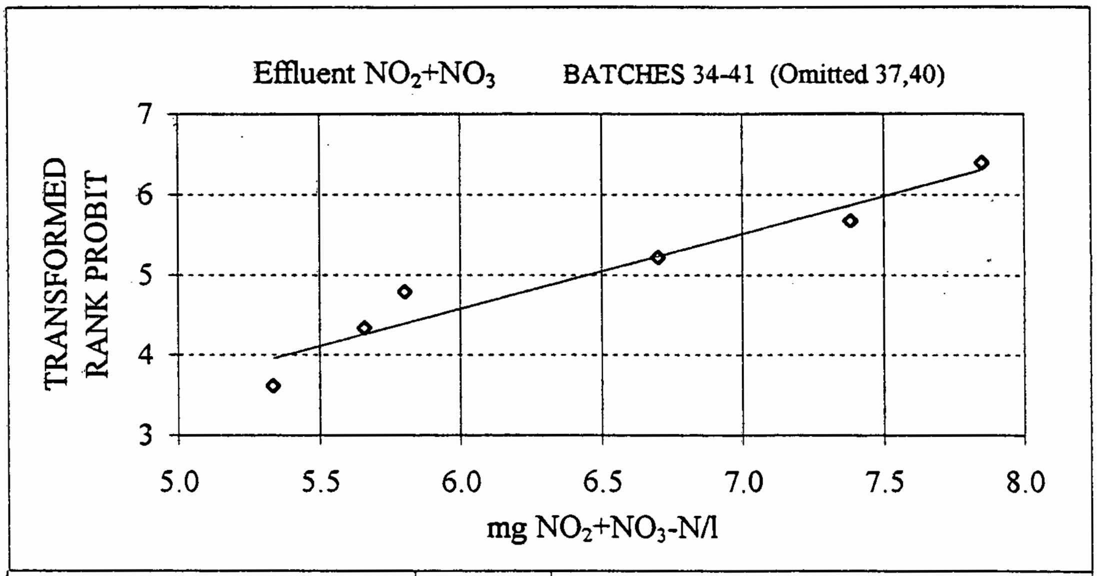
MEDIAN=	1426		std dev. of mean = 60
MEAN =	1430		95% conf. of mean = 1430 +/- 117
s =	169		

Fig CIII.10 Probability distribution of the daily VSS concentration in MLE system from day 491 to day 582.



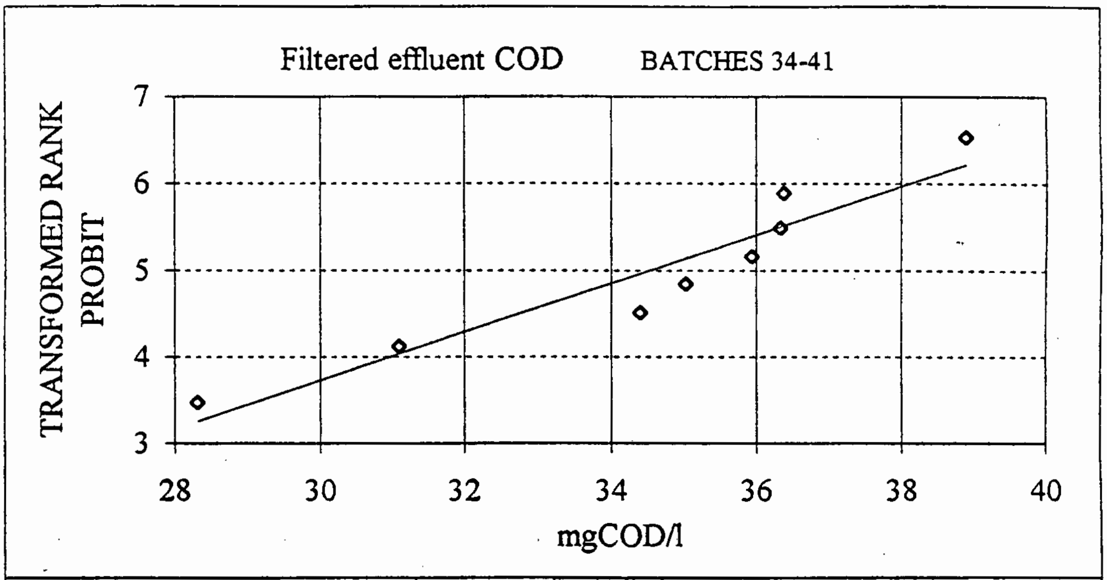
MEDIAN=	0.5		std dev. of mean =	0.1
MEAN =	0.6		95% conf. of mean = 0.6 +/-	0.2
s =	0.3			

Fig CIII.11 Probability distribution of the daily NO_3+NO_2 concentration in anoxic reactor in MLE system from day 491 to day 582.



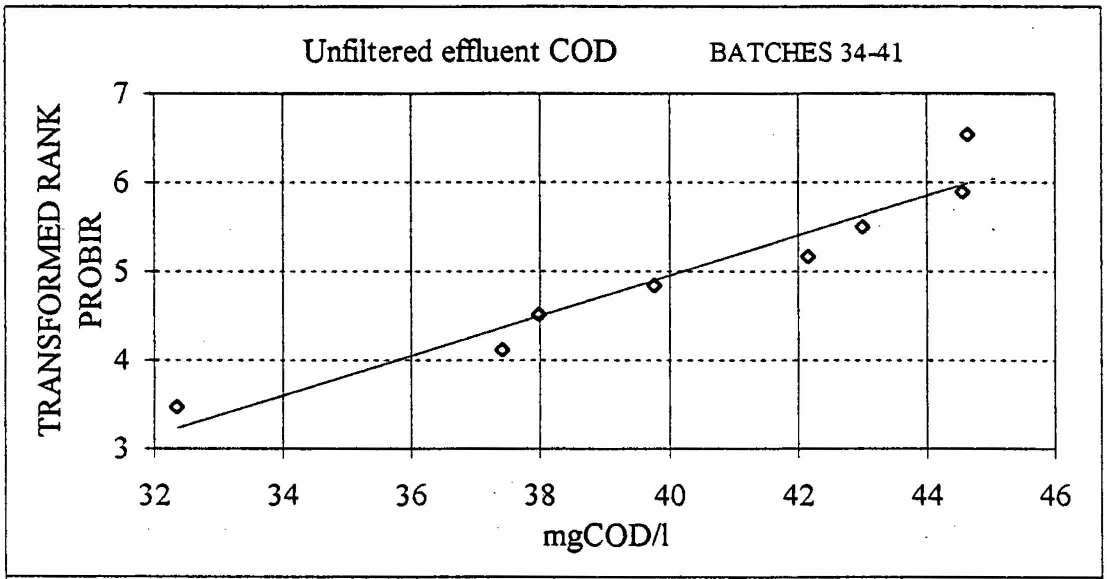
MEDIAN=	6.3		std dev. of mean =	0.4
MEAN =	6.5		95% conf. of mean = 6.5 +/-	0.8
s =	1.0			

Fig CIII.12 Probability distribution of the daily effluent NO_3+NO_2 concentration in MLE system from day 491 to day 582.



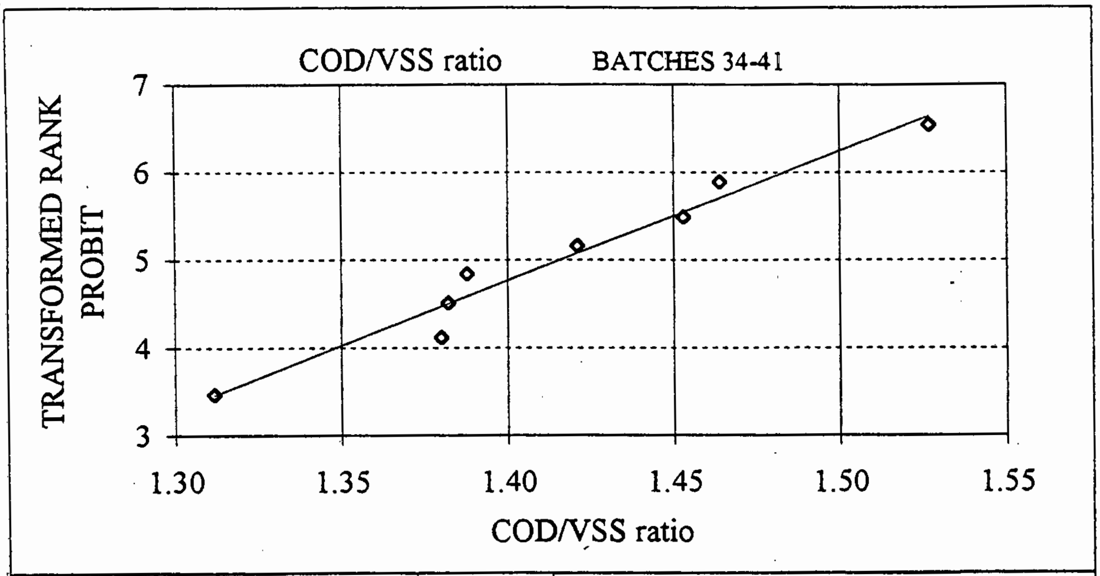
MEDIAN=	35.5		std dev. of mean = 1.2
MEAN =	34.5		95% conf. of mean = 34.5 +/- 2.3
s =	3.3		

Fig CIII.13 Probability distribution of the daily filtered effluent COD concentration in MLE system from day 491 to day 582.



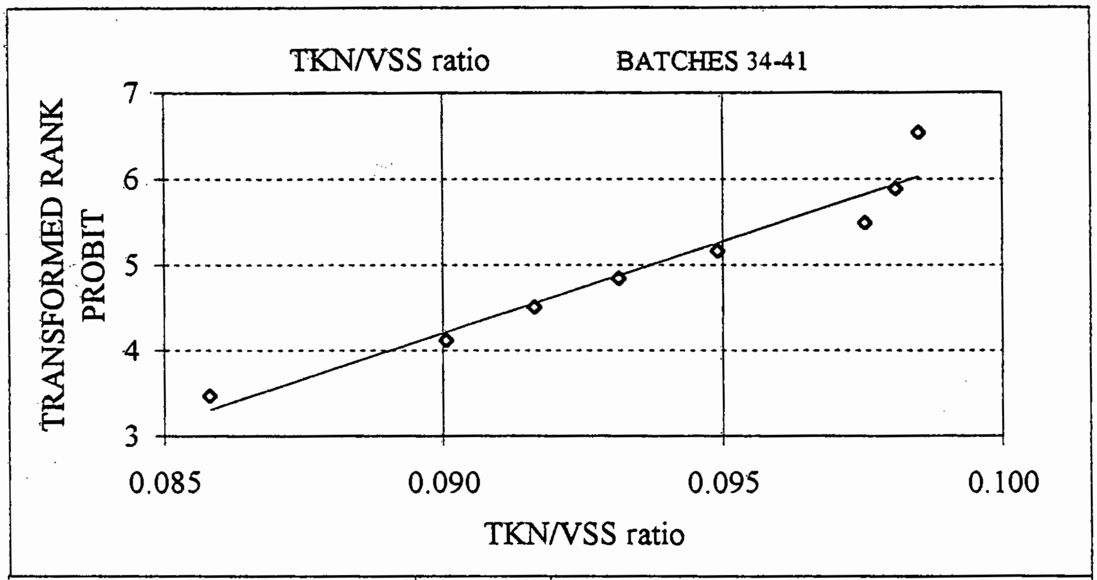
MEDIAN=	41.0		std dev. of mean = 1.5
MEAN =	40.2		95% conf. of mean = 40.2 +/- 2.9
s =	4.2		

Fig CIII.14 Probability distribution of the daily unfiltered effluent COD concentration in MLE system from day 491 to day 582.



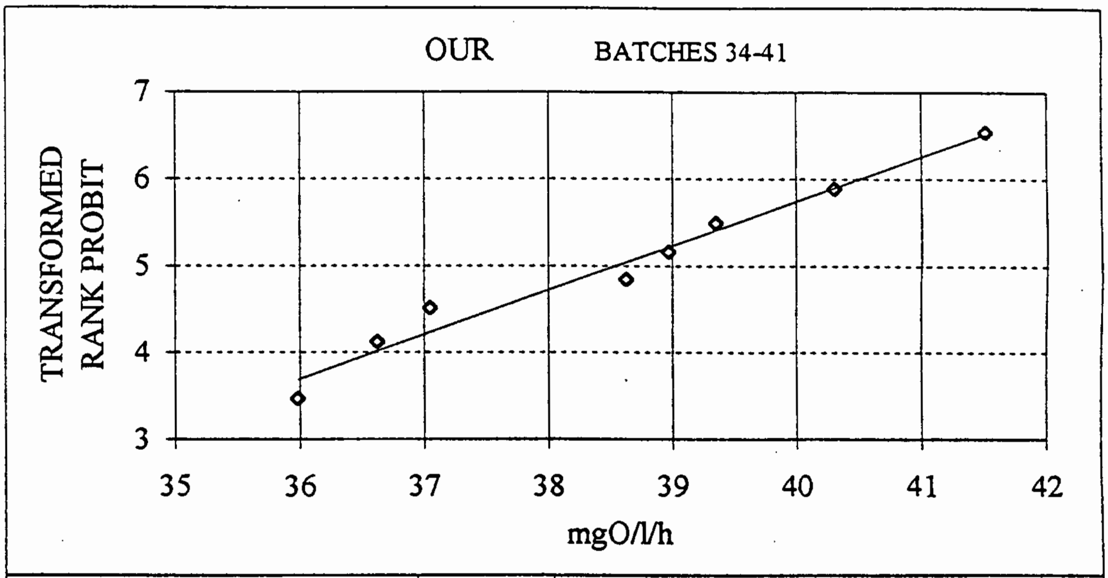
MEDIAN=	1.40		std dev. of mean = 0.02
MEAN =	1.42		95% conf. of mean = 1.42 +/- 0.05
s =	0.07		

Fig CIII.15 Probability distribution of the daily COD/VSS ratio in aerobic reactor in UCT system from day 491 to day 582.



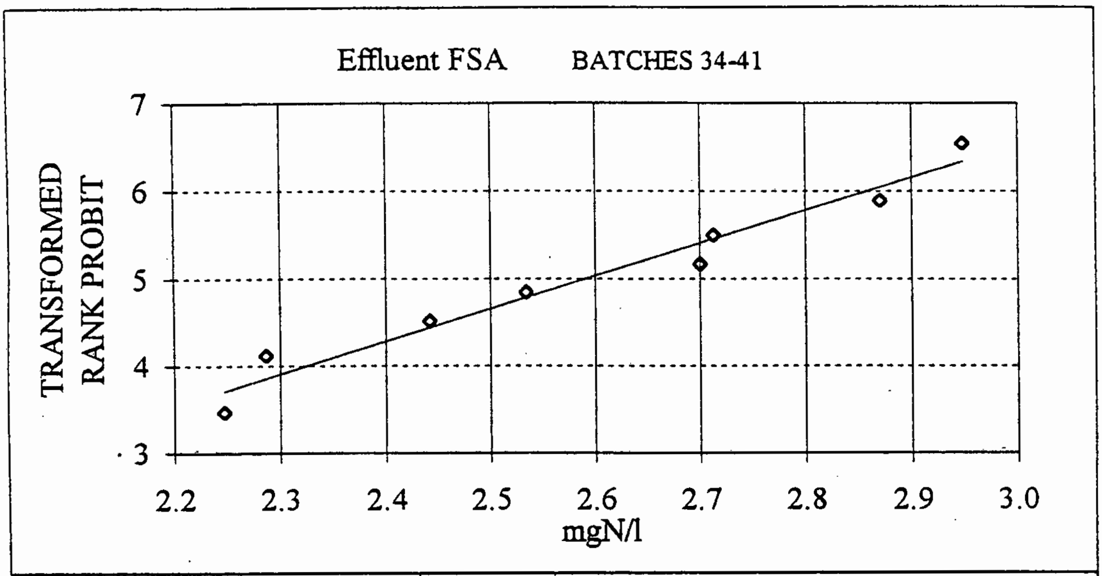
MEDIAN=	0.094		std dev. of mean = 0.002
MEAN =	0.094		95% conf. of mean = 0.094+/- 0.003
s =	0.004		

Fig CIII.16 Probability distribution of the daily TKN/VSS ratio in aerobic reactor in UCT system from day 491 to day 582.



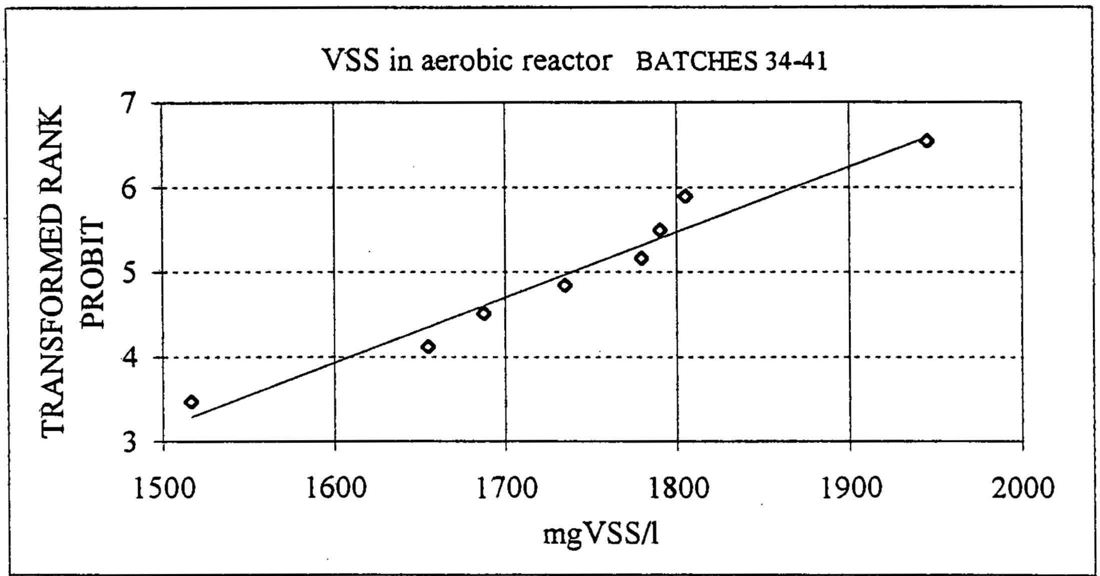
MEDIAN=	38.8		std dev. of mean = 0.7
MEAN =	38.6		95% conf. of mean = 38.6 +/- 1.3
s =	1.9		

Fig CIII.17 Probability distribution of the daily Oxygen Utilization Rate in aerobic reactor in UCT system from day 491 to day 582.



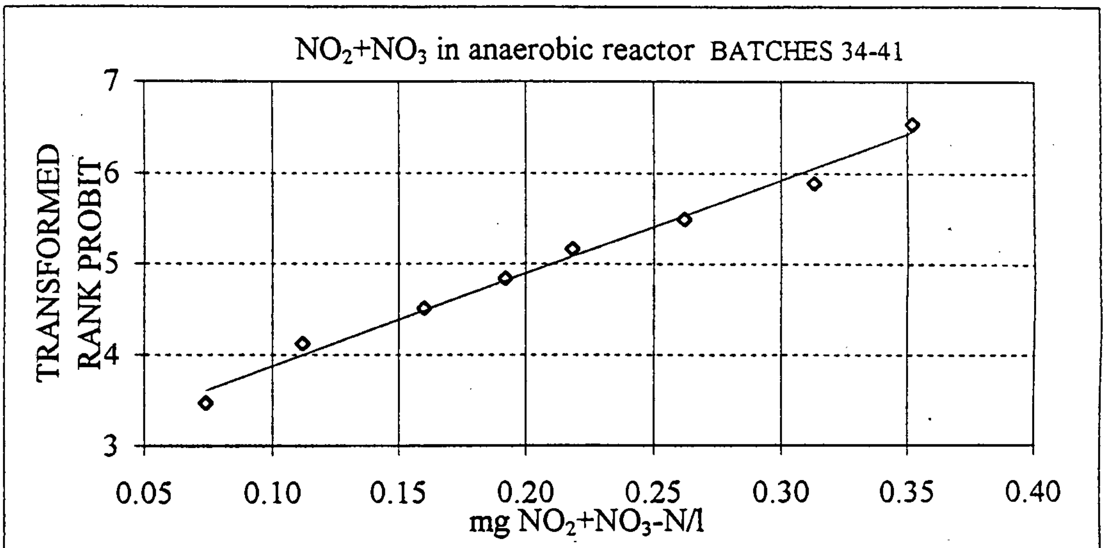
MEDIAN=	2.6		std dev. of mean = 0.1
MEAN =	2.6		95% conf. of mean = 2.6 +/- 0.2
s =	0.3		

Fig CIII.18 Probability distribution of the daily effluent FSA concentration in UCT system from day 491 to day 582.



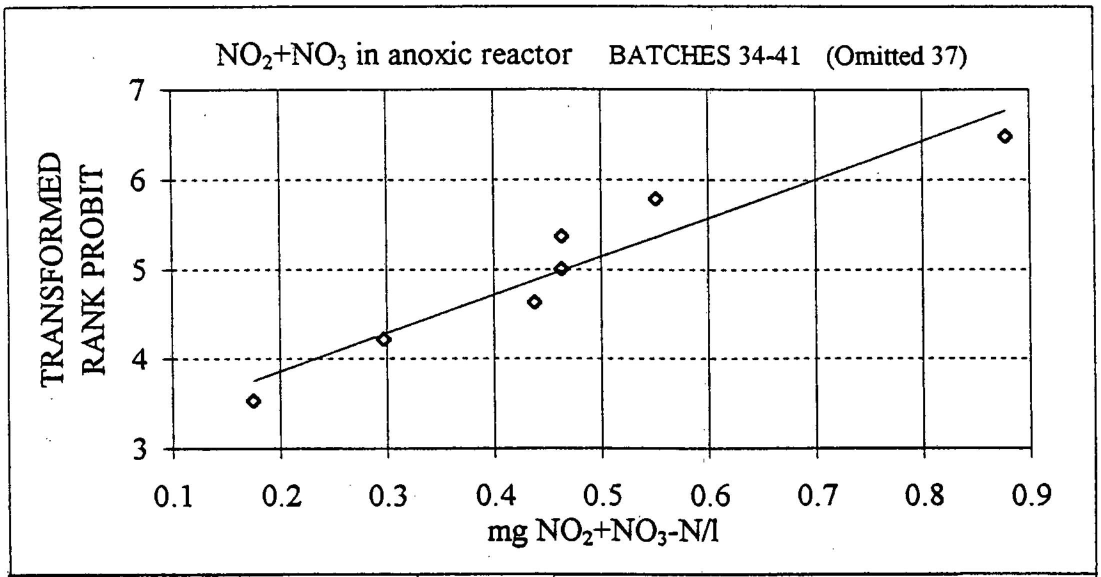
MEDIAN=	1757		std dev. of mean = 44
MEAN =	1739		95% conf. of mean = 1739 +/- 87
s =	126		

Fig CIII.19 Probability distribution of the daily VSS concentration in UCT system from day 491 to day 582.



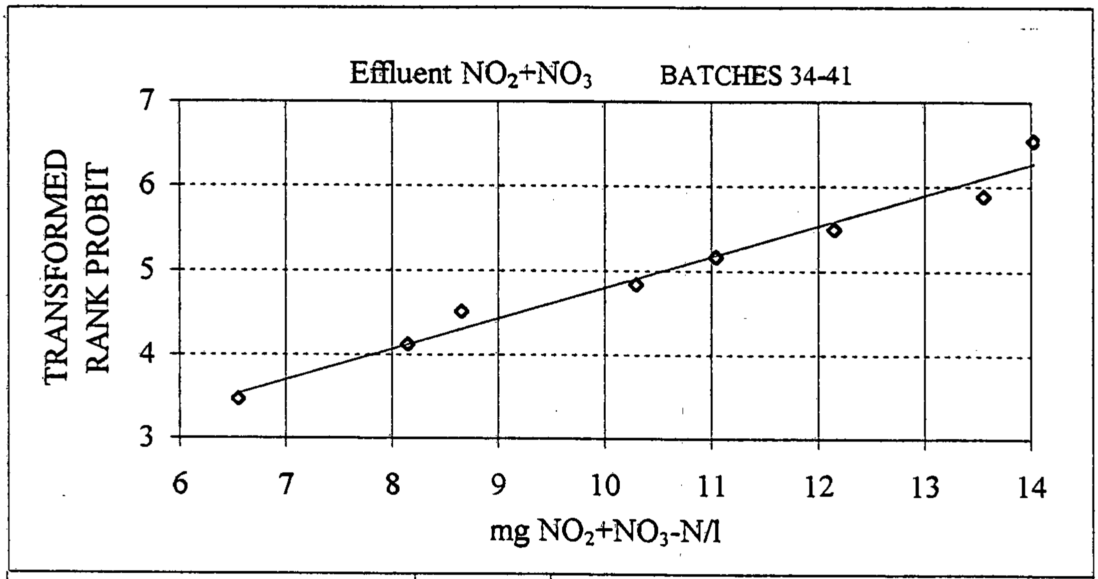
MEDIAN=	0.21		std dev. of mean =	0.03
MEAN =	0.21		95% conf. of mean = 0.21 +/- 0.07	
s =	0.10			

Fig CIII.20 Probability distribution of the daily NO_2+NO_3 concentration in anaerobic reactor in UCT system from day 491 to day 582.



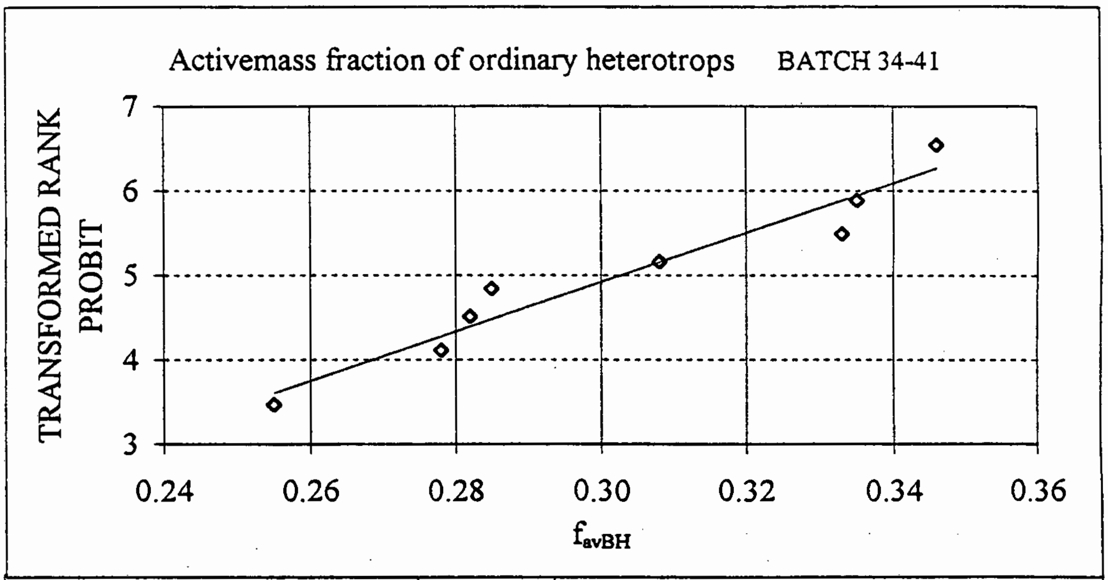
MEDIAN=	0.46		std dev. of mean = 0.08
MEAN =	0.47		95% conf. of mean = 0.47 +/- 0.16
s =	0.22		

Fig CIII.21 Probability distribution of the daily NO_3+NO_2 concentration in anoxic reactor in UCT system from day 491 to day 582.



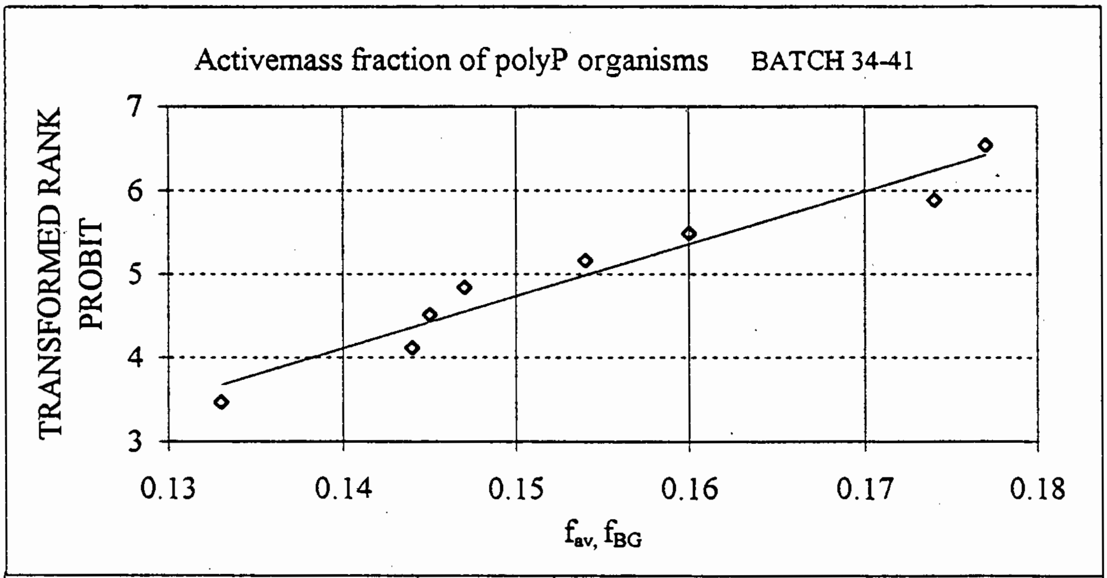
MEDIAN=	10.7		std dev. of mean = 0.9
MEAN =	10.6		95% conf. of mean = 10.6 +/- 1.8
s =	2.7		

Fig CIII.22 Probability distribution of the daily effluent NO_3+NO_2 concentration in UCT system from day 491 to day 582.



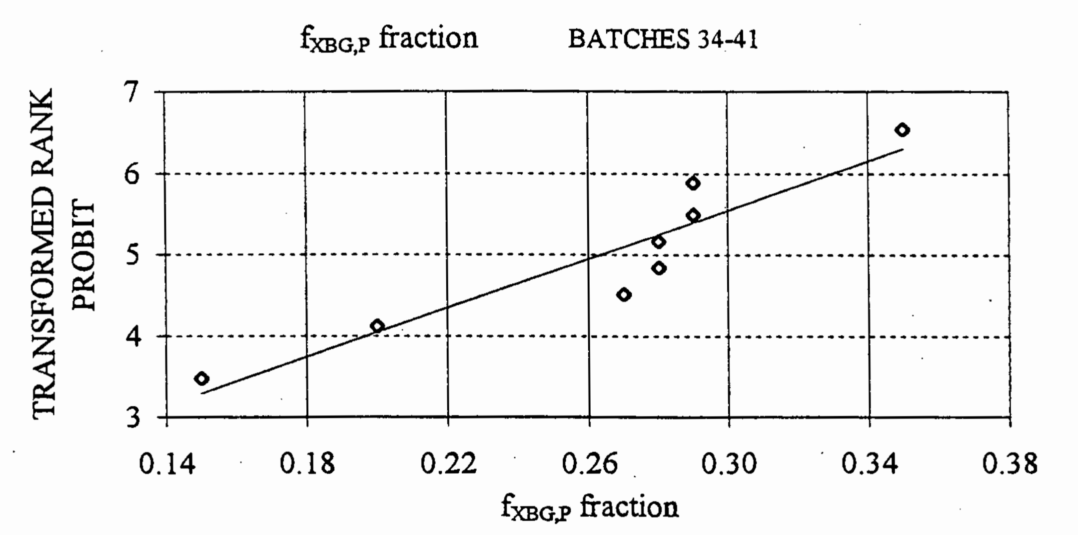
MEDIAN=	0.297		std dev. of mean =	0.012
MEAN =	0.303		95% conf. of mean = 0.303+/- 0.023	
s =	0.033			

Fig CIII.23 Probability distribution of the active mass fraction of ordinary heterotrops f_{av}, f_{OHO} in UCT system from day 491 to day 582.



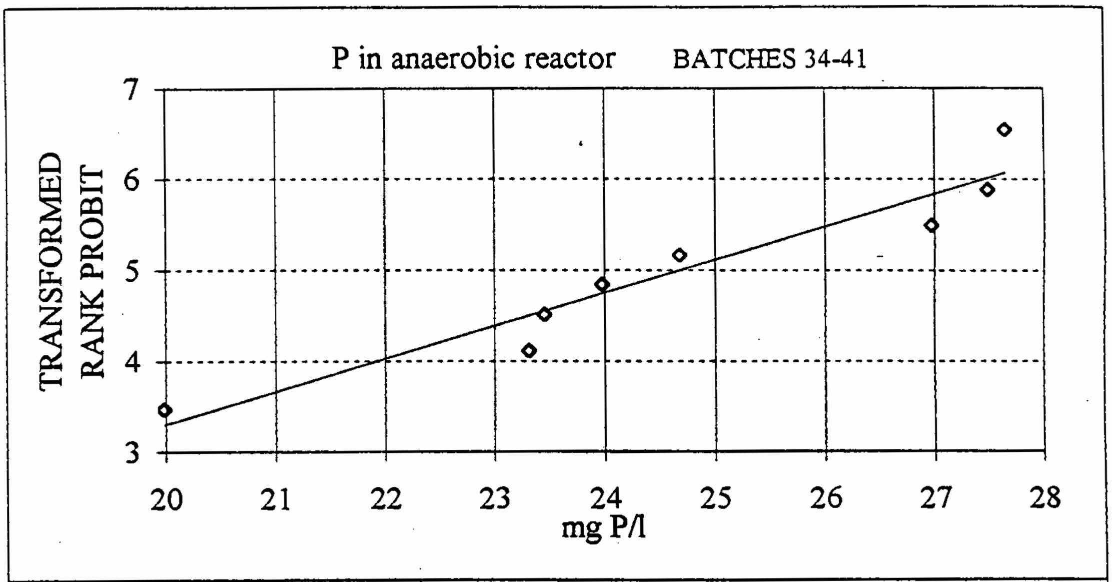
MEDIAN=	0.151		std dev. of mean =	0.005
MEAN =	0.154		95% conf. of mean = 0.154+/- 0.011	
s =	0.015			

Fig CIII.24 Probability distribution of the active mass fraction of polyP organisms f_{av}, f_{BG} in UCT system from day 491 to day 582.



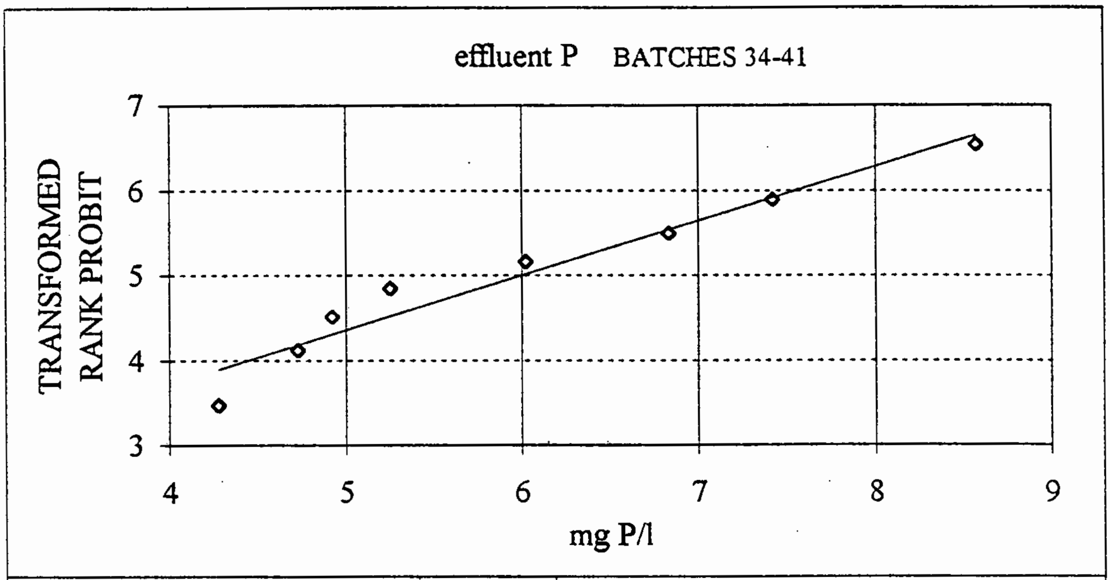
MEDIAN=	0.280		std dev. of mean =	0.022
MEAN =	0.264		95% conf. of mean = 0.264 +/-0.043	
s =	0.061			

Fig CIII.25 Probability distribution of the value for fractional P content of polyP organism active mass f_{av}, $f_{XBG,P}$ in UCT system from day 491 to day 582.



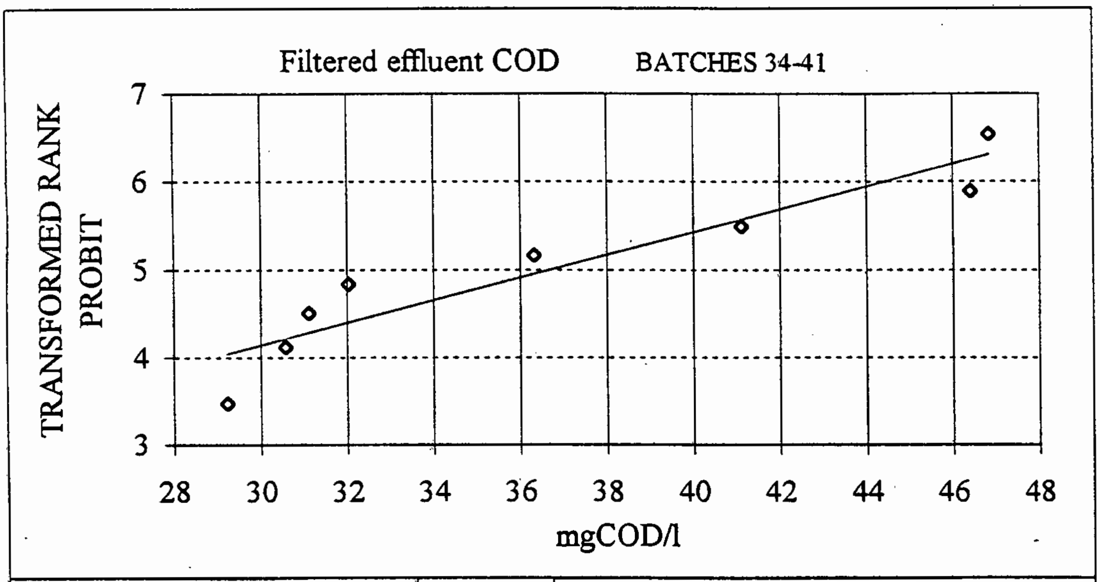
MEDIAN=	24.3		std dev. of mean = 0.9
MEAN =	24.7		95% conf. of mean = 24.7 +/- 1.8
s =	2.6		

Fig CIII.26 Probability distribution of the daily P concentration in anaerobic reactor in UCT system from day 491 to day 582.



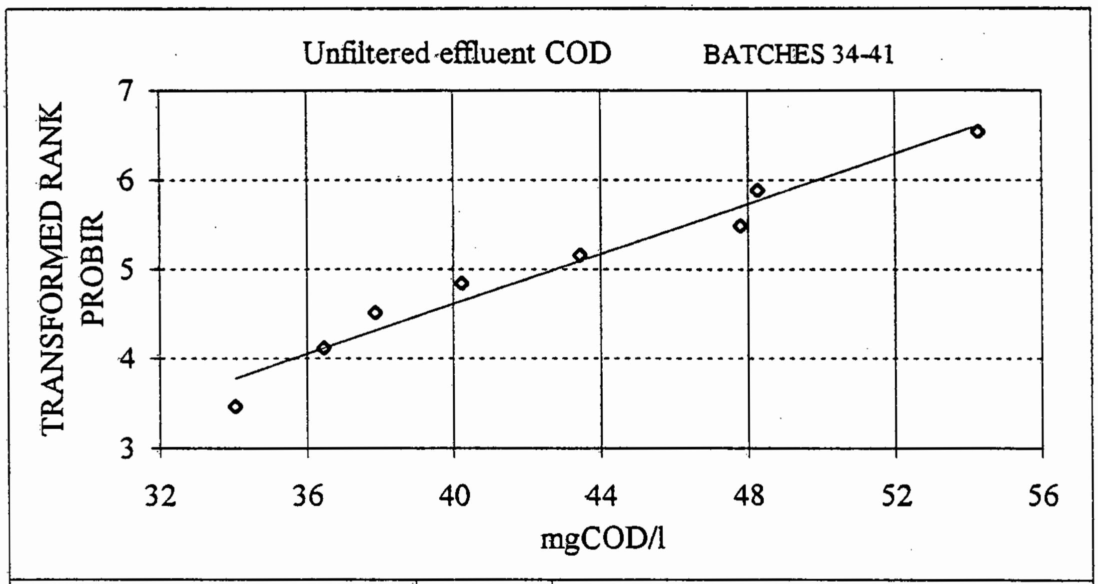
MEDIAN=	5.6		std dev. of mean = 0.5
MEAN =	6.0		95% conf. of mean = 6.0 +/- 1.1
s =	1.6		

Fig CIII.27 Probability distribution of the daily effluent P concentration in UCT system from day 491 to day 582.



MEDIAN=	34.2		std dev. of mean = 2.5
MEAN =	36.7		95% conf. of mean = 36.7 +/- 5.0
s =	7.2		

Fig CIII.28 Probability distribution of the daily filtered effluent COD concentration in UCT system from day 491 to day 582.

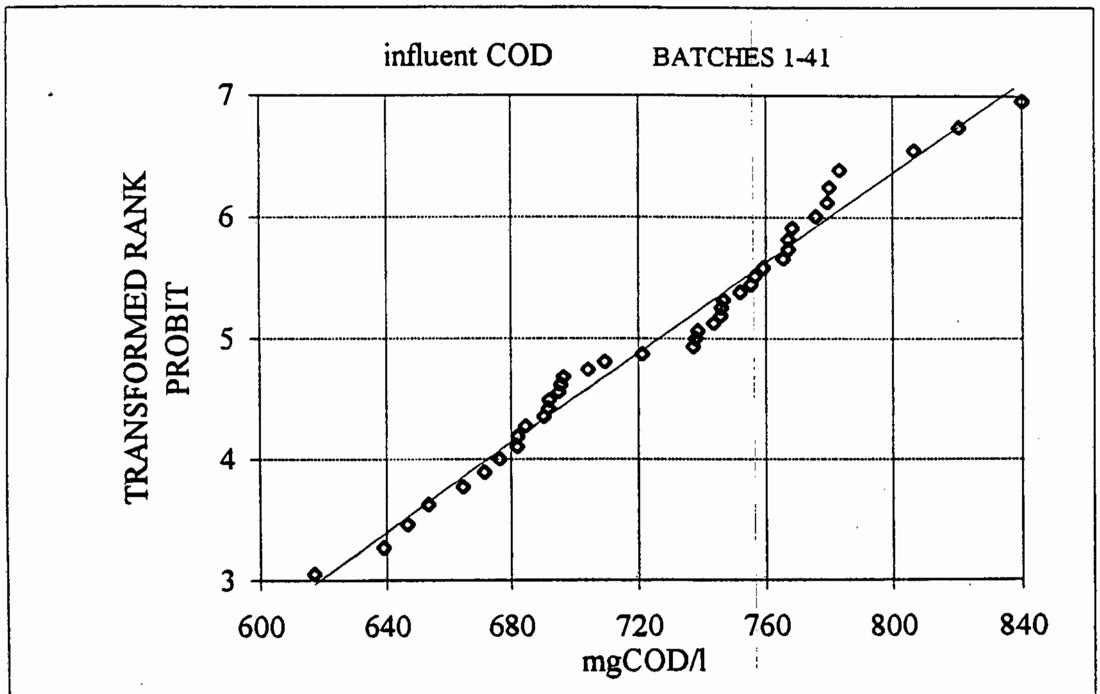


MEDIAN=	41.8		std dev. of mean = 2.4
MEAN =	42.8		95% conf. of mean = 42.8 +/- 4.8
s =	6.9		

Fig CIII.29 Probability distribution of the daily unfiltered effluent COD concentration in UCT system from day 491 to day 582.

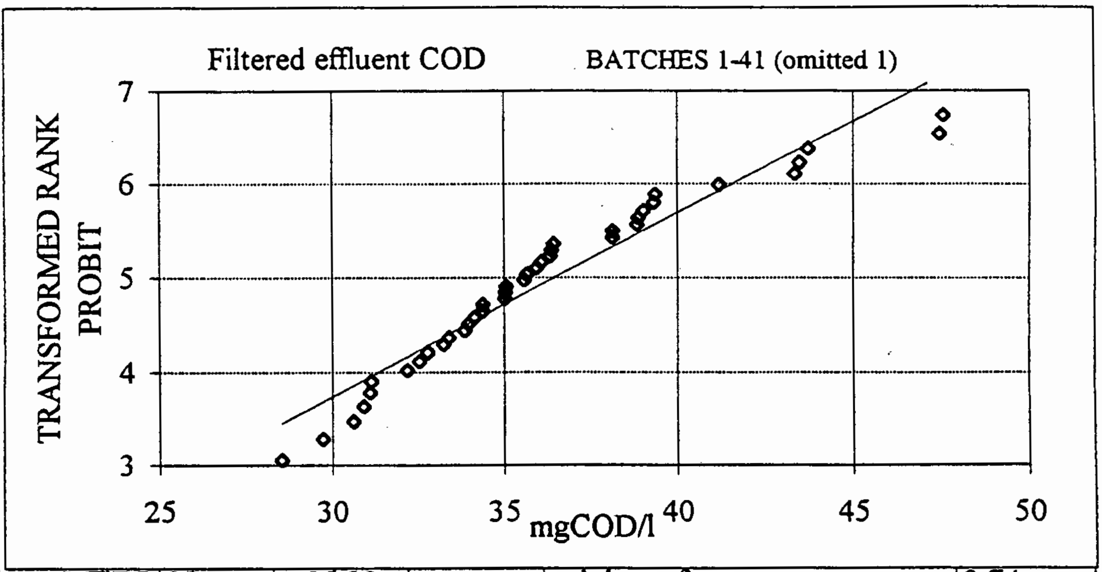
Probability distribution plots for sewage batches over the different periods.

Period CIV (sewage batches 1 to 41; days 1 to 582)



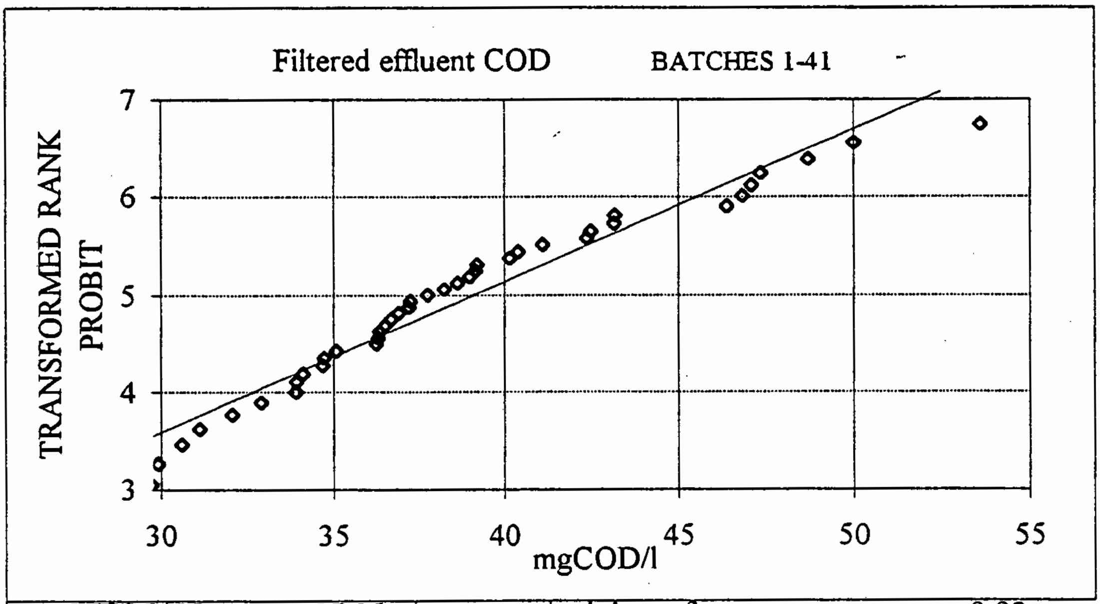
MEDIAN=	738		std dev. of mean =	8
MEAN =	727		95% conf. of mean = 727 +/-	16
s =	51			

Fig CIV.1 Probability distribution of the daily influent COD concentration from day 1 to day 582.



MEDIAN=	35.32		std dev. of mean =	0.74
MEAN =	36.03		95% conf. of mean =36.03 +/-	1.45
s =	4.66			

Fig CIV.2 Probability distribution of the daily filtered effluent COD in MLE system from day no 1 to day no 582.



MEDIAN=	37.25		std dev. of mean =	0.92
MEAN =	38.54		95% conf. of mean =38.54 +/-	1.81
s =	5.91			

Fig CIV.3 Probability distribution of the daily filtered effluent COD in UCT system from day no 1 to day no 582.

APPENDIX D

STEADY STATE SIMULATION RESULTS

```
*******  WASTEWATER CHARACTERISTICS   ********

 Sti       (g COD m-3)             =  751.00
 Nti       (g N m-3)               =   65.00
 Fbs       (g COD g-1 COD)         =    0.23
 Fs,us     (g COD g-1 COD)         =    0.05
 Fs,up     (g COD g-1 COD)         =    0.15
 Fn,a      (g N g-1 N)             =    0.75
 Fnob,p    (g N g-1 N)             =    0.50
 Fn,ous    (g N g-1 N)             =    0.03
 Fs,zbh    (g Zbh COD g-1 COD)     =    0.00
 VSS/TSS   (g VSS g-1 TSS)         =    0.75
 Inf Alk   (mole m-3)              =   10.00




HETEROTROPH KINETIC DATA (Values at 20 degC)
************************

 Mue max soluble             d-1                =   3.200
 Ks soluble         (Ksh)    g COD m-3          =   5.000
 Ks O2              (Koh)    g O2 m-3           =   0.002
 B decay            (bh)     d-1                =   0.620
 Neta (growth)                                  =   0.330
 Ks NO3             (Kno)    g N m-3            =   0.100
 Mue max part       (Kmp)    d-1                =   1.350
 Ks particulate     (Ksp)    g COD g-1 COD      =   0.027
 Ammonification     (Kr)     m3 g-1 COD d-1     =   0.032
 Ks NH3             (Kna)    g N m-3            =   0.010
 Adsorption rate    (Ka)     g-1 COD m3 d-1     =   0.170



AUTOTROPH KINETIC DATA (Values at 20 degC)
*********************

 Mue max auto                d-1                =    0.400
 Ks NH4+           (Ksa)     g N m-3            =    1.000
 Ks O2             (Koa)     g O2 m-3           =    0.002
 B endogenous      (ba)      d-1                =    0.040




STOICHIOMETRIC PARAMETERS
*************************

Yield, hetero     (Yzh)   g COD g-1 COD   =   0.666
Frac inert        (Fe)    g COD g-1 COD   =   0.080
N in biomass     (Fzb,n)  g N g-1 COD     =   0.068
N in inert       (Fze,n)  g N g-1 COD     =   0.068
Yield, auto       (Yza)   g COD g-1 COD   =   0.150
COD:VSS ratio     (Fcv)   g COD g-1 VSS   =   1.480
Max adsorption    (Fma)   g COD g-1 COD   =   1.000
```

```
*****  STEADY STATE RESULTS *****                 Inversions = 6
MPOUND                 INPUT           REACTOR
                                   1       2
n (hetero.)         =     0.0  1115.4  1162.2 g COD m-3
a (autotrophs)      =     0.0    40.4    41.2 g COD m-3
 (endog.)           =     0.0   561.4   566.2 g COD m-3
 (prt unb COD)      =   115.7  1156.5  1156.5 g COD m-3
ds (adsorb.COD)     =     0.0   236.4   137.7 g COD m-3
nm (enmesh COD)     =   460.3    10.0     4.2 g COD m-3
bp (prt bio N)      =     3.2    12.2     9.0 g N m-3
s (sol bio COD)     =   137.5     0.7     0.0 g COD m-3
 (ammonia N)        =    48.8    10.2     2.3 g N m-3
bs (sol org N)      =     3.2     0.7     1.9 g N m-3
3 (nitrate N)       =     0.0     0.1     6.4 g N m-3
kalinity            =    10.0     7.2     6.2 mole m-3
s (sol unb COD)     =    37.5    37.5    37.5 g COD m-3

latile SS           =          2108.2  2073.1 g VSS m-3
tal SS              =          2810.9  2764.1 g TSS m-3
R heterotrophs      =             0.0    26.8 g O2 m-3 h-1
R autotrophs        =             0.0    14.1 g O2 m-3 h-1
R total             =             0.0    40.9 g O2 m-3 h-1
nit. rate           =             2.6     0.0 g NO3-N m-3 h-1
N                   =            12.9     6.1 g N m-3
```

```
             **********  PLANT OPERATING PARAMETERS  **********

 Influent flow               l d-1          =         20.00
 RAS recycle flow            l d-1          =         20.00
 SRT (total)                d               =         10.00
 Process Temperature        degC            =         20.00

 A-recycle flow              l d-1          =         80.00
 Wastage rate flow           l d-1          =          2.00
```

```
 *****  STEADY STATE RESULTS                               Inversions = 6
COMPOUND                INPUT        D.3    -------R
                                  1       2
Zbh (hetero.)       =     0.0   920.2   968.0 g COD m-3
Zba (autotrophs)    =     0.0    38.7    39.5 g COD m-3
Ze (endog.)         =     0.0   619.6   624.9 g COD m-3
Zi (prt unb COD)    =   115.7  1156.5  1156.5 g COD m-3
Sads (adsorb.COD)   =     0.0   114.8     9.6 g COD m-3
Senm (enmesh COD)   =   460.3     8.6     3.7 g COD m-3
Nobp (prt bio N)    =     3.2     4.5     0.7 g N m-3
Sbs (sol bio COD)   =   137.5     0.2     0.0 g COD m-3
Na (ammonia N)      =    48.8    10.0     2.2 g N m-3
Nobs (sol org N)    =     3.2     0.7     1.9 g N m-3
No3 (nitrate N)     =     0.0     0.0     6.7 g N m-3
Alkalinity          =    10.0     7.2     6.2 mole m-3
Sus (sol unb COD)   =    37.5    37.5    37.5 g COD m-3

Volatile SS         =          1931.3  1893.4 g VSS m-3
Total SS            =          2575.1  2524.6 g TSS m-3
OUR heterotrophs    =             0.0    28.7 g O2 m-3 h-1
OUR autotrophs      =             0.0    14.8 g O2 m-3 h-1
OUR total           =             0.0    43.5 g O2 m-3 h-1
Denit. rate         =             2.8     0.0 g NO3-N m-3 h-1
TKN                 =            12.6     6.1 g N m-3




                      ********** PROCESS CONFIGURATION **********

Gp 1. Number of Reactors: =  2

        Gp 2. Reactor Vols, l    Gp 3. Feed Fraction:     Gp 4. Aeration/DO:

No. 1:            10.00                  1.00                   Unaerated
No. 2:            10.00                  0.00                      2.0


Gp 5. Recycles:

    RAS recycle flow to Reactor No.1

    A recycle : Out of Reactor No.2                     Into Reactor No.1




                  **********  PLANT OPERATING PARAMETERS   **********

  1 Influent flow               l d-1           =            20.00
  2 RAS recycle flow            l d-1           =            20.00

  3 SRT (total)                d               =            10.00
  4 Process Temperature        degC            =            30.00

  5 A-recycle flow              l d-1           =            80.00
  6 Wastage rate flow           l d-1           =             2.00
```

```
***  STEADY STATE RESULTS *****                      Inversions = 6
OUND                 INPUT              REACTOR
                             1       2
(hetero.)        =     0.0 1336.9 1383.8 g COD m-3
(autotrophs)     =     0.0   71.4   72.2 g COD m-3
endog.)          =     0.0 1348.3 1354.1 g COD m-3
prt unb COD)     =   115.7 2313.1 2313.1 g COD m-3
 (adsorb.COD)    =     0.0  224.3  117.7 g COD m-3
 (enmesh COD)    =   460.3    8.6    3.9 g COD m-3
 (prt bio N)     =     3.2   12.0    8.2 g N m-3
(sol bio COD)    =   137.5    0.5    0.0 g COD m-3
ammonia N)       =    48.8    9.0    0.8 g N m-3
 (sol org N)     =     3.2    0.7    1.9 g N m-3
(nitrate N)      =     0.0    0.1    7.2 g N m-3
linity           =    10.0    7.2    6.1 mole m-3
(sol unb COD)    =    37.5   37.5   37.5 g COD m-3

tile SS          =         3582.9 3543.8 g VSS m-3
l SS             =         4777.1 4725.1 g TSS m-3
heterotrophs     =            0.0   29.7 g O2 m-3 h-1
autotrophs       =            0.0   15.9 g O2 m-3 h-1
total            =            0.0   45.6 g O2 m-3 h-1
.t. rate         =            3.0    0.1 g NO3-N m-3 h-1
                 =           11.6    4.7 g N m-3
```

```
          **********  PLANT OPERATING PARAMETERS  **********

nfluent flow              l d-1         =          20.00
AS recycle flow           l d-1         =          20.00
RT (total)                d             =          20.00
rocess Temperature        degC          =          20.00

-recycle flow             l d-1         =          80.00
astage rate flow          l d-1         =           1.00
```

```
 *****  STEADY STATE RESULTS *****                    Inversions = 6
OMPOUND                    INPUT          REACTOR
                                   1       2
bh (hetero.)        =        0.0 1054.6  1102.2 g COD m-3
ba (autotrophs)     =        0.0   62.6    63.4 g COD m-3
e (endog.)          =        0.0 1423.1  1429.2 g COD m-3
i (prt unb COD)     =      115.7 2313.1  2313.1 g COD m-3
ads (adsorb.COD)    =        0.0  120.7     9.9 g COD m-3
enm (enmesh COD)    =      460.3    7.9     3.6 g COD m-3
obp (prt bio N)     =        3.2    5.0     0.7 g N m-3
bs (sol bio COD)    =      137.5    0.2     0.0 g COD m-3
a (ammonia N)       =       48.8    9.3     1.3 g N m-3
obs (sol org N)     =        3.2    0.6     2.0 g N m-3
o3 (nitrate N)      =        0.0    0.0     7.2 g N m-3
lkalinity           =       10.0    7.2     6.1 mole m-3
us (sol unb COD)    =       37.5   37.5    37.5 g COD m-3

olatile SS          =             3366.2  3325.2 g VSS m-3
otal SS             =             4488.2  4433.6 g TSS m-3
UR heterotrophs     =                0.0    30.9 g O2 m-3 h-1
UR autotrophs       =                0.0    16.0 g O2 m-3 h-1
UR total            =                0.0    46.9 g O2 m-3 h-1
enit. rate          =                3.0     0.0 g NO3-N m-3 h-1
KN                  =               11.9     5.3 g N m-3




             **********  PLANT OPERATING PARAMETERS   **********

 1 Influent flow              l d-1          =          20.00
 2 RAS recycle flow           l d-1          =          20.00
 3 SRT (total)               d               =          20.00
 4 Process Temperature       degC            =          30.00

 5 A-recycle flow             l d-1          =          80.00
 6 Wastage rate flow          l d-1          =           1.00
```

```
********  WASTEWATER CHARACTERISTICS  ********

 Sti       (g COD m-3)           =  751.000
 Nti       (g N m-3)             =   65.000
 Pti       (g P m-3)             =   15.100
 Fbs       (g COD g-1 COD)       =    0.230
 Fac       (g COD g-1 COD)       =    0.100
 Fs,us     (g COD g-1 COD)       =    0.050
 Fs,up     (g COD g-1 COD)       =    0.154
 Fsup,P    (g COD g-1 COD)       =    0.014
 Fn,a      (g N g-1 N)           =    0.750
 Fnob,p    (g N g-1 N)           =    0.500
 Fn,ous    (g N g-1 N)           =    0.030
 Fs,zbh    (g Zbh COD g-1 COD)   =    0.000
 VSS/TSS   (g VSS g-1 TSS)       =    0.750
 Inf Alk   (mole m-3)            =   10.000




HETEROTROPH KINETIC DATA (Values at 20 degC)
***********************
 Mue max                    d-1                 =   2.500
 Ks COD             (Ksh)   g COD m-3           =   5.000
 B decay            (bh)    d-1                 =   0.620
 Neta (growth)                                  =   0.660
 Hydrolysis rate    (Kmp)   d-1                 =   1.350
 Ks hydrolysis      (Ksp)   g COD g-1 COD       =   0.027
 Ammonification     (Kr)    m3 g-1 COD d-1      =   0.032
 Adsorption rate    (Ka)    m3 g-1 COD d-1      =   0.032
 Conversion rate    (Kc)    m3 g-1 COD d-1      =   0.040


AUTOTROPH KINETIC DATA (Values at 20 degC)
**********************
 Mue max auto               d-1                    =    0.400
 Ks NH4+          (Ksa)     g N m-3                =    1.000
 B endogenous     (ba)      d-1                    =    0.040


POLYP ORGANISM KINETIC DATA (Values at 20 degC)
***************************
 Mue max (No P Limit)   d-1                     =   1.200
 Ks PHB  ( " )  (KsG1)  g COD m-3               =   0.180
 Mue max (P Limit)      d-1                     =   0.420
 Ks PHB  ( " )  (KsG2)  g COD m-3               =   0.180
 B decay        (bG)    d-1                     =   0.040
 PolyP Cleavage (bpp)   d-1                     =   0.030
 HAc Uptake rate (Kp)   d-1                     =   6.000


SWITCHING FUNCTION KINETIC DATA
*******************************
 Ks O2 Hetero     (Koh)   g O2 m-3              =   0.002
 Ks O2 Auto       (Koa)   g O2 m-3              =   0.002
 Ks O2 PolyP      (Kog)   g O2 m-3              =   0.002
 Ks Nh3           (Kha)   g N m-3               =   0.010
 Ks NO3           (Kno)   g N m-3               =   0.100
 Ks PO4           (Kps)   g P m-3               =   0.100
 Ks PolyP         (Kpp)   g P m-3               =   1.000
 Ks HAc           (Kac)   g COD m-3             =   1.000
```

```
ARRHENIUS TEMPERATURE CONSTANTS (THETAS ref 20 degC)
*******************************
 Mue max hetero                           =    1.200
 Ksh hetero                               =    1.000
 B  decay hetero                          =    1.029
 Kmp hydrolysis hetero                    =    1.080
 Ksp hydrol. half-sat.                    =    0.910
 Kr hetero                                =    1.029
 Ka hetero                                =    1.029
 Kc hetero                                =    1.029
 Mue max auto                             =    1.123
 Ksa auto                                 =    1.215
 B decay auto                             =    1.029
 Mue max polyP                            =    1.080
 Ks PHB polyP                             =    1.000
 B decay polyP                            =    1.029
 Bpp polyP                                =    1.029
 Kp polyP                                 =    1.029
```

```
HETEROTROPH STOICHIOMETRIC PARAMETERS
*************************************
Yield            (Yzh)     g COD g-1 COD  =    0.666
Frac inert part  (FEp,H)   g COD g-1 COD  =    0.080
Max ads/hetero   (fma)     g COD g-1 COD  =    1.000
N in biomass     (FZBH,N)  g N g-1 COD    =    0.068
N in endog       (FZEH,N)  g N g-1 COD    =    0.068
P in biomass     (FZBH,P)  g P g-1 COD    =    0.020
P in endog       (FZEH,P)  g P g-1 COD    =    0.020
COD:VSS ratio    (Fcv)     g COD g-1 VSS  =    1.480
```

```
AUTOTROPH STOICHIOMETRIC PARAMETERS
***********************************
Yield            (Yza)     g COD g-1 COD  =    0.150
Frac inert part  (FEp,H)   g COD g-1 COD  =    0.080
N in biomass     (FZBA,N)  g N g-1 COD    =    0.068
N in endog       (FZEA,N)  g N g-1 COD    =    0.068
P in biomass     (FZBA,P)  g P g-1 COD    =    0.020
P in endog       (FZEA,P)  g P g-1 COD    =    0.020
```

```
POLYP ORGANISM STOICHIOMETRIC PARAMETERS
****************************************
Yield            (Yzg)     g COD g-1 COD  =    0.666
Frac inert part  (FEp,G)   g COD g-1 COD  =    0.250
Frac inert sol   (FEs,G)   g COD g-1 COD  =    0.200
N in biomass     (FZBG,N)  g N g-1 COD    =    0.068
N in endog       (FZEG,N)  g N g-1 COD    =    0.068
N in inert sol   (FEsG,N)  g N g-1 COD    =    0.068
P in biomass     (FZBG,P)  g P g-1 COD    =    0.020
P in endog       (FZEG,P)  g P g-1 COD    =    0.020
P rel/HAc up     (Fp,rel)  g P g-1 COD    =    0.500
P up/PHB utiliz  (Fp,upt)  g P g-1 COD    =    0.750
```

```
***** STEADY STATE RESULTS *****                   Inversions = 12
COMPOUND                INPUT           REACTOR
                                   1       2       3
Zbh   (hetero.)         =     0.0   412.3   900.5   954.2 g COD m-3
Zba   (auto.)           =     0.0    18.6    37.5    38.7 g COD m-3
Zbg   (polyP org.)      =     0.0   223.4   449.5   463.5 g COD m-3
Ze    (endog. COD)      =     0.0   247.0   487.1   493.6 g COD m-3
Zi    (inert. COD)      =   115.7   627.4  1139.2  1139.2 g COD m-3
Sads  (adsorbed COD)    =     0.0   353.9   381.9   265.5 g COD m-3
Senm  (enmeshed COD)    =   460.3   109.5    11.8     5.1 g COD m-3
Sphb  (PHB  COD)        =     0.0    76.6    53.5    28.9 g COD m-3
Nobp  (prt bio N)       =     3.2    11.0    13.9    10.8 g N m-3
Ppp   (stored polyP)    =     0.0     9.0    70.3    87.3 g P m-3
Sbs,c  (compl.RBCOD)    =   123.7    17.8     0.3     0.0 g COD m-3
Sbs,a  (SCFA RBCOD)     =    13.7     0.4     0.0     0.0 g COD m-3
Na     (ammonia N)      =    48.8    32.9    14.4     2.4 g N m-3
Nobs   (sol org N)      =     3.2     0.7     0.9     1.8 g N m-3
No3    (nitrate N)      =     0.0     0.0     0.1     9.1 g N m-3
Ps     (soluble P)      =    13.5    43.2    19.2     0.7 g P m-3
Sus    (sol unb COD)    =    37.5    39.4    40.7    41.2 g COD m-3
Alkalinity              =    10.0     9.0     7.8     6.4 mole m-3
Volatile SS             =          1272.0  2294.4  2266.7 g VSS m-3
OUR carbonaceous        =             0.0     0.0    24.5 g O2 m-3 h-1
OUR autotrophs          =             0.0     0.0    13.4 g O2 m-3 h-1
OUR total               =             0.0     0.0    37.9 g O2 m-3 h-1
Denit. rate             =             0.0     3.2     0.0 g NO3-N m-3 h-1
```

```
          **********  PLANT OPERATING PARAMETERS   **********

 1 Influent flow              l d-1          =          20.00
 2 RAS recycle flow           l d-1          =          20.00
 3 SRT (total)               d               =          10.00
 4 Process Temperature       degC            =          20.00

 5 A-recycle flow             l d-1          =          40.00
 5 B-recycle flow             l d-1          =          20.00
 6 Wastage rate flow          l d-1          =           2.03
```

```
  *****  STEADY STATE RESULTS                   Inversions = 13
COMPOUND                   INPUT           REACTOR
                                      1       2       3
Zbh   (hetero.)       =      0.0   341.7   767.6   824.8 g COD m-3
Zba   (auto.)         =      0.0    17.8    35.9    37.0 g COD m-3
Zbg   (polyP org.)    =      0.0   211.1   425.6   439.6 g COD m-3
Ze    (endog. COD)    =      0.0   283.9   560.1   567.7 g COD m-3
Zi    (inert. COD)    =    115.7   627.4  1139.2  1139.2 g COD m-3
Sads  (adsorbed COD)  =      0.0   267.1   141.3     9.7 g COD m-3
Senm  (enmeshed COD)  =    460.3    77.6     6.9     3.6 g COD m-3
Sphb  (PHB  COD)      =      0.0    69.6    37.0    11.6 g COD m-3
Nobp  (prt bio N)     =      3.2     6.6     4.5     0.4 g N m-3
Ppp   (stored polyP)  =      0.0     7.7    69.3    87.0 g P m-3
Sbs,c (compl.RBCOD)   =    123.7    16.5     0.1     0.0 g COD m-3
Sbs,a (SCFA RBCOD)    =     13.7     0.3     0.0     0.0 g COD m-3
Na    (ammonia N)     =     48.8    32.8    14.2     2.2 g N m-3
Nobs  (sol org N)     =      3.2     0.6     0.8     1.9 g N m-3
No3   (nitrate N)     =      0.0     0.0     0.0     9.5 g N m-3
Ps    (soluble P)     =     13.5    44.6    20.1     0.8 g P m-3
Sus   (sol unb COD)   =     37.5    39.9    41.6    42.2 g COD m-3
Alkalinity            =     10.0     9.0     7.8     6.3 mole m-3
Volatile SS           =           1181.8  2074.1  2039.2 g VSS m-3
OUR carbonaceous      =              0.0     0.0    27.1 g O2 m-3 h-1
OUR autotrophs        =              0.0     0.0    14.0 g O2 m-3 h-1
OUR total             =              0.0     0.0    41.1 g O2 m-3 h-1
Denit. rate           =              0.0     3.4     0.0 g NO3-N m-3 h-1
```

```
                  ********** PROCESS CONFIGURATION **********

Gp 1. Number of Reactors: =  3

        Gp 2. Reactor Vols, l    Gp 3. Feed Fraction:     Gp 4. Aeration/DO:

No. 1:              6.00                1.00                   Unaerated
No. 2:              7.00                0.00                   Unaerated
No. 3:             10.00                0.00                      2.0


Gp 5. Recycles:

    RAS recycle flow to Reactor No.2

    A recycle : Out of Reactor No.3         B recycle : Out of Reactor No.2
                Into Reactor No.2                       Into Reactor No.1
```

```
               **********  PLANT OPERATING PARAMETERS   **********

  1 Influent flow              l d-1        =         20.00
  2 RAS recycle flow           l d-1        =         20.00
  3 SRT (total)               d             =         10.00
  4 Process Temperature       degC          =         30.00

  5 A-recycle flow             l d-1        =         40.00
  5 B-recycle flow             l d-1        =         20.00
  6 Wastage rate flow          l d-1        =          2.03
```

```
*****  STEADY STATE RESULTS *****              Inversions = 13
)MPOUND                  INPUT          REACTOR
                                     1      2      3
)h   (hetero.)       =     0.0   512.2 1118.8 1174.9 g COD m-3
)a   (auto.)         =     0.0    33.4   67.3   68.5 g COD m-3
)g   (polyP org.)    =     0.0   378.4  761.3  774.8 g COD m-3
e    (endog. COD)    =     0.0   636.2 1263.5 1271.8 g COD m-3
.    (inert. COD)    =   115.7  1205.7 2295.7 2295.7 g COD m-3
-ds  (adsorbed COD)  =     0.0   345.1  238.8  104.6 g COD m-3
enm  (enmeshed COD)  =   460.3    53.0    6.1    3.8 g COD m-3
)hb  (PHB  COD)      =     0.0    78.4   51.6   25.3 g COD m-3
)bp  (prt bio N)     =     3.2     9.1    8.8    4.7 g N m-3
)p   (stored polyP)  =     0.0    34.0  124.9  143.6 g P m-3
)s,c (compl.RBCOD)   =   123.7    15.1    0.2    0.0 g COD m-3
)s,a (SCFA RBCOD)    =    13.7     0.2    0.0    0.0 g COD m-3
a     (ammonia N)    =    48.8    32.5   13.3    0.8 g N m-3
)bs   (sol org N)    =     3.2     0.6    0.9    1.9 g N m-3
)3    (nitrate N)    =     0.0     0.0    0.1   10.2 g N m-3
s     (soluble P)    =    13.5    47.6   23.2    2.9 g P m-3
1s    (sol unb COD)  =    37.5    40.7   42.9   43.7 g COD m-3
-lkalinity           =    10.0     9.0    7.7    6.2 mole m-3
)latile SS           =          2102.0 3882.0 3844.8 g VSS m-3
JR carbonaceous      =             0.0    0.0   28.2 g O2 m-3 h-1
JR autotrophs        =             0.0    0.0   15.1 g O2 m-3 h-1
JR total             =             0.0    0.0   43.3 g O2 m-3 h-1
enit. rate           =             0.0    3.6    0.1 g NO3-N m-3 h-1
```

```
              **********  PLANT OPERATING PARAMETERS  **********

1 Influent flow             l d-1          =          20.00
2 RAS recycle flow          l d-1          =          20.00
3 SRT (total)              d               =          20.00
4 Process Temperature      degC            =          20.00

5 A-recycle flow            l d-1          =          40.00
5 B-recycle flow            l d-1          =          20.00
6 Wastage rate flow         l d-1          =           1.01
```

```
 *****  STEADY STATE RESULTS *****                 Inversions = 14
COMPOUND                INPUT          REACTOR
                                    1      2      3
Zbh  (hetero.)        =     0.0  395.1  887.4  944.2 g COD m-3
Zba  (auto.)          =     0.0   29.2   59.0   60.1 g COD m-3
Zbg  (polyP org.)     =     0.0  331.8  668.8  681.8 g COD m-3
Ze   (endog. COD)     =     0.0  682.2 1355.2 1364.1 g COD m-3
Zi   (inert. COD)     =   115.7 1205.7 2295.7 2295.7 g COD m-3
Sads (adsorbed COD)   =     0.0  291.7  147.1    8.4 g COD m-3
Senm (enmeshed COD)   =   460.3   62.2    6.0    3.5 g COD m-3
Sphb (PHB  COD)       =     0.0   71.5   37.2   10.8 g COD m-3
Nobp (prt bio N)      =     3.2    7.3    5.0    0.4 g N m-3
Ppp  (stored polyP)   =     0.0   21.2  100.0  118.8 g P m-3
Sbs,c (compl.RBCOD)   =   123.7   14.8    0.1    0.0 g COD m-3
Sbs,a (SCFA RBCOD)    =    13.7    0.2    0.0    0.0 g COD m-3
Na    (ammonia N)     =    48.8   32.6   13.6    1.4 g N m-3
Nobs  (sol org N)     =     3.2    0.6    0.8    1.9 g N m-3
No3   (nitrate N)     =     0.0    0.0    0.0   10.3 g N m-3
Ps    (soluble P)     =    13.5   48.9   24.8    4.4 g P m-3
Sus   (sol unb COD)   =    37.5   41.2   43.8   44.7 g COD m-3
Alkalinity            =    10.0    9.0    7.7    6.2 mole m-3
Volatile SS           =         1983.5 3657.6 3617.8 g VSS m-3
OUR carbonaceous      =            0.0    0.0   29.5 g O2 m-3 h-1
OUR autotrophs        =            0.0    0.0   15.2 g O2 m-3 h-1
OUR total             =            0.0    0.0   44.7 g O2 m-3 h-1
Denit. rate           =            0.0    3.6    0.0 g NO3-N m-3 h-1
```

```
                ***********  PLANT OPERATING PARAMETERS  **********

  1 Influent flow              l d-1        =          20.00
  2 RAS recycle flow           l d-1        =          20.00
  3 SRT (total)               d             =          20.00
  4 Process Temperature       degC          =          30.00

  5 A-recycle flow             l d-1        =          40.00
  5 B-recycle flow             l d-1        =          20.00
  6 Wastage rate flow          l d-1        =           1.01
```

APPENDIX E

EXPERIMENTAL APPARATUS MAKING UP THE MLE AND UCT SYSTEMS

E.1 Introduction

A description of the apparatus making up the MLE and UCT systems used in this research is given in this appendix. Items covered are:

i. the typical design of a completely mixed reactor,
ii. a more detailed description of each reactor,
iii. the setting tank,
iv. general layout,
v. pump and tubing, and
vi. feed container.

The systems as are shown schematically in Fig E.1a MLE system and Fig.1b UCT system The anaerobic, anoxic and aerobic reactors were completely mixed, general description of the make-up of a completely mixed reactor is now covered, after which each reactor is dealt with in more detail.

E.2 Typical reactor design

Schematic drawings of the anaerobic/anoxic and aerobic reactors are given in fig E.2. Each reactor was made of perspex tube with diameters an doperating volumes as follows: MLE system: anoxic reactor – 195mm diameter and 10*l* volume; aerobic reactor 195mm diameter and 10*l* volume – 180mm diameter and 7*l* volume; aerobic reactor – 195mm diameter and 10*l* volume. A flat perspex disc formed the base of each vessel. The inlet and outlet ports were formed by drilling into the base two 10mm diameter holes over which short lengths of perspex tube were glued. The outlet port was connected to an inverted U-tube, the height of which was used to control the liquid in the reactor. Each vessel was also fitted with two vertical perspex baffles, glued opposite eaxh other to the inside walls. Theses baffles improved mixing and prevented the formation of a vortex on the liquid surface.

The top of each reactor was covered with a perspex lid on which was mounted a stirrer motor. This brushless 115 V AC motor had an output of 30 rpm and drove a stainless steel shaft with perspex paddles to keep the reactor contents thoroughly mixed but without creating surface turbulence. The reactor lid had a 40mm diameter access port for cleaning, taking samples and inserting pH and oxygen probes. If the reactor was anaerobic or anoxic, when not in use the port was sealed with a rubber bung. For such reactors, a Styrofoam disc was also floated on the surface to prevent oxygen from dissolving, the stirrer shaft passing through the disc.

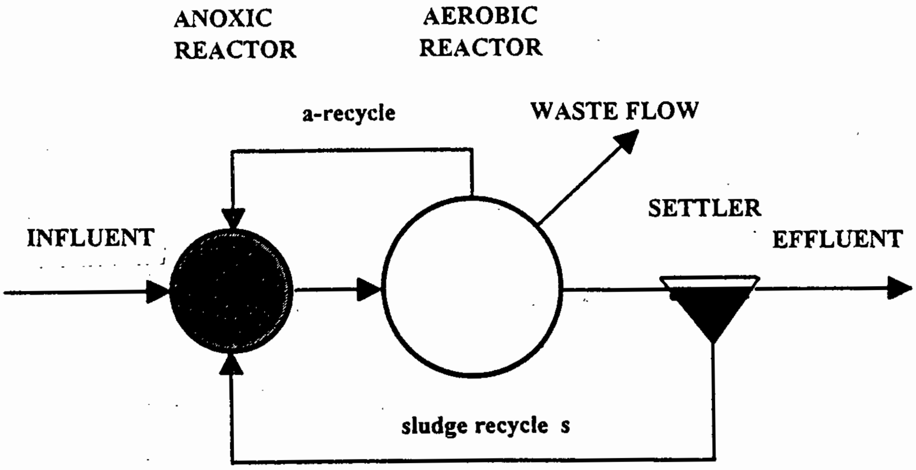


Fig E.1a. Schematic layout of the Modified Ludzack-Ettinger (MLE) system.

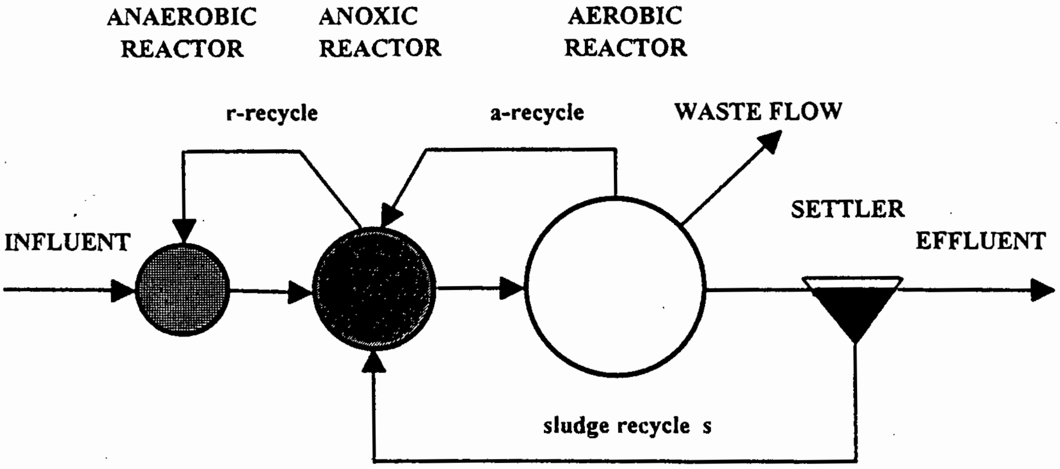


Fig E.1b Schematic layout of the UNIVERSITY OF CAPE TOWN (UCT) system.

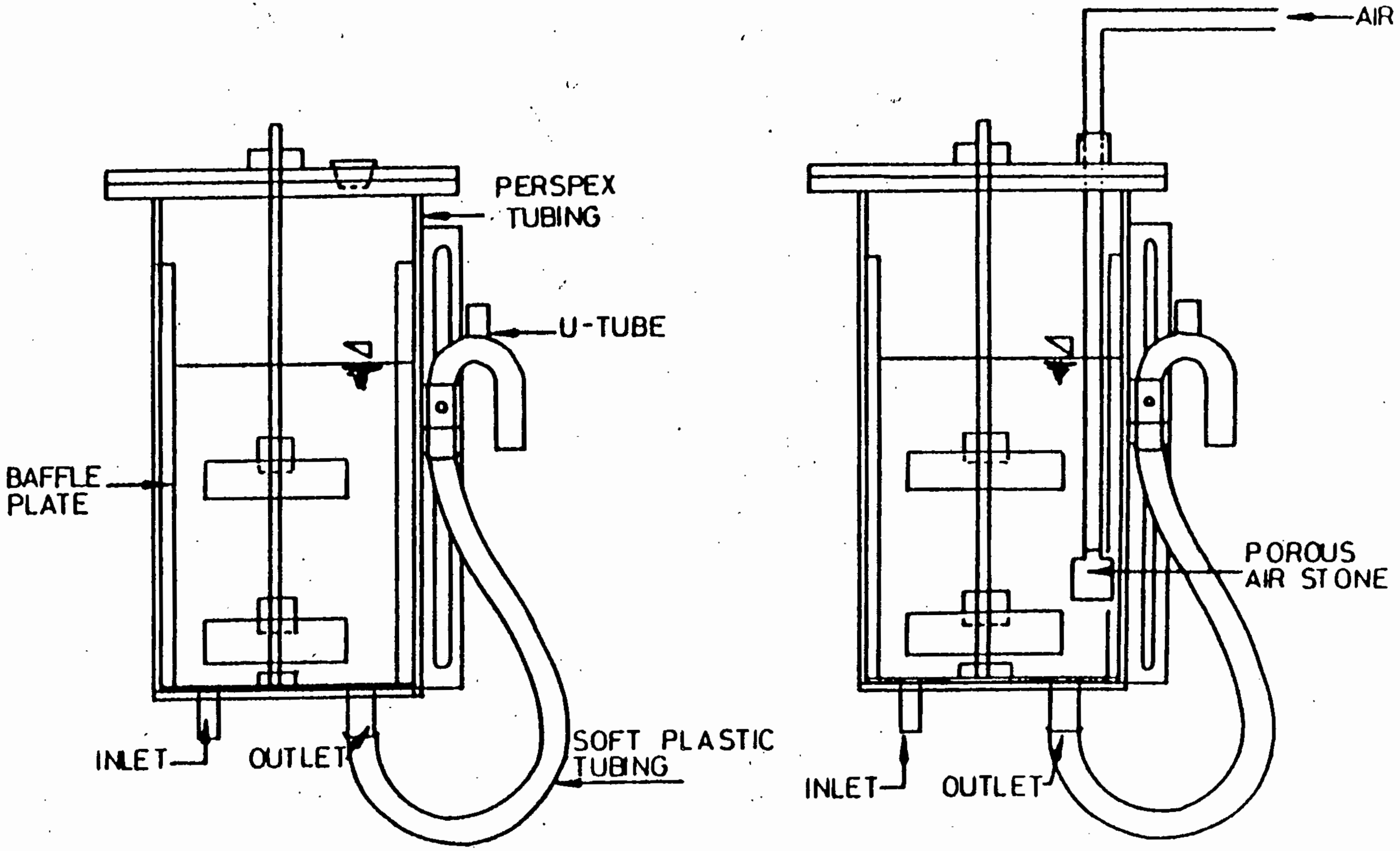


Fig E.2 Details of consruction of the anaerobic/anoxic and aerobic reactors

E.3 Anaerobic reactor

The purpose of the anaerobic reactor (in this investigation only UCT system has anaerobic reactor) was to allow P release to take place as described in Chapter X. It received the influent flow of raw sewage to the system (20*l*/d) as well as the r-recycle from anoxic reactor. The anaerobic reactor was operated at a volume of 6litre and was painted black to prevent light from entering – light encourages algae growth on the inside of the reactor walls.

E.4 Anoxic reactor

The anoxic reactor was completely mixed and was operated at a volumes of 10*l* for MLE and 7*l* for UCT systems respectively. In MLE system influent sewage entered to the anoxic reactor while in UCT system to the anaerobic reactor. These both systems received a recycle stream from the aerobic reactor. The anoxic reactor's purpose was to remove the nitrate load imposed on it via the a recycle and the nitrate load via sludge recycle; s-recycle.

E.5 Aeration reactor

Completely mixed reactor was filled to 10*l* in both systems and a constant stream of air was bubbled through it. Aeration was through a porous stone (of the type normally used in fish tanks) attached to the end of a perspex tube passing through the top cover. The airstone was positioned close to the bottom of the reactor, well out of line of the paddles. Air was supplied via a low pressure line from a large compressor, the airstream being controlled by a fine needle valve. The dissolved oxygen concentration was maintained between two and four mgO/*l* to ensure nitrification while limiting the oxygen entering the anoxic zone via the a-recycle. The overflow from the aerobic flowed into the settling tank.

E.6 Settling tank

The settling tank was constructed from 80mm diameter perspex tube, as shown in Fig E.3. It was mounted on a wooden holder and set at an angle of 60° to the horizontal. The mixed liquor inlet and the underflow recycle outlet were located opposite each other at the bottom of the settler and were set at 90° to each other. The effluent outlet was located near the top of the settler tube.

To prevent sludge from adhering to the sides and bottom of the settler and to prevent the sludge from settling in a solid mass, two wiper blades were attached to a central shaft to sweep the sides and bottom of the tank. The central shaft was driven at 1,33 rpm by a 220V AC electric motor that was controlled by a timer, allowing the shaft to rotate one revolution every 3 minutes.

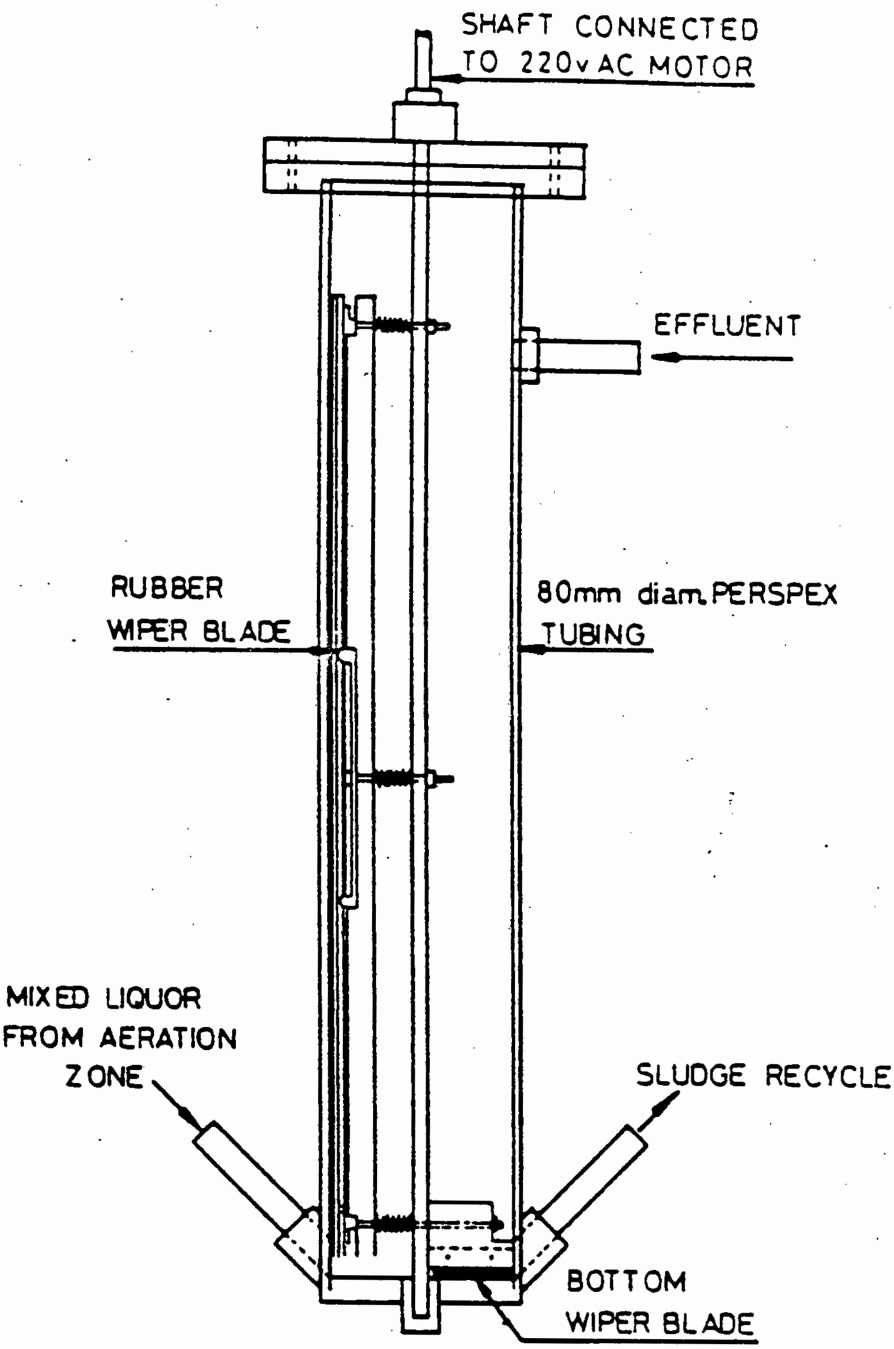


Fig E.3 Details of the construction of the settling tank.

E.7 General layout

The reactors were mounted on a vertical board, each reactor being set with its overflow point than that of the receiving reactor being set with its overflow point higher than that of the receiving reactor so that reactors discharged under gravity from one to the other. The flow through reactors was driven by the same pump as used for the recycles and the feed to the systems. Beneath the whole system, a shallow metal tray was installed to collect and retain any sludge spilled due to blockages, split pipes or broken connections. Spilled sludge was returned to the unit. The both MLE and UCT systems were run in a "hot room" controlled at a temperature of 30°C.

E.8 Pump and tubing

The pumps used for feeding the systems, as well as for the recycles, were of the peristaltic variety developed by the Civil Engineering Workshop at the University of Cape Town. The pumps had eight channels, each calibrated to pump 20*l*/d. The flow rate in a channel could be adjusted by varying the tension of the pump tubing in that particular channel and once the tension was set, the flow remained constant for a considerable time. Pumps tubings were replaced every two months to avoid sludge spillage through perished tubes. The 0,5 kW brushless 115V AC motors driving the peristaltic pumps were extremely reliable and required little maintenance. The pumps connected to an on/off timer thus enabling the daily low rates to be set very accurately.

The tubings used to connect the various reactors were of soft transparent plastic of the type used in hospitals. By using soft plastic, wall growths could easily be dislodged by periodical squeezing and tapping of the tubing. The tube lengths between reactors were kept as short as possible to prevent excess reaction time outside the vessels themselves. Tube diameters were small (10mm or less) to maintain high flow velocities thereby minimising the settlement of solids.

E.9 Feed container

The daily sewage feeds for the systems were stored in an upright length of 310mm diameter PVC tubings with flat base glued to them. The outlets were located in the centre of the bases in order that no sewage or solids remained behind at the end of the feed period. The feed buckets had a maximum capacity of 35*l* and theg contents were kept completely mixed by a 10 rpm motors mounted on a cross-member resting on top of the containers. A flat-bladed paddles were used for mixing, of a size just large enough to keep the solids in the sewage in suspension without causing turbulence on the surface that might have resulted in air being drawn into feed. The containers were placed in a large chest refrigerator at a temperature of 5 – 8 °C to minimise biological degradation of the sewage.

APPENDIX F

PROCEDURES FOR THE OPERATION, SAMPLING AND TESTING OF THE MLE AND UCT SYSTEMS

F.1 Introduction

This appendix describes the methods employed for the operation, sampling and testing of the MLE and UCT systems used in the investigation. The procedures covered are: (MLE and UCT)

i. sewage collection and storage.
ii. feed preparation for the activated sludge unit.
iii. General system operation and maintenance.
iv. sampling from each reactor.
v. testing performed on samples from the MLS and UCT systems.

F.2 Sewage collection and storage

The wastewater source for the activated sludge MLE and UCT systems was raw sewage for the Mitchell's Plain sewage works near Cape Town. The wastewater was primarily of domestic origin with a very small industrial component. The TKN and COD levels of the sewage varied throughout the day, a high TKN/COD ratio of up to 0,185mgTKN /mgCOD normally being reached at mid-morning and a low ratio of 0,075 mgTKN/mgCOD in the mid-afternoon. Such extreme ratios are not suitable for steady state investigation in the MLE and UCT systems; consequently the wastewater was collected between 12h00 and 14h00 when the COD was approximately 1000mgCOD/*l* and the TKN about 90 – 100mgN/.

The raw sewage was collected from a manhole upstream of WWTP and was transferred by a 1m^3 tanker batches via a centrifugal pump. Wastewater was collected every 10 to 20 days since experience has shown that storage of the sewage for periods longer than this led to H_2S build-up which has a detrimental effect on the P removal capability of the activated sludge unit. After each collection, the tanker was thoroughly cleaned to remove all traces of sewages that may serve as an innoculum of H_2S organisms in the next batch of sewage.

At the laboratory, the sewage was gravitated from the tanker through a macerator into three 400*l* stainless steel vessels in a cold room at 4°C. The macerator shredded the large organic solids and this minimised blockages of the laboratory scale pumps and pipelines by sewage particles. During the drum filling operation, the contents of the tanker were violently agitated by compressed air for thorough mixing.

organic solids and this minimised blockages of the laboratory scale pumps and pipelines by sewage particles. During the drum filling operation, the contents of the tanker were violently agitated by compressed air for thorough mixing.

With each new batch of sewage, the COD and TKN concentrations were measured. This enabled the daily feed to the activated sludge unit to be diluted approximately. The average daily influent feed was diluted to approximately 1000 mgCOD/*l* whilst the influent TKN varied between 80 and 110 mgN/*l* (according to the TKN/COD ratio of the sewage batch).

F.3 Feed preparation for the activated sludge unit

At a set time each day, the feed containers were filled with the daily batch volume of sewage 20*l* per system for the ensuing 24-hour period. Towards the end of the feed period, the sewage often contained an abnormal amount of particulate material that had settled out over the 24 hours (despite the continuos stirring of the feed). On occasion, the feed ran out slightly before the end of the 24hr period, in which case air bubbles would have been present in the feed line. For these reasons, the feeding was set at 10 AM, well away from the unit sampling and testing period: samples were taken and tested each morning at 07h00, at which time a reasonable amount of sewage was left in the feed container.

Before the batches of sewage were taken from a storage tank, the contents of the tank were thoroughly mixed with a large wooden disc fixed at right angles to a long steel rod. Keeping the disc parallel to the bottom of the tank, mixing was achieved by rapidly moving the rod up and down. A set volume of wastewater (30*l*) was then drawn off from a tap at the base of the tank and passed through a sieve into a graduated 40*l* plastic bucket. The sieve captured the larger sewage particles that would block the pumps and pipes in the activated sludge units – particles that could be broken up were rubbed through the sieve, the rest discarded. The required COD concentration (750 mgCOD/*l*) was attained by addition of a calculated amount of tap water.

Further adjustments to the wastewater that needed to be made were those of pH value. The pH of the systems was controlled by monitoring the pH in the aerobic reactors. This was kept between 7,5 and 8,10 by adding 1,5 level teaspoon of sodium bicarbonate to 40*l* of total for the both systems.

After the above additions, the feed solution was thoroughly mixed with a hand-held wooden rod and a 200ml sample taken in a small plastic jar with a screw top lid. Two drops of 8,6-g/*l* mercuric chloride solution were added to the sample to halt all bacterial action, after which it was stored in the 4°C refrigerator for analysis the following day. The sewage mixture was then added to the daily feed containers. Each day, after the feeds were depleted, the feed containers and stirrer were thoroughly rinsed with hot water.

F.4 Continously fed system operation and maintenance

Each day, other than feeding, various procedures had to be carried out to ensure smooth operation of the MLE and UCT systems. These procedures included control of sludge age, dislodged pipe blockages and wall growths and generally checking for broken connections or mechanical disorders.

F.4.1 Control of sludge age

The sludge age (R_S) was set by 'hydraulic control'. This involved discarding a fraction $1/R_S$ of the *effective* volume of the mixed liquor in the systems each day. The effective volume was that volumes which contained all the system sludge masses at the concentration in the aerobic reactors. The only reactor not having the same MLSS concentration as the aerobic reactor was the anaerobic reactor – in the UCT system with a r-recycle of 1:1, the anaerobic reactor has an MLSS concentration half that of the aerobic reactor and consequently half its volume (for the system used) of 20*l*. The sludge age was set at 10 days for the both MLE and UCT systems hence 2*l* of mixed liquor was discarded each day from each systems. The effective volumes of the mixed liquor required for testing (see later) was normally 650ml for MLE and 675ml for UCT system, hence 1350ml and 1325ml were wasted from the aerobic reactors of these systems respectively each day.

F.4.2 Cleaning

The liquid levels in each reactor needed to be checked every day to make sure the vessels were filled to their correct operating volumes. Occasionally, attached growths caused blockage of reactor inlet or outlet ports or connecting piping – an abnormal reactor liquid level often was an indication of this. Removing the blockage was achieved by squeezing and tapping the plastic tubing. Growths adhering to the inside of the reactor walls were removed by regular brushing (about twice per day). Approximately every five to six weeks the both units were dismantled completely and cleaned with hot water and sodium hypochlorite solution to remove the build-up of attached growths in both the pipes and reactors. While this was being done, the mixed liquors from the systems was kept aerated in open plastic buckets.

F.4.3 General maintenance

Other maintenance procedures consisted of checking for loose pipes connections, perished or split peristaltic pump tubes, dealing with mechanical breakdown.
Since the sludge age of the systems was kept at a fixed value by wasting a certain amount of sludge each day, any accidental loss of sludge altered the sludge age from the desired value. Because of this, a careful lookout was kept for loose pipe connections and pump tubes where sludge could escape. Peristaltic pump tubes needed to be replaced every two months – if these did split, not only did spillage of sludge result, but leakage of the sludge into pump could result in an electrical short and an associated fire hazard.

