

ACTIVATED SLUDGE SYSTEM SIMULATION PROGRAMS

**NITRIFICATION
AND
NITRIFICATION/DENITRIFICATION SYSTEMS**

VERSION 1.0

by

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FOREWORD

Since the early 1970s significant developments have taken place in activated sludge technology, particularly in the biological nutrient (nitrogen and phosphorus) removal field. Today single sludge systems are available that will remove carbonaceous material, nitrogen and phosphorus, mediated by biological processes. Progressively, as objectives have expanded from carbonaceous material removal only, to include nitrification, denitrification and biological excess phosphorus removal, and as the effluent quality requirements have become more stringent, so activated sludge systems have become more complex, requiring multi-reactor configurations comprising aerated and unaerated reactors and inter-reactor recirculation flows. Concomitantly the number of biological processes influencing the effluent quality, and the number of compounds involved in these processes, have increased. With such complexity the performance of any proposed system can be determined only by experimentation or by a mathematical model that simulates the response accurately.

The Water Research Commission (WRC) has sponsored research into the activated sludge system at the University of Cape Town (UCT) since 1973. The research has resulted in the formulation of a comprehensive mathematical model for describing the behaviour of single sludge activated sludge systems incorporating aerated and unaerated reactors. However, the model does not yet include biological excess phosphorus removal; this aspect is being actively pursued.

The model has found application in the development of optimal design procedures, identification and solution of operational problems, and development of plant control strategies. The value of the model has been recognized by the International Association on Water Pollution Research and Control (IAWPRC); their Task Group on Modelling of Wastewater Treatment suggested some modifications to the UCT model and made a considerable contribution in the method for presenting this and other biological models.

The WRC requested the authors to develop user-friendly interactive computer programs of both the UCT and IAWPRC model versions, suitable for personal computers. By sponsoring development of the programs the Commission aims to facilitate transfer of technology to the end user, persons involved in the design, management and operation of activated sludge systems.

P E Odendaal

Executive Director
Water Research Commission

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- Dr L H Lötter, Principal Scientific Officer, Johannesburg City Council, for her invaluable editorial comments on the manual.
- Mr Taliep Lakay, laboratory assistant, for his invaluable help in running the experimental units and laboratory.
- Mrs Heather Bain, clerical assistant, for so cheerfully typing and retyping this document.
- The numerous postgraduate students who over the years have passed through the laboratory; the model is a synthesis of their ideas and research effort.

SCOPE OF MODELS

The *Activated Sludge System Simulation Programs - Nitrification and nitrification/denitrification systems*, includes two programs for simulation of single sludge activated sludge systems incorporating carbonaceous energy removal, nitrification and denitrification. The two programs, UCTOLD and IAWPRC, are based on what are, arguably, the two most up to date mechanistic models of the activated sludge system. UCTOLD is based on the model developed by the research group at the University of Cape Town (UCT) over the past fifteen years. IAWPRC is based on a model proposed by a Task Group of the International Association on Water Pollution Research and Control (IAWPRC) incorporating some modifications by the UCT group. With appropriate calibration the two models give predictions that are closely equal for most situations.

Both programs presented with this manual can be applied to predict steady state and cyclic dynamic response behaviour for a range of system reactor configurations, operating conditions and waste flow and loads:

- The programs can be used to predict response of single or in-series *completely mixed* reactor systems with or without inter-reactor recycles (recycles opposite to the direction of flow through the system) over the range of temperatures from 14 to 22°C. The reactors may be aerated or unaerated and the sludge age may vary from 2 to 30 days. Waste flow and/or loads may be steady state or cyclic.
- The programs predict the response of the following compounds with their various contributory components; chemical oxygen demand (COD), oxygen, volatile suspended solids (as COD), nitrogen and alkalinity.

Application of the programs has some limitations:

- The programs cannot be used to predict the behaviour of systems in which within a single reactor a part is anoxic and a part aerobic.
- The programs do not provide for prediction of biological excess phosphorus (P) removal. Prediction of P removal behaviour requires a substantial increase in the number of processes and compounds to account for the response of the P removal organisms (which can constitute up to 40 percent of the organism mass in P removal systems treating municipal effluents). Despite this constraint experience has shown that the models give reasonable prediction of the sludge masses, nitrification/denitrification, oxygen utilization and effluent COD and nitrogen of single sludge biological excess P removal systems. A separate model to include biological excess P removal is under development.
- The programs have been developed from observations made on systems treating municipal waste flows at laboratory, pilot and full scale. Default values assigned to the constants in the programs, in particular to wastewater characteristics and organism growth rates, are approximate averages observed when treating South African municipal waste flows for temperatures in the range 14 to 22°C. Application of the programs to systems treating municipal waste flows in other countries may require that some of the constants have to be redetermined - the characteristics of such waste flows may consistently differ from those in South Africa, and/or temperatures may fall outside the 14 to 22°C range. In this manual the user is given some direction as to the situations under which the constants may change. Also, procedures for independent determination of some of these constants are briefly set out. (The programs have not been tested to simulate systems treating industrial waste flows).

NOTICES

- The views expressed in this manual are those of the authors and do not necessarily constitute endorsement or recommendation by the Water Research Commission.
- The contents of this manual are subject to change without notice.
- All efforts have been made to ensure the accuracy of the programs and the contents of this manual. Should users find any errors the Water Research Commission will greatly appreciate being informed.
- The above notwithstanding, the Water Research Commission and the authors can assume no responsibility for any errors in the programs or the consequences of such errors.

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- **IMPORTANT** – The computer programs presented with this user manual are a codification and rationalization of research investigation into kinetic behaviour of the activated sludge system, in particular over the last 15 years. These computer programs are very easy and simple to use by following this user manual, even for those who do not have much experience and knowledge with the activated sludge system. However, for those without considerable knowledge and experience in activated sludge behaviour, these programs should not be regarded as replacement for knowledge and experience. It is strongly recommended that a working knowledge and sound familiarity is held by the user on the research embodied in the models incorporated in the programs. Only with such knowledge does the user have the insight and critical ability to determine the reasonableness of the computer output for the particular application and so ensure that the programs are being appropriately used and their output meaningfully interpreted. A list of references outlining the research on which the models are based is given at the back of this user guide.

DISCLAIMER

While it is believed that the programs are based on the best available knowledge and that considerable effort has been expended in eliminating errors, users are warned that in the application of the programs the results obtained are the sole responsibility of the user.

TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	(iii)
ACKNOWLEDGEMENTS	(iv)
SCOPE OF MODELS	(v)
NOTICES	(vi)
DISCLAIMER	(vi)
TABLE OF CONTENTS	(vii)
LIST OF SYMBOLS	(x)
CHAPTER 1: INTRODUCTION	1. 1
BACKGROUND	1. 1
COMPUTER PROGRAMS	1. 2
ABOUT THIS MANUAL	1. 2
CHAPTER 2: MODELS AND WASTEWATER CHARACTERISTICS	2. 1
INTRODUCTION	2. 1
UNIVERSITY OF CAPE TOWN MODEL (UCTOLD)	2. 1
Steady state aerobic model	2. 1
Dynamic model	2. 2
UCTOLD process model description	2. 5
UCTOLD system model	2. 9
UCTOLD system model solution	2. 9
INTERNATIONAL ASSOCIATION ON WATER POLLUTION RESEARCH AND CONTROL MODEL (IAWPRC)	2.10
IAWPRC model origins	2.10
IAWPRC process model description	2.11
IAWPRC system model	2.14
IAWPRC system model solution	2.14
INFLUENT WASTEWATER CHARACTERISTICS	2.15
Carbonaceous material	2.15
Nitrogenous material	2.17
CHAPTER 3: INSTALLING THE PROGRAMS	3. 1
THE SUPPLIED DISKS	3. 1
BACK-UP COPIES	3. 1
FILES ON THE DISTRIBUTION DISK	3. 2
SYSTEM REQUIREMENTS	3. 2
SETTING UP ON A FLOPPY DISK SYSTEM	3. 3
SETTING UP ON A HARD DISK SYSTEM	3. 4
CHAPTER 4: RUNNING THE PROGRAMS	4. 1
STARTING PROGRAM EXECUTION	4. 1
Floppy disk system	4. 1
Hard disk system	4. 2
INTERACTIVE DATA INPUT BY USER	4. 2
UNITS FOR REACTOR VOLUMES AND FLOW RATES	4. 3
THE MAIN MENU	4. 4

INFLUENT DATA	4. 6
Entering steady state influent data	4. 7
Entering a diurnal influent pattern	4.10
Retrieving a diurnal pattern from disk	4.16
PLANT CONFIGURATION	4.21
Single reactor configuration	4.22
Multiple reactor configuration	4.25
OPERATING PARAMETERS	4.31
STEADY STATE SIMULATION	4.36
DIURNAL SIMULATION	4.39
Simulate	4.40
Hardcopy of results	4.42
Graphical output	4.44
Check/change screen/printed output	4.50
Check/change integration parameters	4.53
Store data on disk	4.56
Check/change wastage pattern	4.59
KINETIC CONSTANTS	4.61
STOICHIOMETRY	4.64
 CHAPTER 5: APPLICATION AND VERIFICATION	 5. 1
INTRODUCTION	5. 1
AEROBIC COMPLETELY MIXED REACTOR SYSTEMS	5. 3
Constants flow and load	5. 3
Cyclic flow and load	5. 9
AEROBIC BATCH TESTS	5.19
Batch test with nitrification	5.20
Batch test with nitrification inhibition	5.23
ANOXIC/AEROBIC SYSTEMS - PLUGFLOW ANOXIC REACTORS	5.25
ANOXIC/AEROBIC SYSTEMS - BATCH DIGESTION	5.28
ANOXIC/AEROBIC SYSTEMS - COMPLETELY MIXED REACTORS	5.28
Constant flow and load	5.28
Cyclic flow and load	5.33
CONTACT-STABILIZATION SYSTEM	5.38
Constant flow and load	5.38
Cyclic flow and load	5.42
CONCLUSIONS	5.47
 CHAPTER 6: DETERMINATION OF MODEL CONSTANTS	 6. 1
INTRODUCTION	6. 1
INFLUENT COD CHARACTERISTICS	6. 1
Determination of readily biodegradable COD (RBCOD)	6. 2
Determination of unbiodegradable soluble and particulate COD	6. 7
INFLUENT TKN CHARACTERISTICS	6.12
UPON	6.14
USON	6.14
BSON	6.15
BPON	6.15
Revised estimates for organic N fractions	6.15
KINETIC AND STOICHIOMETRIC CONSTANTS	6.16
Measurement of $\hat{\mu}_H$ and $\hat{\mu}_A$	6.17
 REFERENCES	 R. 1

APPENDIX A: RETRIEVAL OF DIURNAL RESPONSE DATA	
INTRODUCTION	A. 1
PARAMETERS FOR UCTOLD	A. 1
PARAMETERS FOR IAWPRC	A. 1
STRUCTURE OF DATA FILE	A. 2
PROGRAM RETRIEVE FOR RETRIEVING DATA	A. 3
LISTING OF PROGRAM RETRIEVE	A. 4
APPENDIX B: MODEL REPRESENTATION IN MATRIX FORMAT	
INTRODUCTION	B. 1
MATHEMATICAL DESCRIPTION OF A MODEL	B. 1
MATRIX METHOD FOR MODEL REPRESENTATION	B. 1
Setting up the matrix (process model)	B. 1
System model	B. 3
Switching functions	B. 4
APPENDIX C: REACTOR NUMBERING CONVENTION	
1. 4-STAGE BARDENPHO SYSTEM	C. 1
2. MODIFIED UCT SYSTEM	C. 1
3. CONTACT STABILIZATION SYSTEM	C. 2
4. JOHANNESBURG (JHB) SYSTEM	C. 3
5. INADMISSIBLE CONFIGURATIONS	C. 4
	C. 5
APPENDIX D: SYMBOL SYSTEM	
	D. 1

LIST OF SYMBOLS

The symbols for the various compounds, kinetic constants, stoichiometric constants and switching function parameters used in UCTOLD and IAWPRC are listed in this section. Details of the symbol system are given in Appendix D.

PARAMETERS FOR UCTOLD

The following compounds, kinetic constants, stoichiometric constants and switching function parameters are utilized in the model UCTOLD.

Compounds

Z_{BH}	- biological (active) heterotrophic mass
Z_E	- endogenous mass
Z_{BA}	- biological (active) autotrophic mass
S_{ads}	- adsorbed slowly biodegradable substrate
S_{enm}	- enmeshed slowly biodegradable substrate
Z_I	- inert mass
N_{obp}	- particulate biodegradable organic nitrogen
S_{bs}	- soluble readily biodegradable substrate
N_a	- ammonia nitrogen
N_{obs}	- soluble biodegradable organic nitrogen
N_{o3}	- nitrate nitrogen
Alk	- $H_2CO_3^*$ alkalinity
S_{us}	- soluble unbiodegradable substrate
O	- dissolved oxygen

Kinetic parameters

$\hat{\mu}_H$	- maximum specific growth rate of the heterotrophs when utilizing soluble readily biodegradable COD
K_{SH}	- half-saturation coefficient for heterotroph growth when utilizing soluble readily biodegradable COD
K_{MP}	- maximum specific growth rate of the heterotrophs when utilizing adsorbed particulate slowly biodegradable COD
K_{SP}	- half-saturation coefficient for heterotroph growth when utilizing adsorbed particulate slowly biodegradable COD
b_H	- heterotrophic organism specific death rate
K_A	- slowly biodegradable COD adsorption rate
K_R	- conversion rate of soluble organic nitrogen to free and saline ammonia
η_G	- correction factor for anoxic heterotrophic growth
$\hat{\mu}_A$	- maximum specific growth rate of the autotrophs (nitrifiers)
K_{SA}	- half-saturation coefficient for autotroph growth on ammonia
b_A	- autotrophic organism specific death rate

Stoichiometric parameters

Y_{ZH}	- heterotroph yield in COD units
Y_Z	- autotroph yield in COD units
f_{MA}	- maximum ratio of adsorbed substrate to heterotroph mass
f_E	- inert fraction of the active organism mass
$f_{ZB, N}$	- fraction of biological (active) mass which is nitrogen
$f_{ZE, N}$	- fraction of endogenous/inert mass which is nitrogen

Switching function parameters

K_{OH}	- switching constant for oxygen-limited heterotroph growth (switch from aerobic to anoxic growth)
K_{OA}	- switching constant for oxygen-limited autotrophic growth
K_{HA}	- switching constant for ammonia-limited aerobic heterotroph growth
K_{NO}	- switching constant for nitrate-limited anoxic heterotroph growth

PARAMETERS FOR IAWPRC

The following compounds, kinetic constants, stoichiometric constants and switching function parameters are utilized in the model IAWPRC.