Fortunately, the brushless motors of the peristaltic pumps were relatively maintenance-free and a disruption of the unit's steady state operation due to a mechanical failure of the pumps was very seldom.

Now that the feeding, operation and maintenance of the continuously fed MLE and UCT systems have been dealt with, the sampling and testing procedures are described.

F.5 Sampling from the MLE and UCT systems

F.5.1 Effluent and completely mixed reactor sampling

Sampling from the units commenced with the systems effluents which collected in a 20*l* open bucket. After thoroughly mixing the contents of the bucket, a 200ml sample was taken and filtered through Whatman's No.1 filter paper, after which two drops of mercuric chloride were added.

Sampling then proceeded to the aerobic reactor, anoxic reactor and finally the anaerobic reactor (in UCT system only), in that order. In this way, none of the system contents upstream of the particular sample were distributed by the sample 50ml mixed liquor samples were pipetted from the chloride were added and the samples were then stored with the effluent and reactor samples at 4°C until testing.

F.6 Testing performed on the MLE and UCT systems

The influent and effluent samples, as well as those taken from each reactor of the systems were stored at 4°C and tested for the parameters listed in Table F.1. Samples to be analysed for COD and TKN were normally tested on the same day or on the day after they were taken. Samples to be analysed for phosphorus and nitrate were stored for two to three days before analysis (these concentrations wrer determined via methods allowing a large number of samples to be tested simultaneously).

Table F.1 Collected sample position and parameter measurement.

Test	Influent	Anaerobic	Anoxic	Aerobic	Effluent
COD	•			•	• O
TKN	•			•	• O
NH_3	•				O
NO_3		∅	∅	∅	O
Total P	•	∅	∅	∅	• O
pH				*	
OUR				*	
VSS				*	
TSS				*	
DSVI				*	

•	Unfiltered sample
O	Sample filtered through prefilter glass fiber- GF50
∅	Sample centrifuged and filtered through glass fiber- GF50
*	Measurement taken

The method for analysing of COD, TKN and MLVSS were obtained from "Standard Methods for the Examination of Water and Wastewater", 16th Edition (1985). Nitrate and nitrite concentrations were measured on an Auto-analyser in accordance with the Industrial Methods 33,68 and 35,69 W test techniques as set out in the Technician Auto-analyser methodology. Mixed liquors pH were measured in the aerobic reactors via a Radiometer type 80 pH meter. Dissolved oxygen was monitored with a Yellow Springs Instrumnet Co. probes connected to HiTec DO meter concentration being kept at 3mgO/*l*. The procedure for measuring the toatal phosphate concentration involved converting all the phosphorus to the orthophosphate form. This is described below.

Procedure for determining the total P concentration in a sample

Equipment	
Glass boiling tubes	(150mm x 25mm)
20ml test tubes	(150mm x 15mm)
100°C water bath	
Spectrophotometer	(operated at 470mm)

Reagents

1) Sulphuric Acid
   6,1ml concentrated H_2SO_4 in 1litre distilled water

2) Potassiun persulphate solution:
   3g $K_2\ (SO_4)_2$ in 100ml distilled water.
   Make up fresh solution daily

3) Colour reagent
   40g ammonium molybdate
   2g ammonium vanadate
   Dissolve in about 1*l* de-ionized water. Add 280ml concentrtaed nitric acid and make up to 2liter with de-ionized water.

Method

1) Filter through Whatman's No.1 filter paper.
2) Add 20ml filtrate to boiling tube (or 10ml filtrate and 10ml de-ionized water).
3) Add 5ml H_2SO_4 solution to boiling tube.
4) Add 5ml potassium persulphate solution to boiling tube.
5) Repeat 2 to 4 for standards.
6) Cover tubes with foil.
7) Place in hot water bath for 1 hour at 100°C.
8) Remove tubes, cool and filter contents through Whatman's No.1 filter paper.
9) Add 5ml of colour reagent to 5ml of filtrate.
10) Read absorbence on spectrophometer.
11) From a plot of the phosphate concentrations of the standards versus their spectrophotometer readings, the various phosphate concentrations of the samples may be determined.

F.7 Sludge settleability

The DSVI test was used in this investigation as a measure of the sludge settleability. It is more consistent than the SVI test (Lee *et al.*,1983) and the exact procedure is set out by Stobbe (1964).

APPENDIX G

EQUIPMENT AND PROCEDURES EMPLOYED IN THE BATCH TEST EXPERIMENT.

G.1 INTRODUCTION

This appendix describes the equipment and procedures for:

SET I: Aerobic batch tests to establish:
- (a) Nitrification behaviour (μ_{max} of nitrifiers) in the aerobic zones of the MLE and UCT systems.
- (b) Additional P uptake behaviour in the aerobic zone of the UCT system.

SET II: Anoxic batch tests to establish:
- (a) Denitrification behaviour (K_1, K_2 and K_2' rates) in the anoxic zones of the MLE and UCT systems.
- (b) P uptake behaviour in the anoxic zone of the UCT system.

SET III: Anaerobic batchs tests to establish:
- (a) P release behaviour in the anaerobic zone of the UCT system with addition of raw sewage.
- (b) P release behaviour in the anaerobic zone of the UCT system with addition of acetate.
- (c) Extra P release behaviour in the anaerobic zone of the UCT system with addition of acetate.

G.2 EQUIPMENT USED FOR BATCH TEST EXPERIMENTS

Batch tests were done in reactors identical to some of the reactors used in the laboratory scale activated sludge systems (see Fig E.2). Reactors were selected that have a volume of about *3l*, diameter 120mm. The inlet and outlet ports were sealed off, the contents poured into the vessel through the access port in the cover of the reactor at the start of the tests. As in the continnously-fed unit, the reactor contents in the batch tests were stirred with a motor-driven paddle. In the anoxic and anaerobic batch tests the surface of the batch liquid was covered by plastic chips to prevent air entering the liquid.

Aeration in the aerobic batch tests, for OUR measurement, was automatically monitored by a Yellow Springs Instrument Co. oxygen probe with the HiTech DO instrument box. The DO concentration in the batch reactor was controlled by intermittant (on-off) aeration the DO instrument automatically recording and storing the DO data during the off period with the time and automatically determines the OUR. At the the beginning of the tests the DO range was set of 2.0 to 4.5mgO/*l*.

Table G.1 Frequency of sampling in different SETs of batch tests.

Time (min)	SET I to III Sample No	SET I(a) for MLE Sample No
0	1	1
5	-	2
10	2	3
15	-	4
20	3	5
30	4	6
40	5	7
50	6	8
60	7	9
75	8	10
90	9	11
120	10	12
150	11	13
210	12	14
270	13	15
330	14	16

G.3 EXPERIMENTAL PROCEDURE FOR SETS OF I(a) AND I(b) (Nitrification)

Test sets I (a) and I (b) were carried out comcomitantly in the same batch reactor.Batch tests in SET I (a) were designed to determine nitrification in aerobic reactors of the MLE and UCT systems. Both sets in SET I (b) was designed to determine additional P uptake in the aerobic zone in the UCT system. (Additionally because some uptake took place in the anoxic reactor).
Total volumes of 3*l* of mixed liquor were drawn from anoxic reactors of the both systems, and tranferred to the batch reactors as quickly as possible. Because test conditions were to be reproduced, the next step was to ensure that during the batch tests there were sufficient ammonia concentration in the batch reactors (SET I), and sufficient phosphorus in batch reactor SET I (b) procedure. Usually the initial concentrations of FSA and P were not enough, the batches were supplemented with FSA by adding 50ml of 1000ppm FSA (NH_4Cl) solution to the 3*l* batch reactors to ensure a starting FSA concentration of about 40mg N/*l*. Simultaneously 5ml of 3000ppm phosphate (K_2HPO_4) solution was added to the 3*l* batch reactor SET I (b) procedure, to ensure a starting concentration of about 25mg P/*l*.
Once the initial test conditions had been established sampling commenced. Samples (50ml) were pipetted out of the batch reactors. Immeditely after first samples were taken, the aeration in the batch reactors were switched on. Aeration was monitored automatically, as stated in G.2 above.

All the samples were immediately vacuumed filtered through Whatman's GF filter paper after which two drops of 8.6g/*l*HgCl was added to the filtrated to stop all biological action. Usually the samples were stored overnight in the cold room (+4°C).

The following day the nitrogen samples were analyzed for NH_3-N, NO_3-N, NO_2-N and phosphorus samples for total P. For the nitrification tests the VSS cocentrations were determined in the first and last samples from the both reactors.Frequency of sampling in a batch test is given Table G.1.
During aerobic batch tests it was important to monitor and controll the pH of the mixed liquor, and, if necessary add 1/4 tee spoonfull of $NaHCO_3$ to maintain the pH between 7.0 and 8.0. A pH that was too high for an extended period could give rise to phosphate precipitation; a pH that was too low could inhibit nitrification. After the last samples had been taken, the OUR values and associated batch times were down loaded from the HiTech DO instrument boxes.

G.4 EXPERIMENTAL PROCEDURE FOR SETS OF II(a) AND II(b) (Denitrification, P uptake)

Tests sets II (a) and II(b) were carried out usually at the same time.Batch tests in SET II(a) were to determine denitrification rates in anoxic reactors of the MLE and UCT systems. The tests in II(b) was to determine possible P uptake in the anoxic reactor in the UCT system.
In SET II(a) a mixed liquor sample of 1,5*l* was drawn from the aerobic reactor of each of the MLE and UCT systems (Table G.2), and tranferred to batch reactors as quickly as possible. The samples then were stripped of any oxygen that may have been introduced during the transfer of mixed liquor from the system to the batch reactor, but mostly was present in the aerobic reactor mixed liquor, when it was sampled. Oxygen was stripped by bubbling nitrogen gas through the batch reactors, while the contents was stirred with a motor-driven paddle. The DO was monitored by a Yellow Spring Instrument Co oxygen probe and HiTech instrument box, as discussed in Section G.2. It was important that the DO meter was accurately zeroed and calibrated since even a low concentration of DO inhibits denitrification. In all the systems SET II(a) batches it was necessary to ensure that sufficient NO_3 was present so that NO_3 did not decrease to zero in the anoxic tests. Usually the initial concentrations of nitrate was not enough, and the batche was supplemented with NO_3 by adding 40ml of 2000ppm NO_3 ($NaNO_3$) solution. To reproduce the conditions in anoxic zones of the MLE and UCT systems in the test: On the MLE mixed liquor raw sewage was diluted to give approximate 750mgCOD/*l*, was preheated to 30°C and 1.5*l* was added to the MLE batch of 1.5*l*, to give a total volume of 3*l*. In the batch from the UCT system the 1,5*l* UCT system, 1.5*l* anaerobic mixed liquor was added 1.5*l* aerobic mixed liquor batch to give a total volume of 3*l*.Usually starting NO_3 concentration in the 3*l* batches was about 30mg NO_3-N/*l*.
The test SET II(b) to determine P changes, was done on the same finally constitute batch of 3*l* as prepared for the UCT test in SET II(a). No P supplementation was needed.

Once the initial test conditions had been established sampling commenced. Samples (50ml) were pipetted out of the batch reactors. All the samples were immediately vacuumed filtered through Whatman's GF filter paper after which two drops of 8.6g/*l* HgCl was added to the filtrated to stop all biological action. Usually the samples were stored overnight in the cold room (+4°C). The following day the nitrogen samples were analyzed for NO_3-N, NO_2-N and phosphorus samples for total P. For the denitrification tests the VSS concentrations were determined in the first and last

samples from the both reactors.Frequency of sampling in a batch test is given Table G.1.
Throughout the test, precautions were taken to ensure no oxygen dissolved in the mixed liquor. The stream of nitrogen gas bubbling through the batch reactor was maintained over the whole period. Not only did this purge any oxygen that might have dissolved, it served to form an inert layer of gas between the mixed liquor surface and the air above, preventing further oxygen dissolution. Small plastic chips were also floated on the surface of the reactors, to prevent air entering the liquid.

During these anoxic batch tests it was important to monitor and controll the pH of the mixed liquor. Denitrification being a process producing alkalinity, the pH of the batch reactor tended to rise throughout the test period. The monitored pH during the batch test usually rose from about 7.5 to 8.2 and no acid addition was needed to control the pH in the batch reactors to less about 8.5.

G.5 EXPERIMENTAL PROCEDURE P RELEASE IN ANAEROBIC REACTOR SETS III(a)

The objective of this test was to estimate the P release when sewage was added to mixed liquor under anaerobic conditions similar to that in the anaerobic reactor of the UCT system. In that process mixed liquor flow from the anoxic reactor was recycled to the anaerobic reactor in the ratio 1:1 with the influent flow to the anaerobic reactor. Accordingly in the batch test a mixed liquor sample of 1.5*l* was drawn from the anoxic reactor and mixed with 1.5*l* of influent sewage approximate 750mgCOD/*l*. This made the concentration of sewage in the test equal to 750/2 = 375mgCOD/*l* approximately. The P release was monitored for a period of up to 5.5 hours.

In regard to the test procedure it was important that no oxygen or nitrate was present in the mixed liquor sample before the sewage was added as these caused that some RBCOD in the sewage would be utilized by the normal heterotrops and hence not available for P release by the polyP organisms. To ensure that any oxygen absorbed during transfer of mixed liquor from the anoxic reactor, oxygen was stripped by bubbling nitrogen gas through the sample, and the sample DO was monitored by the means of a DO probe until DO equaled zero. It was accepted that in the anoxic reactor there were no nitrate present even though the experimental NO_3-N on the anoxic mixed liquor gave 0.4mgN/*l* or less. In this investigation these conditions were always satisfied.

Once the initial test conditions had been established sampling commenced. Samples (25ml) were pipetted out of the batch reactors at regular intervals over the time period 5.5 hours. Each sample was immediately vacuum filtered through Whatman's GF filter paper after which two drops of 8.6g/*l* HgCl was added to the filtrate to stop all biological action. Usually the samples were stored overnight in the cold room (+4°C) and the following day the phosphorus samples were analyzed for total phosphorus. Nitrate concentration was determined only on the first sample. Frequency of sampling in a batch test is given Table G.1. The pH was monitored in the beginning and at the end of the test being usually ranged between 7.5 to 8.0.

G.6 EXPERIMENTAL PROCEDURE P RELEASE IN ANAEROBIC REACTOR SETS III(b)

The objective of this batch test was to estimate the P release when acetate solution was added to a mixed liquor sample under anaerobic conditions similar to that in the anaerobic reactor of the UCT system. This batch test, SET III(b) was similar to test SET III(a) where sewage was added to mixed liquor batch under anaaerobic conditions.

Accordingly in the batch test a mixed liquor sample of 1.5*l* was drawn from the anoxic reactor and mixed with 1.5*l* of acetate solution (HA_c) with a measured COD concentration that could ranged from 140 to 180 mg/*l*. A COD concentration of 140 mg/*l* was about the same COD concentration the estimated RBCOD concentration in the raw sewage of COD 750mg/*l*. The acetate solution was prepared by adding 600mg of sodium acetate (CH_3COONa) to a 1liter of distilled water and the COD of the acetate solution was measured. This solution was prepared just before this batch test commenced. P release was monitored for a period of up to 5.5 hours. Batch test with acetate was done usually concomitantly with the batch test in which sewage was added.

The test procedure was identical to that in test SET III(a) in which sewage was added, Appendix G5.

G.7 EXPERIMENTAL PROCEDURE EXTRA P RELEASE IN ANAEROBIC REACTOR SETS III(c)

The objective of this test was to determined of any extra P was released when acetate solution was added under anaerobic conditions to mixed liquor when leaving the anaerobic reactor and entering to anoxic reactor of the UCT system.

Accordingly in the batch test mixed liquor sample of 1.5*l* was drawn from the anaerobic reactor and mixed with 1.5*l* of acetate solution (HA_c) with a measured COD concentration of about 150 mg/*l*. This was done by adding 600mg of sodium acetate (CH_3COONa) to a 1liter of distilled water similarly as in set III(b) Appendix G.5. Addionally, in the middle of the test period a few drops (1 to 5 drops) of concentrated HA_c solution was added to the batch mixed liquor to ensure excess substrate was available.Extra P release was monitored for a period of up to 5.5 hours.

The test procedure was identical to those in SET III(a), (b) Appendix G.5 and G.6.

Table G.2 Batch tests procedure for the MLE and UCT systems.

BATCH TEST PROCEDURE FOR THE MLE AND UCT SYSTEMS AT 30C AND 20C.

SET No of the test	Process	Sludge from reactor; and volume ( )	Doses	Measurements	Number of samples	Reason for test
MLE SYSTEM						
I (a)	Nitrification	Anoxic; (3*l*)	NH_3	NO_2, NO_3, NH_3 OUR, pH	14	1.μ_{max} of nitrifiers
II (a)	Denitrification	Aerobic; (1.5*l*)	Raw sewage, NO_3	NO_2, NO_3, pH	16	1.Denitrification rates
UCT SYSTEM						
I (a) I (b)	Nitrification, P uptake	Anoxic; (3*l*)	NH_3, PO_4	NO_2, NO_3, NH_3 Tot P, OUR, pH	14	1.μ_{max} of nitrifiers 2.P uptake
II (a) II (b)	Denitrification P uptake	Anaerobic; (1.5*l*) Aerobic; (1.5*l*)	NO_3	NO_2, NO_3, pH Tot P, pH	14	1.Denitrification rate 2.P uptake
III (a)	P release	Anoxic; (1.5*l*)	Raw sewage	NO_2, NO_3 Tot P, pH	14	P release with available RBCOD
III (b)	P release	Anoxic; (1.5*l*)	Acetate	NO_2, NO_3 Tot P, pH	14	P release with sc available VFA
III (c)	Extra P release	Anaerobic; (1.5*l*)	Acetate	NO_2, NO_3 Tot P, pH	14	P release with available VFA

APPENDIX H

Graphical presentation of batch tests.

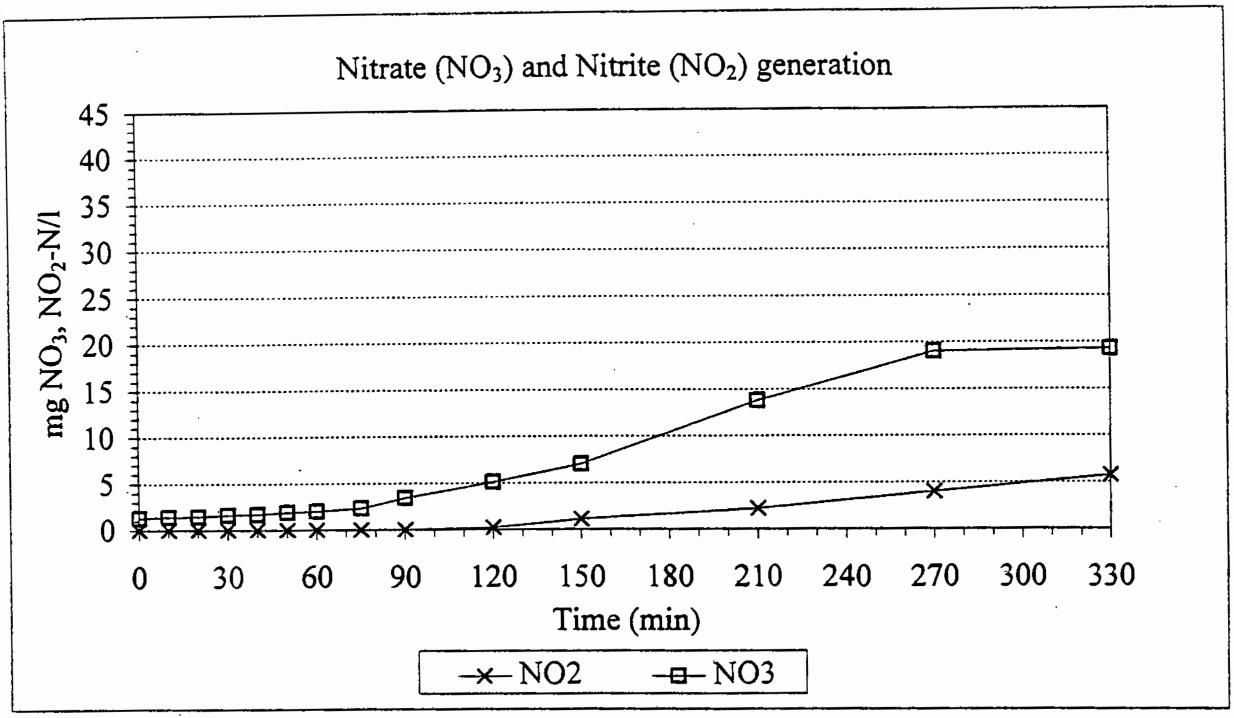
Description of batch test		From page to page
BATCH TESTS ON MLE SYSTEM AT 30C		
Nitrification	Test 1-16N	H.1 to H.8
Denitrification	Test 1-21D	H.9 to H.19
BATCH TESTS ON UCT SYSTEM AT 30C		
Nitrification and P uptake	Test 1-4N and 5-18 N P up	H.20 to H.28
Denitrification	Test 1-11D and 12-27 D P up	H.29 to H.42
P release with addition of acetate	Test 1-15 A Prel	H.43 to H.54
P release with addition of sewage	Test 1-15 S Prel	H.55 to H.69
Excess P release with addition of sewage	Test 1-10 Ex P rel	H.70 to H.74
BATCH TESTS ON MLE SYSTEM AT 20C		
Nitrification	Test 1-2 N	H.75
Denitrification	Test 1-8 D	H.76 to H.79
BATCH TESTS ON UCT SYSTEM AT 20C		
Nitrification and P uptake	Test 1-4 N P up	H.80 to H.81
Denitrification	Test 1-11D P up and 12-13 D	H.82 to H.88
P release with addition of acetate	Test 1-3 A Prel	H.89 to H.91
P release with addition of sewage	Test 1-5 S Prel	H.92 to H.96
Excess P release with addition of sewage	Test 1-2 Ex P rel	H.97

NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

Date: 19.10.1995

TEST 1 N

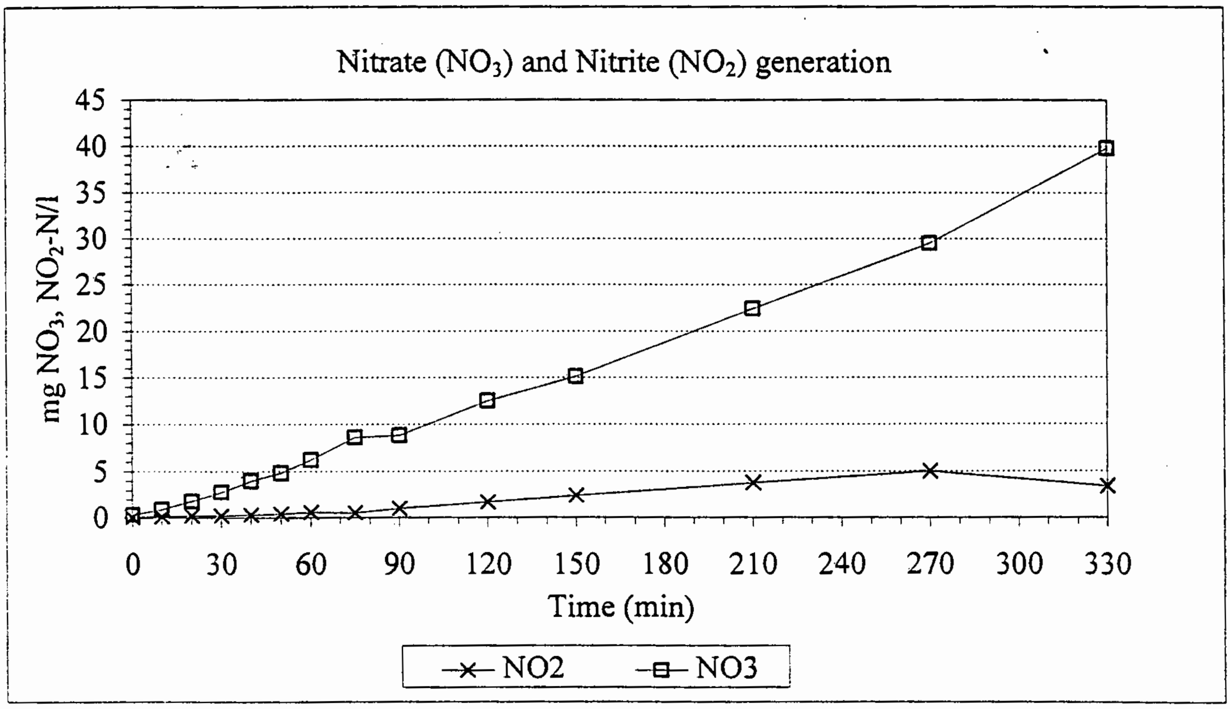
Temperature: 30 C



Date: 26.10.1995

TEST 2 N

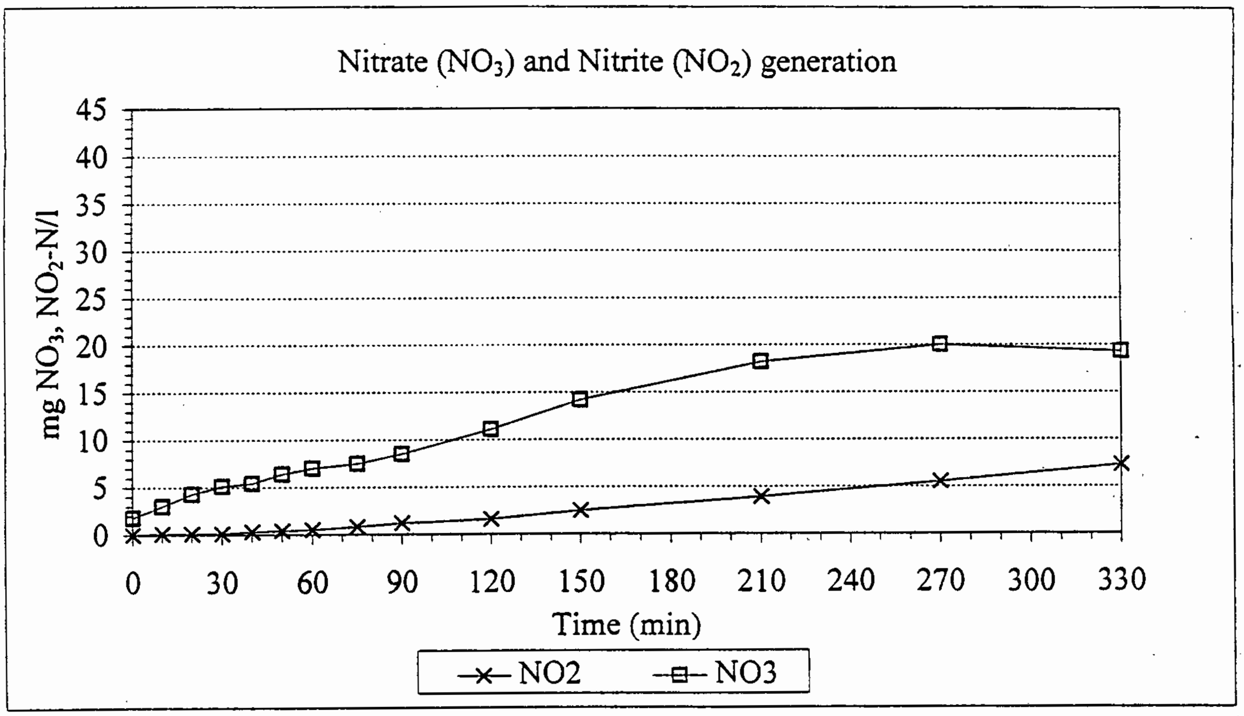
Temperature: 30 C



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

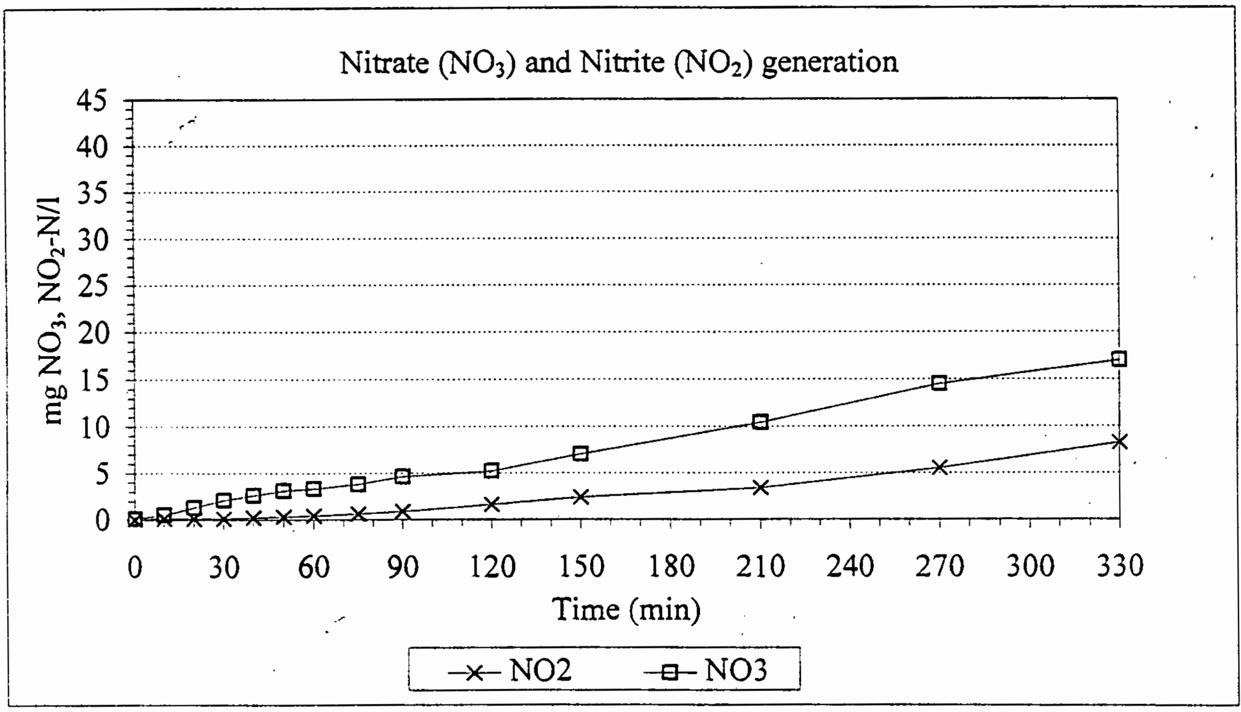
Date: 02.11.1995
Temperature: 30 C

TEST 3 N



Date: 04.11.1995
Temperature: 30 C

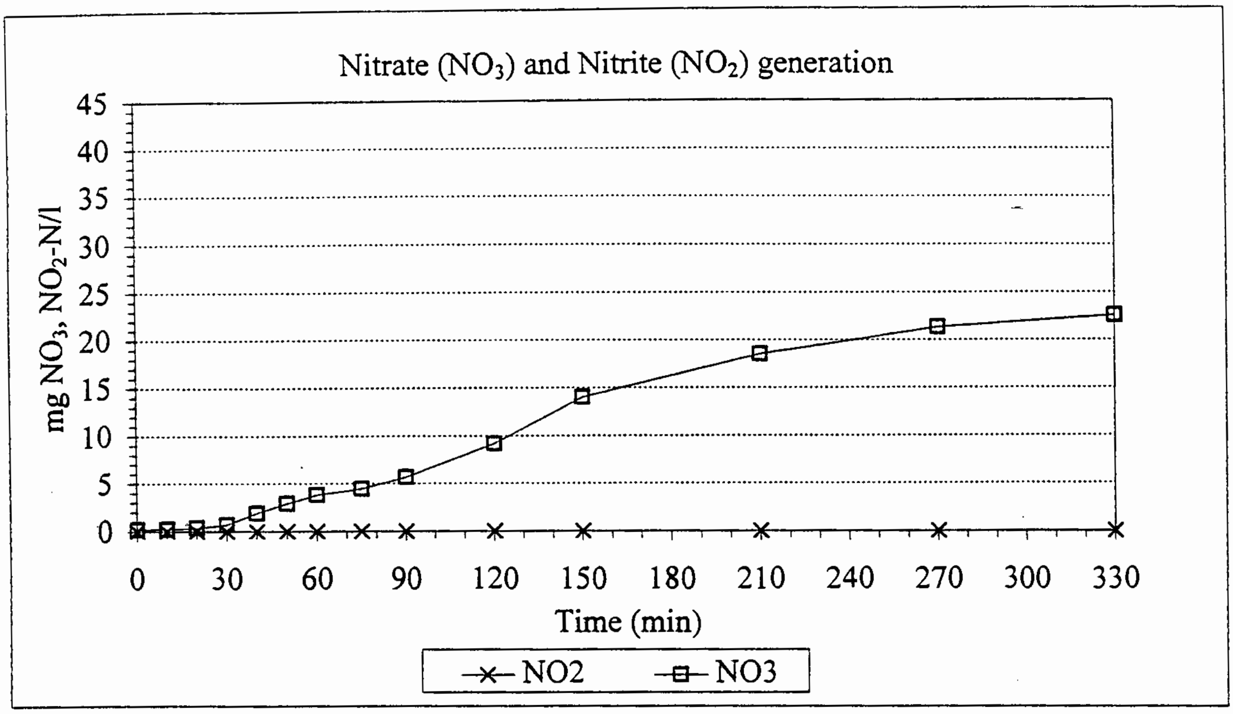
TEST 4 N



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

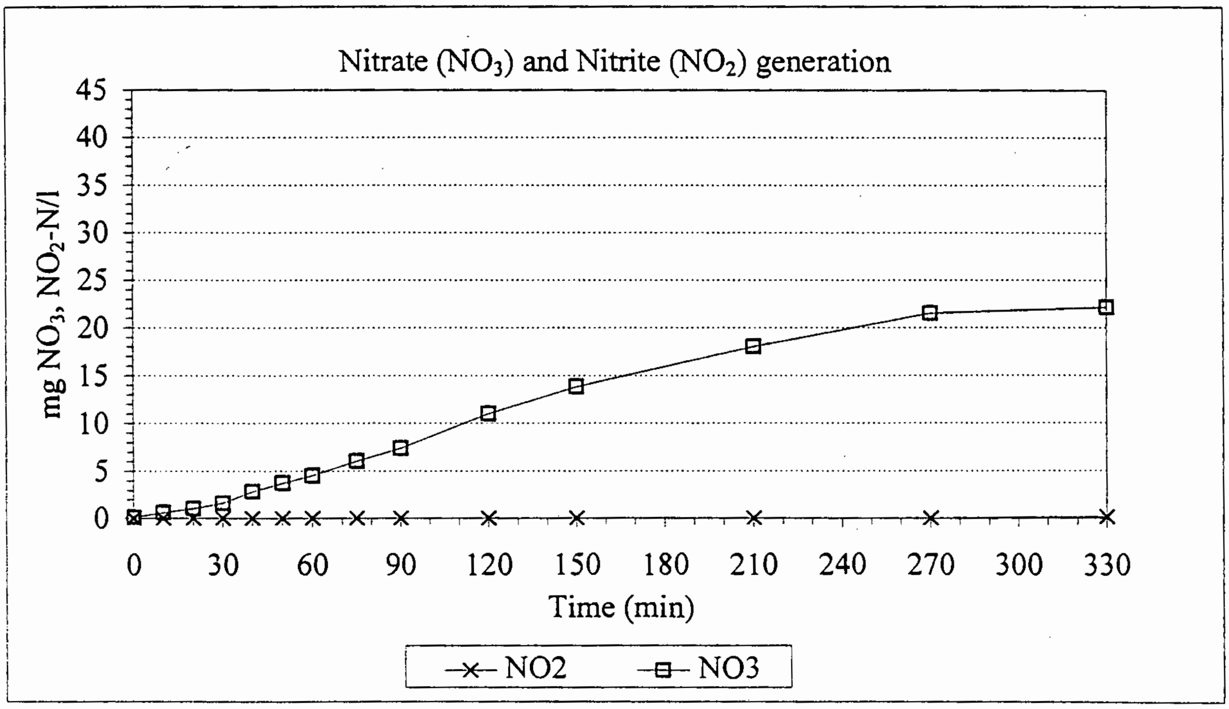
Date: 18.12.1995
Temperature: 30 C

TEST 5 N



Date: 27.12.1995
Temperature: 30 C

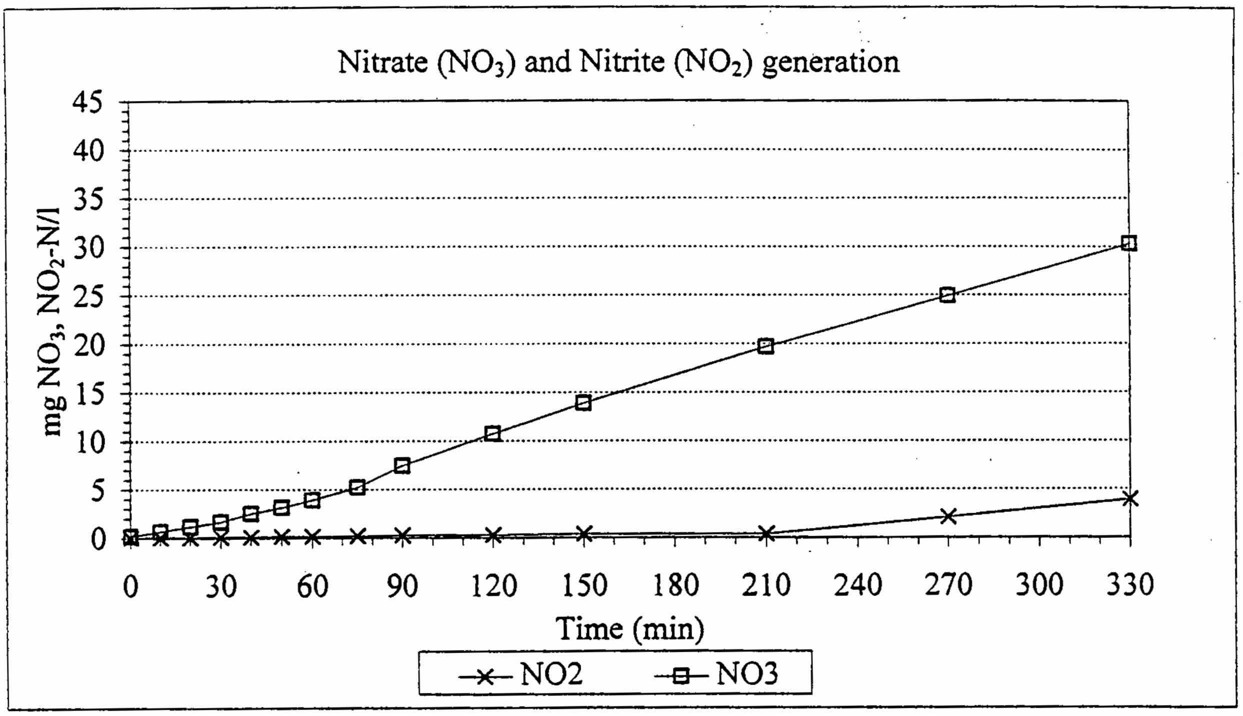
TEST 6 N



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

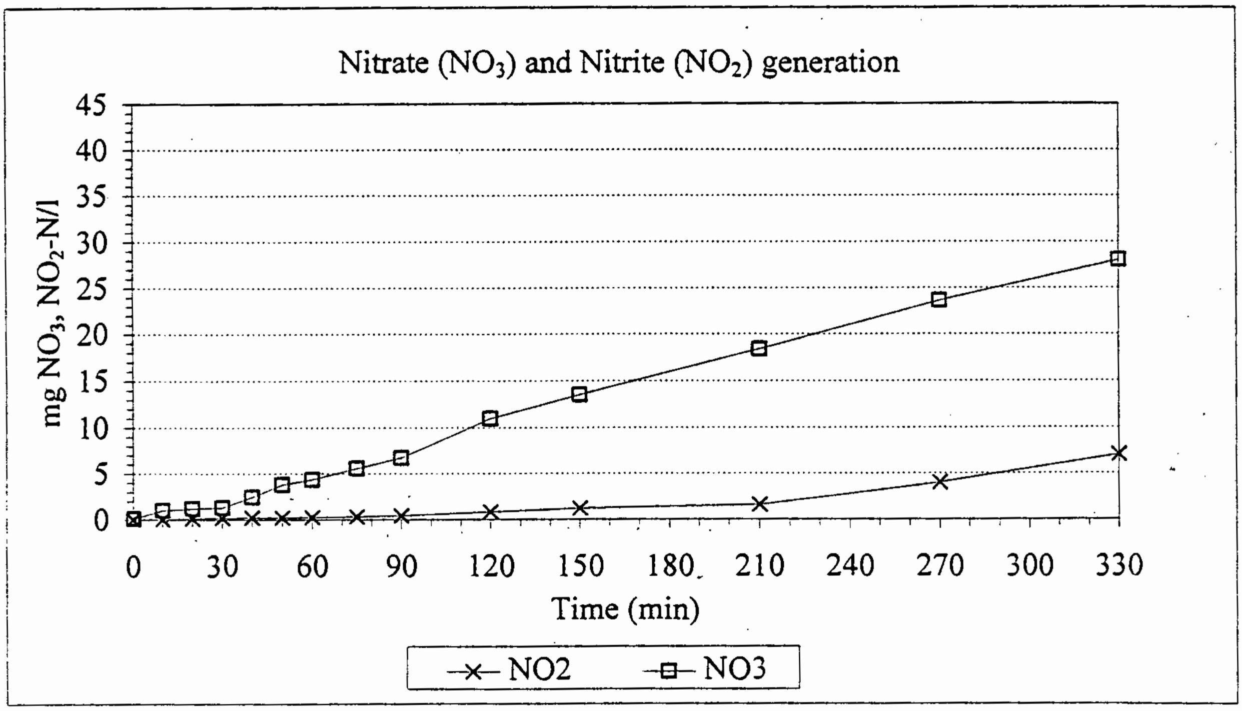
Date: 01.01.1996
Temperature: 30 C

TEST 7 N



Date: 08.01.1996
Temperature: 30 C

TEST 8 N

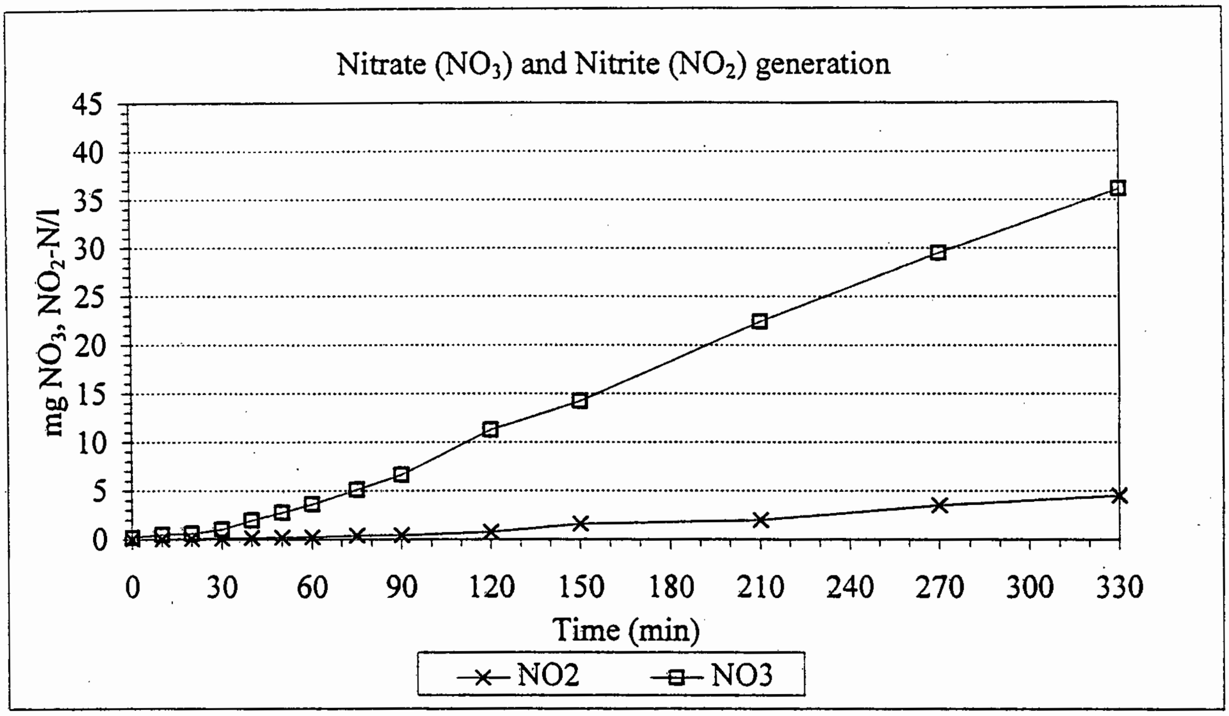


NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

Date: 20.01.1996

TEST 9 N

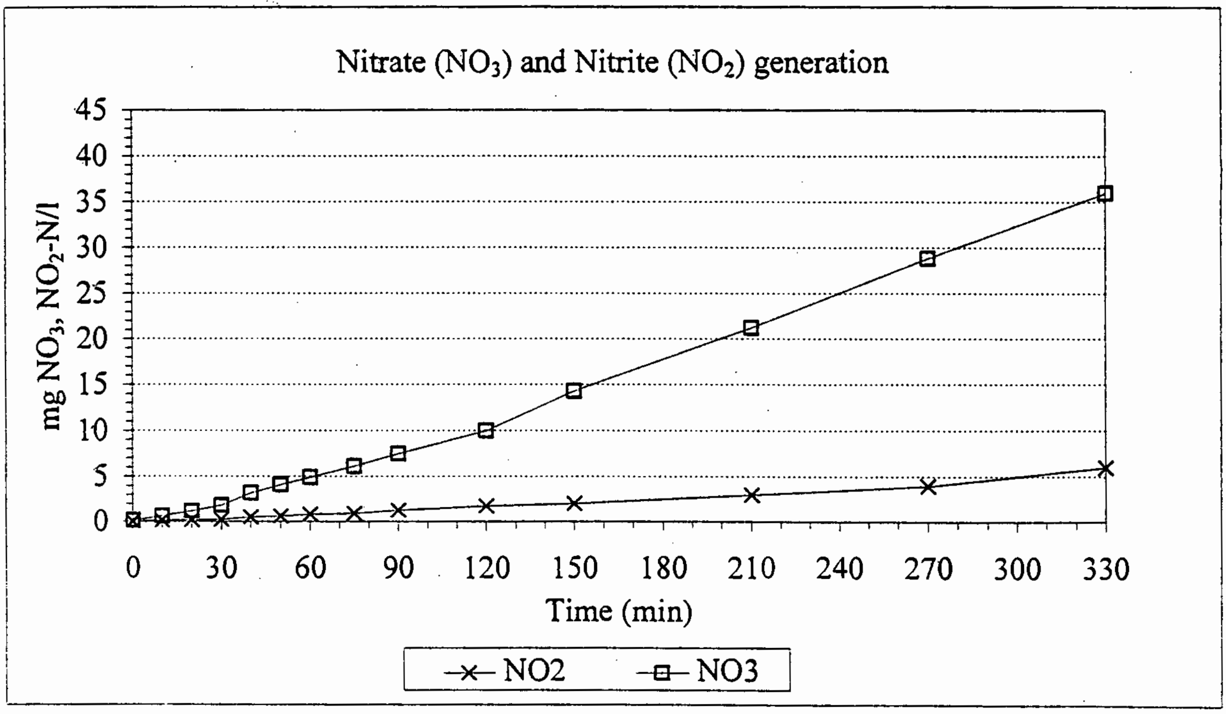
Temperature: 30 C



Date: 25.01.1996

TEST 10 N

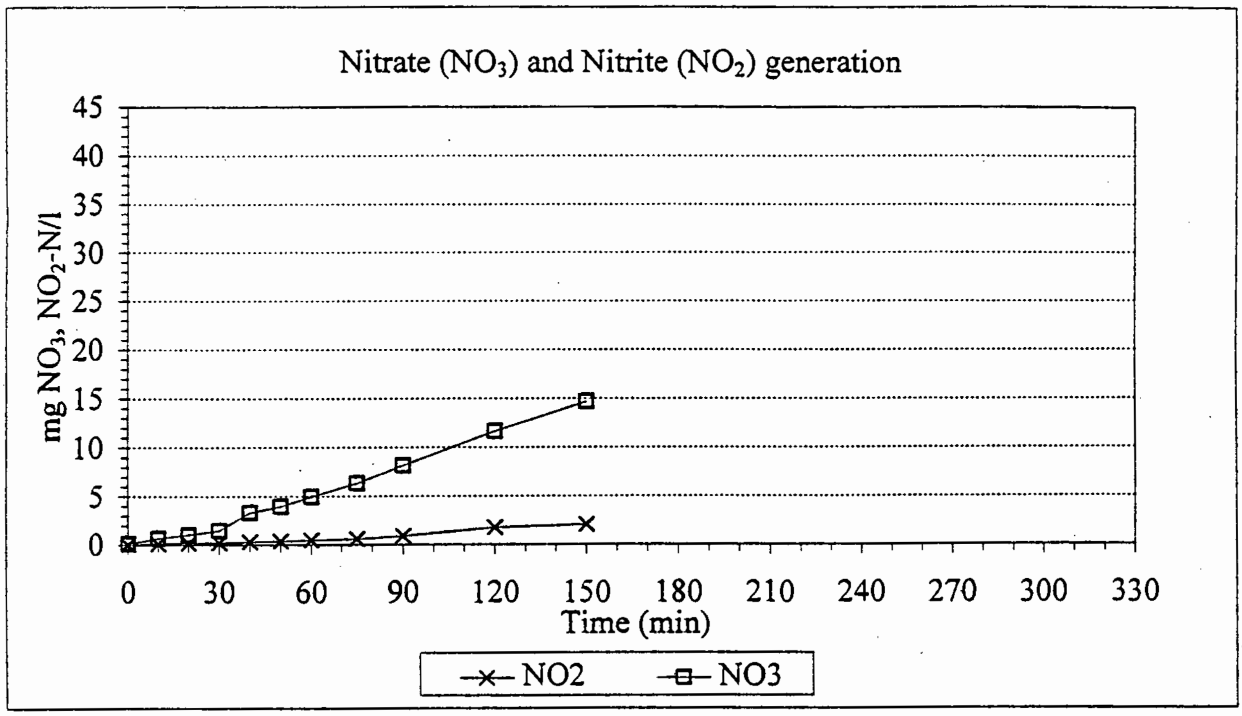
Temperature: 30 C



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

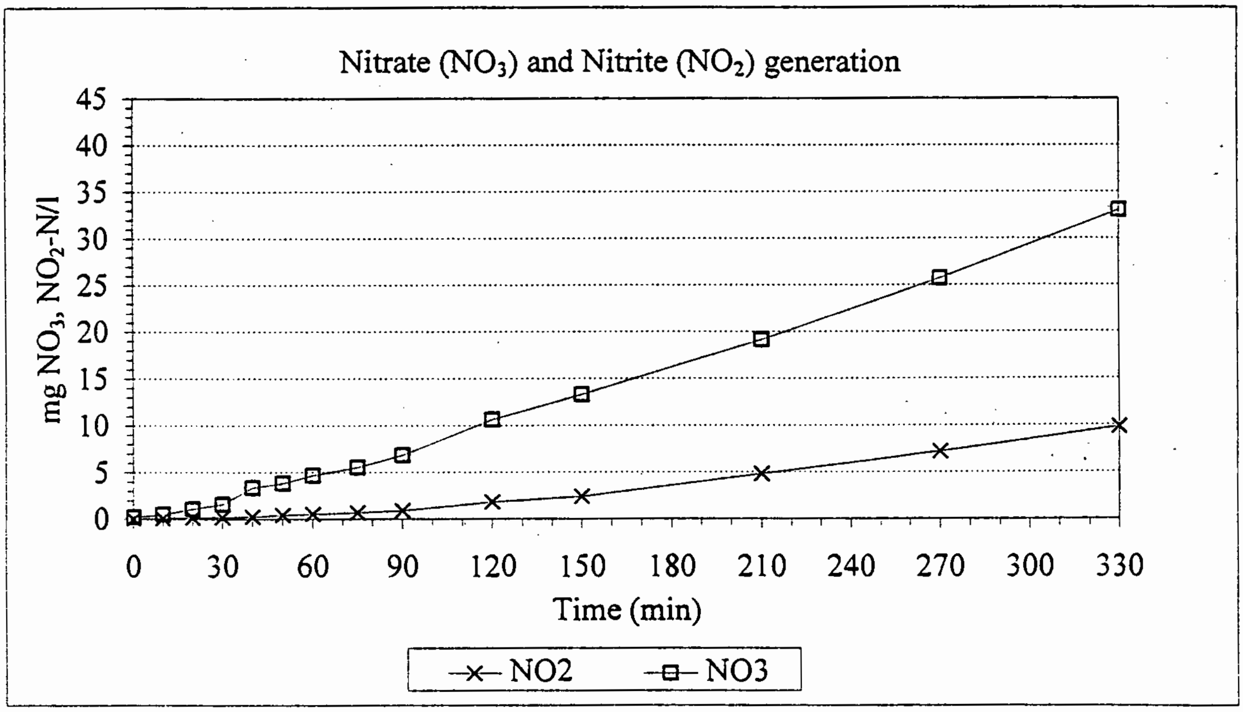
Date: 27.01.1996
Temperature: 30 C

TEST 11 N



Date: 29.01.1996
Temperature: 30 C

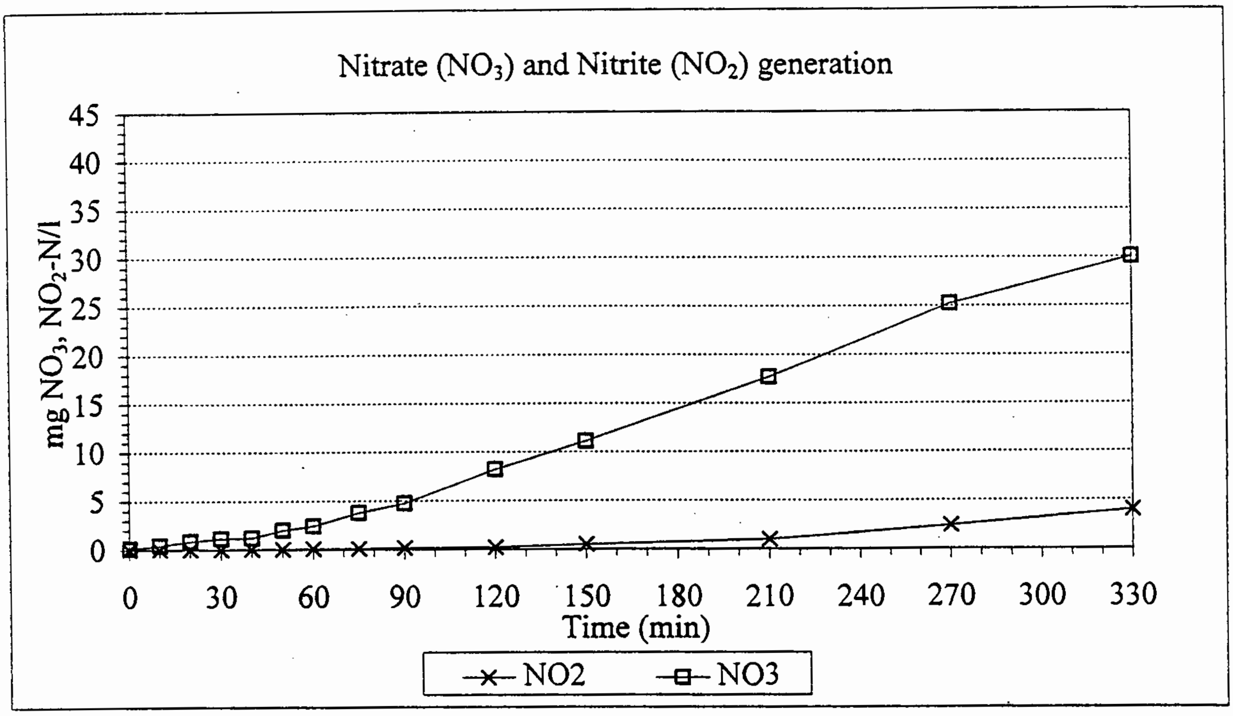
TEST 12 N



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

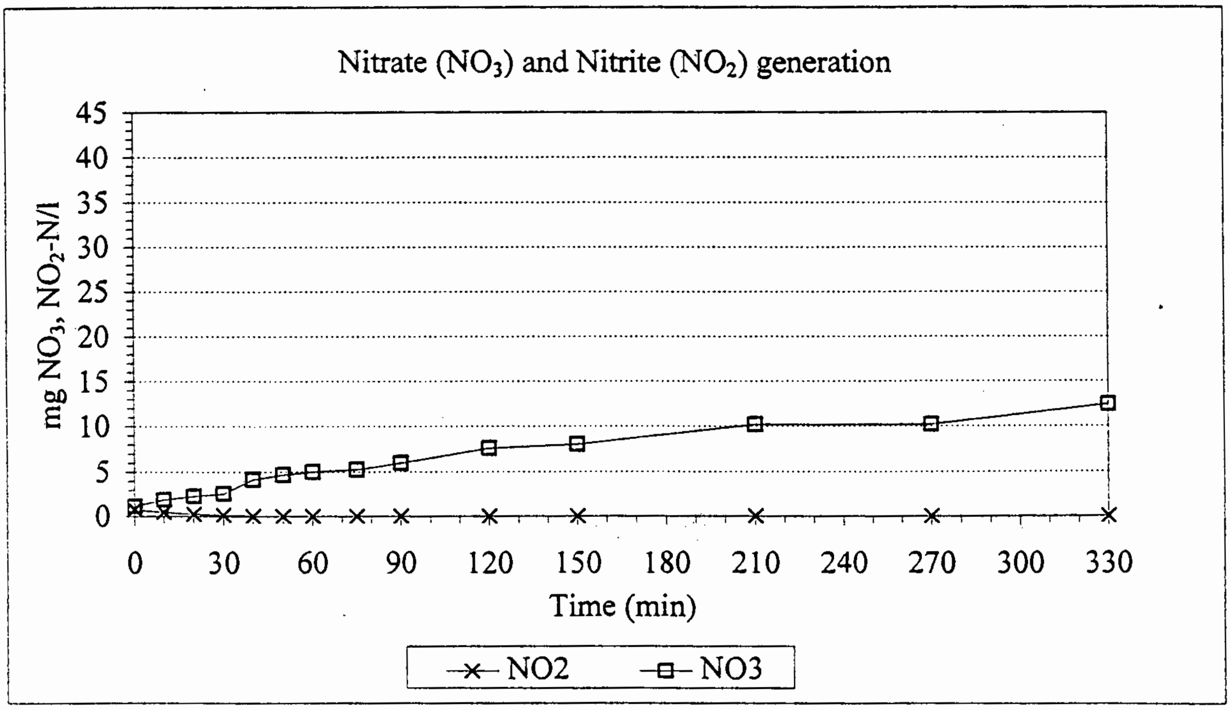
Date: 16.02.1996
Temperature: 30 C

TEST 13 N



Date: 21.05.1996
Temperature: 30 C

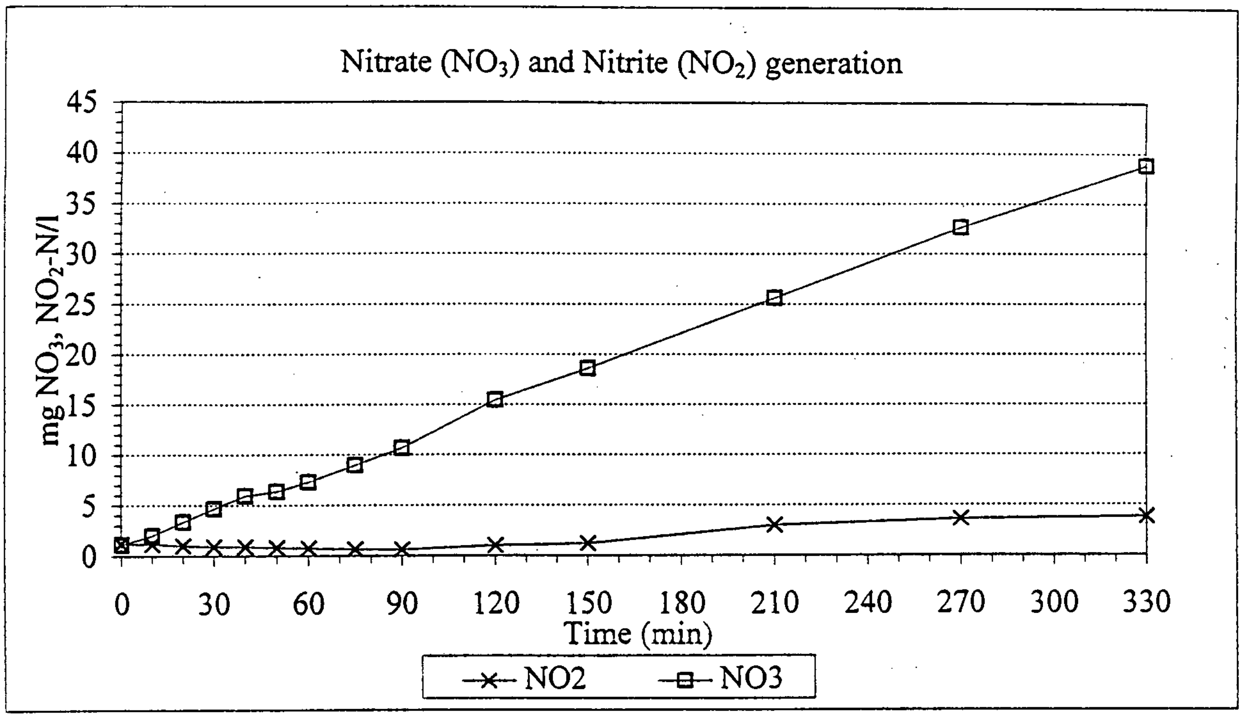
TEST 14 N



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

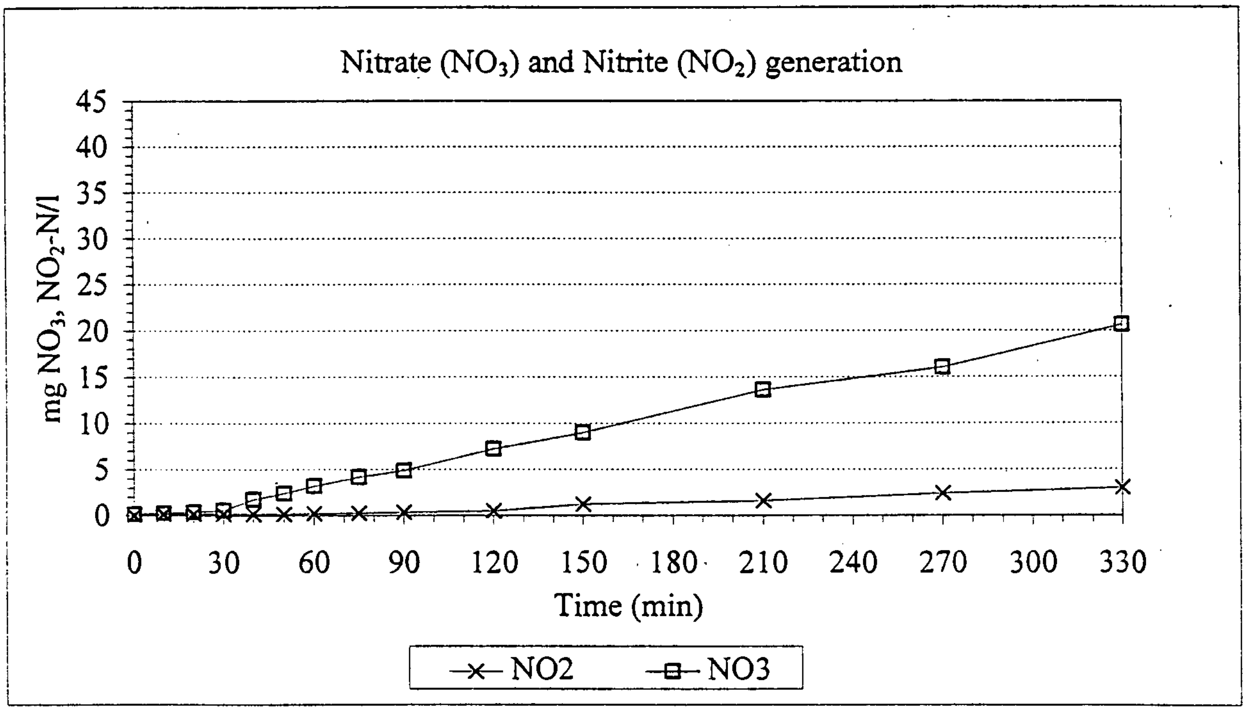
Date: 27.05.1996
Temperature: 30 C

TEST 15 N



Date: 01.07.1996
Temperature: 30 C

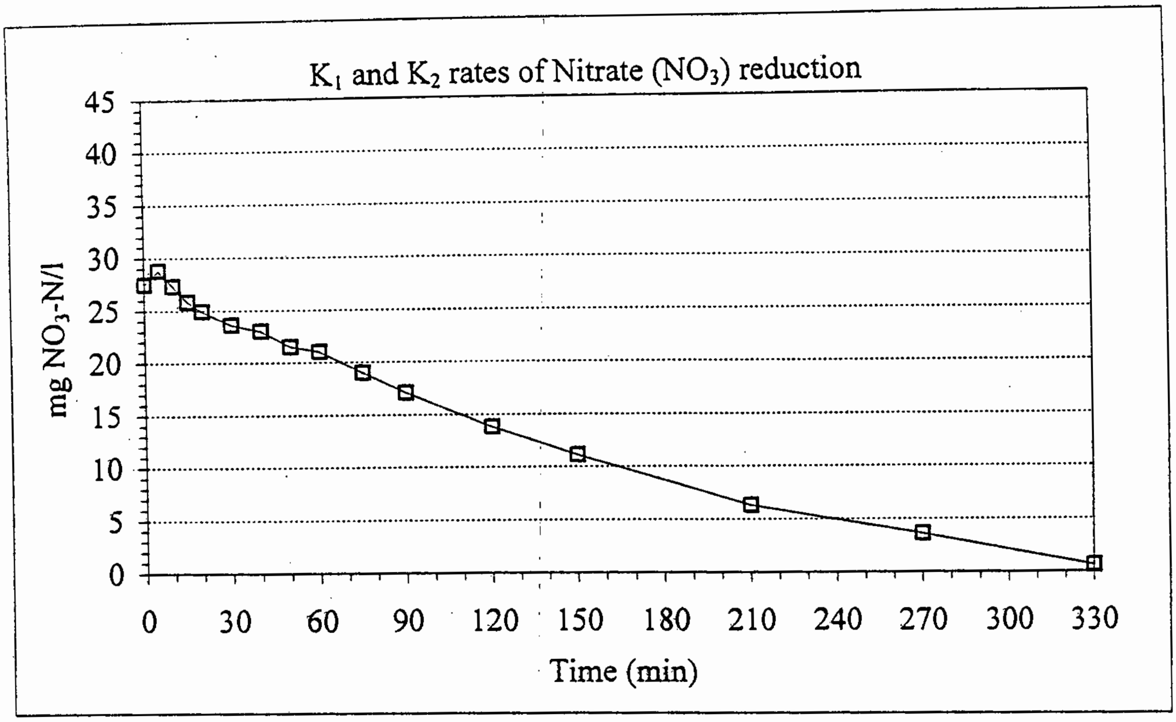
TEST 16 N



NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

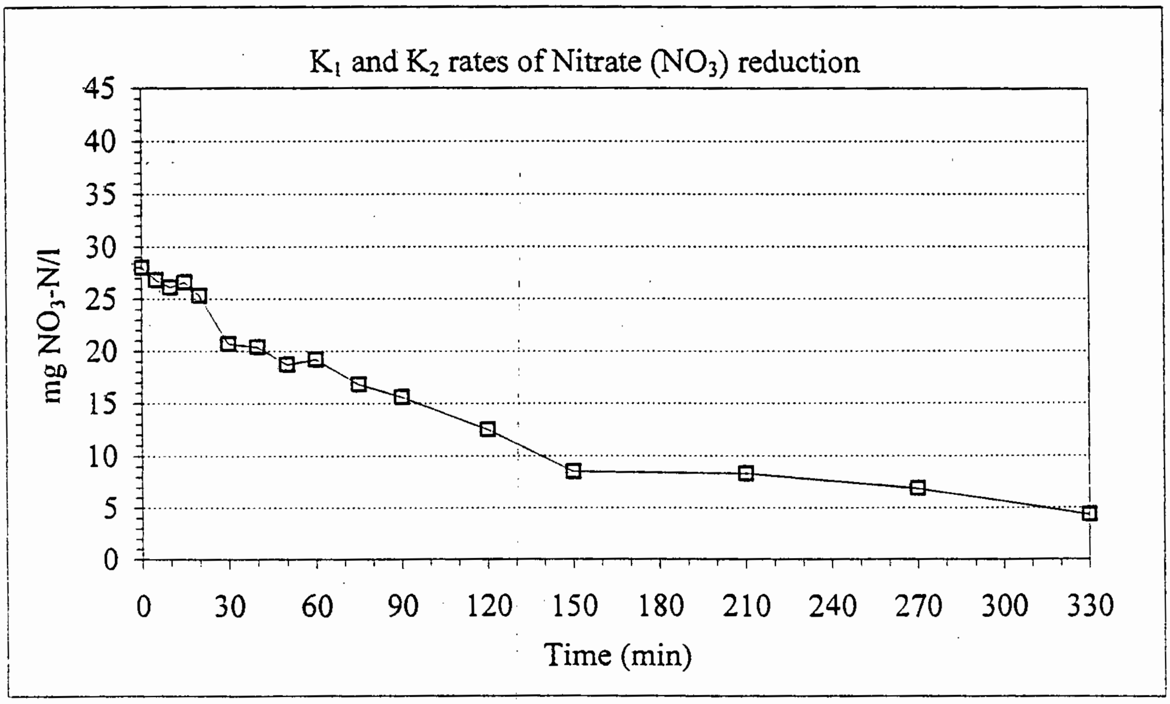
Date: 22.09.1995
Temperature: 30 C

TEST 1 D



Date: 27.09.1995
Temperature: 30 C

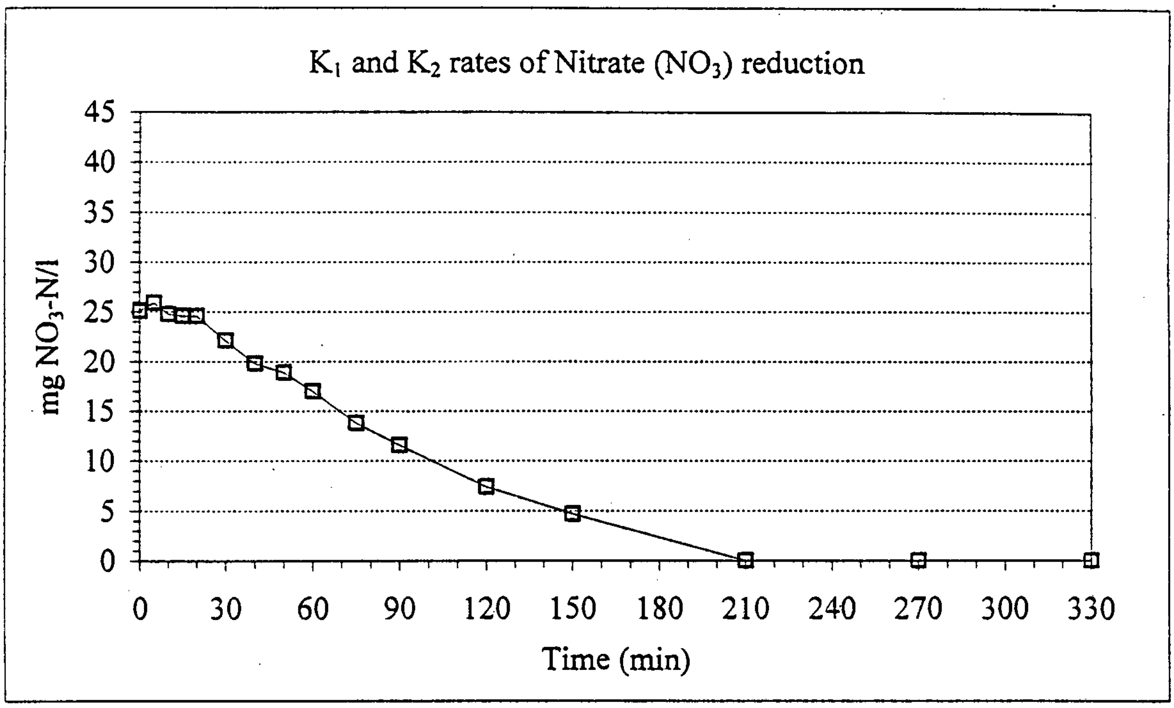
TEST 2 D



NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

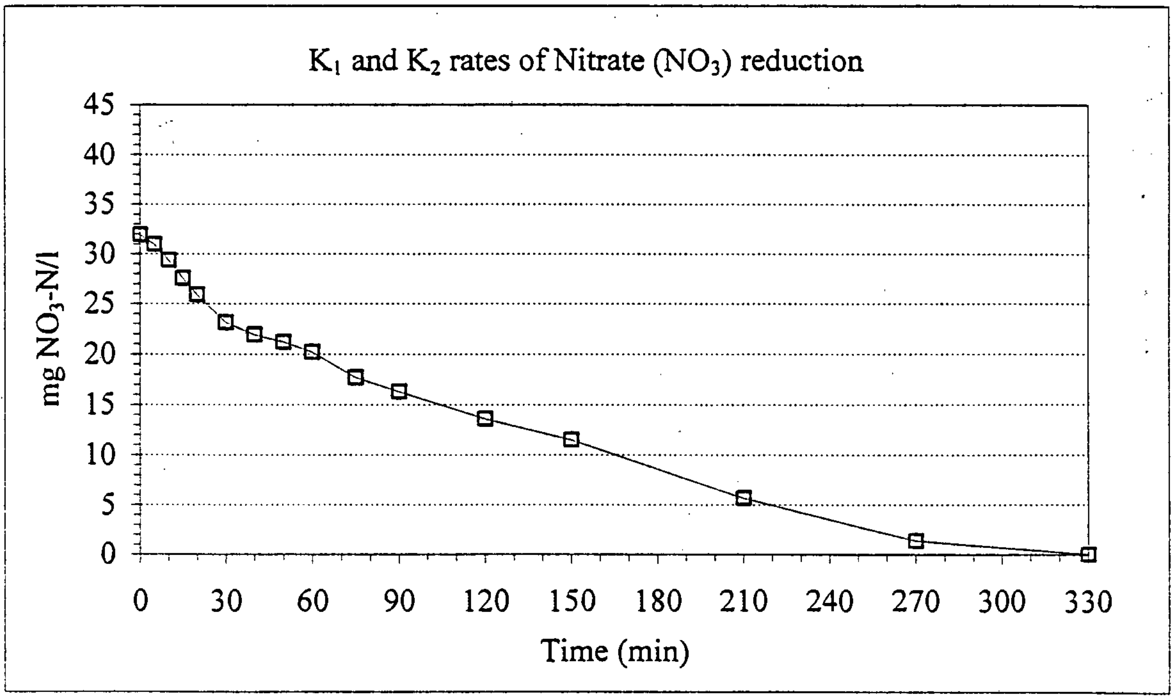
Date: 02.10.1995
Temperature: 30 C

TEST 3 D



Date: 06.10.1995
Temperature: 30 C

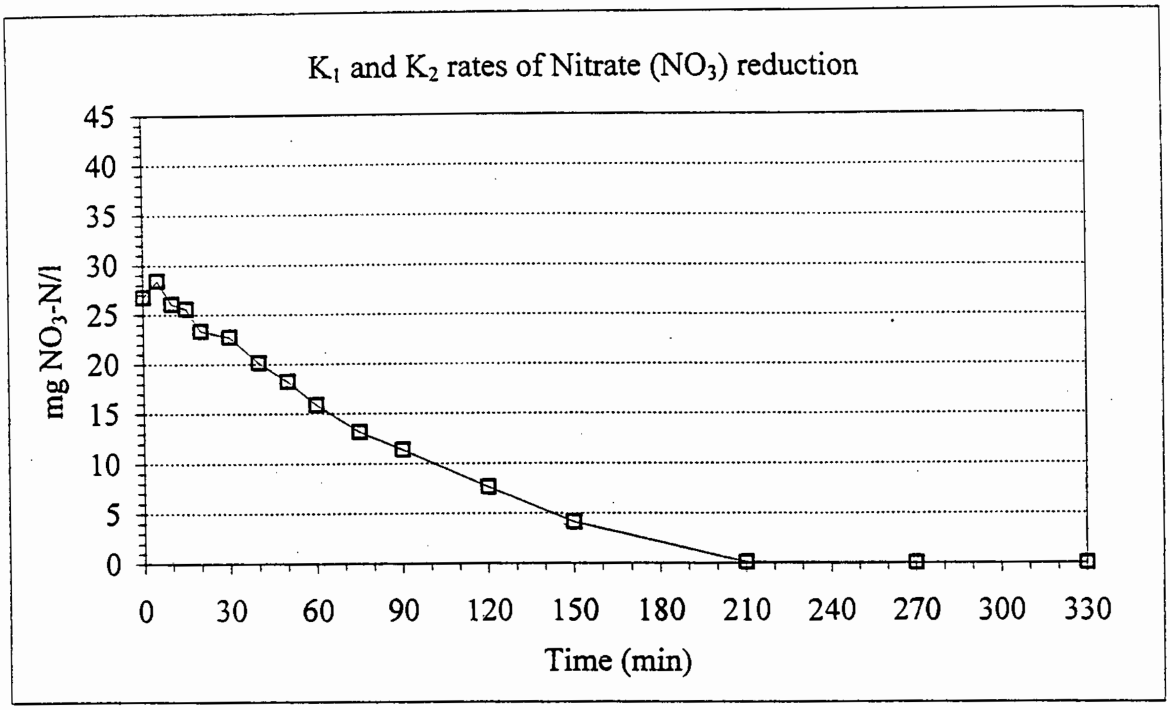
TEST 4 D



NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

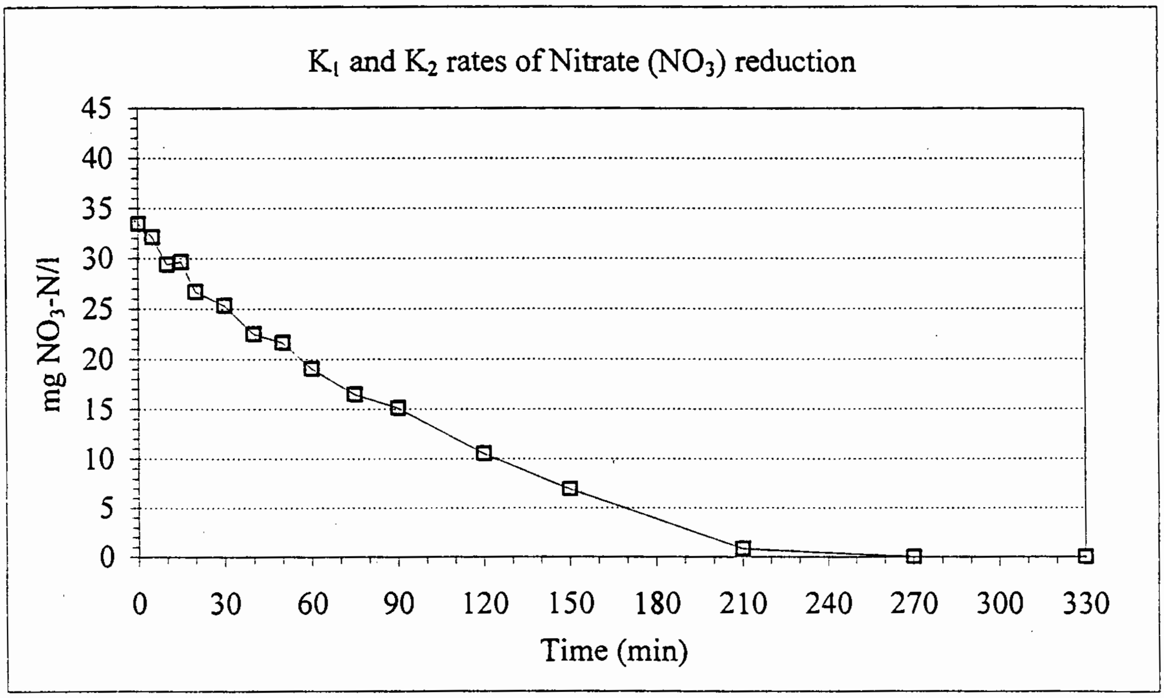
Date: 11.10.1995
Temperature: 30 C

TEST 5 D



Date: 16.10.1995
Temperature: 30 C

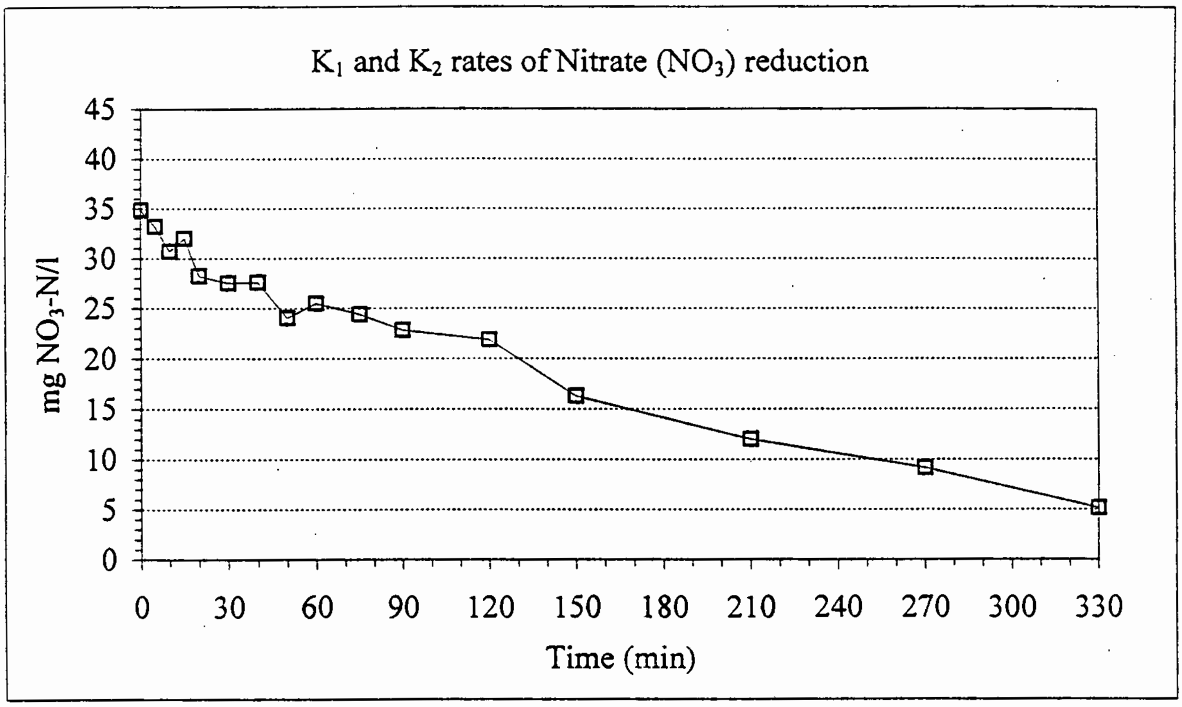
TEST 6 D



NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

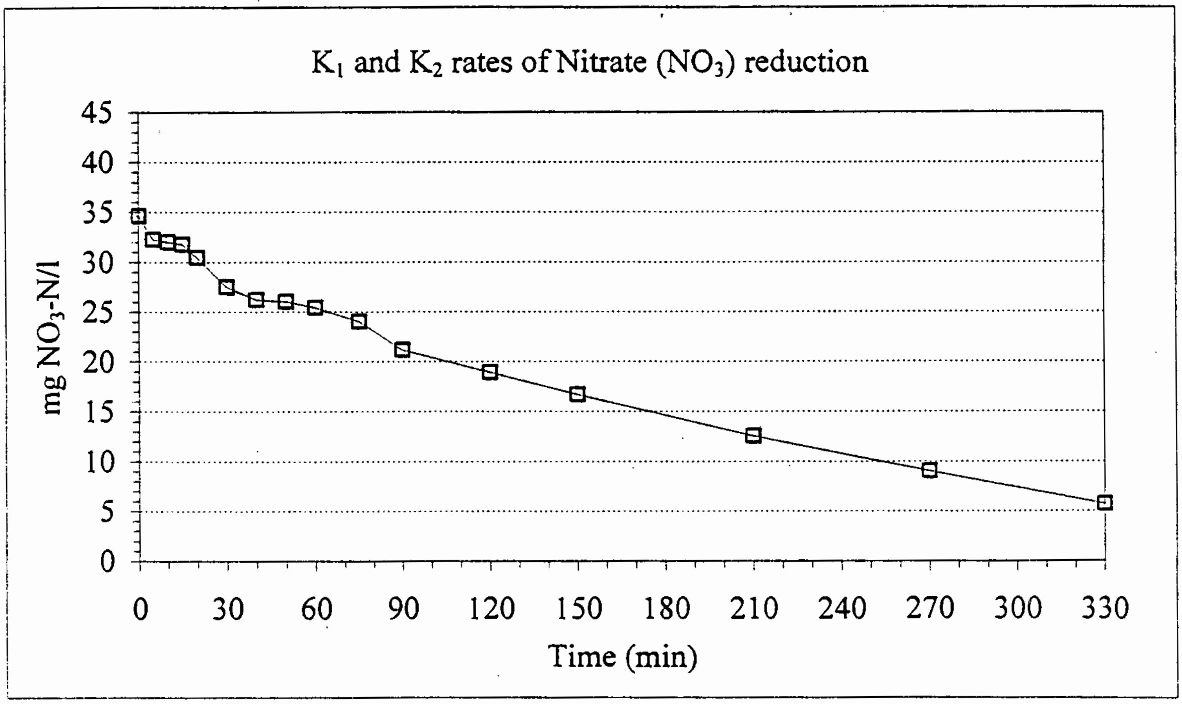
Date: 23.10.1995
Temperature: 30 C

TEST 7 D



Date: 30.10.1995
Temperature: 30 C

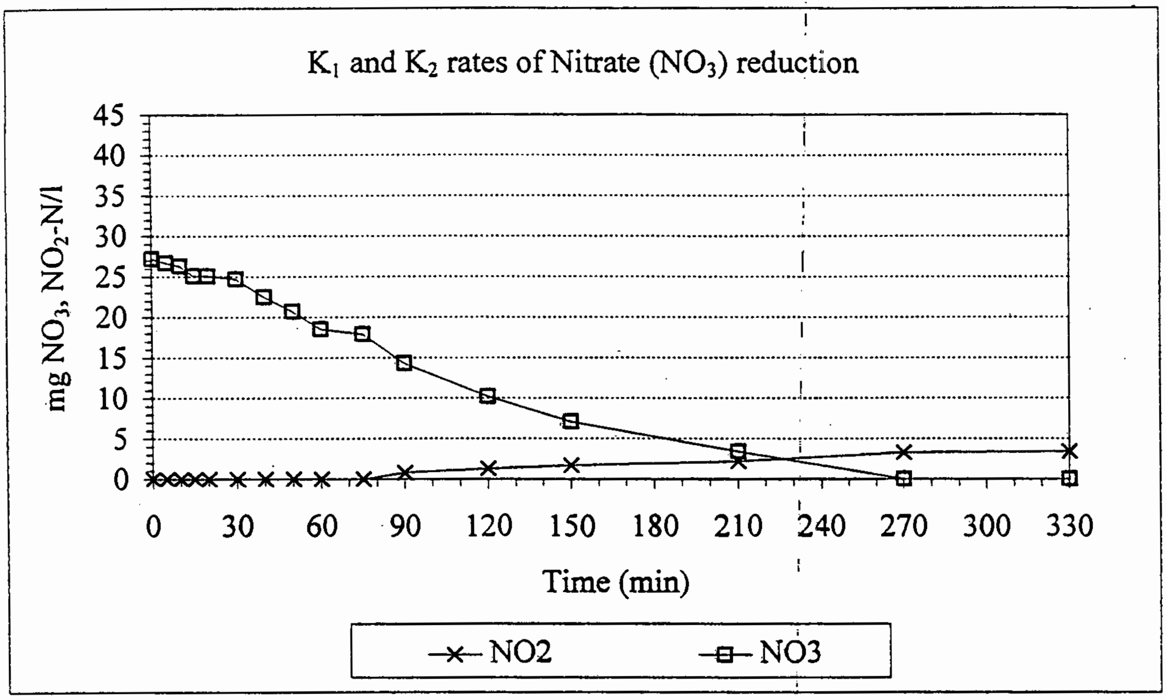
TEST 8 D



NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

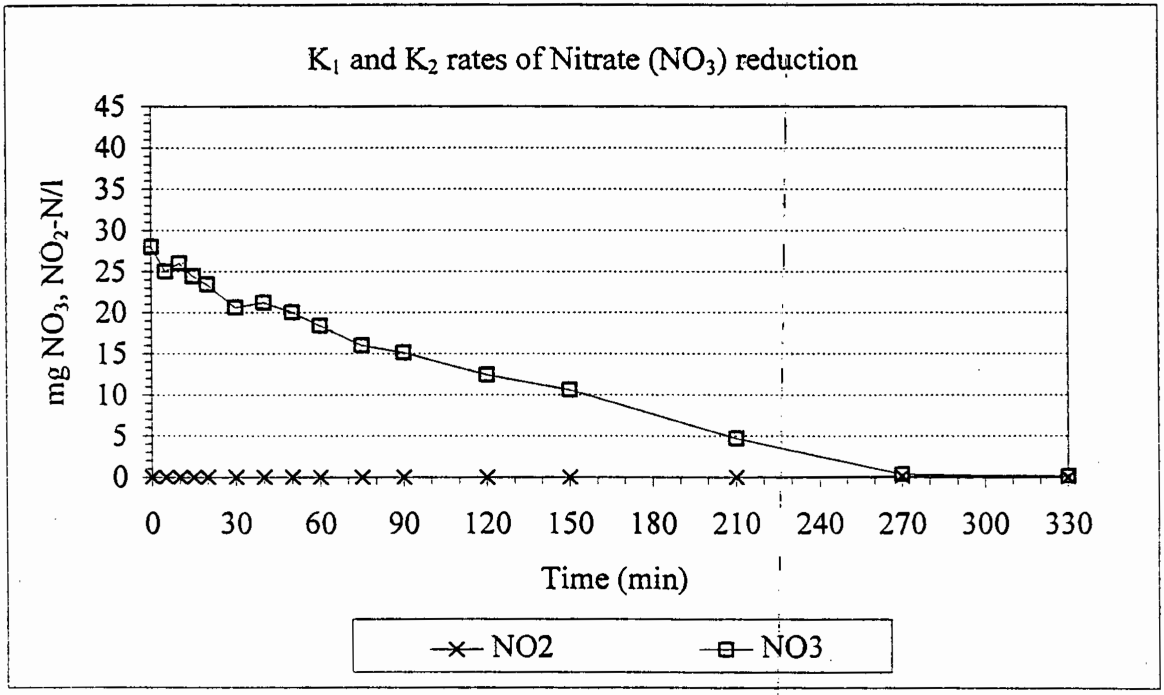
Date: 21.12.1995
Temperature: 30 C

TEST 9 D



Date: 30.12.1995
Temperature: 30 C

TEST 10 D

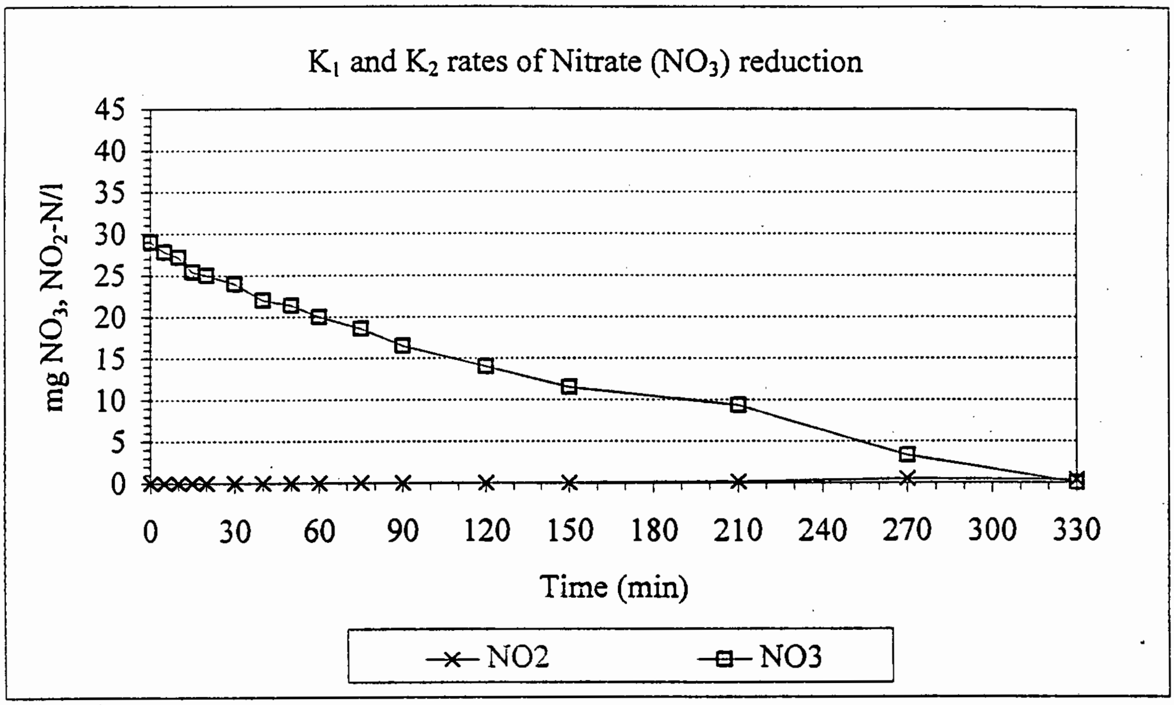


NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

Date: 04.01.1996

Temperature: 30 C

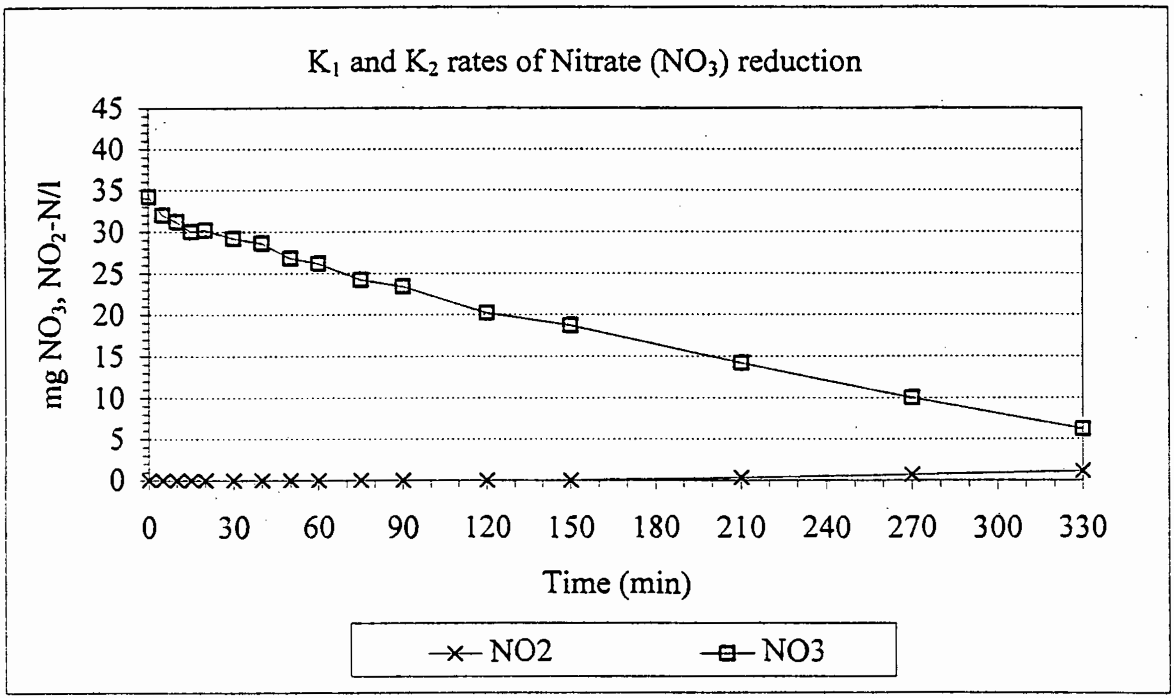
TEST 11 D



Date: 05.01.1996

Temperature: 30 C

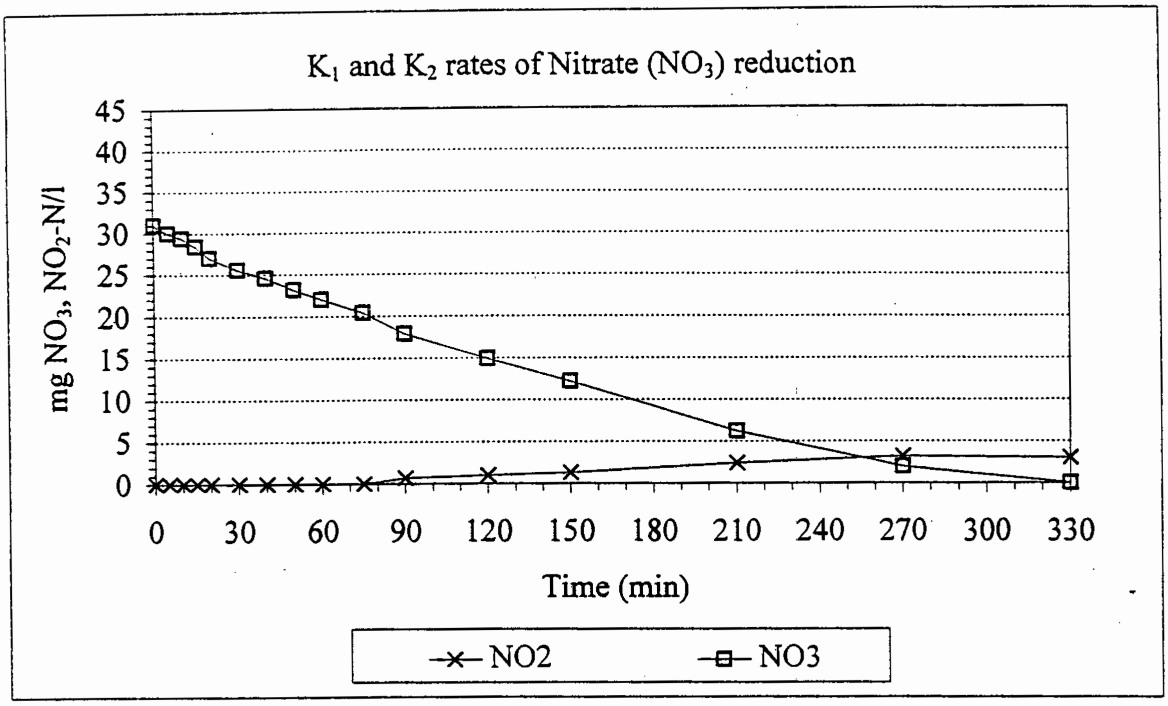
TEST 12 D



NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

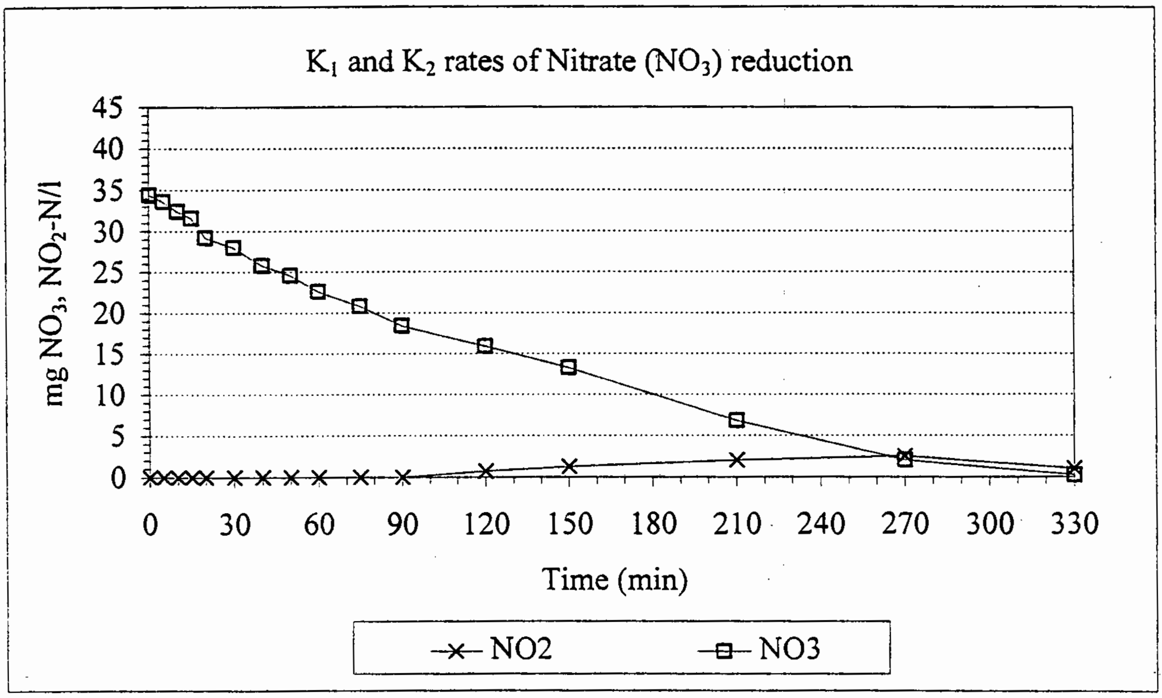
Date: 11.01.1996
Temperature: 30 C

TEST 13 D



Date: 15.01.1996
Temperature: 30 C

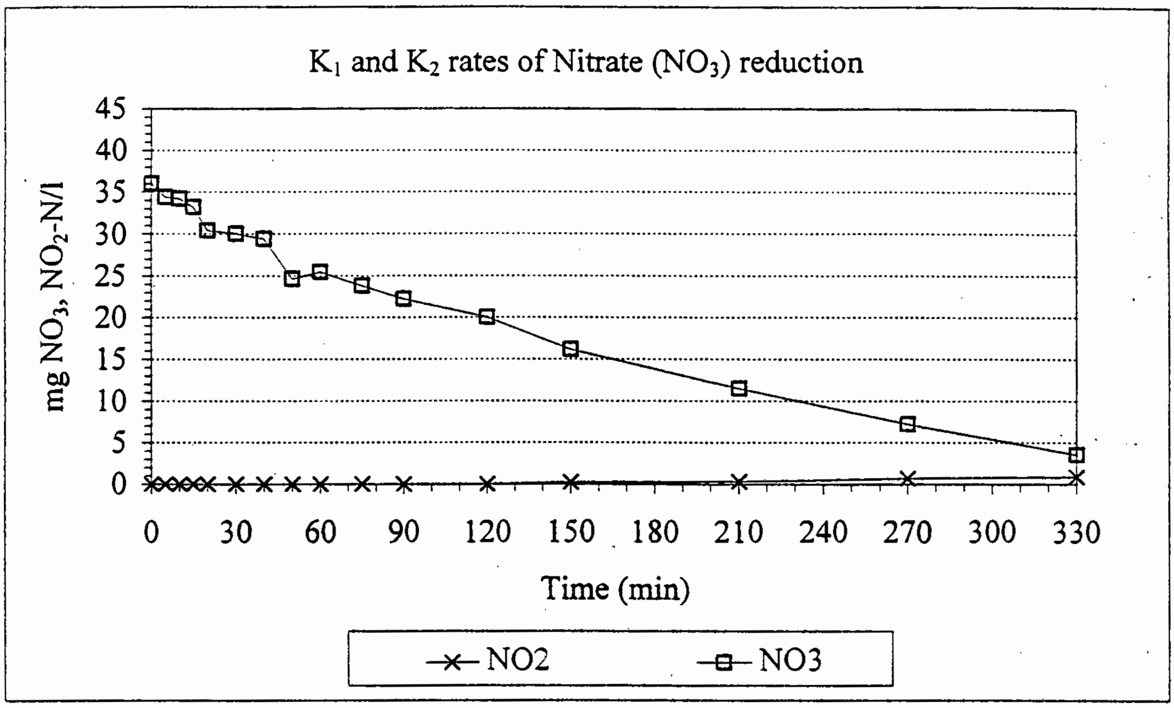
TEST 14 D



NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

Date: 18.01.1996
Temperature: 30 C

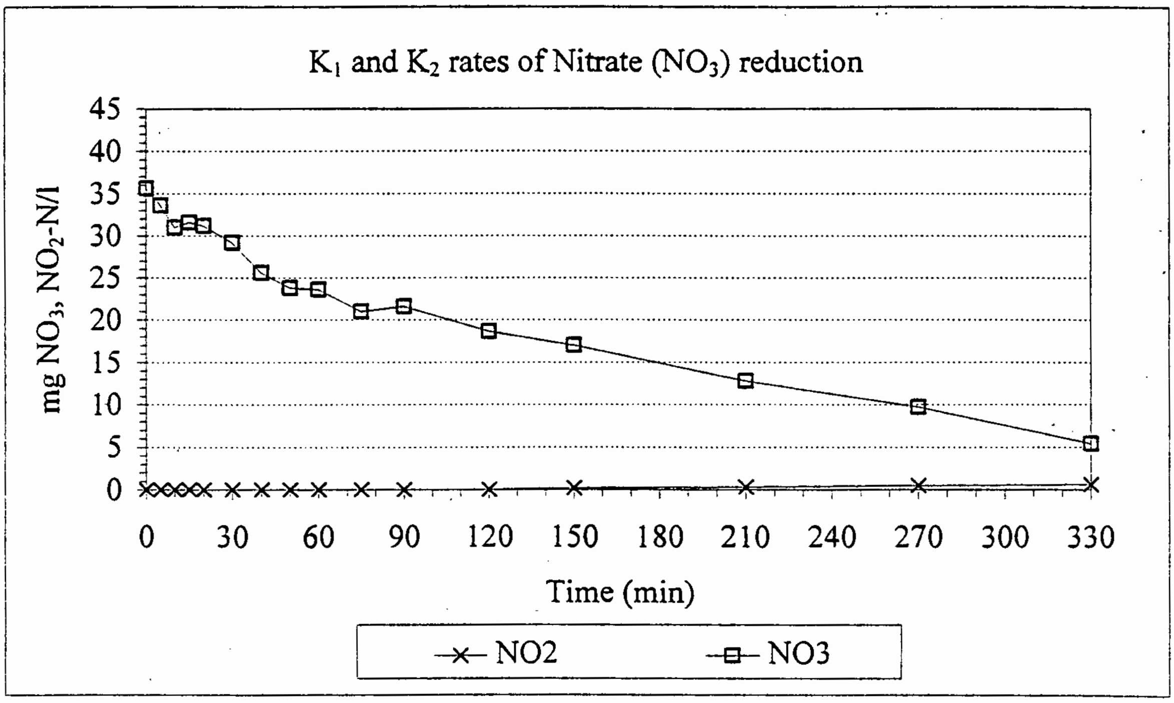
TEST 15 D



K_1 and K_2 rates of Nitrate (NO_3) reduction

Date: 24.01.1996
Temperature: 30 C

TEST 16 D

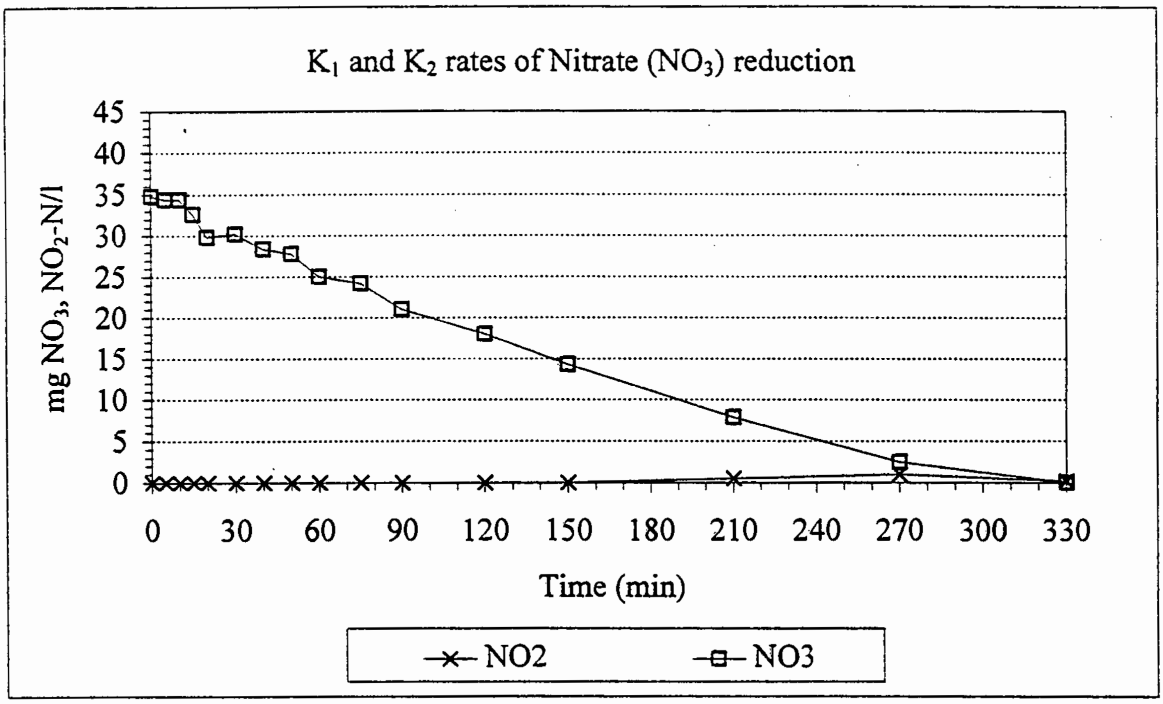


K_1 and K_2 rates of Nitrate (NO_3) reduction

NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

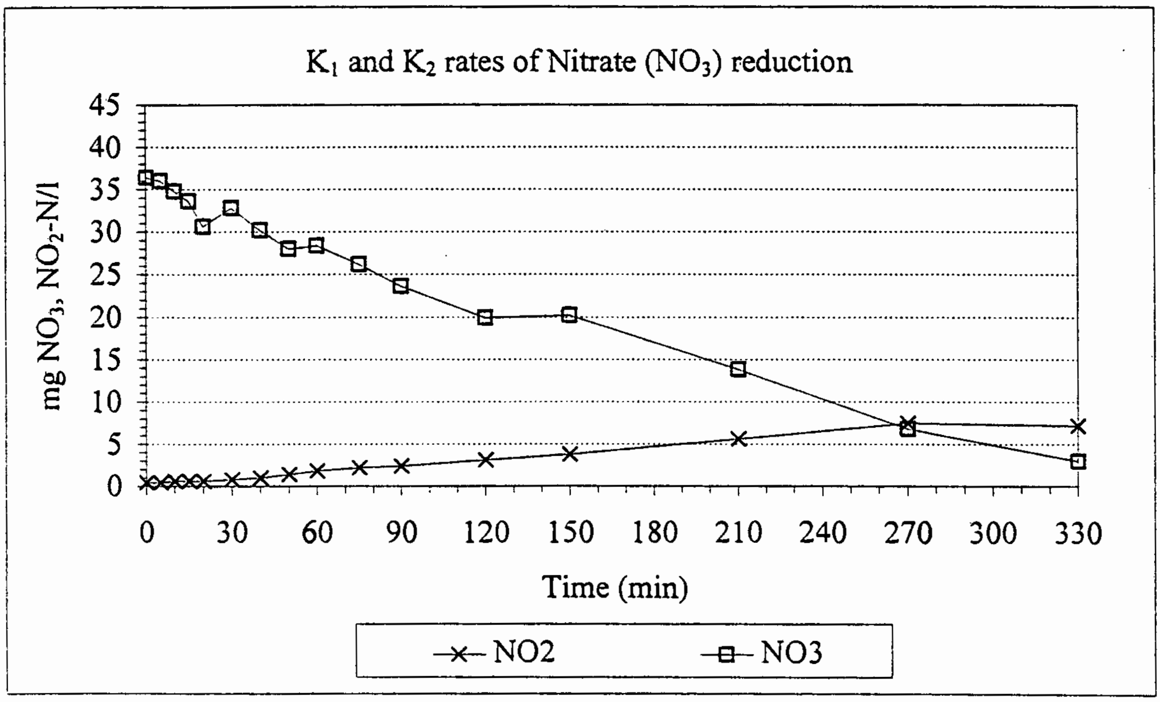
Date: 26.01.1996
Temperature: 30 C

TEST 17 D



Date: 10.05.1996
Temperature: 30 C

TEST 18 D

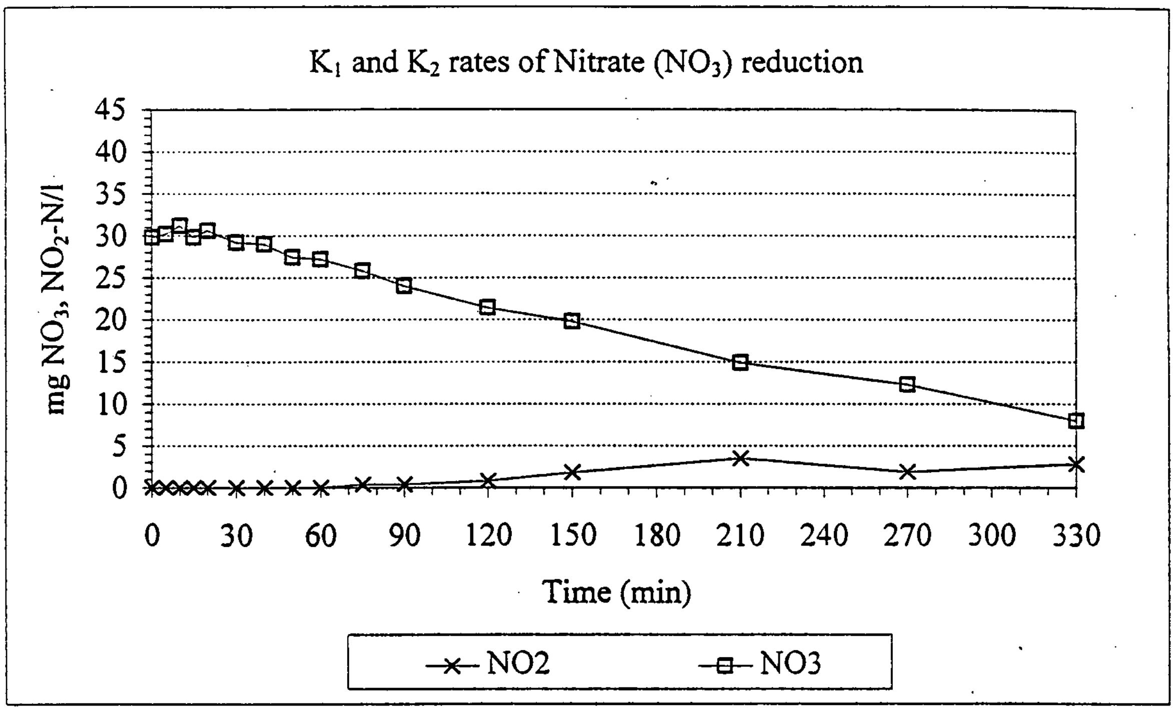


NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

Date: 17.05.1996

TEST 19 D

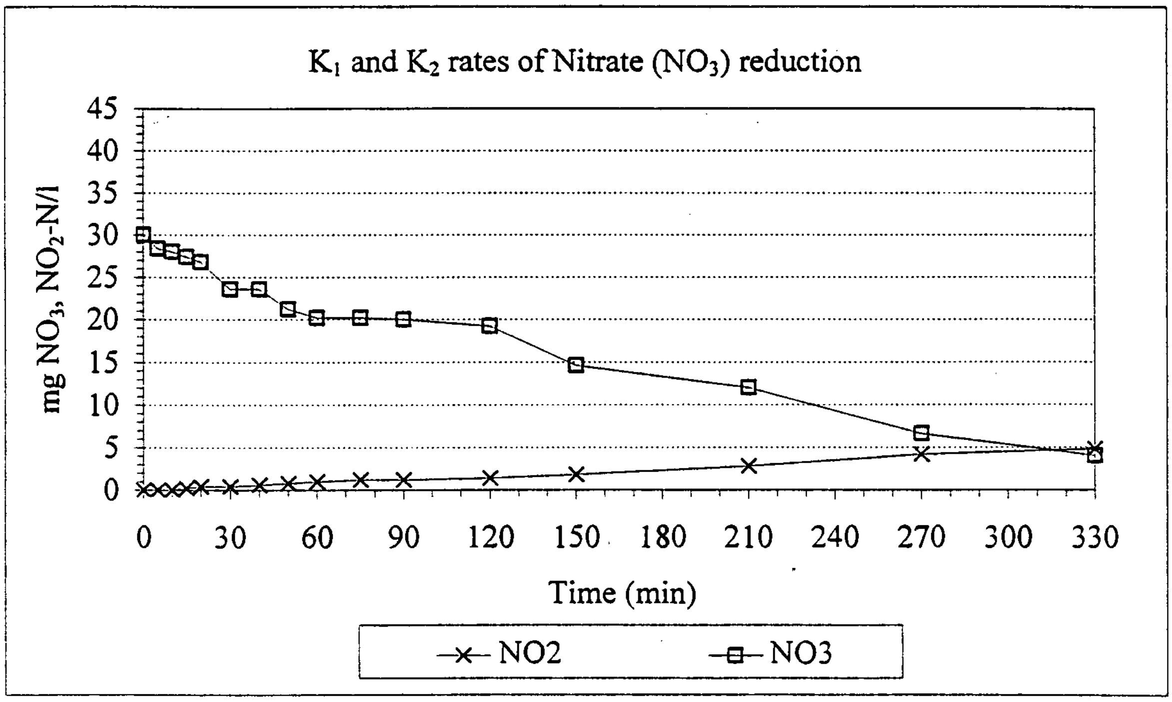
Temperature: 30 C



Date: 26.06.1996

TEST 20 D

Temperature: 30 C

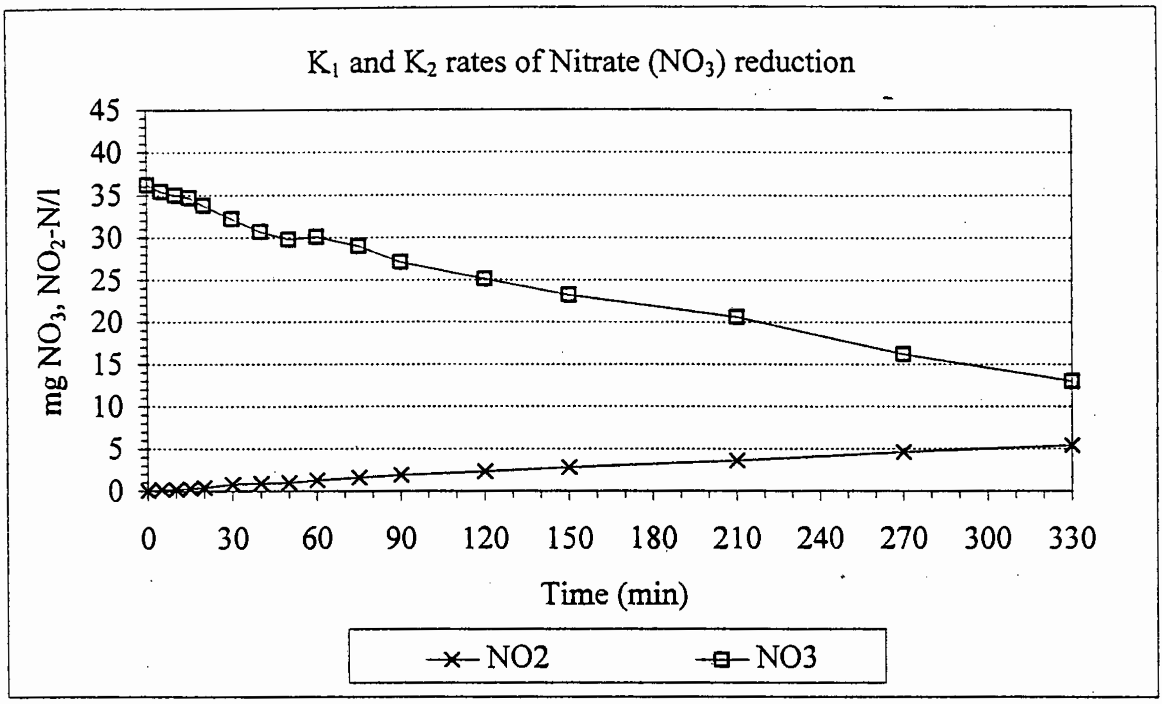


NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

Date: 30.07.1996

TEST 21 D

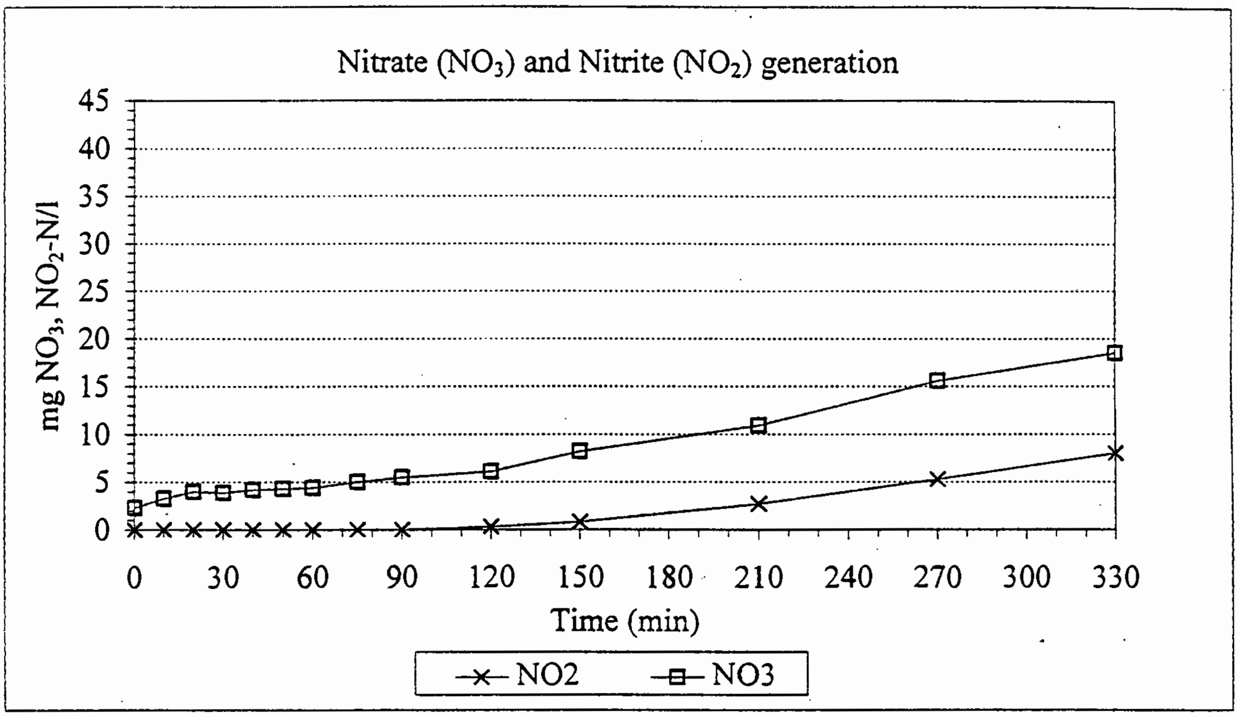
Temperature: 30 C



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

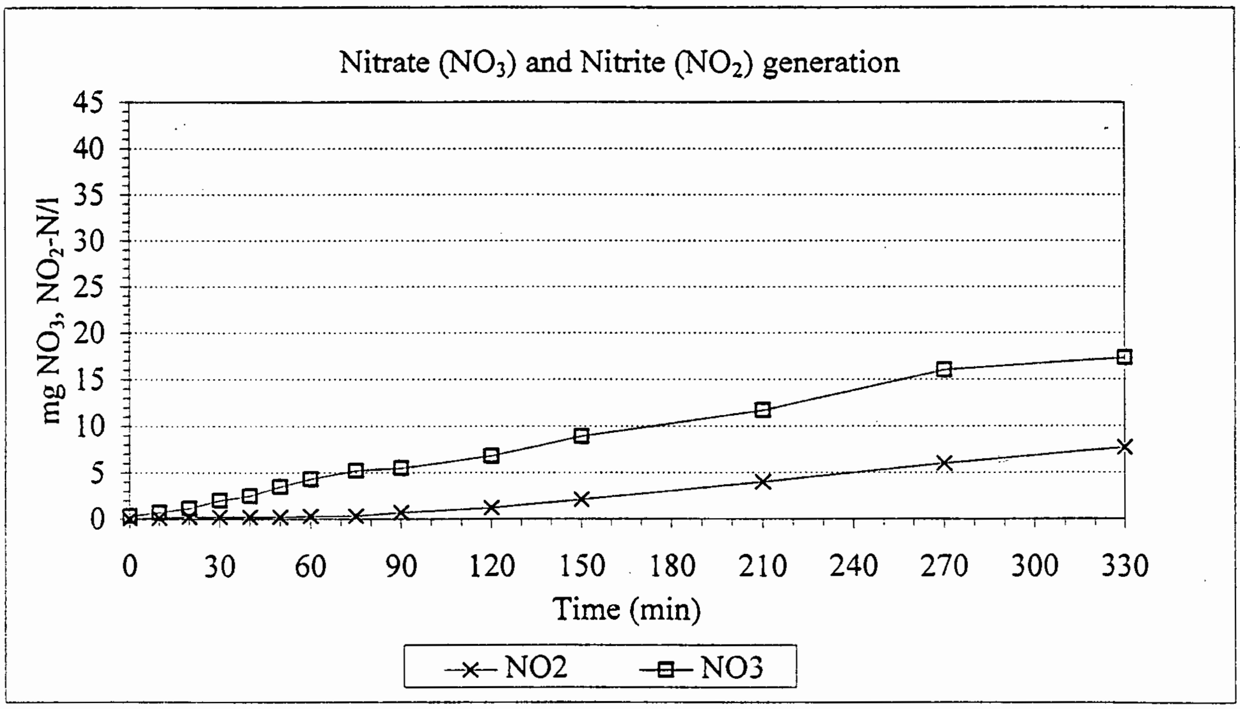
Date: 19.10.1995
Temperature: 30 C

TEST 1 N



Date: 26.10.1995
Temperature: 30 C

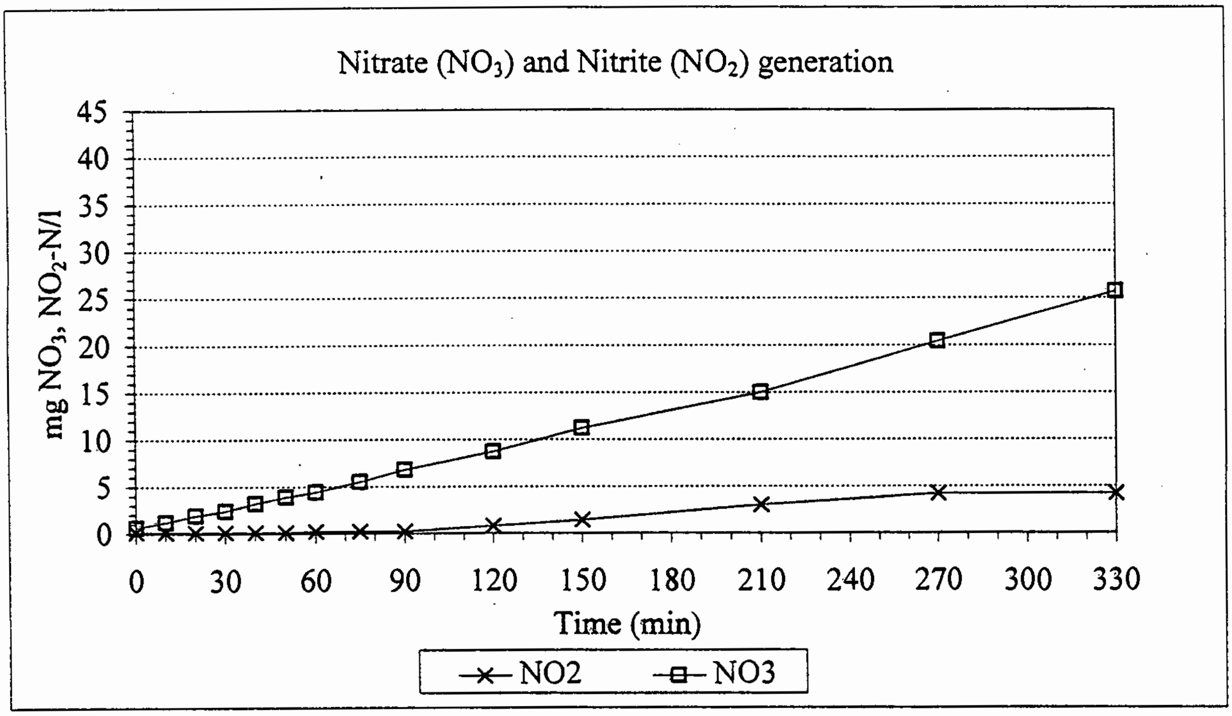
TEST 2 N



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

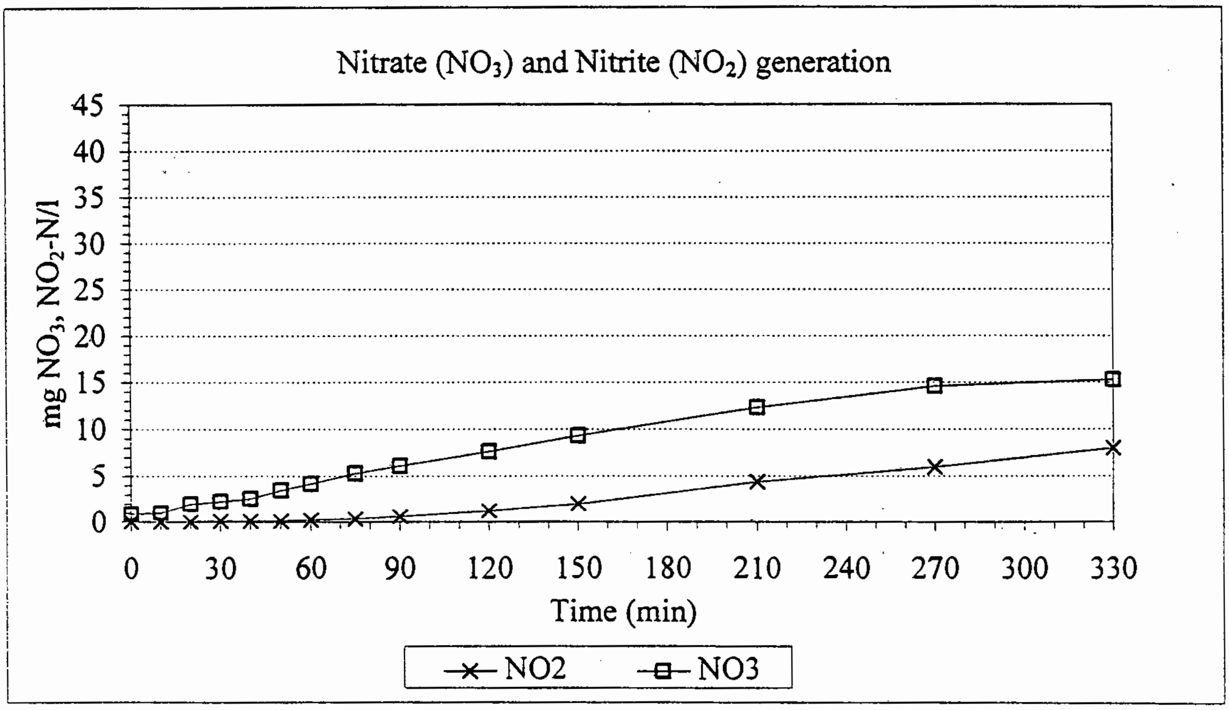
Date: 02.11.1995
Temperature: 30 C

TEST 3 N



Date: 04.11.1995
Temperature: 30 C

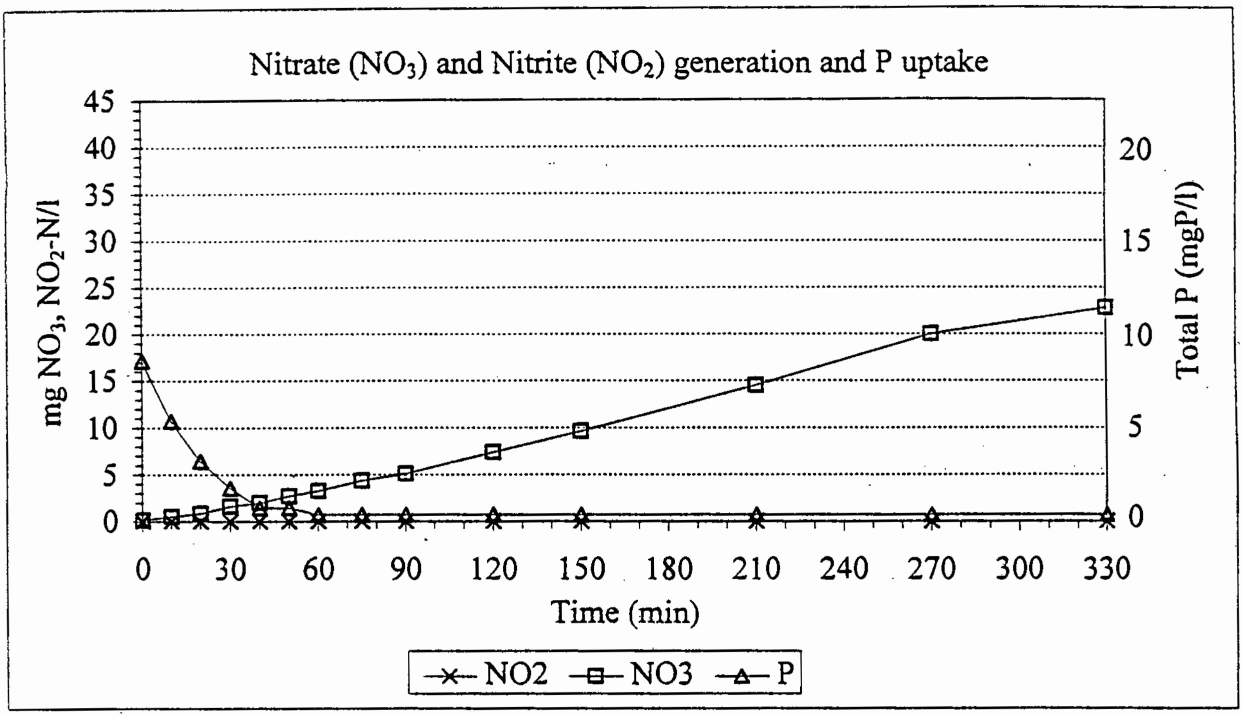
TEST 4 N



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

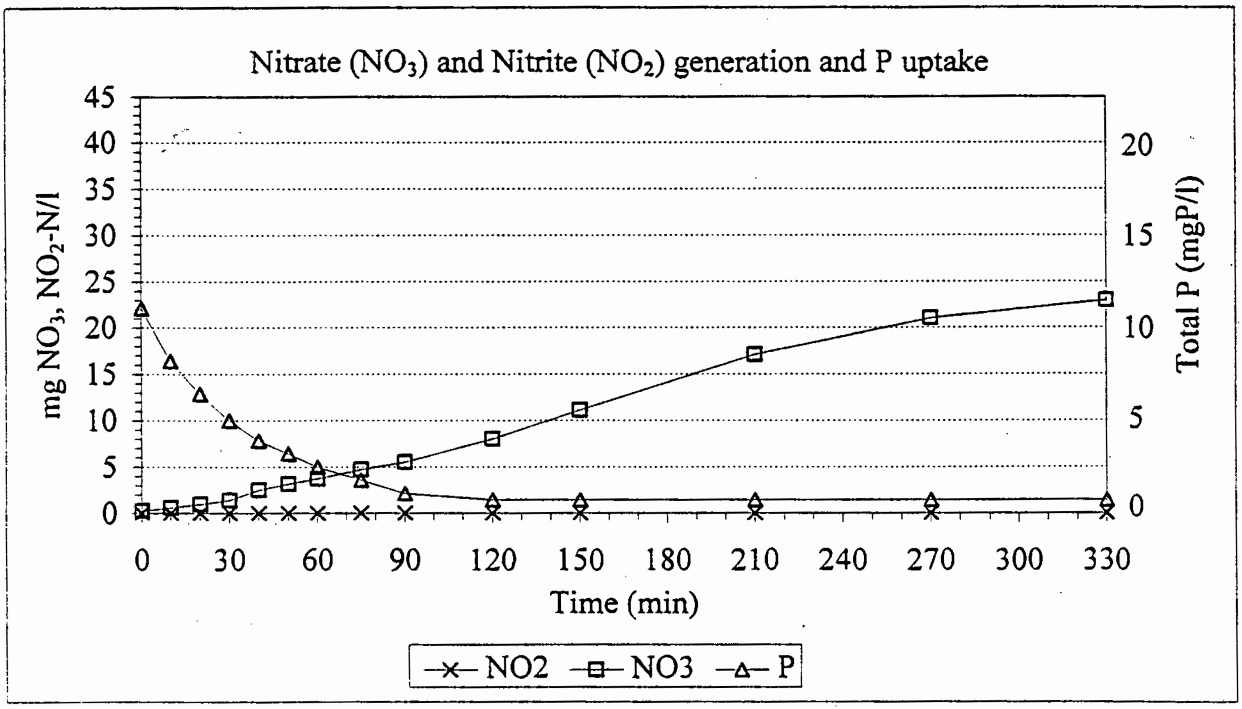
Date: 11.12.1995
Temperature: 30 C

TEST 5 N P up



Date: 18.12.1995
Temperature: 30 C

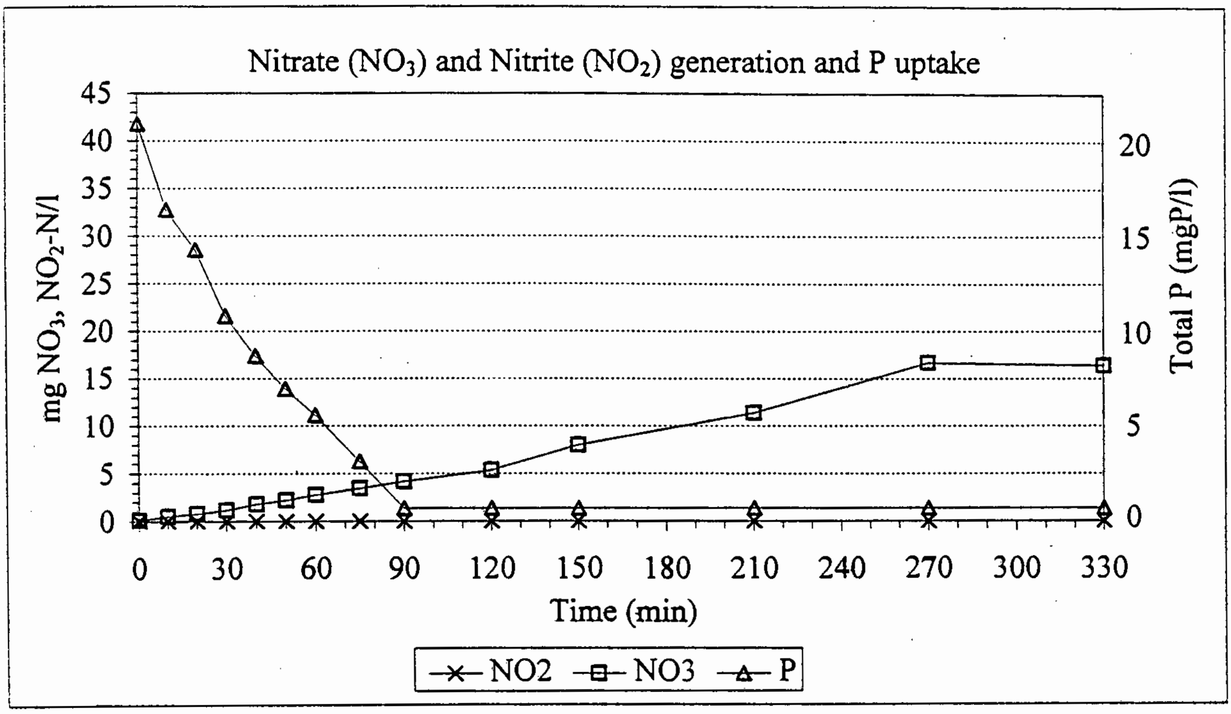
TEST 6 N P up



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

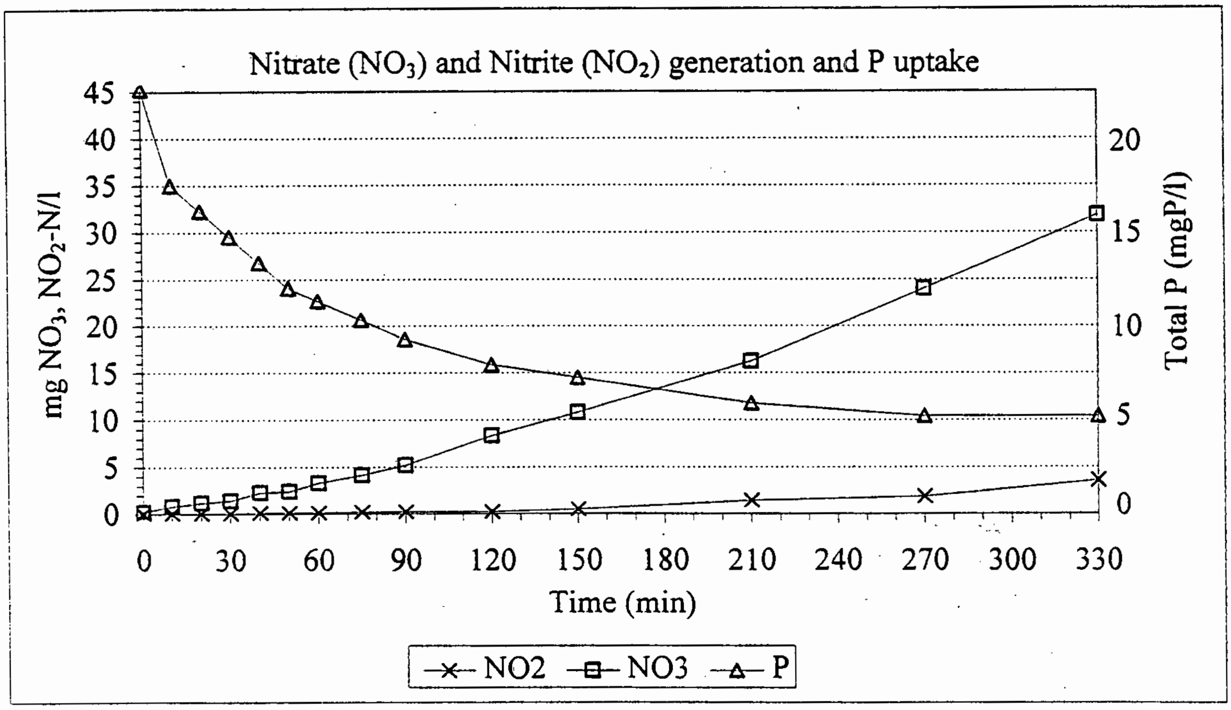
Date: 27.12.1995
Temperature: 30 C

TEST 7 N P up



Date: 01.01.1996
Temperature: 30 C

TEST 8 N P up

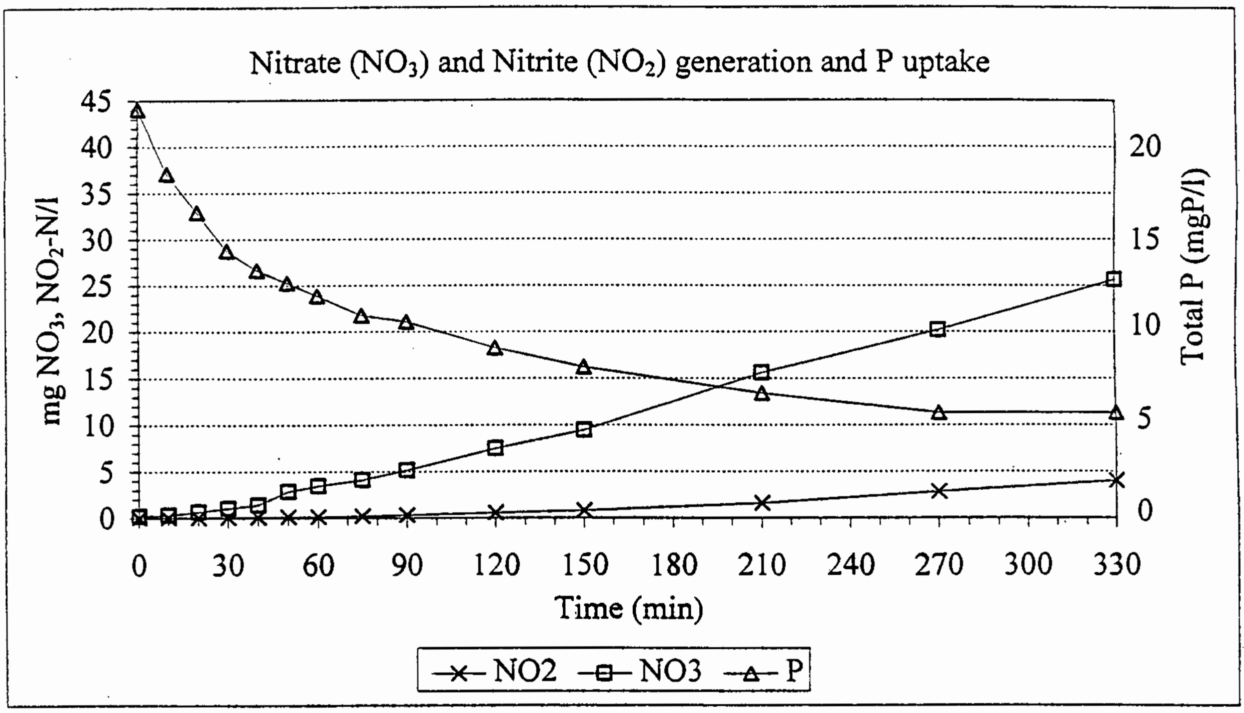


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

Date: 08.01.1996

TEST 9 N P up

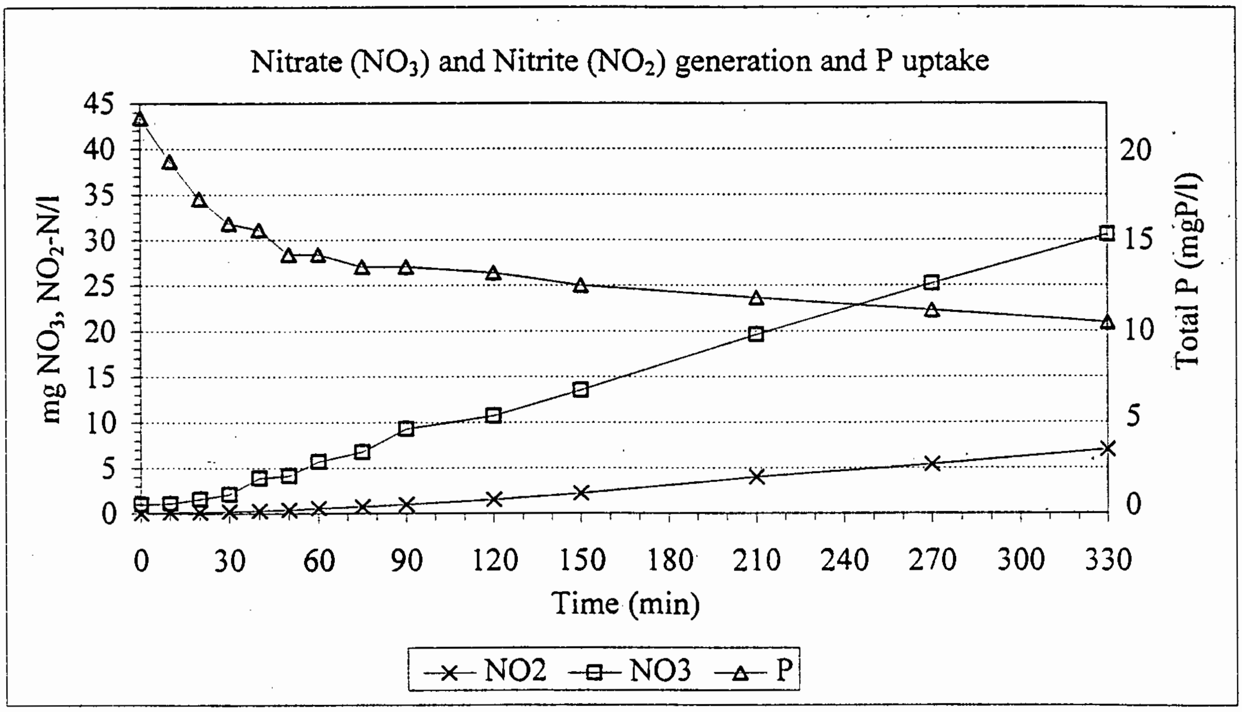
Temperature: 30 C



Date: 20.01.1996

TEST 10 N P up

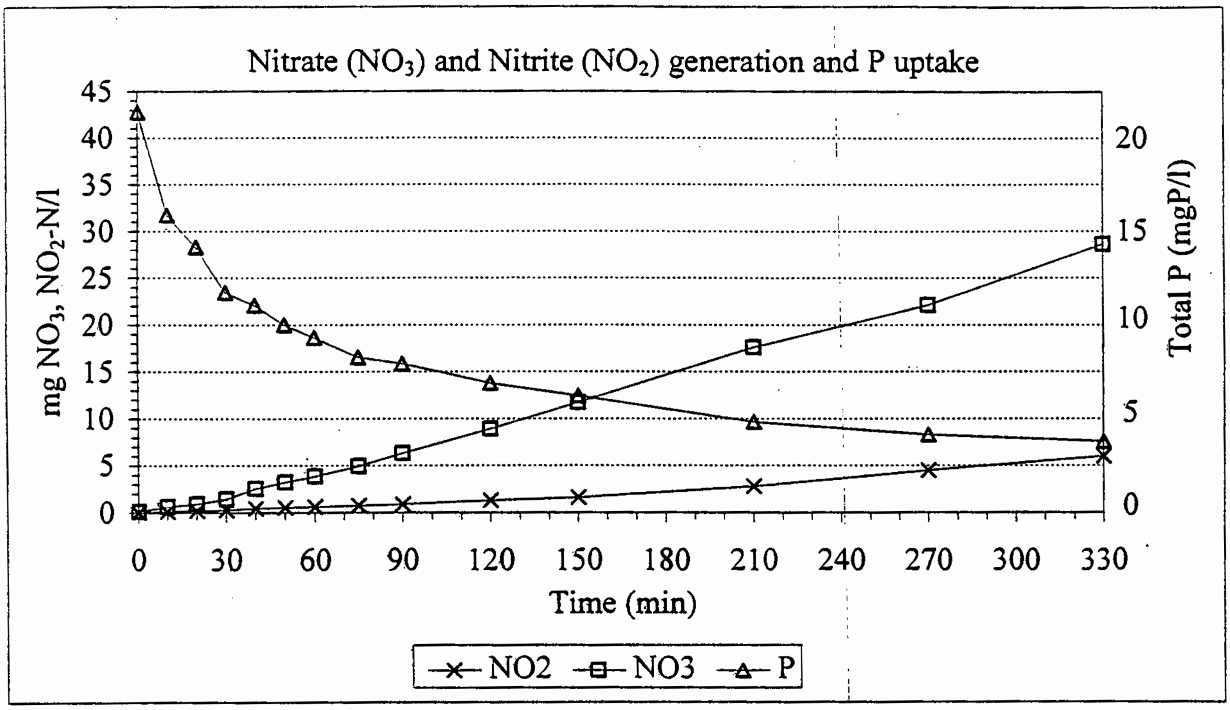
Temperature: 30 C



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

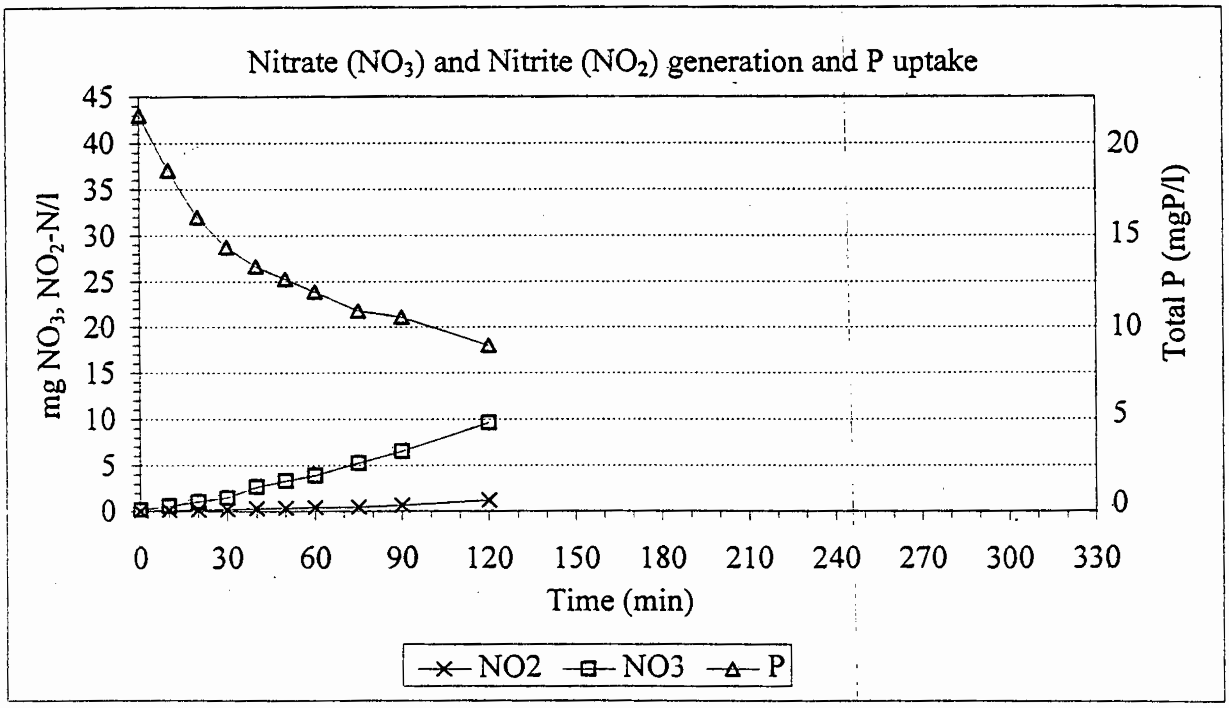
Date: 25.01.1996
Temperature: 30 C

TEST 11 N P up



Date: 27.01.1996
Temperature: 30 C

TEST 12 N P up

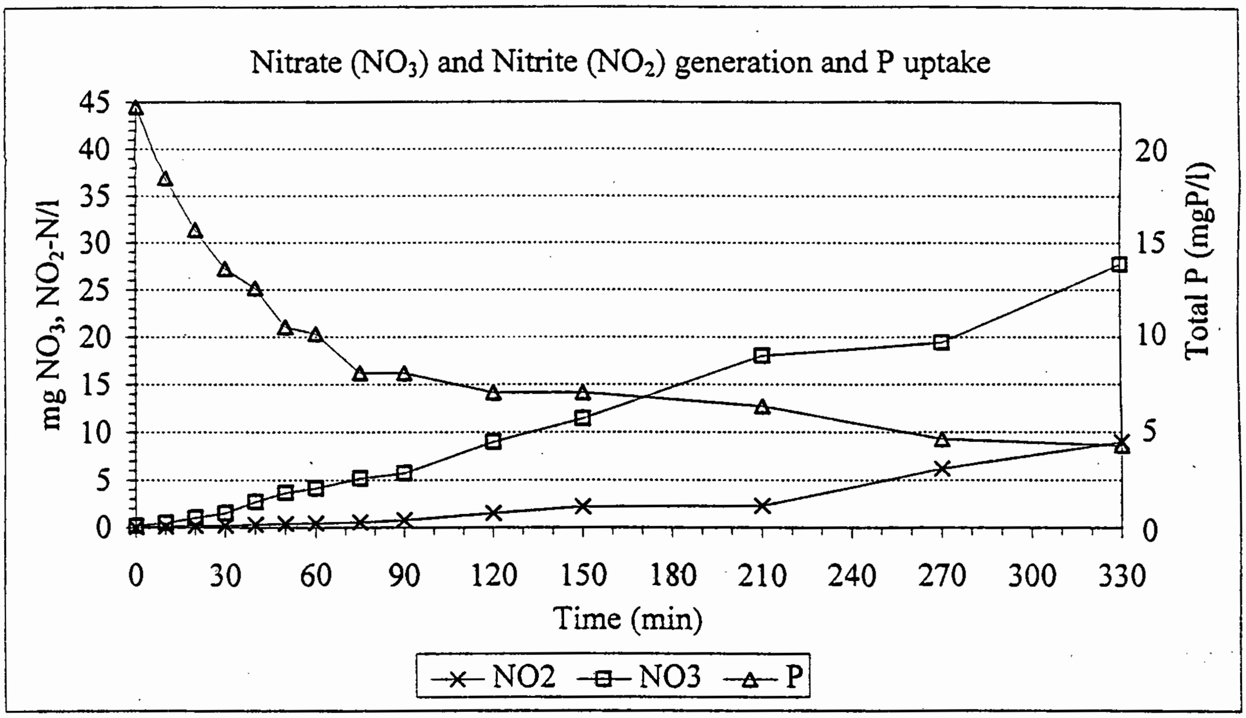


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

Date: 29.01.1996

TEST 13 N P up

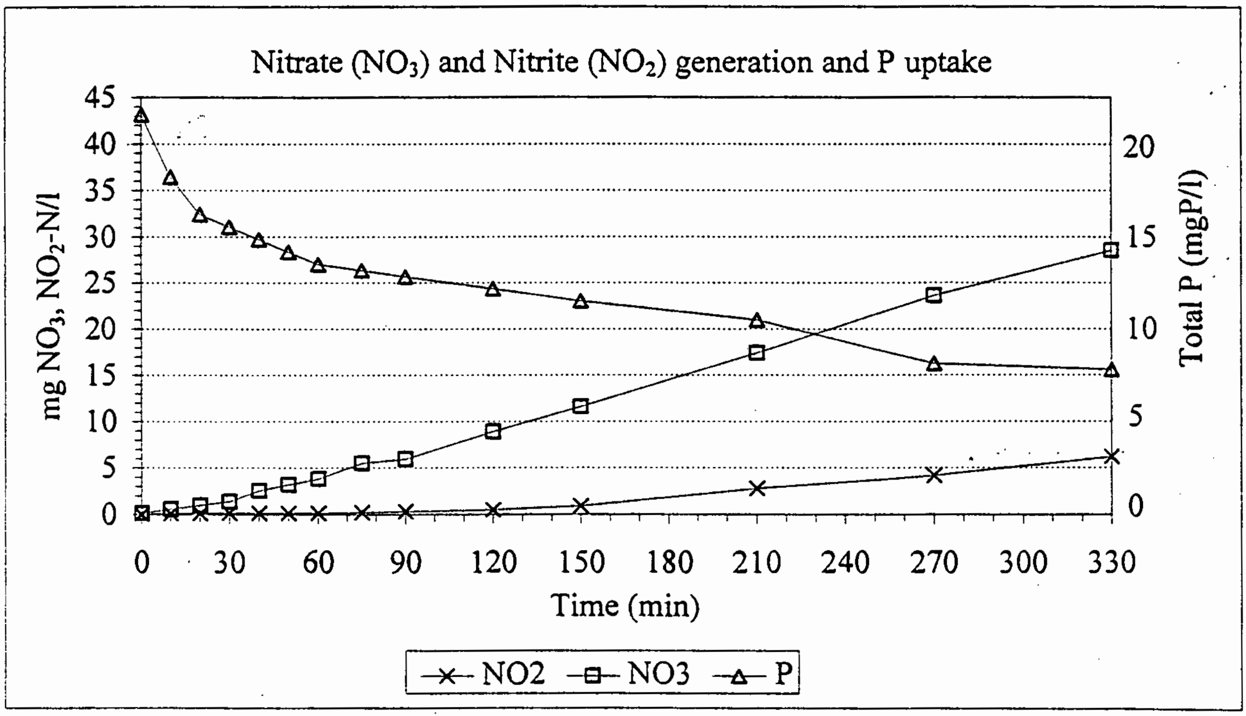
Temperature: 30 C



Date: 16.02.1996

TEST 14 N P up

Temperature: 30 C

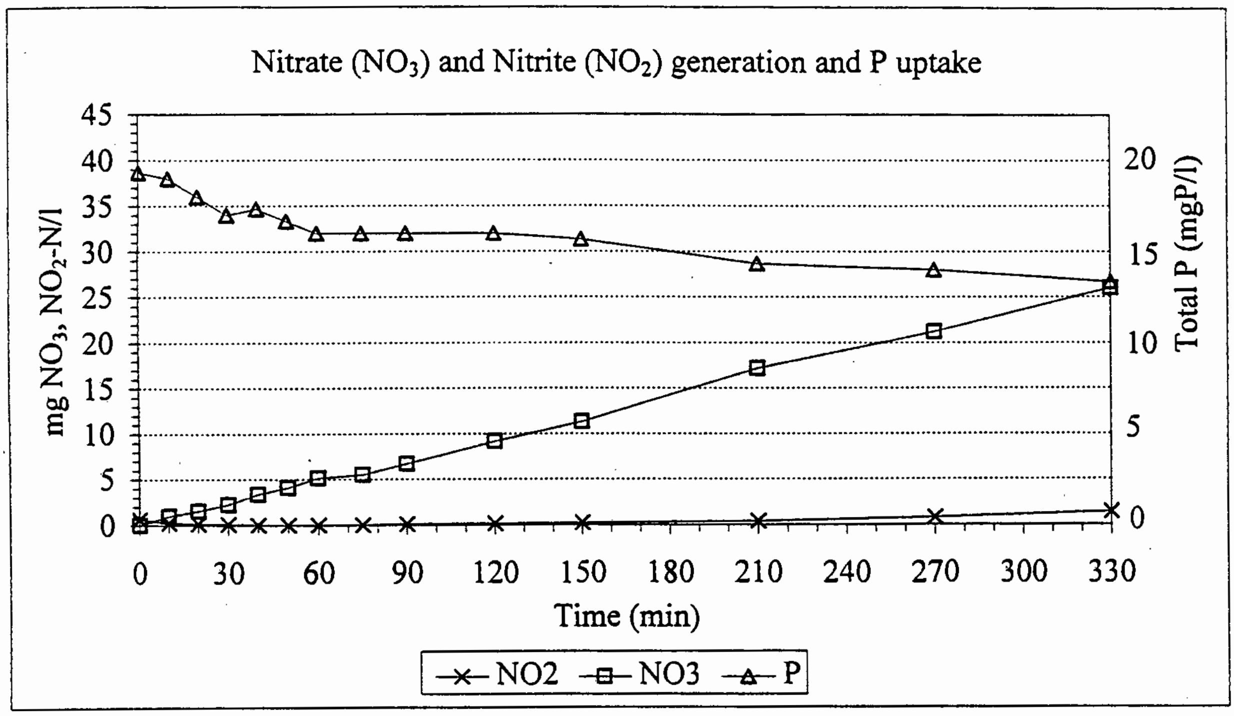


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

Date: 21.05.1996

TEST 15 N P up

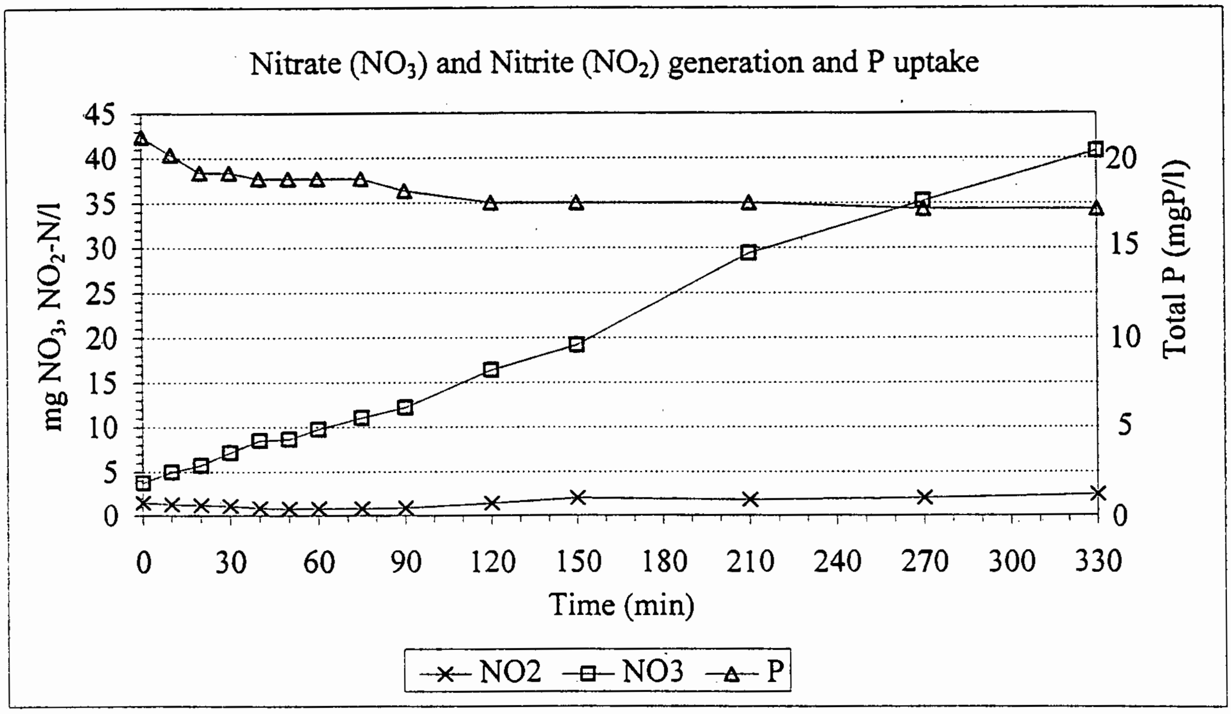
Temperature: 30 C



Date: 27.05.1996

TEST 16 N P up

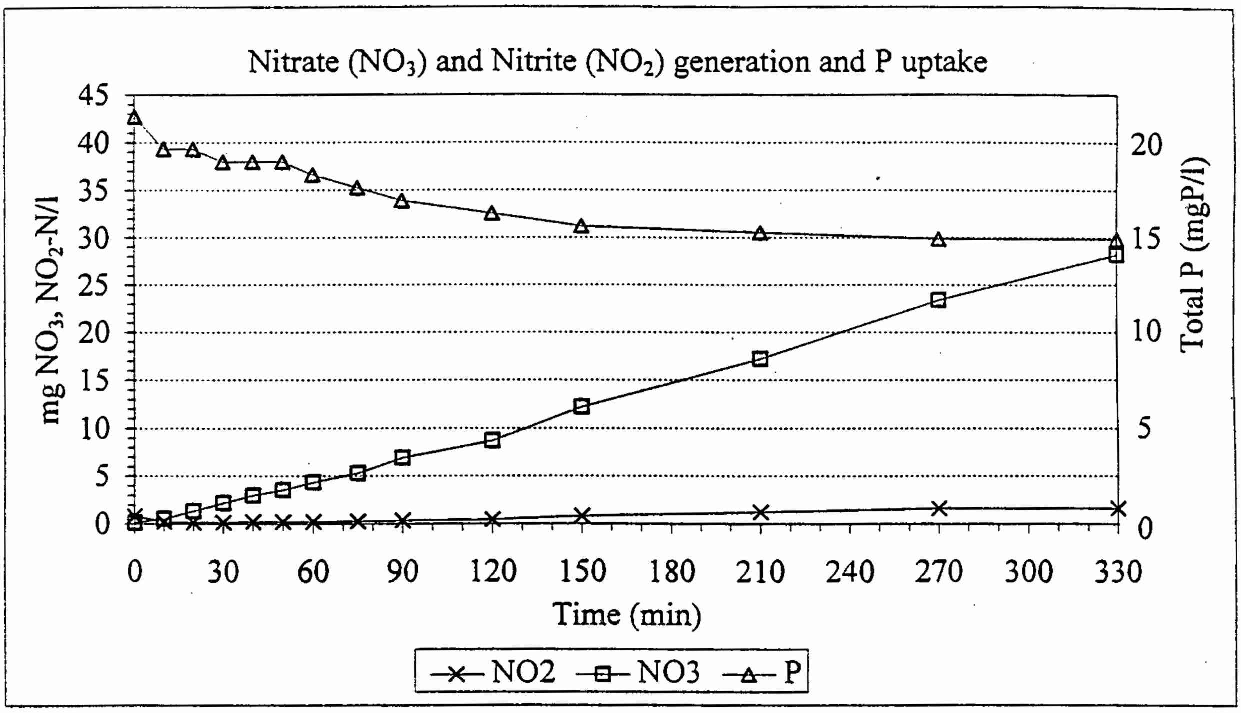
Temperature: 30 C



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

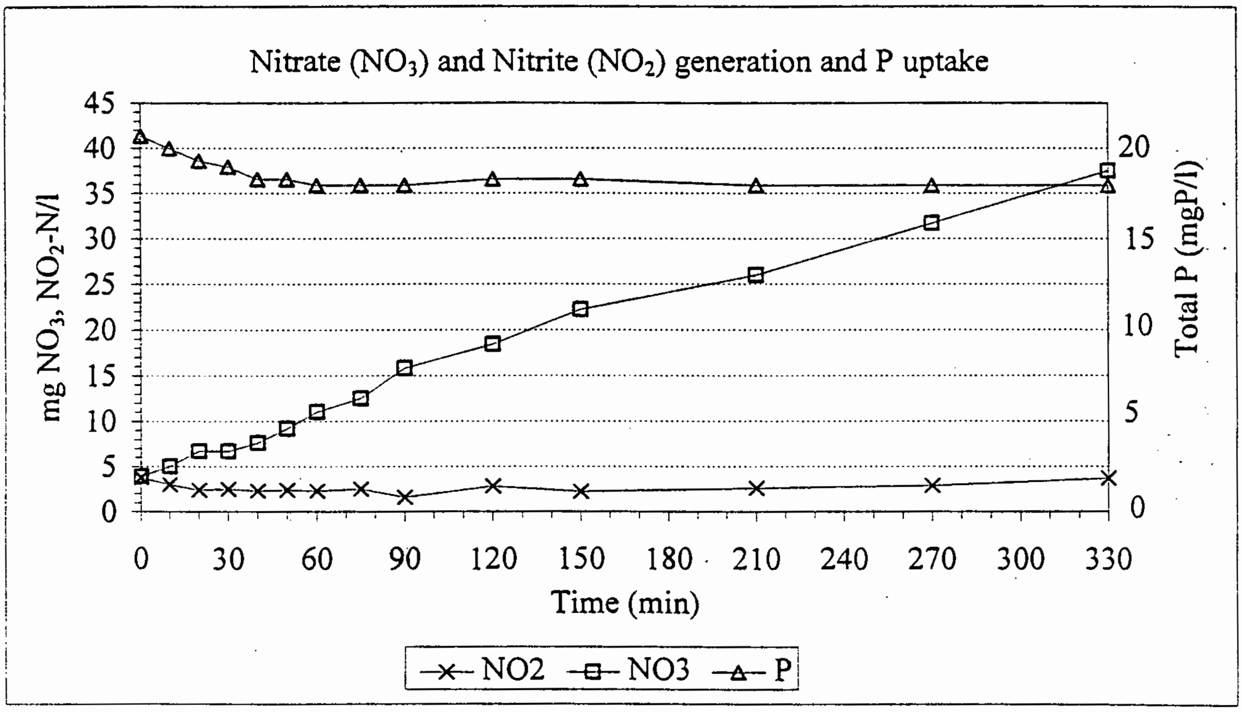
Date: 01.07.1996
Temperature: 30 C

TEST 17 N P up



Date: 01.08.1996
Temperature: 30 C

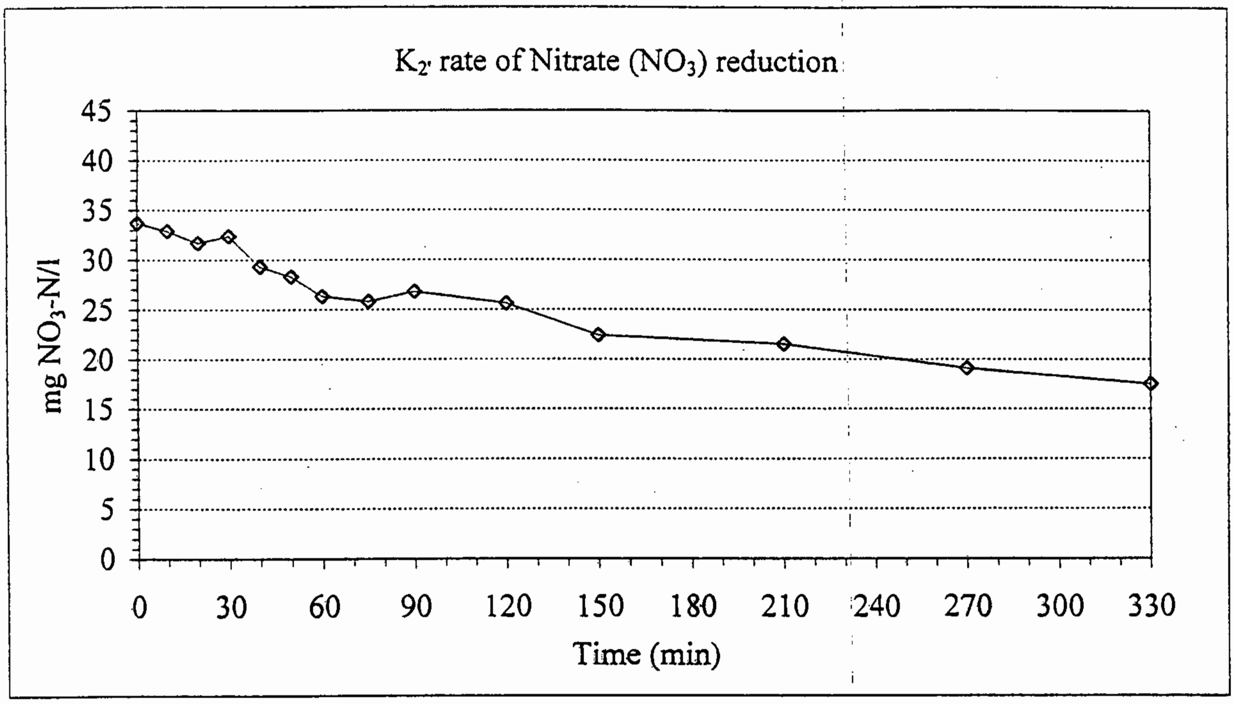
TEST 18 N P up



NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

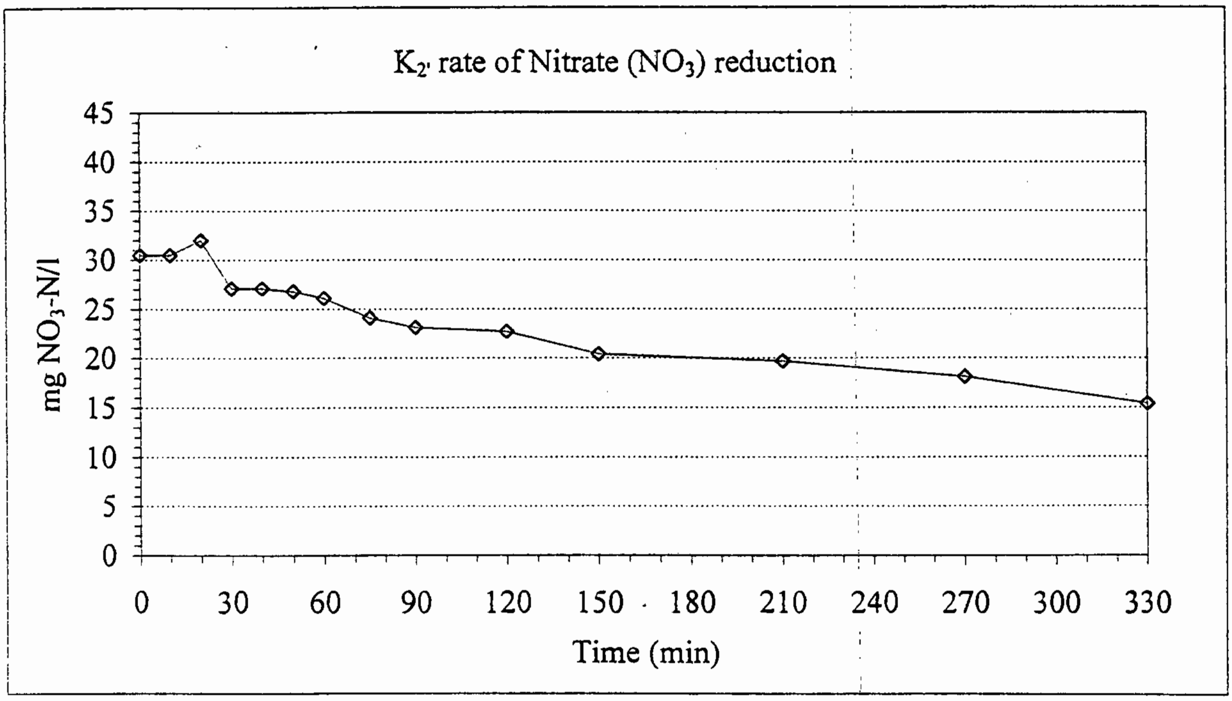
Date: 22.09.1995
Temperature: 30 C

TEST 1 D



Date: 27.09.1995
Temperature: 30 C

TEST 2 D

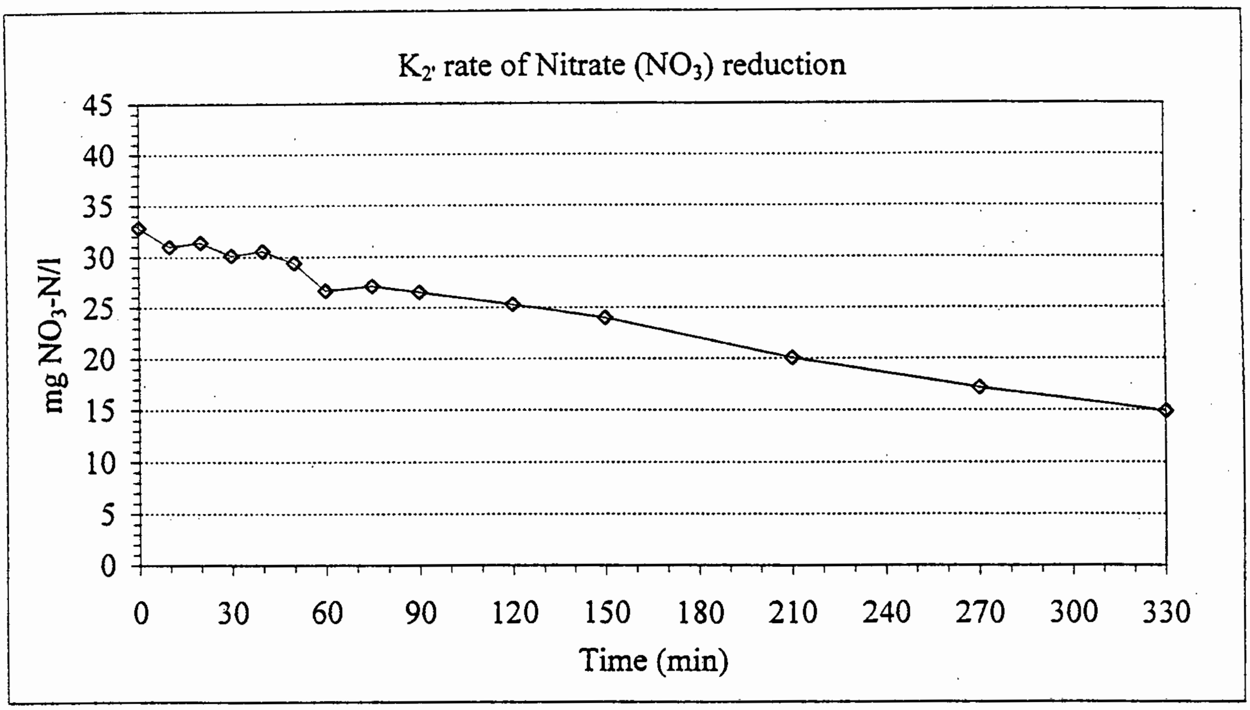


NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 02.10.1995

Temperature: 30 C

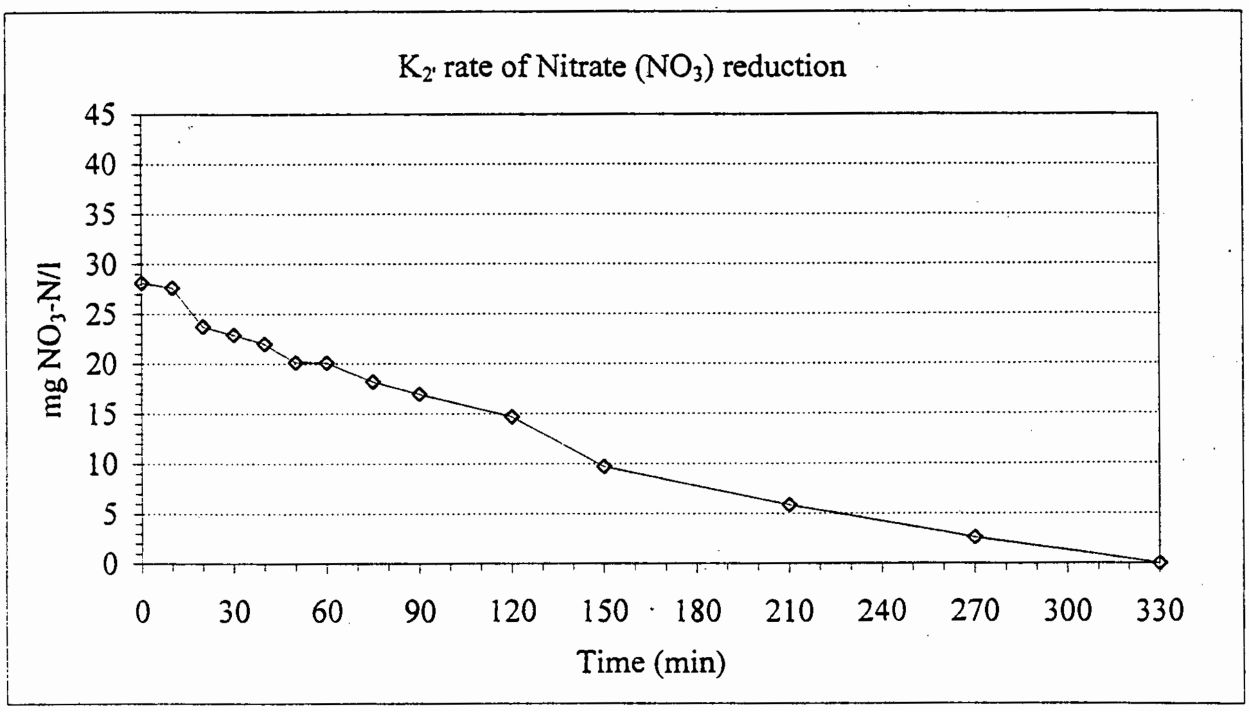
TEST 3 D



Date: 06.10.1995

Temperature: 30 C

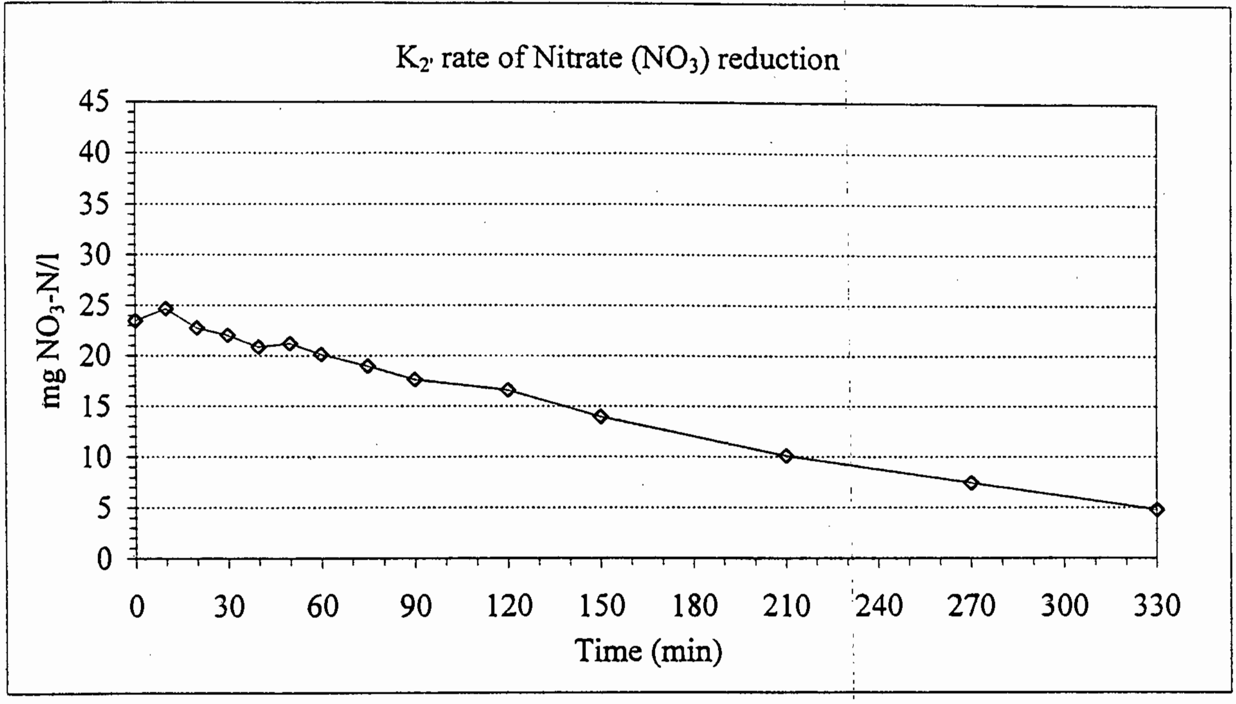
TEST 4 D



NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

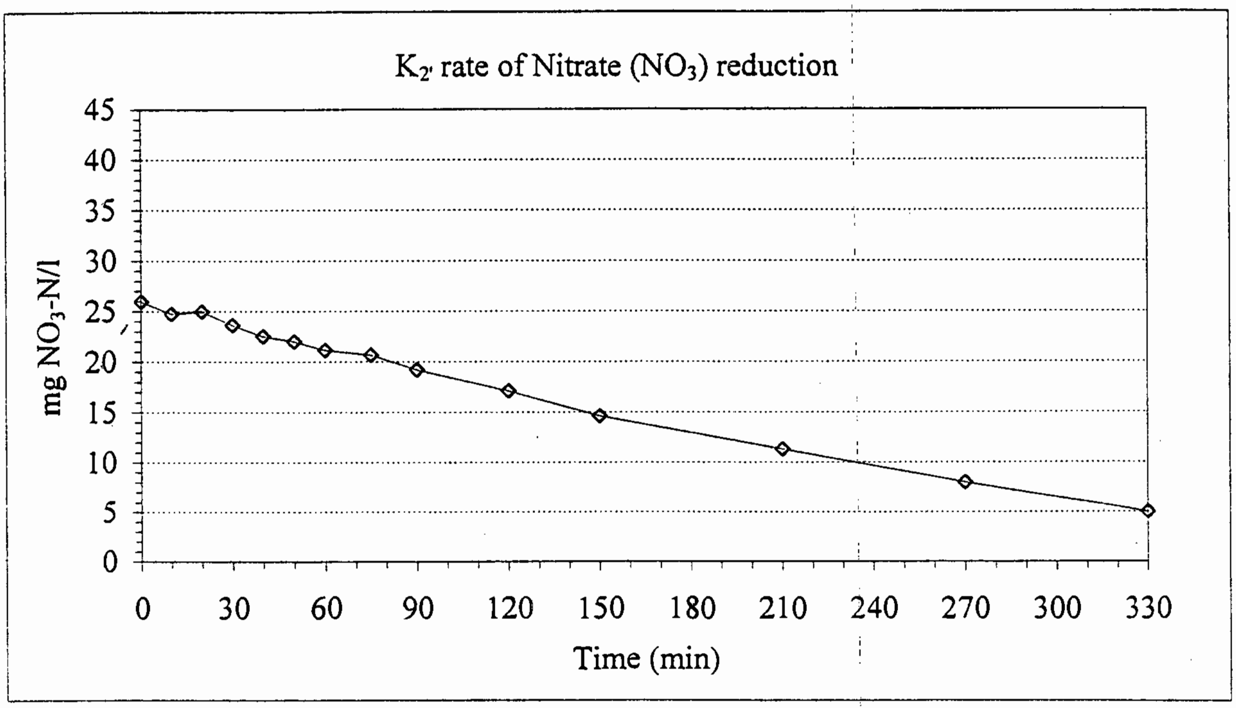
Date: 11.10.1995
Temperature: 30 C

TEST 5 D



Date: 16.10.1995
Temperature: 30 C

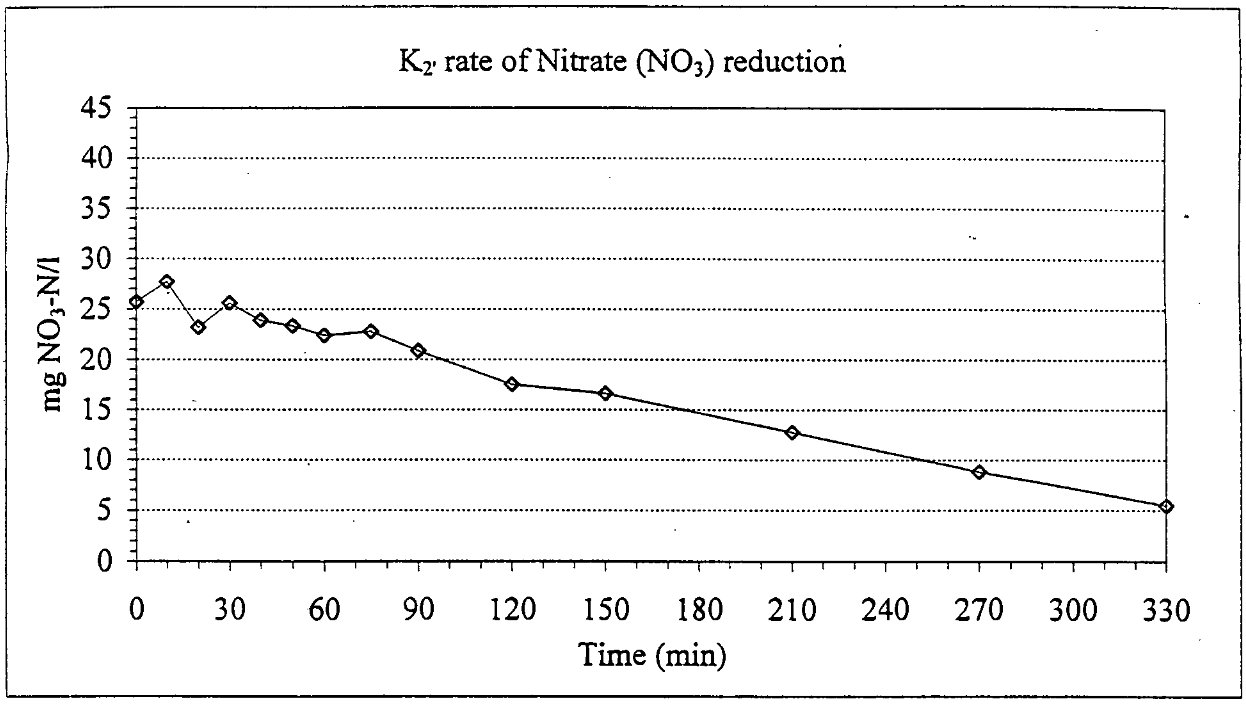
TEST 6 D



NITRATE CONCENTRATION VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

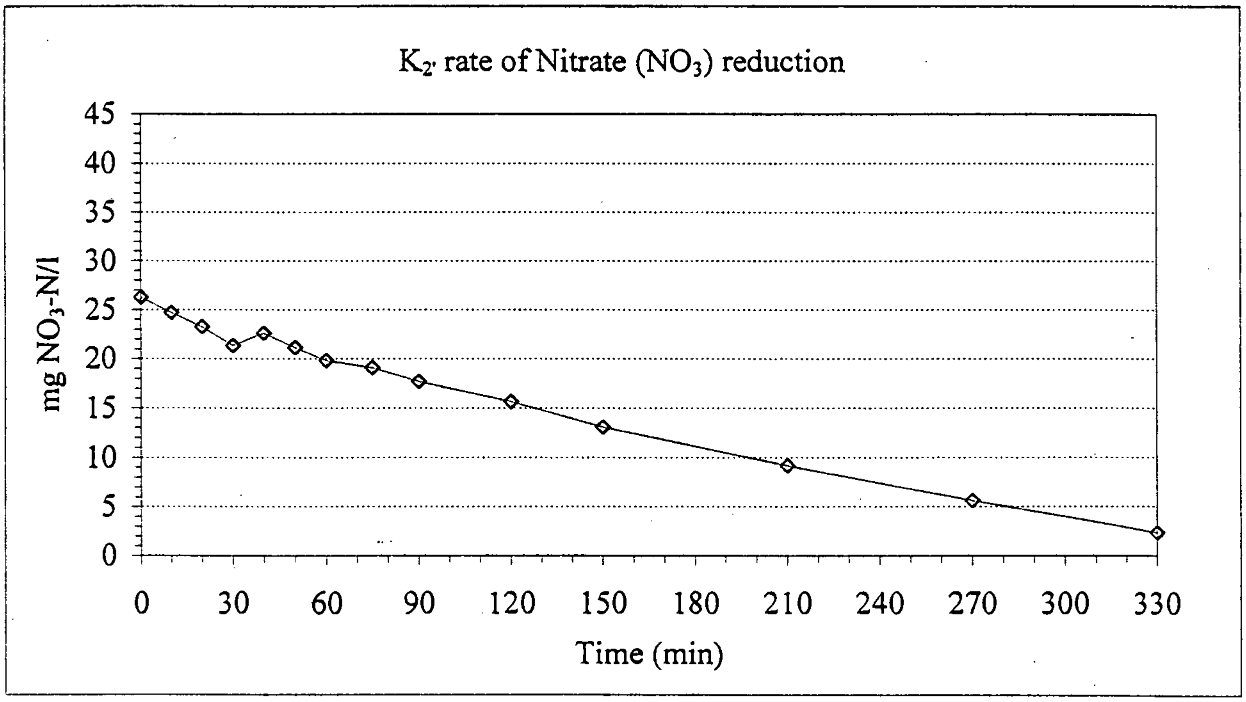
Date: 23.10.1995
Temperature: 30 C

TEST 7 D



Date: 30.10.1995
Temperature: 30 C

TEST 8 D

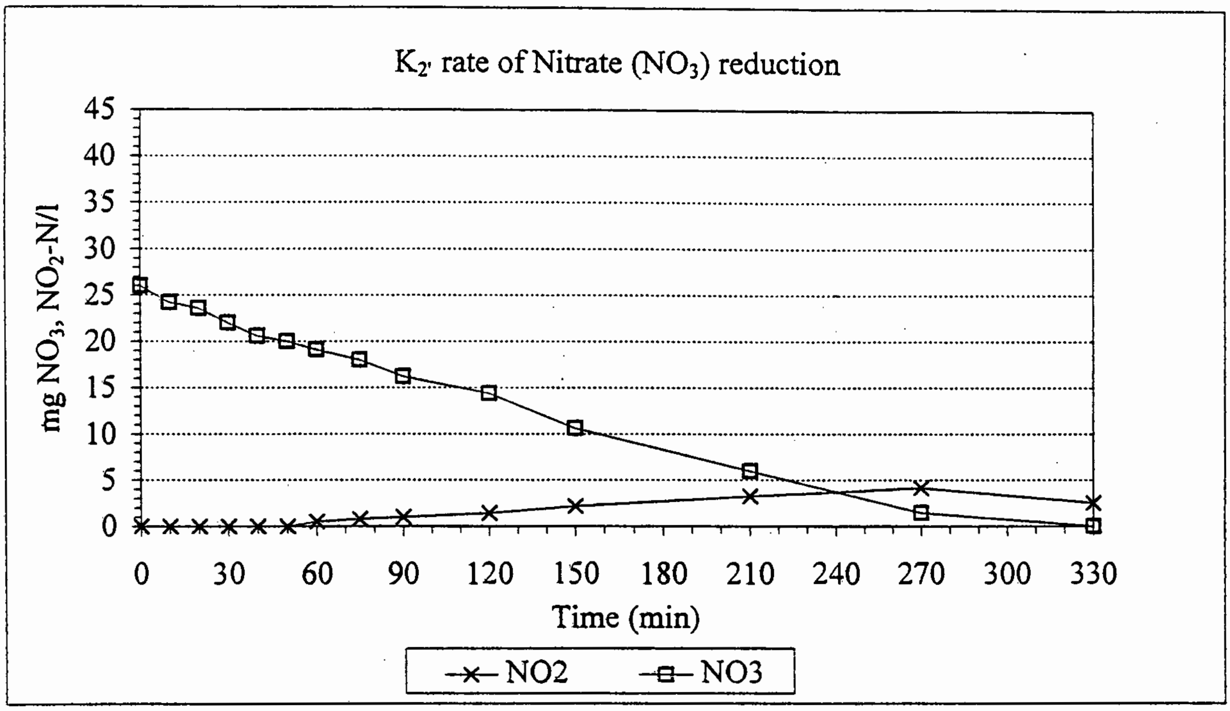


NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 07.12.1995

TEST 9 D

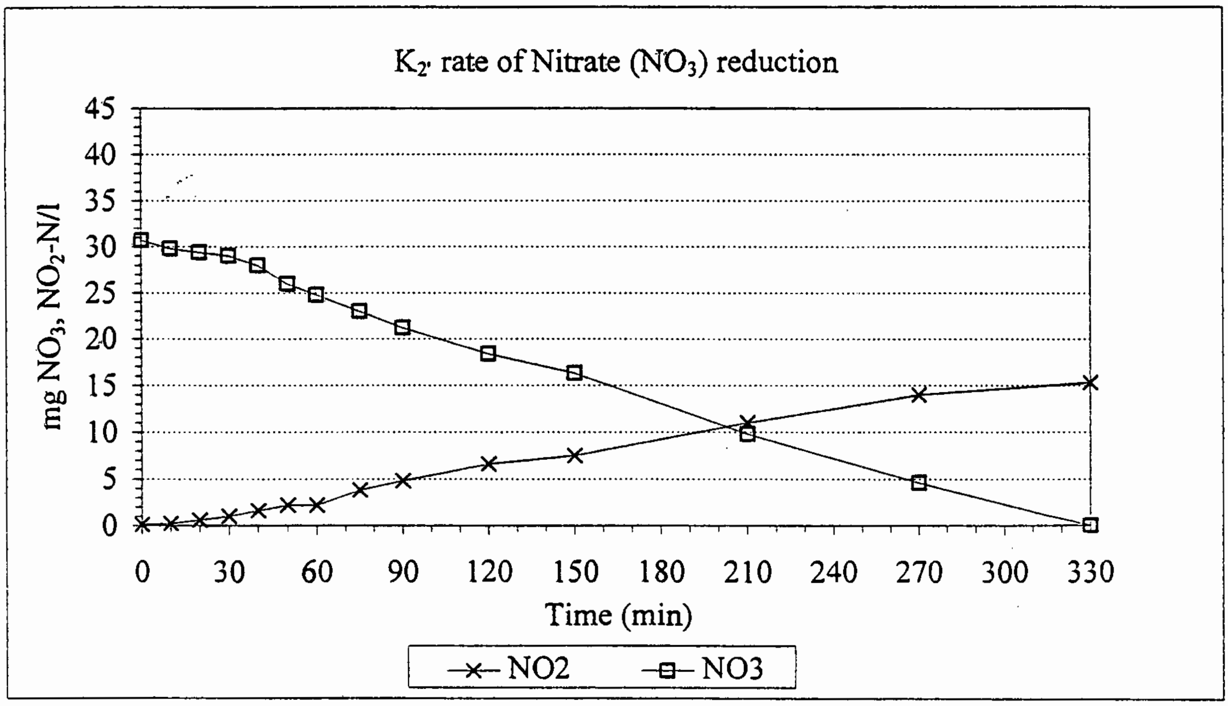
Temperature: 30 C



Date: 14.11.1996

TEST 10 D

Temperature: 30 C

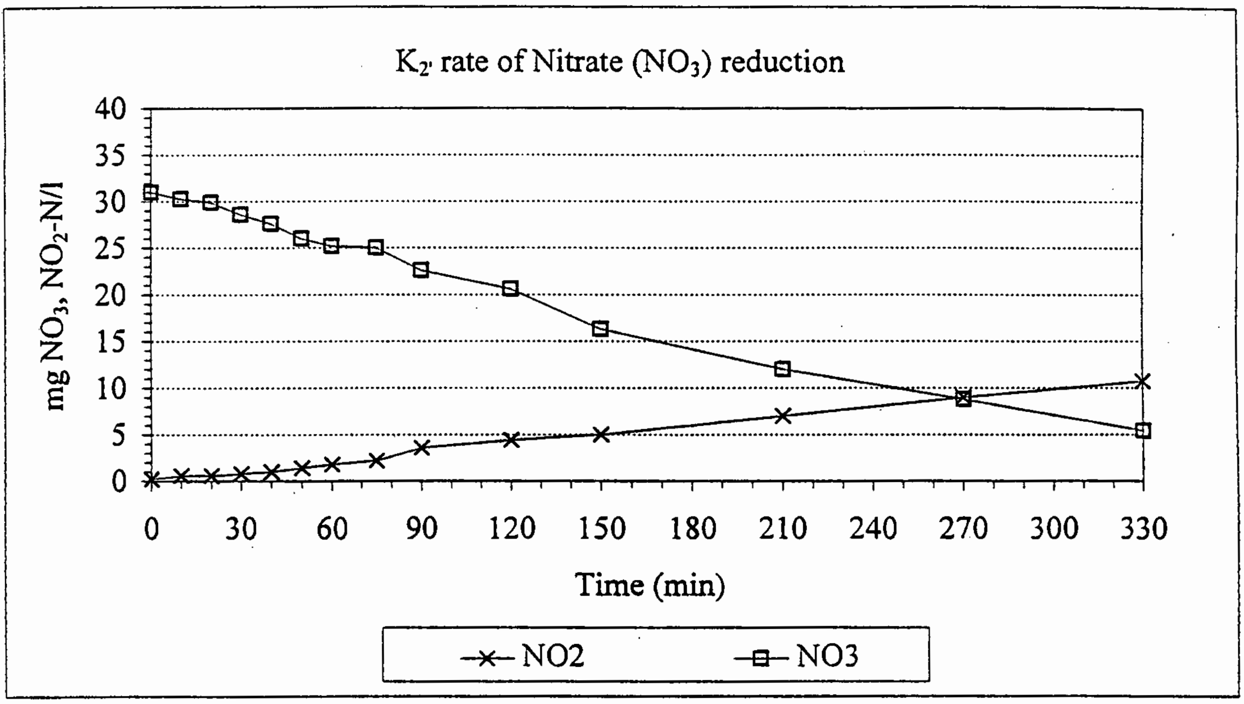


NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 19.11.1996

TEST 11 D

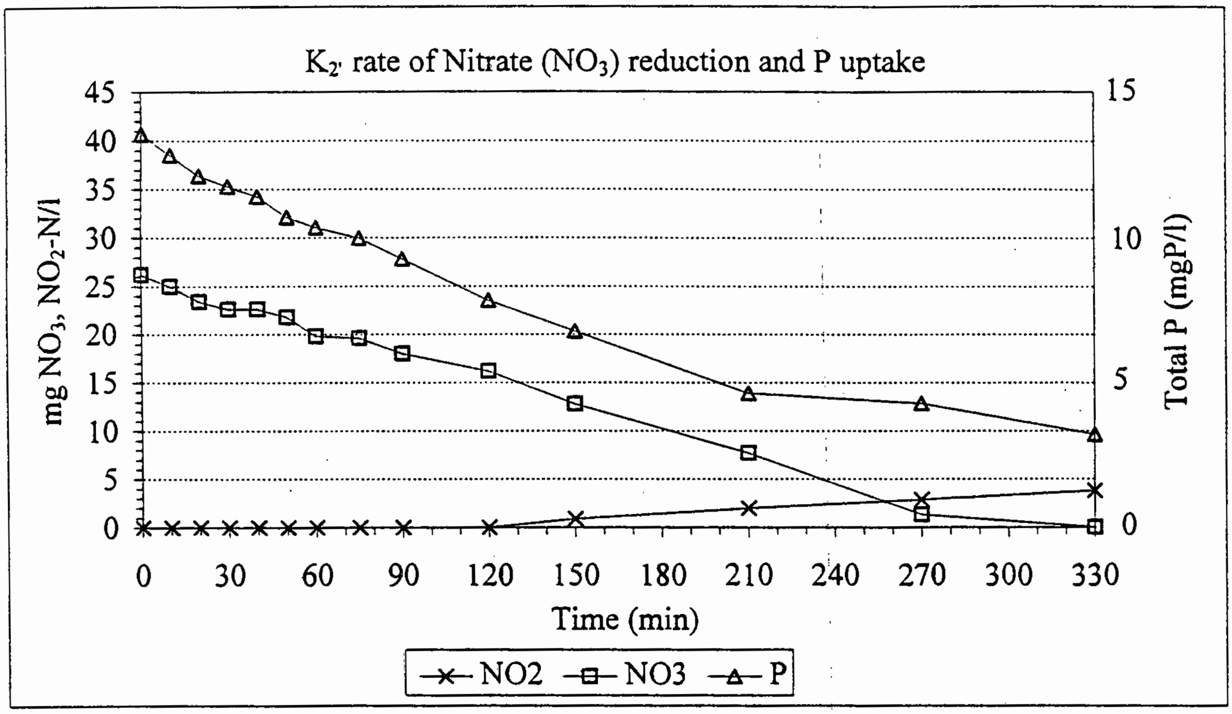
Temperature: 30 C



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

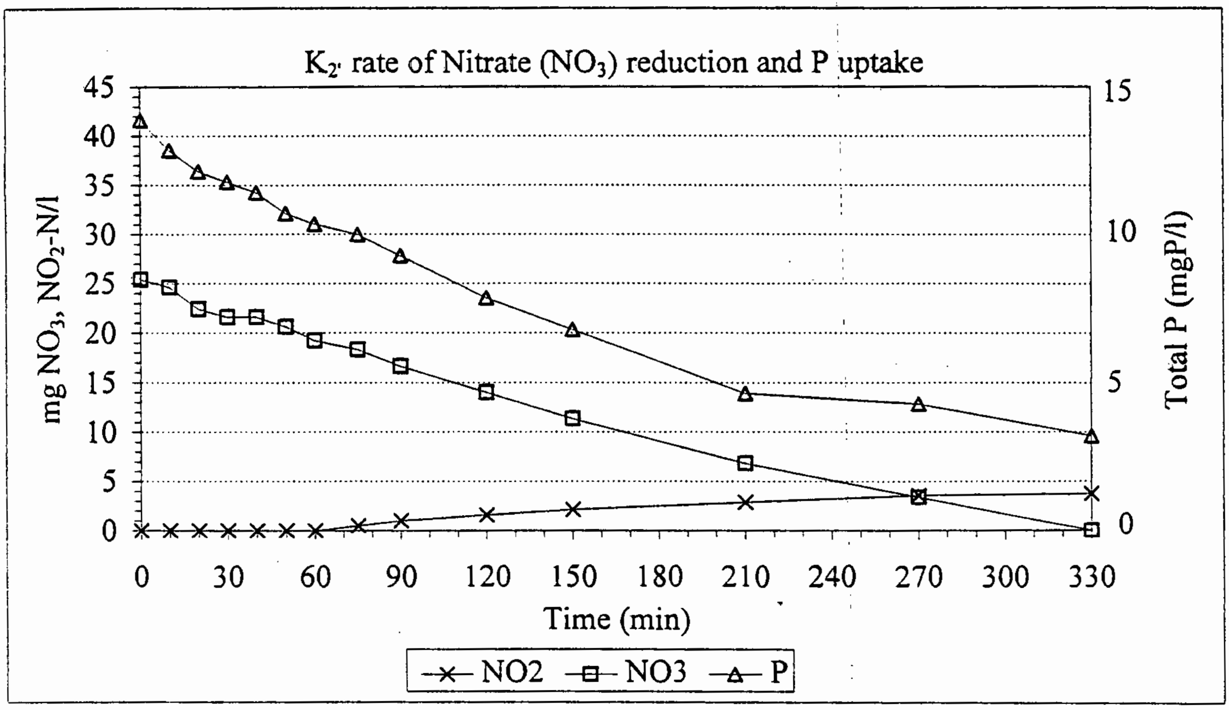
Date: 14.12.1995
Temperature: 30 C

TEST 12 D P up



Date: 21.12.1995
Temperature: 30 C

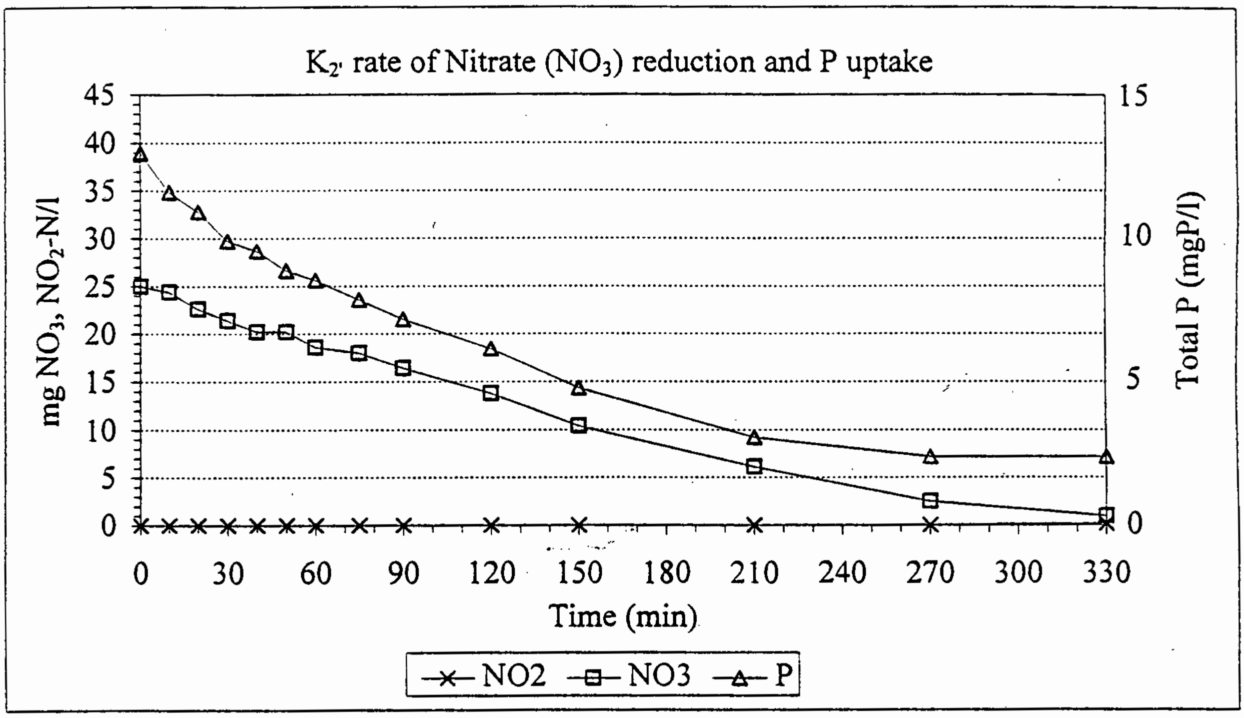
TEST 13 D P up



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

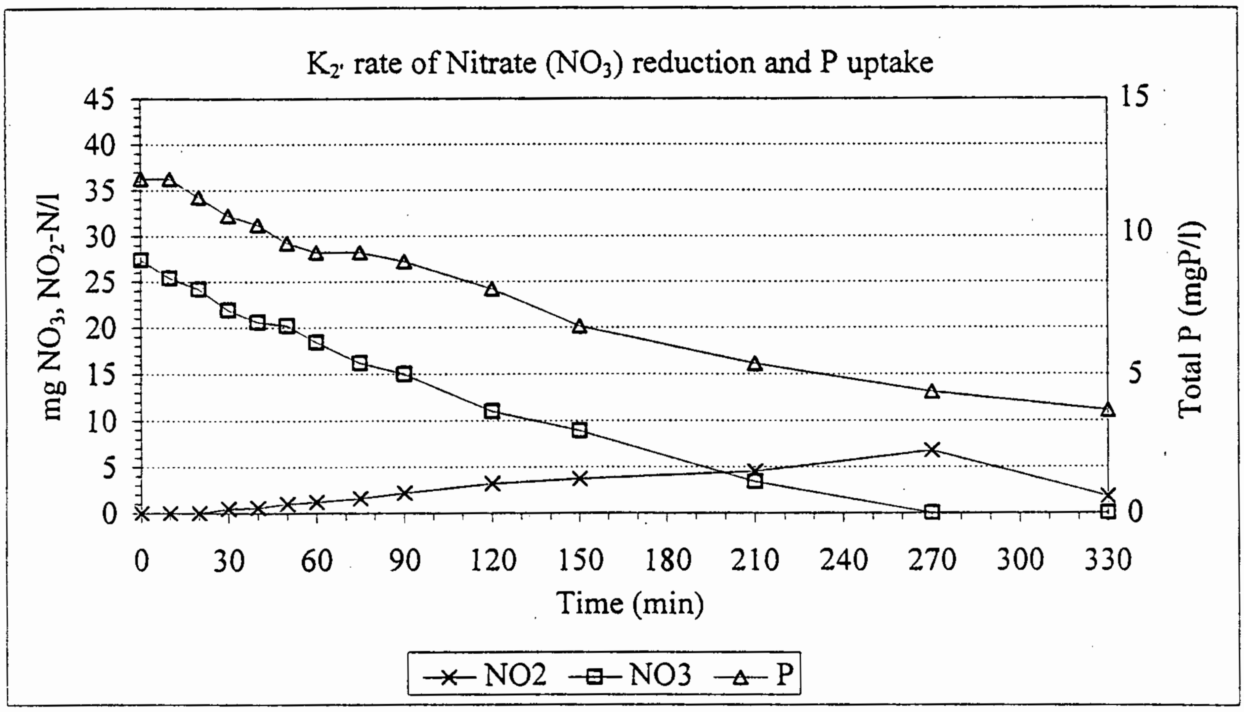
Date: 30.12.1995
Temperature: 30 C

TEST 14 D P up



Date: 04.01.1996
Temperature: 30 C

TEST 15 D P up

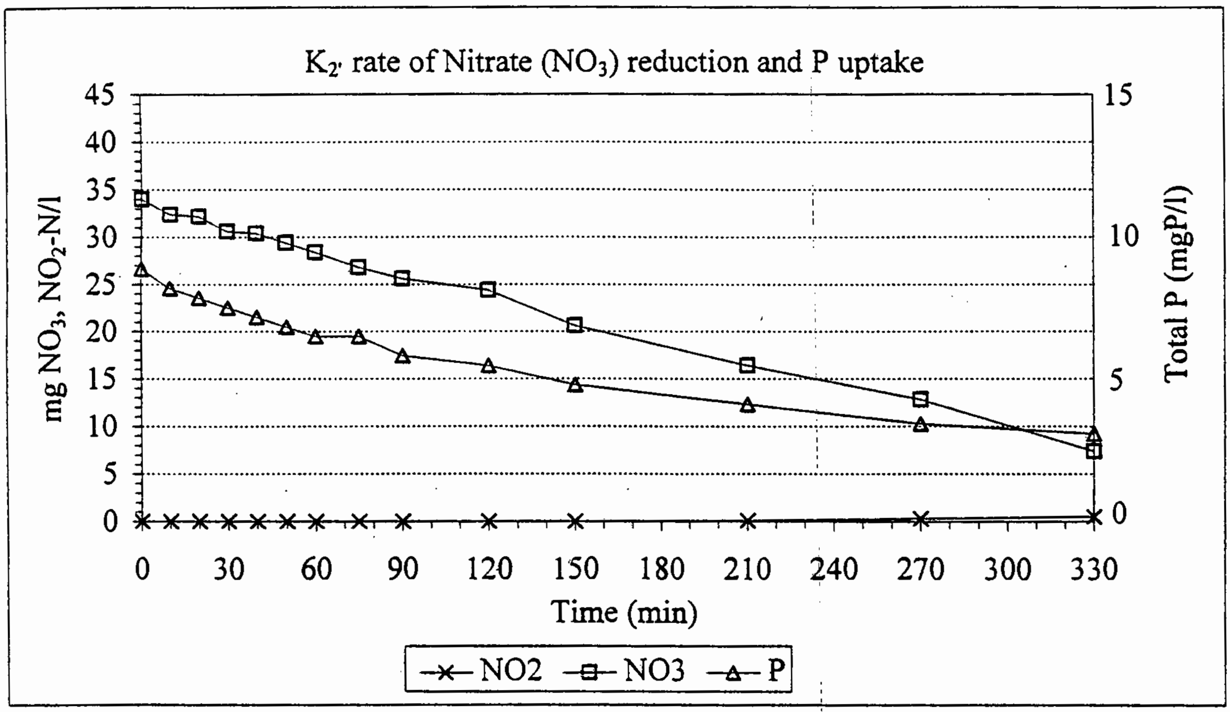


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 11.01.1996

TEST 16 D P up

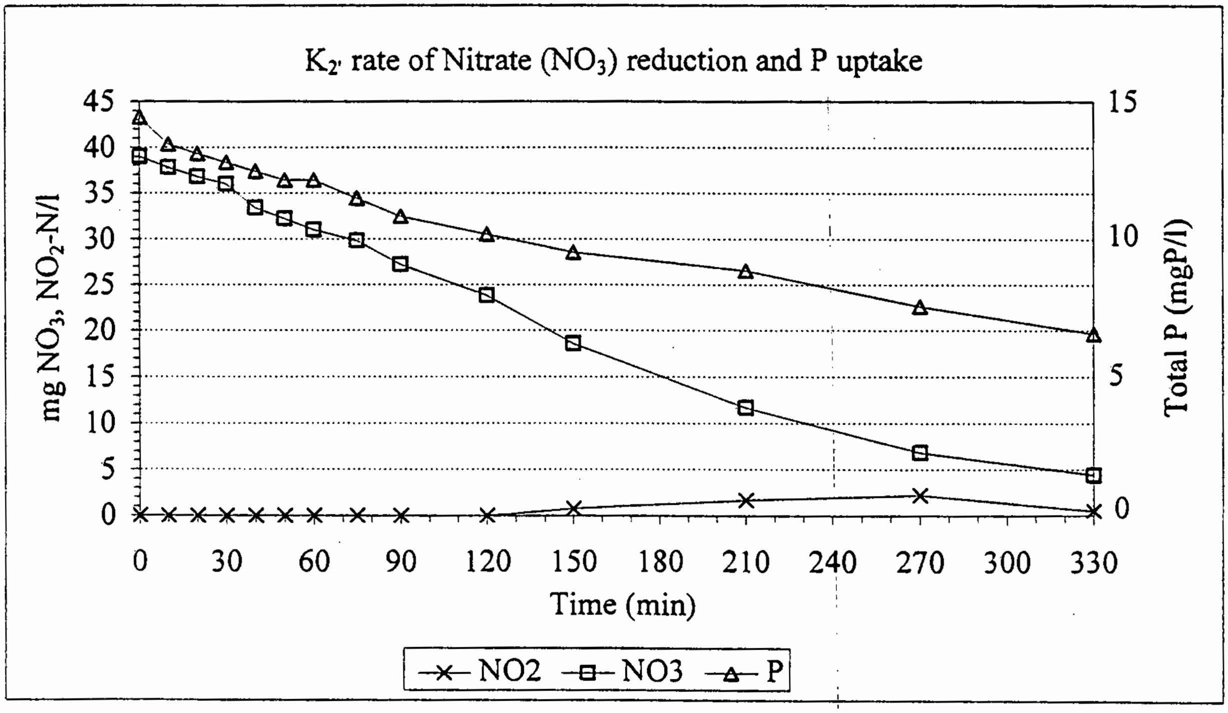
Temperature: 30 C



Date: 15.01.1996

TEST 17 D P up

Temperature: 30 C

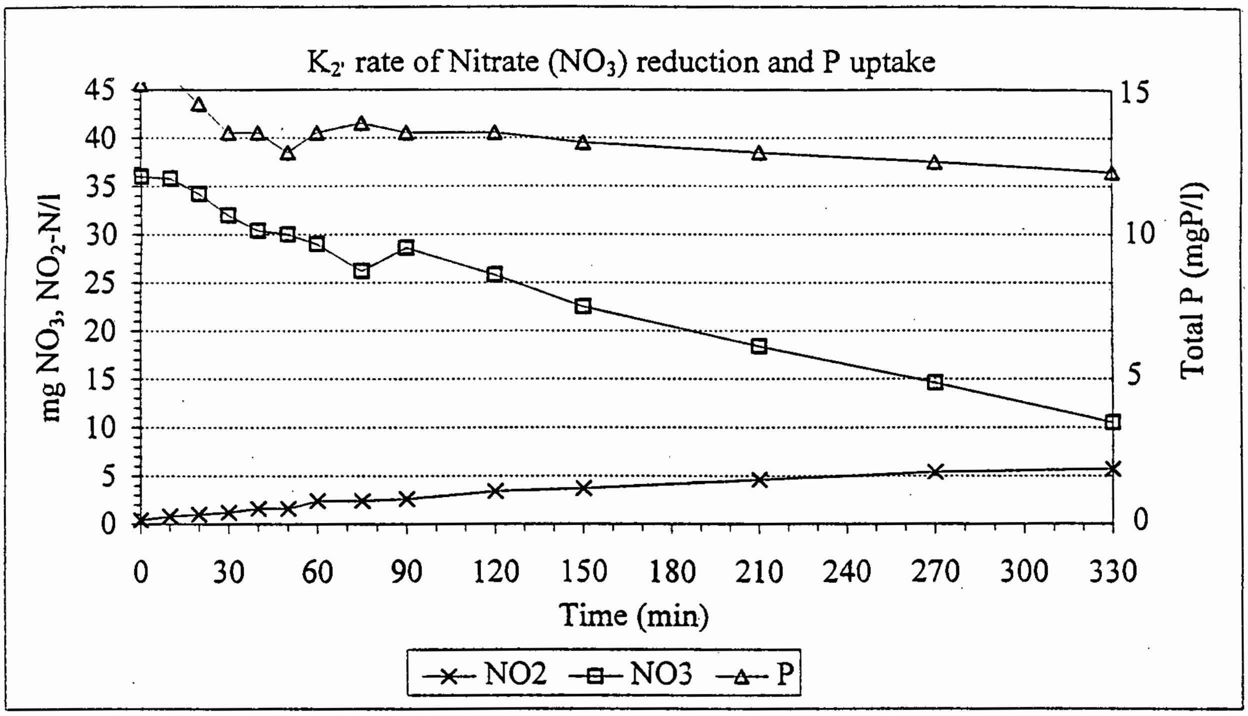


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 10.05.1996

Temperature: 30 C

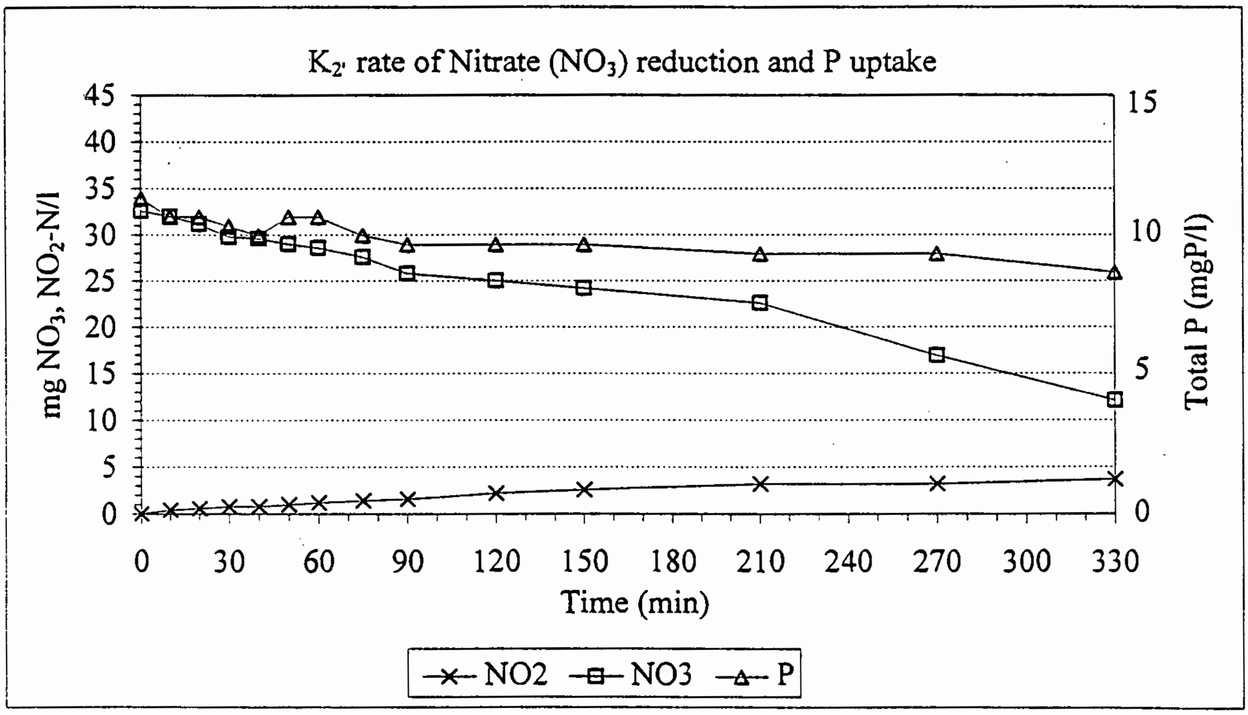
TEST 18 D P up



Date: 17.05.1996

Temperature: 30 C

TEST 19 D P up

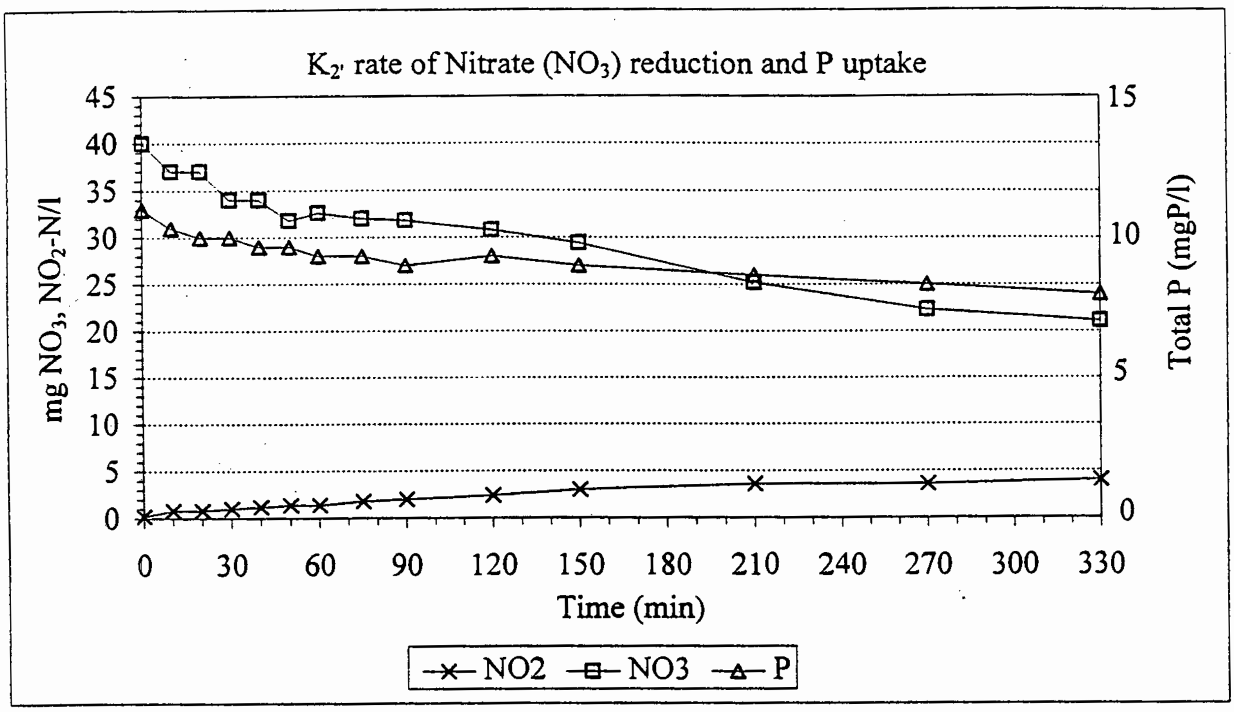


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 24.05.1996

TEST 20 D P up

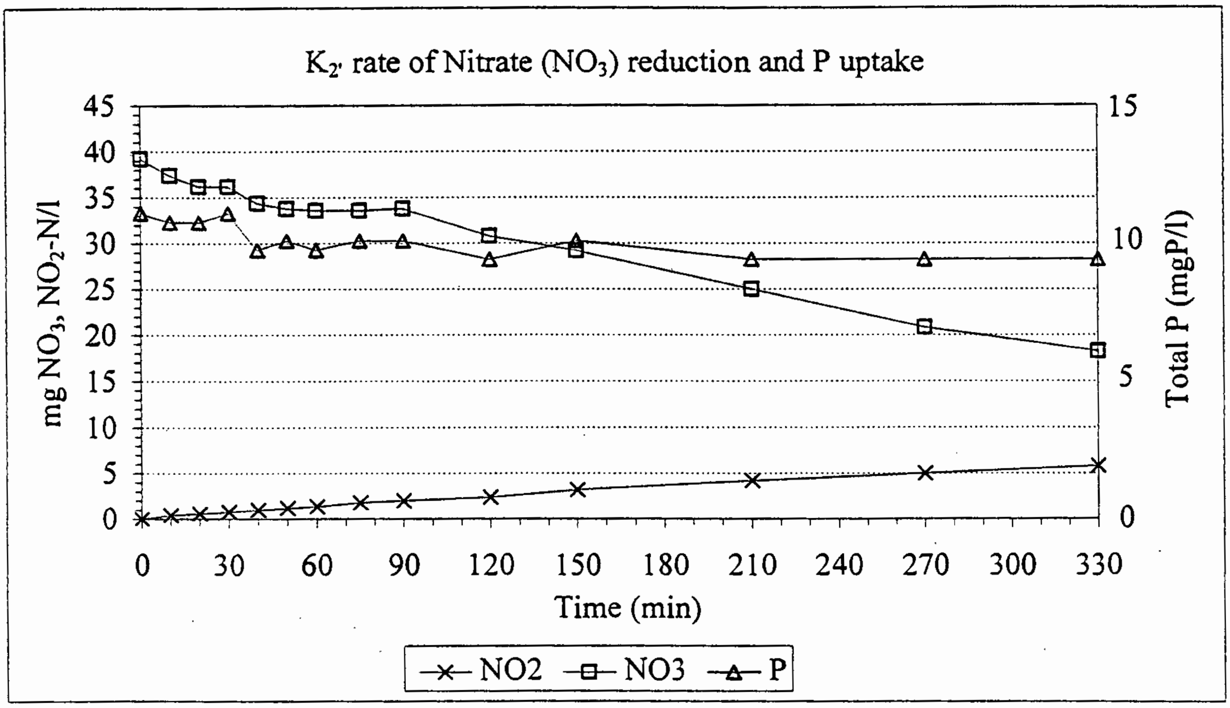
Temperature: 30 C



Date: 29.05.1996

TEST 21 D P up

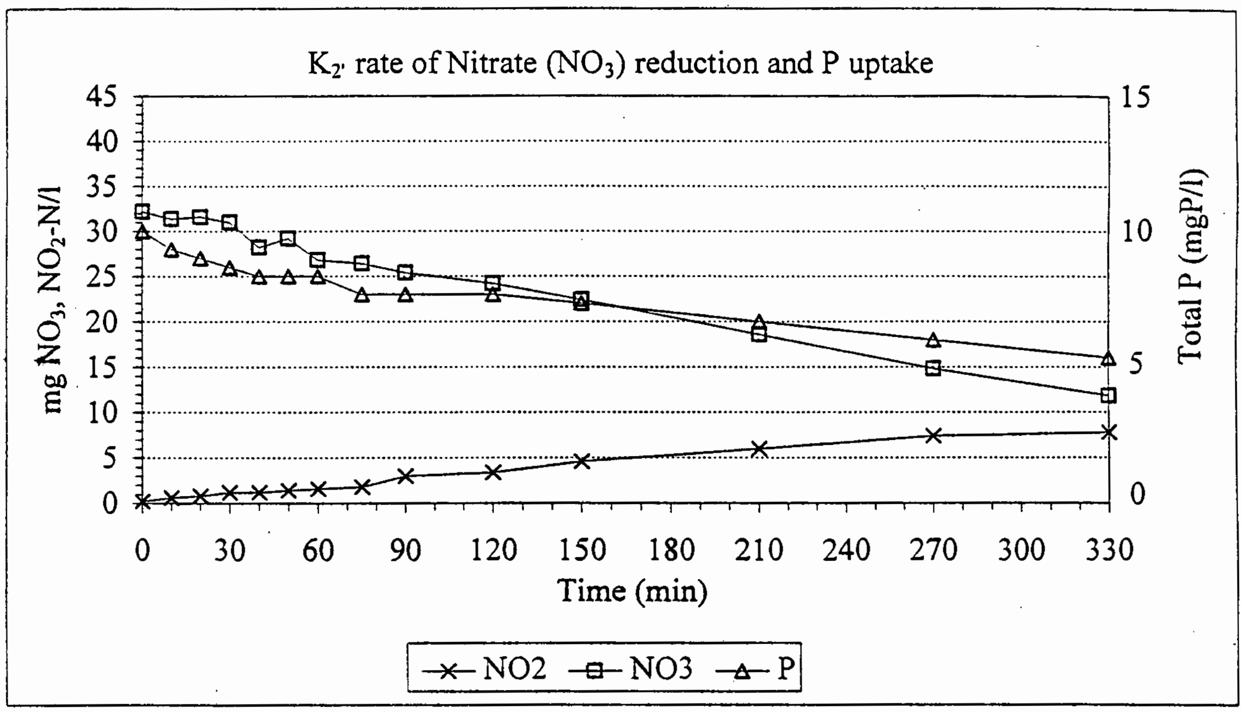
Temperature: 30 C



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

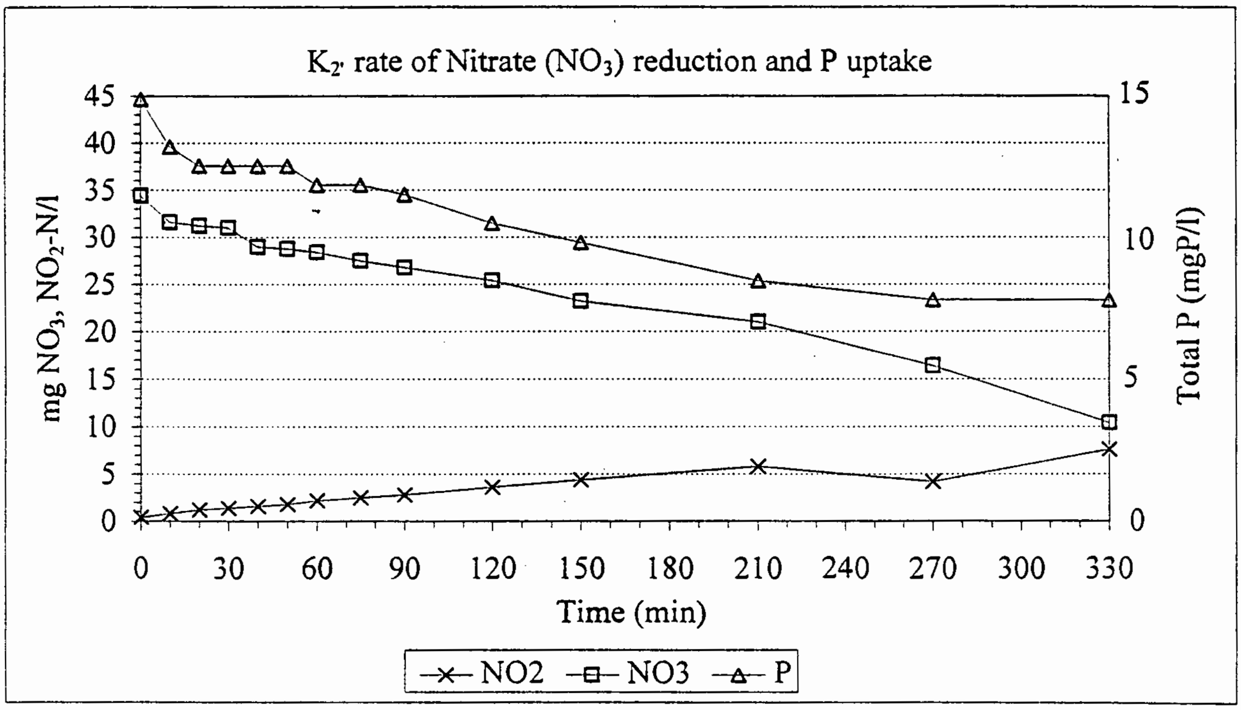
Date: 26.06.1996
Temperature: 30 C

TEST 22 D P up



Date: 03.07.1996
Temperature: 30 C

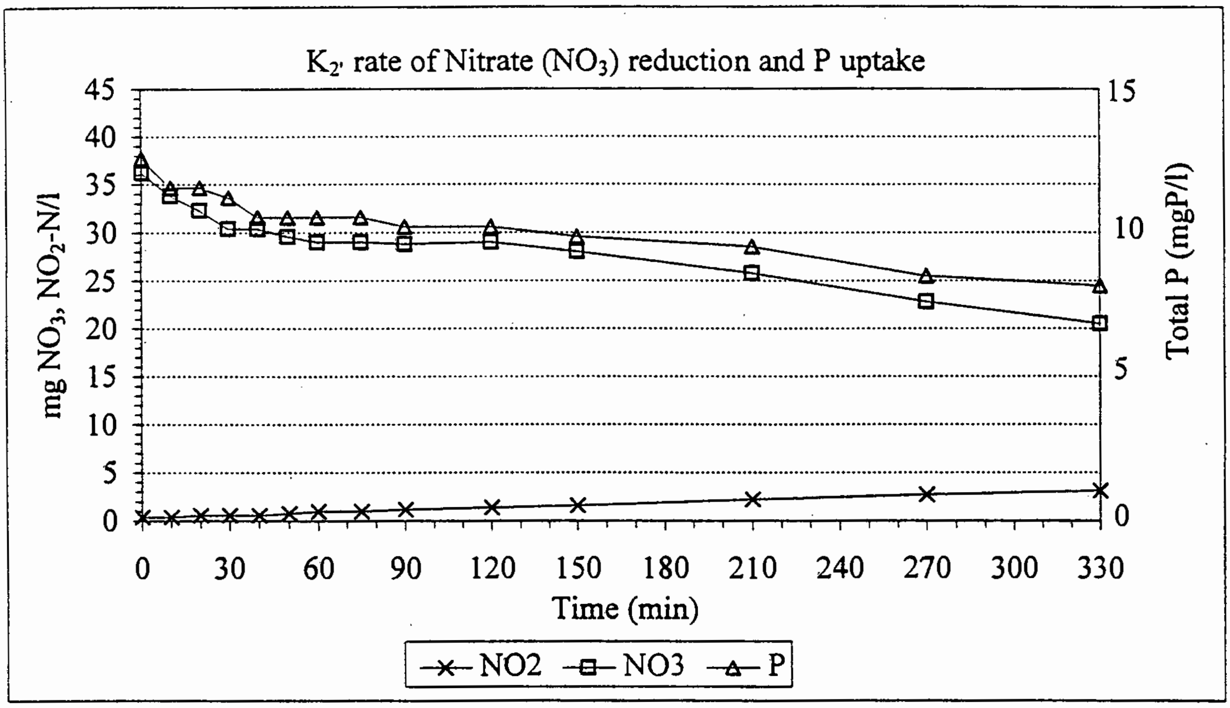
TEST 23 D P up



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

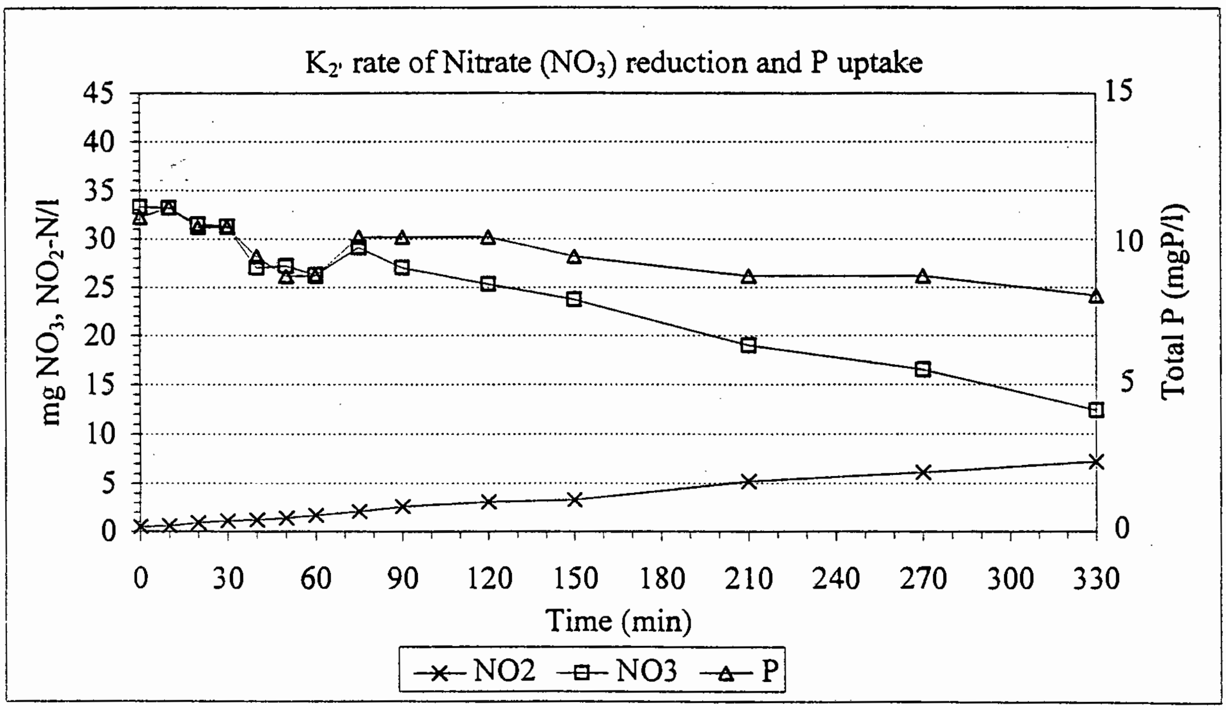
Date: 17.07.1996
Temperature: 30 C

TEST 24 D P up



Date: 25.07.1996
Temperature: 30 C

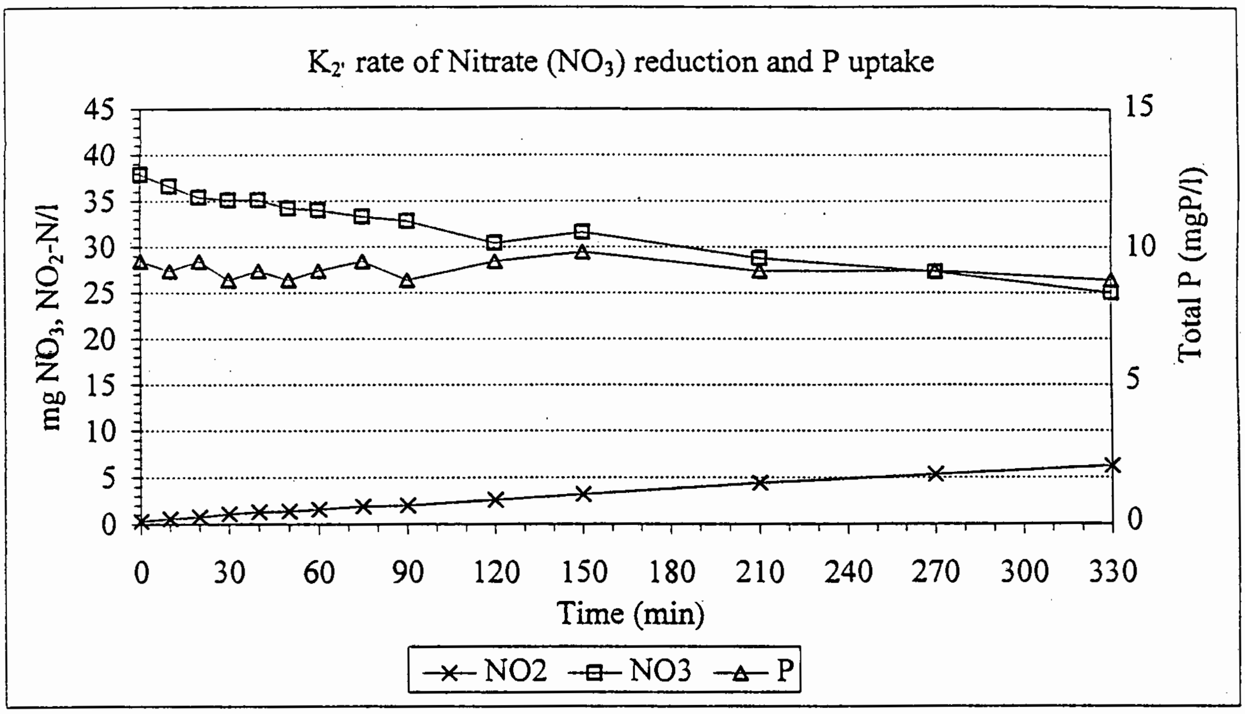
TEST 25 D P up



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

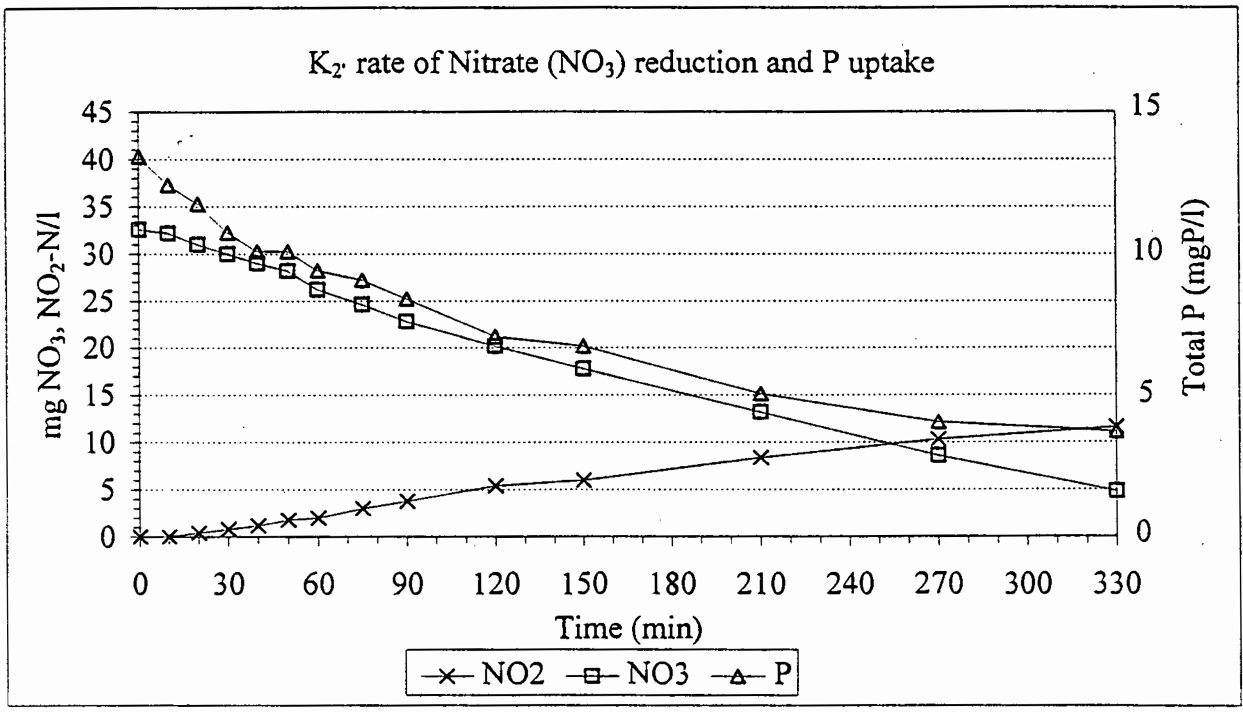
Date: 30.07.1996
Temperature: 30 C

TEST 26 D P up



Date: 22.11.1996
Temperature: 30 C

TEST 27 D P up

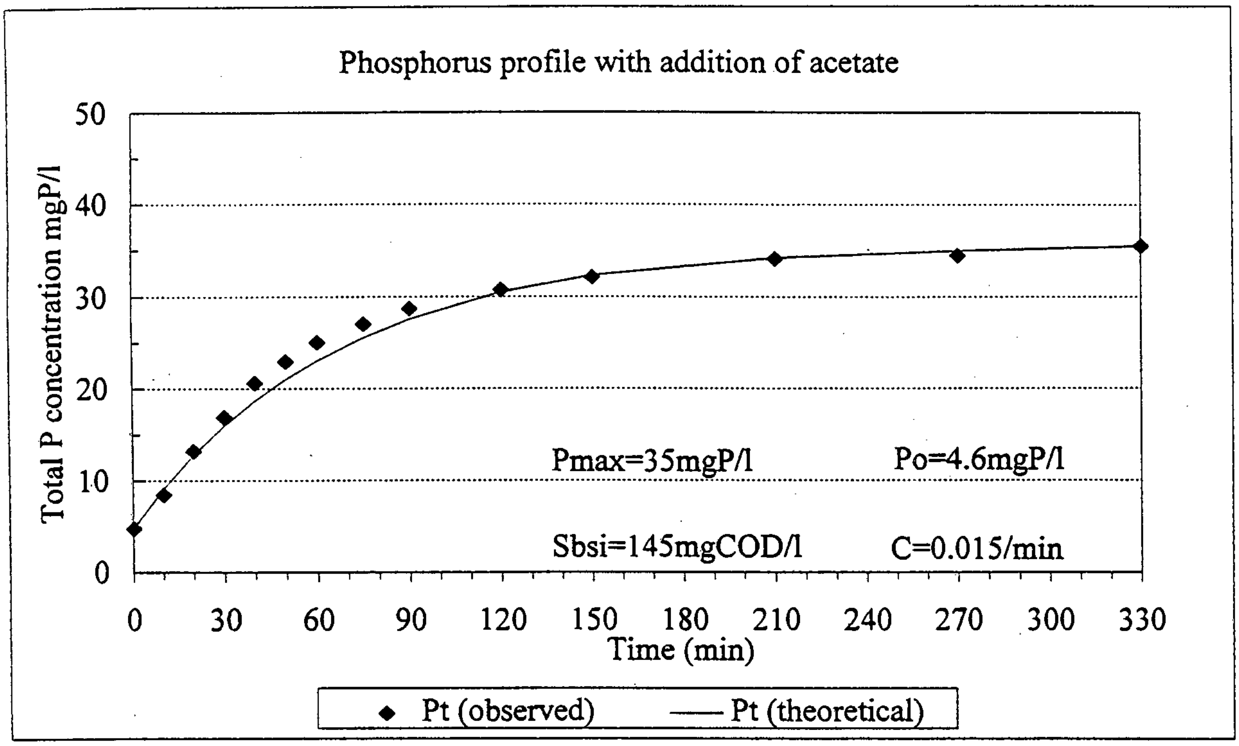


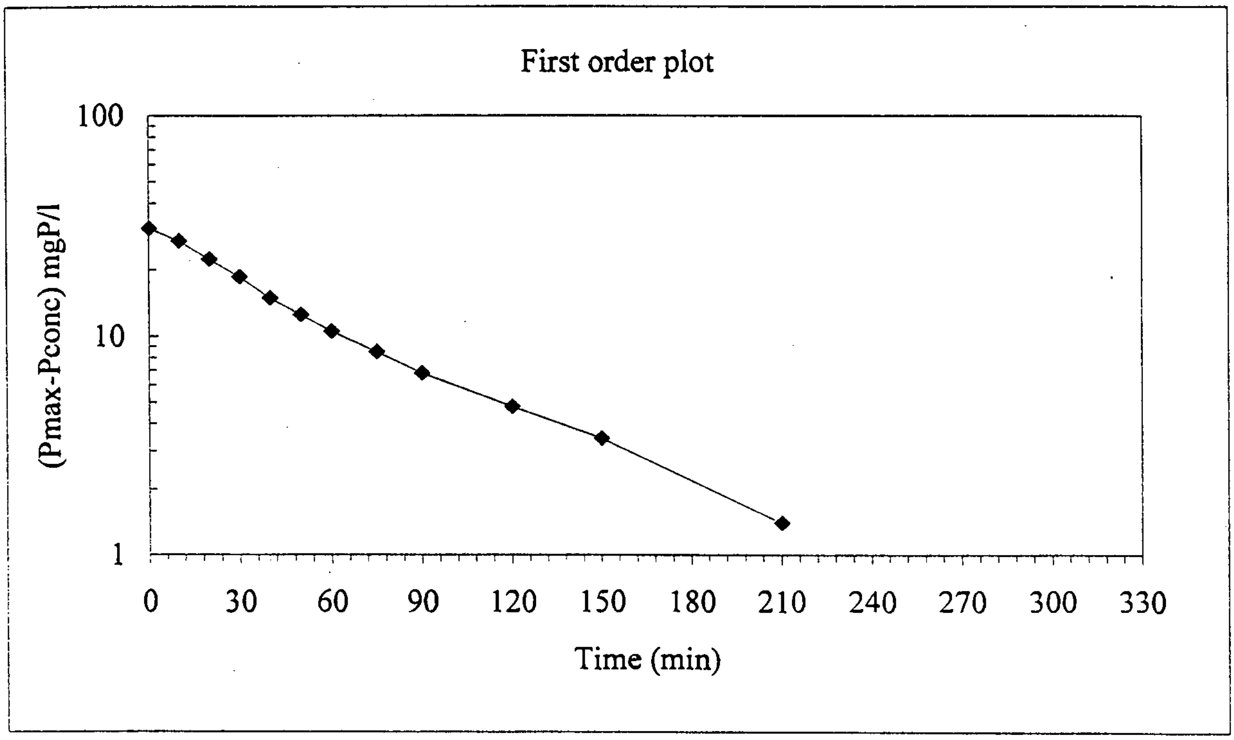
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 12.12.1995

TEST 1 A P rel

Temperature: 30 C



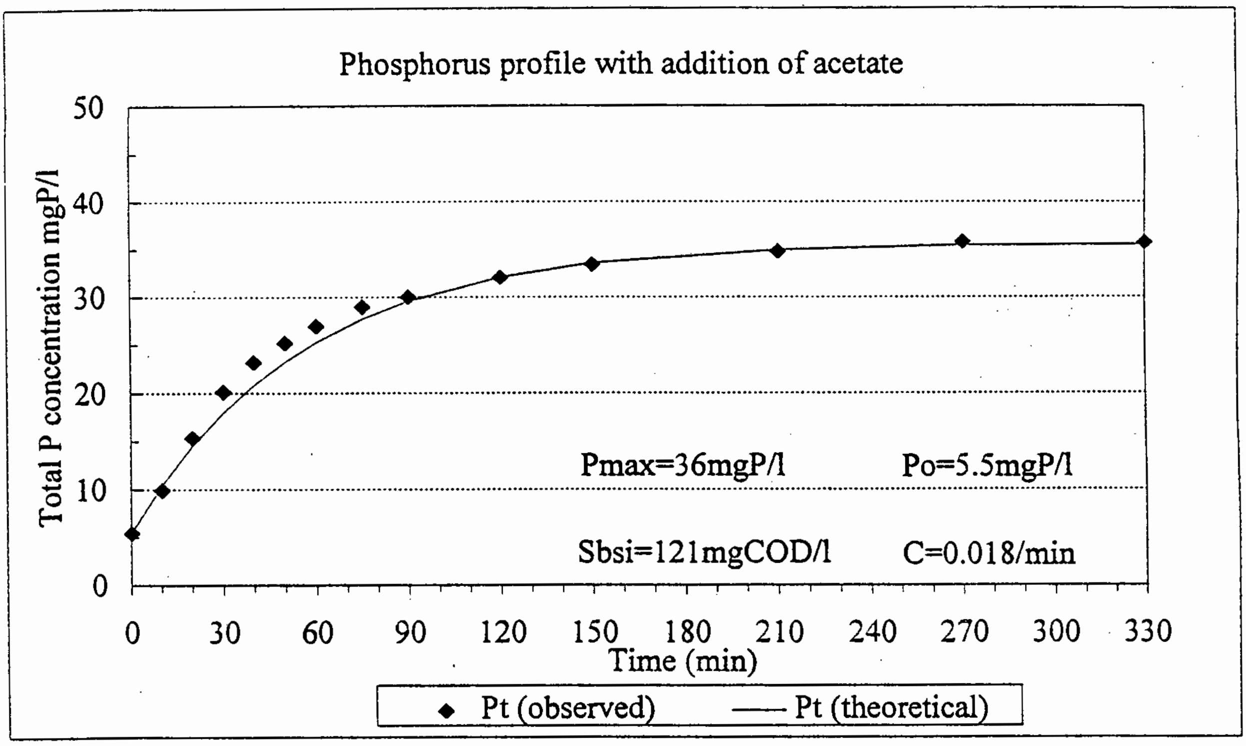


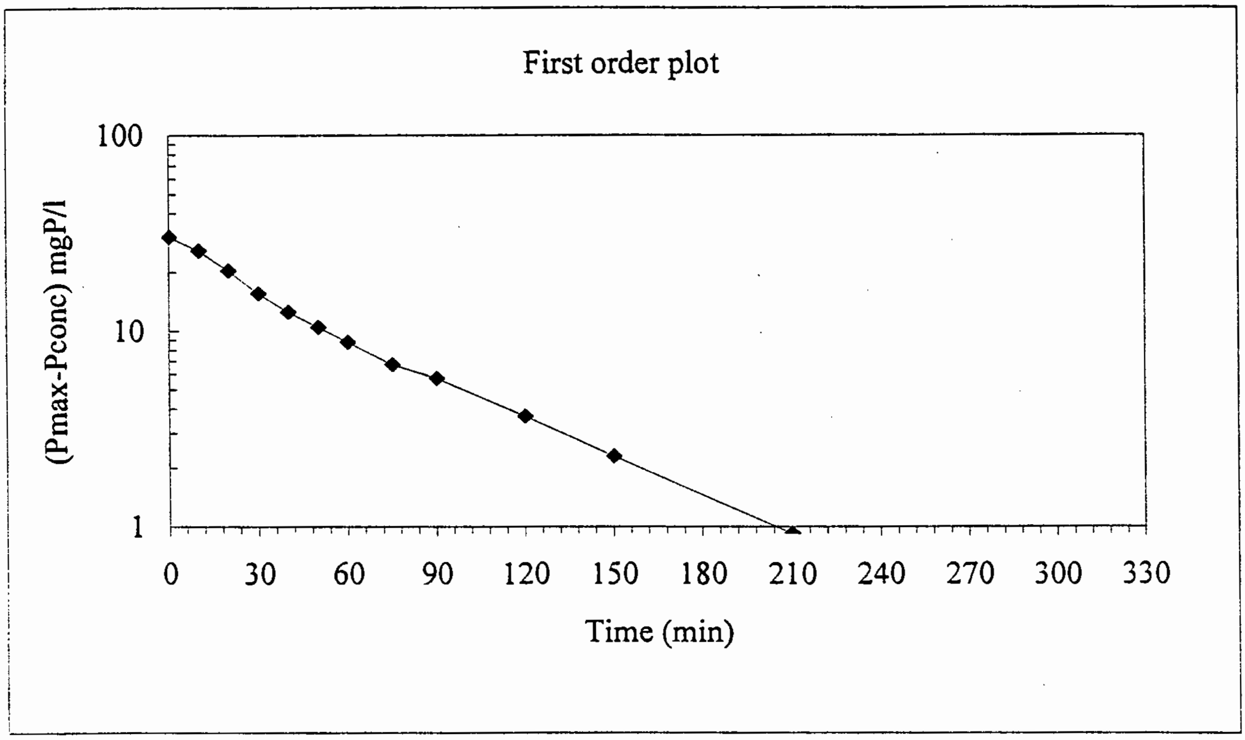
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 20.12.1995

TEST 2 A P rel

Temperature: 30 C

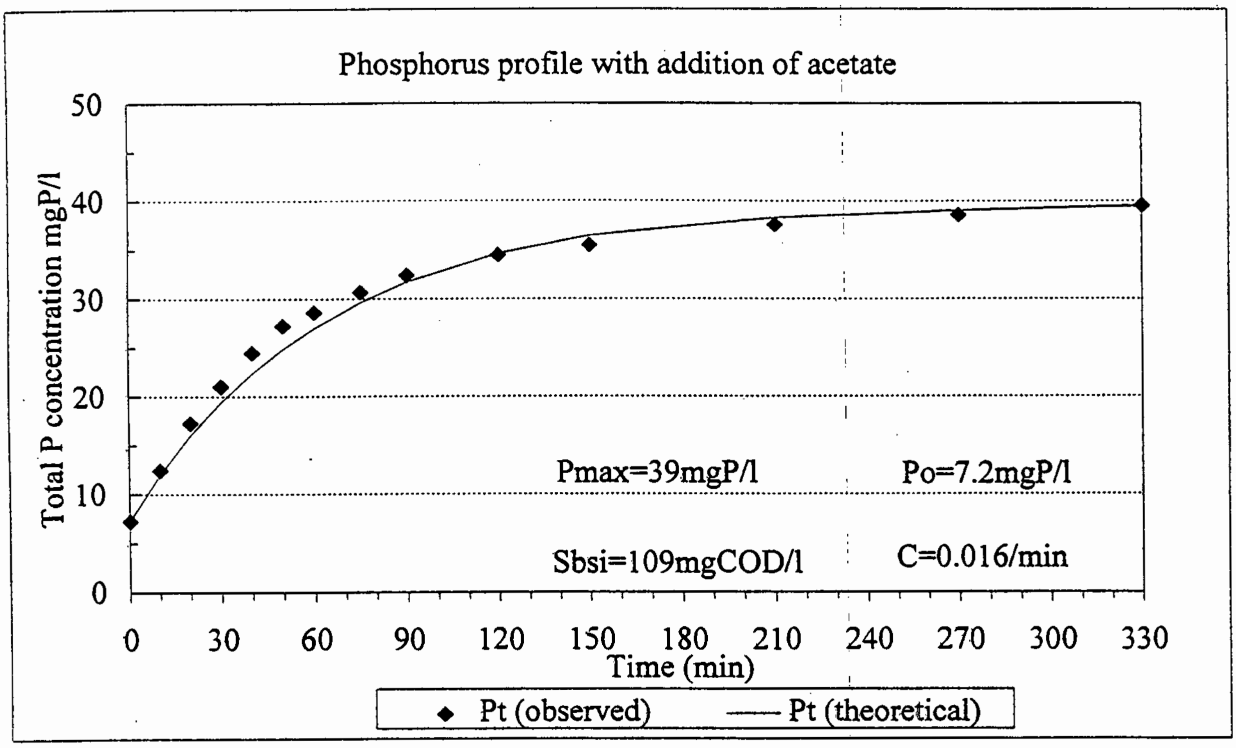


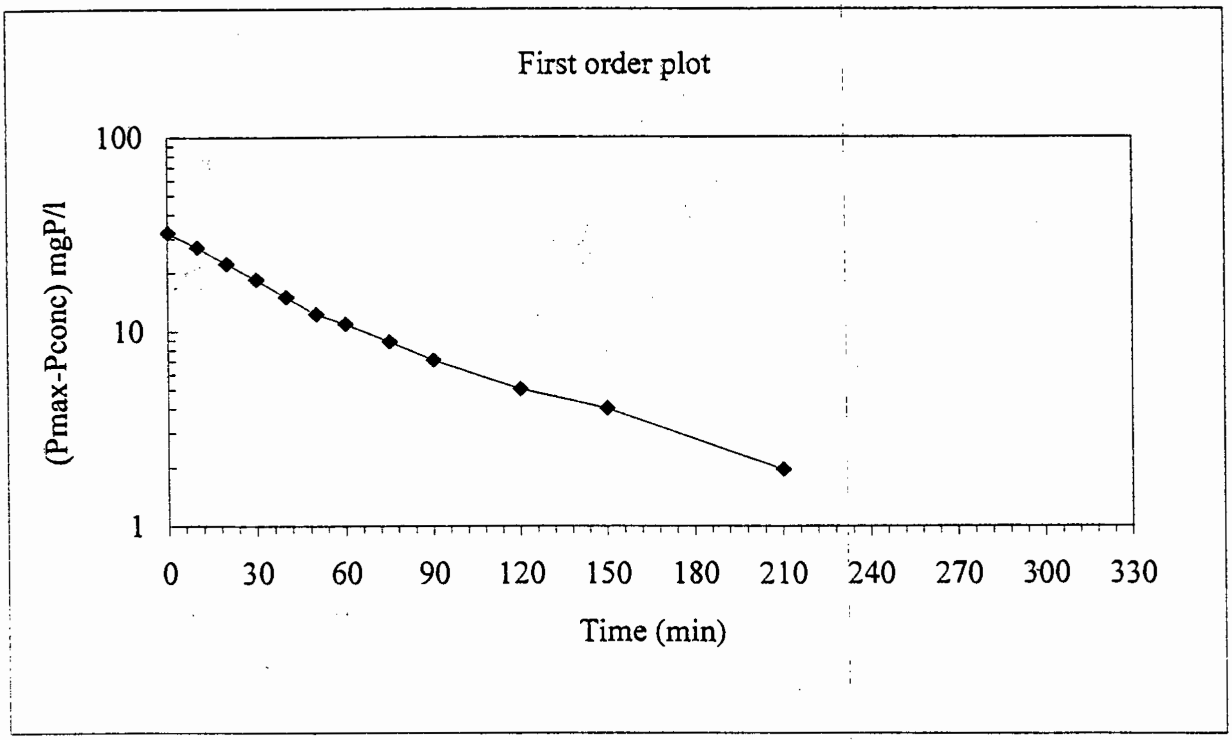


PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 28.12.1995
Temperature: 30 C

TEST 3 A P rel



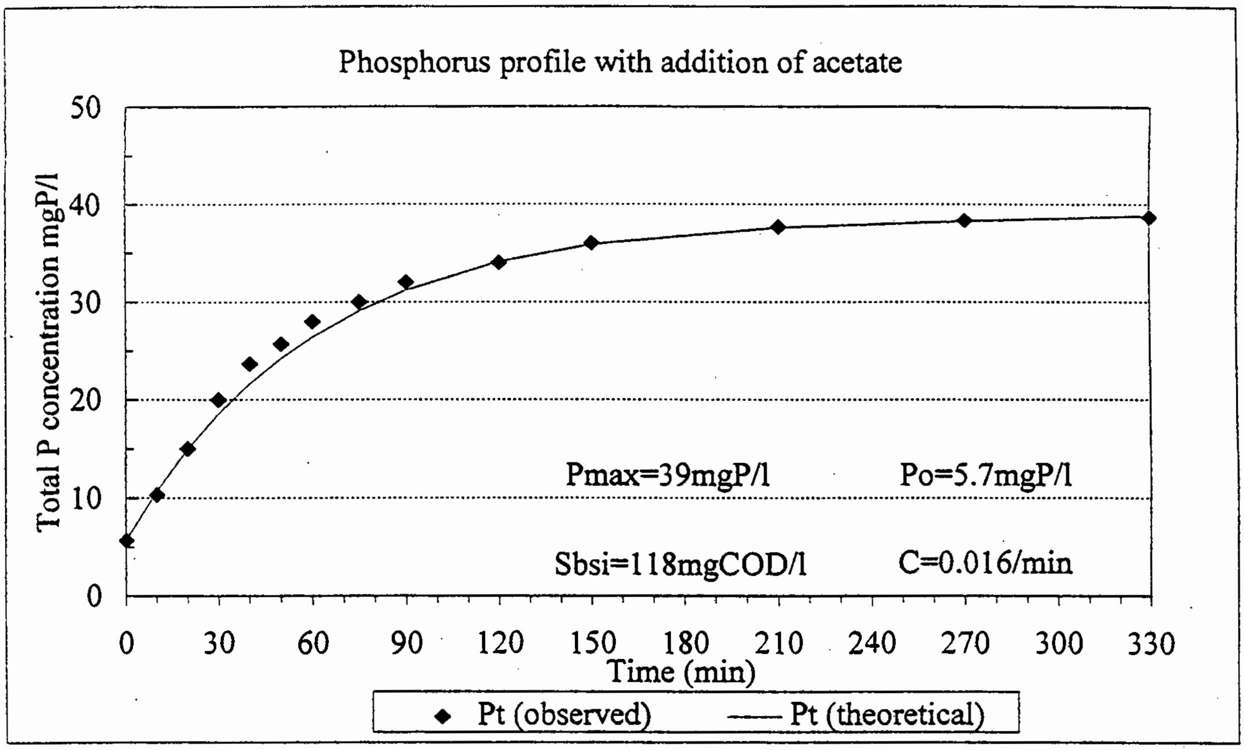


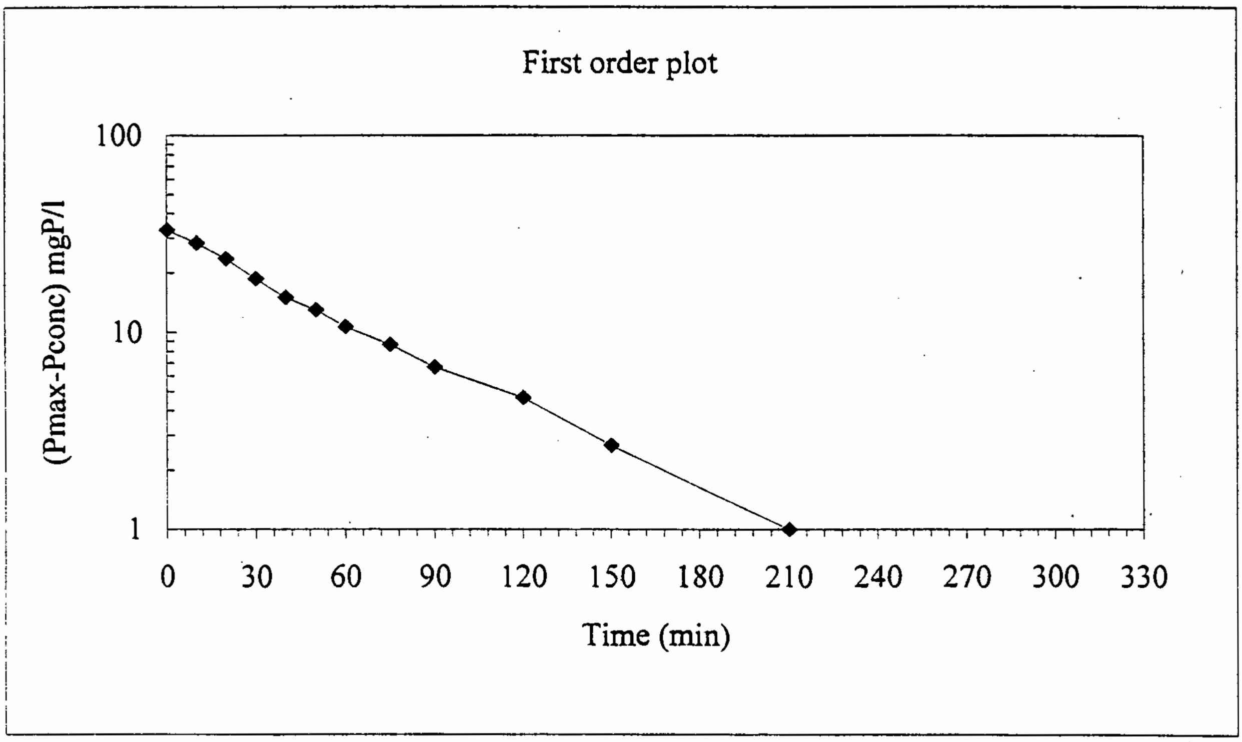
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 02.01.1996

TEST 4 A P rel

Temperature: 30 C



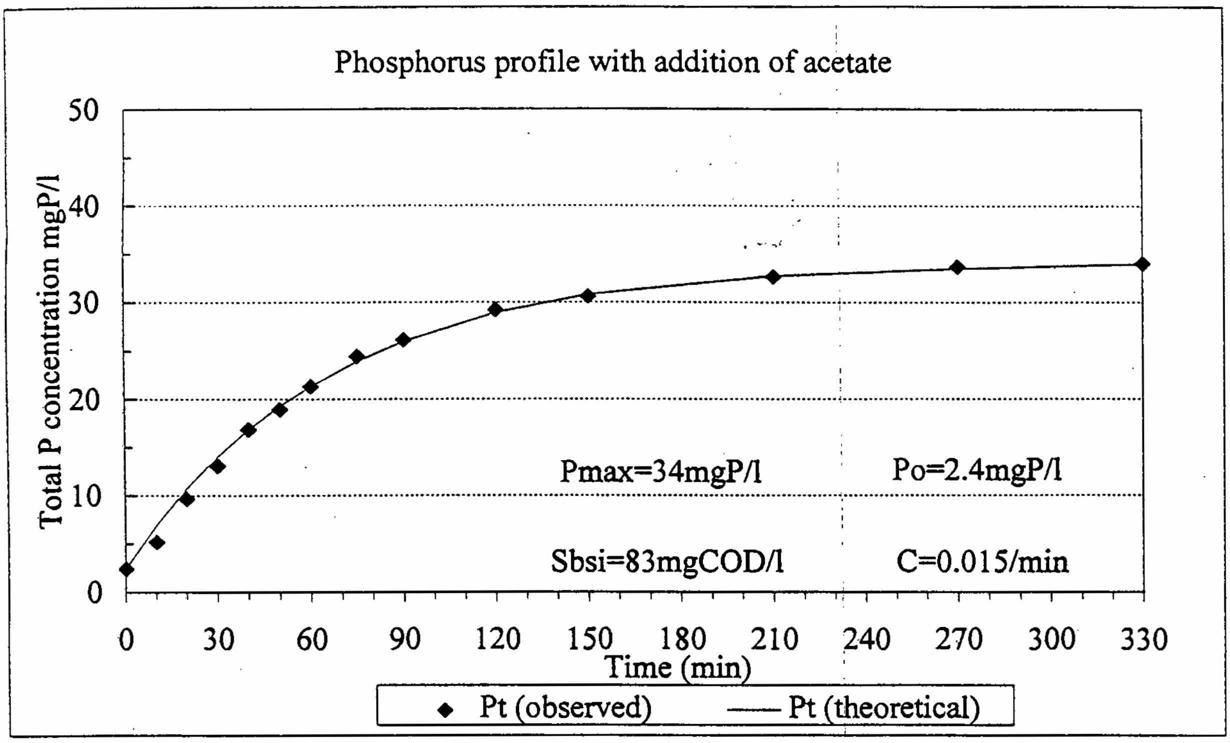


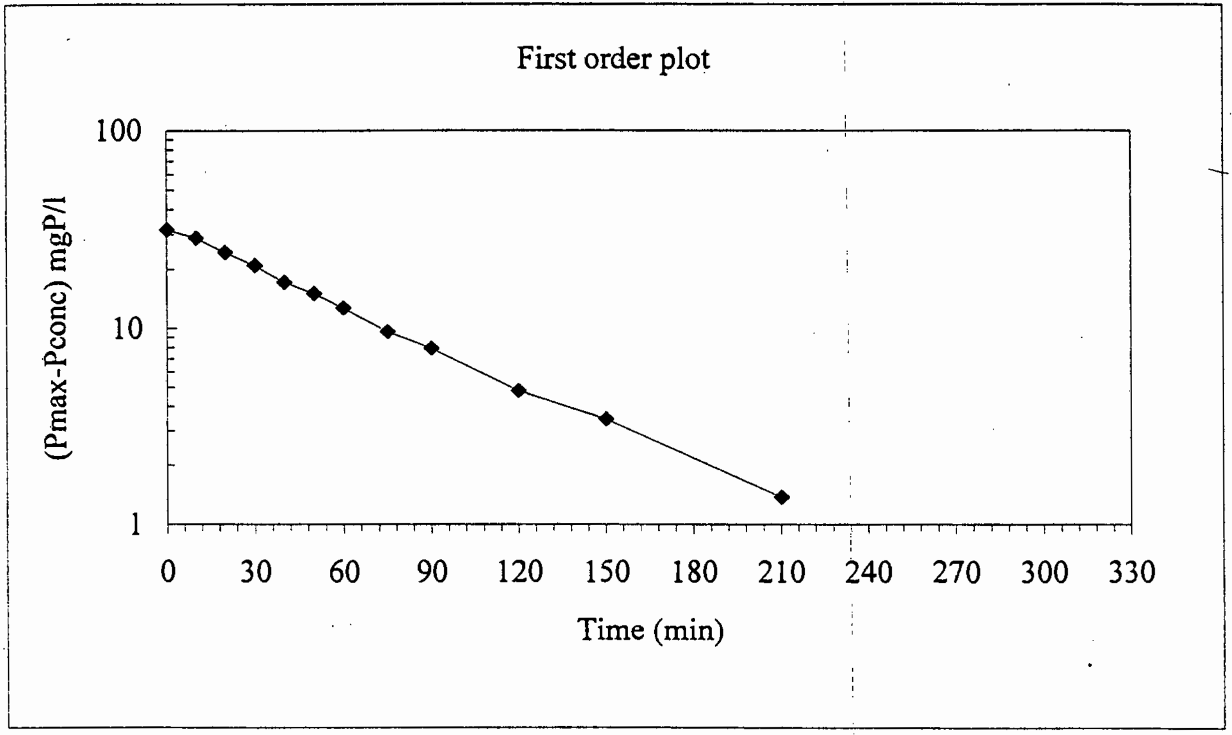
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 09.01.1996

TEST 5 A P rel

Temperature: 30 C



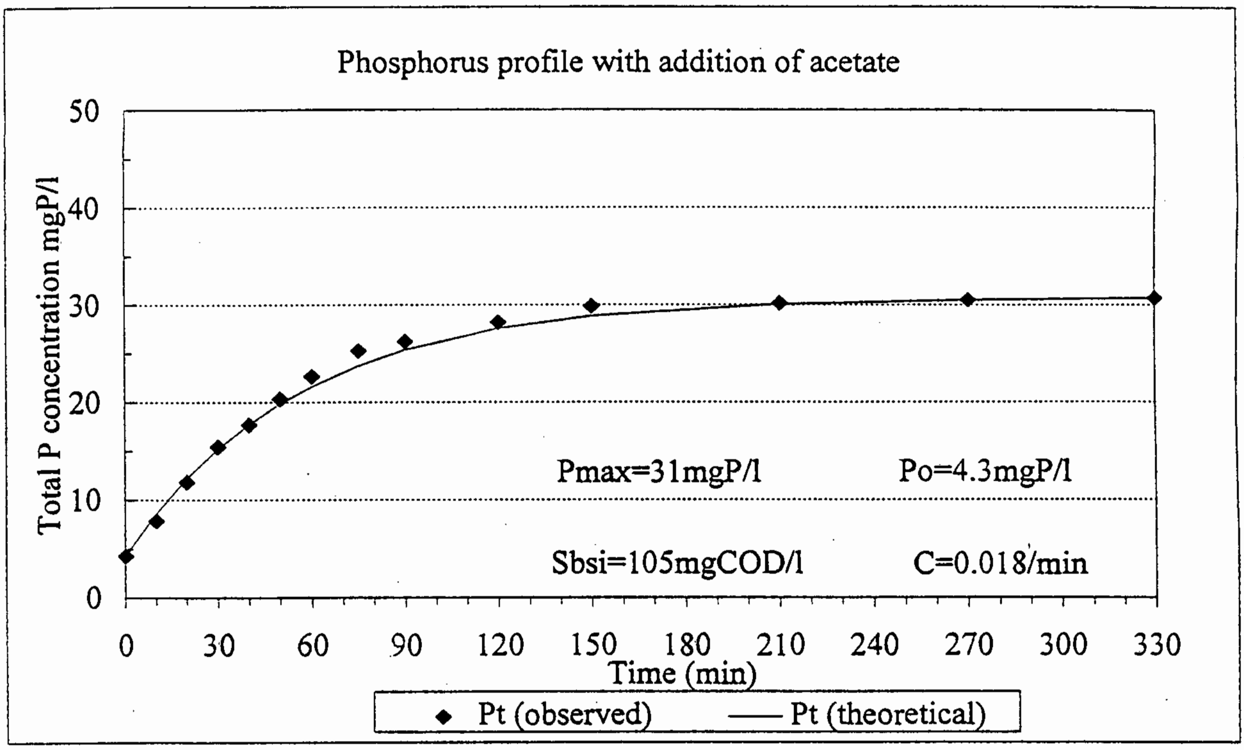


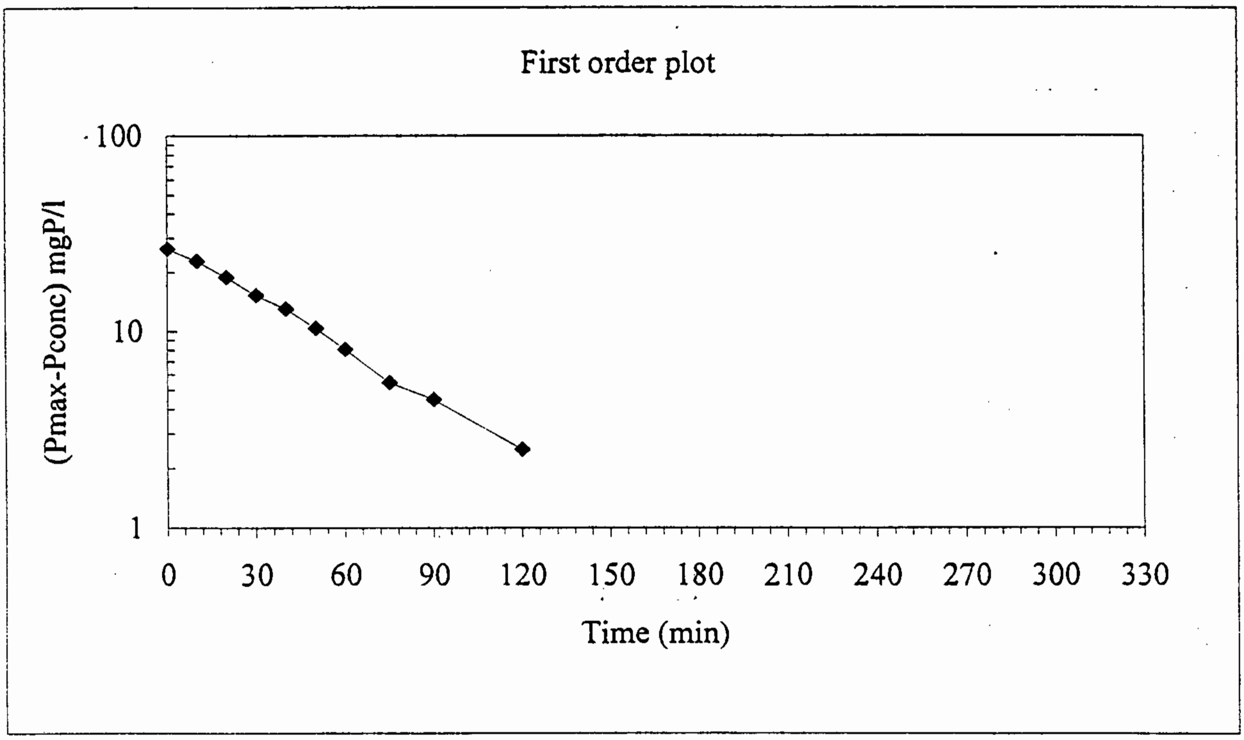
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 17.01.1996

TEST 6 A P rel

Temperature: 30 C



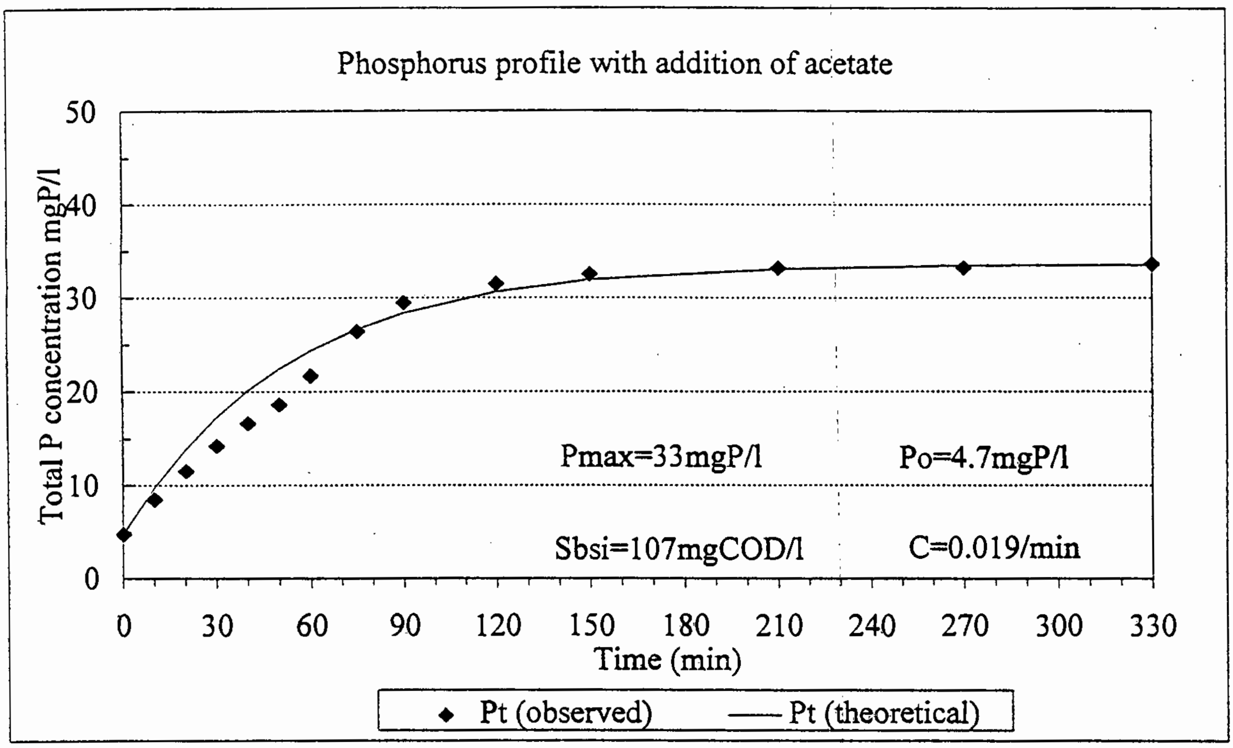


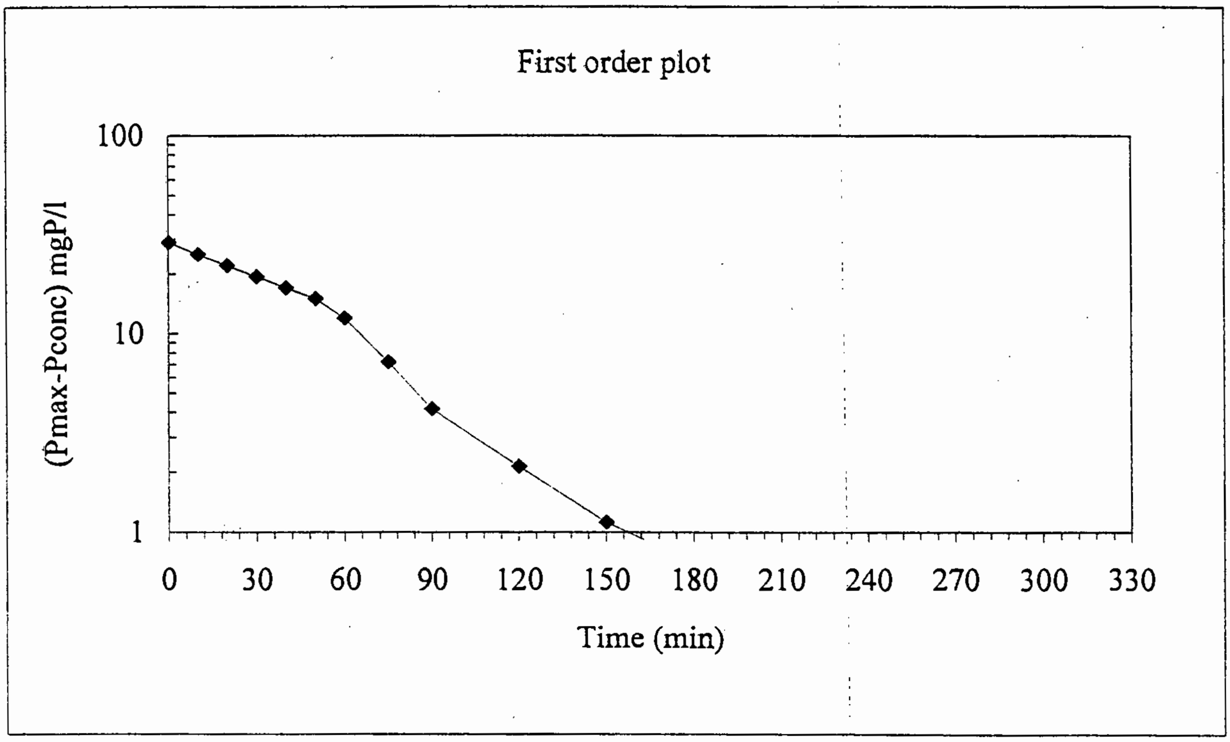
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 23.01.1996

TEST 7 A P rel

Temperature: 30 C



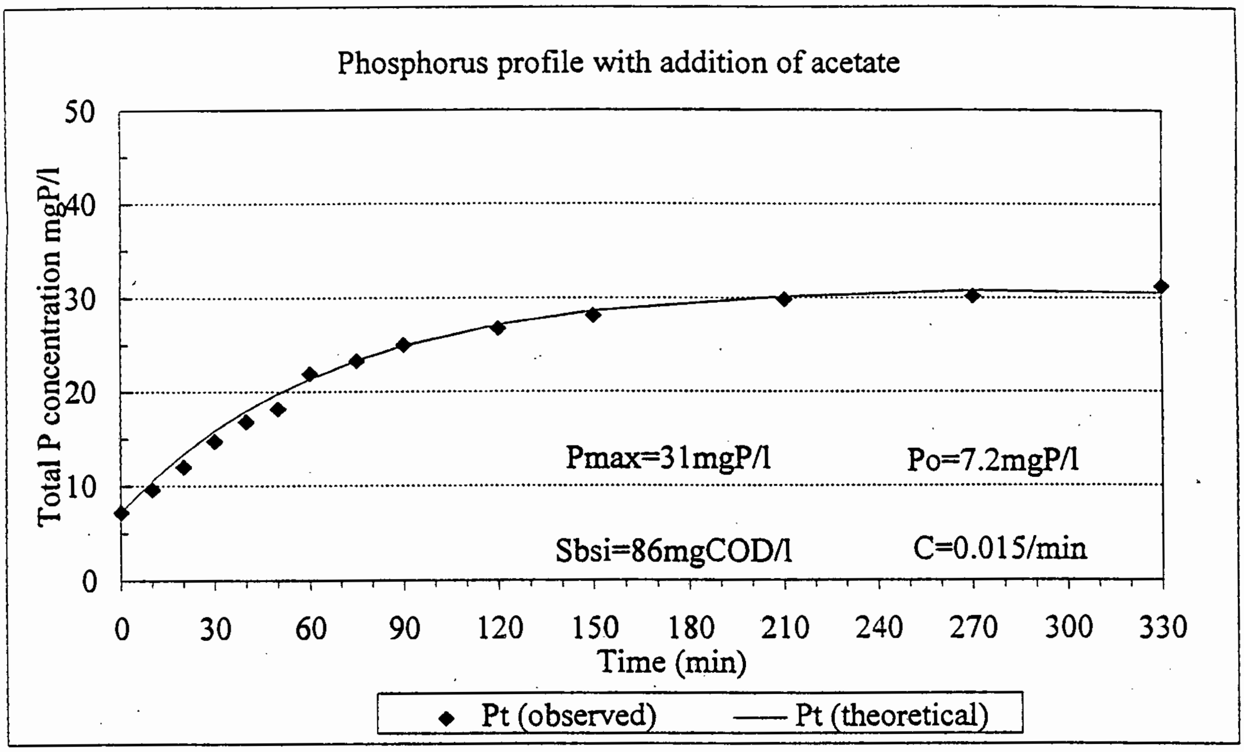


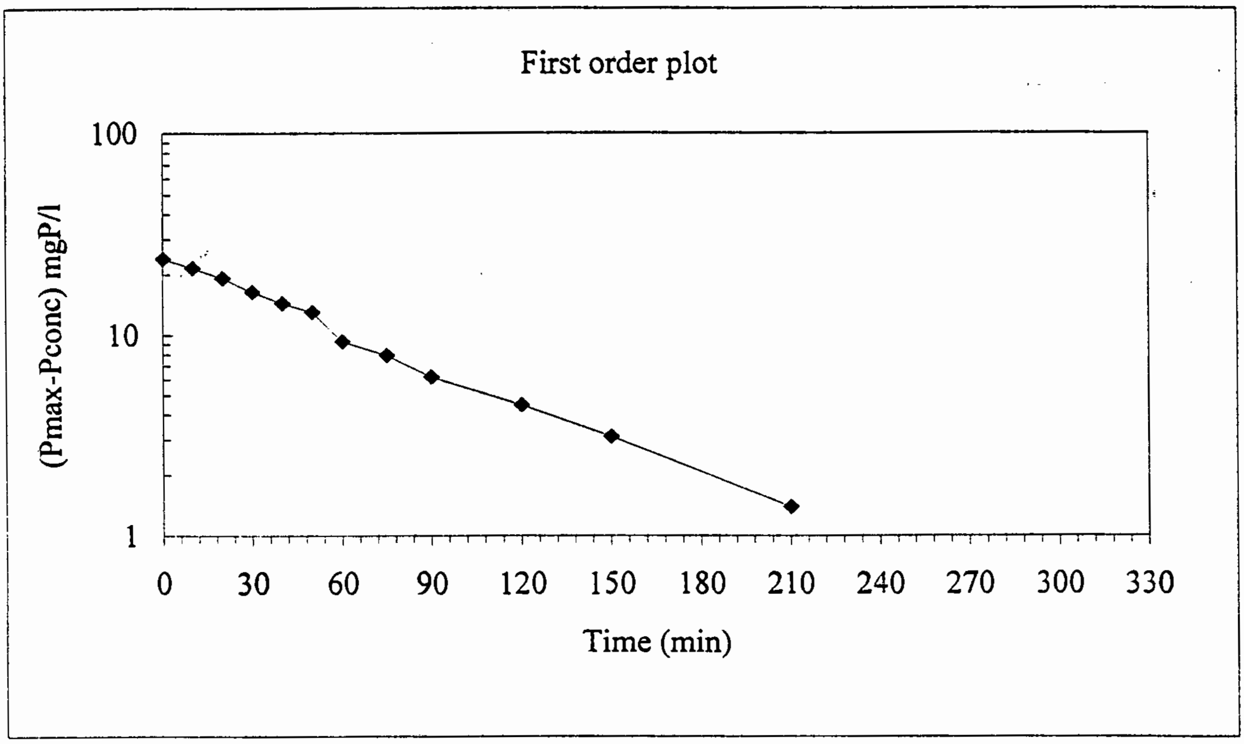
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 30.01.1996