Compounds

Z_{BH}	- biological (active) heterotrophic mass
Z_E	- endogenous mass
Z_{BA}	- biological (active) autotrophic biomass
S_{enm}	- enmeshed slowly biodegradable substrate
Z_I	- inert mass
N_{obp}	- particulate biodegradable organic nitrogen
S_{bs}	- soluble readily biodegradable substrate
N_a	- ammonia nitrogen
N_{obs}	- soluble biodegradable organic nitrogen
N_{o3}	- nitrate nitrogen
Alk	- $H_2CO_3^*$ alkalinity
S_{us}	- soluble unbiodegradable substrate
O	- dissolved oxygen

Kinetic parameters

$\hat{\mu}_H$	- maximum specific growth rate of the heterotrophs
K_{SH}	- half-saturation coefficient for heterotroph growth
K_H	- maximum specific hydrolysis rate
K_X	- half-saturation coefficient for hydrolysis
b_H	- heterotrophic organism specific death rate
K_R	- conversion rate of soluble organic nitrogen to free and saline ammonia
η_S	- correction factor for anoxic hydrolysis
η_G	- correction factor for anoxic heterotrophic growth
$\hat{\mu}_A$	- maximum specific growth rate of the autotrophs (nitrifiers)
K_{SA}	- half-saturation coefficient for autotroph growth
b_A	- autotrophic specific organism death rate

Stoichiometric parameters

Y_{ZH}	- heterotroph yield in COD units
Y_{ZA}	- autotroph yield in COD units
f_E	- inert fraction of the active organism mass
$f_{ZB, N}$	- fraction of biological (active) mass which is nitrogen
$f_{ZE, N}$	- fraction of endogenous/inert mass which is nitrogen

Switching function parameters

K_{OH}	- switching constant for oxygen-limited heterotroph growth (switch from aerobic to anoxic growth)
K_{OA}	- switching constant for oxygen-limited autotrophic growth
K_{HA}	- switching constant for ammonia-limited aerobic heterotroph growth
K_{NO}	- switching constant for nitrate-limited anoxic heterotroph growth

PARAMETERS DEFINING INFLUENT WASTEWATER CHARACTERISTICS

Carbonaceous material

- $f_{S, us}$ - fraction of the total influent COD which is unbiodegradable soluble
- $f_{S, up}$ - fraction of the total influent COD which is unbiodegradable particulate
- f_{bs} - fraction of the biodegradable influent COD which is readily biodegradable

Nitrogenous material

- $f_{N, a}$ - fraction of the total influent TKN which is free and saline ammonia
- $f_{N, ous}$ - fraction of the total influent TKN which is organic unbiodegradable soluble
- $f_{Nob, p}$ - fraction of the biodegradable organic TKN which is particulate

CHAPTER 1

INTRODUCTION

BACKGROUND

In the past, design, operation and control of activated sludge systems were based on relatively simplistic ideas about the behaviour of the systems, and on experience acquired in running such systems. Since about 1970 extensive development has taken place in the activated sludge method of treating wastewaters. The function of the single sludge system has expanded from carbonaceous energy removal to include nitrification, denitrification and phosphorus removal, all of these mediated biologically. These extensions have impacted on the system configuration in that multiple in-series reactors, some aerated and others not, with inter-reactor recycles have to be incorporated.

Not only have the system configuration and its operation increased in complexity, but more stringent standards for effluent quality have to be satisfied. To meet these effluent standards, the design of the selected system must be optimized and the system operated optimally. With such complexity it is no longer possible to make a reliable quantitative, or sometimes even qualitative prediction as to the effluent quality to be expected from a design, or to assess the effect of a system or operational modification without some model of the system behaviour.

To design the system optimally and to operate it effectively, concerted efforts have been made over the past 15 to 20 years to model the behaviour of these systems. This has been the case in South Africa, where development of a reliable mathematical model has been given intensive attention. The result of this research endeavour is a very powerful model that gives a reliable description of the nitrification and nitrification/denitrification (ND) system response over wide ranges of system configuration (single and in-series reactor systems, aerated and non-aerated reactors, inter-reactor recycles), wastewater characteristics (COD, TKN, flow pattern) and operational parameters (sludge age, temperature, dissolved oxygen concentration). Although this model is grounded on a mechanistic interpretation of the behaviour of the organisms mediating the process reactions, this interpretation is a subjective one, a gross simplification of the complex nature of the phenomena. However, that the model gives a reliable description of the system response over a wide range of conditions indicates that this simplification is acceptable.

The model has had a significant impact on design and operational procedures of single sludge nitrification and ND activated sludge systems. With regard to design, the model has led to the identification of procedures to estimate the optimal or near optimal design configuration, reactor sizes and operational parameters (e.g. sludge age) and to estimate the expected response (WRC, 1984). *Once the system has been designed*, the time response under dynamic flow and load conditions can be estimated using the model. Thereupon the design can be modified if necessary to achieve improved performance, or, the sensitivity of the design to changes in flow and load conditions or to operational modifications can be assessed. In full-scale plant operation it has also found application in assessing the effects of changes in waste flows and loads, operational modifications (e.g. changes in recycles), and

proposed modifications to plant configuration. It has also proved valuable in operator training; through simulation exercises using the model the operator acquires "instant" experience in the behaviour to be expected with changes in inputs, system configuration and operational strategies.

To make the model more widely available at the different levels of application, a computer program of the model is now presented that (1) is suitable for personal computers, (2) is "user friendly", (3) is flexible, and (4) provides rapid solutions, numerical or graphical.

COMPUTER PROGRAMS

This manual accompanies two computer programs of mechanistic models for simulating activated sludge wastewater treatment system behaviour on IBM PC or compatible computers. The first program, UCTOLD, is based on the model developed by the research group at the University of Cape Town (UCT). The second program, IAWPRC, is based on the model proposed by a task group of the International Association on Water Pollution Research and Control (IAWPRC), which in turn is based largely on the UCT model; the model and the program incorporate some further modifications by the UCT group.

The two programs are "menu driven". That is, for the most part the user selects a desired program option from a list of possible options displayed on the screen. This approach should be familiar to users of many commercial software packages and is adopted to simplify program operation, and to minimize the amount of typing by the user. A number of other features have been included in the programs in an effort to make these as "user friendly" as possible; for example:

- The user will find that it is very difficult to upset program operation when inputting data. Protection against typing incorrect keys is built into the program wherever possible.
- A consequence of the complexity of the models is that they incorporate a large number of constants, kinetic, stoichiometric, and others. Default values for all the constants, wastewater characteristics, etc., are included. These values have been selected and calibrated for South African conditions; the default values can be updated by the user if necessary for the situation where the model is applied. In the sections of the manual dealing with kinetic and stoichiometric constants and wastewater characteristics, guidance is given as to situations in which the constants may require alteration.
- Installation of the programs is very simple. The size of memory in the computer determines the maximum number of reactors in a system that can be simulated. This is detected automatically by the program. Also, the program automatically detects the type of graphics adapter installed in the computer.