TEST 8 A P rel

Temperature: 30 C



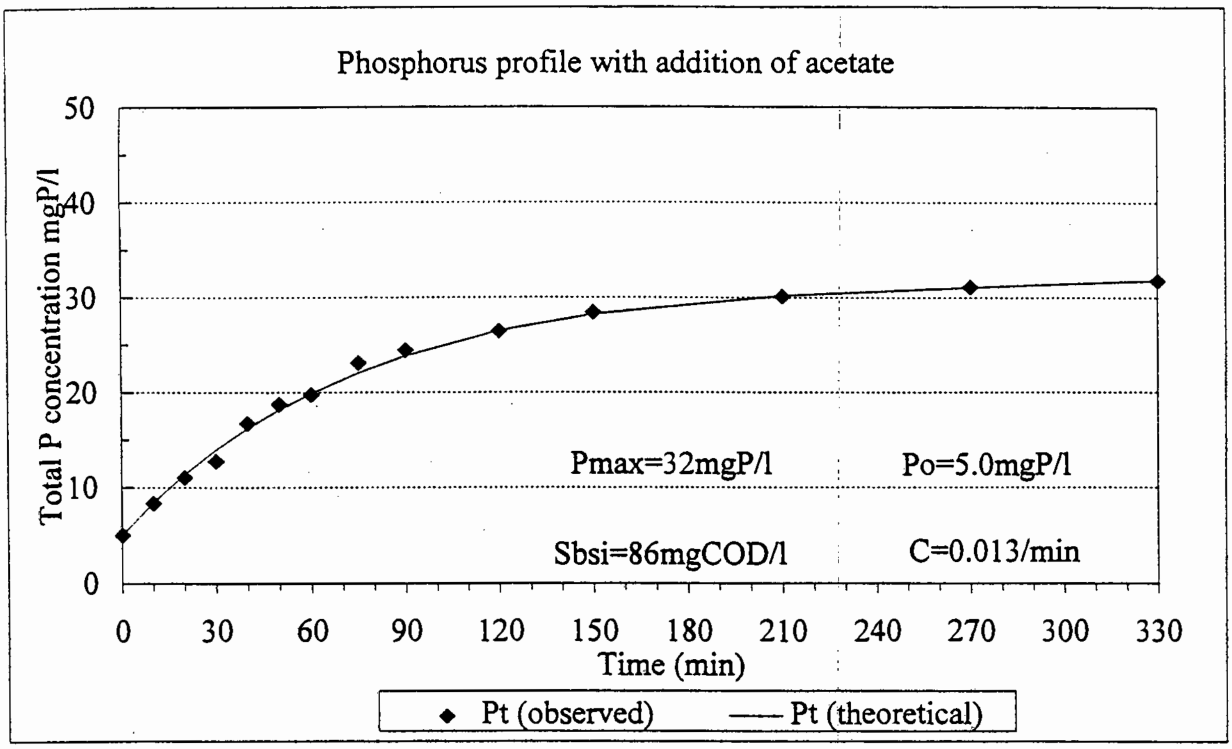


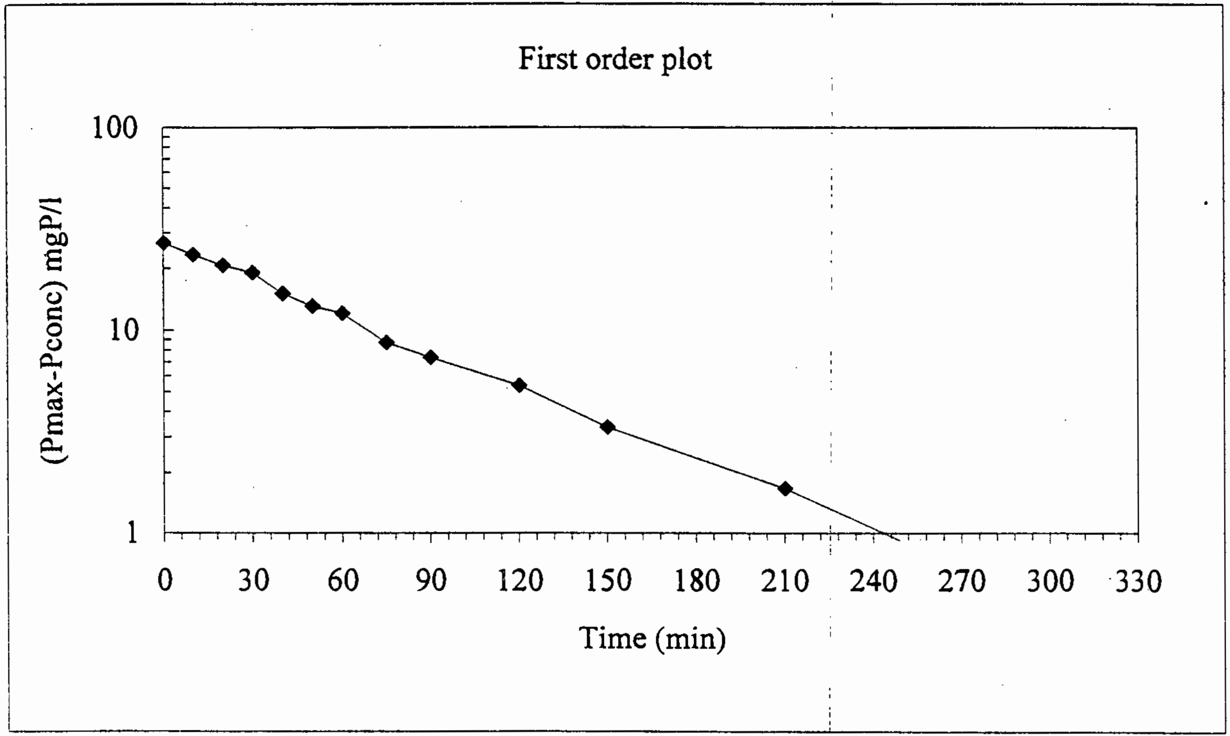
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 20.02.1996

TEST 9 A P rel

Temperature: 30 C



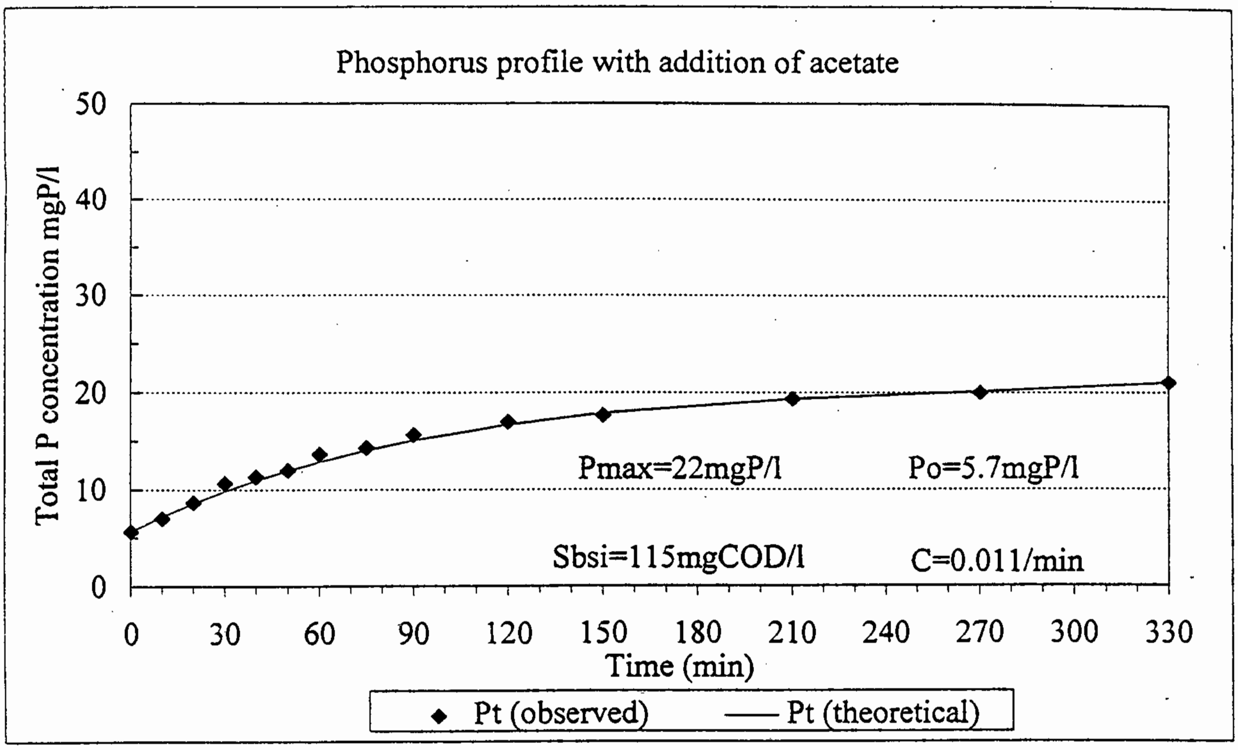


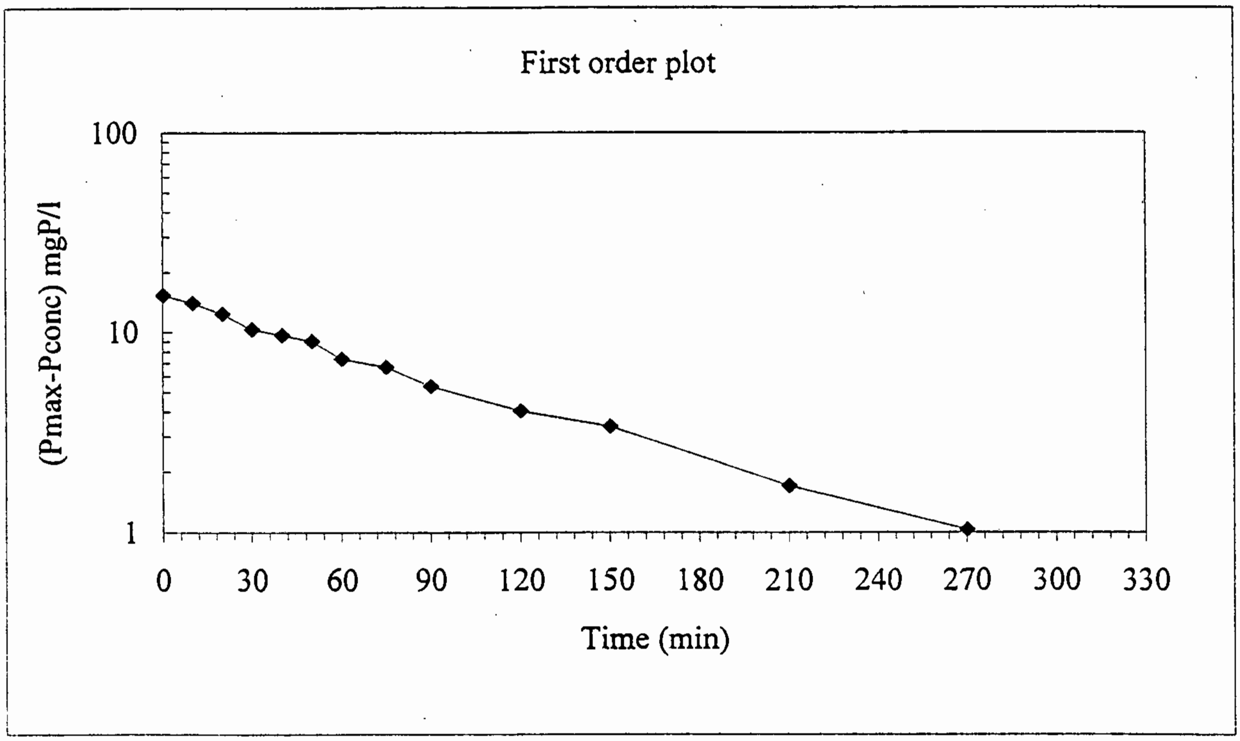
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 14.05.1996

TEST 10 A P rel

Temperature: 30 C



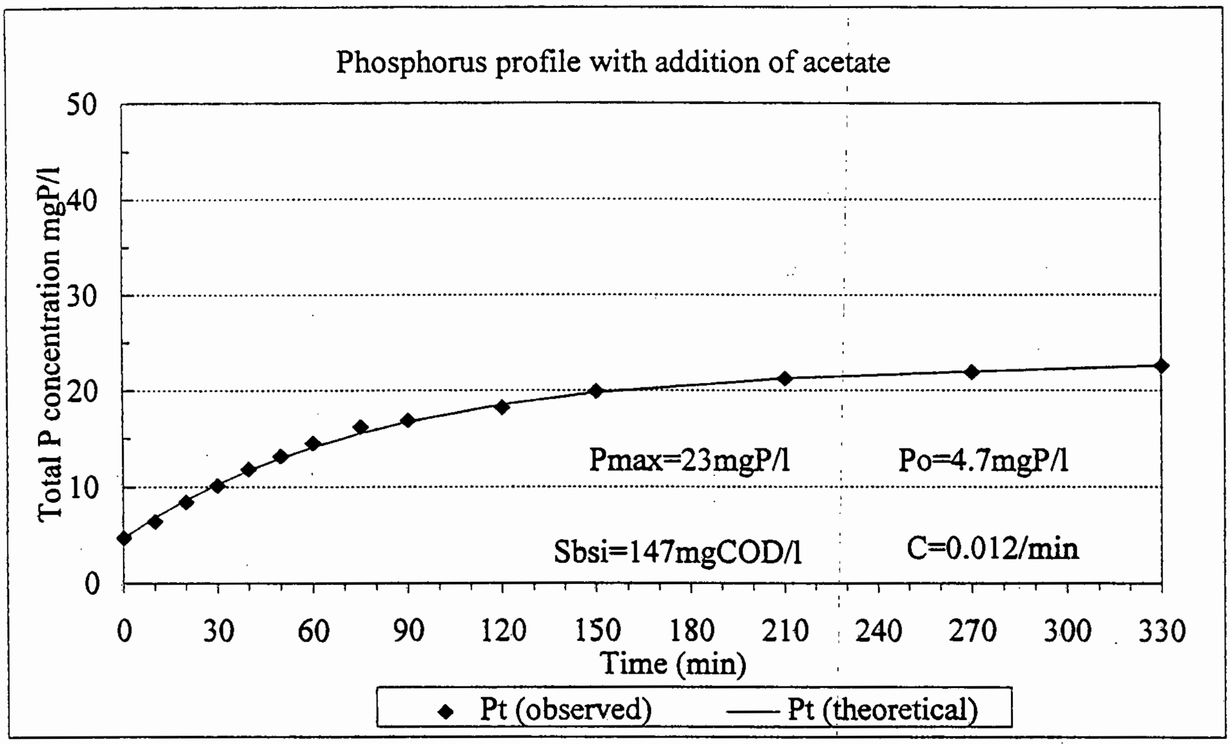


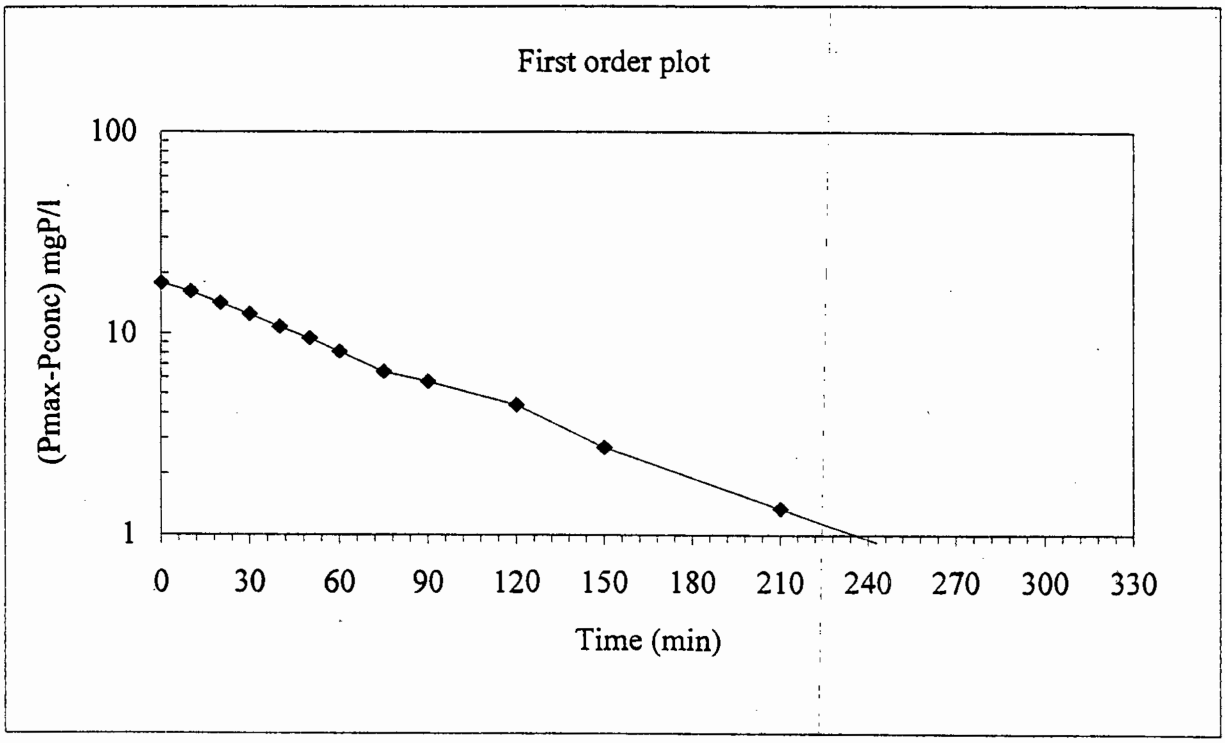
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 05.07.1996

TEST 11 A P rel

Temperature: 30 C



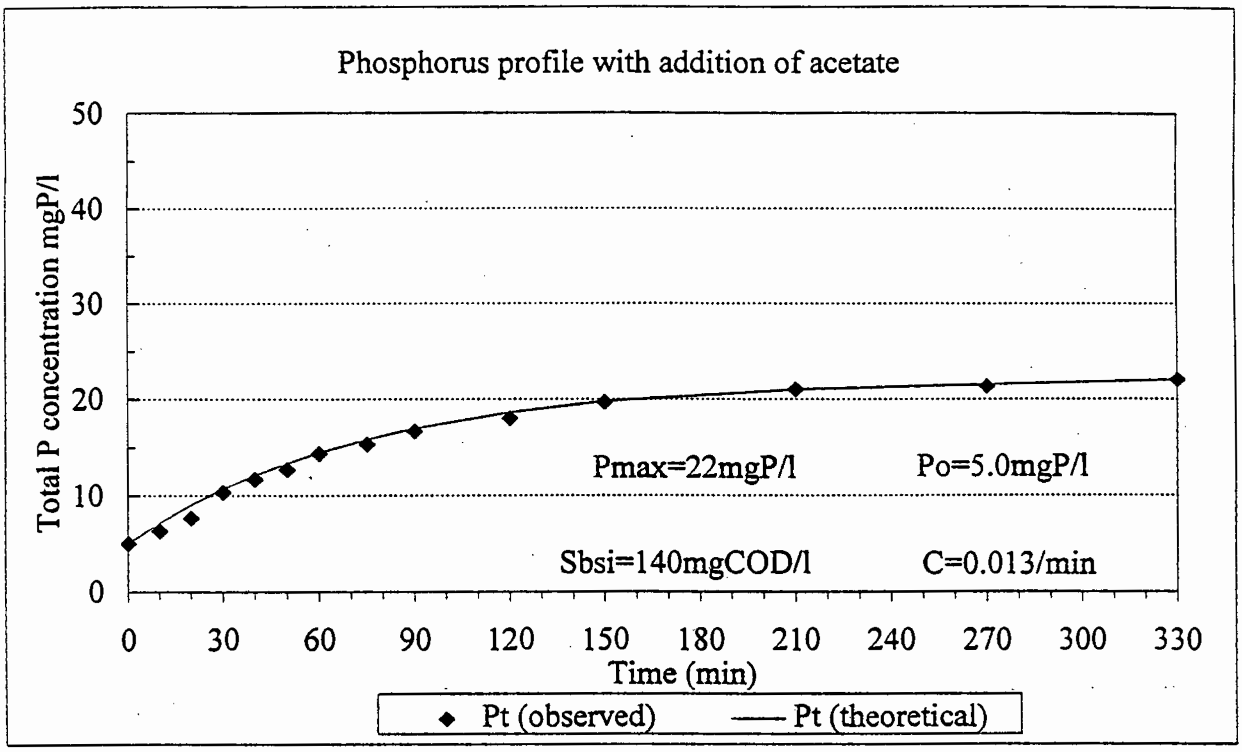


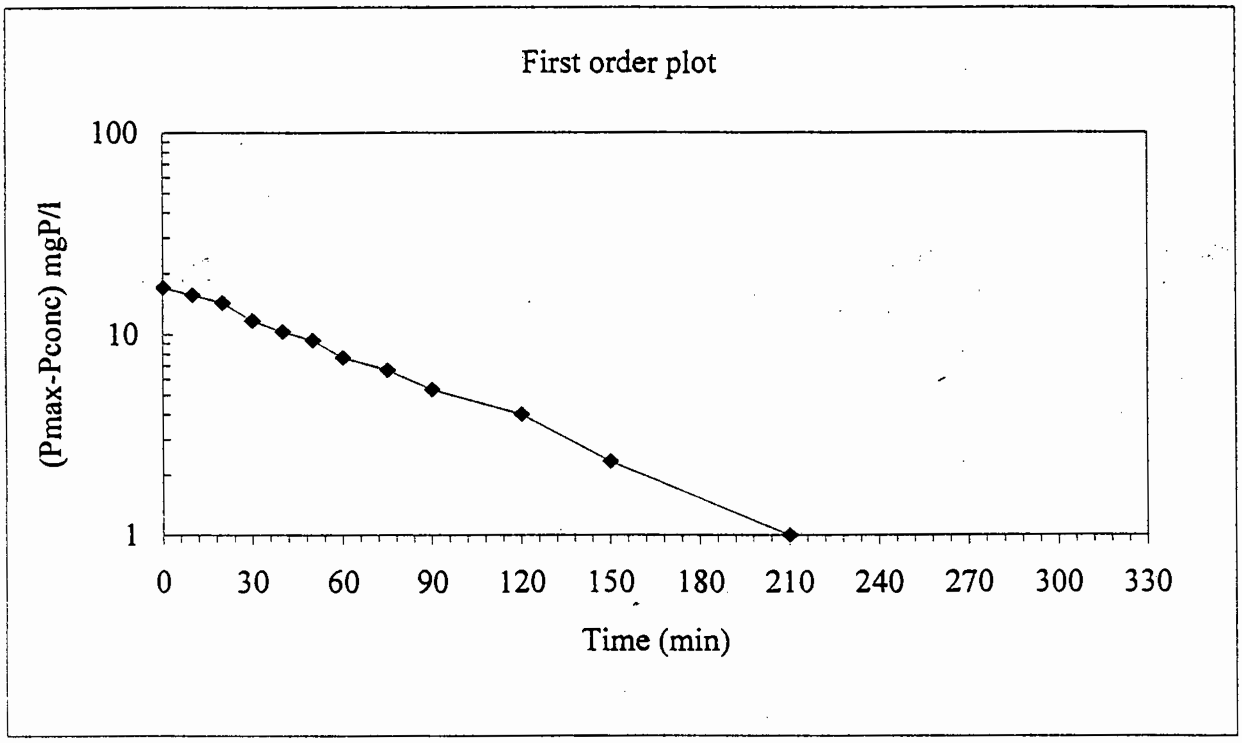
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 08.07.1996

TEST 12 A P rel

Temperature: 30 C



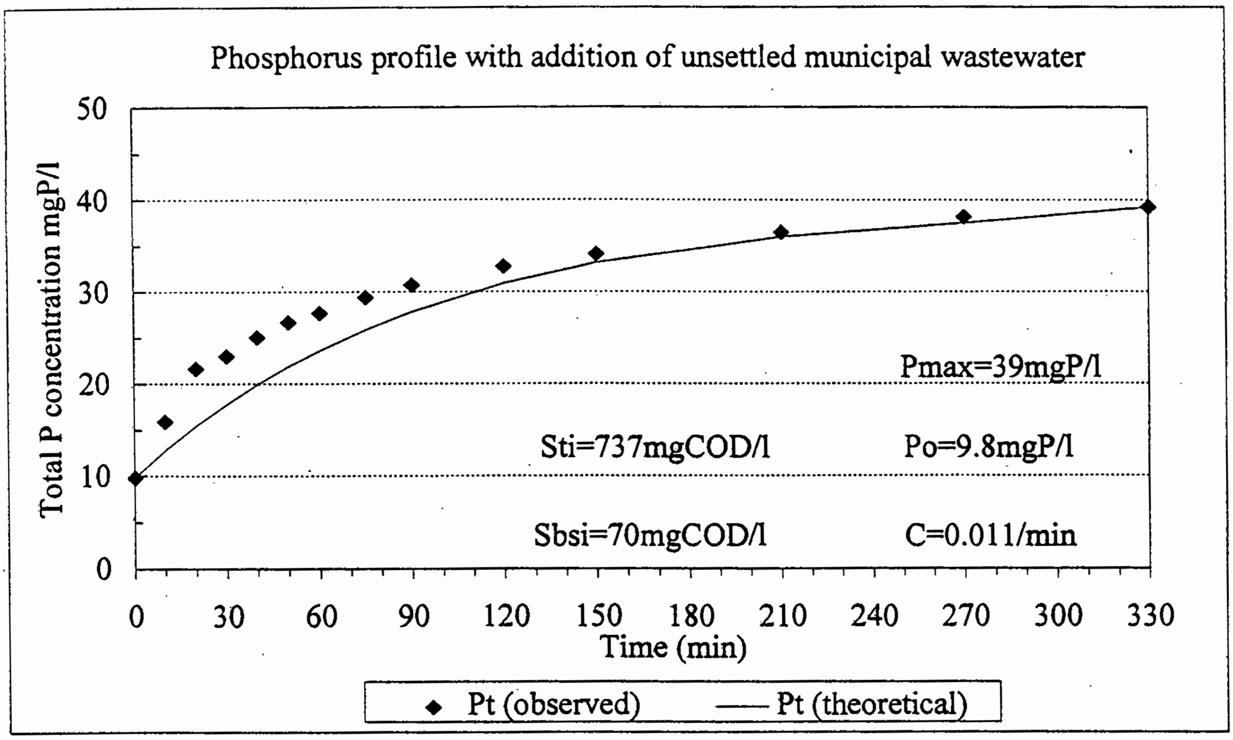


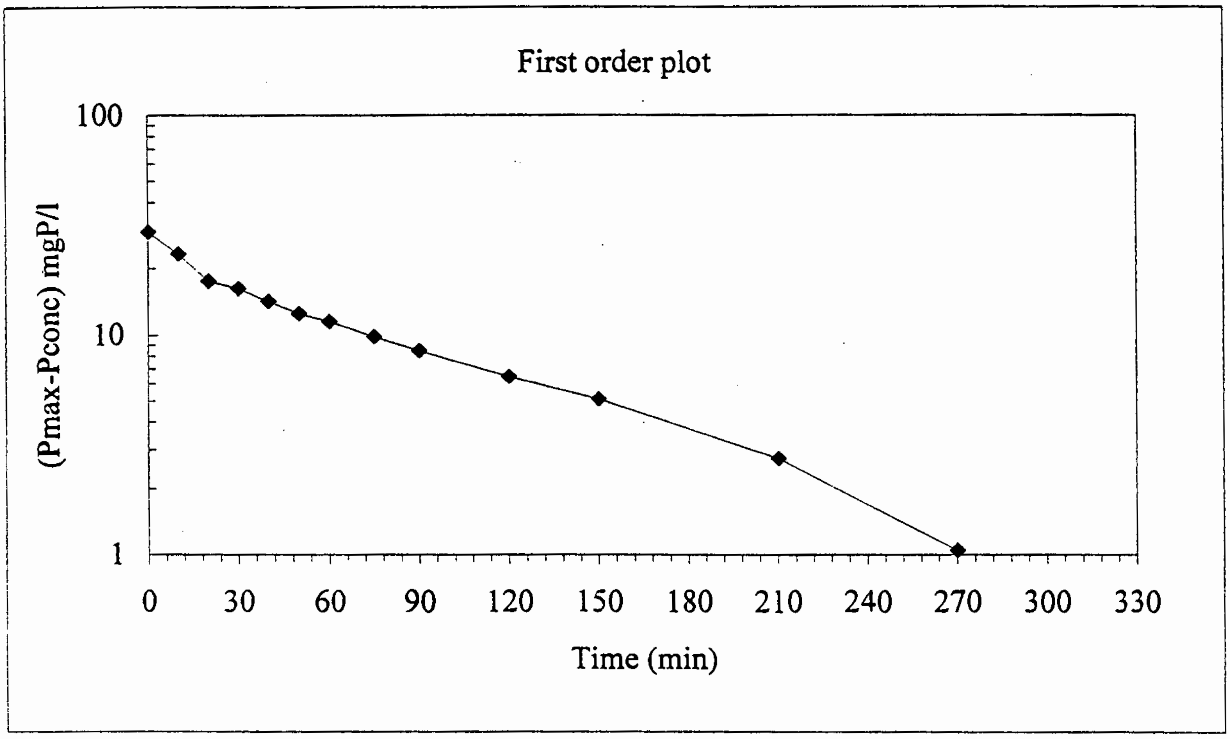
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 05.12.1995

TEST 1 S P rel

Temperature: 30 C



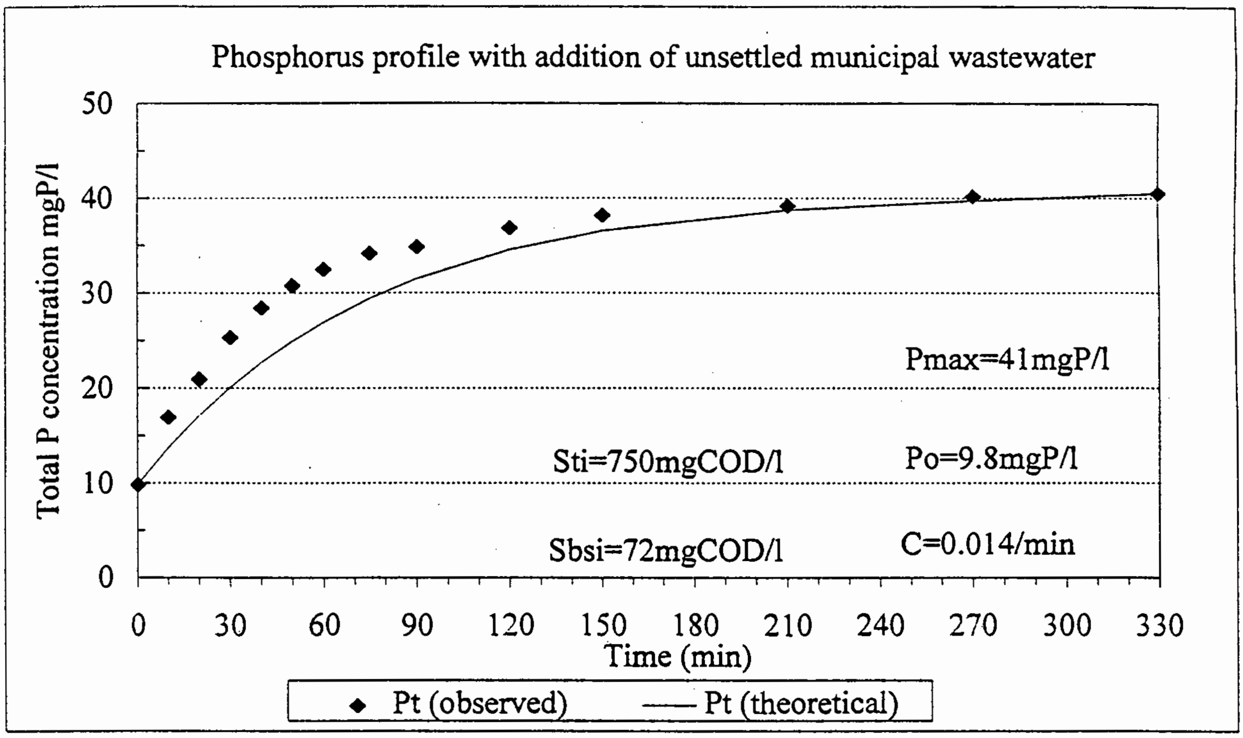


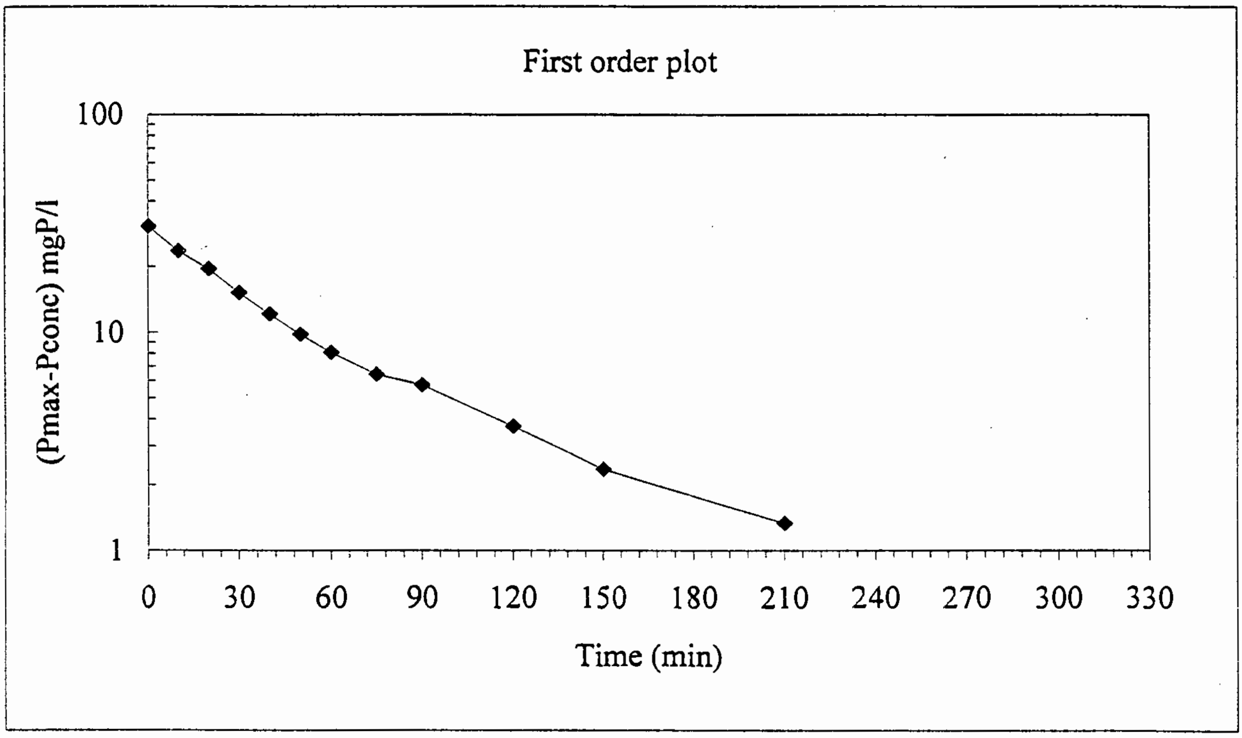
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 12.12.1995

TEST 2 S P rel

Temperature: 30 C



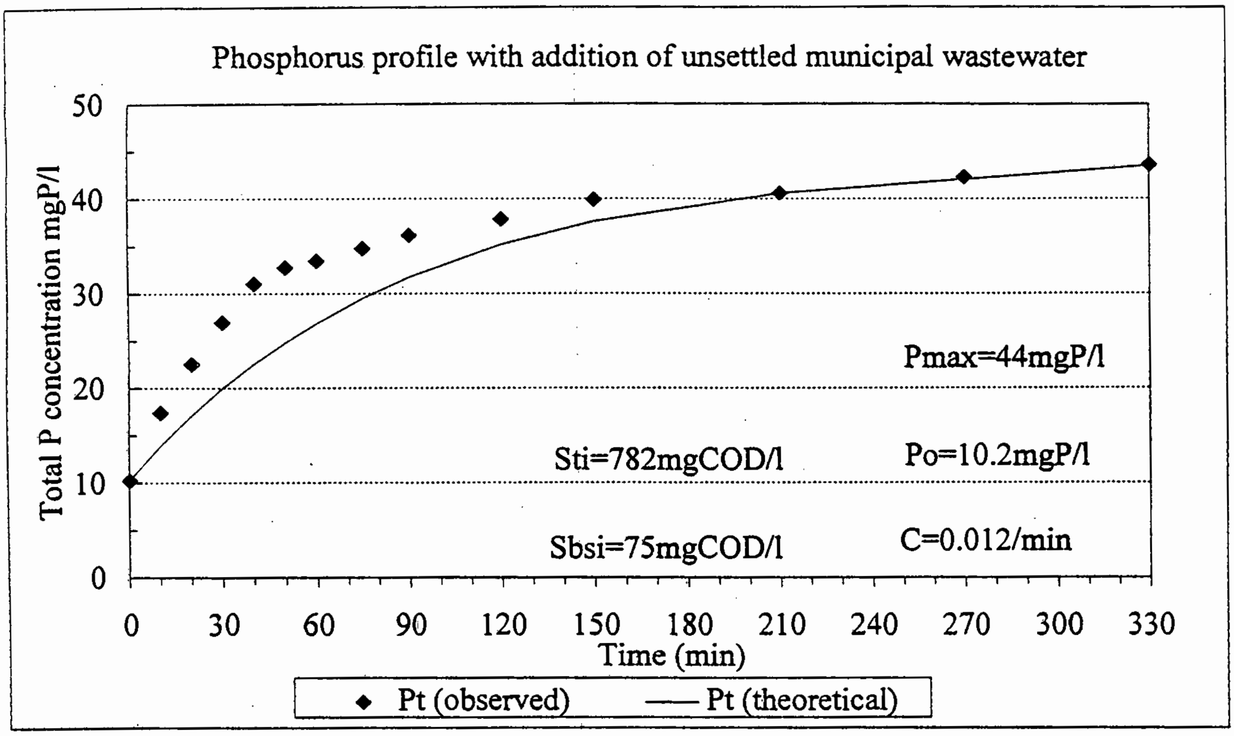


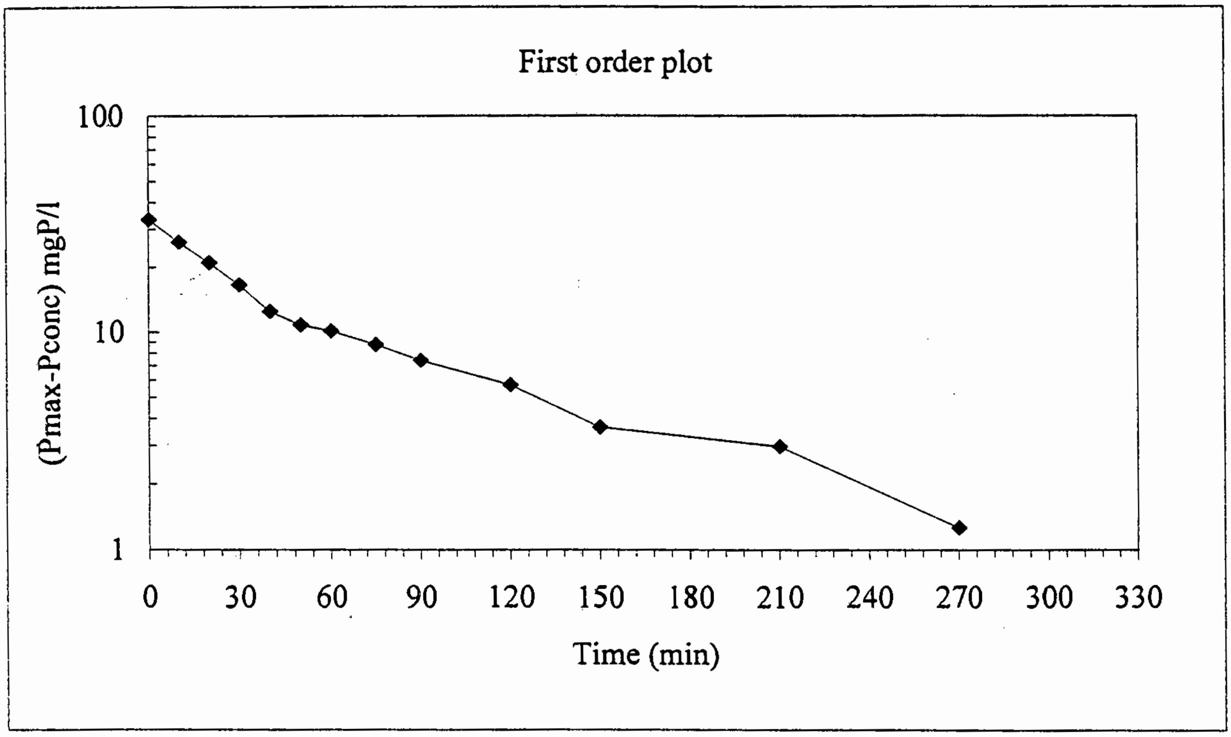
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 20.12.1995

TEST 3 S P rel

Temperature: 30 C



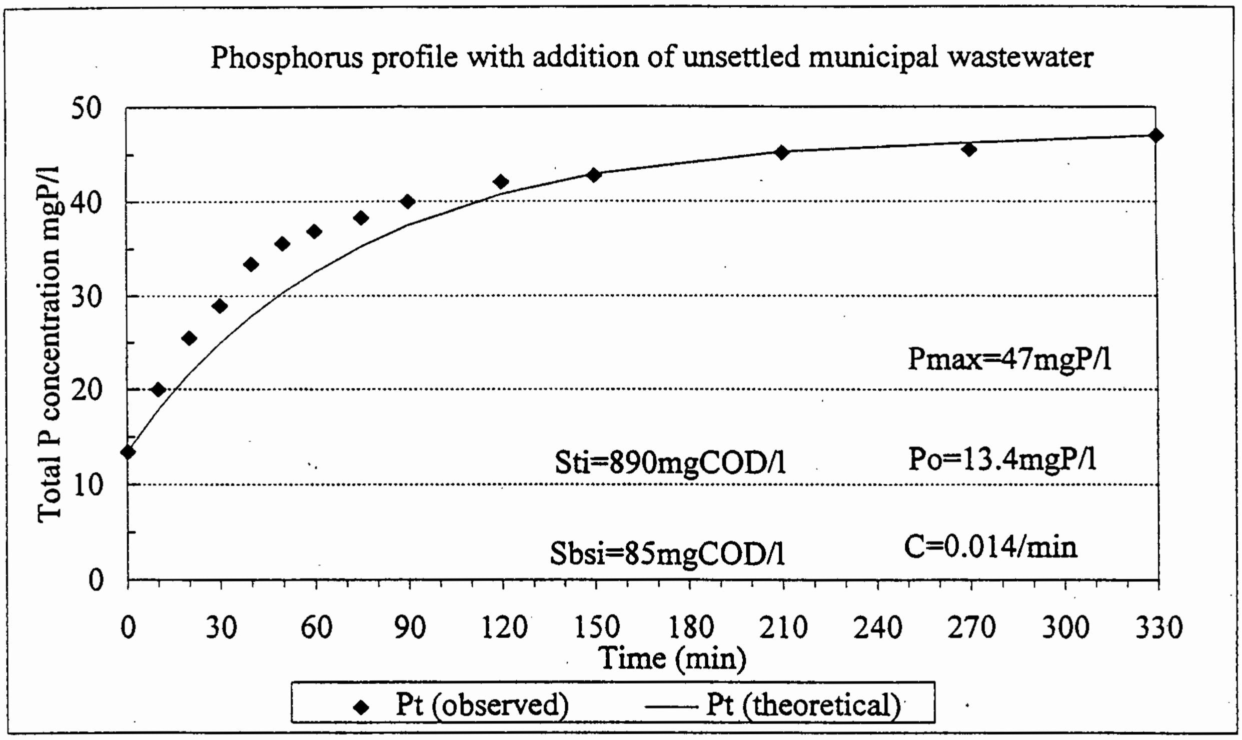


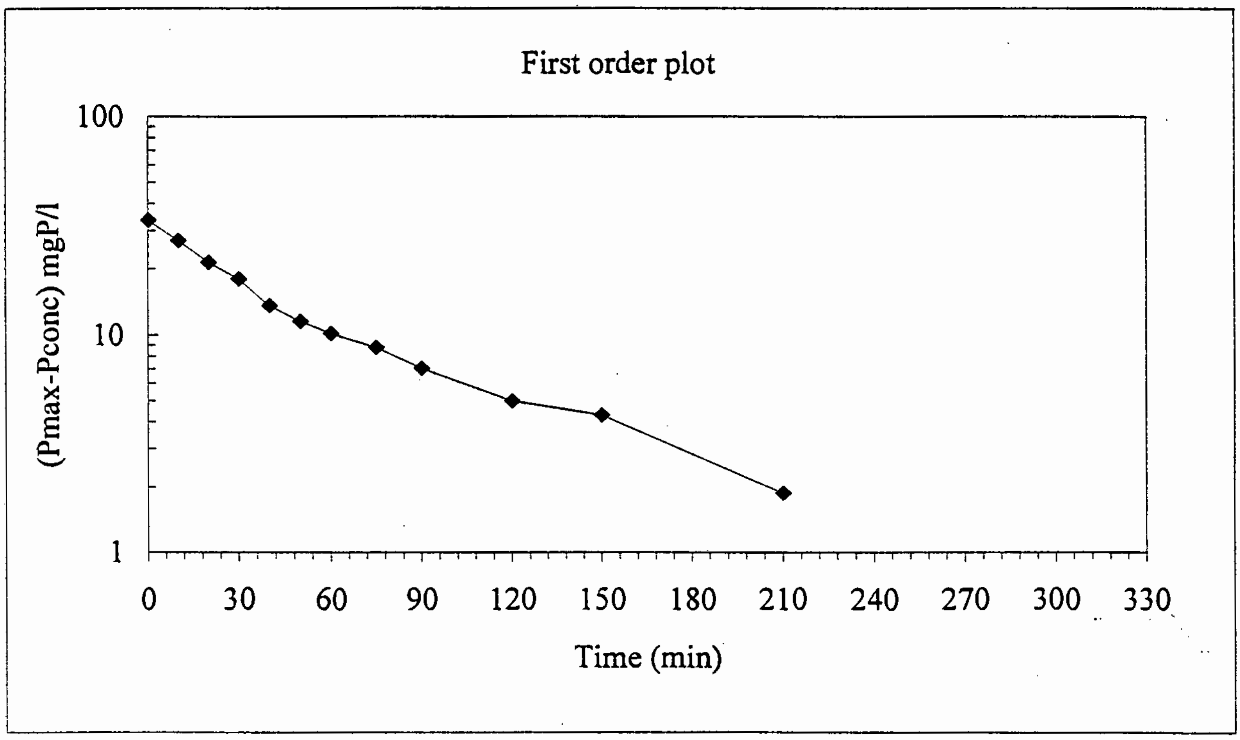
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 28.12.1995

TEST 4 S P rel

Temperature: 30 C



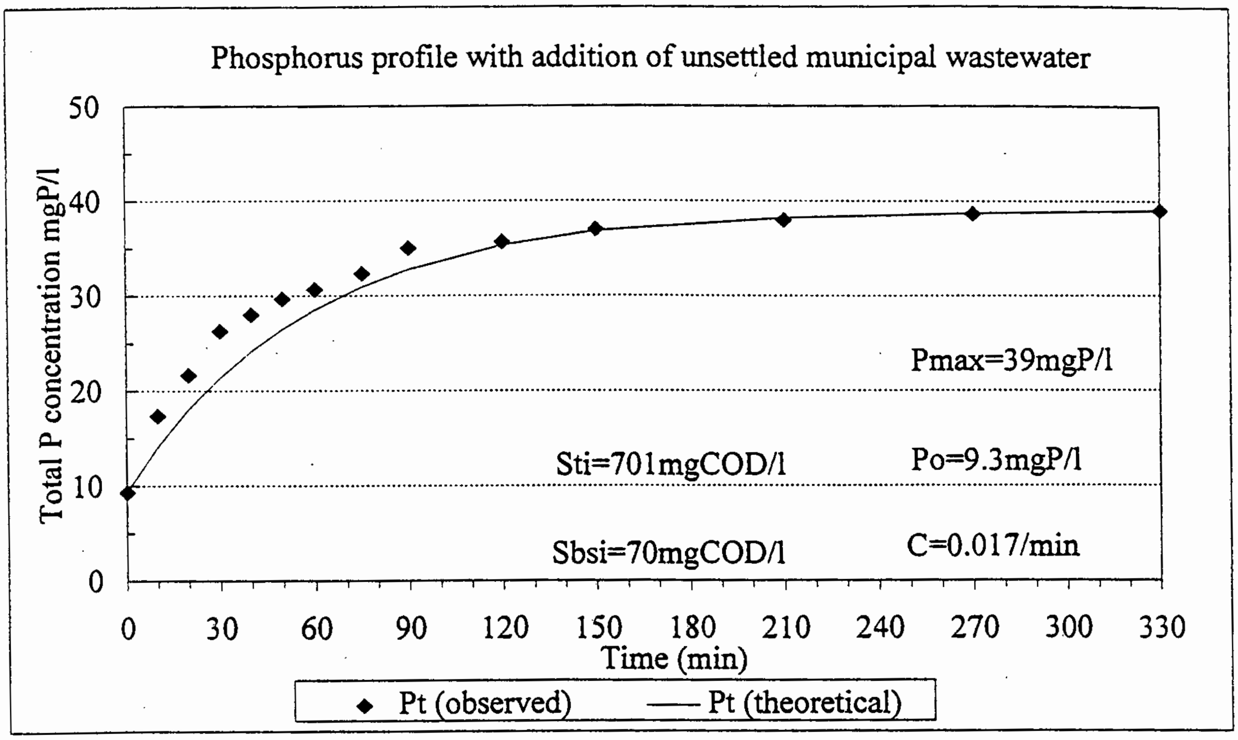


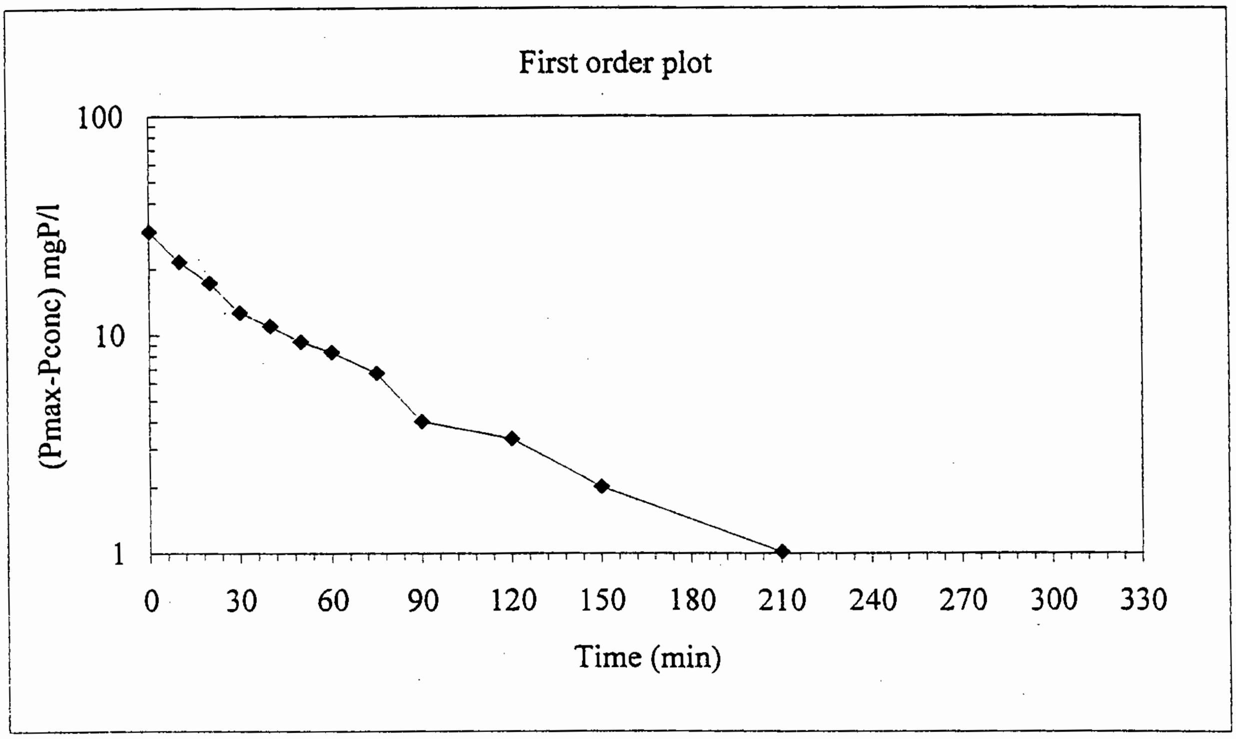
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 02.01.1996

TEST 5 S P rel

Temperature: 30 C



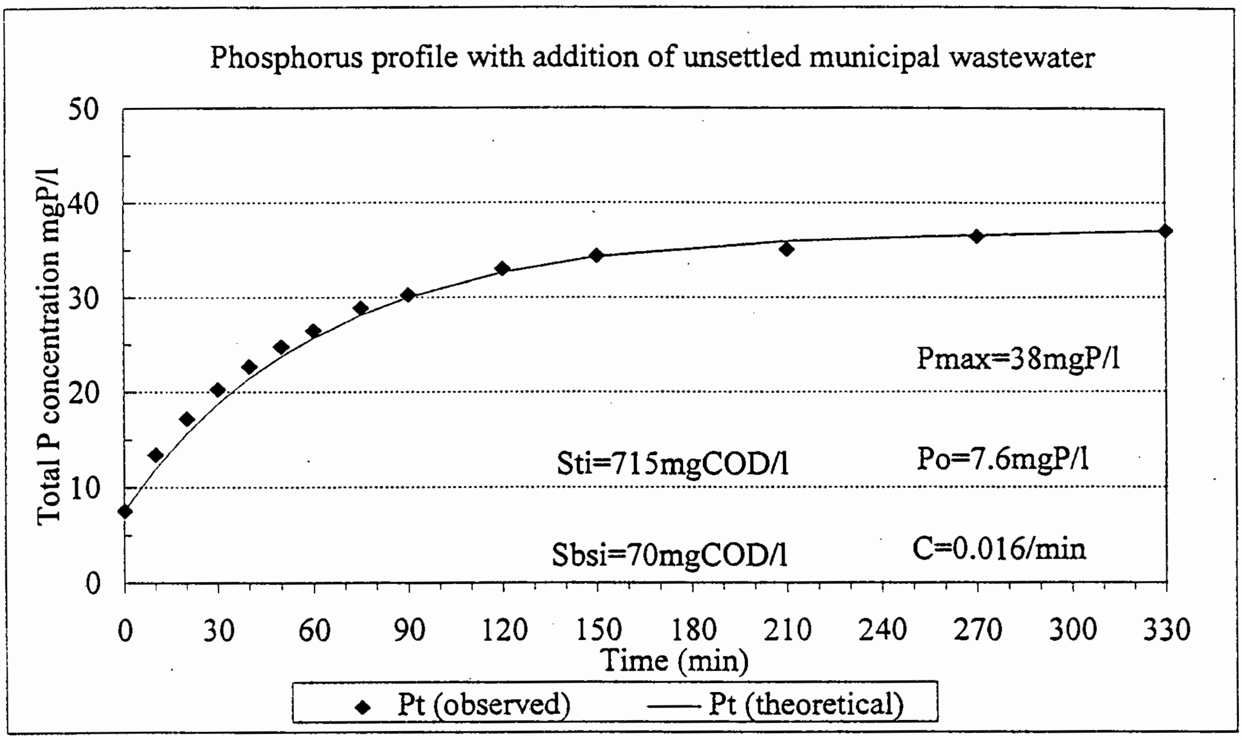


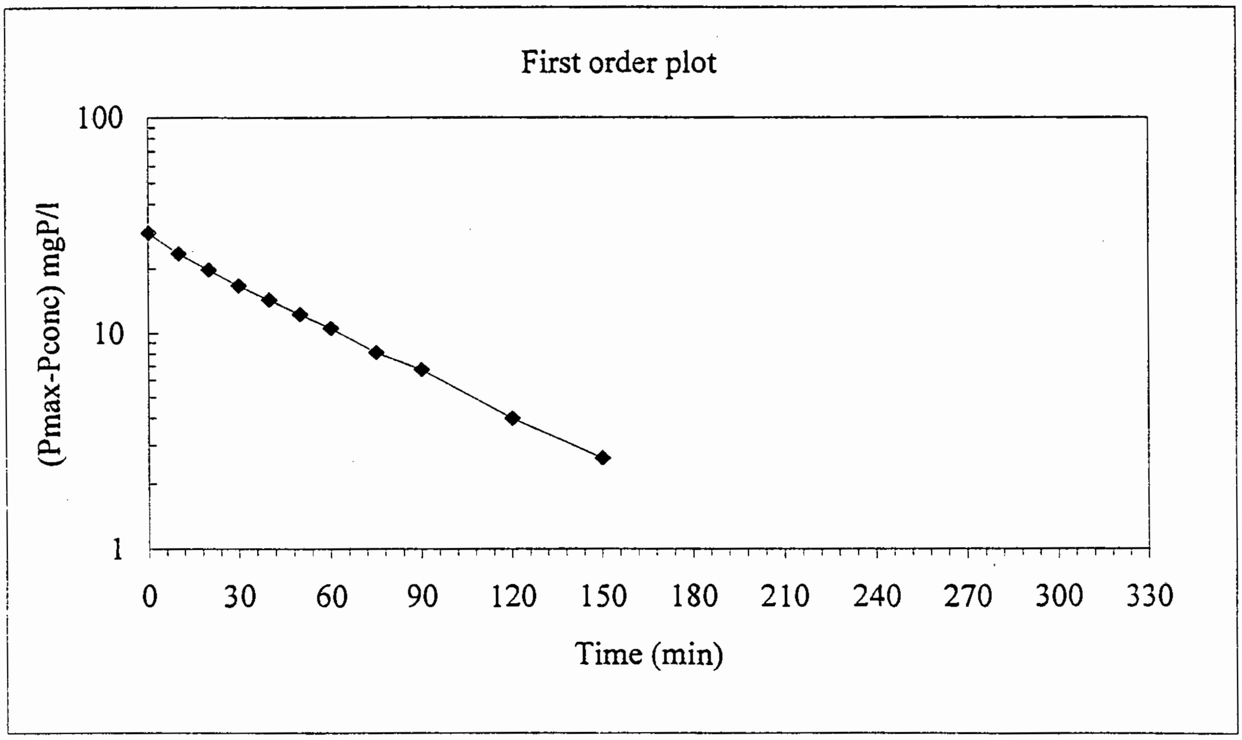
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 09.01.1996

TEST 6 S P rel

Temperature: 30 C



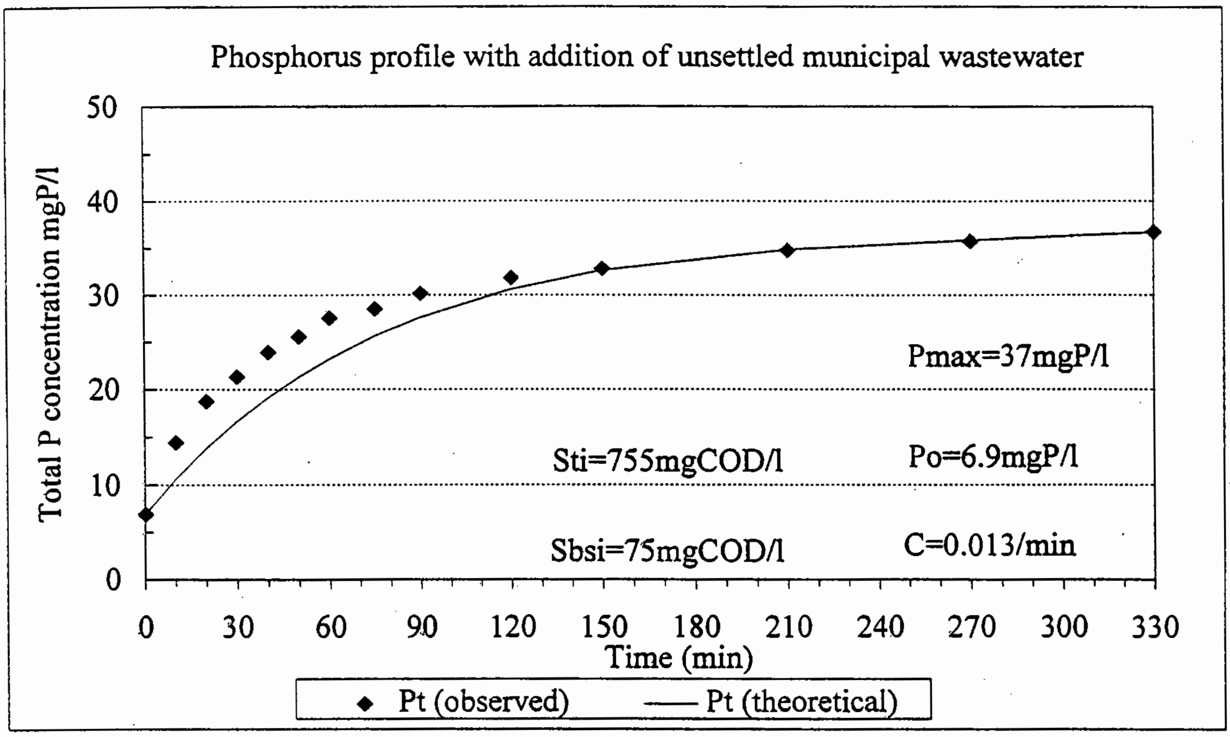


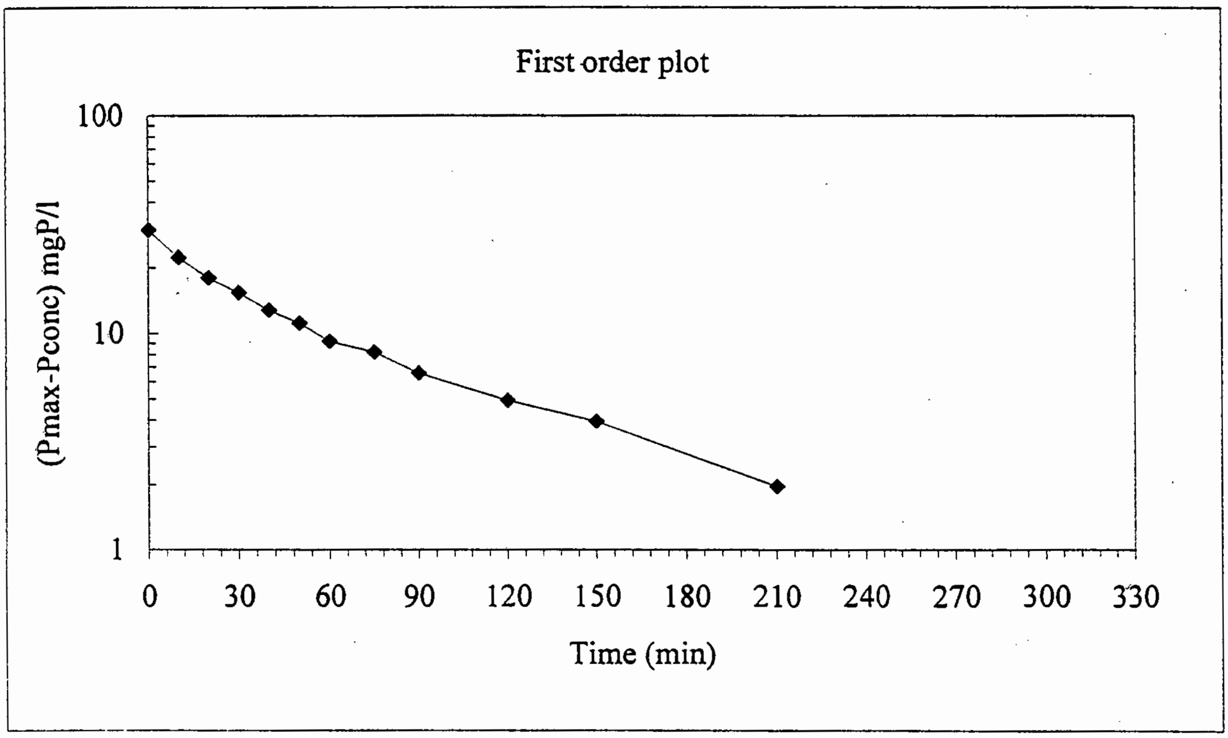
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 17.01.1996

TEST 7 S P rel

Temperature: 30 C



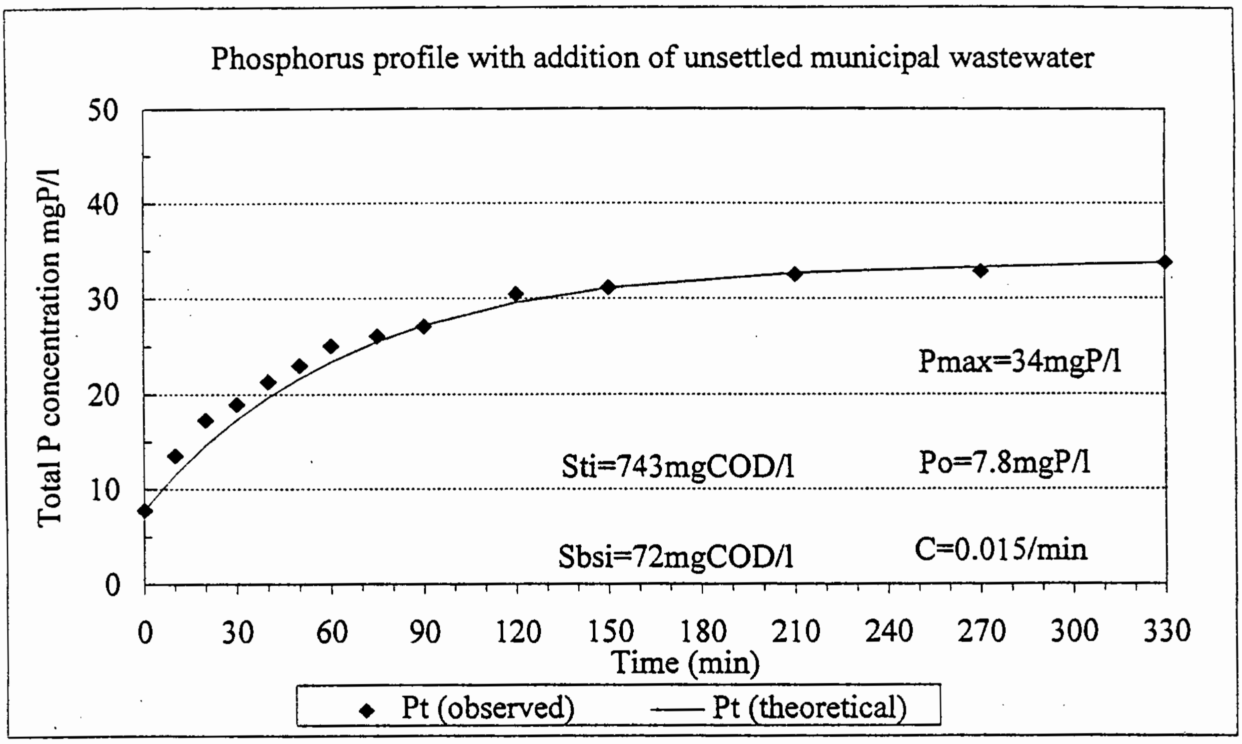


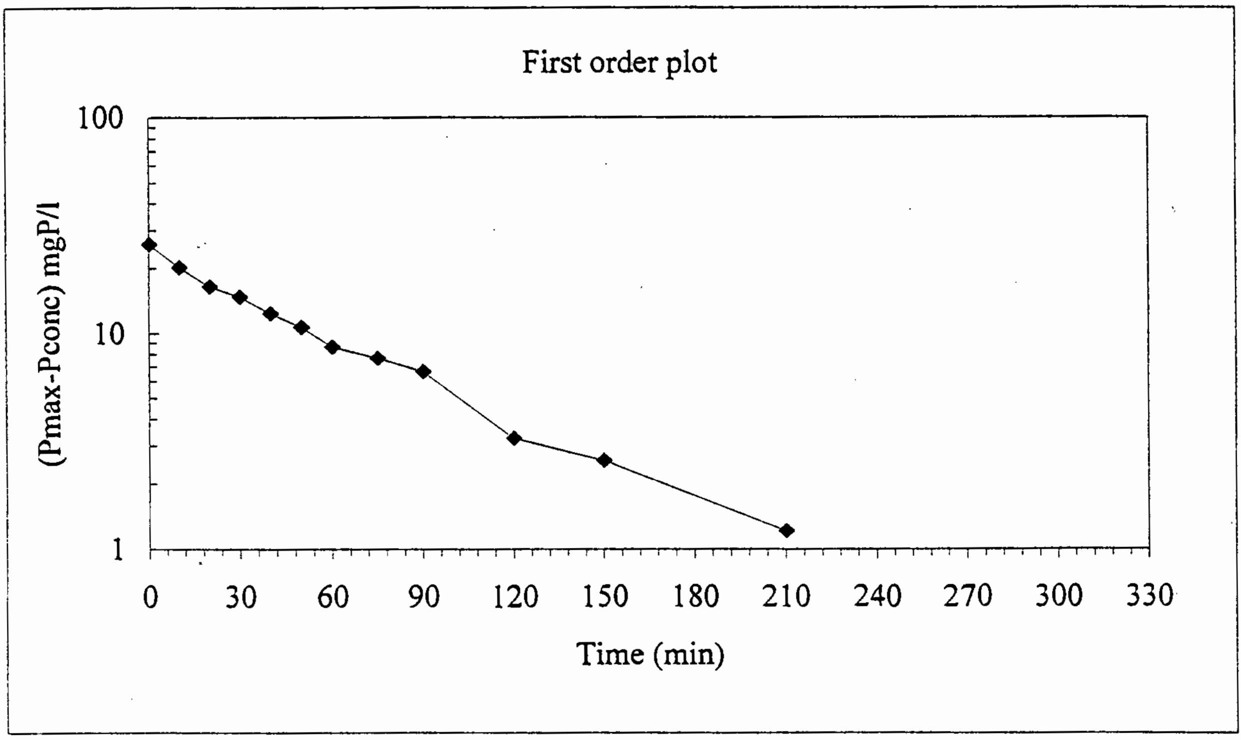
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 23.01.1996

TEST 8 S P rel

Temperature: 30 C



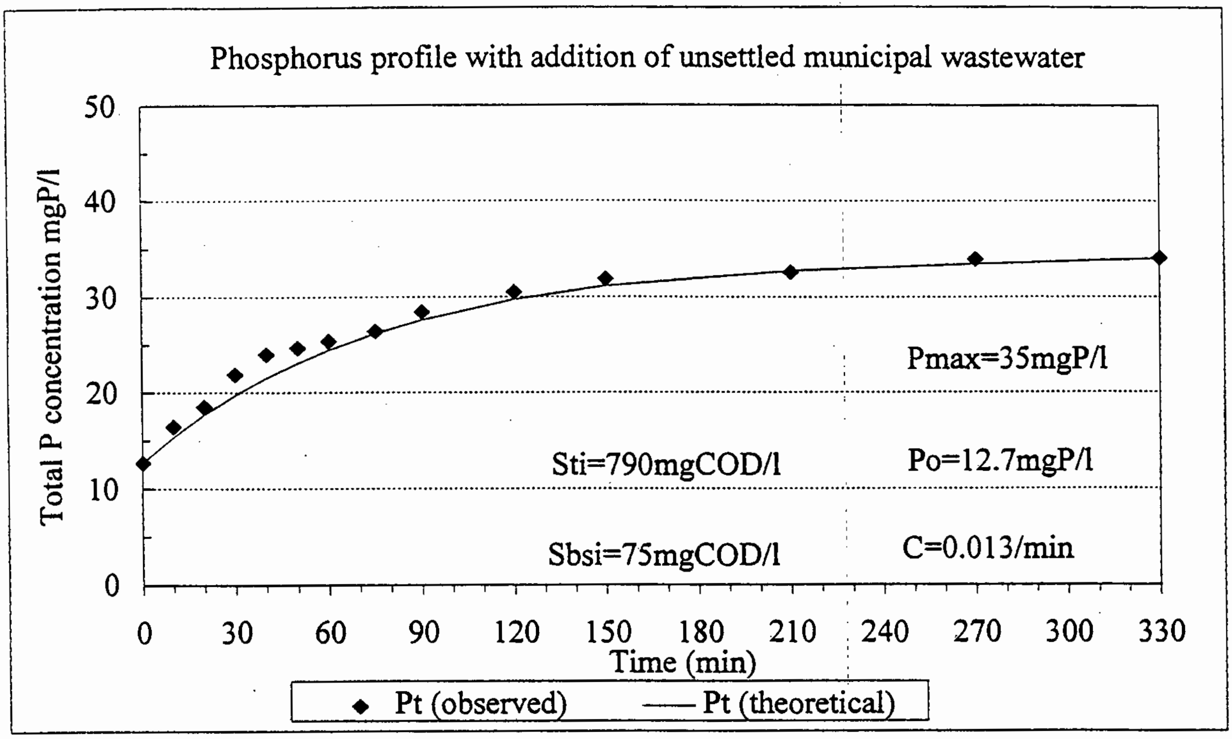


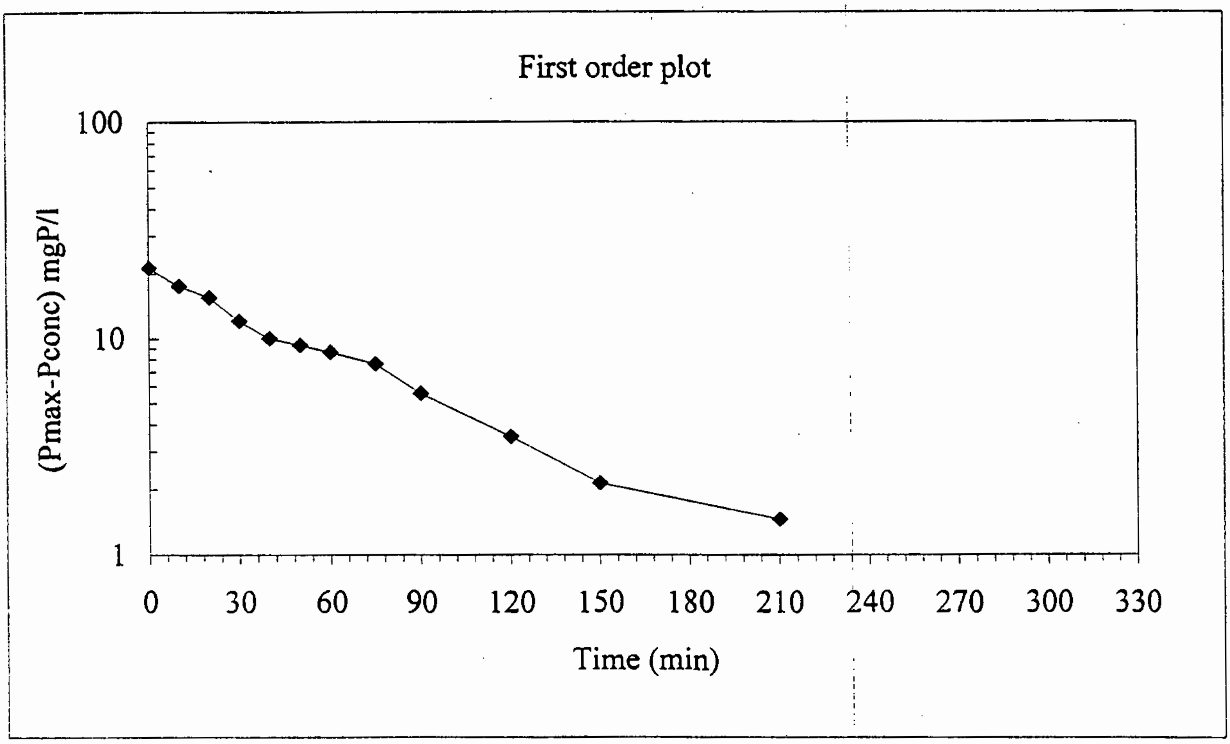
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 30.01.1996

TEST 9 S P rel

Temperature: 30 C


Phosphorus profile with addition of unsettled municipal wastewater

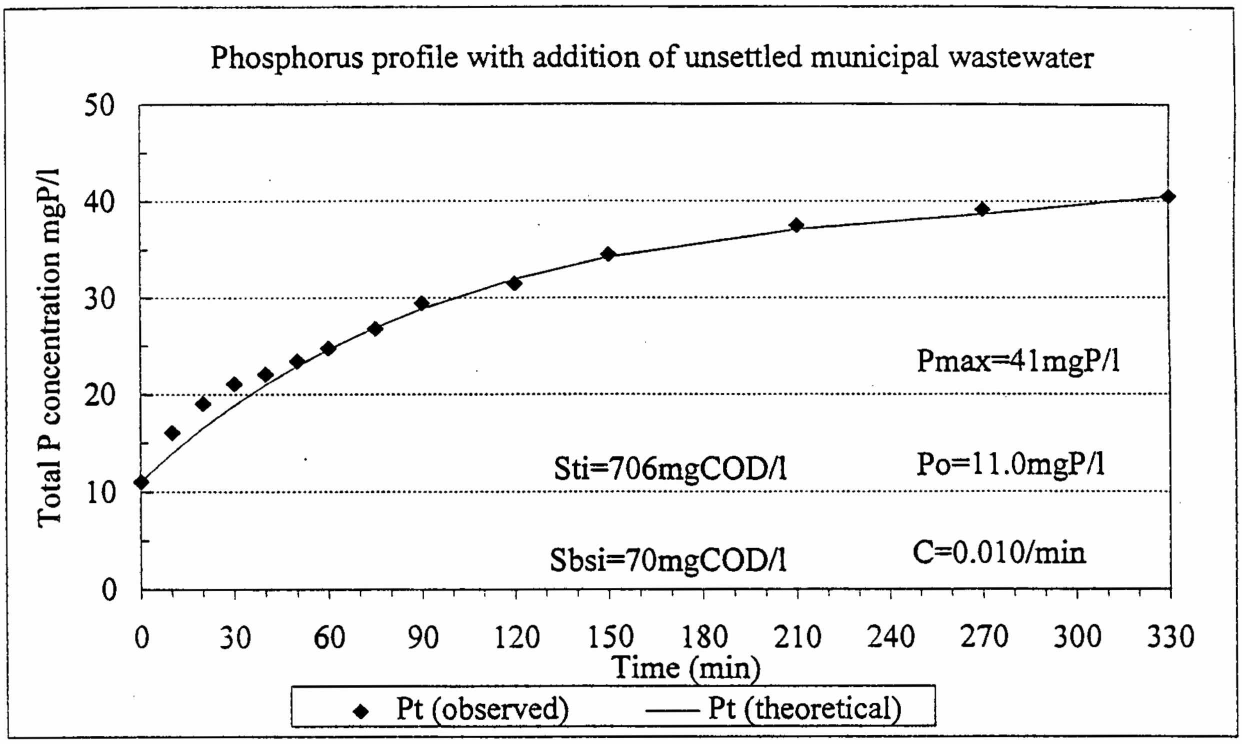

First order plot

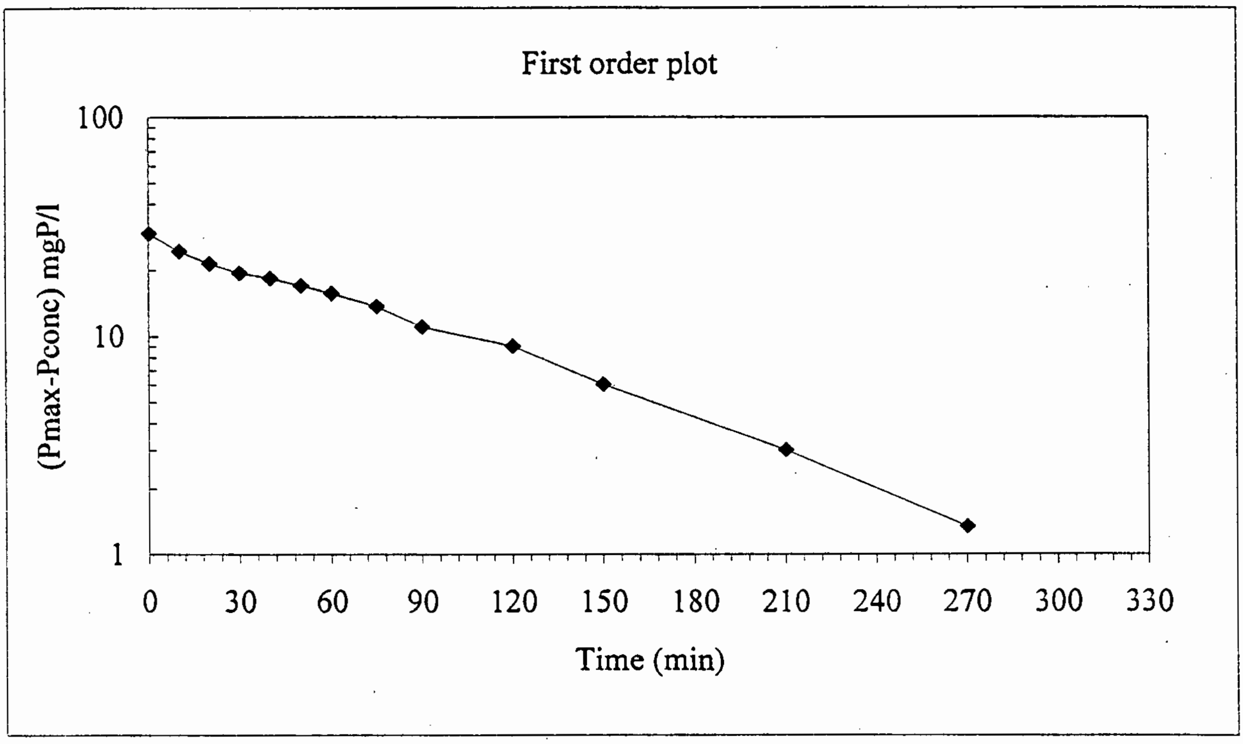
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 20.02.1996

TEST 10 S P rel

Temperature: 30 C



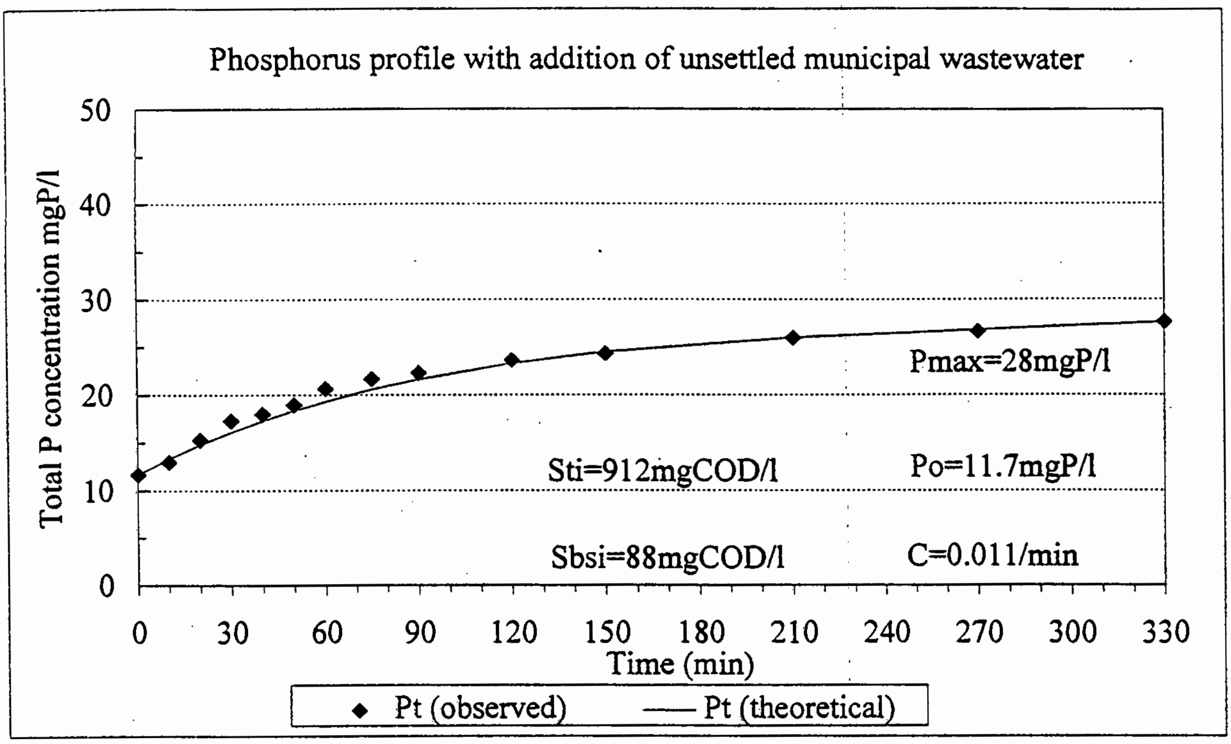


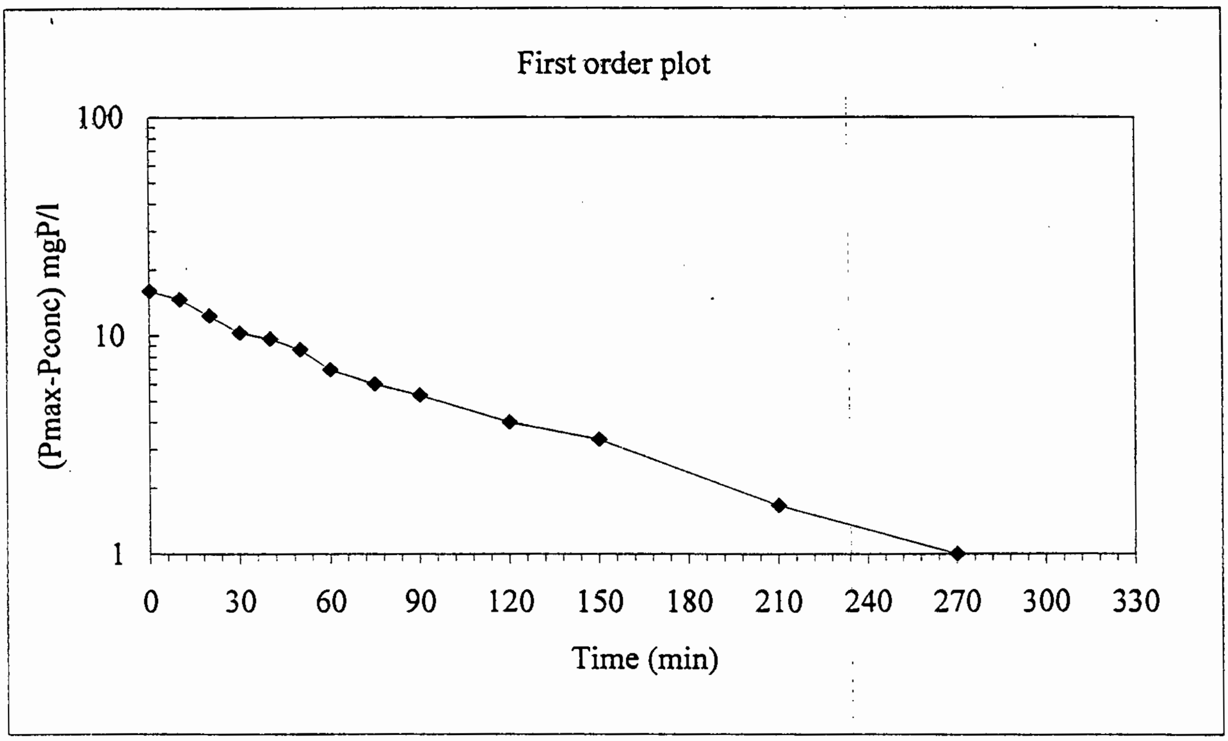
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 14.05.1996

TEST 11 S P rel

Temperature: 30 C



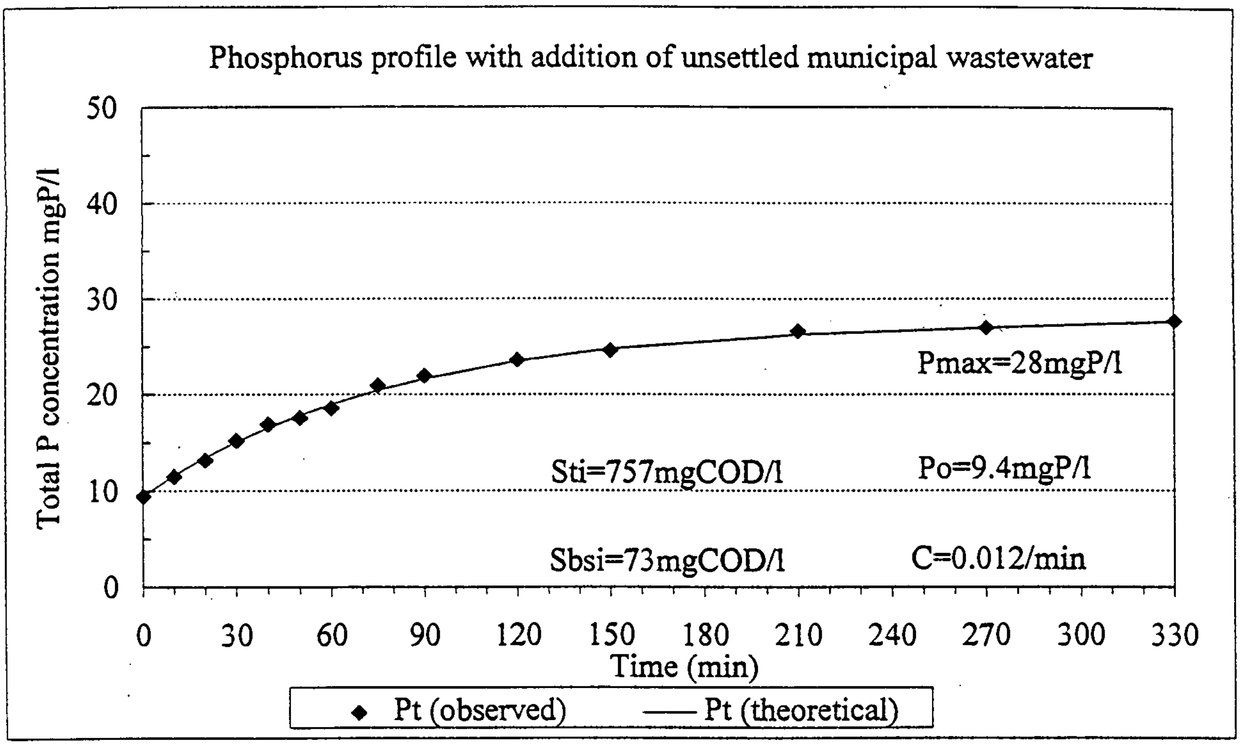


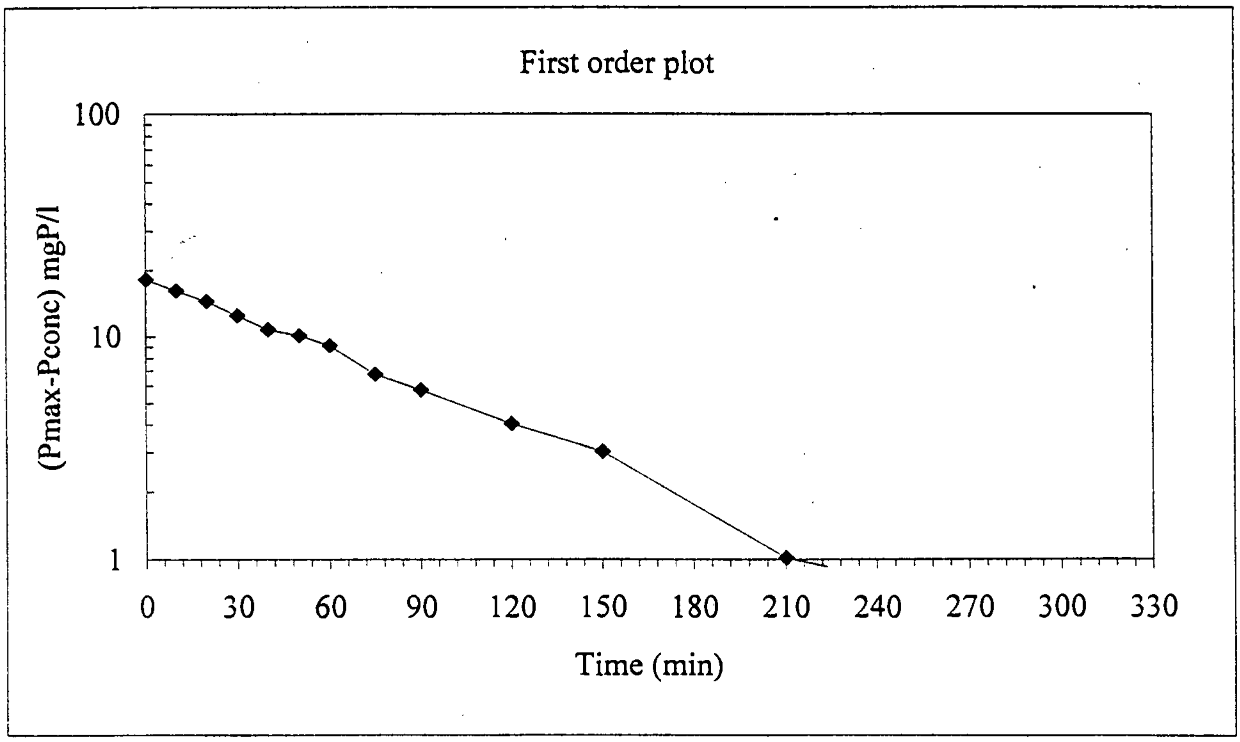
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 05.07.1996

TEST 12 S P rel

Temperature: 30 C



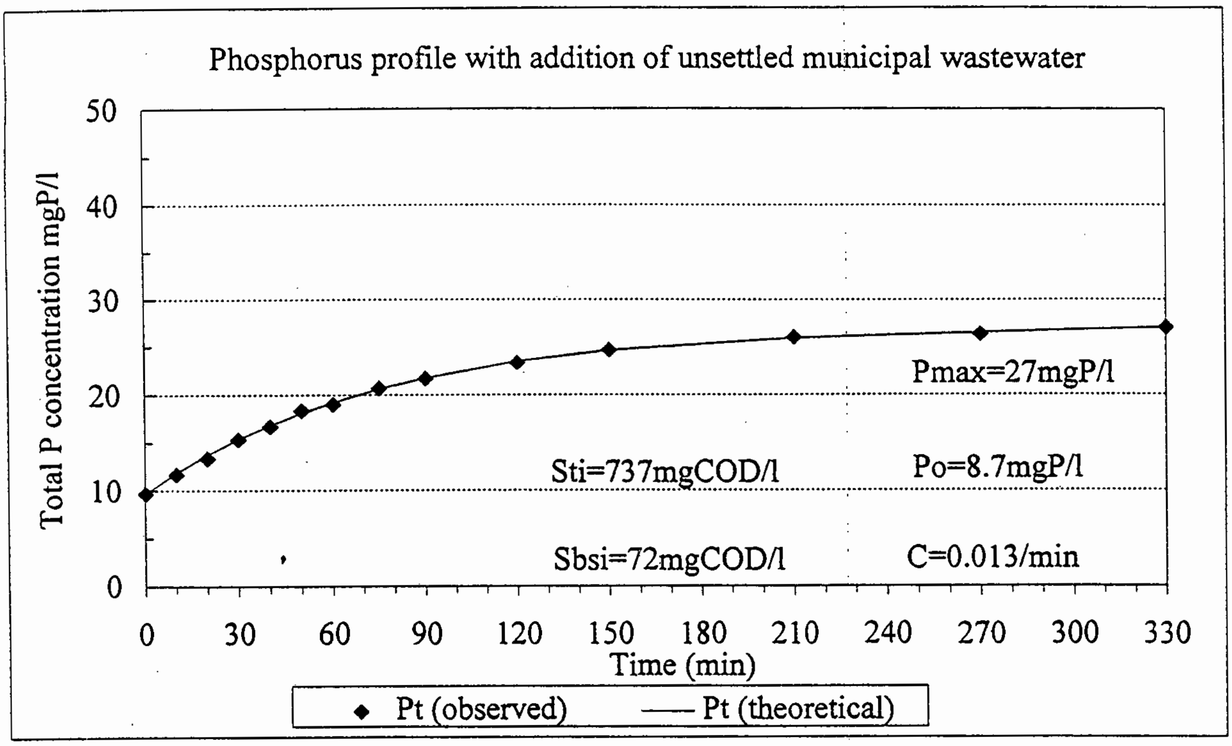


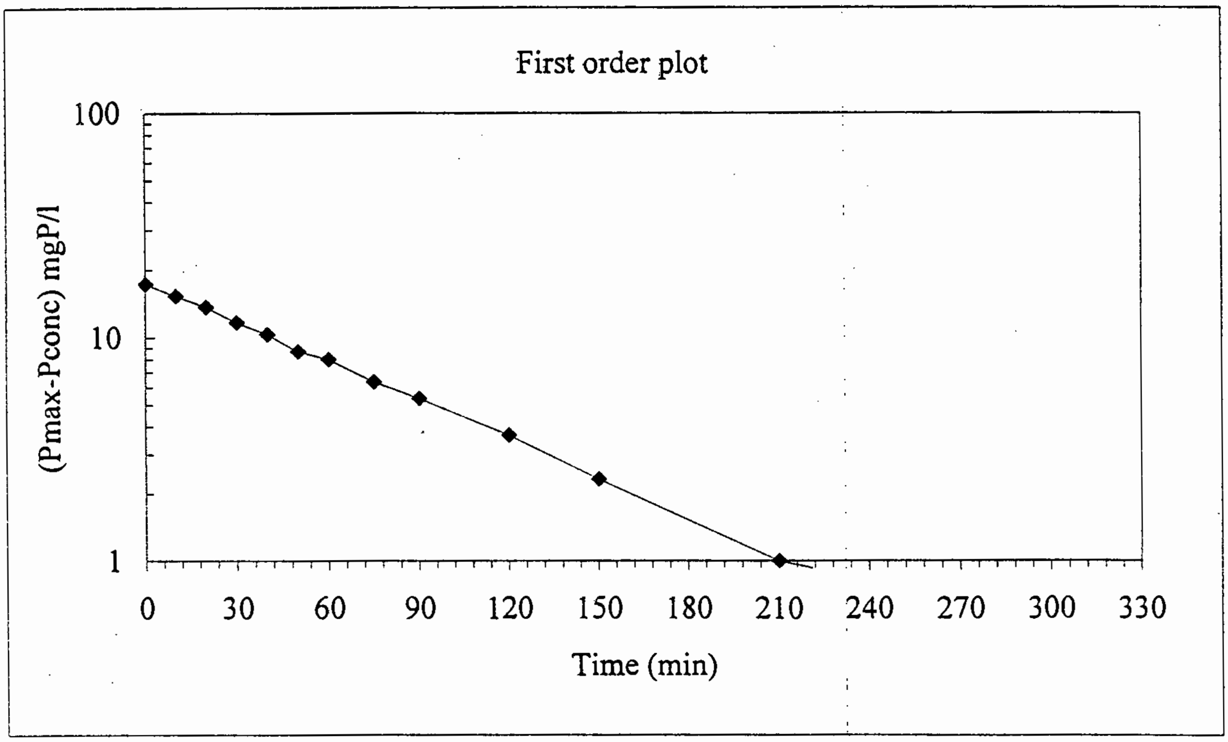
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 08.07.1996