ABOUT THIS MANUAL

This manual has been designed to give complete support to users of the two simulation programs:

Chapter 2: Models and Wastewater Characteristics presents the models and briefly highlights the key features. The division of the influent wastewater COD and TKN fractions into various sub-fractions is described; e.g. biodegradable/unbiodegradable, soluble/particulate, and so on.

Chapter 3: Installing the Programs provides instructions on how to set up working programs from the "distribution disk" accompanying the manual.

Chapter 4: Running the Programs demonstrates use of the programs in detail, and explains features of the various menus and sub-menus.

Chapter 5: Application and verification illustrates simulation of various experimental systems and includes comparison of the predicted and experimental data.

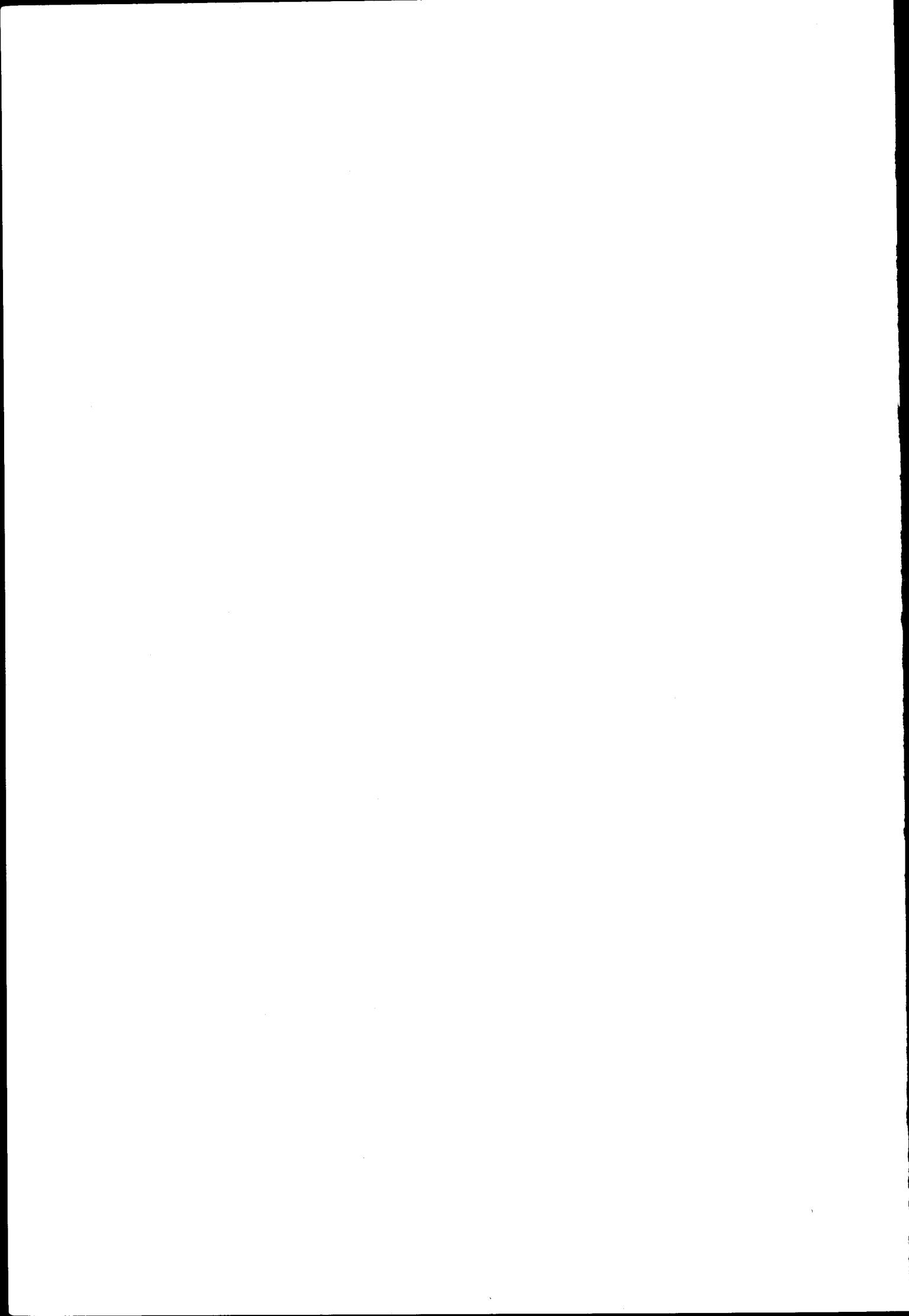
Chapter 6: Determination of model constants sets out procedures for determination of influent COD and TKN fractions and maximum specific growth rates for heterotrophs and autotrophs.

Appendix A: Retrieval of Diurnal Response Data shows how the data in a file of diurnal results may be re-arranged in a form suitable for off-line analysis. A program for making the conversion is provided; this allows the data to be imported into a spreadsheet package such as *Lotus 1-2-3* or Borland's *Quattro* should the user wish to, say, plot results in a specific format.

Appendix B: Model Representation in Matrix Format describes the matrix format used for presenting the models in Chapter 2.

Appendix C: Reactor Numbering Convention provides examples of the convention used for reactor numbering in the programs.

Appendix D: Symbols System sets out the basis for the system of symbols used in this manual.



CHAPTER 2

MODELS AND WASTEWATER CHARACTERISTICS

INTRODUCTION

Two activated sludge system models are included in the simulation package. These are UCTOLD and IAWPRC. In this Chapter the origins and key features of the two models are described briefly.

A matrix format is used for presenting the processes in the model, their kinetics and their stoichiometric interaction with the compounds. This format was recommended by the IAWPRC Task Group on Mathematical Modelling of Wastewater Treatment (Henze *et al.*, 1987; IAWPRC Task Group, 1987), and merits study; it provides an explicit "fingerprint" of the processes and facilitates understanding of complex biological models. For those not familiar with this form of presentation, Appendix B describes elements of the matrix presentation method.

UNIVERSITY OF CAPE TOWN MODEL (UCTOLD)

Steady state aerobic model

The dynamic activated sludge system model incorporated in the UCTOLD program, evolved out of the steady state aerobic model of Marais and Ekama (1976). This steady state model constituted a development from a number of previous models for **carbonaceous** and **nitrogenous** material conversion and removal.

Carbonaceous material

Modelling of carbonaceous material conversion conformed principally to the proposals of McKinney (1962) and McKinney and Ooten (1969). These researchers proposed three mixed liquor volatile solids fractions; active, endogenous-inert and inert, the last named derived from the influent. Further, they proposed (1) a relationship between the mass of substrate utilized and the active mass of organisms synthesized, and an expression for the rate of organism mass synthesis; (2) an accumulation of volatile endogenous-inert solids (endogenous residue) associated with active mass loss due to endogenous respiration, and an expression for the rate of active mass loss; (3) a relationship between the oxygen demand and the organism active mass synthesized; (4) a relationship between the oxygen demand and the active mass loss due to endogenous respiration; and (5) an accumulation of inert volatile solids due to the presence of this material in the influent. Marais and Ekama (1976) accepted these proposals, with the exception of McKinney's proposal for the rate of synthesis of active mass. Instead they accepted Lawrence and McCarty's (1970) proposal linking the specific organism growth rate to the concentration of substrate surrounding the organism via the Monod relationship.

Marais and Ekama (1976) rejected the biochemical oxygen demand (BOD) as a suitable parameter for defining the carbonaceous material. Instead they accepted the electron donating capacity of the carbonaceous material in its equivalent form, the chemical oxygen demand (COD). They proposed that the influent COD be

divided into three fractions; (1) biodegradable, (2) unbiodegradable particulate, and (3) unbiodegradable soluble. The growth and endogenous respiration processes were formulated in terms of the COD, or, where appropriate, in terms of an associated parameter the volatile suspended solids (VSS). Based on these considerations Marais and Ekama (1976) developed steady state equations for single and in-series completely mixed reactor activated sludge systems receiving a constant flow and load, i.e. equations for the active, endogenous and inert volatile solids concentrations and for oxygen consumption rates due to synthesis and endogenous respiration, these as functions of sludge age (organism retention time).

Nitrogenous material

Marais and Ekama (1976) proposed that the influent nitrogen (N) be divided into four fractions; (1) unbiodegradable soluble, (2) unbiodegradable particulate, (3) biodegradable organic, and (4) free and saline ammonia. Again they developed steady state equations for the utilization of ammonia for active cell mass synthesis, release of organic nitrogen due to endogenous respiration, conversion of biodegradable organic nitrogen to ammonia, incorporation of unbiodegradable nitrogen in inert material, and conversion of ammonia to nitrate (nitrification) as functions of sludge age. For the conversion of ammonia to nitrate they followed the Monod approach, as set out by Downing, Painter and Knowles (1964).

Summary

The most important features of the model of McKinney/Marais & Ekama can be summarized as follows:

In carbonaceous material conversion –

- subdivision of the influent COD into the three fractions;
- distinction between active, endogenous and inert sludge fractions;
- formulation of the biological reactions in terms of the active organism mass concentration; and
- linking oxygen utilization to the synthesis and endogenous processes.

In nitrogenous material conversion –

- subdivision of the influent nitrogen into the four fractions;
- formulation of the oxygen requirements for nitrification; and
- incorporation of nitrogen in the various sludge fractions.

Dynamic model

The steady state model, when it was applied to simulate single and in-series reactor systems under cyclic flow and load conditions, gave predictions that deviated significantly from that observed experimentally. When unaerated reactors were incorporated within the series for denitrification ("anoxic" reactors), even greater deviation from the model predictions were observed. Eventually these problems were resolved by the development of a dynamic model for the activated sludge system based on a mechanistic conceptualization of the aerobic and denitrification kinetic behaviour of the organisms in such a system. The development of this model is sketched below.

Progressively three models were produced, by Ekama, van Haandel and Marais (1979), Dold, Ekama and Marais (1980), and van Haandel, Ekama and Marais (1981); the last named model is the one incorporated in the UCTOLD program. Two key features of the model are of particular importance, namely, the *bisubstrate* and *death-regeneration* hypotheses.

Bisubstrate hypothesis

In nitrification/denitrification systems under constant flow and load, Stern and Marais (1974) had shown that in plugflow anoxic reactors upstream of the aerobic reactor (primary anoxic reactor) denitrification took place in two linear phases, a rapid first phase which persisted for a short period then terminated, and a second slow phase which continued for the retention time in the reactor. In plugflow anoxic reactors downstream of the aerobic reactor (secondary anoxic reactor), only one linear denitrification phase was operative, at a slow rate of about two thirds that of the slow second rate in the primary anoxic reactor. Ekama *et al.* (1979) hypothesized that the two linear phases in the primary anoxic reactor arose from the utilization of two biodegradable COD fractions in the influent, readily biodegradable (RBCOD) and slowly biodegradable (SBCOD); the first denitrification phase they connected to the RBCOD and the second to SBCOD. The slow rate single denitrification phase observed in secondary anoxic reactors they ascribed to endogenous mass loss. Based on these observations they developed a denitrification design procedure for in-series multi reactor systems under *constant* flow and load conditions. In 1980 Dold *et al.* incorporated RBCOD and SBCOD in an aerobic nitrification activated sludge kinetic model that gave very good predictions of system behaviour under cyclic flow and load conditions. Their study established the importance of RBCOD and SBCOD in describing the kinetic behaviour of the aerobic activated sludge system. In the model they postulated that the two COD substrate types, readily and slowly biodegradable, are acted on independently by the total active organism mass in the system:

Readily biodegradable substrate (RBCOD): The RBCOD, they hypothesized, consists of small simple molecules that can pass directly through the cell wall (by passive or active uptake) for synthesis and oxidative metabolism by the organism. The rate of synthesis of active mass from the RBCOD is formulated according to the Monod equation linking the specific growth rate of the active mass to the RBCOD concentration in the liquid phase. The reaction rate is rapid.

Slowly biodegradable substrate (SBCOD): The SBCOD, they hypothesized, consists of larger complex molecules that cannot pass directly through the cell wall. Utilization of this fraction involves four distinct phases; (1) enmeshment by the sludge mass, (2) adsorption, (3) extracellular enzymatic breakdown of the complex organic molecules to simpler components which pass directly through the cell wall, and (4) metabolism of the simpler components by the organism. For phase (1), the enmeshment of the SBCOD was assumed to be instantaneous and so was not explicitly modelled. For phases (3) and (4), the overall reaction rate is slow and appears to be limited by the rate of extracellular breakdown (hydrolysis) of the adsorbed SBCOD material [phase (3)] rather than the rate of metabolism of the hydrolysed material which passes through the cell wall [phase (4)]. Since hydrolysis is the rate limiting process, absorption and subsequent metabolism of the hydrolysis products were not explicitly modelled. Hence, the utilization of SBCOD could be modelled as a two-stage process; (1) adsorption of the material by the organism mass, and (2) enzymatic breakdown (hydrolysis) of the substrate. It is important to note that the hydrolysis products pass directly to the organism, not to the solution surrounding the organism.

Van Haandel *et al.* (1981) incorporated denitrification in the Dold *et al.* model to produce a general nitrification/denitrification activated sludge kinetic model. Van Haandel *et al.* found that the denitrification kinetic behaviour could be modelled in terms of RBCOD and SBCOD, and that the same formulations proposed by Dold *et al.* for RBCOD and SBCOD utilization under aerobic conditions could be used to model their utilization under anoxic conditions, except that the rate of SBCOD hydrolysis/utilization under anoxic conditions was reduced to about 1/3 that under aerobic conditions. Using the general nitrification/denitrification model, simulations of the denitrification response in primary and secondary anoxic plugflow reactors predicted near linear two phase denitrification behaviour in the primary anoxic reactor, and a single near linear phase in the secondary anoxic reactor, as observed by Stern and Marais (1974). Van Haandel *et al.* (1981) concluded that, in the plugflow primary anoxic reactor the first phase linear denitrification rate arose from utilization of RBCOD/adsorbed SBCOD and the second from utilization of adsorbed SBCOD. In the plugflow secondary anoxic reactor the single denitrification phase arose from utilization of adsorbed SBCOD generated from organism death.