TEST 13 S P rel

Temperature: 30 C



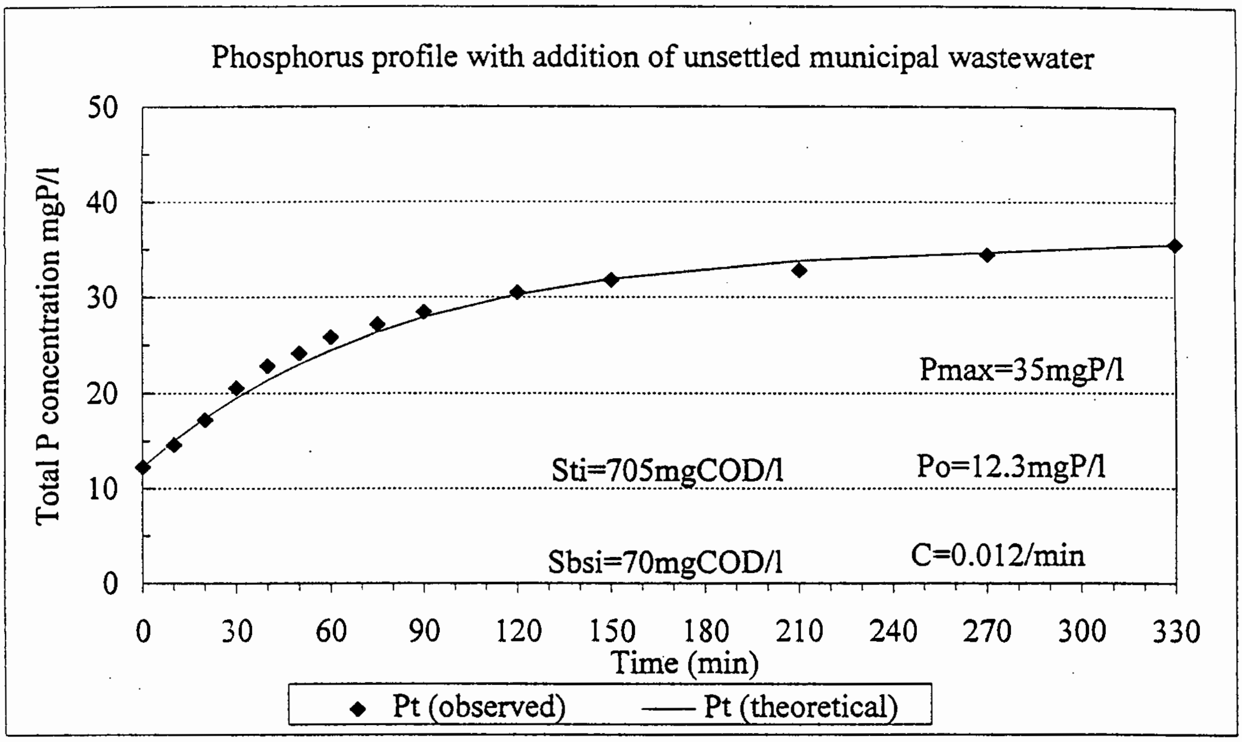


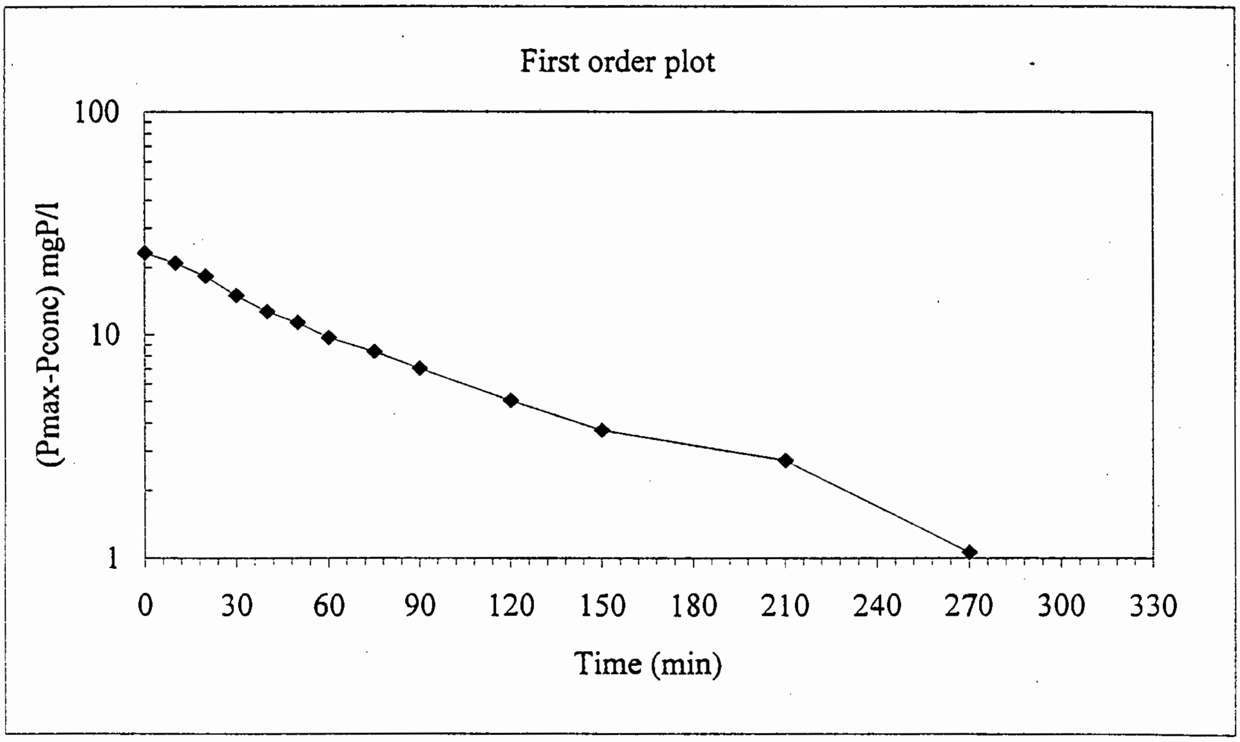
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 20.11.1996

TEST 14 S P rel

Temperature: 30 C



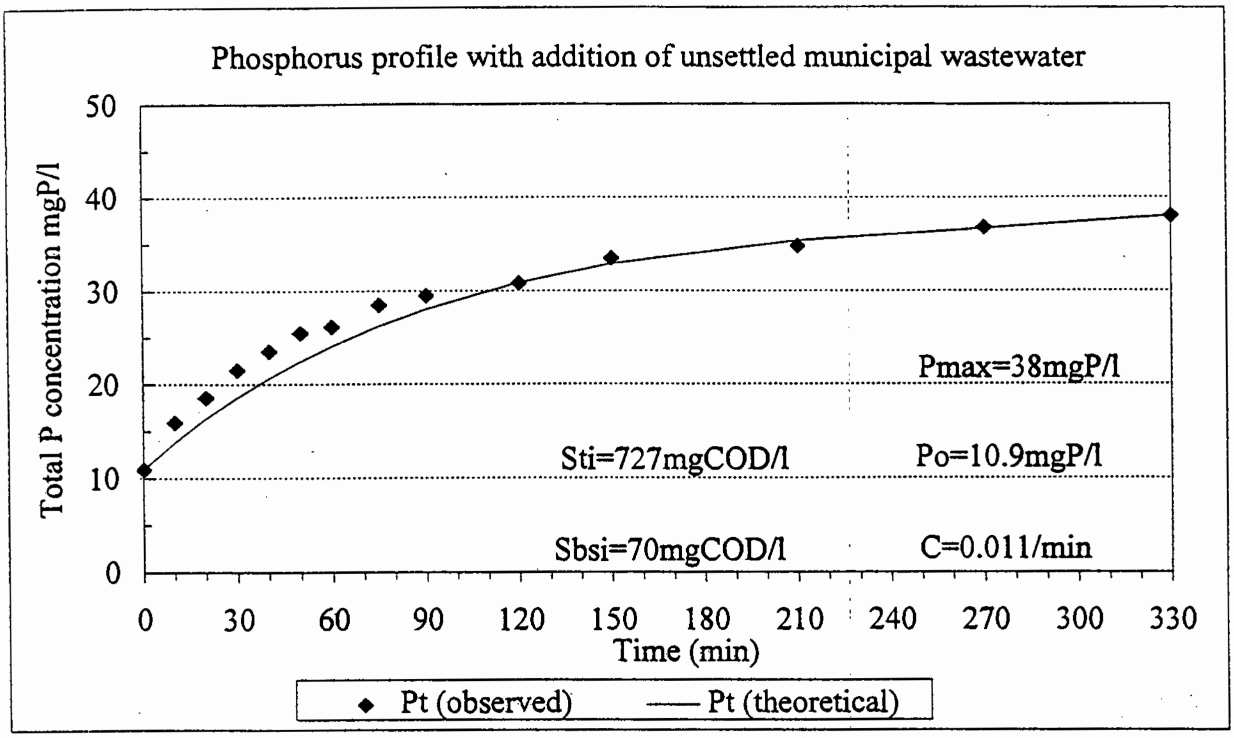


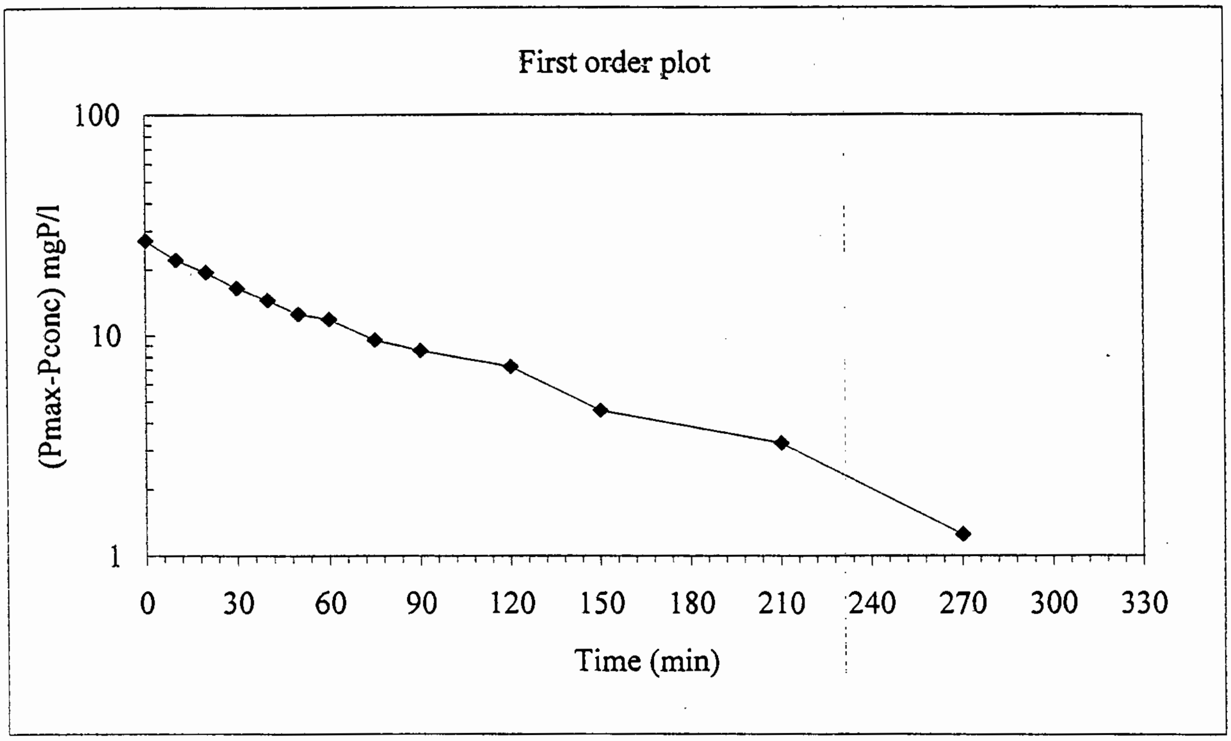
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 21.11.1996

TEST 15 S P rel

Temperature: 30 C



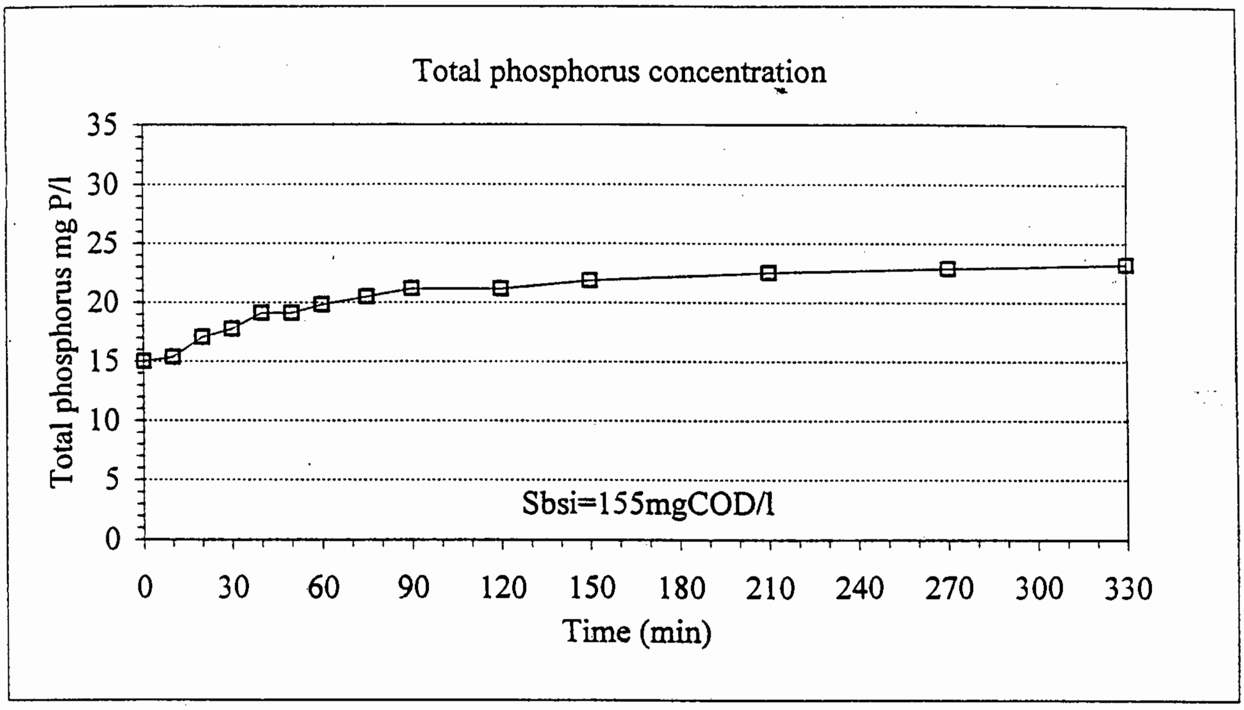


EXCESS PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST ADDING EXCESS ACETATE SOLUTION AS A SUBSTRATE SOURCE

Date: 16.12.1995

TEST 1 Ex P rel

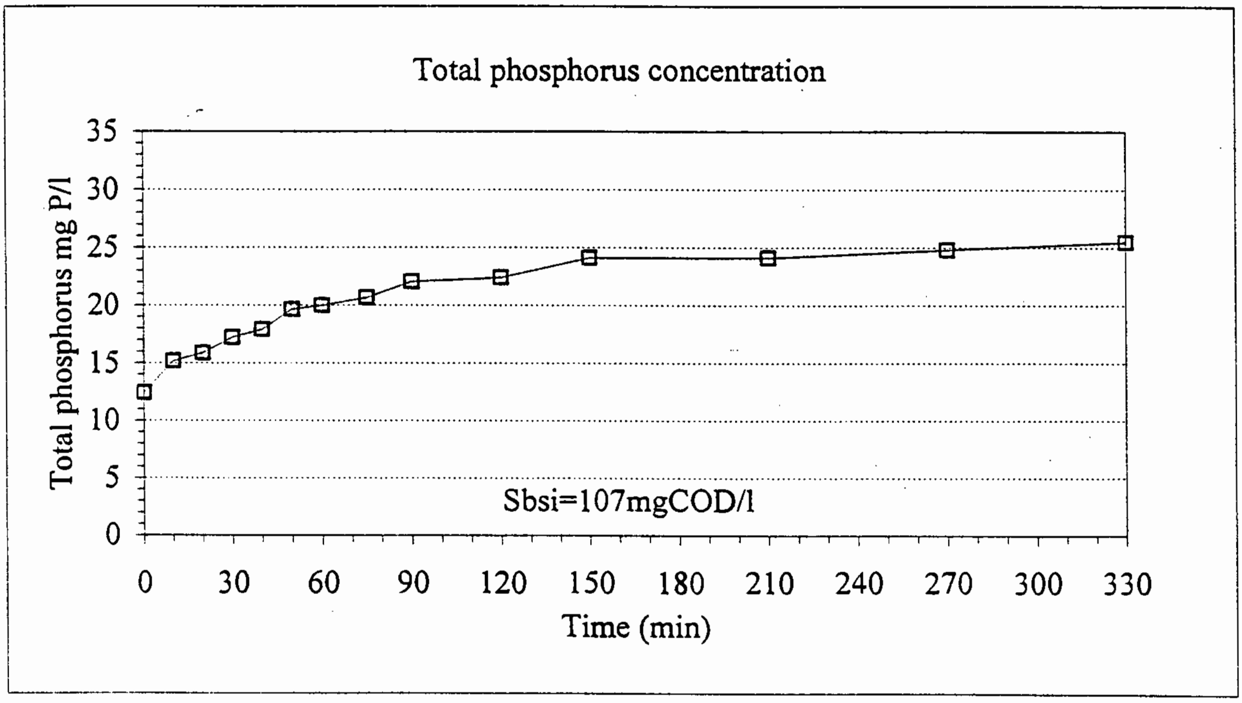
Temperature: 30 C



Date: 23.12.1995

TEST 2 Ex P rel

Temperature: 30 C

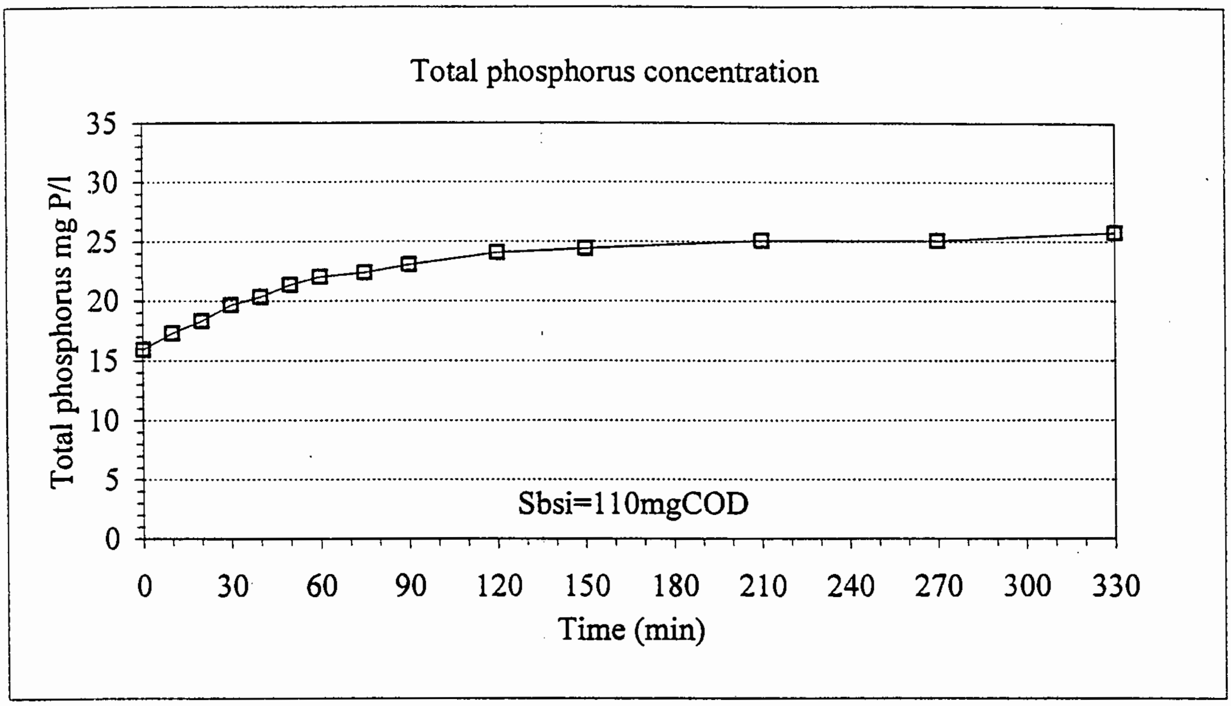


EXCESS PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST ADDING EXCESS ACETATE SOLUTION AS A SUBSTRATE SOURCE

Date: 29.12.1995

TEST 3 Ex P rel

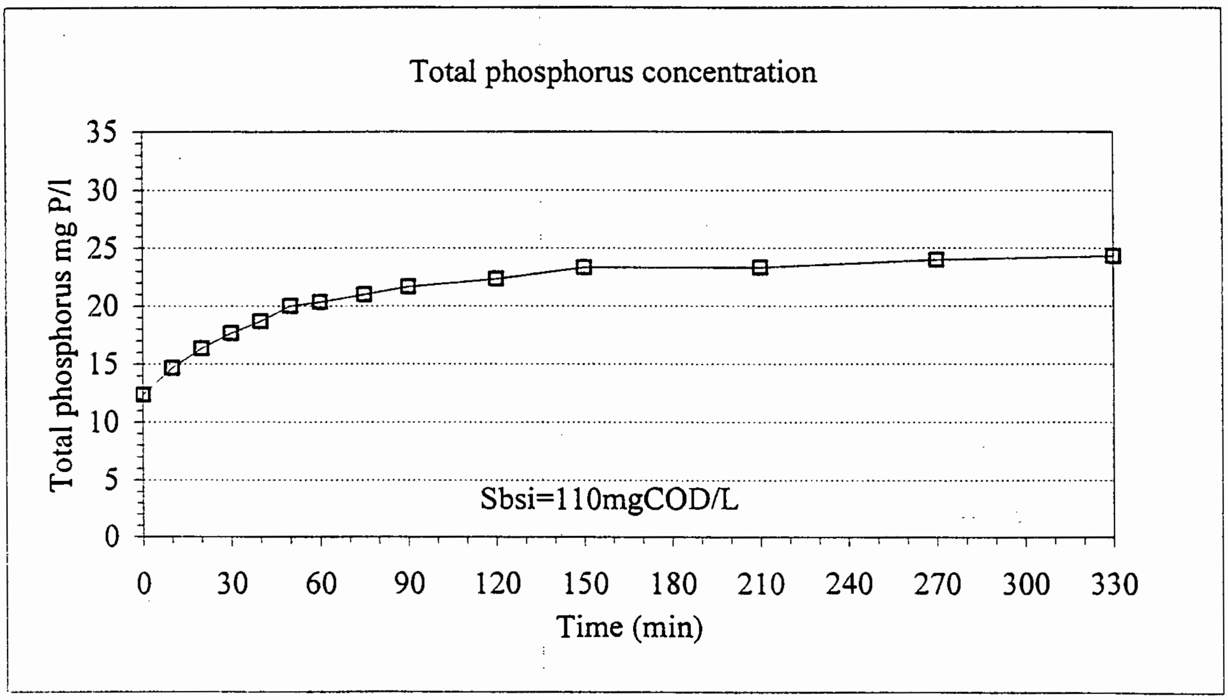
Temperature: 30 C



Date: 05.01.1996

TEST 4 Ex P rel

Temperature: 30 C

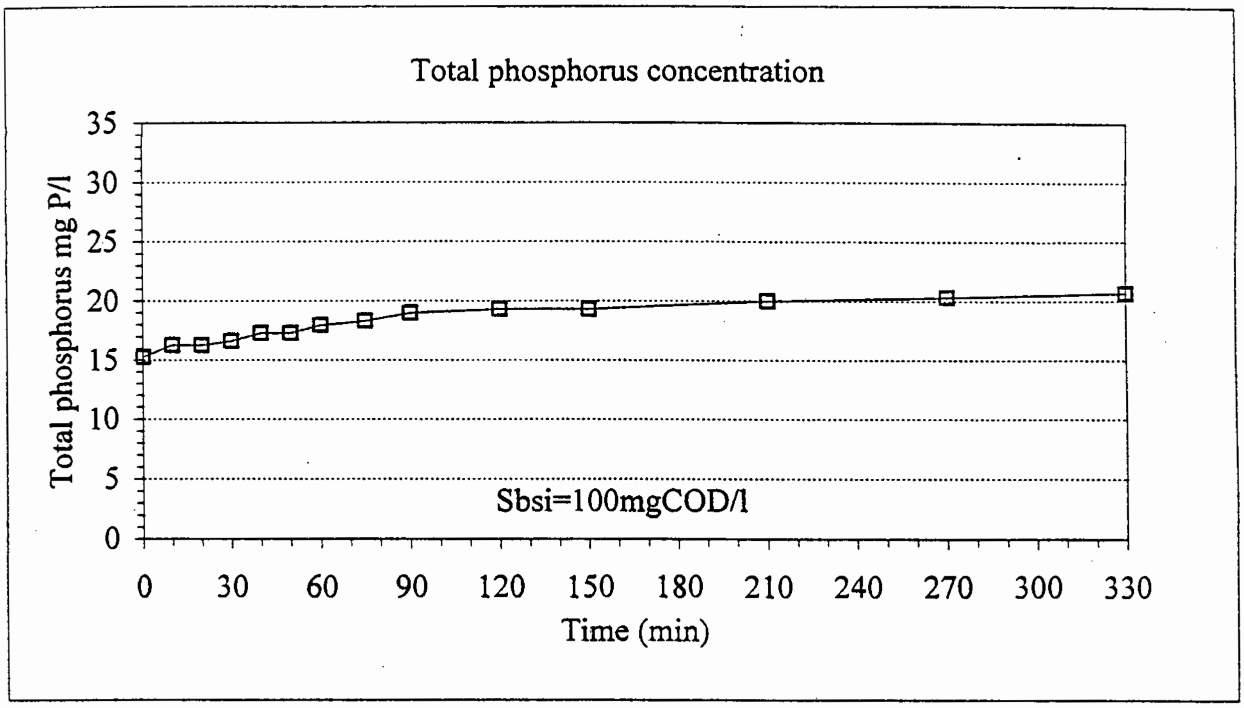


EXCESS PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST ADDING EXCESS ACETATE SOLUTION AS A SUBSTRATE SOURCE

Date: 14.01.1996

TEST 5 Ex P rel

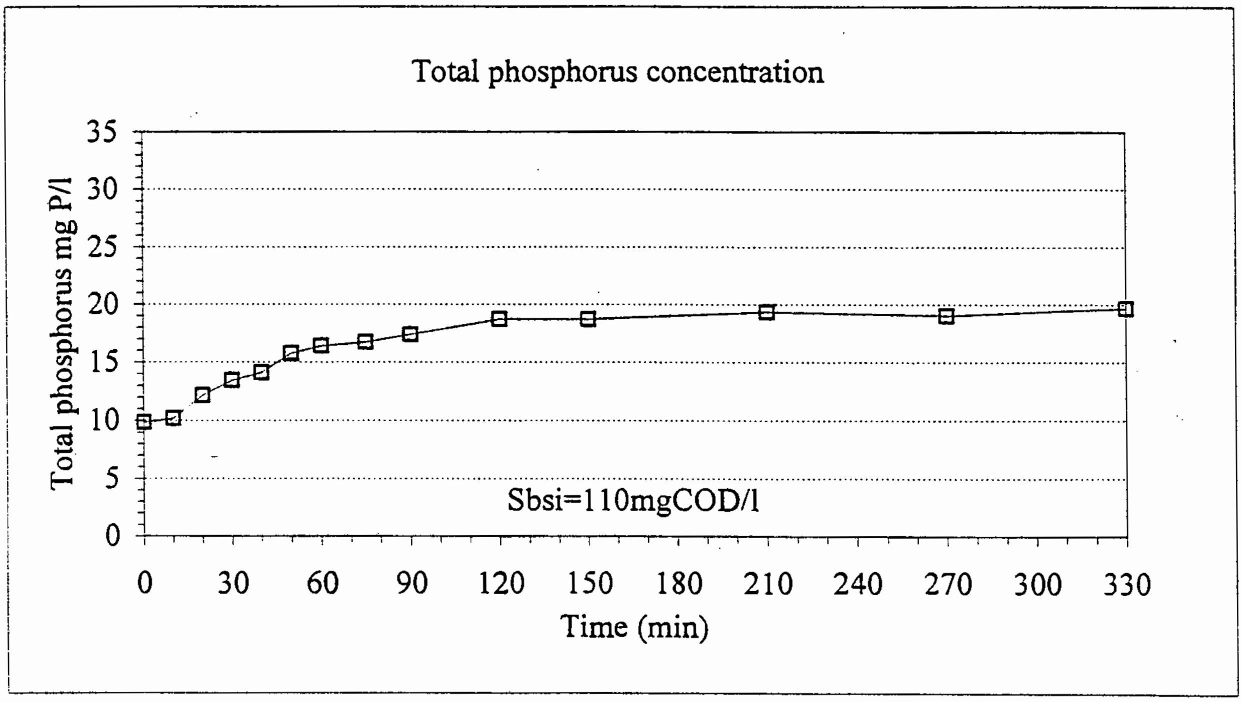
Temperature: 30 C



Date: 18.01.1996

TEST 6 Ex P rel

Temperature: 30 C

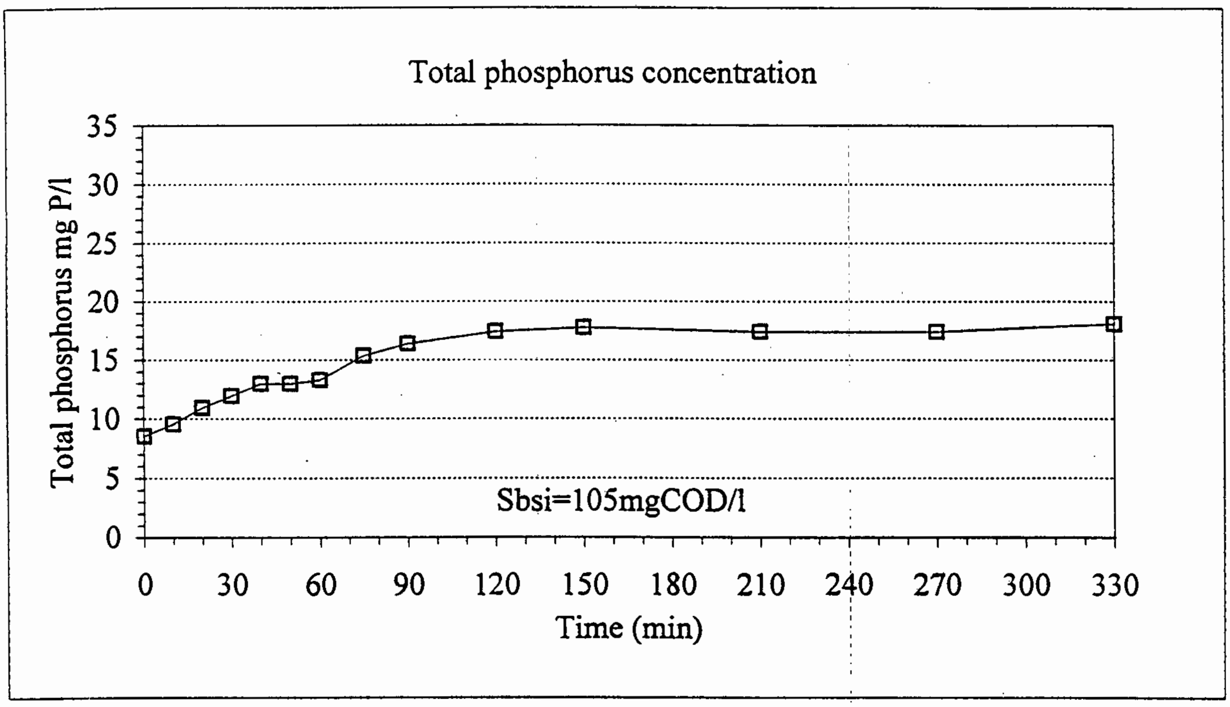


EXCESS PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST ADDING EXCESS ACETATE SOLUTION AS A SUBSTRATE SOURCE

Date: 24.01.1996

TEST 7 Ex P rel

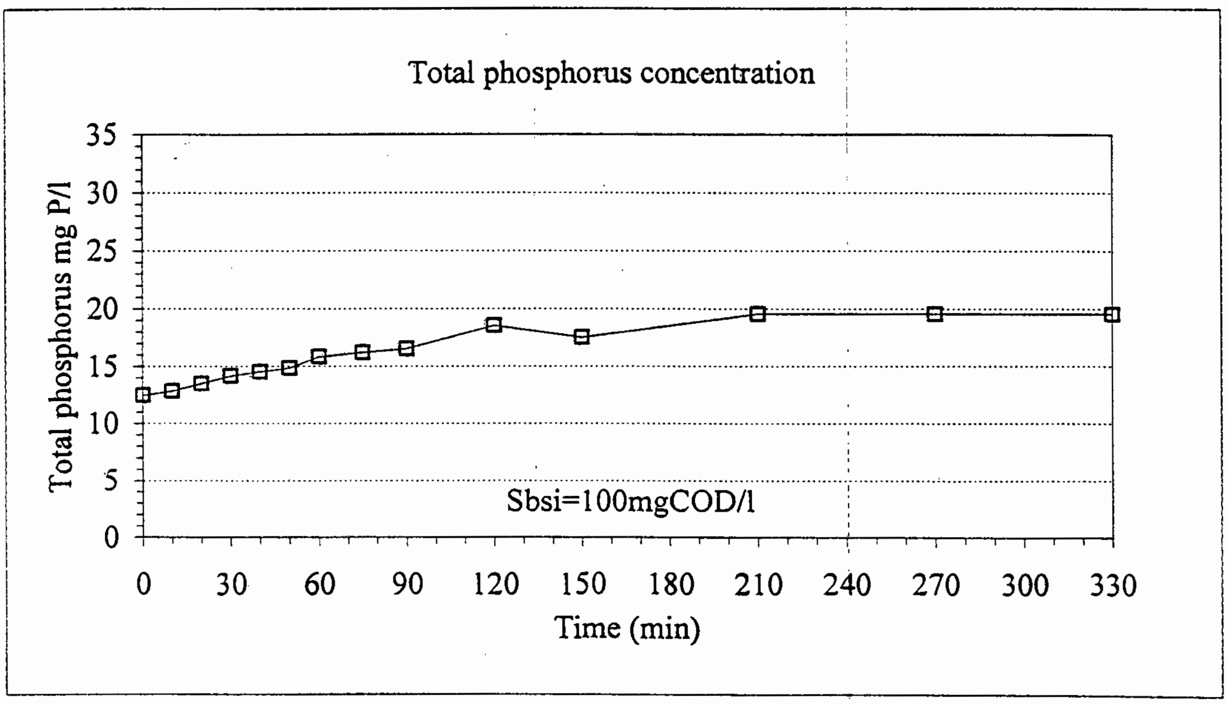
Temperature: 30 C



Date: 26.01.1996

TEST 8 Ex P rel

Temperature: 30 C

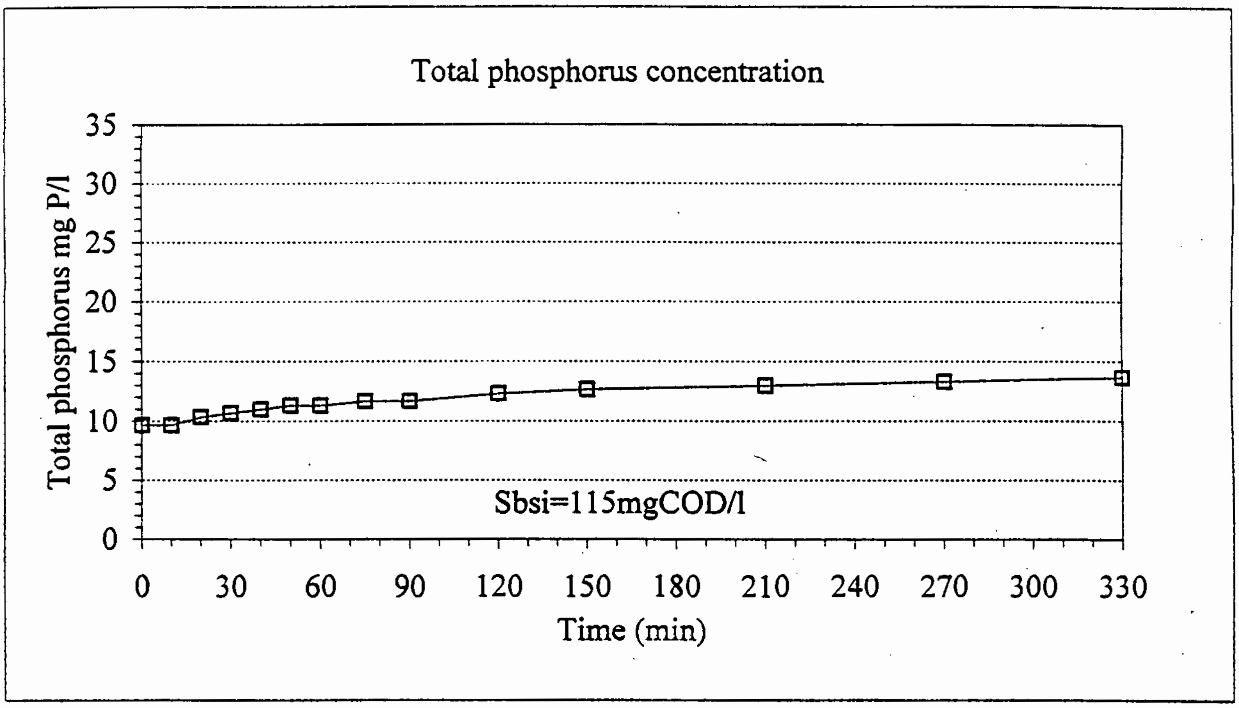


EXCESS PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST ADDING EXCESS ACETATE SOLUTION AS A SUBSTRATE SOURCE

Date: 24.06.1996

TEST 9 Ex P rel

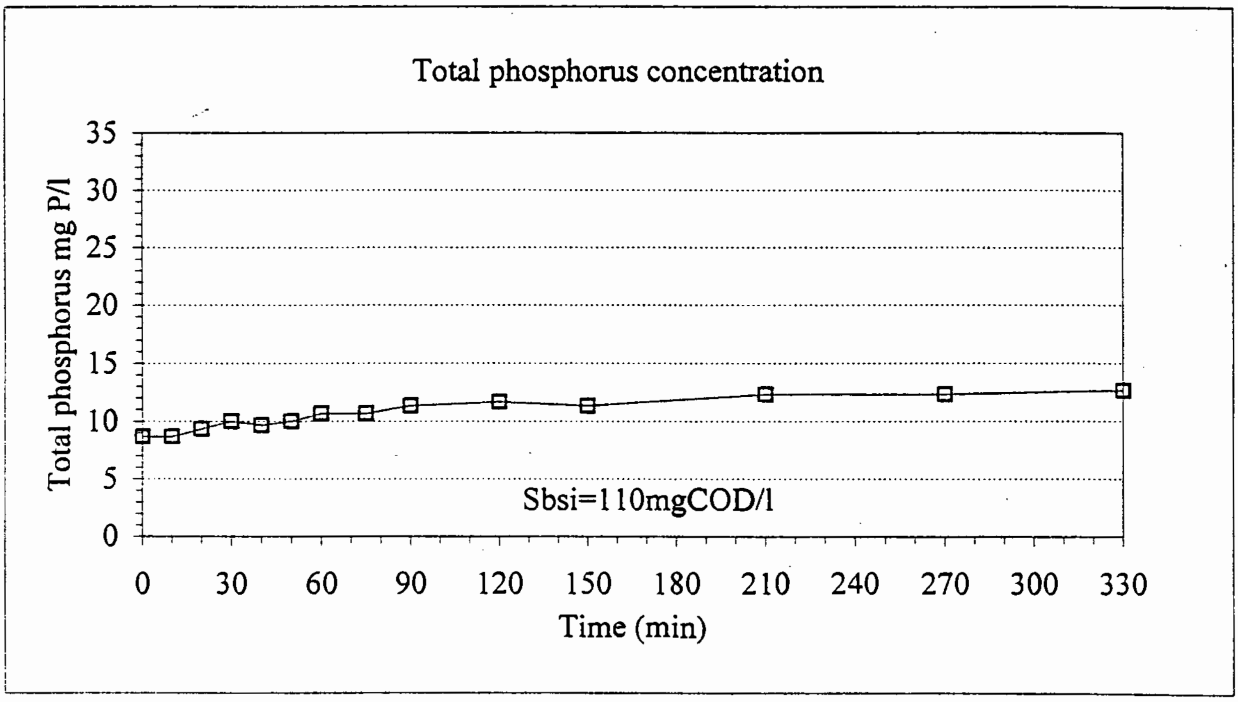
Temperature: 30 C



Date: 25.06.1996

TEST 10 Ex P rel

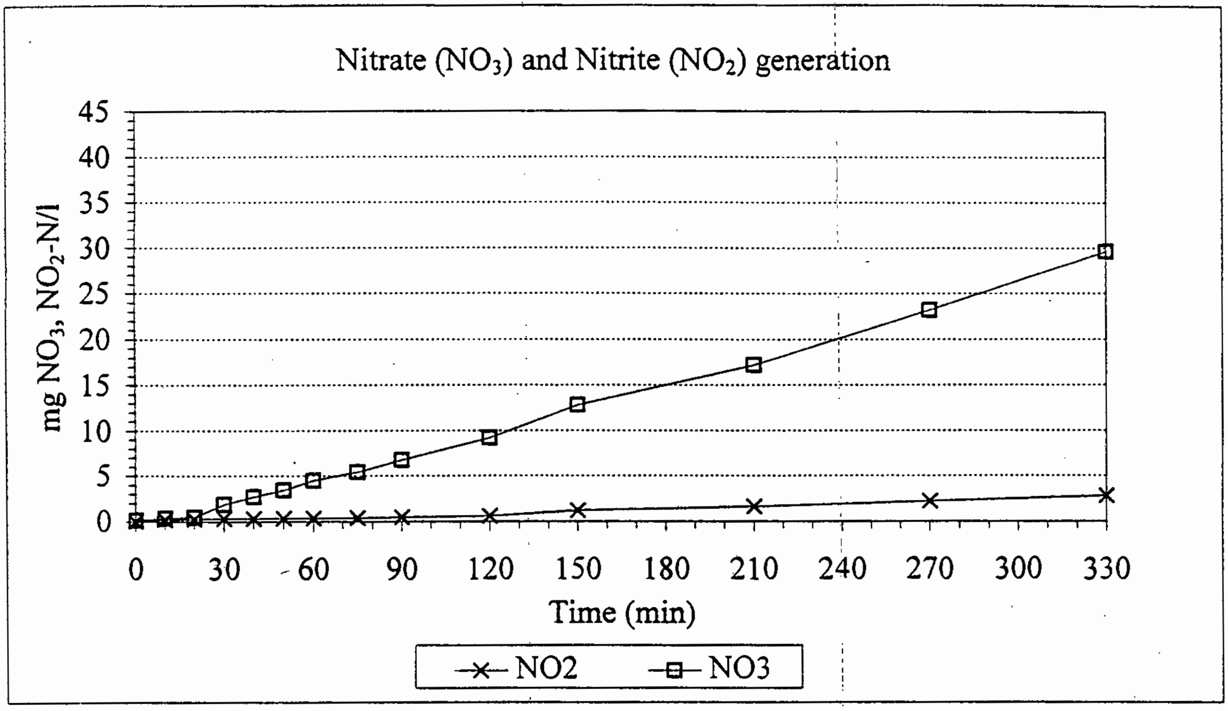
Temperature: 30 C



NITRATE AND NITRITE AND CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE MLE SYSTEM

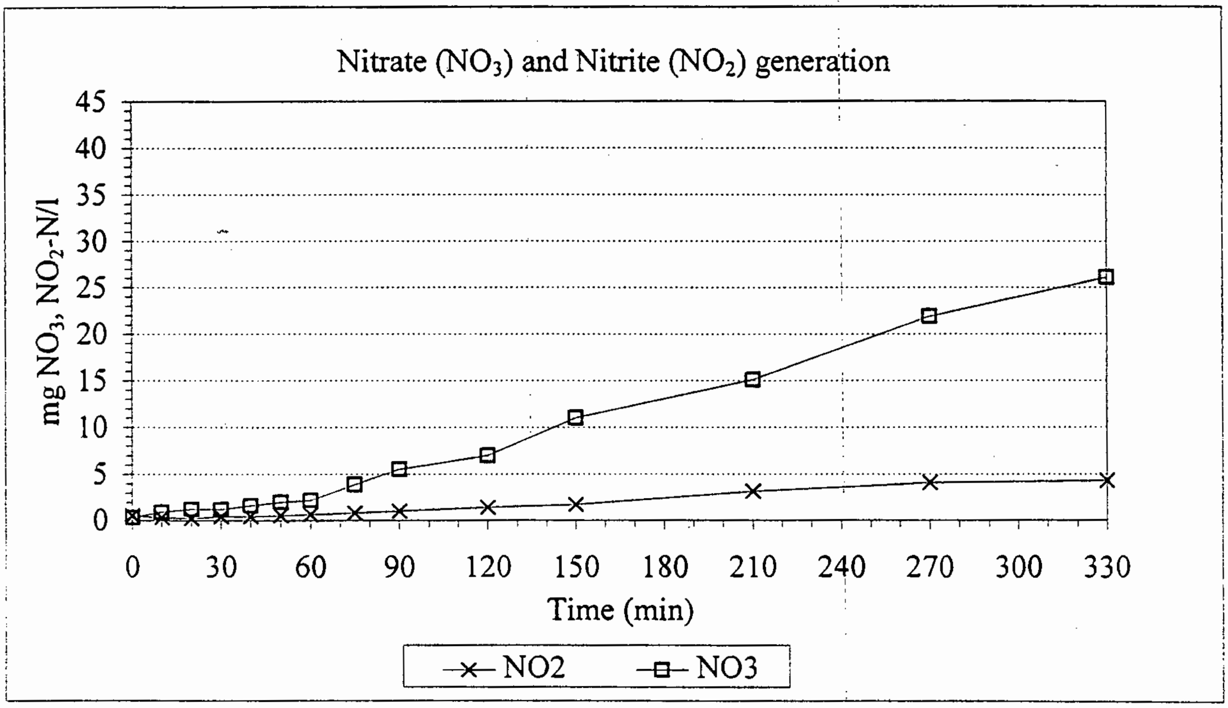
Date: 01.07.1996
Temperature: 20 C

TEST 1 N



Date: 01.08.1996
Temperature: 20 C

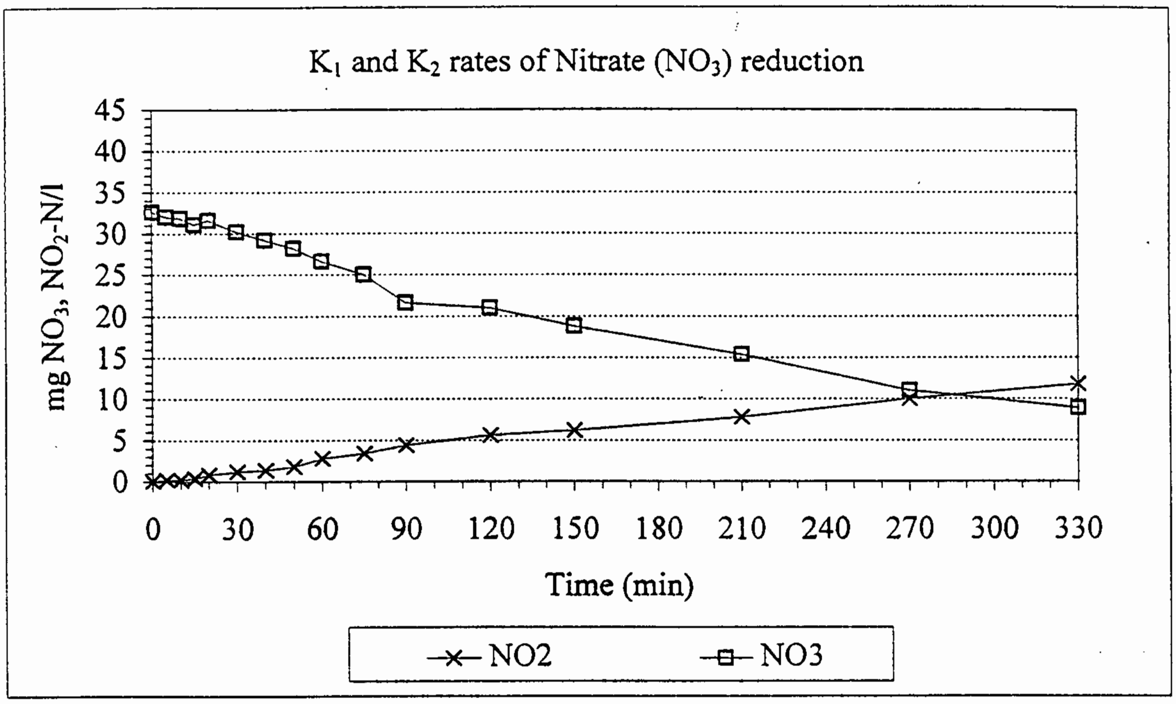
TEST 2 N



NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

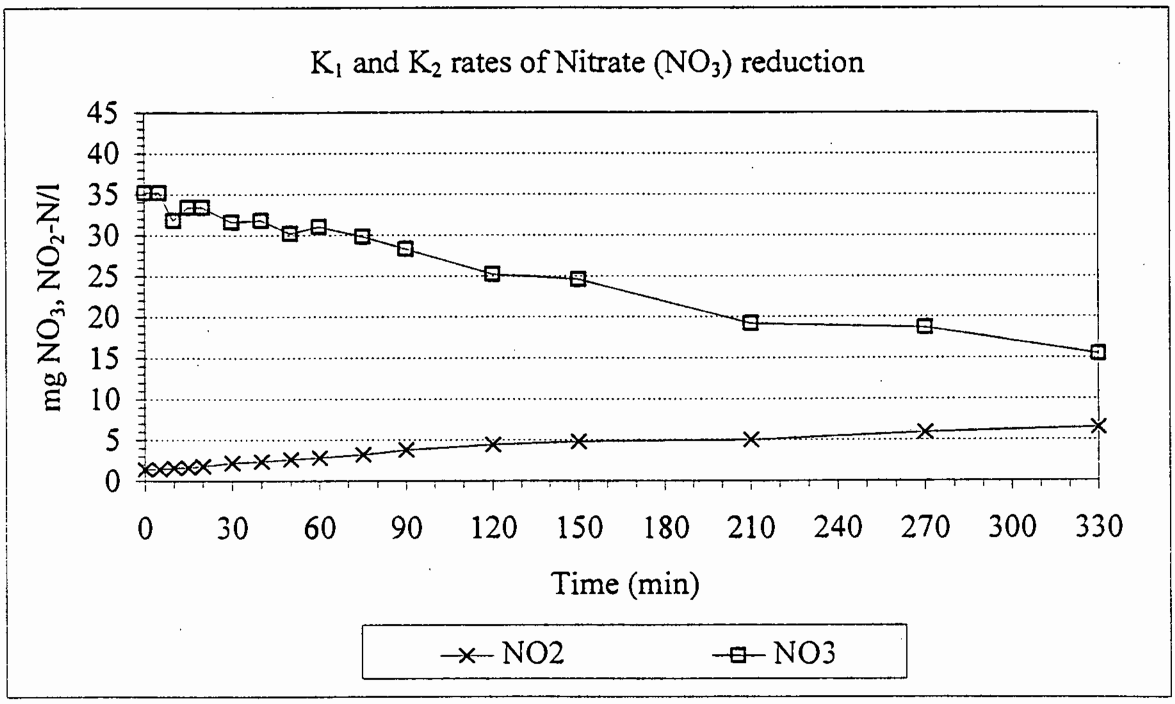
Date: 26.06.1996
Temperature: 20 C

TEST 1 D



Date: 03.07.1996
Temperature: 20 C

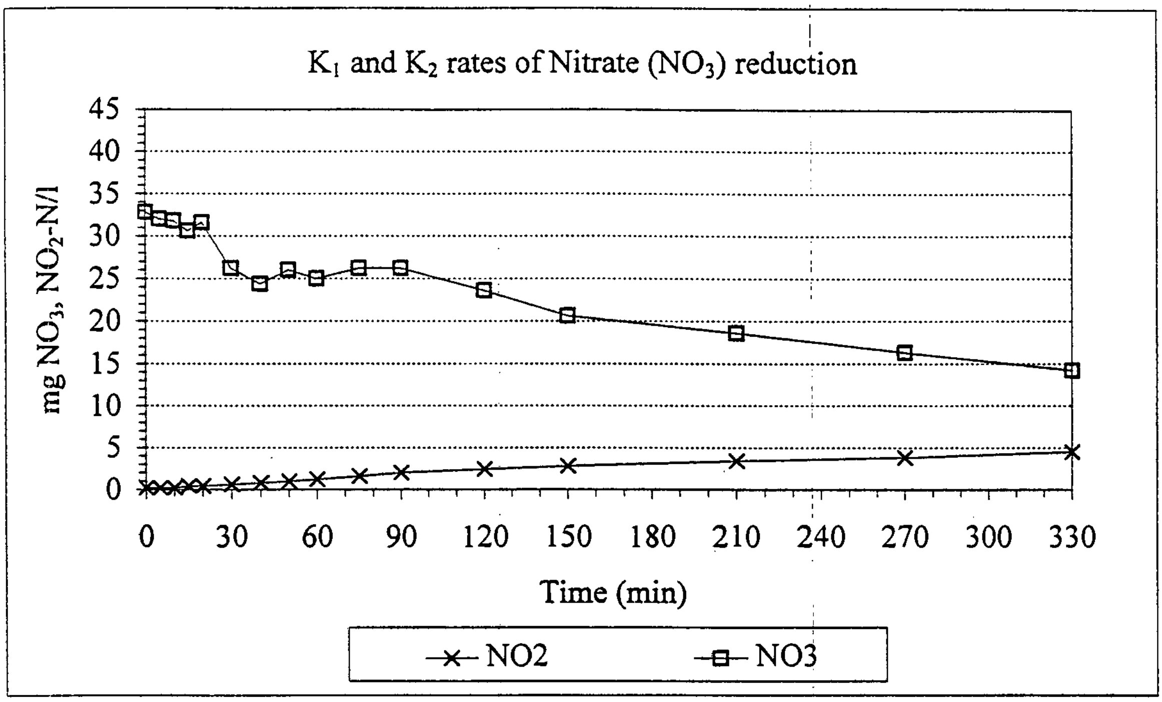
TEST 2 D



NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

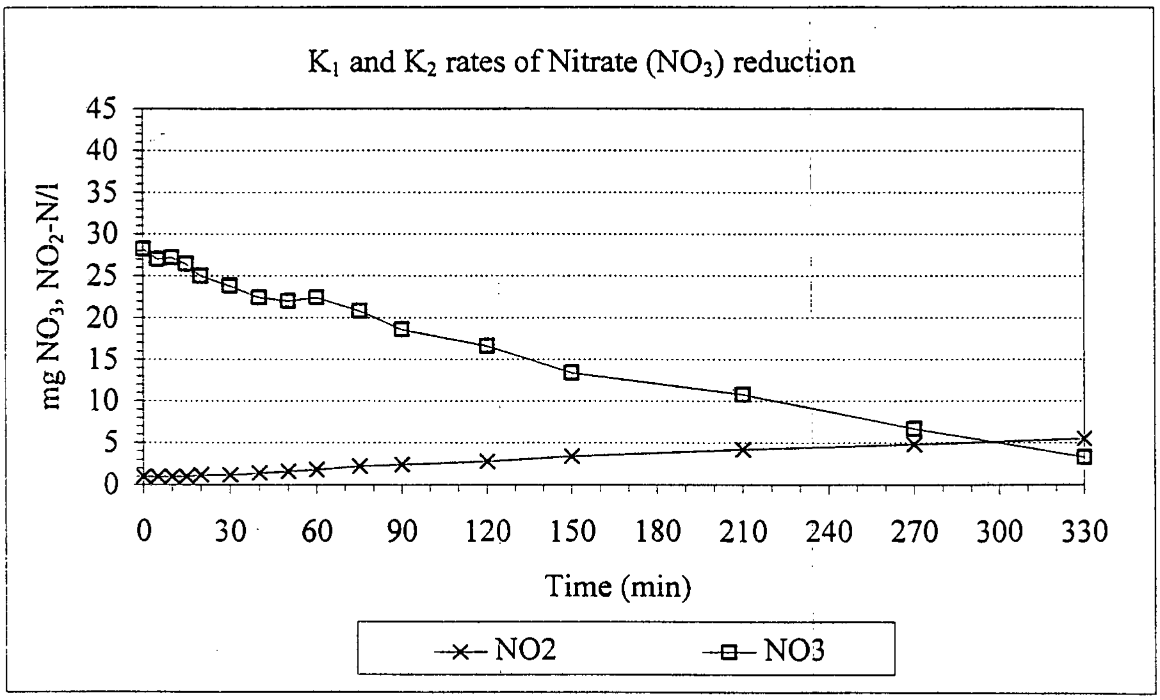
Date: 17.07.1996
Temperature: 20 C

TEST 3 D



Date: 20.07.1996
Temperature: 20 C

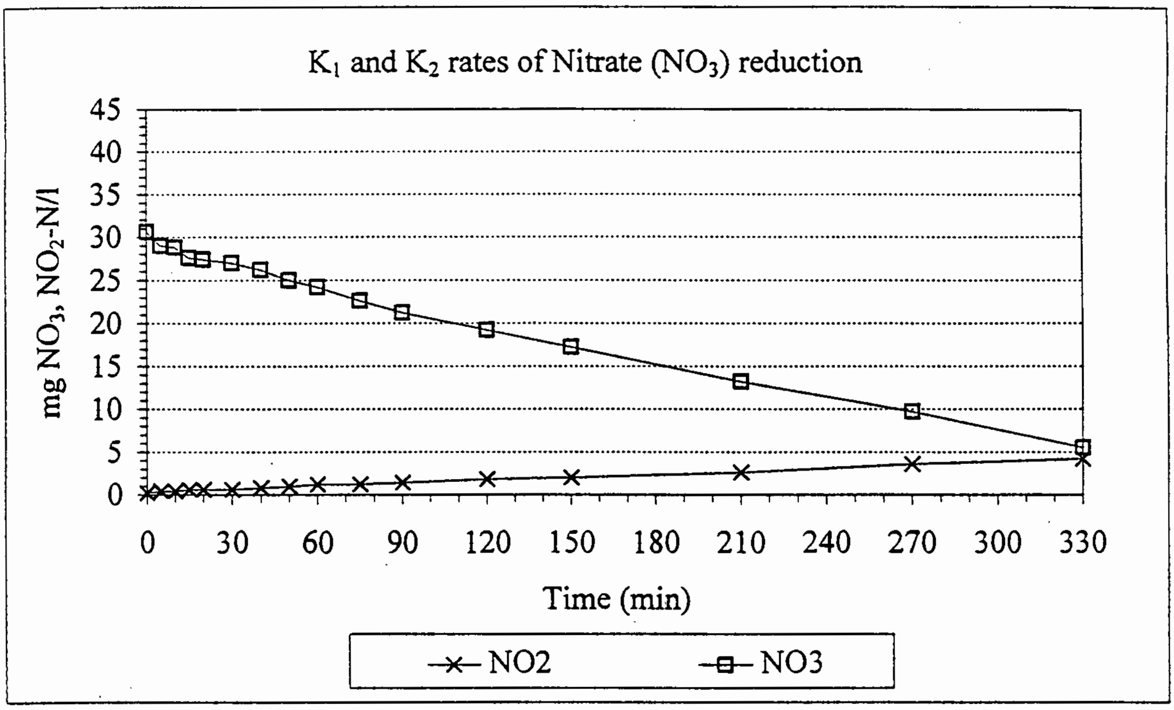
TEST 4 D



NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

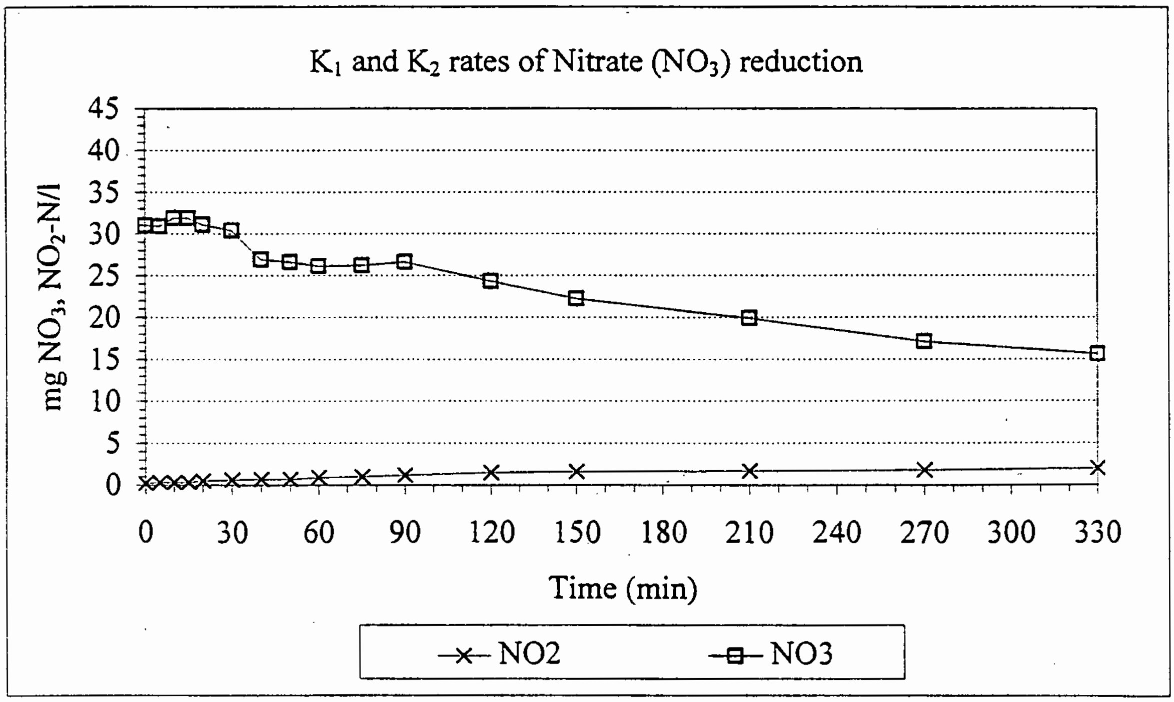
Date: 21.07.1996
Temperature: 20 C

TEST 5 D



Date: 23.07.1996
Temperature: 20 C

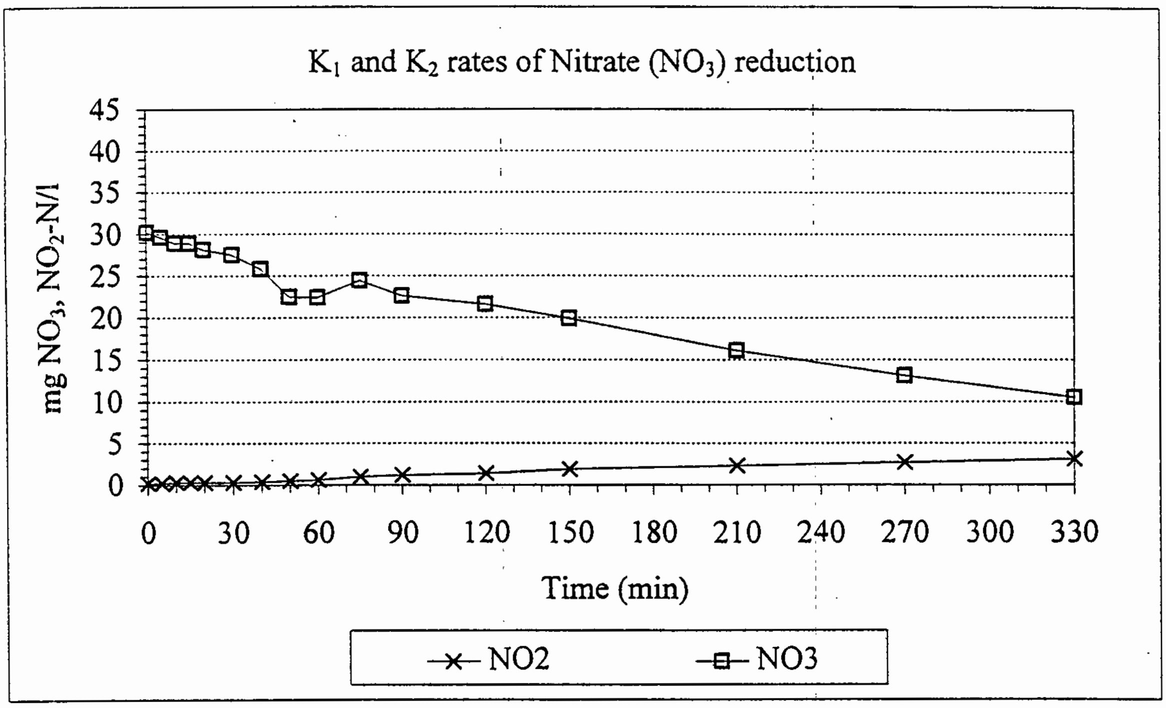
TEST 6 D



NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE MLE SYSTEM

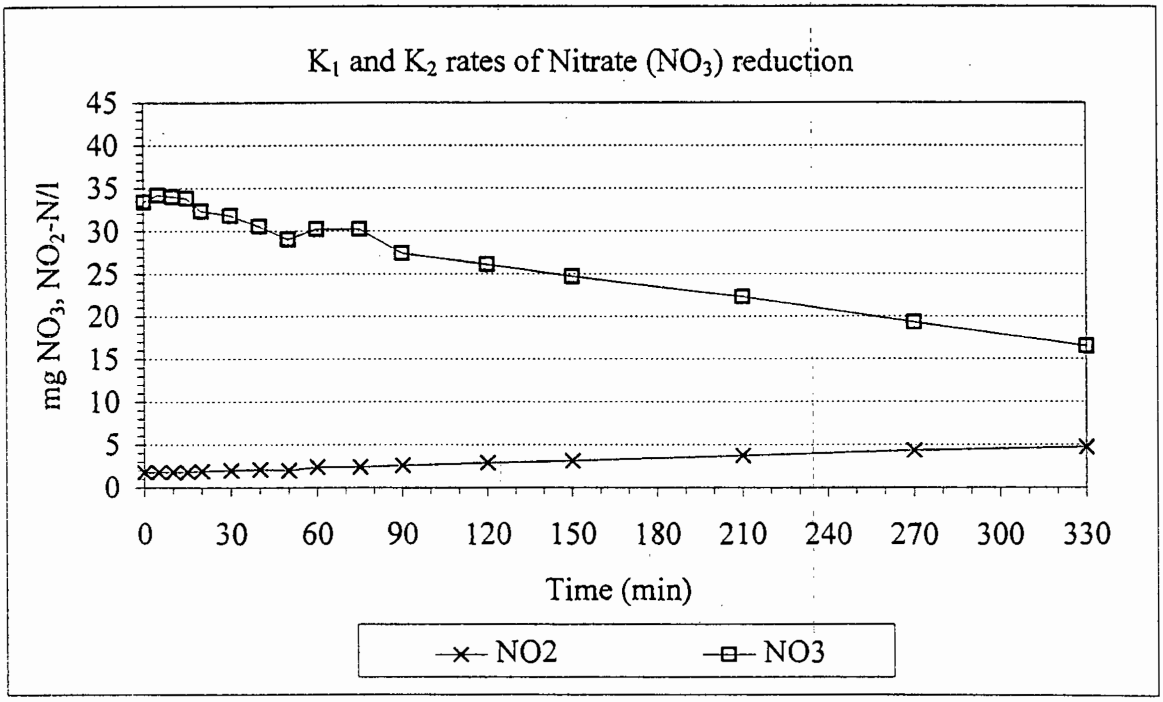
Date: 25.07.1996
Temperature: 20 C

TEST 7 D



Date: 30.07.1996
Temperature: 20 C

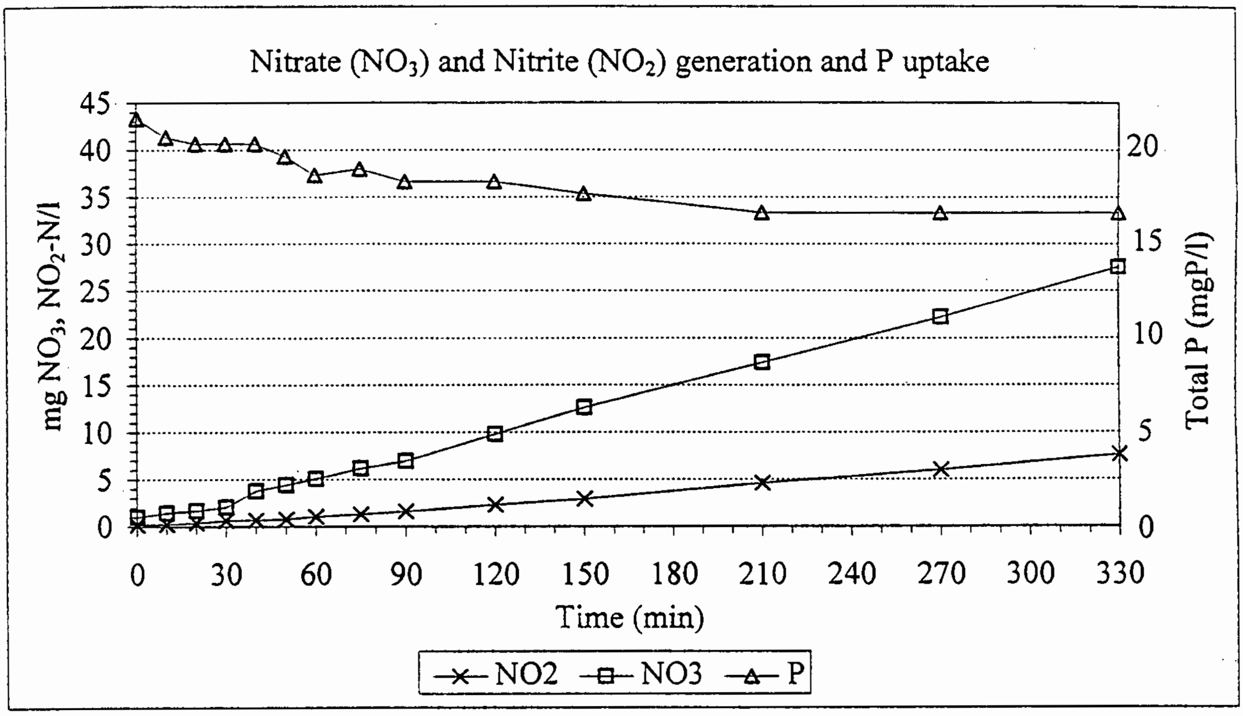
TEST 8 D



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

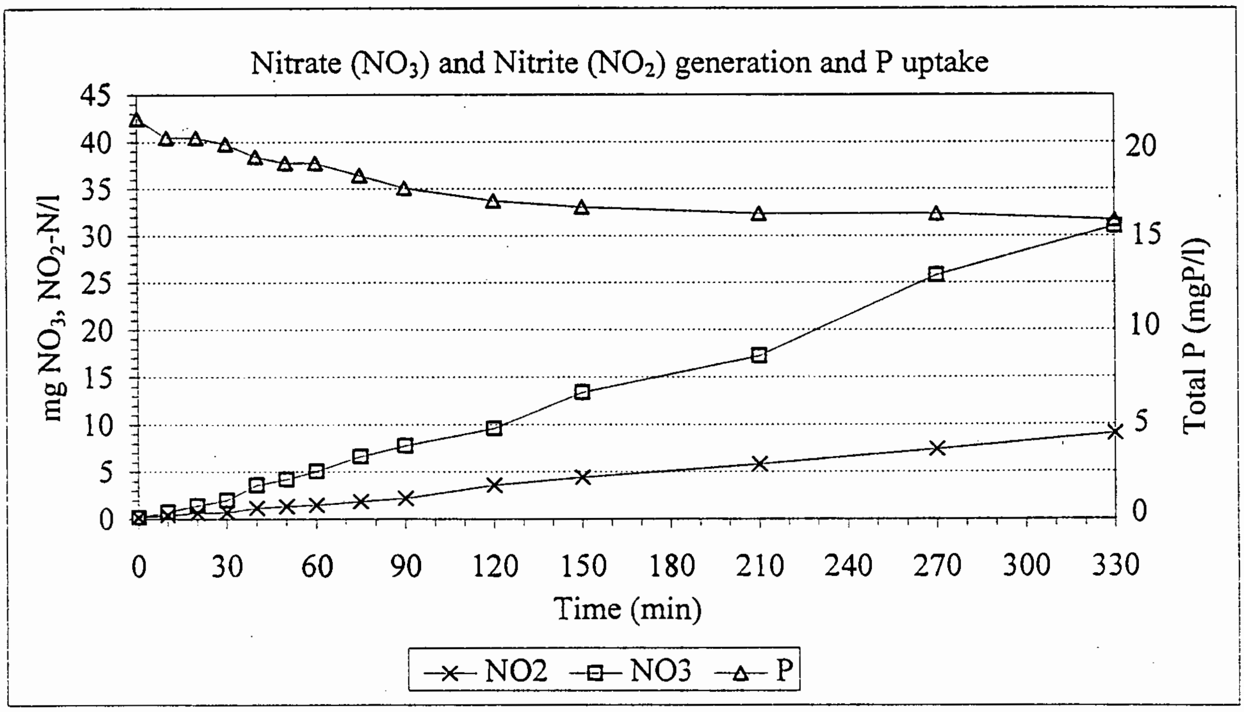
Date: 21.05.1996
Temperature: 20 C

TEST 1 N P up



Date: 27.05.1996
Temperature: 20 C

TEST 2 N P up

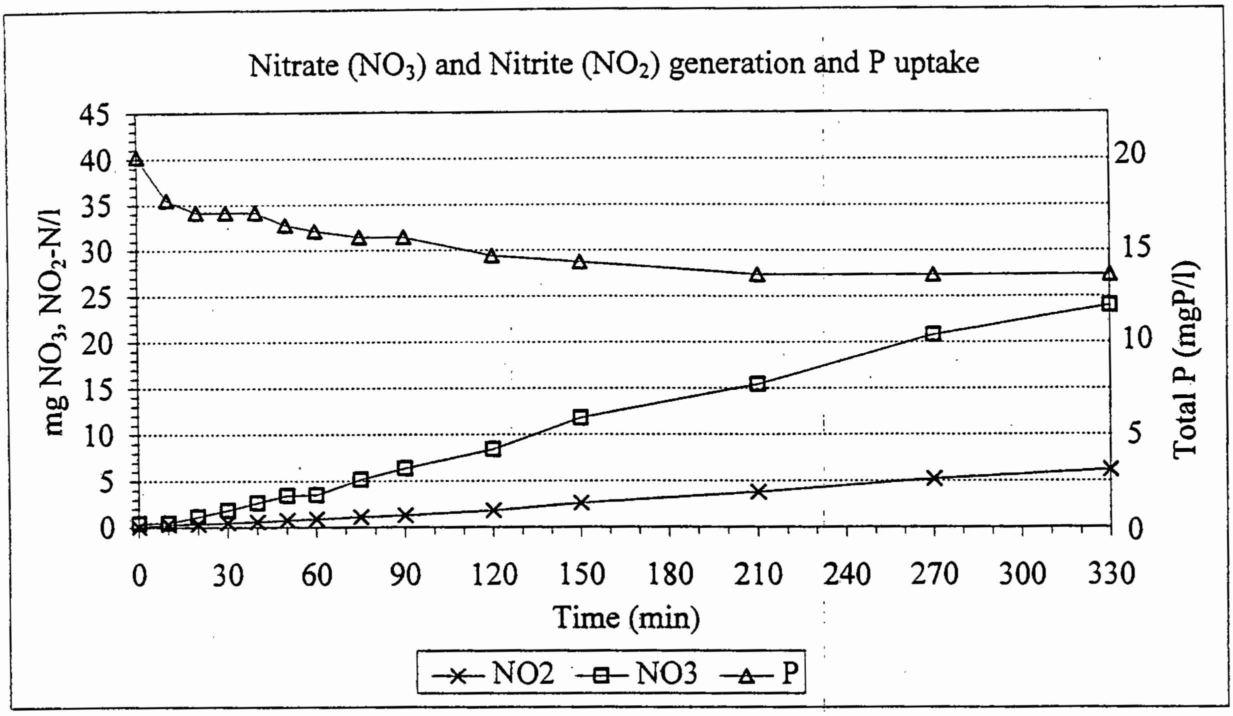


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE AEROBIC BATCH TEST OF THE UCT SYSTEM

Date: 01.07.1996

TEST 3 N P up

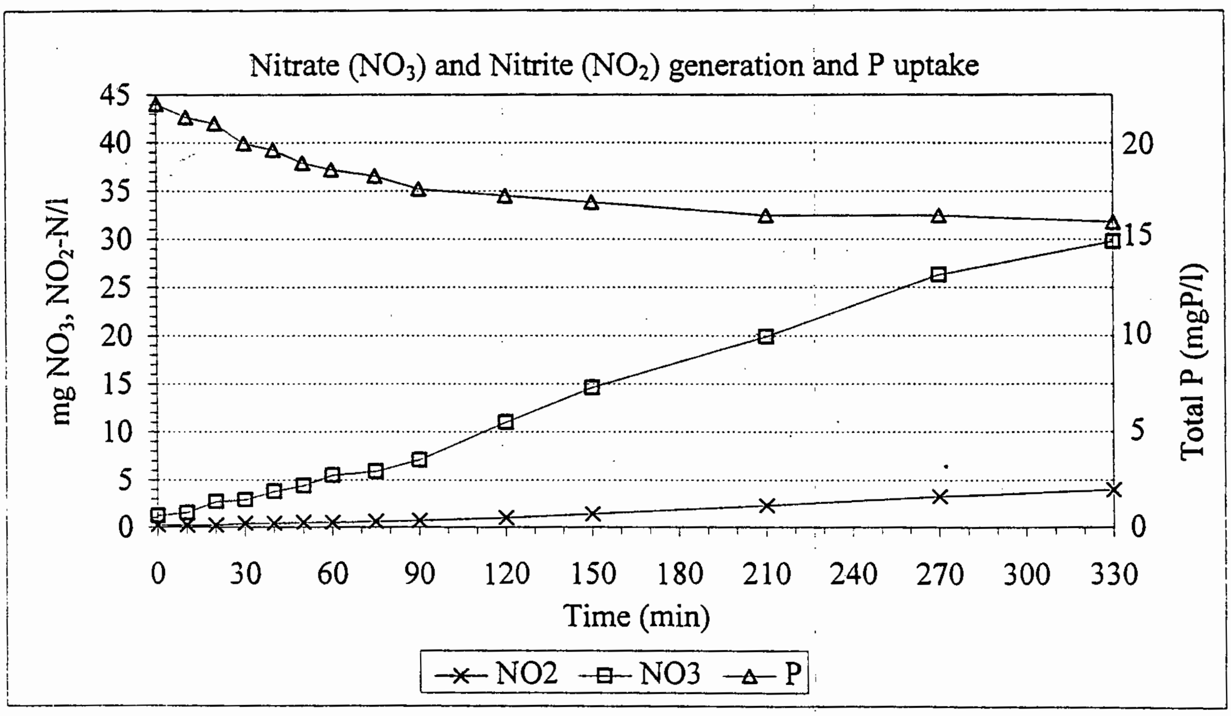
Temperature: 20 C



Date: 01.08.1996

TEST 4 N P up

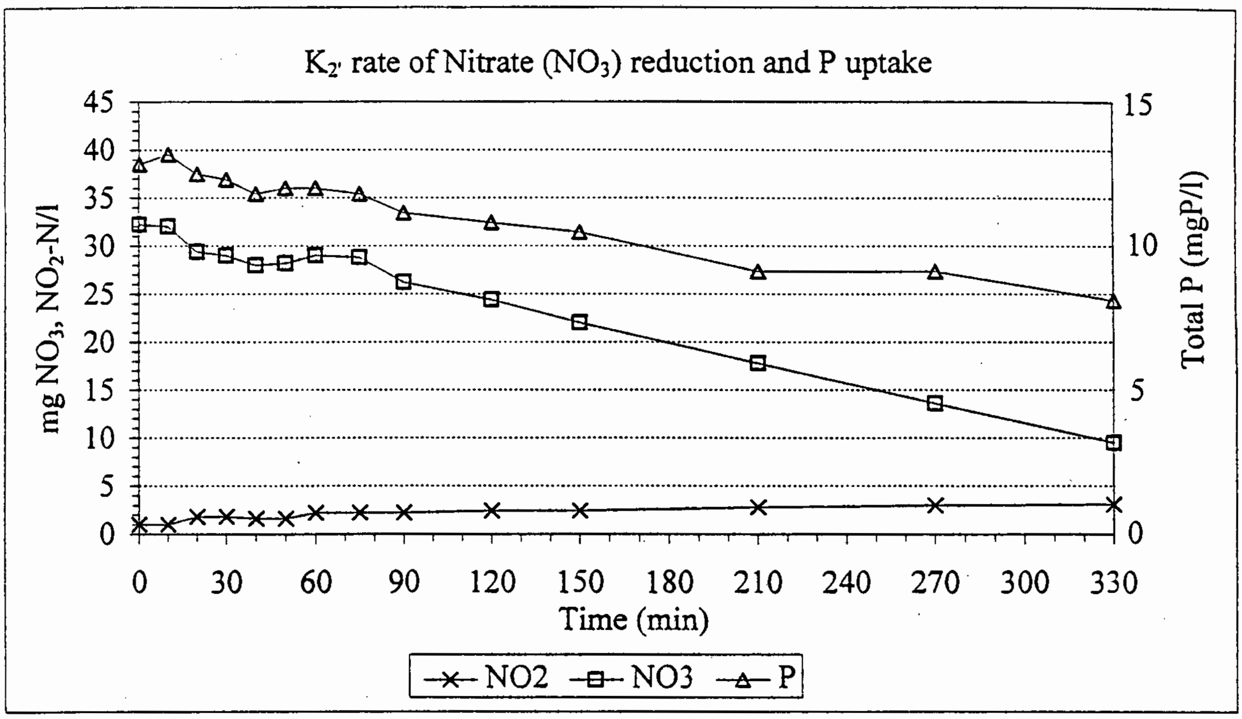
Temperature: 20 C



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

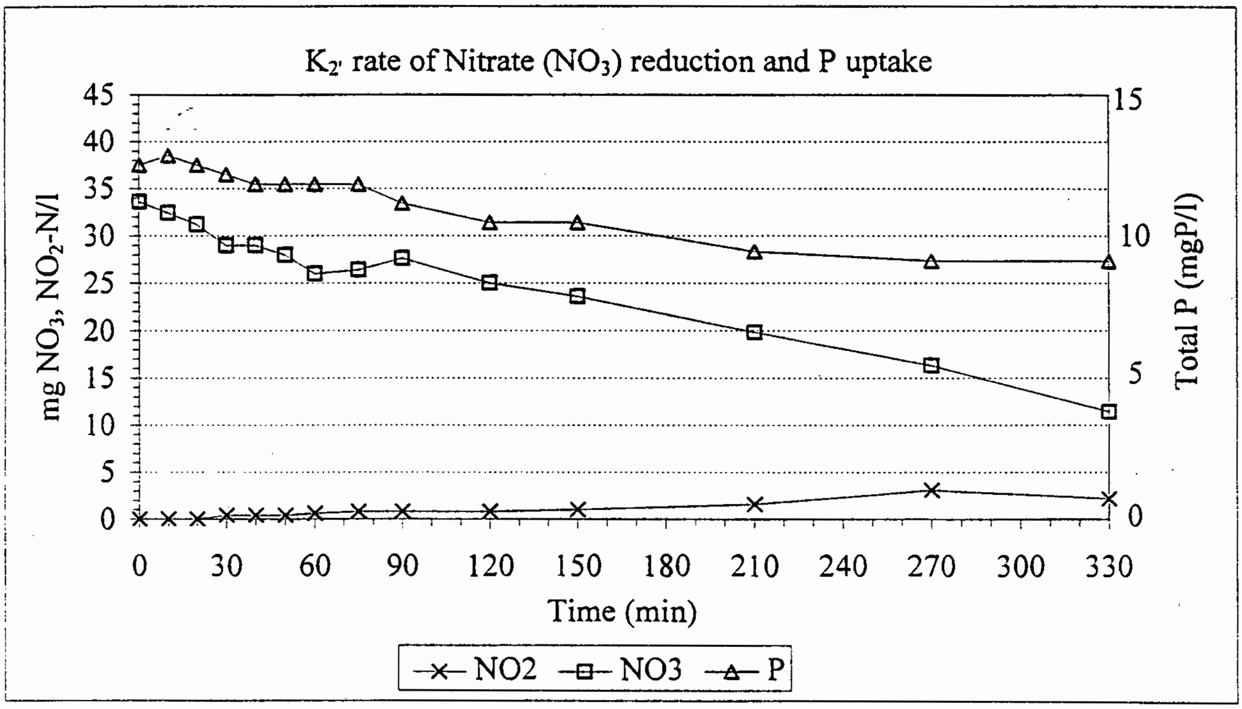
Date: 10.05.1996
Temperature: 20 C

TEST 1 D P up



Date: 17.05.1996
Temperature: 20 C

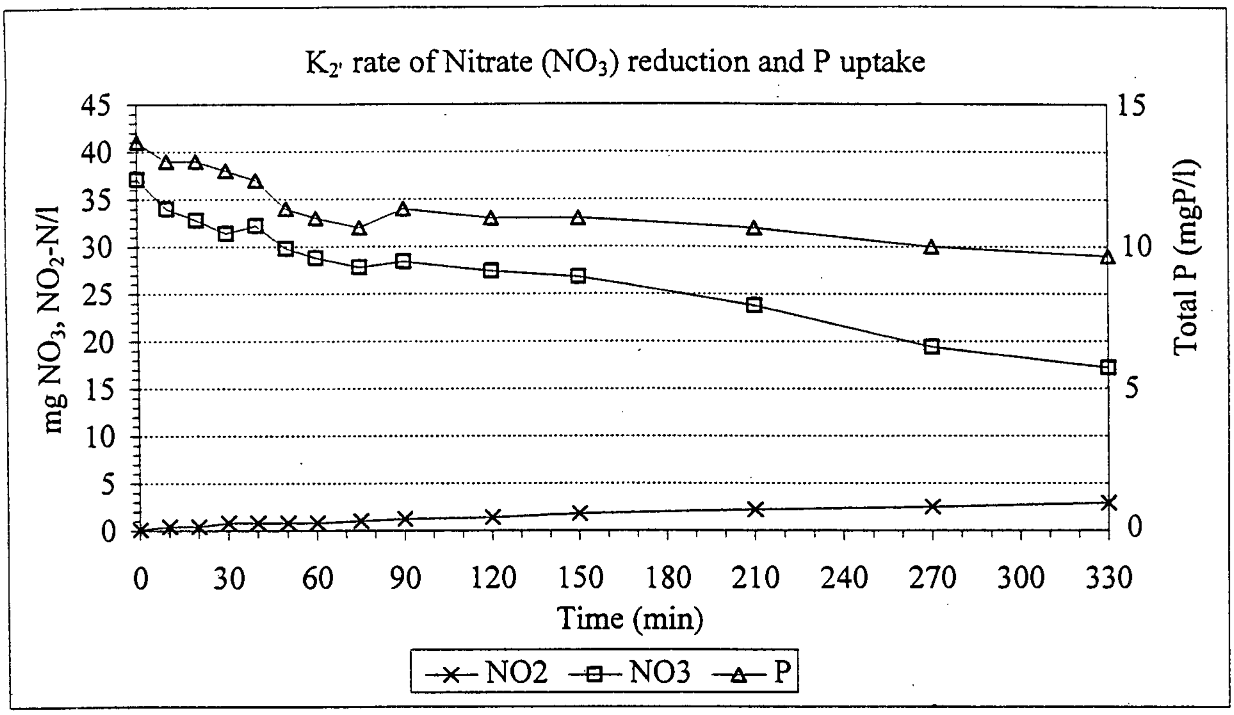
TEST 2 D P up



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

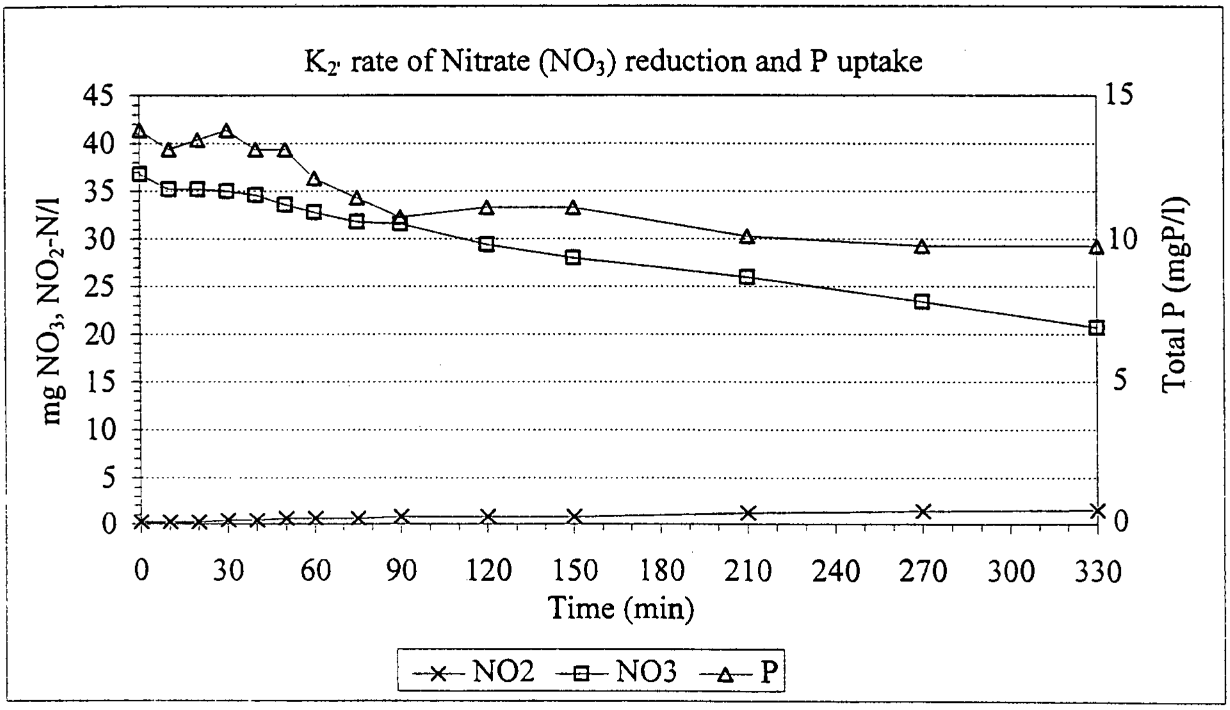
Date: 24.05.1996
Temperature: 20 C

TEST 3 D P up



Date: 29.05.1996
Temperature: 20 C

TEST 4 D P up

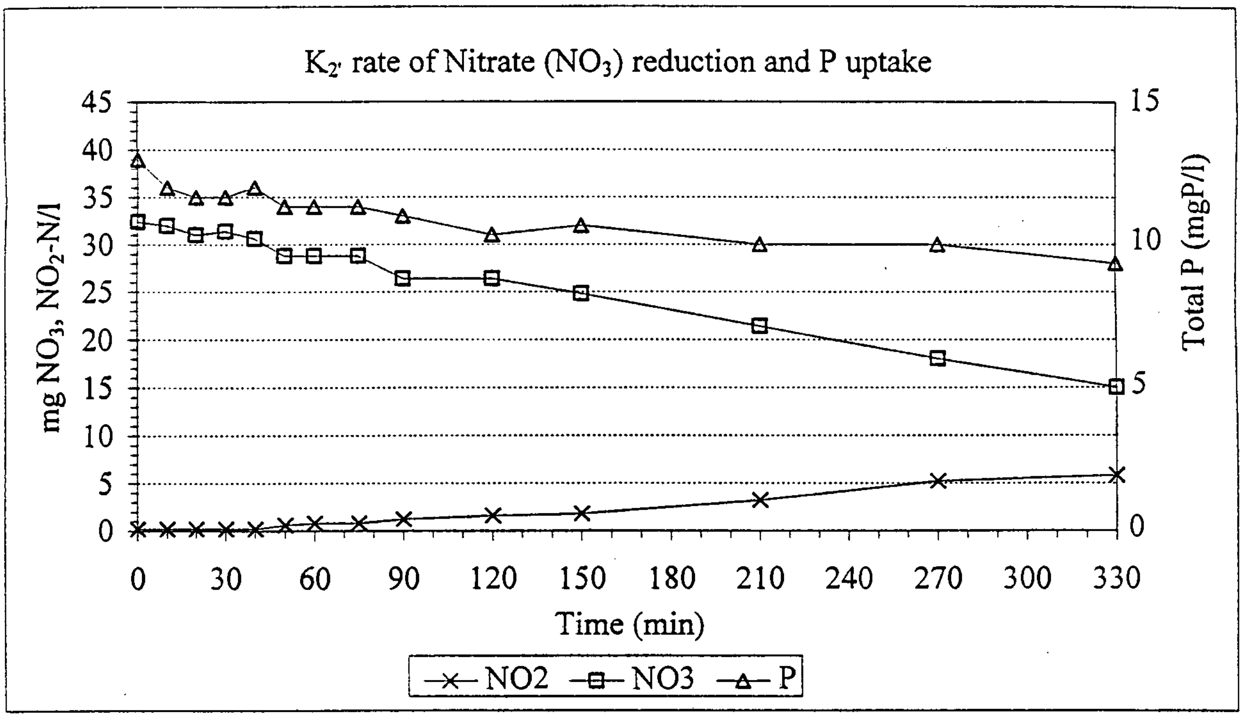


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 26.06.1996

TEST 5 D P up

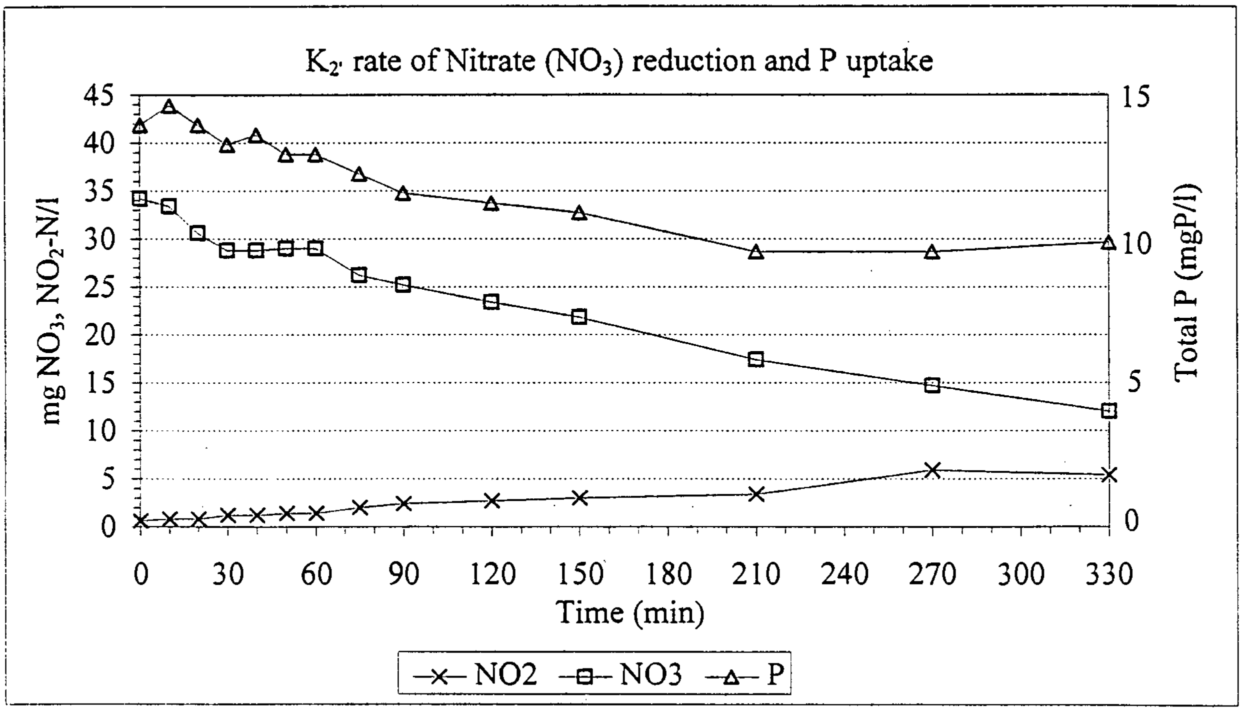
Temperature: 20 C



Date: 03.07.1996

TEST 6 D P up

Temperature: 20 C

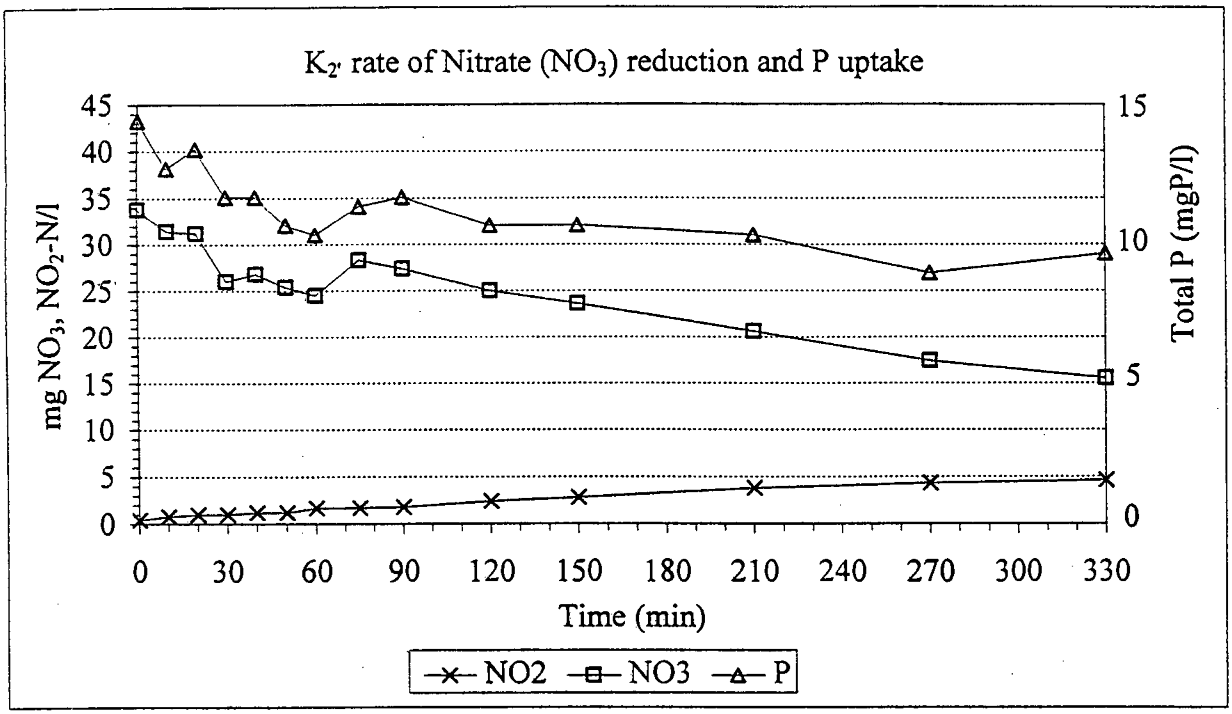


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 17.07.1996

TEST 7 D P up

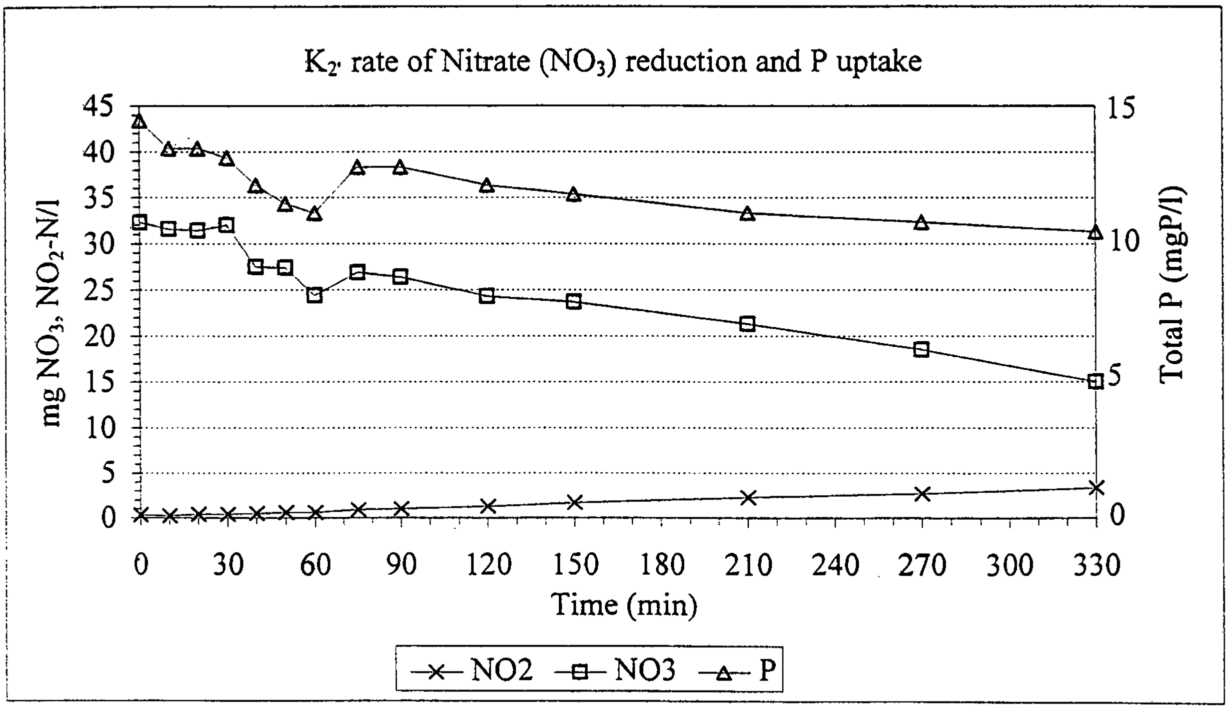
Temperature: 20 C



Date: 23.07.1996

TEST 8 D P up

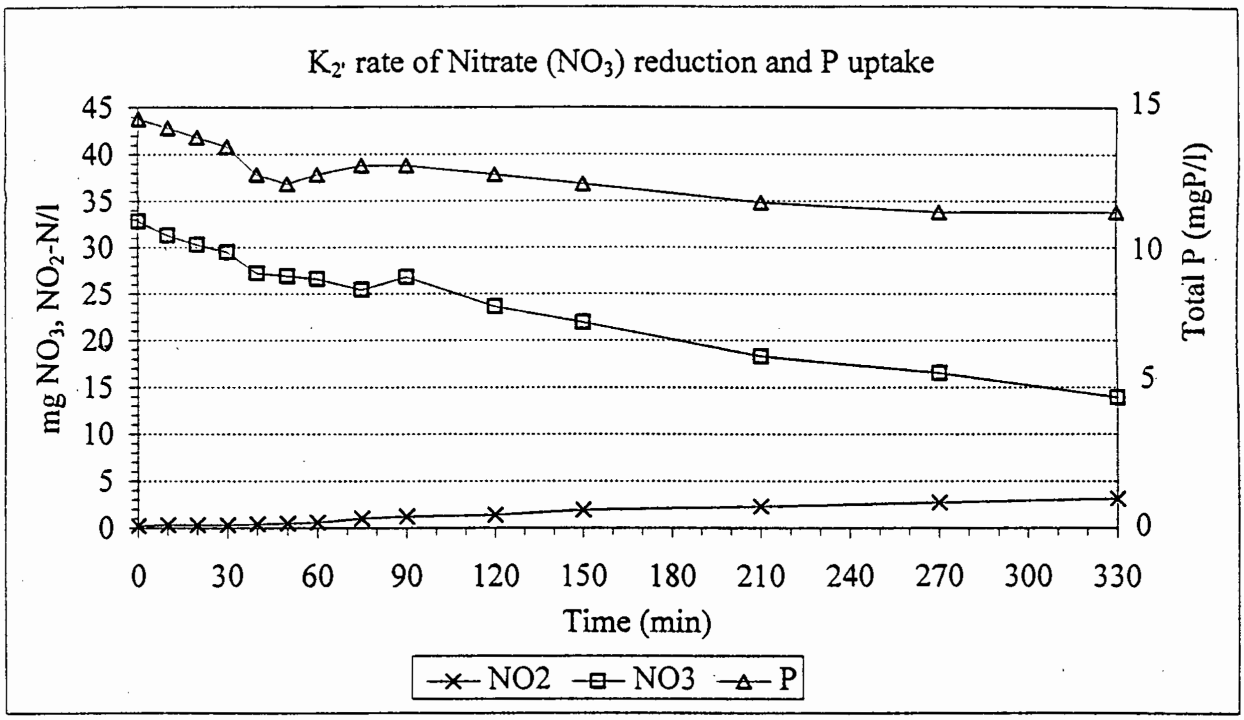
Temperature: 20 C



NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

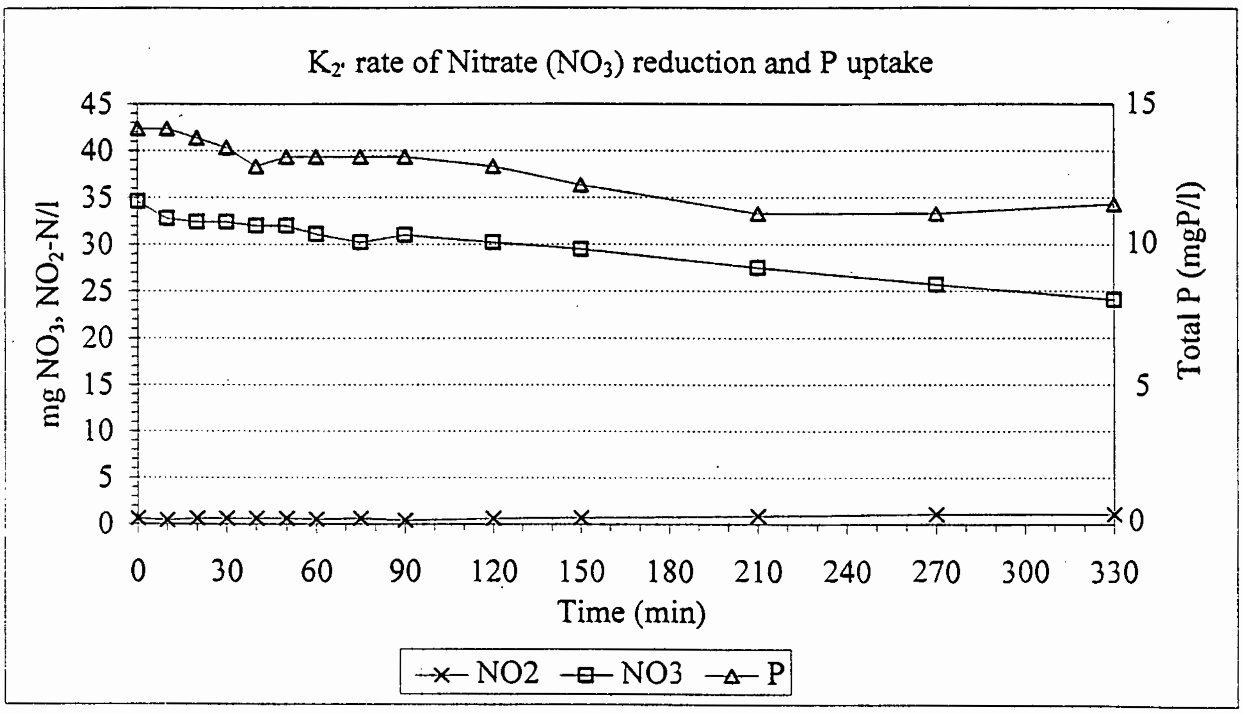
Date: 25.07.1996
Temperature: 20 C

TEST 9 D P up



Date: 30.07.1996
Temperature: 20 C

TEST 10 D P up

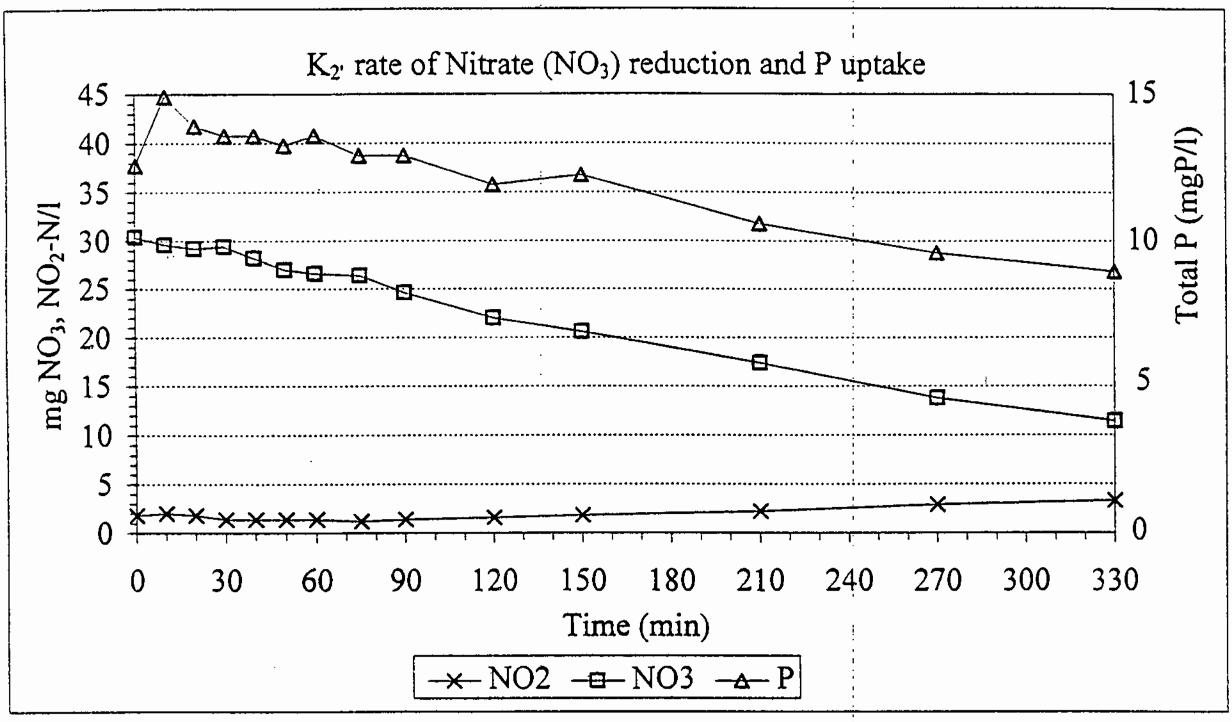


NITRATE, NITRITE AND PHOSPHORUS CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