Death-regeneration hypothesis

In earlier models the endogenous respiration concept was used to explain the phenomenon of active mass loss, i.e. a reduction in active volatile mass with time. This process was attributed to an energy requirement for organism maintenance, where a fraction of the organism mass disappears to provide energy for maintenance. However, in a reactor with sequential aerobic and anoxic states under constant flow and load conditions, in situations where the concentration of both oxygen and nitrate were zero for a period (i.e. anaerobic state), it was observed that when oxygen (or nitrate) was reintroduced the initial oxygen (or nitrate) demand increased significantly over that expected from the classical synthesis endogenous respiration approach. The increased oxygen (or nitrate) demand was found to be equal to the total demand that would have been expected if oxygen (or nitrate) had been available during the anaerobic period. The endogenous respiration approach could not explain this observation. Thus there was a need to develop an alternative model which could reflect the situation where aerobically (anoxically) generated organisms were placed in an anaerobic state for a short period. This led to the formulation of the death-regeneration model.

In the death-regeneration model an attempt is made to separate out the reactions which take place during the organism's "death phase". Disappearance of live active mass is hypothesized to be due to the net effect of death (natural or predation) and regeneration of organisms: On death the cell material is released through lysis; a fraction is unbiodegradable and remains as an unbiodegradable endogenous residue; the remaining fraction is biodegradable and becomes part of the SBCOD in the liquid, returning to the same cycle of adsorption, hydrolysis and, finally, synthesis of new cell mass (i.e. regeneration), giving rise to an associated oxygen demand. The classical endogenous oxygen demand thus in effect becomes a resynthesis oxygen demand. The main implication of this approach is that "maintenance energy" *per se* (the oxygen requirement for maintenance) is considered to be so small that it can be lumped with, and completely swamped by, the oxygen demand for the synthesis of new cell mass from the lysed substrate.

Simulation studies utilizing the endogenous respiration and the death-regeneration approaches respectively showed that for dynamic modelling of aerobic and anoxic/aerobic activated sludge systems there is little difference in the predictions given by the two approaches. However, when modelling in-series reactor activated sludge systems that incorporate "anaerobic" reactors (i.e. oxygen and nitrate limited conditions) the endogenous respiration approach gave very poor predictions, whereas the death-regeneration approach gave very good predictions. In the death-regenera-

tion approach, when the nitrate concentration becomes zero in an unaerated reactor, synthesis ceases but organism death continues with the associated release of biodegradable substrate back into the liquid; this results in a build up of biodegradable material in the reactor. When the liquid passes to a downstream plugflow aerated reactor, the utilization of the accumulated biodegradable material results in an initial high oxygen utilization rate, much higher than that obtained when using the classical endogenous respiration approach.

Nitrogen transformations

Besides the carbonaceous conversion aspects described above, van Haandel *et al.* (1981) found that the bisubstrate death-regeneration approach could be integrated in a consistent manner with the transformations of nitrogen, in synthesis, death-regeneration, nitrification and denitrification.

UCTOLD process model description

The process model describes the processes, their kinetics and the compounds on which they act and defines the behaviour at a single point in a system. The process model incorporated in the UCTOLD program is presented in matrix form in Table 2.1. This matrix provides a quantitative description of interrelationships between the processes (j) and associated compounds (i). Details of the symbol system used in this manual are given in Appendix D. The stoichiometric, kinetic and switching function constants in the UCTOLD process model are defined in the section 'List of Symbols' and their numerical values are listed in Table 2.2; these are the default values for use in the program. In Chapter 6, guidance is given on the determination of some of the constants. The switching functions used in the matrix are formulated in Table 2.3. A short description of the processes and their stoichiometric interactions with the compounds, is set out below.

Processes 1 and 2 Aerobic growth of heterotrophs on readily biodegradable COD (RBCOD): These two processes are responsible for removal of RBCOD under aerobic conditions. A fraction of the RBCOD is used for the production (growth) of heterotrophic biological (active) organism mass (synthesis) and the balance is oxidized for energy giving rise to an associated synthesis oxygen demand. The growth is modelled using Monod kinetics. In Process 1, concomitant with growth, ammonia is used as a nitrogen source for synthesis, and there is an associated alkalinity change. Should ammonia become limiting, nitrate can serve as an alternative nitrogen source for synthesis, Process 2. This is accomplished by incorporating switching functions dependent on the ammonia concentration, which switch Process 1 'off' and Process 2 'on' when ammonia reduces to near zero but nitrate is available as a nitrogen source. Should both ammonia and nitrate reduce to zero, growth Processes 1 and 2 are switched off. Additional switching functions in both Processes 1 and 2 ensure that these processes only operate if oxygen is present as electron acceptor – as the oxygen concentration reduces to zero there is a switch from aerobic to anoxic growth (Processes 3 and 4) with nitrate as electron acceptor.

Processes 3 and 4 Anoxic growth of heterotrophs on readily biodegradable COD (RBCOD): In the absence of oxygen, the heterotrophic organism population is capable of using nitrate, if available, as electron acceptor with RBCOD as substrate. In these two processes, a fraction of the RBCOD is used for production (growth) of heterotrophic biological (active) organism mass and the balance is oxidized giving rise to reduction of nitrate to nitrogen gas. The anoxic growth is modelled using the same Monod kinetics used for aerobic growth (Processes 1 and 2). As in aerobic growth (with RBCOD), ammonia (Process 3) or nitrate (Process 4) can serve as nitrogen source for cell synthesis; this is accommodated through switching

Table 2.1: Matrix representation of UCT model

COMPOUND	i	Z_{BH}	Z_{BA}	z_E	3	4	5	6	7	S_{obs}	8	S_{obs}	9	10	11	12	13	14	PROCESS RATES, P_j
1 Aerobic growth of Z_{BH} on S_{obs} with N_a	1									-1/Y _{ZH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
2 Aerobic growth of Z_{BH} on S_{obs} with N_{a3}	1									-1/Y _{ZH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
3 Anoxic growth of Z_{BH} on S_{obs} with N_a	1									-1/Y _{ZH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
4 Anoxic growth of Z_{BH} on S_{obs} with N_{a3}	1									-1/Y _{ZH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
5 Aerobic growth of Z_{BH} on S_{ads} with N_a	1									-1/Y _{ZH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
6 Aerobic growth of Z_{BH} on S_{ads} with N_{a3}	1									-1/Y _{ZH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
7 Anoxic growth of Z_{BH} on S_{ads} with N_a	1									-1/Y _{ZH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
8 Anoxic growth of Z_{BH} on S_{ads} with N_{a3}	1									-1/Y _{ZH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
9 Death of Z_{BH}	-1									f_{E-}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
10 Adsorption of S_{obs}										f_{E-}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
11 Hydrolysis of N_{obs}										f_{E-}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
12 Ammonification of N_{obs}										f_{E-}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	Z_{BH}	
13 Aerobic growth of Z_{BA}	1									f_{E-}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	
14 Death of Z_{BA}	-1									f_{E-}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	Z_{BA}	
15 Inert mass																			KEY
16 Biologocal (active) heterotrophic mass																			$A^* = \frac{1-Y_{ZH}}{14*2.86/Z_{BH}} - f_{ZB-N}/14$
17 Biologocal (active) autotrophic mass																			$B^* = \frac{1-Y_{ZH}}{2.86/Z_{BH}} - f_{ZB-N}$
18 Biodegradable soluble substrate																			$C^* = \frac{1-Y_{ZH}}{14*2.86/Z_{BH}} + f_{ZB-N}/14$