Date: 22.11.1996

TEST 11 D P up

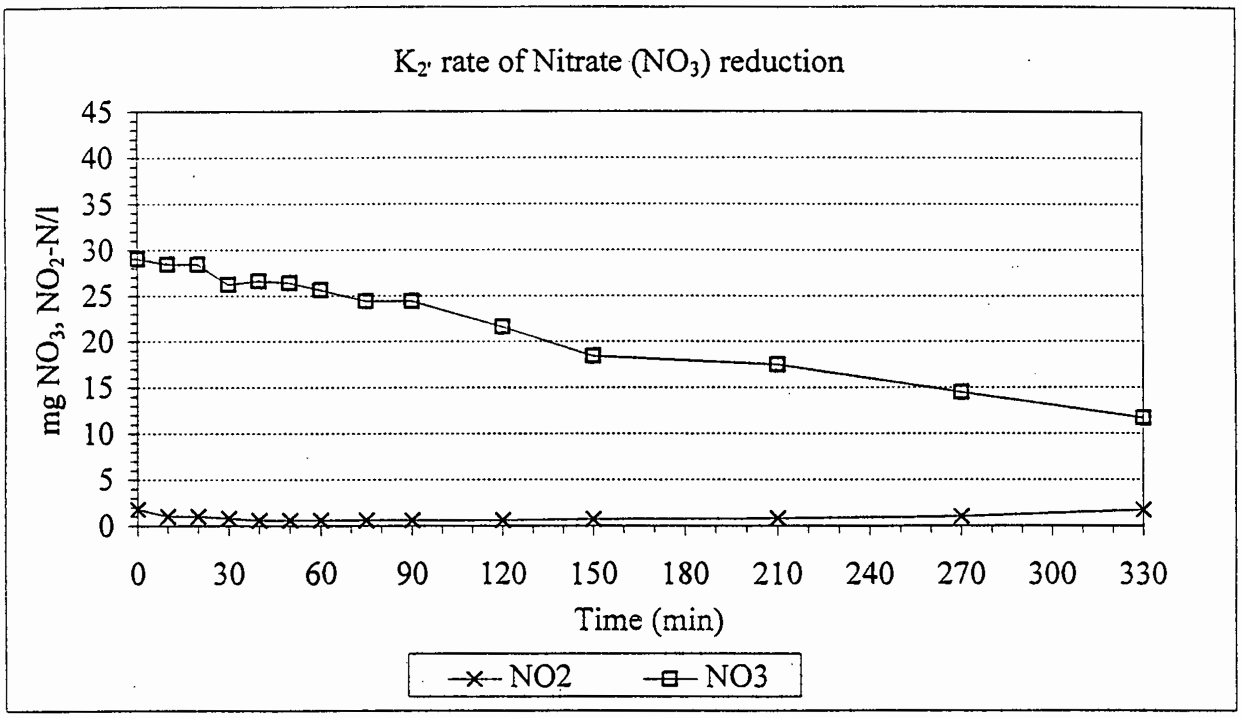
Temperature: 20 C



NITRATE AND NITRITE CONCENTRATIONS VERSUS TIME FOR THE ANOXIC BATCH TEST OF THE UCT SYSTEM

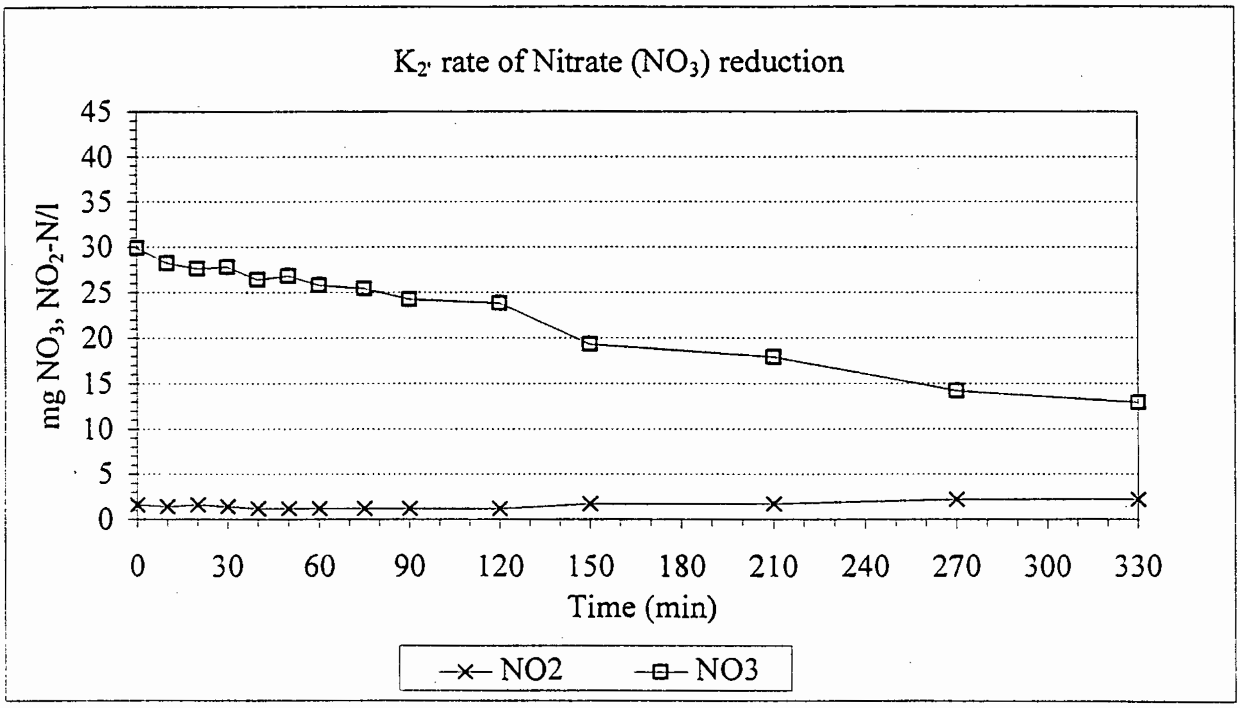
Date: 14.11.1996
Temperature: 20 C

TEST 12 D



Date: 19.11.1996
Temperature: 20 C

TEST 13 D

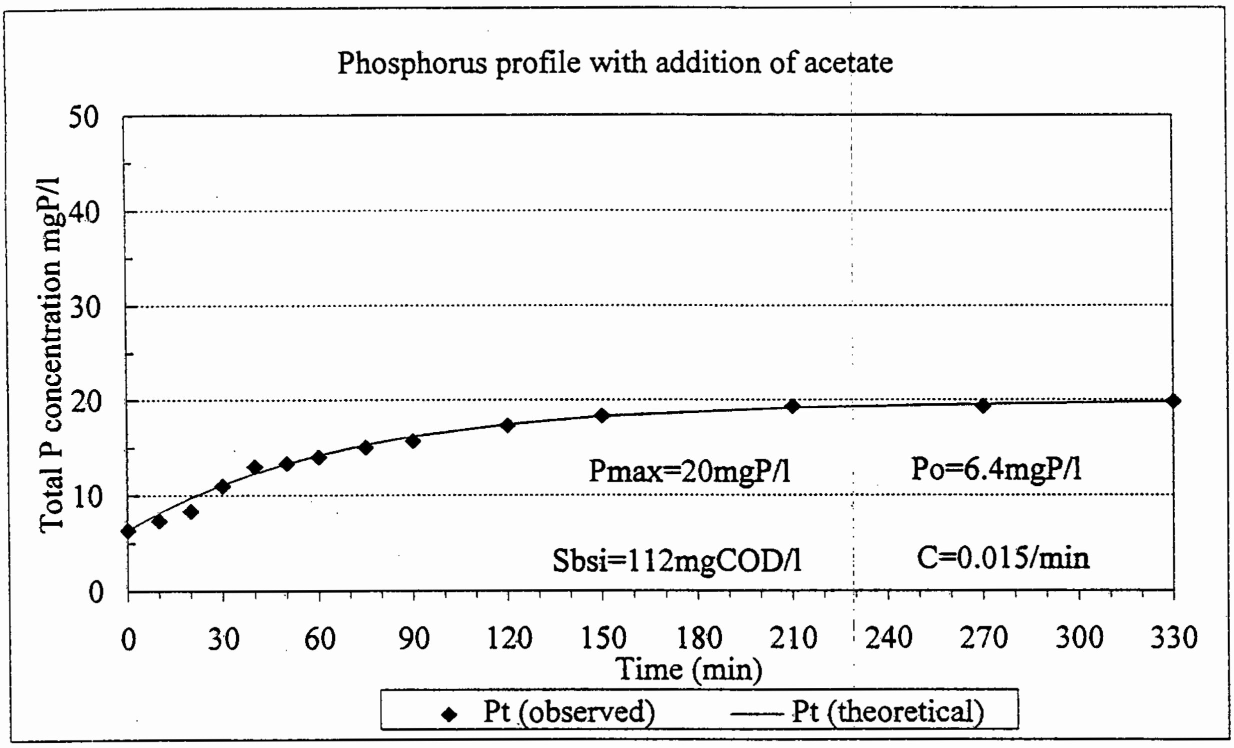


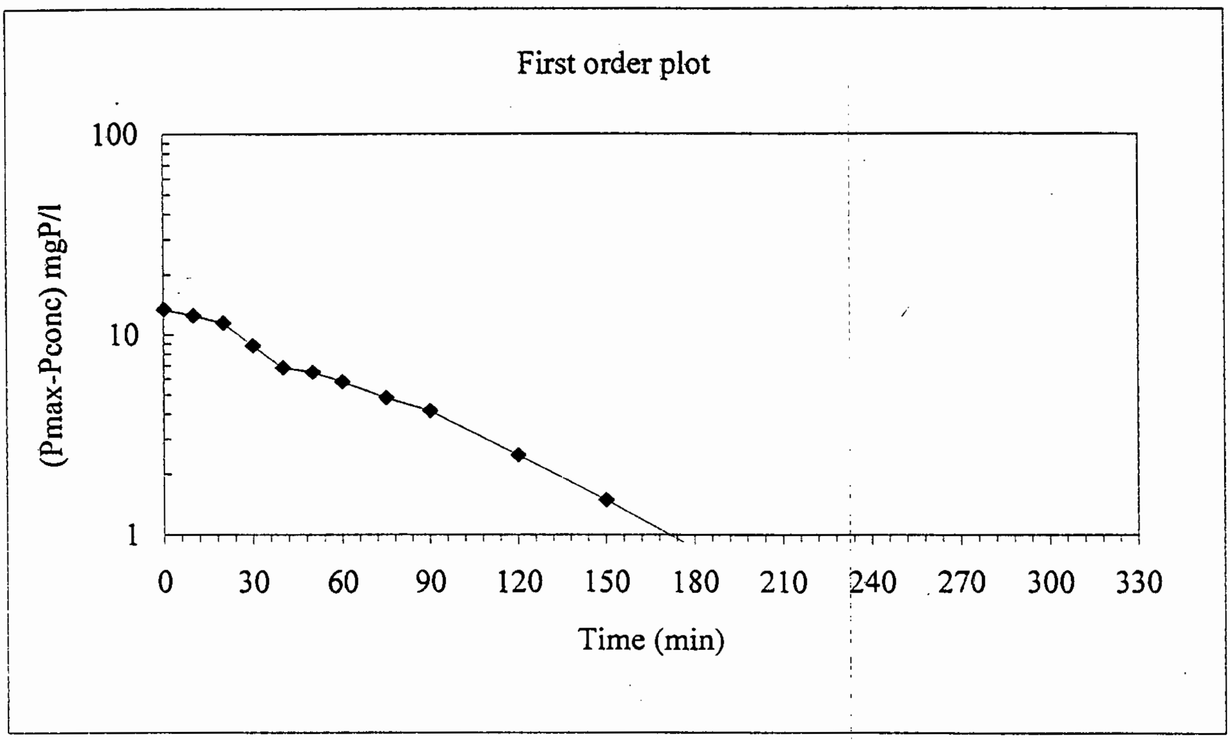
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 14.05.1996

TEST 1 A P rel

Temperature: 20 C



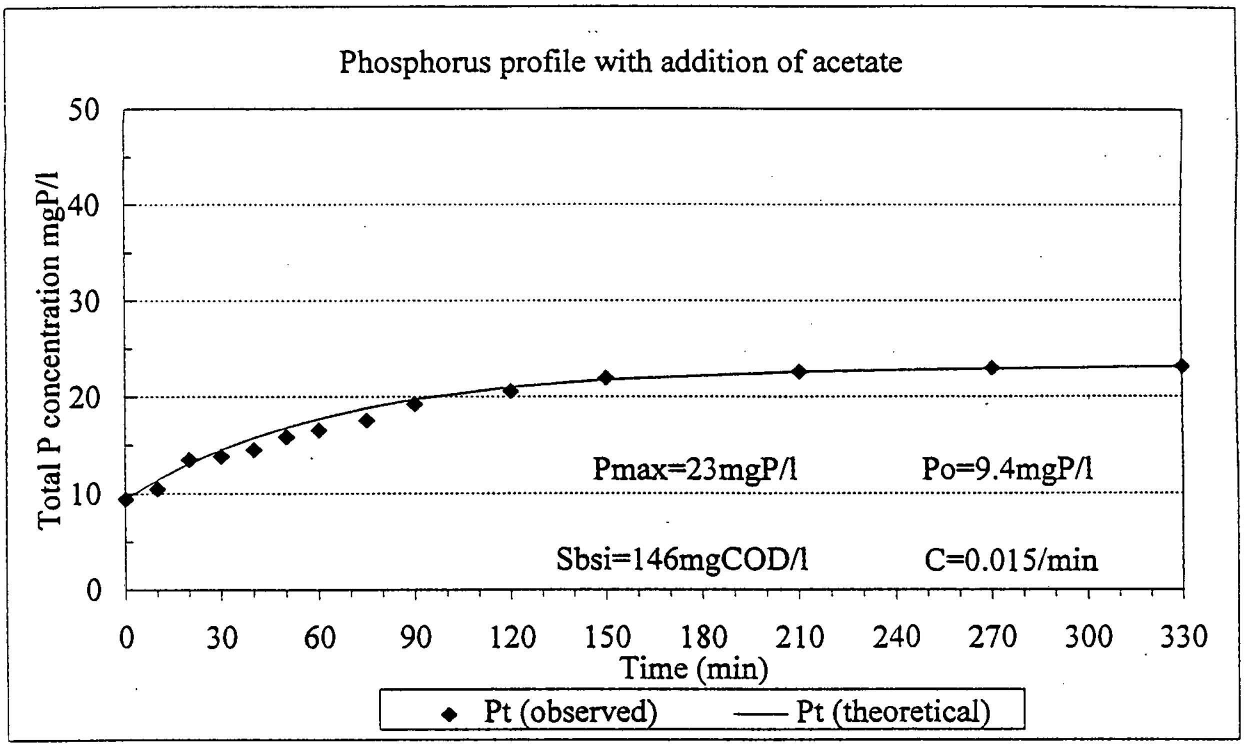


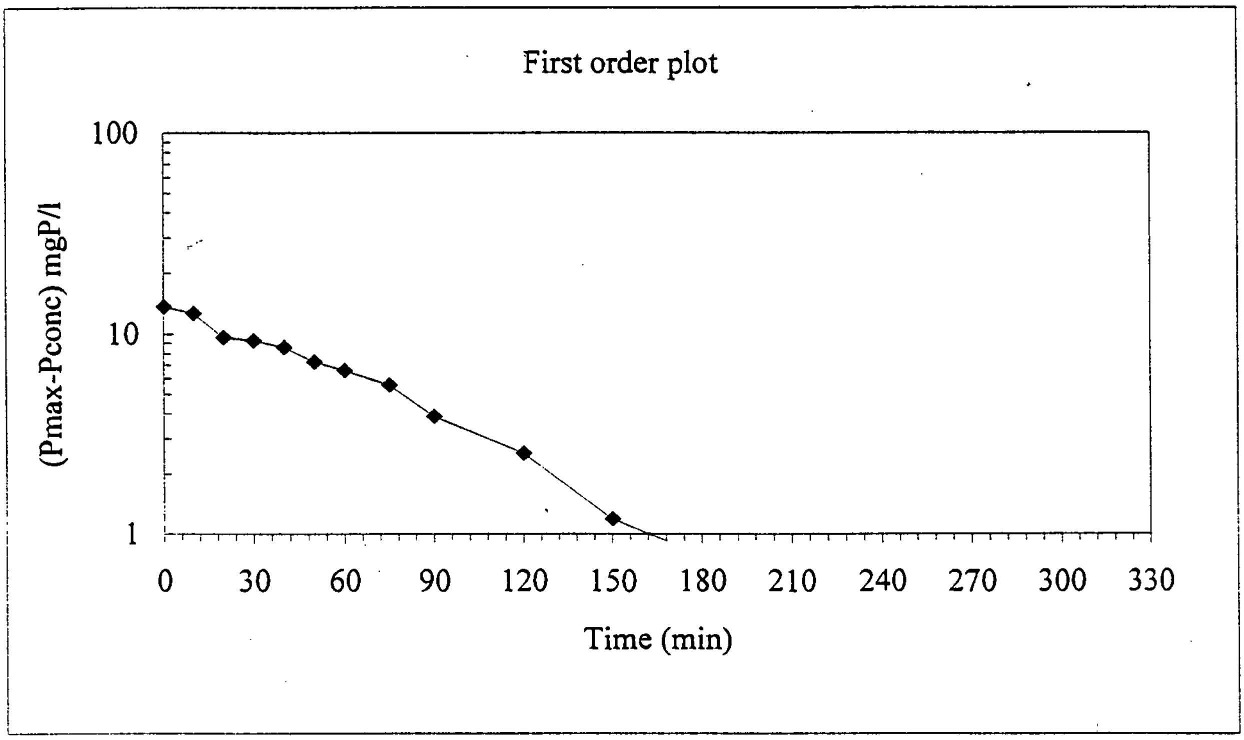
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 05.07.1996

TEST 2 A P rel

Temperature: 20 C



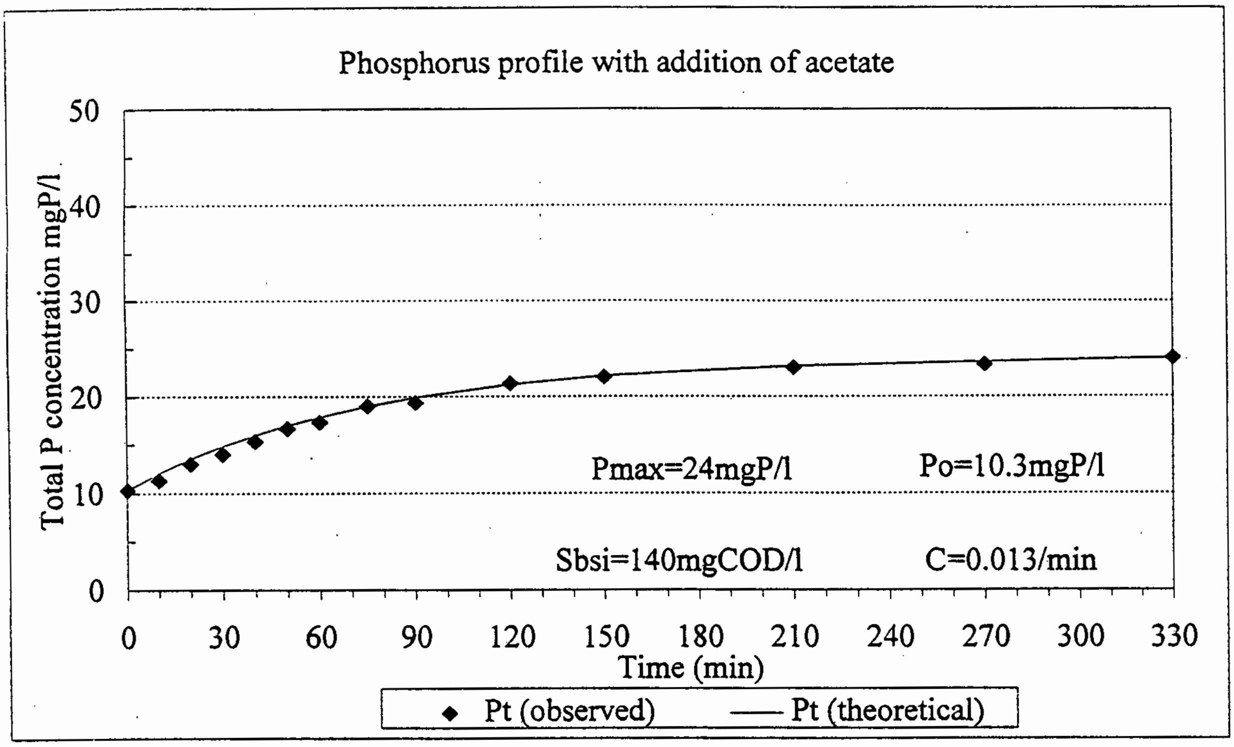


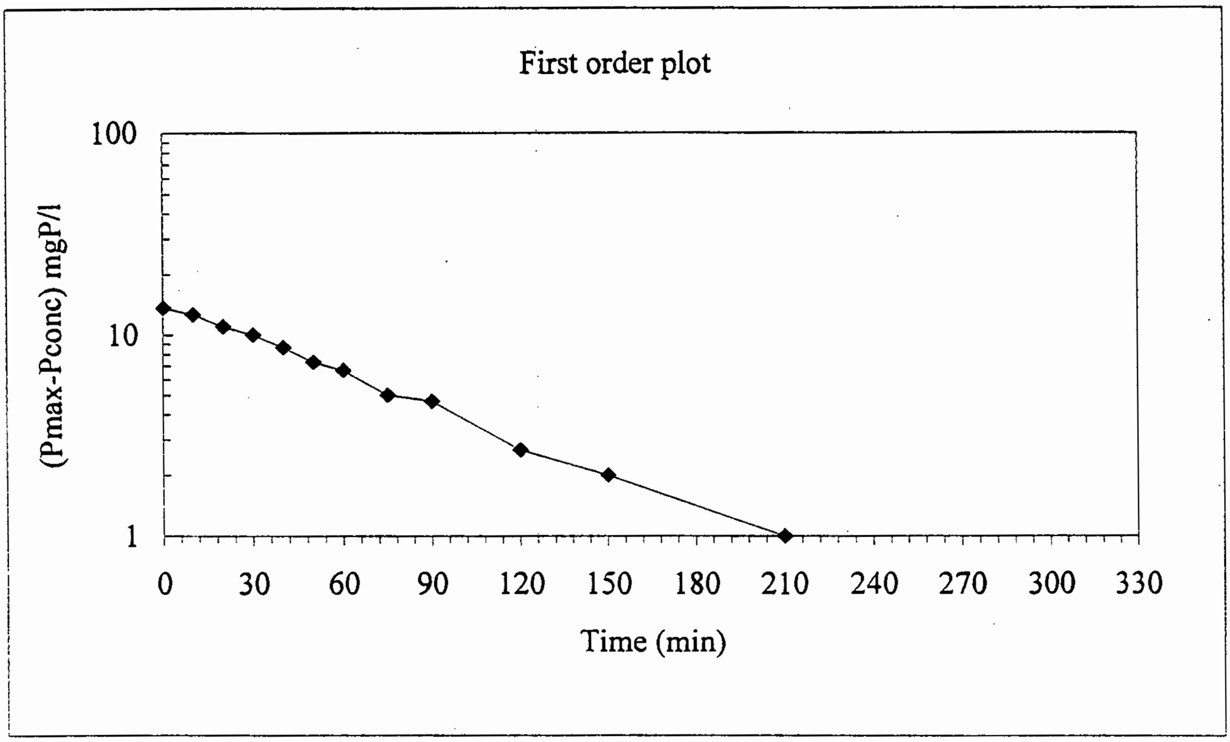
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF ACETATE IN THE UCT SYSTEM

Date: 08.07.1996

TEST 3 A P rel

Temperature: 20 C



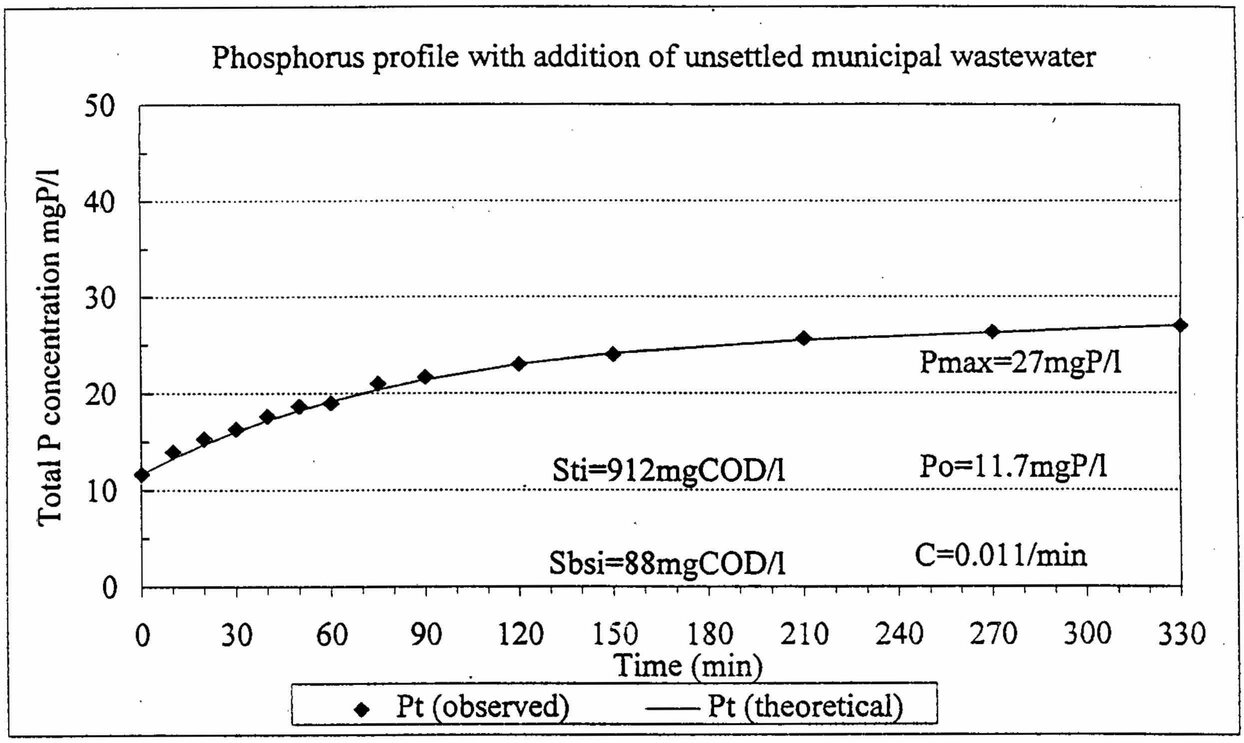


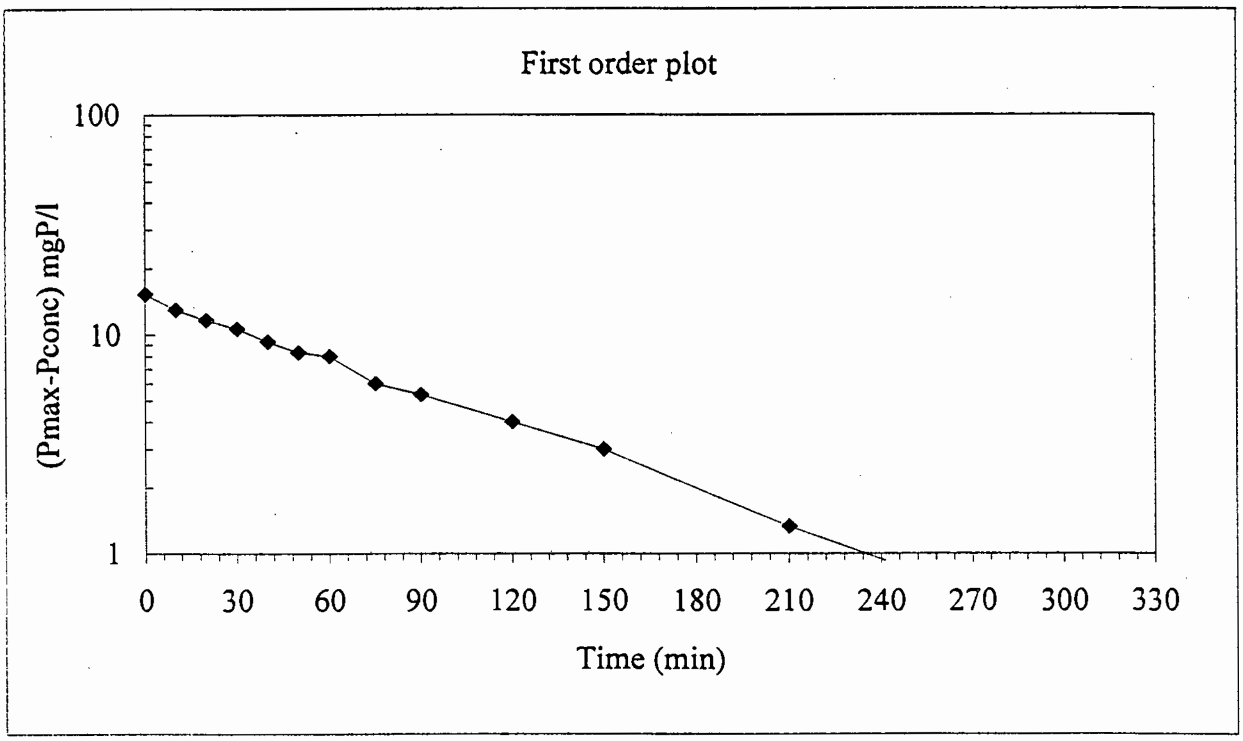
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 14.05.1996

TEST 1 S P rel

Temperature: 20 C



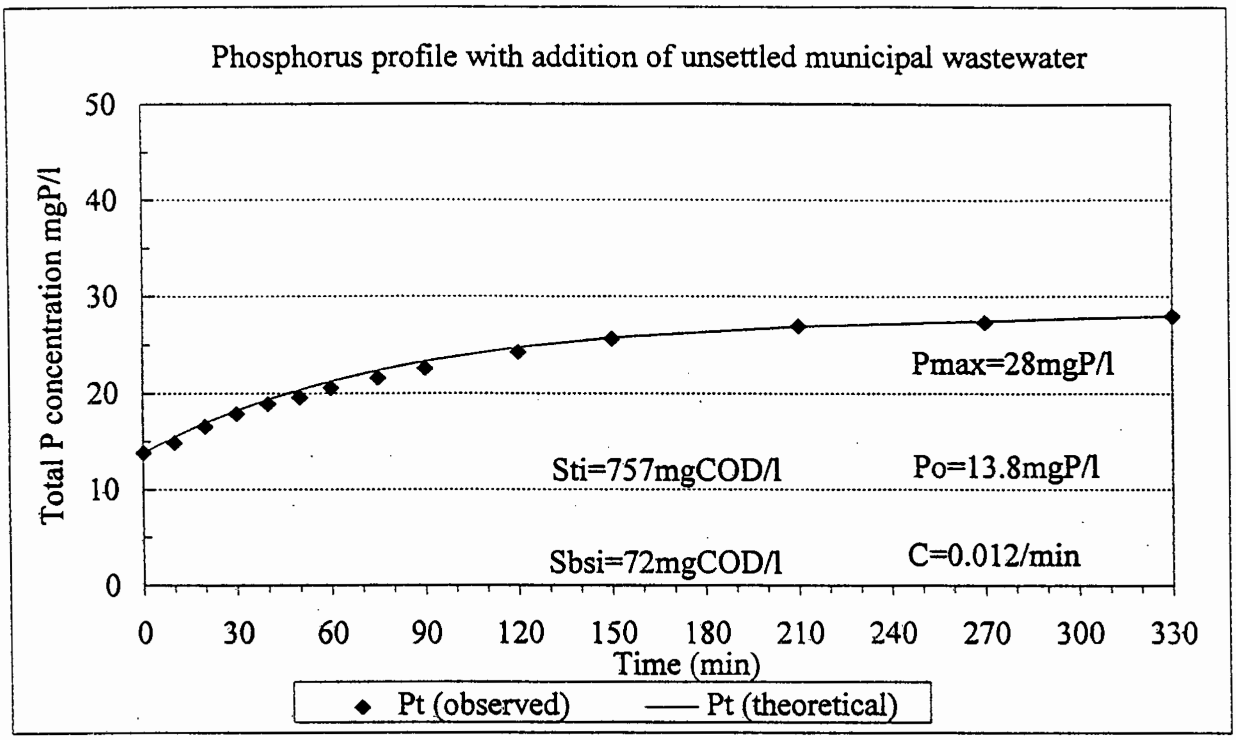


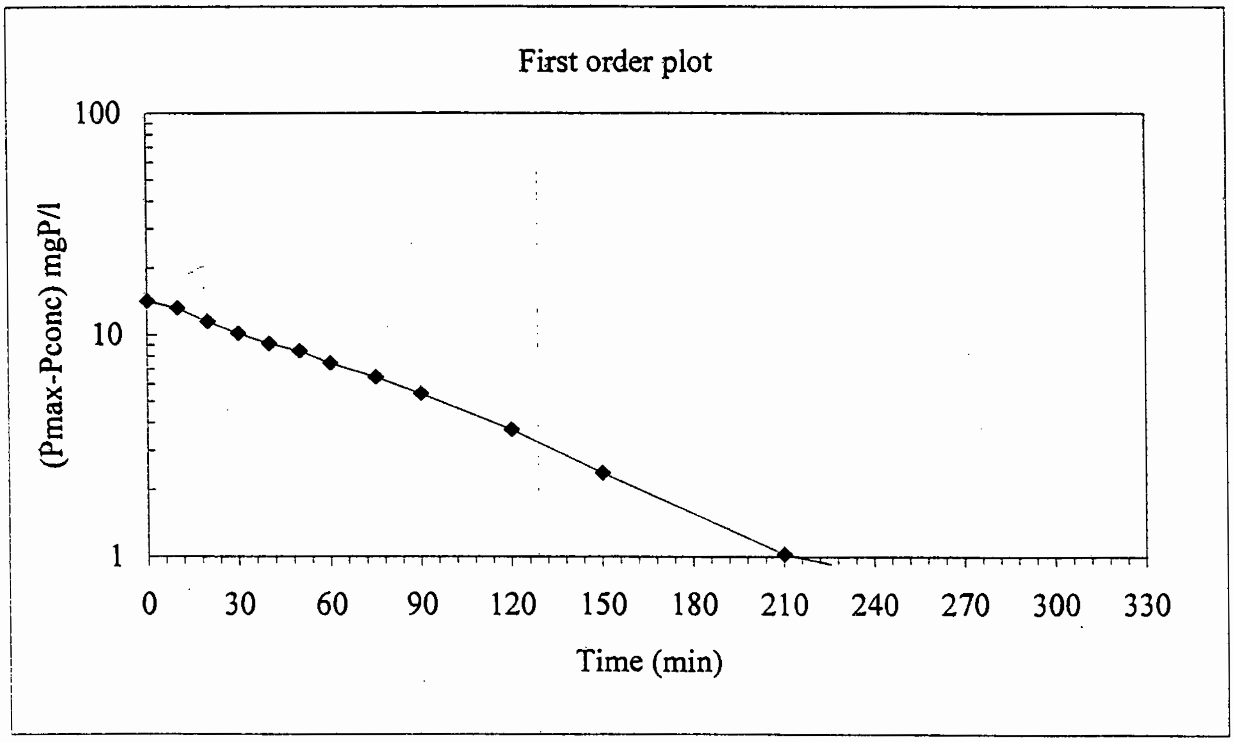
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 05.07.1996

TEST 2 S P rel

Temperature: 20 C



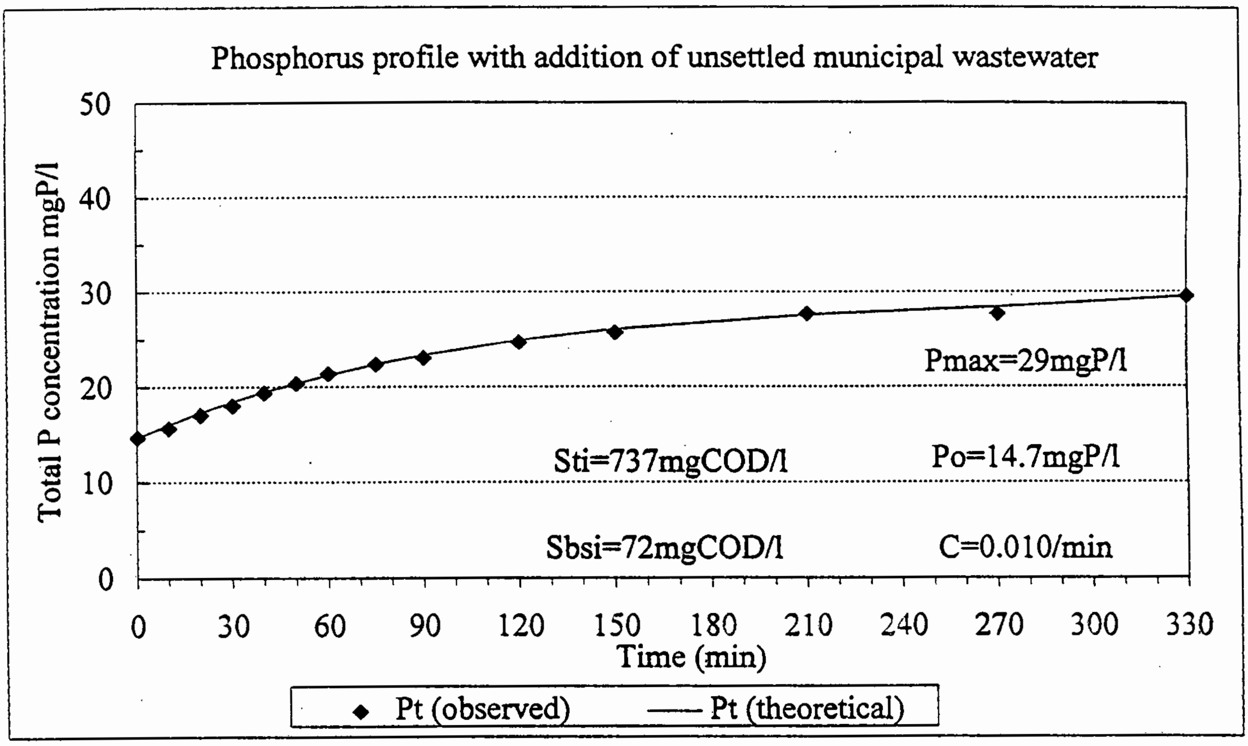


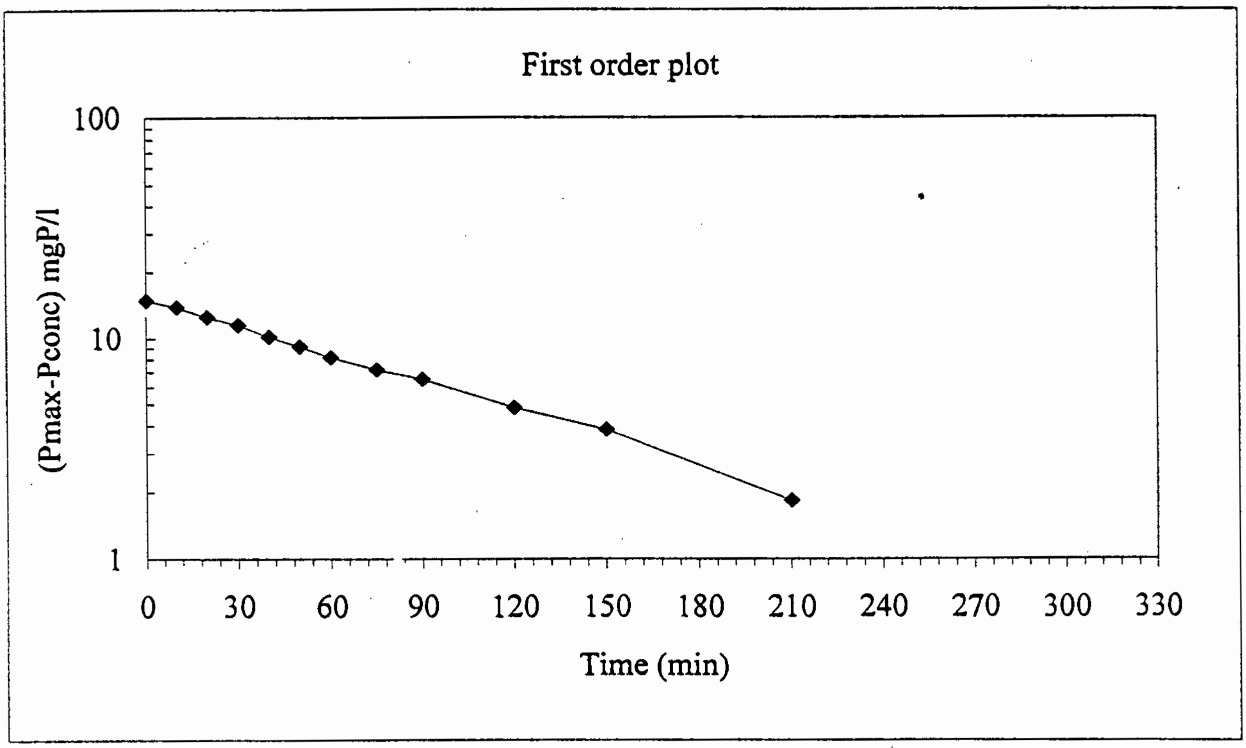
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 08.07.1996

TEST 3 S P rel

Temperature: 20 C



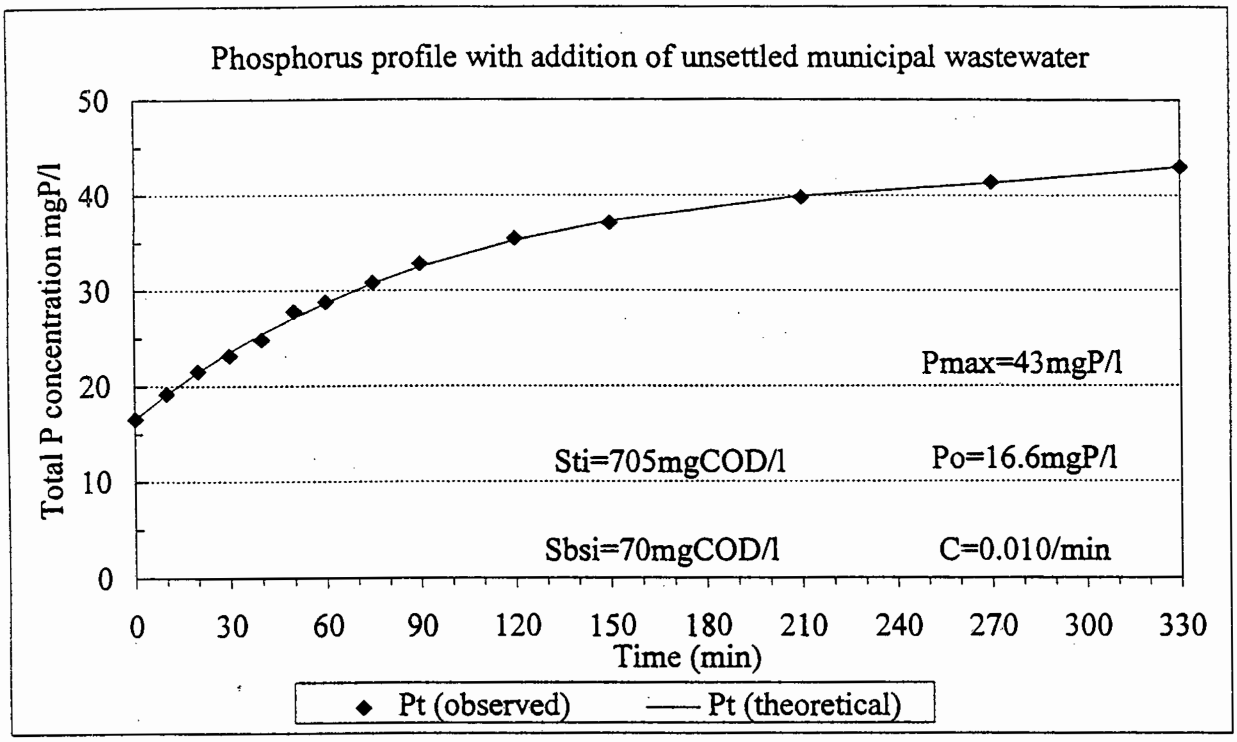


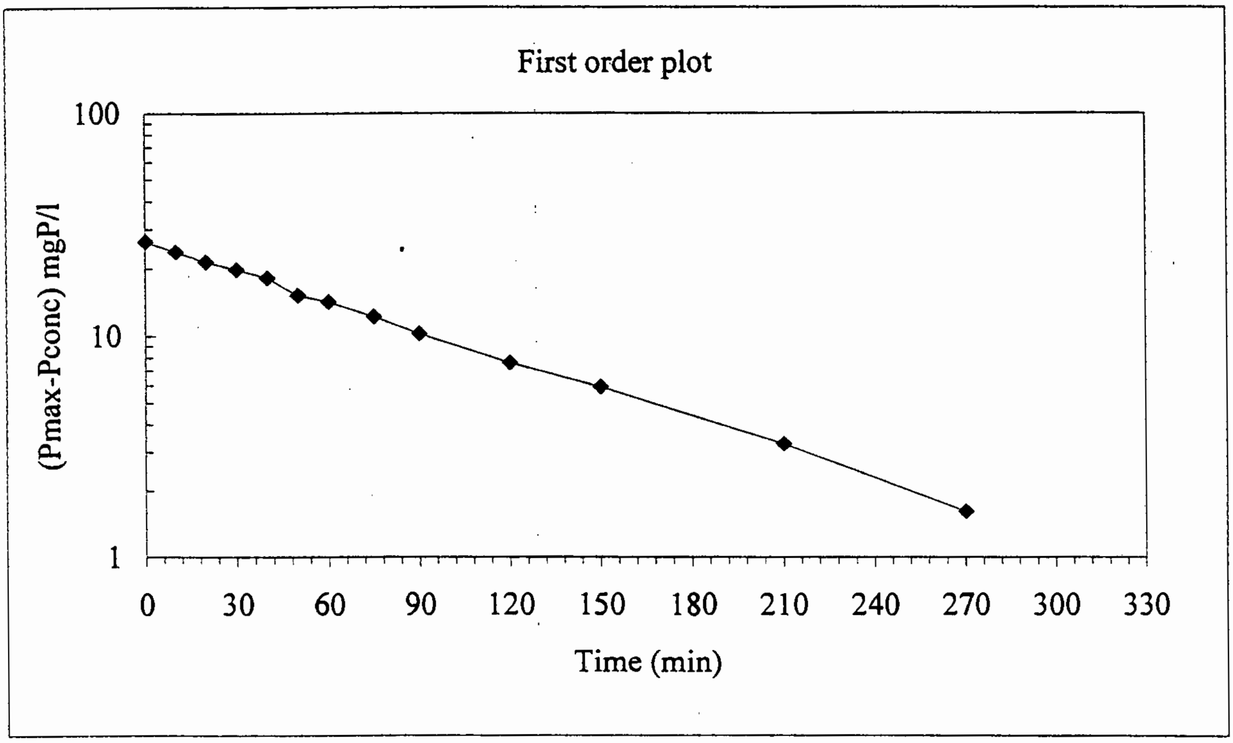
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 20.11.1996

TEST 4 S P rel

Temperature: 20 C



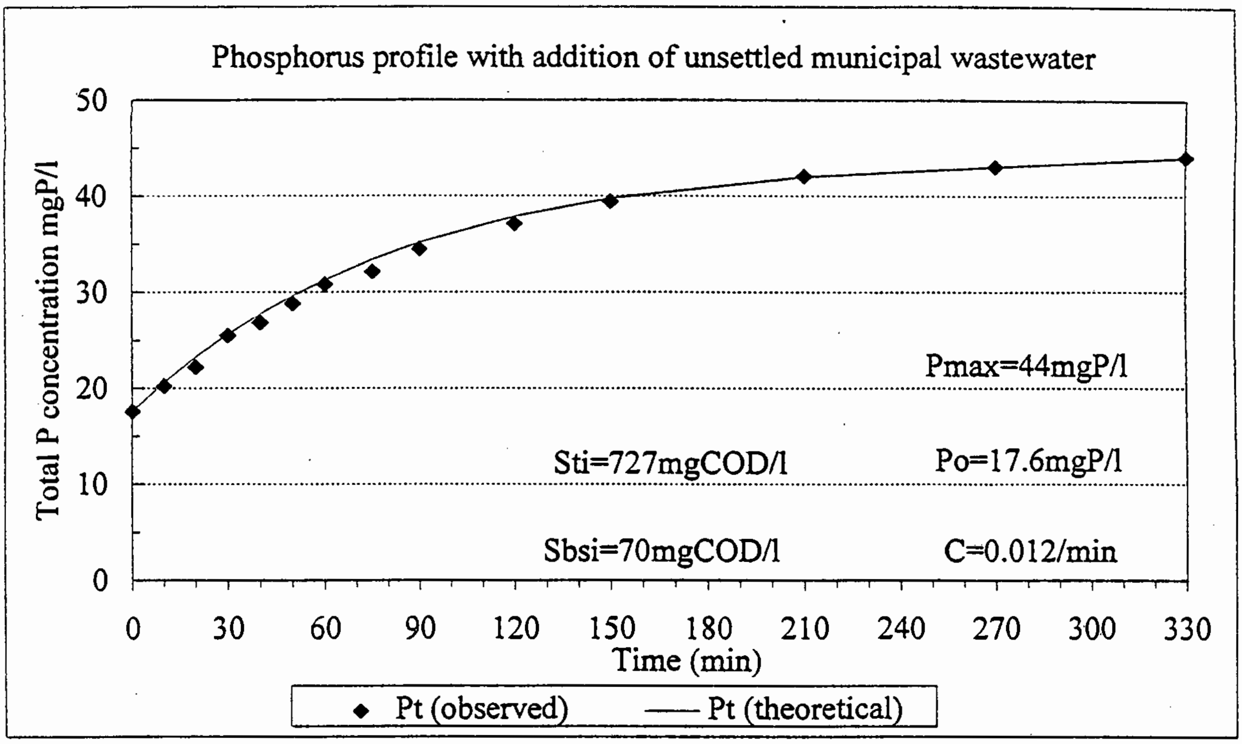


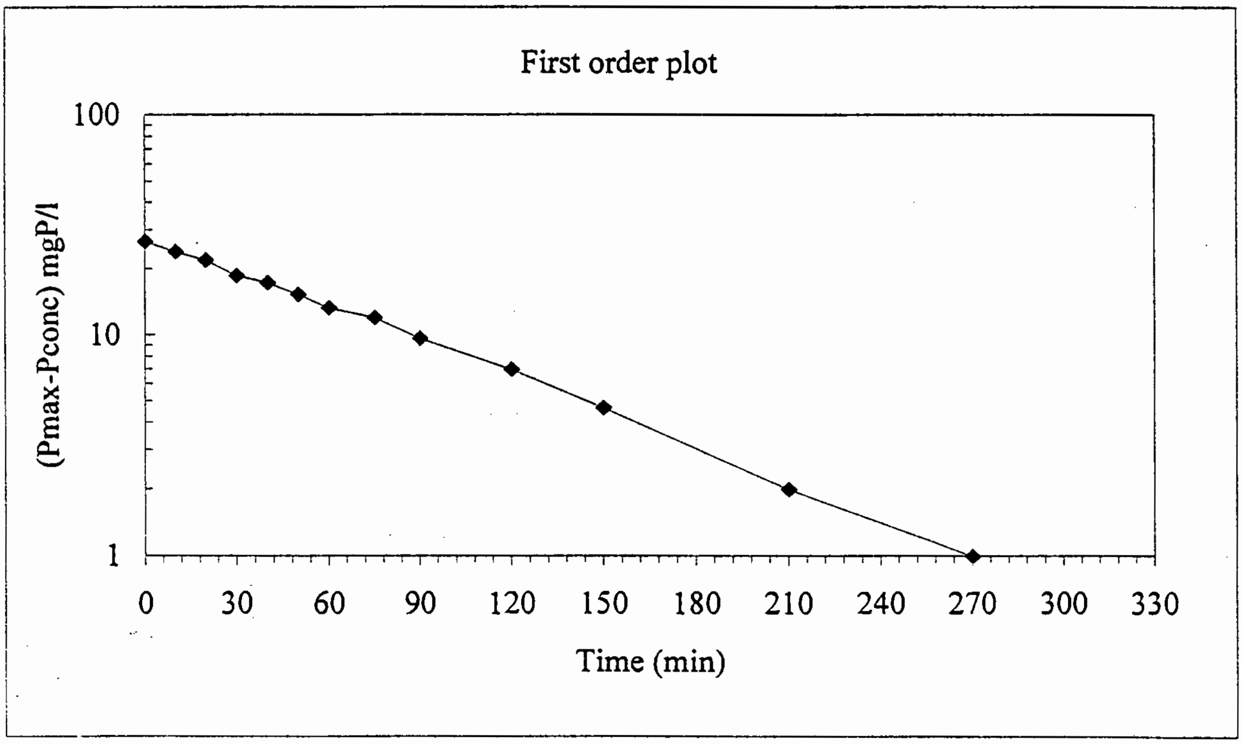
PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST WITH ADDITION OF UNSETTLED MUNICIPAL WASTEWATER IN THE UCT SYSTEM

Date: 21.11.1996

TEST 5 S P rel

Temperature: 20 C



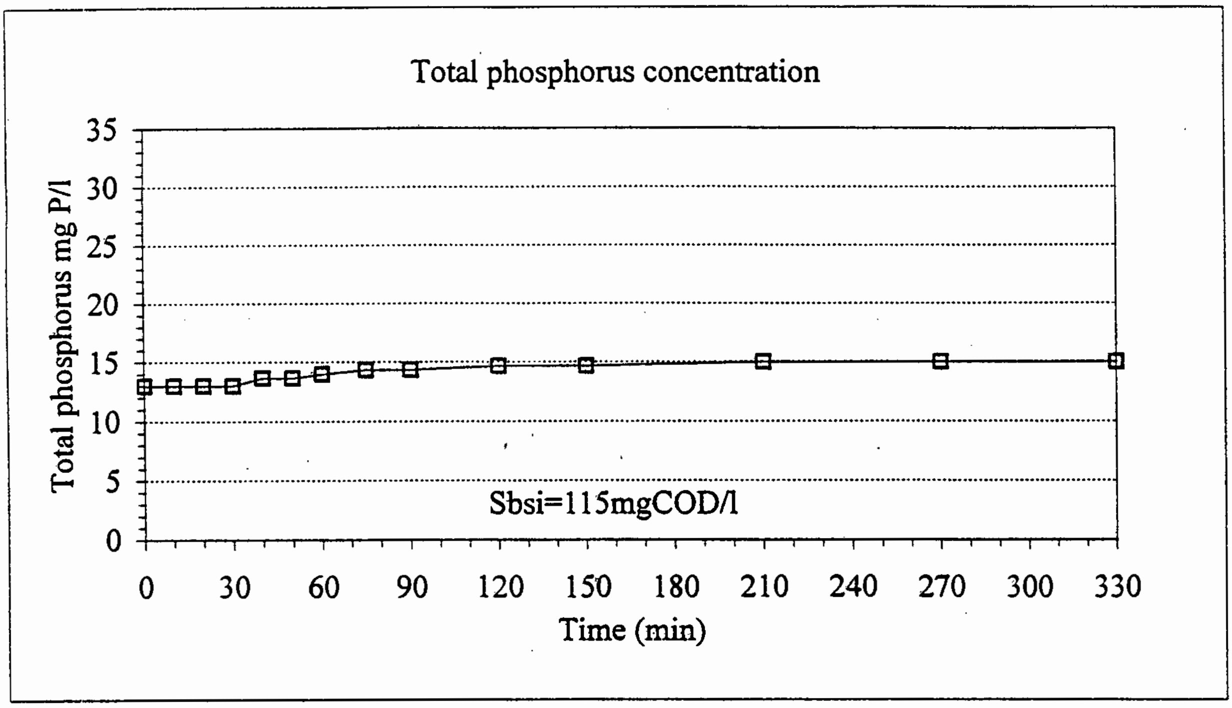


EXCESS PHOSPHORUS RELEASE UNDER ANAEROBIC BATCH TEST ADDING EXCESS ACETATE SOLUTION AS A SUBSTRATE SOURCE

Date: 24.06.1996

TEST 1 Ex P rel

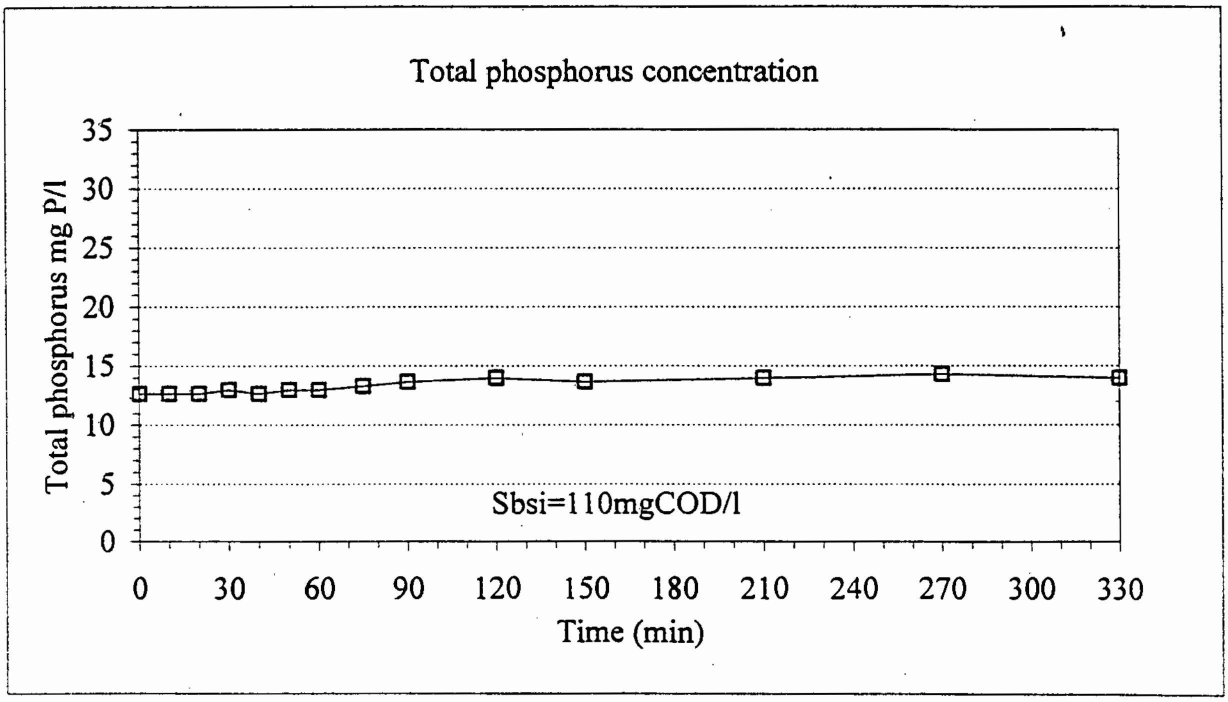
Temperature: 20 C



Date: 25.06.1996

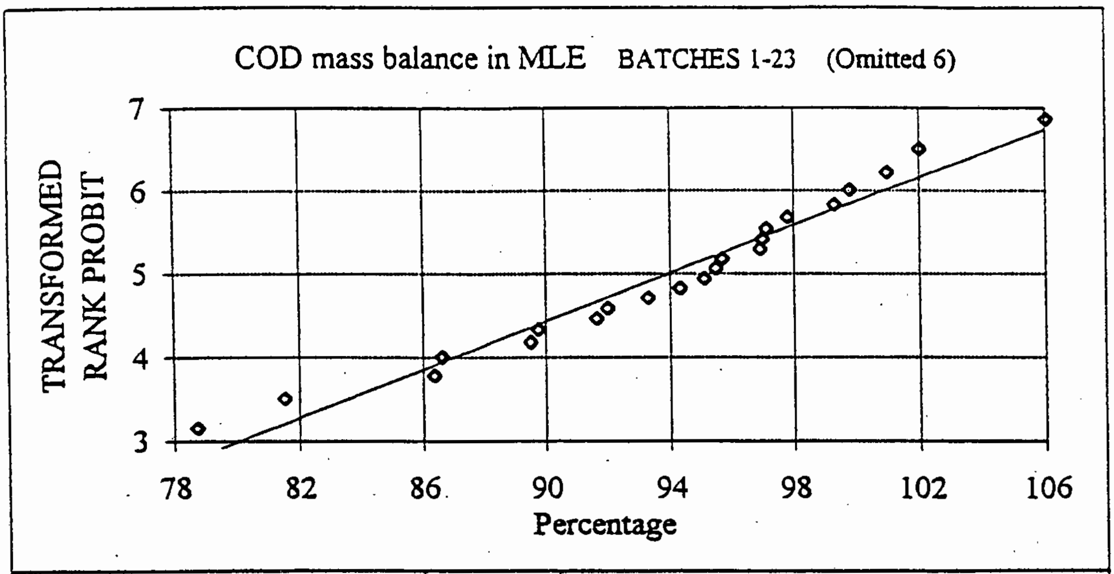
TEST 2 Ex P rel

Temperature: 20 C



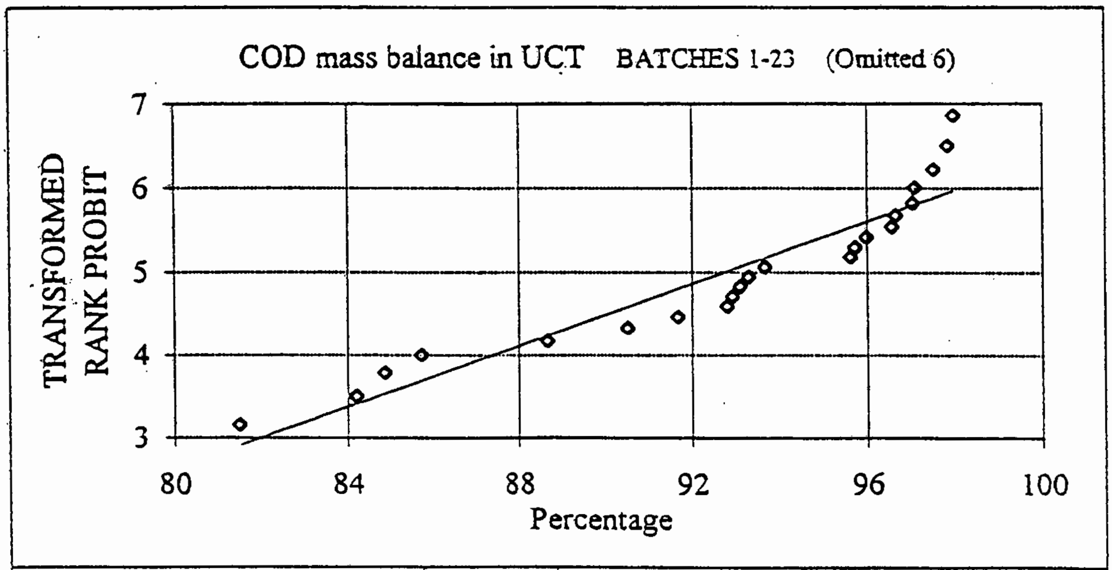
APPENDIX I

STATISTICAL PLOTS OF COD AND N MASS BALANCES FOR LONG TERM PERIOD I, II AND III.



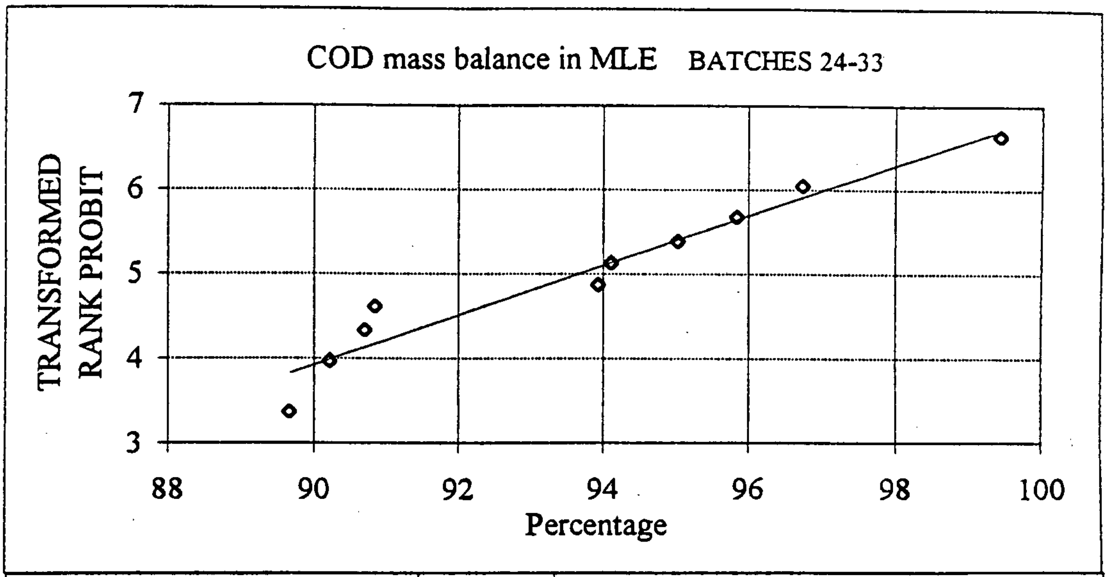
MEDIAN=	95		std dev. of mean =	1.4
MEAN =	94		95% conf. of mean = 94 +/-	2.8
s =	7			

Fig I.1 Probability distribution of the COD mass balance in MLE system (period I) from day no 1 to day no 360.



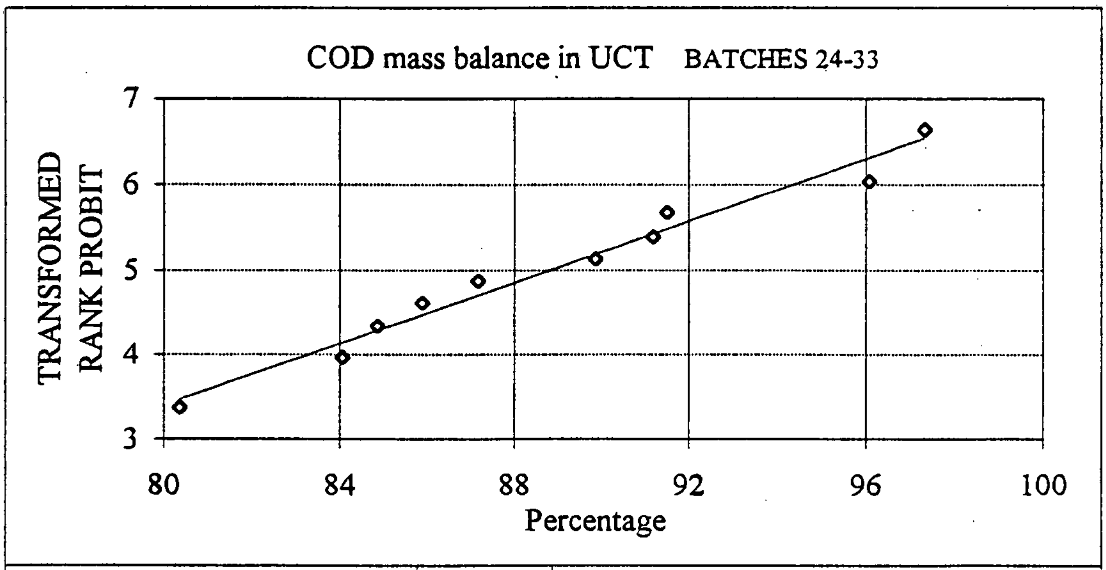
MEDIAN=	93		std dev. of mean =	1.0
MEAN =	93		95% conf. of mean = 93 +/-	2.1
s =	5			

Fig I.2 Probability distribution of the COD mass balance in UCT system (period I) from day no 1 to day no 360.



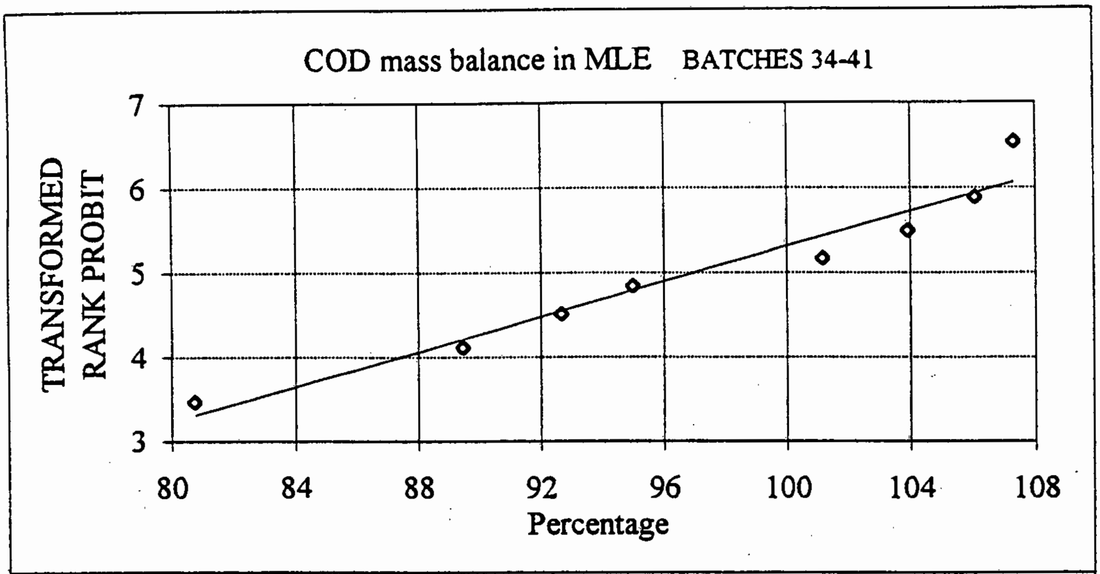
MEDIAN=	94		std dev. of mean = 1.0
MEAN =	94		95% conf. of mean = 94 +/- 2.0
s =	3		

Fig I.3 Probability distribution of the COD mass balance in MLE system (period II) from day no 361 to day no 490.



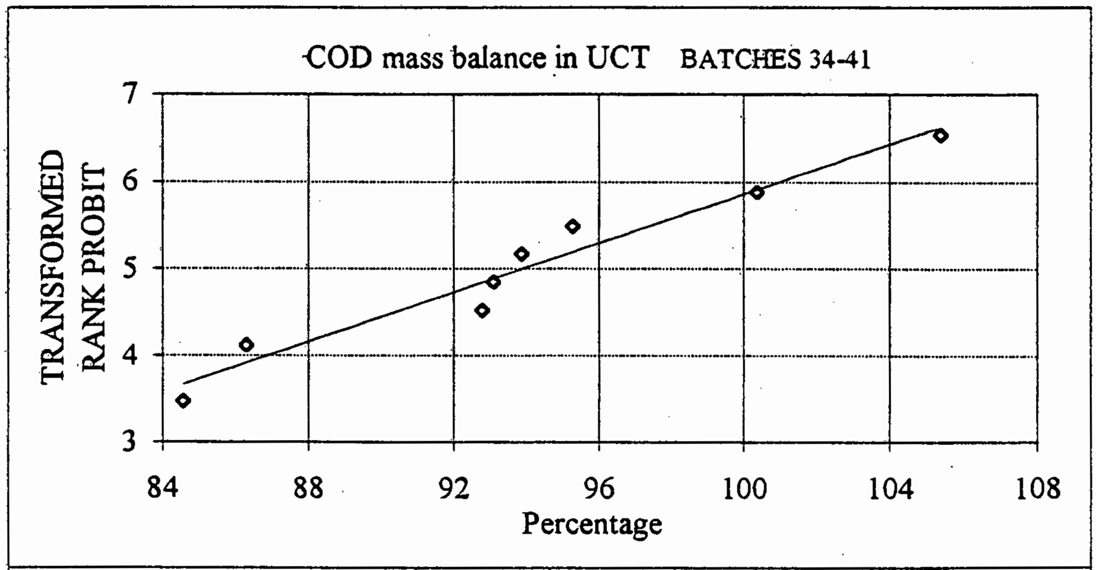
MEDIAN=	89		std dev. of mean = 1.7
MEAN =	89		95% conf. of mean = 89 +/- 3.3
s =	5		

Fig I.4 Probability distribution of the COD mass balance in UCT system (period II) from day no 361 to day no 490.



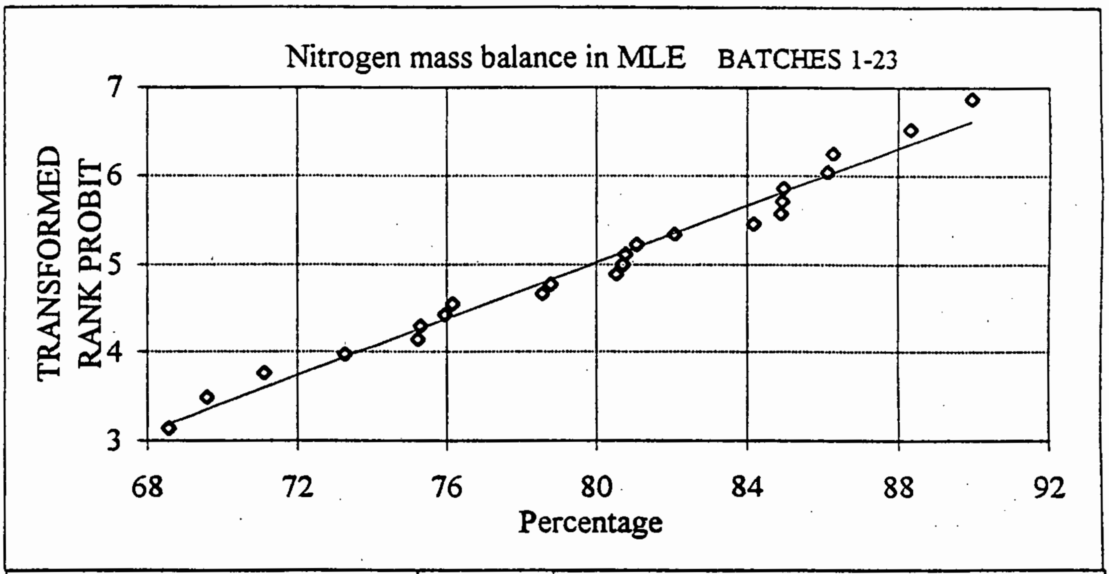
MEDIAN=	98		std dev. of mean =	3.3
MEAN =	97		95% conf. of mean = 97 +/-	6.4
s =	9			

Fig I.5 Probability distribution of the COD mass balance in MLE system (period III) from day no 491 to day no 582.



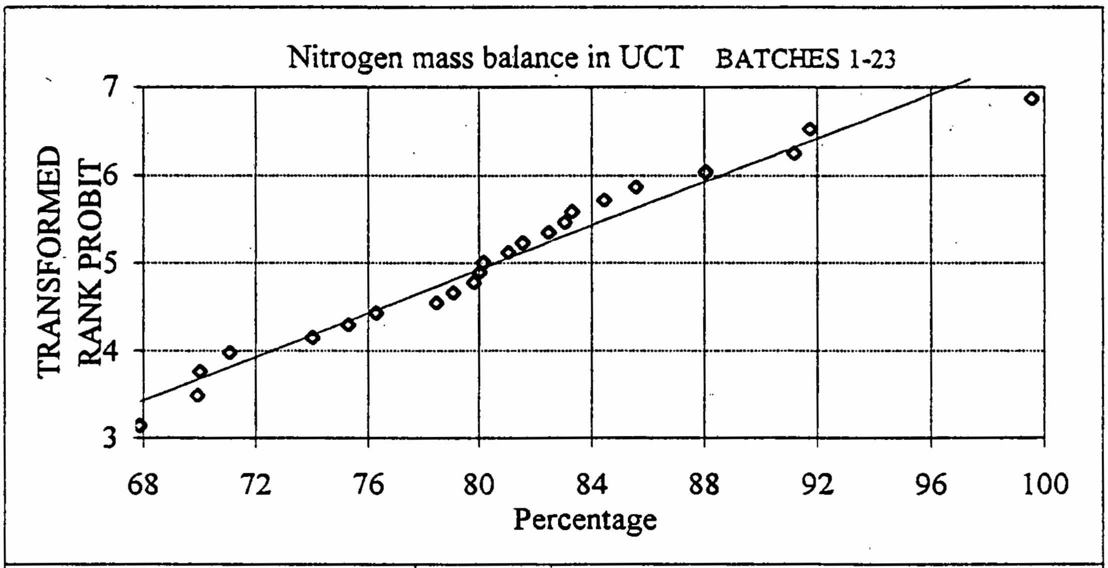
MEDIAN=	93		std dev. of mean =	2.4
MEAN =	94		95% conf. of mean = 94 +/-	4.7
s =	7			

Fig I.6 Probability distribution of the COD mass balance in UCT system (period III) from day no 491 to day no 582.



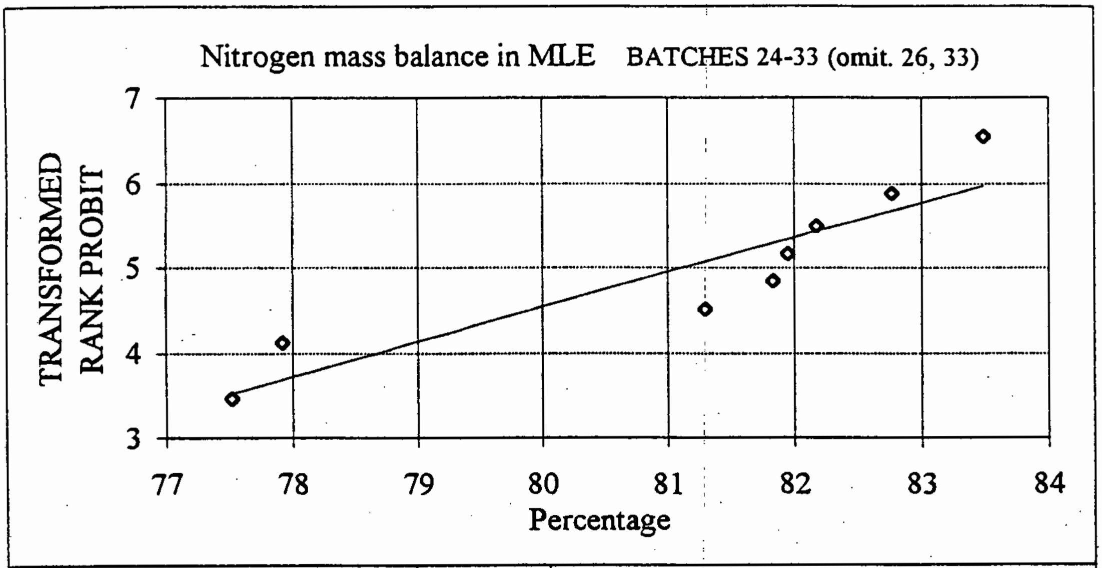
MEDIAN=	81		std dev. of mean = 1.2
MEAN =	80		95% conf. of mean = 80 +/- 2.4
s =	6		

Fig I.7 Probability distribution of the Nitrogen mass balance in MLE system (period I) from day no 1 to day no 360.



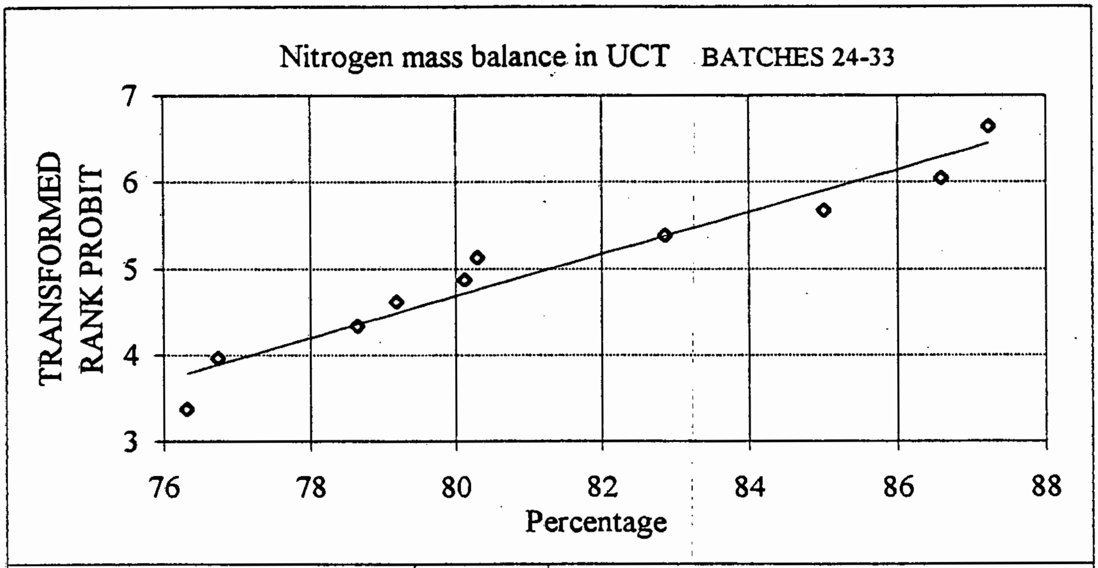
MEDIAN=	80		std dev. of mean = 1.6
MEAN =	81		95% conf. of mean = 81 +/- 3.1
s =	8		

Fig I.8 Probability distribution of the Nitrogen mass balance in UCT system (period I) from day no 1 to day no 360.



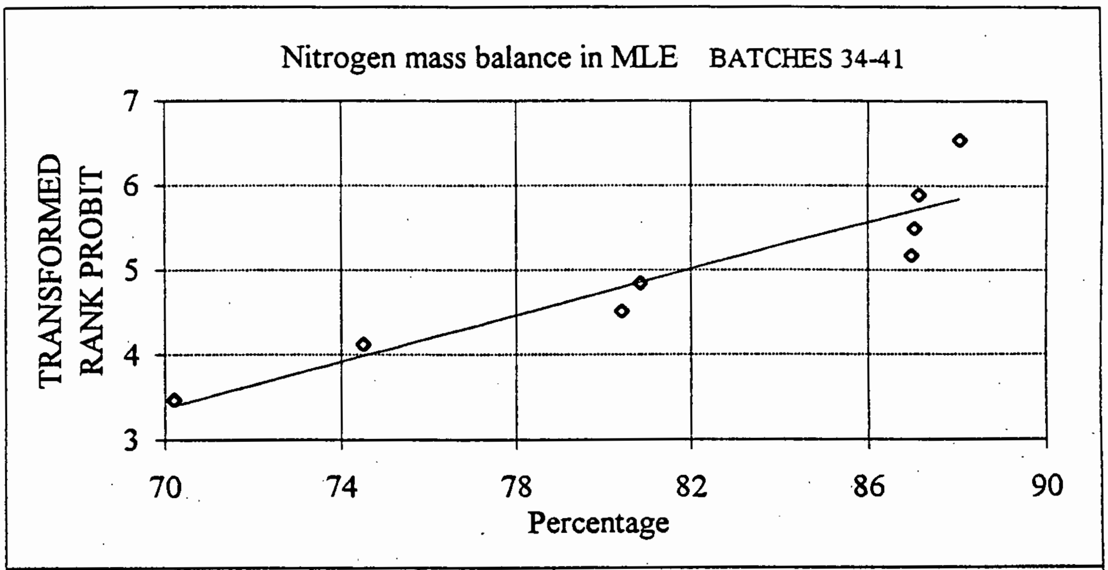
MEDIAN=	82		std dev. of mean =	0.8
MEAN =	81		95% conf. of mean = 81 +/-	1.5
s =	2			

Fig I.9 Probability distribution of the Nitrogen mass balance in MLE system (period II) from day no 361 to day no 490.



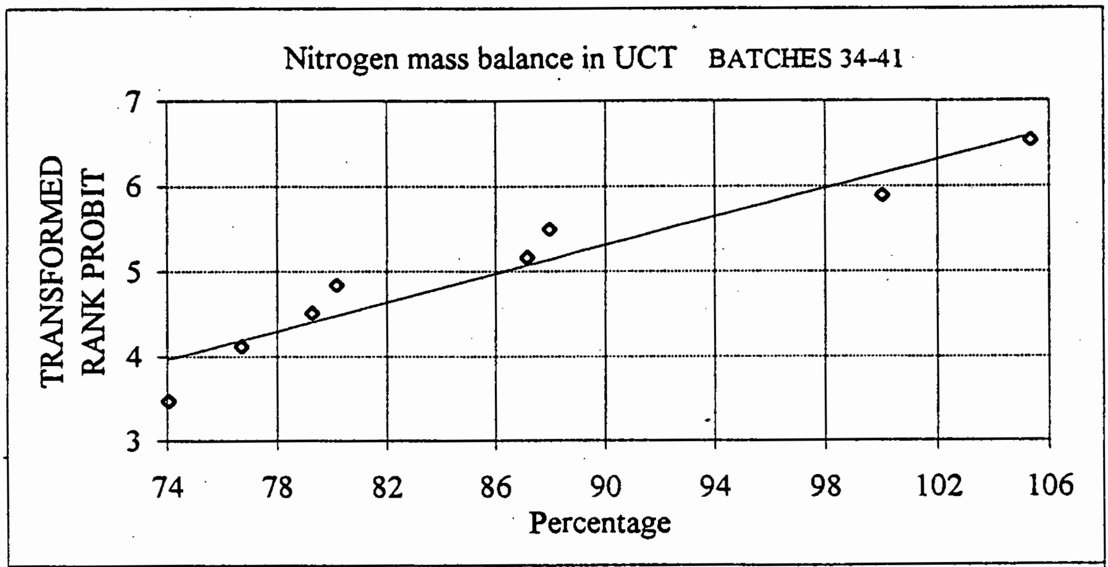
MEDIAN=	80		std dev. of mean =	1.2
MEAN =	81		95% conf. of mean = 81 +/-	2.4
s =	4			

Fig I.10 Probability distribution of the Nitrogen mass balance in UCT system (period II) from day no 361 to day no 490.



MEDIAN=	84		std dev. of mean = 2.4
MEAN =	82		95% conf. of mean = 82 +/- 4.6
s =	7		

Fig I.11 Probability distribution of the Nitrogen mass balance in MLE system (period III) from day no 491 to day no 582.



MEDIAN=	84		std dev. of mean = 4.0
MEAN =	86		95% conf. of mean = 86 +/- 7.8
s =	11		

Fig I.12 Probability distribution of the Nitrogen mass balance in UCT system (period III) from day no 491 to day no 582.

APPENDIX J

BULKING FILMENT IDENTIFICATION OF MLE AND UCT SYSTEMS.

Description of data	Page
Filament identification of MLE and UCT systems (Day No 308 to 534)	J.1
Filament identification of MLE and UCT systems (Day No 565)	J.2

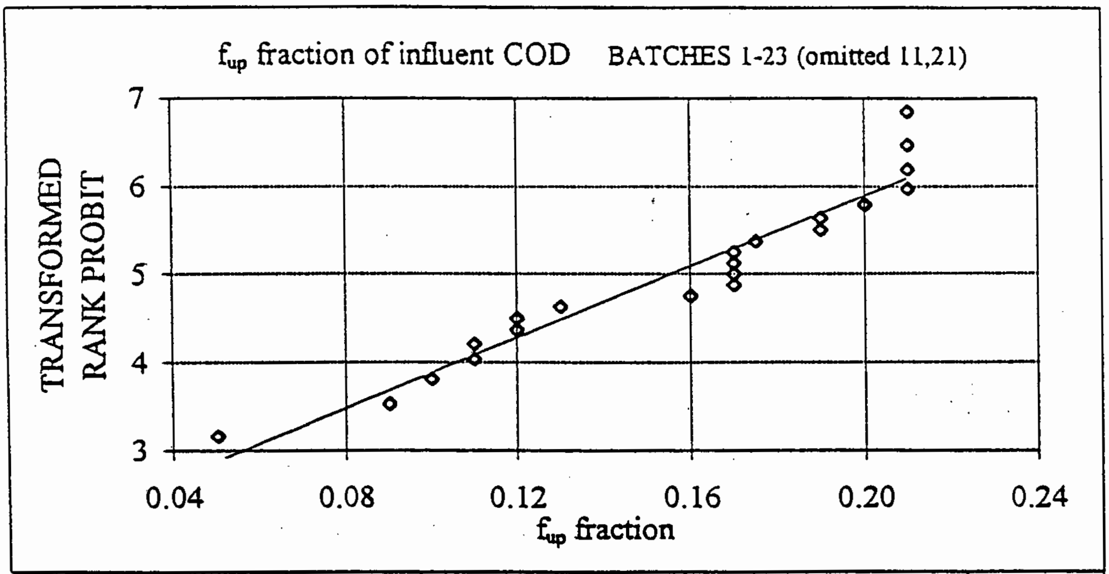
FILAMENT IDENTIFICATIONS 1996

							At Stairs		At Centre
DATE	Analyst	SYSTEM	HMMLE30	HMUCT30	MSUCT20E	MSUCT20C	MUMLE	MUMLEL	HMMLE20
03-Mar-96	PT	Dominant	S. natans	S. natans	S. natans		S. natans	M parvicella	S. natans
		Secondary	M parvicella	type 1851	M parvicella		M parvicella	S. natans	M parvicella
Day no 308		Other	N limicola II	N limicola II	type 0041 type 0875		type 1851	type 1851 N limicola	
		Amount	common	Abundant	common		some	some	v Common
		Remarks						USED TO MAKE MSUCT20CL	
02-Apr-96	PT	Dominant	type 0092	type 0092	type 0092	type 0092	type 0092		type 0092
		Secondary	M parvicella	S. natans	M parvicella	M parvicella	M parvicella		M parvicella
Day no 338		Other	type-1851 S. natans	M parvicella type 1851	N limicola II S. natans	Type 1851 S. natans	Type 1851 type 0041		Type 1851 S. natans
		Amount	Common	Some	Few	Some	Common		Some
		Remarks							
02-Apr-96	JHB	Dominant	type 0092	type 0092	type 0092	type 0092	type 0092		type 0092
		Secondary	H hydrossis type 0803	H hydrossis 021N	type 0803	021N H hydrossis	H hydrossis Type 0041		H hydrossis type 0803
Day no 338		Other	M parvicella	type 0803 Type 0041 M parvicella	Type 0041 021N	type 0803 Thiothrix	type 0803 M parvicella		Type 0041 021N
		Amount	V. common	vc-ab	vc	vc	common		vc
		Remarks	Flocs small Rotifers	Scanty bridg Few crawling ciliates	No bridging	Few rotifres No brigdging	flocs med to large Few flagelates		No brigdgin
07-May-96	PT	Dominant	type 0092	type 0092	type 0092	type 0092	type 0092		type 0092
		Secondary	M parvicella type 1851	M parvicella S. natans	M parvicella S. natans	M parvicella S. natans	M parvicella type 1851		M parvicella type 1851
Day no 373		Other	S. natans	type 1851	N limicola II	type 1851 type 0914	S. natans		S. natans type 0914
		Amount	common	common	some	some	common		some
		Remarks							
07-Jun-96	PT	Dominant	type 0092	M parvicella	M parvicella	M parvicella	type 0092		M parvicella
		Secondary	M parvicella	type 0092 . S. natans	type 0092 type 1851	type 0092 type 1851	M parvicella S. natans		type 0092 N limicola II
Day no 404		Other		Beggiatoa	Beggiatoa	Beggiatoa	type 0041		
		Amount		some	some	common	common		some
		Remarks							
23-Jul-96	PT	Dominant	type 0092	type 0092	type 0092	type 0092	type 0092		type 0092
		Secondary	M parvicella 021N	M parvicella 021N	M parvicella 021N	M parvicella type 1851	M parvicella 021N		M parvicella 021N
Day no 450		Other	H hyrossis type 1863	type 1863 Acineto bact	type 1851 H hyrossis	021N Spirochetes	Nocardia Spirochetes		type 1863 Acineto bac
		Amount	some	some	common	some	some		common
		Remarks							
22-Aug-96	JHB	Dominant	type 0092	type 0092	Mp (dam'gd)	Mp (dam'gd)	O21N		O21N
		Secondary	O21N M parvicella	M parvicella O21N	type 0041 O21N	type 0092 Thiothrix	type 0041 type 0092		type 0041 type 0092
Day no 480		Other	type 0803 H hydrossis N limicola II	H hydrossis	H hydrossis type 0092	H hydrossis O21N type 1701	typ 0961 Thiothrix H hydrossis		type 0803 H hydrossis
		Amount	vc	vc	vc	common	vc		common
		Remarks							
26-Aug-96	PT	Dominant	type 0092	type 0092	type 0092	type 0092	type 0092		type 0092
		Secondary	M parvicella type 1851	M parvicella 021N	M parvicella 021N	M parvicella type 1851	M parvicella 021N		M parvicella 021N
Day no 484		Other	021N	type 1851 H hyrossis	Thiothrix	021N	type 1851		
		Amount	vc	vc	common	common	common		common
		Remarks							
18-Sep-96	PT	Dominant	type 0092	type 0092	type 0092	type 0092	type 0092		type 0092
		Secondary	M parvicella 021N	M parvicella type 1851	M parvicella 021N	M parvicella type 1851	M parvicella 021N		M parvicella 021N
Day no 507		Other			type 1851	021N Acineto bact	type 1851 type 0041		type 1851
		Amount	common	some	some	some	common		common
		Remarks							
		SYSTEM	HMMLE30	HMUCT30	MSUCT20E	MSUCT20C	ZHMLEX		ZHMLEC
15-Oct-96	JHB	Dominant	type 0041	type 0092	type 0041	type 0092	type 0092		type 0092
		Secondary	type 0092 type 0675	type 0675 type 0041	type 0092 type 0675	type 0041 Thiothrix II	type 0041 M parvicella		type 0041 H hydrossis
Day no 534		Other	H hyrossis	M parvicella H hydrossis O21N, Begg	M parvicella H hydrossis	H hydrossis M parvicella	H hydrossis type 0675		type 0675
		Amount	some	c-vc	common	common	some		some- com
		Remarks	vc Protozoa		Mp damaged		Diatoms vc		protozoa- c

15-Nov-96	PT	Dominant	1851	1851	1851	M.parvicella	1851	1851
Day no		Secondary	Type 021N	Type 021N	M.parvicella	1851	Type 021N	type 0092
565			M.parvicella	M.parvicella	Type 021N	Type 021N	type 0092	M.parvicella
		Other	type 0092	type 0092	type 0092	type 0092	M.parvicella	Type 021N
			H hydrossis	H hydrossis			H hydrossis	H hydrossis
		Amount	common	common	some	common	common	common
		Remarks	Abundance refers to extended filament length and not to filamnets in floc					
15-Nov-96	JHB	Dominant	type 0092	type 0092	type 0092	type 0041	type 0092	type 0092
		Secondary	type 0041	type 0041	type 0041	type 0092	type 0041	type 0675
Day no					type 0675			type 0041
565		Other	H hydrossis	0675, H hyd	0803, H hyd	type 0675	H hyd;M par	H hyd; 0961
			0803, 021N	0803, Begg	M parvicella	H hyd;M par	type 0961	type 0803
		Amount	vc	c - vc	common	abundant	some-com	c-vc
		Remarks	Many protozo	Flocs small	Various Prot	Heavy bridg	Var prots	Prots com
				Zoogloea	common	Prots comm	common	Few Rotifer

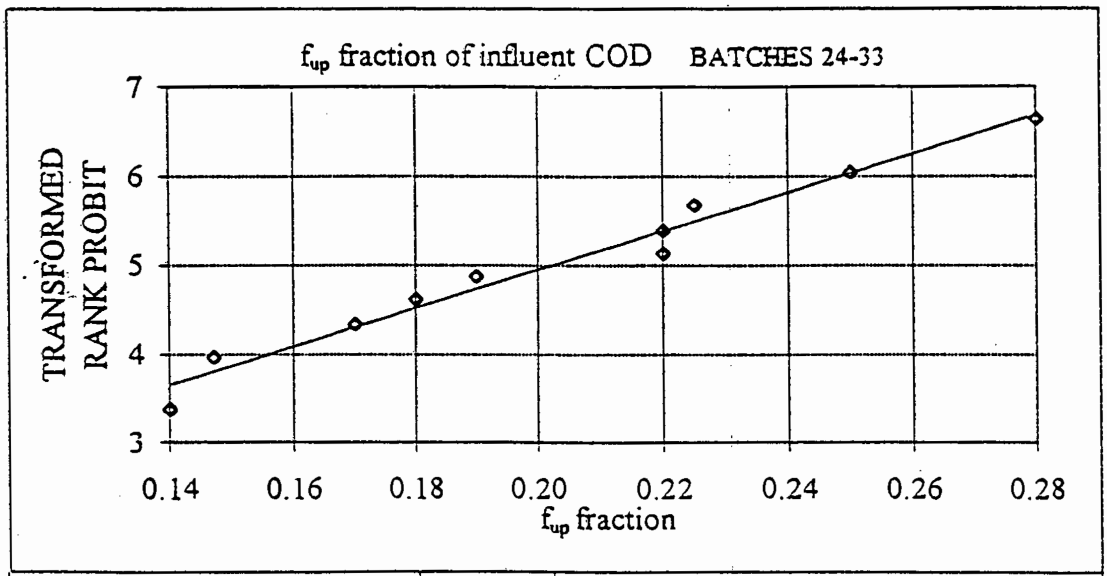
APPENDIX K

STATISTICAL PLOTS OF THE fup FRACTIONS OF DAILY INFLUENT COD OVER LONG TERM PERIODS I, II, III AND IV IN MLE AND UCT SYSTEMS.



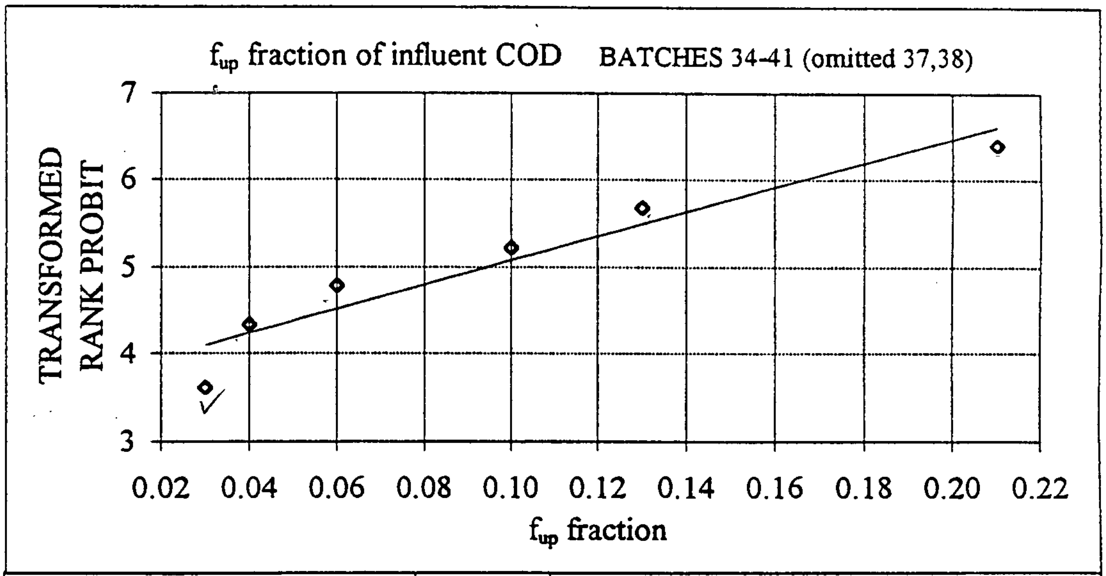
MEDIAN=	0.170		std dev. of mean =	0.010
MEAN =	0.155		95% conf. of mean = 0.155 +/- 0.020	
s =	0.047			

Fig K.1 Probability distribution of the f_{up} fraction of daily influent COD in MLE system (period I) from day no 1 to day no 360 WRC (1984) steady state.



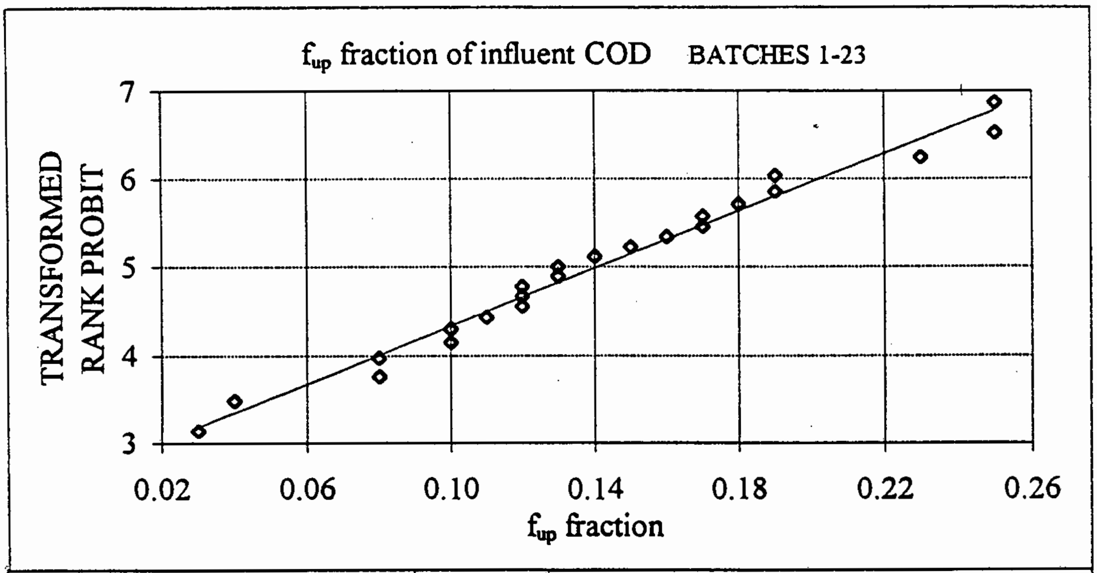
MEDIAN=	0.220		std dev. of mean =	0.014
MEAN =	0.202		95% conf. of mean = 0.202 +/- 0.028	
s =	0.045			

Fig K.2 Probability distribution of the f_{up} fraction of daily influent COD in MLE system (period II) from day no 361 to day no 490 WRC (1984) steady state.



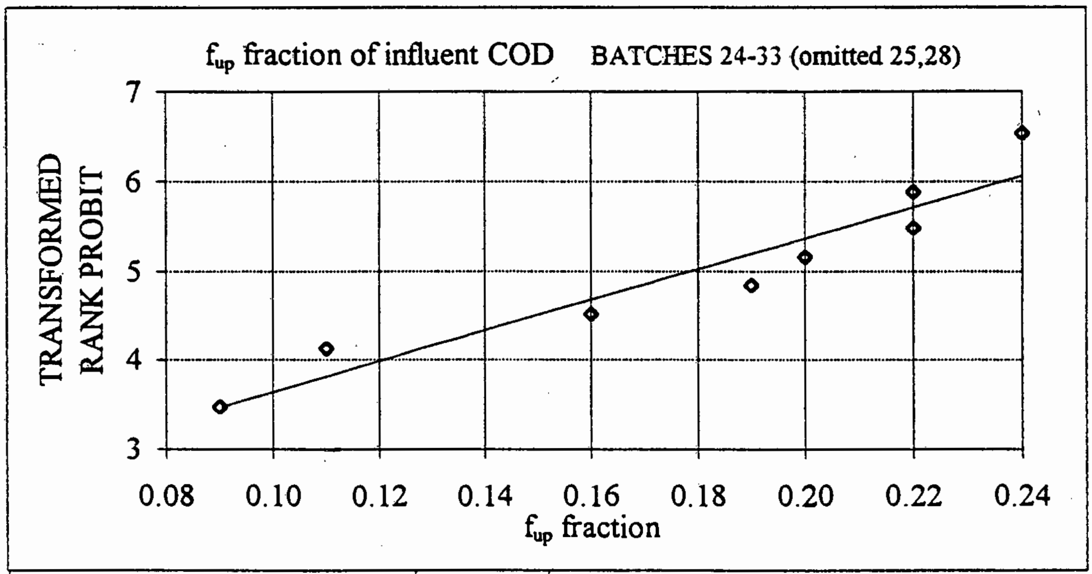
MEDIAN=	0.080		std dev. of mean = 0.028
MEAN =	0.095		95% conf. of mean = 0.095 +/- 0.054
s =	0.068		

Fig K.3 Probability distribution of the f_{up} fraction of daily influent COD in MLE system from day no 491 to day no 582 WRC (1984) steady state.



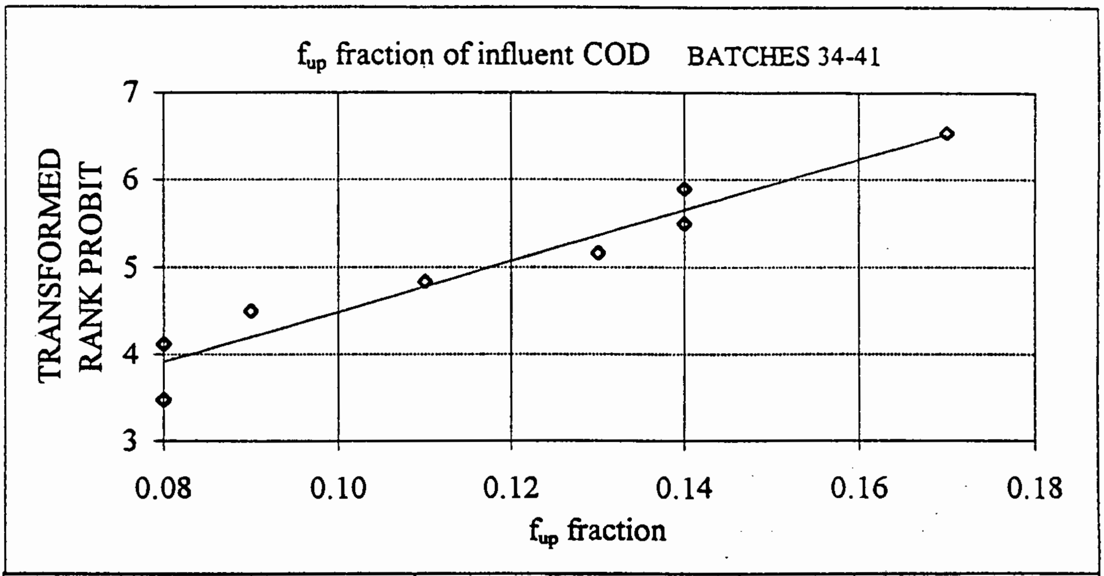
MEDIAN=	0.130		std dev. of mean = 0.012
MEAN =	0.141		95% conf. of mean = 0.141 +/- 0.024
s =	0.059		

Fig K.4 Probability distribution of the f_{up} fraction of daily influent COD in UCT system from day no 1 to day no 360 Wentzel *et.al.,* (1990).



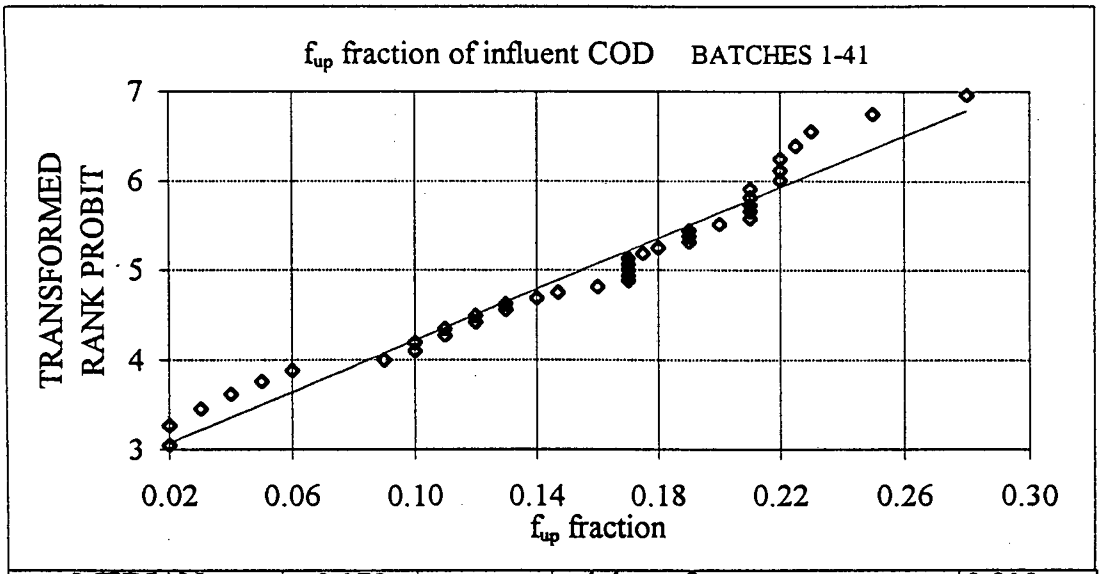
MEDIAN=	0.195		std dev. of mean = 0.019
MEAN =	0.179		95% conf. of mean = 0.179 +/- 0.038
s =	0.054		

Fig K.5 Probability distribution of the f_{up} fraction of daily influent COD in UCT system from day no 361 to day no 490 Wentzel et.al., (1990).



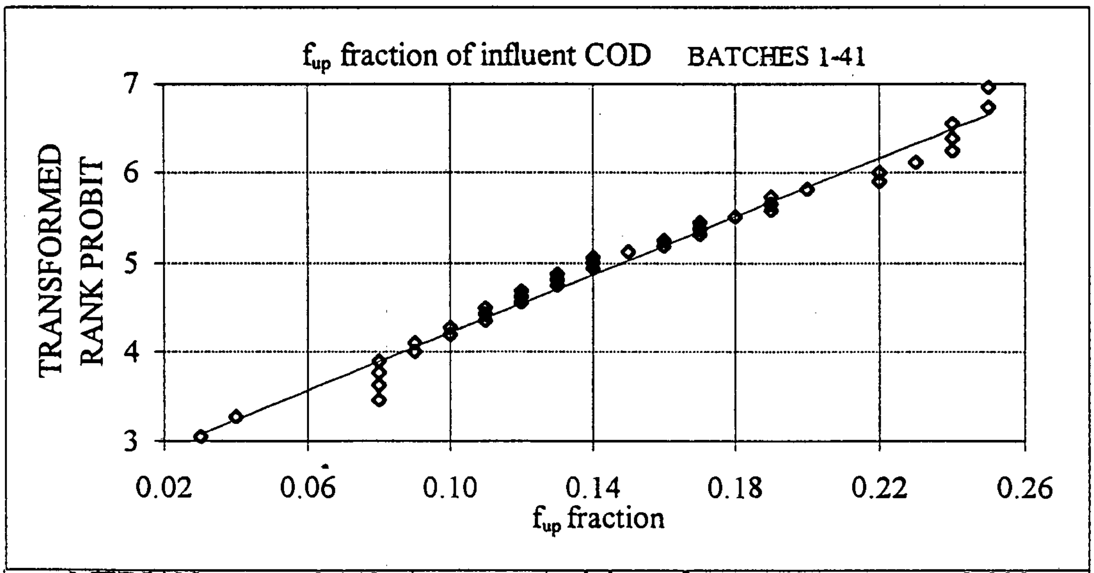
MEDIAN=	0.120		std dev. of mean =	0.012
MEAN =	0.118		95% conf. of mean = 0.118 +/- 0.023	
s =	0.033			

Fig K.6 Probability distribution of the f_{up} fraction of daily influent COD in UCT system from day no 491 to day no 582 Wentzel et.al., (1990).



MEDIAN=	0.170		std dev. of mean =		0.010
MEAN =	0.155		95% conf. of mean =	+/-	0.020
s =	0.066				

Fig K.7 Probability distribution of the f$_{up}$ fraction of daily influent COD in MLE system from day no 1 to day no 582 WRC (1984) steady state.



MEDIAN=	0.140		std dev. of mean =		0.009
MEAN =	0.149		95% conf. of mean =	+/-	0.018
s =	0.059				

Fig K.8 Probability distribution of the f$_{up}$ fraction of daily influent COD in UCT system from day no 1 to day no 582 Wentzel et al. (1990) steady state.

APPENDIX L

Calculations for batch tests on MLE and UCT systems at 30°Cand 20°C and Statistical plots of the calculated results

Table L.1 AEROBIC BATCH TEST OF THE MLE SYSTEM AT 30°C.

			SYSTEM				AEROBIC BATCH TEST							
PERIOD NUMBER	DAY NUMBER	SEWAGE BATCH	NO3 GENER mgNO3-N/d	NO3 GENER mgNO3-N/l	MXn mg VSS	Xn mgXn/l	NO3-GENER. mgNO3-N/l	DURATIO hour	NO3-GENER. mgNO3-N/l/h	NO3-GENER. mgNO3-N/l/d	O2-GENER mgNO2-N/l	DURATION hour	O2-GENER. mgNO2-N/l/	µnm30
1	172	11	415	41.5	271	13.56	30.0	4.25	7.06	208.5	5.7	3.5	1.63	1.249
	179	11	440	44.0	288	14.38	42.0	5.50	7.64	203.7	3.4	4.0	0.85	1.275
	186	12	548	54.8	358	17.91	21.0	3.50	6.00	187.8	7.3	4.0	1.83	0.804
	188	12	535	53.5	350	17.48	26.0	4.50	5.78	187.9	8.2	4.0	2.05	0.793
	232	14	474	47.4	310	15.48	27.6	5.21	5.30	127.1	0.0			0.821
	241	15	450	45.0	294	14.71	27.6	5.38	5.13	123.1	0.0			0.837
	246	15	475	47.5	311	15.54	32.4	5.34	6.07	193.7	4.0	2.0	2.00	0.938
	253	15	446	44.6	292	14.59	33.1	5.34	6.20	232.8	7.0	2.0	3.50	1.020
	265	16	592	59.2	387	19.33	40.0	5.09	7.86	219.5	4.5	3.5	1.29	0.976
	270	16	527	52.7	344	17.21	37.8	5.50	6.88	197.0	6.0	4.5	1.33	0.959
	272	17	395	39.5	258	12.92	16.4	2.50	6.57	176.9	2.0	2.5	0.80	1.221
	274	17	352	35.2	230	11.50	37.9	5.25	7.22	210.8	7.8	5.0	1.56	1.507
	292	18	471	47.1	308	15.39	33.5	4.99	6.70	188.3	4.0	3.5	1.14	1.046
2	387	26	768	76.8	502	25.10	13.6	5.50	2.47	59.2	0.0			0.236
	393	26	608	60.8	397	19.87	40.0	5.50	7.27	197.3	3.8	4.0	0.95	0.878
	428	29	551	55.1	360	18.01	16.6	5.21	3.18	94.2	3.0	4.0	0.75	0.423

↑ Includes nitrate generation rate.

↑ excludes nitrite generation rate.

69 × 20 = 1400
25 × 20
5
~~10~~
39 × 20 = 800

Table L.2 AEROBIC BATCH TEST OF THE UCT SYSTEM AT 30°C

			SYSTEM				AEROBIC BATCH TEST							
PERIOD NUMBER	DAY NUMBER	SEWAGE BATCH	NO3 GENER mgNO3-N/d	NO3 GENER mgNO3-N/l	MXn mg VSS	Xn mgXn/l	NO3-GENER. mgNO3-N/l	DURATION hour	NO3-GENER. mgNO3-N/l/h	NO3-GENER. mgNO3-N/l/d	O2-GENE mgNO2-N/l	DURATIO hour	O2-GENER. gNO2-N/l/	μnm30
1	172	11	547	54.7	357.5	17.88	27.0	5.0	5.40	129.6	8.0			0.725
	179	11	472	47.2	308.5	15.42	27.0	5.5	4.91	117.8	7.7			0.764
	186	12	531	53.1	347.1	17.35	29.0	5.5	5.27	126.5	4.2			0.729
	188	12	728	72.8	475.8	23.79	28.0	5.5	5.09	122.2	8.0			0.514
	225	14	496	49.6	324.4	16.22	24.1	5.4	4.49	107.7	0.0	3.5	0.00	0.664
	232	14	473	47.3	309.3	15.46	26.7	5.3	5.03	120.8	0.0	4.0	0.00	0.781
	241	15	518	51.8	338.3	16.92	20.0	5.2	3.84	92.1	3.0	4.0	0.75	0.545
	246	15	412	41.2	269.3	13.46	32.0	5.0	6.36	152.7	3.6	4.0	0.90	1.134
	253	15	447	44.7	292.2	14.61	28.5	5.1	5.63	135.0	5.7			0.924
	265	16	607	60.7	396.7	19.84	36.7	5.4	6.77	162.4	7.0			0.819
	270	16	590	59.0	385.6	19.28	33.3	5.2	6.39	153.2	6.0	2.0	3.00	0.795
	272	17	365	36.5	238.6	11.93	10.3	1.7	6.02	144.4	1.2	2.0	0.60	1.211
	274	17	427	42.7	279.0	13.95	33.6	5.3	6.33	151.9	9.0	3.5	2.57	1.089
	292	18	520	52.0	339.9	16.99	33.8	5.1	6.57	157.8	6.2	4.5	1.38	0.928
2	387	26	850	85.0	555.6	27.78	27.1	5.5	4.93	118.3	1.4	2.5	0.56	0.426
	393	26	744	74.4	486.3	24.31	36.6	5.5	6.66	159.8	2.4	5.0	0.48	0.657
	428	29	746	74.6	487.6	24.38	30.3	5.4	5.64	135.3	1.6	3.5	0.46	0.555
	459	31	1132	113.2	739.9	36.99	33.9	5.5	6.16	147.9	3.7			0.400

Excludes [illegible] generation rate

↑
Excludes nitrite generation rate.

Table L.3 ANOXIC BATCH TEST OF THE MLE SYSTEM (30°C)

PERIOD No	DAY No	BATCH No	BATCH VSS mgVSS/l	CT.FRACT f_{av}	CT.MASS mgVASS/l	O3 RED.K mgNO3-N/l	TIME hour	O3 RED.K mgNO3-N/l	TIME hour	NO3 RED/ mgNO3/l/h	NO3 RED/ mgNO3/l/h	**1-NO3 RED./AVS** mgNO3-N/mgVASS*d	2-NO3 RED./AVS mgNO3-N/mgVASS*d	Nitrite mgNO2-N/l	NO2 GENER mgNO2/l/h	2-NO2 GENER./AVS mgNO3-N/mgVASS*d	**K2-NO3 RED./AVSS** mgNO3-N/mgVASS*d
1	145	1	1133	0.330	373	3.93	0.33	26.23	4.5	11.91	5.83	**0.76556**	0.37470				**0.37470**
	150	2	1346	0.330	444			26.23	3.42		7.67		0.41501				**0.41501**
	155	3	1353	0.330	446			27.54	2.53		10.89		0.58597				**0.58597**
	159	4	1345	0.336	453	7.21	0.45	25.57	4.36	16.02	5.86	**0.84968**	0.31101				**0.31101**
	164	5	1362	0.336	458	3.28	0.37	26.23	2.89	8.86	9.08	**0.46425**	0.47531				**0.47531**
	169	6	1397	0.336	470	3.93	0.37	29.51	3.63	10.62	8.13	**0.54231**	0.41507				**0.41507**
	176	7	1580	0.278	440	4.59	0.33	26.23	5.5	13.91	4.77	**0.75923**	0.26032				**0.26032**
	183	8	1605	0.278	447	4.59	0.33	26.23	5.5	13.91	4.77	**0.74741**	0.25627				**0.25627**
	235	9	1051	0.328	345			27.54	3.67		7.50		0.52202				**0.52202**
	244	10	1148	0.285	327	3.93	0.37	24.92	4.11	10.62	6.06	**0.77882**	0.44458				**0.44458**
	249	11	1038	0.285	296	3.28	0.24	26.23	4.32	13.67	6.07	**1.10829**	0.49239				**0.49239**
	250	12	1027	0.285	293	3.28	0.24	26.23	5.5	13.67	4.77	**1.12016**	0.39089	1.1	0.37	0.018	**0.40892**
	256	13	1173	0.285	334	3.28	0.37	28.2	4.81	8.86	5.86	**0.63616**	0.42072	3.0	0.71	0.030	**0.45111**
	260	14	978	0.316	309	3.93	0.33	30.16	4.77	11.91	6.32	**0.92597**	0.49162	1.0	1.00	0.047	**0.53827**
	263	15	1046	0.316	330	3.93	0.37	32.13	5.26	10.62	6.11	**0.77218**	0.44407	0.9	0.26	0.011	**0.45529**
	269	16	987	0.316	312	4.59	0.33	26.89	5.5	13.91	4.89	**1.07161**	0.37668	0.6	0.17	0.008	**0.38460**
	271	17	1086	0.316	343	3.93	0.29	32.79	4.44	13.55	7.39	**0.94890**	0.51711	0.2	0.20	0.008	**0.52552**
2	376	18	957	0.324	310	3.28	0.33	26.89	5.5	9.94	4.89	**0.76940**	0.37846	6.8	1.36	0.063	**0.44163**
	383	19	1115	0.324	361			25.58	5.5		4.65		0.30901	2.8	1.40	0.056	**0.36482**
	423	20	1090	0.241	263			26.23	5.5		4.77		0.43575	4.8	0.96	0.053	**0.48838**
	457	21	1090	0.283	308			19.67	5.5		3.58		0.27873	5.4	1.08	0.051	**0.32923**

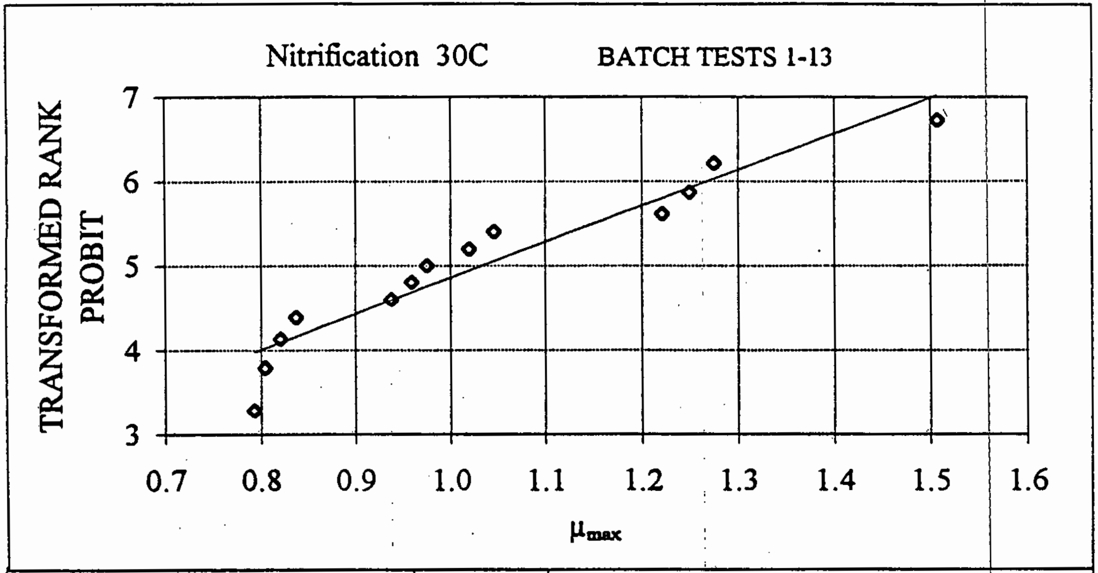
Table L.4 ANOXIC BATCH TEST OF THE UCT SYSTEM (30°C)

PERIOD NUMBER	DAY No	BATCH No	BATCH VSS mgVSS/l	ACT.FRACT. favBH	ACT.MASS mgVASS/l	NO3 RED. mgNO3-N/l	TIME hour	NO3 RED/ mgNO3/h	NO3 RED./VASS mgNO3-N/mgVASS/h	NO3 RED./VASS mgNO3-N/mgVASS*d	Nitrite mgNO2-N/l	NO2 GENER mgNO2/l/h	NO2 GENER./A mgNO2-N/mgAVSS*d	K2-NO3 RED./AVSS mgNO3-N/mgAVSS*d
9	145	1	1446	0.298	431	19.31	5.5	3.51	0.00815	0.19554				0.19554
9	150	2	1641	0.298	489	19.31	5.5	3.51	0.00718	0.17231				0.17231
9	155	3	1902	0.298	567	19.31	5.5	3.51	0.00619	0.14866				0.14866
10	159	4	1976	0.279	551	27.28	3.9	6.99	0.01269	0.30451				0.30451
10	164	5	1465	0.279	409	24.83	5.42	4.58	0.01121	0.26900				0.26900
10	169	6	1906	0.279	532	26.21	5.5	4.77	0.00896	0.21507				0.21507
1 11	176	7	2230	0.238	531	22.76	5.5	4.14	0.00780	0.18713				0.18713
11	183	8	2158	0.238	514	26.21	5.17	5.07	0.00987	0.23690				0.23690
14	221	9	1417	0.294	417	25.52	4.93	5.18	0.01243	0.29821	2.5	0.56	0.006	0.30386
14	228	10	1642	0.294	483	26.21	5.42	4.84	0.01002	0.24041	3.8	1.09	0.010	0.24993
14	235	11	1719	0.294	505	24.14	5.5	4.39	0.00868	0.20843	3.4	0.76	0.006	0.21476
15	244	12	1733	0.269	466	24.83	4.47	5.55	0.01192	0.28598				0.28598
15	249	13	1582	0.269	426	26.21	4.76	5.51	0.01294	0.31054	1.5	0.30	0.003	0.31327
15	256	14	1485	0.269	399	26.9	5.5	4.89	0.01224	0.29385				0.29385
16	260	15	1560	0.289	451	38.62	5	7.72	0.01713	0.41118	0.6	0.17	0.002	0.41276
25	376	16	1718	0.208	357	21.38	5.5	3.89	0.01088	0.26108	5.7	1.04	0.009	0.26976
25	383	17	1582	0.208	329	15.86	5.5	2.88	0.00876	0.21032	3.7	0.67	0.006	0.21644
26	390	18	1661	0.231	384	15.86	5.5	2.88	0.00752	0.18037	4.0	0.80	0.007	0.18731
26	395	19	1676	0.231	387	16.55	5.5	3.01	0.00777	0.16654	5.8	1.05	0.009	0.19560
2 28	423	20	1673	0.221	370	13.1	5.5	2.38	0.00644	0.15461	7.8	1.42	0.012	0.16681
29	430	21	1696	0.219	371	17.24	5.5	3.13	0.00844	0.20254	7.6	1.38	0.012	0.21427
30	444	22	1577	0.272	429	12.41	5.5	2.26	0.00526	0.12625	3.1	0.62	0.006	0.13191
30	452	23	1473	0.272	401	14.48	5.5	2.63	0.00657	0.15771	7.2	1.44	0.014	0.17178
31	457	24	1406	0.301	423	6.9	5.5	1.25	0.00296	0.07115	6.2	1.13	0.012	0.08269
40	564	25	1458	0.282	411	19.31	5.5	3.51	0.00854	0.20494	15.3	2.78	0.027	0.23241
3 40	569	26	1540	0.282	434	18.62	5.5	3.39	0.00780	0.18709	10.7	1.95	0.018	0.20528
40	572	27	1491	0.282	420	20.69	5.5	3.76	0.00895	0.21472	11.6	2.32	0.022	0.23713

ANOXIC BATCH TEST OF THE UCT SYSTEM (20°C)

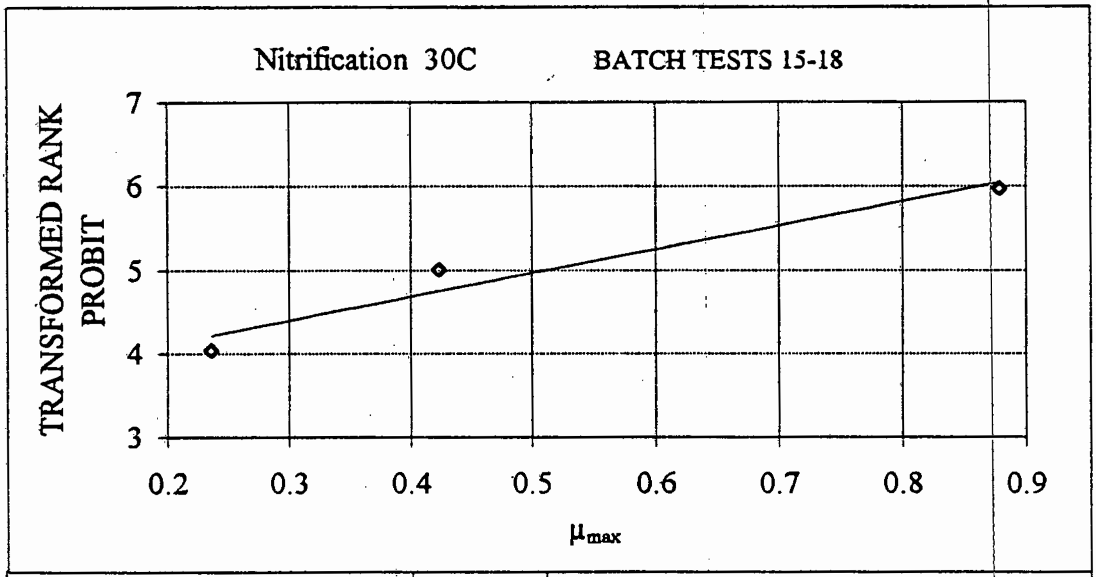
PERIOD NUMBER	DAY No	TEST NUMBER	BATCH VSS mgVSS/l	ACT.FRACT. favBH	ACT.MASS mgVASS/l	NO3 RED. mgNO3-N/l	TIME hour	NO3 RED/ mgNO3/h	NO3 RED./VASS mgNO3-N/mgAVSS/h	NO3 RED./VASS mgNO3-N/mgAVSS*d	Nitrite mgNO2-N/l	NO2 GENER mgNO2/l/h	NO2 GENER./A mgNO3-N/mgVASS*d	K2-NO3 RED./AVSS mgNO3-N/mgVASS*d
2	376	1	1727	0.249	430	24	5.5	4.36	0.01015	0.24354	2.1	0.42	0.004	0.24004
	383	2	1741	0.249	434	20	5.5	3.64	0.00839	0.20132	2.0	0.40	0.003	0.19801
	390	3	1694	0.263	446	19	5.5	3.45	0.00775	0.18609	3.0	0.55	0.005	0.18146
	395	4	1767	0.263	465	18	5.5	3.27	0.00704	0.16902	1.9	0.38	0.003	0.16592
	423	5	1856	0.261	484	13	5.5	2.36	0.00488	0.11710	5.0	1.00	0.008	0.10935
	430	6	1747	0.213	372	24	5.5	4.36	0.01173	0.28144	5.0	0.91	0.007	0.27395
	444	7	1511	0.28	423	20	5.5	3.64	0.00859	0.20628	4.0	0.73	0.007	0.19935
	450	8	1869	0.28	523	18	5.5	3.27	0.00625	0.15009	3.0	0.55	0.004	0.14589
	452	9	1783	0.28	499	20	5.5	3.64	0.00728	0.17481	3.3	0.60	0.005	0.16997
	457	10	1377	0.234	322	9	5.5	1.64	0.00508	0.12188				0.12188
3	564	11	1388	0.29	403	20	5.5	3.64	0.00903	0.21682	1.0	0.20	0.002	0.21474
	569	12	1273	0.29	369	19	5.5	3.45	0.00936	0.22458				0.22458

mean = 0,257



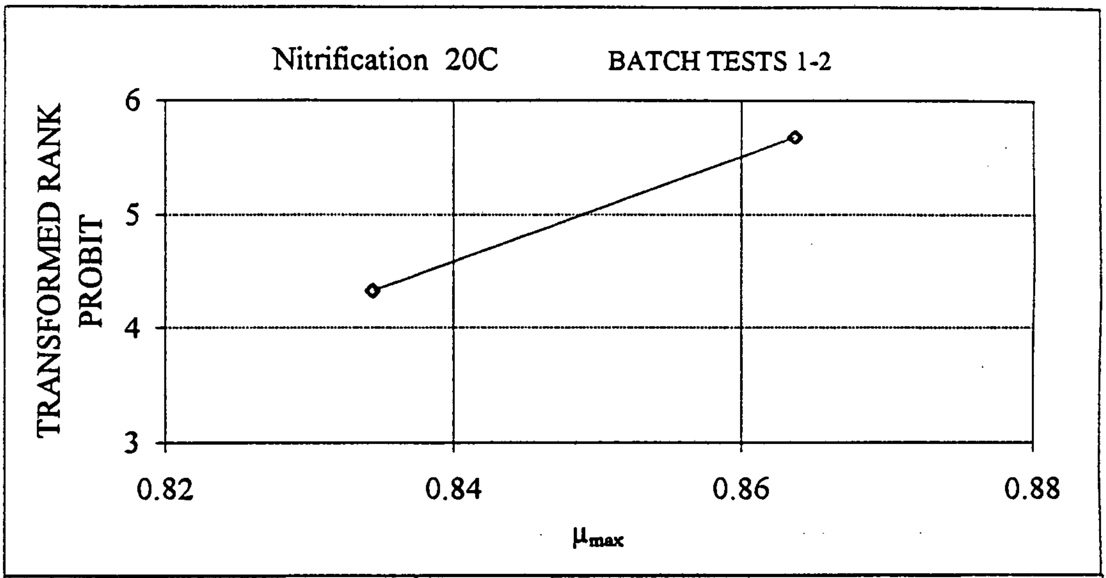
MEDIAN=	0.976		std dev. of mean = 0.064
MEAN =	1.033		95% conf. of mean = 1.033 +/- 0.125
s =	0.229		

Fig L.1 Probability distribution of the μ_{max} value in nitrification batch tests No 1-13 in MLE system from day no 1 to day no 360 (period I).



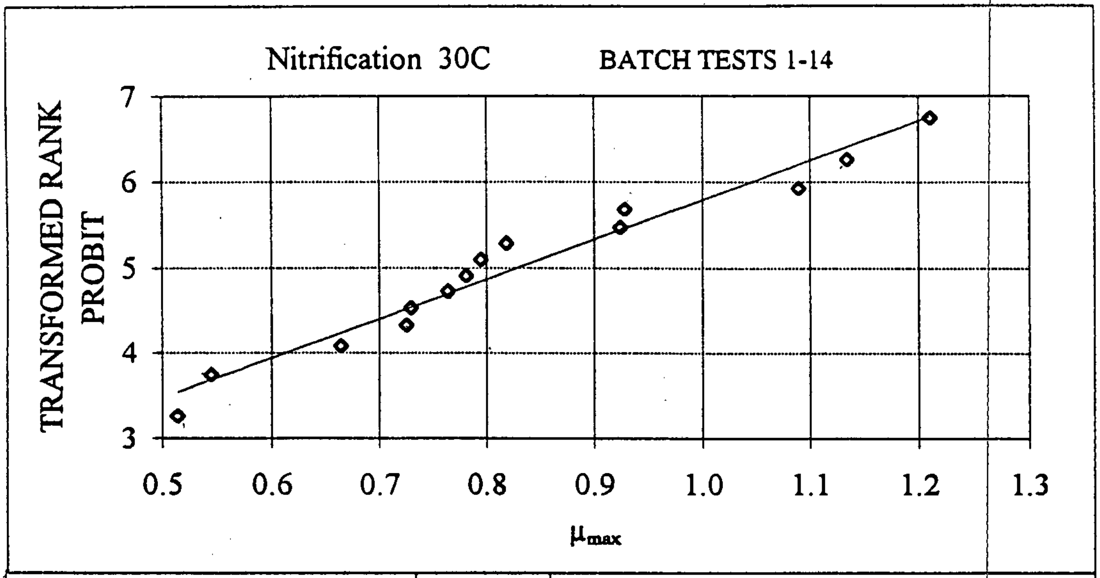
MEDIAN=	0.491		std dev. of mean = 0.060
MEAN =	0.510		95% conf. of mean = 0.510 +/- 0.117
s =	0.120		

Fig L.2 Probability distribution of the μ_{max} value in nitrification batch tests No 15-18 in MLE system from day no 361 to day no 490 (period II).



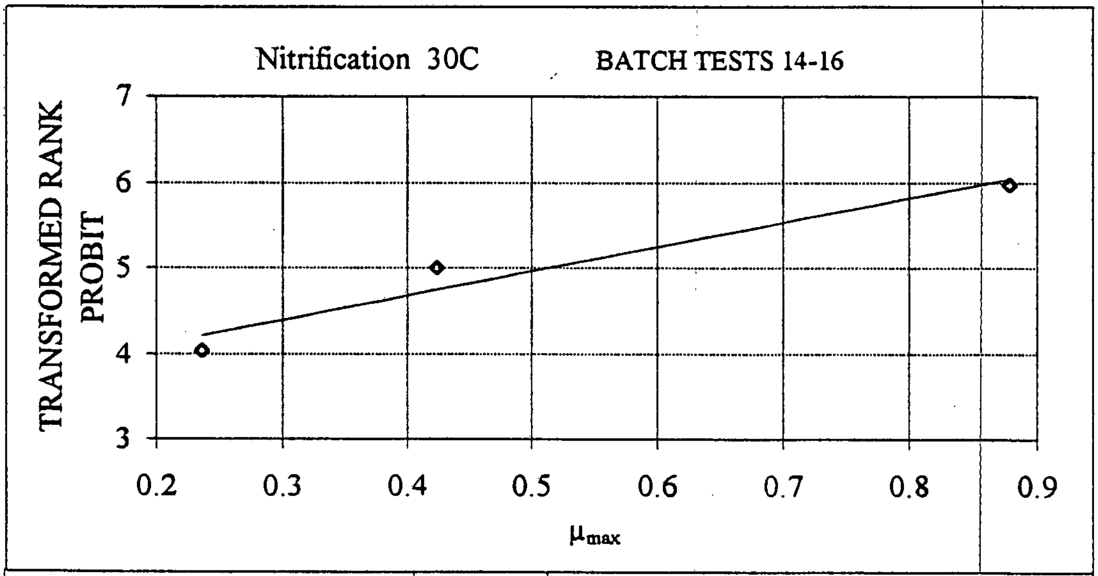
MEDIAN=	0.849		std dev. of mean = 0.015
MEAN =	0.849		95% conf. of mean = 0.849 +/- 0.029
s =	0.021		

Fig L.3 Probability distribution of the μ_{max} value in nitrification batch tests No 1-2 in MLE system from day no 361 to day no 490 (period II).



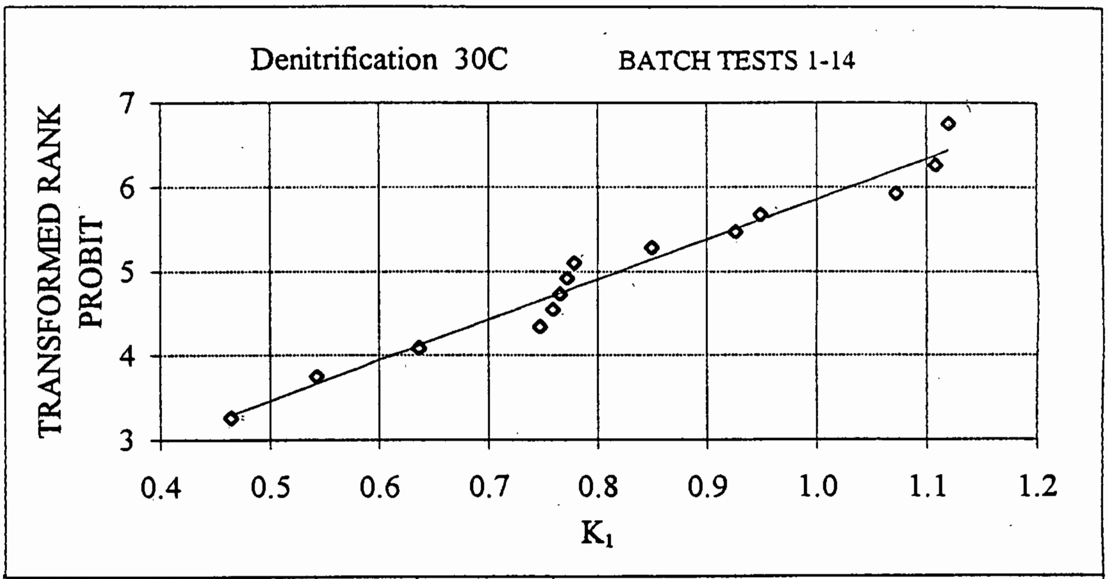
MEDIAN=	0.788		std dev. of mean = 0.054
MEAN =	0.810		95% conf. of mean = 0.810 +/- 0.106
s =	0.202		

Fig L.4 Probability distribution of the μ_{max} value in nitrification batch tests No 1-14 in UCT system from day no 1 to day no 360 (period I).



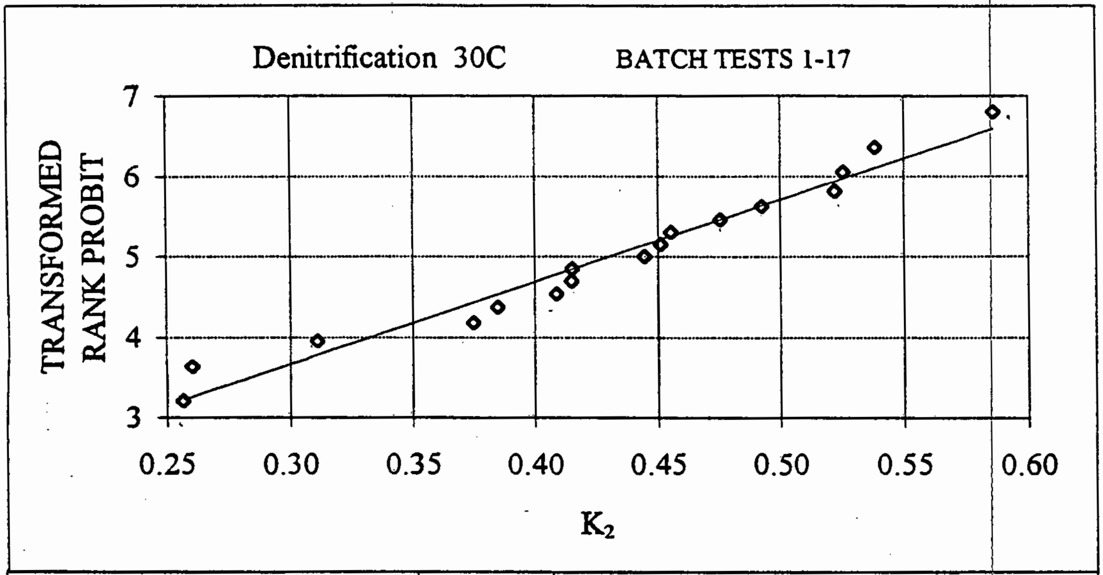
MEDIAN=	0.423		std dev. of mean = 0.191
MEAN =	0.513		95% conf. of mean = 0.513 +/- 0.374
s =	0.330		

Fig L.5 Probability distribution of the μ_{max} value in nitrification batch tests No 14-16 in UCT system from day no 361 to day no 490 (period II).



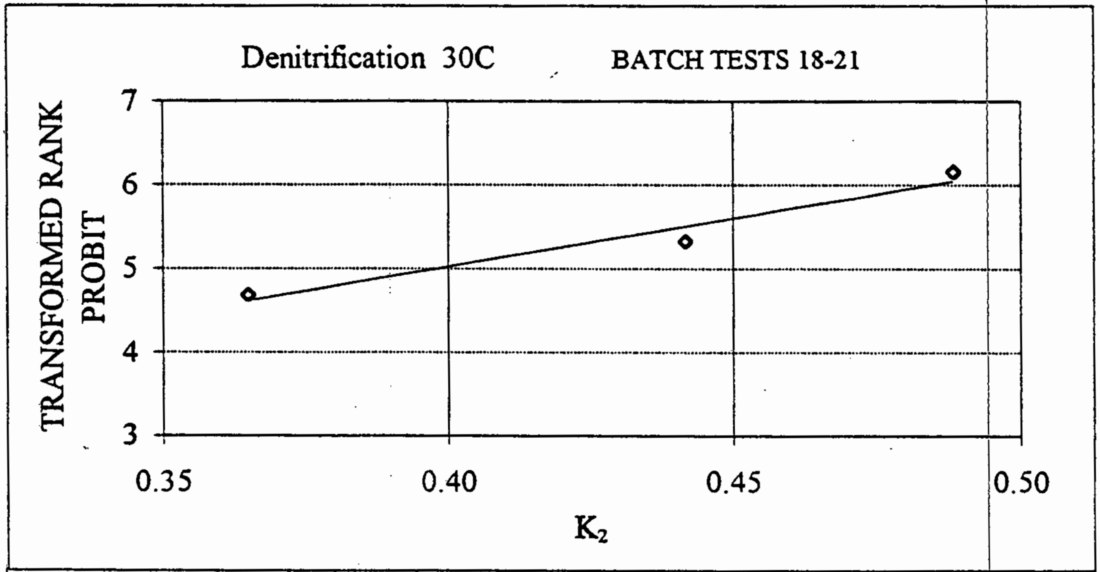
MEDIAN=	0.775		std dev. of mean = 0.053
MEAN =	0.821		95% conf. of mean = 0.821 +/- 0.105
s =	0.200		

Fig L. .6 Probability distribution of the K_l value in denitrification batch tests No 1-14 in MLE system from day no 1 to day no 360 (period I).



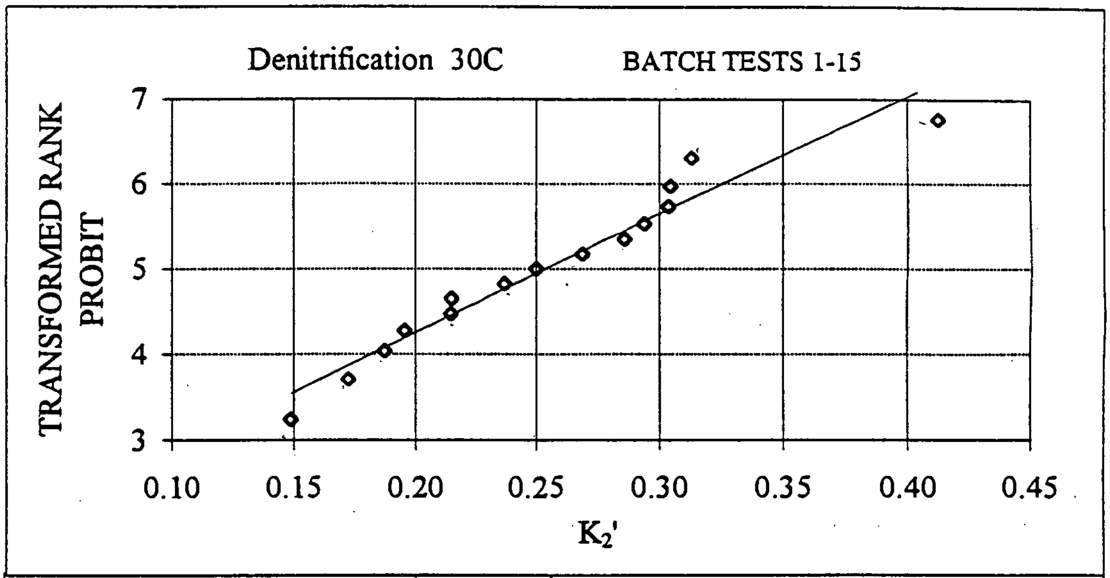
MEDIAN=	0.445		std dev. of mean = 0.023
MEAN =	0.430		95% conf. of mean = 0.430 +/- 0.044
s =	0.094		

Fig L.7 Probability distribution of the K_2 value in denitrification batch tests No 1-17 in MLE system from day no 1 to day no 360 (period I).



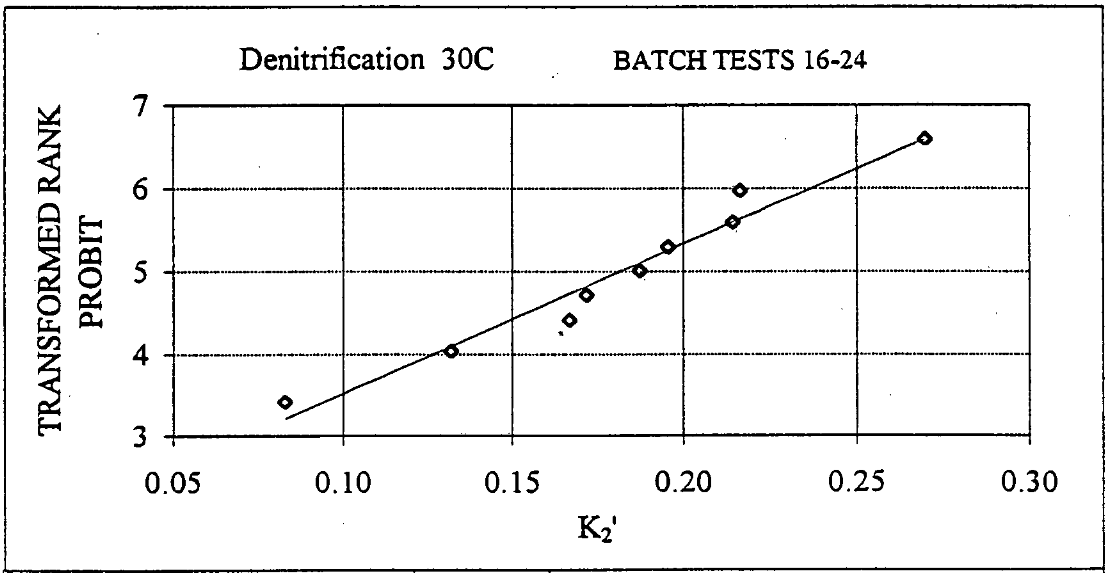
MEDIAN=	0.403		std dev. of mean = 0.036
MEAN =	0.406		95% conf. of mean = 0.406 +/- 0.071
s =	0.072		

Fig L.8 Probability distribution of the K_2 value in denitrification batch tests No 18-21 in MLE system from day no 361 to day no 490 (period II).



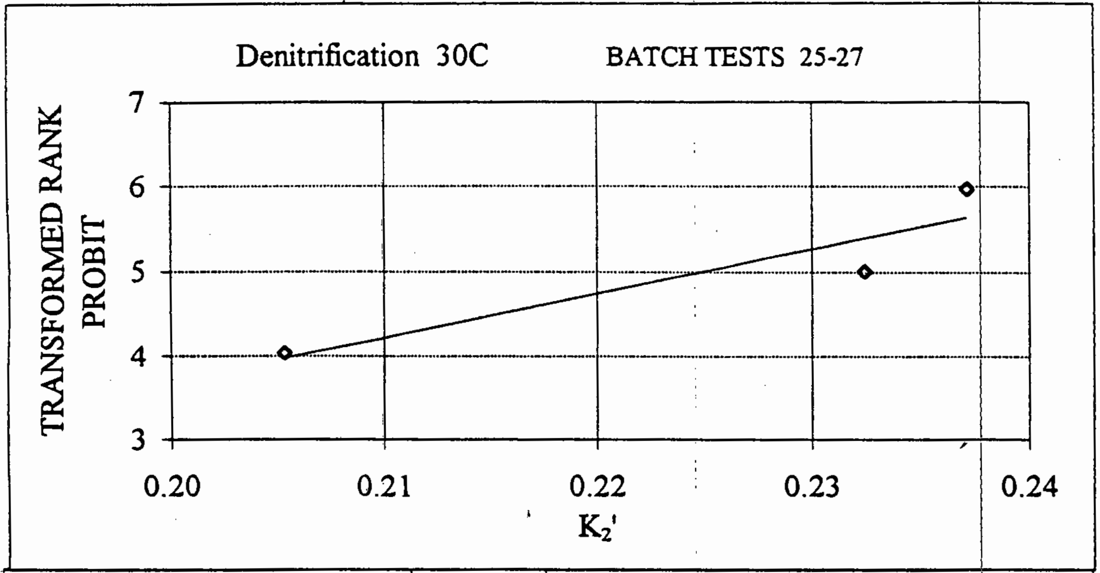
MEDIAN=	0.250		std dev. of mean = 0.018
MEAN =	0.254		95% conf. of mean = 0.254 +/- 0.035
s =	0.068		

Fig L.9 Probability distribution of the K_2' value in denitrification batch tests No 1-15 in UCT system from day no 1 to day no 360 (period I).



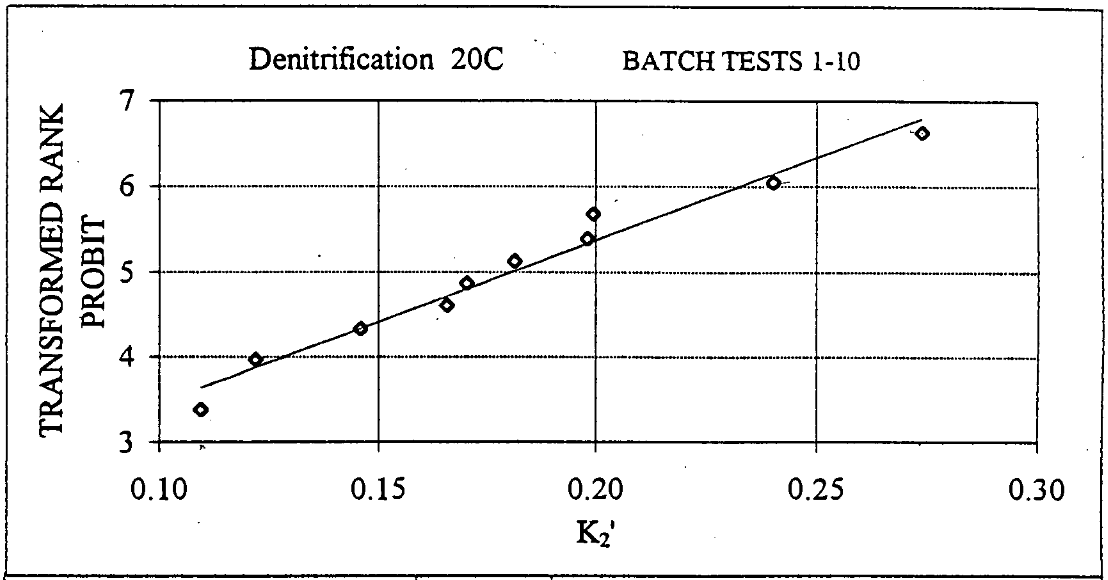
MEDIAN=	0.187		std dev. of mean = 0.018
MEAN =	0.182		95% conf. of mean = 0.182 +/- 0.035
s =	0.053		

Fig L.10 Probability distribution of the K_2' value in denitrification batch tests No 16-24 in UCT system from day no 361 to day no 490 (period II).



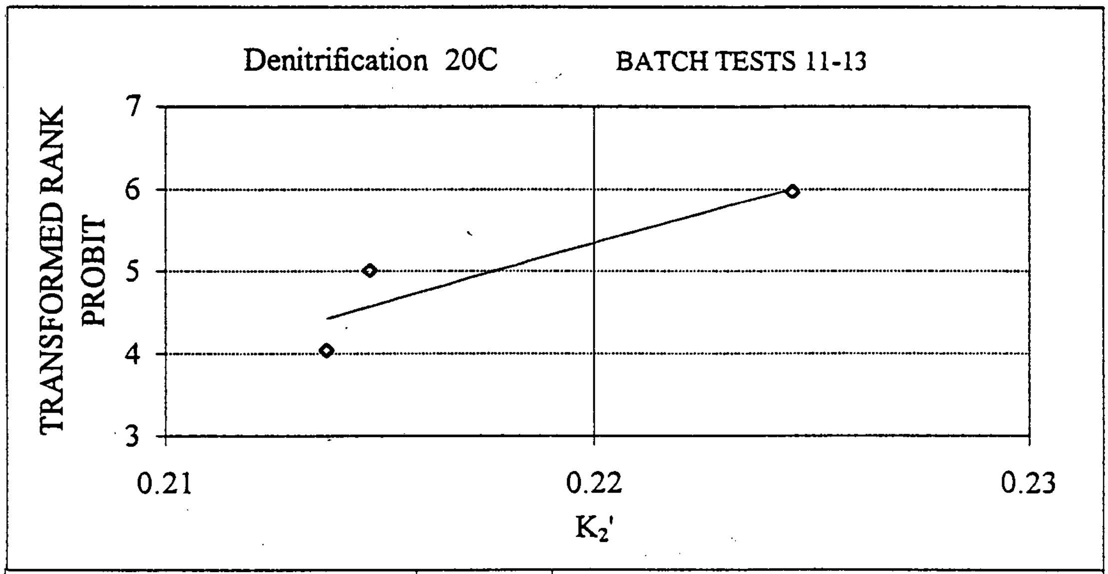
MEDIAN=	0.232		std dev. of mean =	0.010
MEAN =	0.225		95% conf. of mean = 0.225 +/-	0.019
s =	0.017			

Fig L.11 Probability distribution of the K_2' value in denitrification batch tests No 25-27 in UCT system from day no 491 to day no 582 (period III).



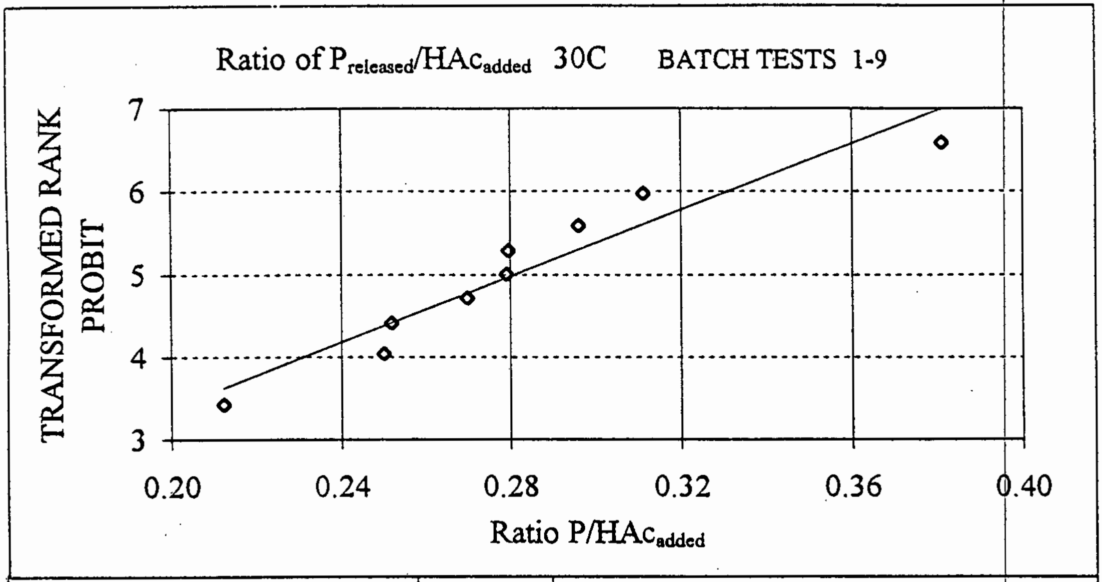
MEDIAN=	0.176		std dev. of mean =		0.016
MEAN =	0.181		95% conf. of mean =	+/-	0.031
s =	0.051				

Fig L.12 Probability distribution of the K'_2 value in denitrification batch tests No 1-10 in UCT system from day no 361 to day no 490 (period II).



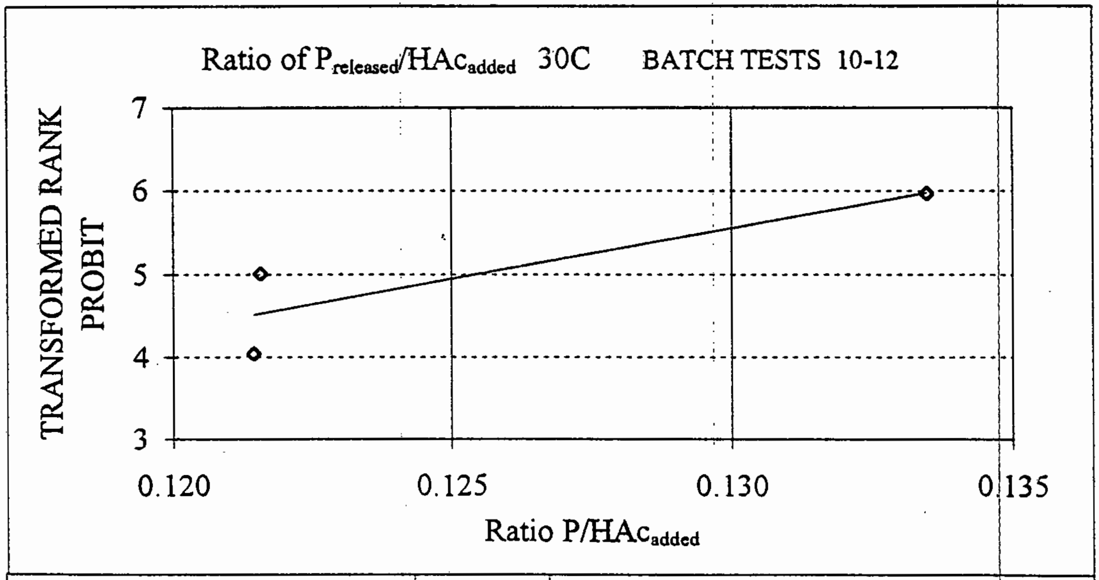
MEDIAN=	0.215		std dev. of mean =		0.003
MEAN =	0.218		95% conf. of mean =	+/-	0.007
s =	0.006				

Fig L.13 Probability distribution of the K_2' value in denitrification batch tests No 11-13 in UCT system from day no 491 to day no 582 (period III).



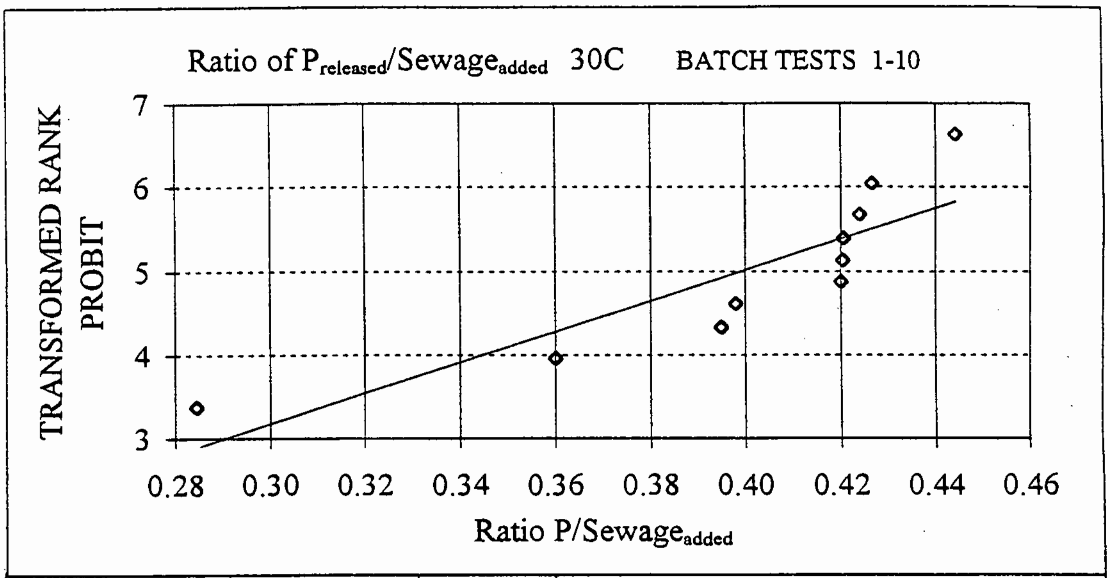
MEDIAN=	0.279		std dev. of mean = 0.016
MEAN =	0.281		95% conf. of mean = 0.281 +/- 0.031
s =	0.047		

Fig L.14 Probability distribution of the ratio of P released Acetate added in batch tests No 1-9 in UCT system from day no 1 to day no 360.



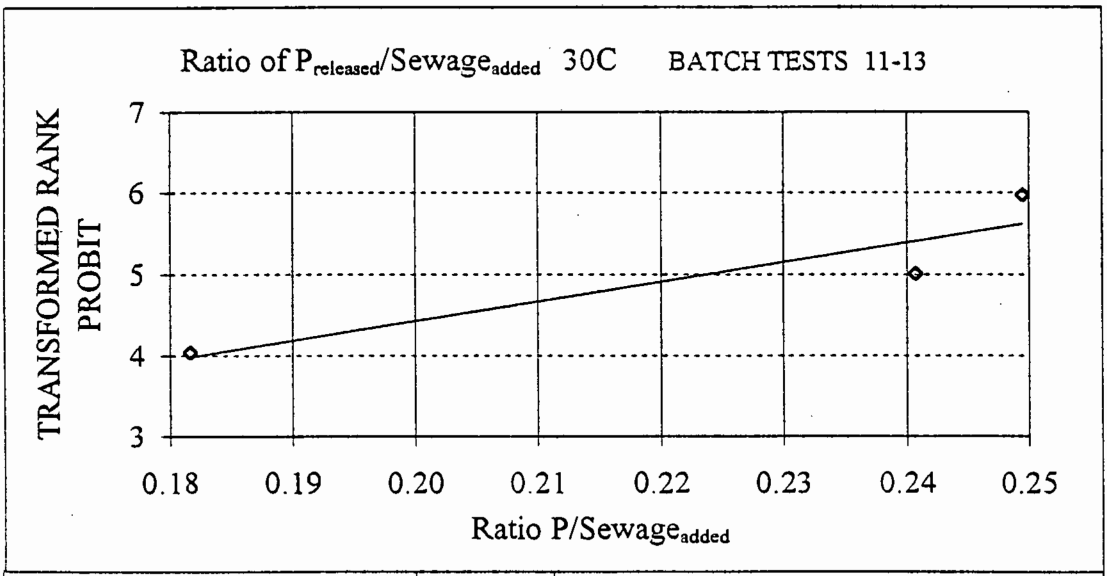
MEDIAN=	0.122		std dev. of mean = 0.004
MEAN =	0.125		95% conf. of mean = 0.125 +/- 0.008
s =	0.007		

Fig L.15 Probability distribution of the ratio of P released Acetate added in batch tests No 10-12 in UCT system from day no 361 to day no 490.



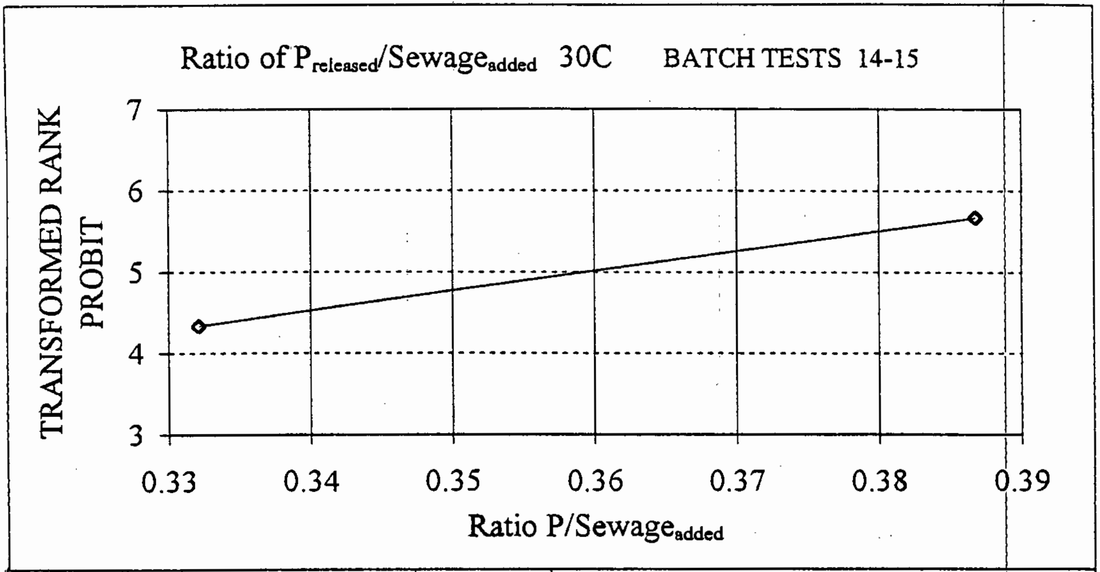
MEDIAN=	0.420		std dev. of mean = 0.015
MEAN =	0.399		95% conf. of mean = 0.399 +/- 0.029
s =	0.047		

Fig L.16 Probability distribution of the ratio of P released Raw sewage added in batch tests No 1-10 in UCT system from day no 1 to day no 360.



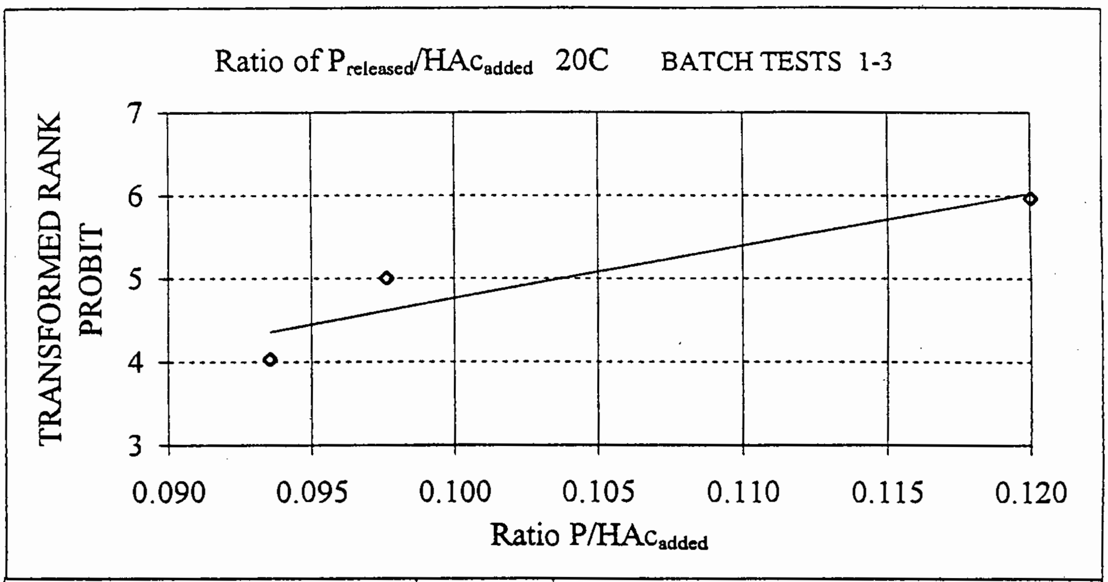
MEDIAN=	0.241		std dev. of mean = 0.021
MEAN =	0.224		95% conf. of mean = 0.224 +/- 0.042
s =	0.037		

Fig L.17 Probability distribution of the ratio of P released Raw sewage added in batch tests No 11-13 in UCT system from day no 361 to day no 490.



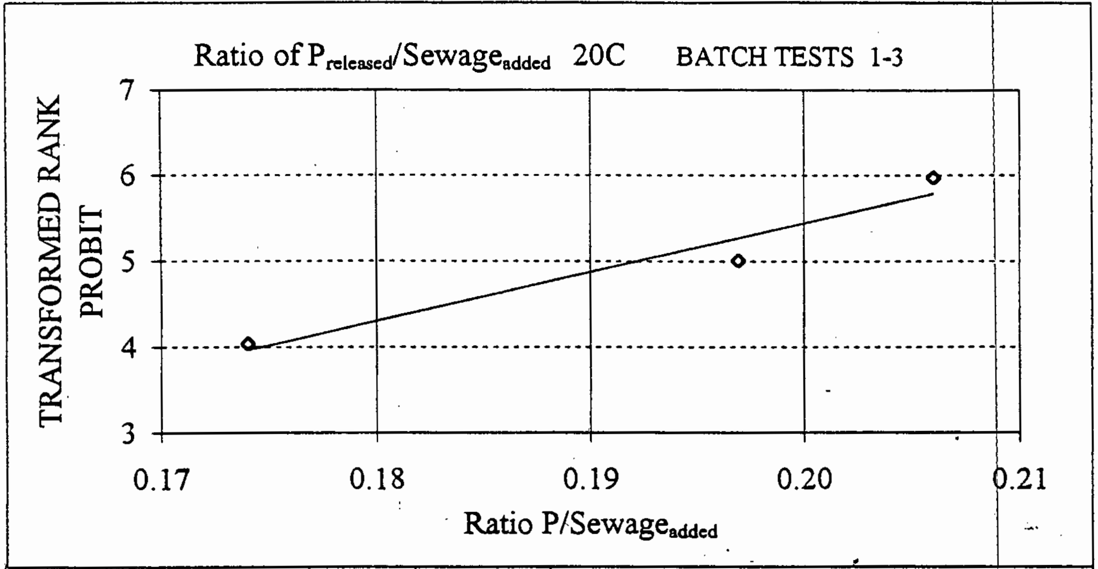
MEDIAN=	0.359		std dev. of mean = 0.027
MEAN =	0.359		95% conf. of mean = 0.359 +/- 0.054
s =	0.039		

Fig L.18 Probability distribution of the ratio of P released Raw sewage added in batch tests No 14-15 in UCT system from day no 491 to day no 582.



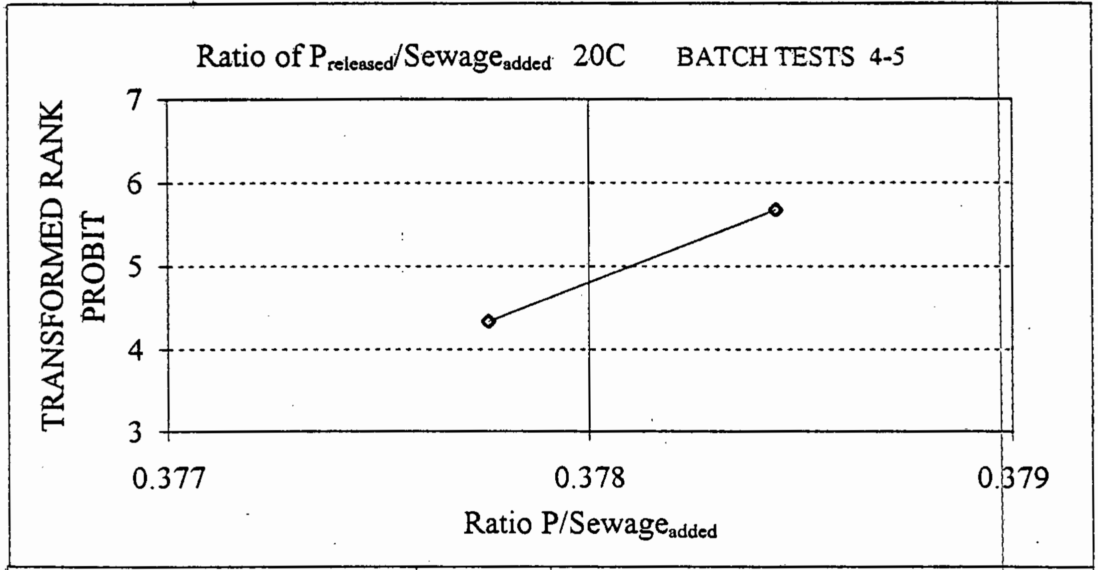
MEDIAN=	0.098		std dev. of mean = 0.008
MEAN =	0.104		95% conf. of mean = 0.104 +/- 0.016
s =	0.014		

Fig L.19 Probability distribution of the ratio of P released Acetate added in batch tests No 1-3 in UCT system from day no 361 to day no 490.



MEDIAN=	0.197		std dev. of mean = 0.010
MEAN =	0.192		95% conf. of mean = 0.192 +/- 0.019
s =	0.016		

Fig L.20 Probability distribution of the ratio of P released Raw sewage added in batch tests No 1-3 in UCT system from day no 361 to day no 490.



MEDIAN=	0.378		std dev. of mean = 0.000
MEAN =	0.378		95% conf. of mean = 0.378 +/- 0.001
s =	0.000		

Fig.L.21 Probability distribution of the ratio of P released Raw sewage added in batch tests No 4-5 in UCT system from day no 491 to day no 582.

APPENDIX M

EXPERIMENTAL MEAN VALUES AND MODEL PREDICTIONS FOR THE LONG TERM PERIOD IV (sewage batches 1 to 41).

Table M.1 Observed data and predicted values WRC (1984) during the batch of sewages 1 to 41 in the MLE system at 30°C.

Sewage batch No	Sti [mgCOD/l]	f_{up} [2]	S_{us} [mgCOD/l]	f_{us}	f_{bs}(Ubisi) [1]	Nti [mgN/l]	Obs.VSS [mg/l]	Obser. P_{REM} [mgP/l]	COD/VSS ratio	$f_{av,OHO}$
1	744	0.10	51.7	0.07	0.23	58	1593	5.4	1.48	0.42
2	747	0.05	47.5	0.06	0.23	55	1396	6.6	1.48	0.50
3	737	0.11	43.5	0.06	0.23	62	1608	6.6	1.51	0.41
4	767	0.19	38.1	0.05	0.23	78	2006	5.5	1.47	0.31
5	759	0.21	47.6	0.06	0.23	98	2100	7.2	1.40	0.28
6	692	0.11	41.2	0.06	0.23	63	1514	4.6	1.45	0.40
7	776	0.09	31.1	0.04	0.23	61	1683	6.4	1.42	0.43
8	739	0.12	38.8	0.05	0.23	73	1697	6.1	1.40	0.38
9	738	0.17	36.4	0.05	0.23	71	1868	5.3	1.48	0.33
10	807	0.17	43.7	0.05	0.23	66	2002	7.4	1.49	0.33
11	779	0.22	36.1	0.05	0.23	59	2210	7.2	1.41	0.28
12	780	0.12	39.0	0.05	0.23	71	1783	7.0	1.43	0.39
13	746	0.13	38.1	0.05	0.23	66	1738	6.1	1.49	0.38
14	768	0.17	33.2	0.04	0.23	60	1974	6.9	1.43	0.33
15	765	0.21	35.1	0.05	0.23	50	2139	7.0	1.42	0.29
16	840	0.17	34.1	0.04	0.23	68	2246	7.4	1.33	0.32
17	757	0.19	32.5	0.04	0.23	56	2123	8.7	1.33	0.29
18	746	0.18	34.4	0.05	0.23	61	1940	7.5	1.42	0.32
19	755	0.16	28.5	0.04	0.23	68	1957	6.6	1.35	0.33
20	752	0.20	32.2	0.04	0.23	68	2018	7.2	1.47	0.31
21	767	0.23	32.8	0.04	0.23	63	2130	7.7	1.56	0.28
22	710	0.21	35.6	0.05	0.23	84	1928	6.1	1.50	0.29
23	696	0.21	39.3	0.06	0.23	71	1855	4.4	1.52	0.30
24	695	0.15	35.7	0.05	0.23	63	1695	5.2	1.41	0.35
25	676	0.18	43.4	0.06	0.23	65	1683	3.1	1.57	0.33
26	704	0.17	39.4	0.06	0.23	82	1786	4.5	1.46	0.33
27	653	0.25	33.9	0.05	0.23	58	1890	3.9	1.49	0.26
28	682	0.28	35.0	0.05	0.23	68	2039	4.5	1.53	0.24
29	682	0.22	30.9	0.05	0.23	72	1860	4.3	1.56	0.28
30	692	0.23	30.6	0.04	0.23	85	1918	4.9	1.52	0.28
31	639	0.22	34.0	0.05	0.23	78	1760	3.4	1.49	0.28

0,155 ±0,047

0,203 ± 0,045

0,045 ± 0,031

32	665	0.19	33.4	0.05	0.23	77	1662	4.6	1.66	0.33
33	721	0.14	29.7	0.04	0.23	92	1661	5.2	1.65	0.38
34	671	0.21 ✓	28.3	0.04	0.23	62	1748	4.7	1.63	0.31
35	647	0.13 ✓	31.1	0.05	0.23	68	1530	4.0	1.58	0.36
36	783	0.03 ✓	35.0	0.04	0.23	59	1397	4.8	1.34	0.54
37	697	0.06 ✓	35.9	0.05	0.23	81	1456	3.0	1.16	0.46
38	820	0.02	38.9	0.05	0.23	59	1443	4.7	1.07	0.56
39	685	0.02	34.4	0.05	0.23	72	1170	5.0	0.88	0.56
40	690	0.04 ✓	36.4	0.05	0.23	72	1289	4.1	1.02	0.52
41	617	0.10 ✓	36.3	0.06	0.23	69	1409	2.1	1.15	0.38
AVERAGE	727	0.15	36.4	0.05	0.23	69	1778	5.5	1.42	0.36

1. f_{bs} value is proportion to S_{bi} value.

2. f_{up} value to match predicted VSS concentration (Calculated from MXv devided by equivalent system volume 20*l* - see Table 3.1) to that observedin aerobic reactor.

↓

(A1) 0,055 ± 0,066

II

9,1927
9055

III

9118.7
9033

32	665	0.11	35.1	0.05	0.23	77	1535	11.4	9.2	1.47	0.335	0.120	0.27
33	721	0.09	29.7	0.04	0.23	92	1590	14.8	8.4	1.42	0.335	0.162	0.15
34	671	0.11	30.6	0.05	0.23	62	1654	14.0	11.2	1.38	0.308	0.154	0.27
35	647	0.09	31.1	0.05	0.23	68	1516	13.1	10.7	1.42	0.335	0.160	0.28
36	783	0.08	46.4	0.06	0.23	59	1735	16.2	13.3	1.53	0.346	0.177	0.29
37	697	0.13	46.8	0.07	0.23	81	1780	14.3	9.3	1.38	0.285	0.144	0.28
38	820	0.08	36.3	0.04	0.23	59	1945	17.7	9.7	1.31	0.333	0.174	0.15
39	685	0.14	29.2	0.04	0.23	72	1805	14.6	14.0	1.39	0.278	0.145	0.35
40	690	0.14	32.0	0.05	0.23	72	1790	14.6	12.2	1.45	0.282	0.147	0.29
41	617	0.17	41.1	0.07	0.23	69	1688	12.8	8.6	1.46	0.255	0.133	0.20
AVERAGE	727	0.15	38.5	0.05	0.23	69	1894	14.6	11.4	1.45	0.284	0.135	0.256

1. f_{bs} value is proportion to S_{bi} value.
2. Predicted P removal for $f_{XBG,P} = 0.38$.
3. $f_{XBG,P}$ value to match predicted P removal to that observed.
4. f_{up} value to match predicted VSS concentration (Calculated from MXv devided by equivalent system volume 20*l* - see Table 3.1) to that observed

Table M.2 Observed data and predicted values Wentzel *et al.*, (1990) during the batch of sewages 1 to 41 in the UCT system at 30°C.

Sewage batch No	Sti [mgCOD/l]	f_{up} [4]	S_{us} [mgCOD/l]	f_{us}	f_{bs}(Ubisi) [1]	Nti [mgN/l]	Obs.VSS [mg/l]	Model P_{REM} [2] [mgP/l]	Obser. P_{REM} [mgP/l]	COD/VSS ratio	$f_{av,OHO}$	$f_{av,PAO}$	$f_{XBG,P}$ [3]
1	744	0.08	43.2	0.06	0.23	58	1663	15.1	11.1	1.48	0.346	0.171	0.24
2	747	0.04	48.7	0.07	0.23	55	1507	14.9	10.8	1.48	0.397	0.192	0.24
3	737	0.03	47.1	0.06	0.23	62	1462	14.3	12.1	1.66	0.419	0.195	0.30
4	767	0.08	47.4	0.06	0.23	78	1654	15.0	10.4	1.75	0.362	0.173	0.22
5	759	0.10	50.0	0.07	0.23	98	1672	9.9	10.9	1.49	0.371	0.081	0.45
6	692	0.11	53.6	0.08	0.23	63	1631	13.5	10.8	1.47	0.314	0.150	0.27
7	776	0.12	34.7	0.04	0.23	61	1916	16.3	11.8	1.45	0.302	0.154	0.23
8	739	0.10	39.2	0.05	0.23	73	1780	15.2	12.6	1.37	0.318	0.156	0.28
9	738	0.12	39.1	0.05	0.23	71	1854	15.6	11.0	1.43	0.298	0.155	0.23
10	807	0.14	42.5	0.05	0.23	66	2105	17.3	15.7	1.44	0.279	0.149	0.33
11	779	0.19	37.8	0.05	0.23	59	2216	16.9	13.7	1.43	0.238	0.132	0.27
12	780	0.13	36.5	0.05	0.23	71	2050	16.4	15.9	1.36	0.268	0.146	0.36
13	746	0.17	39.0	0.05	0.23	66	2042	15.7	13.1	1.45	0.256	0.134	0.29
14	768	0.13	37.2	0.05	0.23	60	1962	16.0	13.9	1.47	0.294	0.149	0.31
15	765	0.15	33.9	0.04	0.23	50	2064	16.7	14.1	1.42	0.269	0.146	0.30
16	840	0.12	36.9	0.04	0.23	68	2166	18.4	13.3	1.32	0.289	0.155	0.23
17	757	0.16	29.9	0.04	0.23	56	2162	16.7	14.4	1.30	0.252	0.136	0.30
18	746	0.19	40.4	0.05	0.23	61	2205	16.4	13.6	1.35	0.229	0.128	0.28
19	755	0.17	32.9	0.04	0.23	68	2180	16.7	13.5	1.31	0.243	0.133	0.27
20	752	0.18	37.2	0.05	0.23	68	2135	16.3	13.8	1.38	0.241	0.132	0.29
21	767	0.25	38.6	0.05	0.23	63	2410	16.9	14.0	1.49	0.199	0.118	0.28
22	710	0.25	40.1	0.06	0.23	84	2205	14.3	12.9	1.47	0.204	0.101	0.32
23	696	0.23	38.2	0.05	0.23	71	2020	13.1	9.2	1.53	0.227	0.100	0.19
24	695	0.16	36.2	0.05	0.23	63	1882	14.5	10.5	1.39	0.261	0.132	0.22
25	676	0.24	42.4	0.06	0.23	65	2011	14.2	8.6	1.51	0.208	0.114	0.15
26	704	0.22	43.2	0.06	0.23	82	2082	12.6	8.2	1.43	0.231	0.087	0.15
27	653	0.23	36.7	0.06	0.23	58	1937	13.5	8.7	1.49	0.217	0.114	0.16
28	682	0.24	36.3	0.05	0.23	68	2012	13.0	8.4	1.55	0.221	0.100	0.15
29	682	0.24	33.9	0.05	0.23	72	2081	12.8	10.2	1.46	0.219	0.088	0.25
30	692	0.20	34.1	0.05	0.23	85	1873	10.0	7.9	1.54	0.272	0.066	0.21
31	639	0.19	34.7	0.05	0.23	78	1668	6.5	3.6	1.53	0.301	0.026	0.00

I

fup
0,141
1000

II