Table 2.2: Default values for kinetic, stoichiometric and switching function constants in the UCT model

SYMBOL	VALUE	UNITS
Kinetic parameters (20°C)		
$\hat{\mu}_H$	1,5 - 3,5	d^{-1}
K_{SH}	5,0	$g \text{ COD m}^{-3}$
K_{MP}	(1,35)	$g \text{ COD (g cell COD.d)}^{-1}$
K_{SP}	0,027	$g \text{ COD (g cell COD)}^{-1}$
b_H	0,62	d^{-1}
K_A	0,17	$g \text{ COD (g cell COD.d)}^{-1}$
K_R	0,032	$m^3 \text{ (g cell COD.d)}^{-1}$
$\hat{\mu}_A$	0,2 - 0,75	d^{-1}
K_{SA}	1,0	$g \text{ NH}_3\text{-N m}^{-3}$
b_A	0,04	d^{-1}
η_G	0,33	-
Stoichiometric parameters		
Y_{ZH}	0,666	$g \text{ cell COD (g COD utilized)}^{-1}$
Y_{ZA}	0,15	$g \text{ cell COD (g N utilized)}^{-1}$
f_{MA}	1,00	$g \text{ COD (g cell COD)}^{-1}$
f_E	0,08	-
$f_{ZB,N}$	0,068	$g \text{ N (g COD)}^{-1} \text{ in active mass}$
$f_{ZE,N}$	0,068	$g \text{ N (g COD)}^{-1} \text{ in endogenous mass}$
Switching function parameters		
K_{OH}	0,002	$g \text{ O}_2 \text{ m}^{-3}$
K_{OA}	0,002	$g \text{ O}_2 \text{ m}^{-3}$
K_{HA}	0,01	$g \text{ NH}_3\text{-N m}^{-3}$
K_{NO}	0,1	$g \text{ NO}_3\text{-N m}^{-3}$
Arrhenius temperature dependency constants		
$K_{i,T} = K_{i,20} \theta^{(T-20)}$		
where $K_{i,T} = K_i$ at $T^\circ\text{C}$ $\theta = \text{Arrhenius constant}$		
$\hat{\mu}_H$	1,200	-
K_{SH}	1,000	-
K_{MP}	1,080 —	-
K_{SP}	0,910	-
b_H	1,029	-
K_A	1,029.	-
f_{MA}	1,000	-
K_R	1,029	-
$\hat{\mu}_A$	1,123	-
K_{SA}	1,123	-
b_A	1,029	-

Table 2.3: Switching functions used in UCT model (Table 2.1) and IAWPRC Task Group model (Table 2.4)

SWITCHING FUNCTION	FORMULATION
1 [H Air On]	$\frac{O}{K_{OH} + O}$
2 [H Air Off]	$\frac{K_{OH}}{K_{OH} + O}$
3 [A Air On]	$\frac{O}{K_{OA} + O}$
4 [N _a Limit]	$\frac{N_a}{K_{HA} + N_a}$
5 [1-N _a Limit]	$\frac{K_{HA}}{K_{HA} + N_a}$
6 [N _{O3} Limit]	$\frac{N_{O3}}{K_{NO} + N_{O3}}$

functions. Further switching functions in both Processes 3 and 4 ensure that the anoxic growth rates decrease to zero at low nitrate concentrations.

Processes 5 and 6 Aerobic growth of heterotrophs on adsorbed slowly biodegradable COD (SBCOD): In these two processes the SBCOD, which has been adsorbed on the organism (Process 10), is utilized under aerobic conditions. This utilization consists of two steps, hydrolysis of the adsorbed SBCOD and direct utilization of the hydrolysis products for the production (growth) of active organism mass (synthesis) and its associated oxygen demand. Since the rate limiting step is hydrolysis, only this step is modelled, using Levenspiel's surface reaction kinetics (Dold *et al.*, 1980). As in aerobic growth on RBCOD, ammonia (Process 5) or nitrate (Process 6) can serve as a nitrogen source for cell synthesis; this is accomplished by incorporating switching functions dependent on the ammonia concentration. Also, switching functions ensure that both processes operate only if oxygen is present as electron acceptor; at low oxygen concentrations there is a switch to anoxic growth (Processes 7 and 8) with nitrate as electron acceptor.

Processes 7 and 8 Anoxic growth of heterotrophs on adsorbed slowly biodegradable COD (SBCOD): These processes are modelled in the same way as for the aerobic growth Processes 5 and 6 except that in the absence of oxygen, nitrate serves as an alternative electron acceptor and that the Levenspiel surface reaction for the hydrolysis/utilization kinetic rate expression is multiplied by the factor η_G . Again, either ammonia (Process 7) or nitrate (Process 8) can serve as nitrogen source for cell synthesis. Switching functions in both Processes 7 and 8 ensure that the anoxic growth rates decrease to zero at low nitrate concentrations.

Process 9 Death of heterotrophs: The process is modelled according to the death-regeneration hypothesis. That is, the heterotrophic organism mass dies at a certain rate per unit organism mass; a portion of the material from the death is unbiodegradable particulate and adds to the unbiodegradable endogenous residue while the remainder adds to the pool of SBCOD. Nitrogen associated with the

biodegradable portion adds to the pool of particulate organic nitrogen. The process of organism death is assumed to continue under aerobic, anoxic and anaerobic conditions.

Process 10 Adsorption of slowly biodegradable COD (SBCOD): SBCOD is assumed to be enmeshed in the sludge mass immediately on contact with mixed liquor. The adsorption process transfers the enmeshed SBCOD to the adsorbed SBCOD.

Process 11 Hydrolysis of particulate organic nitrogen: Biodegradable particulate organic nitrogen is broken down to soluble organic nitrogen at a rate linked directly to the rate of hydrolysis/utilization of adsorbed SBCOD under both aerobic (Processes 5 and 6) and anoxic (Processes 7 and 8) conditions. The product of breakdown adds to the pool of soluble organic nitrogen.

Process 12 Ammonification of soluble organic nitrogen: Biodegradable soluble organic nitrogen is converted to free and saline ammonia, a process mediated by the heterotrophic biological active mass. Hydrogen ions consumed in the conversion process results in an alkalinity change.

Process 13 Aerobic growth of autotrophs: In this process ammonia is oxidized to nitrate via a single step resulting in production (growth) of autotrophic biological active mass and giving rise to an associated nitrification oxygen demand. The process requires the presence of oxygen; a switching function ensures that the process operates only if oxygen is present. This process has a marked effect on the predicted total oxygen demand; the effect on total MLVSS is small as the yield of autotrophic nitrifiers is low. As with the growth of heterotrophs, ammonia nitrogen is incorporated in the new cells and the alkalinity is affected.

Process 14 Death of autotrophs: The process parallels that for heterotrophs (Process 9).

UCTOLD system model

The process model of the compounds, processes and rates presented above defines the behaviour at a single point in a system. To obtain the response of the system the following need to be incorporated: System configuration (single or multiple reactors), system type (continuously fed, batch, etc.), hydraulic mixing regime in each reactor (plug flow or completely mixed), and recycle flows between reactors. These, together with the process model, form the system model. (Details on how to develop the system model from the process model are given in Appendix B). The system model in the UCTOLD program presented with this manual is for the resolution of the response of a system consisting of single or in-series completely mixed reactors; with up to two inter-reactor recycles and a single underflow recycle, all opposite to the direction of flow; any reactor can be aerated or unaerated; influent flow and COD and nitrogen loads can be constant or cyclic; sludge draw off to control the sludge age takes place from the reactor immediately upstream of the settling tank; solids separation in the settling tank is assumed to be 100 percent; and the mass of sludge in the settler is assumed negligible.

UCTOLD system model solution

Solution techniques and algorithms used in the UCTOLD computer program, to solve the system model within the boundaries described above, are set out in Billing (1987) and Billing and Dold (1988a, b and c).

**INTERNATIONAL ASSOCIATION ON WATER POLLUTION RESEARCH
AND CONTROL MODEL (IAWPRC)**

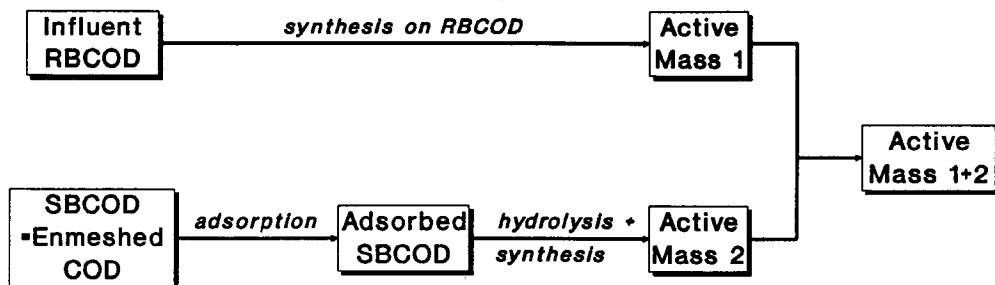
IAWPRC model origins

In 1982 the IAWPRC appointed a Task Group to review modelling of activated sludge systems. Their deliberations culminated in a proposal for an activated sludge model (Henze *et al.*, 1987; IAWPRC, 1987). This model is based largely on the existing model of the UCT Group, but with two principal changes, these are, in the enmeshment-adsorption (storage) and in the solubilization (hydrolysis) hypotheses.

The Task Group agreed with the proposal in the UCT model that the particulate material is enmeshed virtually instantaneously by the sludge mass. However, they rejected the UCT proposal that the enmeshed slowly biodegradable COD (SBCOD) is adsorbed on the organism mass. Instead they proposed that the enmeshed SBCOD is hydrolysed to readily biodegradable COD (RBCOD) by the action of extracellular enzymes secreted by the organism mass to the bulk liquid. The SBCOD thus hydrolysed to RBCOD adds to the RBCOD derived from the influent and the total is then available for synthesis. With these modifications the need to model the rate of adsorption (as in the UCT model) falls away.

The differences between the two approaches with respect to substrate utilization are set out in Fig 2.1. When appropriately calibrated the two approaches give virtually identical predictions, see Chapter 5.

UCT MODEL (UCTOLD)



IAWPRC MODEL (IAWPRC)

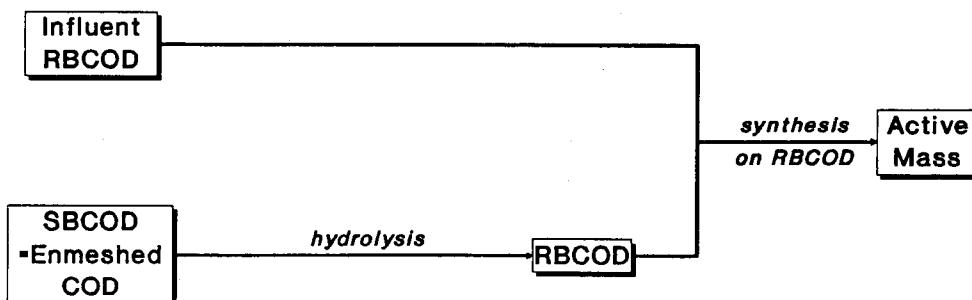


Fig 2.1: Diagram illustrating similarities/differences between the UCT and IAWPRC approaches with respect to hydrolysis/synthesis of carbonaceous material.

A second aspect in which the Task Group model differs from the UCT model is that in the UCT model provision is made for nitrate to serve as a nitrogen source for cell synthesis if ammonia is not available. This provision was not included in the original IAWPRC Task Group model (Dold and Marais, 1985), but is included in the version incorporated in this manual and in the computer program called IAWPRC.

IAWPRC process model description

The process model is presented in matrix format in Table 2.4. This provides a quantitative description of the model and shows the inter-relationships between the processes (j) and associated compounds (i). Details of the symbol system used in this manual are given in Appendix D. The switching functions used in the matrix are formulated in Table 2.3. The stoichiometric, kinetic and switching function constants in the IAWPRC process model are defined in the section "List of Symbols" and the numerical values are listed in Table 2.5; these are the default values for use in the program. In Chapter 6, guidance is given on the determination of some of the constants. A short description of the processes and the stoichiometric interactions with the compounds is set out below.

In the IAWPRC model, heterotrophic growth takes place only on readily biodegradable COD (RBCOD), Processes 1, 2, 3 and 4.

Processes 1 and 2 Aerobic growth of heterotrophs: Processes 1 and 2 are responsible for removal of RBCOD [from the influent and generated from slowly biodegradable COD (SBCOD) hydrolysis, Process 6] under aerobic conditions. A fraction of the RBCOD is used for the production (growth) of heterotrophic biological active organism mass (synthesis) and the balance is oxidized for energy giving rise to an associated oxygen demand. The growth is modelled using Monod kinetics. In Process 1, concomitant with growth, ammonia is used as a nitrogen source for synthesis, and there is an associated alkalinity change. Should ammonium become limiting, nitrate can serve as an alternative nitrogen source for synthesis, Process 2, and there is an associated alkalinity change. The switch from ammonia to nitrate as nitrogen source for synthesis is accomplished by incorporating switching functions dependent on the ammonia concentration, which switch Process 1 "off" and Process 2 "on" when ammonia reduces to near zero but nitrate is available. Should both ammonia and nitrate reduce to zero, growth Processes 1 and 2 are switched off. Further switching functions in both Processes 1 and 2 ensure that these processes only operate if oxygen is present as electron acceptor; at low oxygen concentrations there is a switch from aerobic to anoxic growth (Processes 3 and 4) with nitrate as electron acceptor.

Processes 3 and 4 Anoxic growth of heterotrophs: In the absence of oxygen the heterotrophic organism population is capable of using nitrate, if available, as electron acceptor with RBCOD as substrate. In these two processes, a fraction of the RBCOD is used for production (growth) of active organism mass and the balance gives rise to reduction of nitrate to nitrogen gas with an associated alkalinity change. The anoxic growth is modelled using the same Monod kinetics used for aerobic growth (Processes 1 and 2) except that the kinetic rate expression is multiplied by the factor η_G . (For the present it is assumed that the potential growth rate is the same under anoxic as under aerobic conditions, i.e. $\eta_G = 1$. The limitation in growth rate under anoxic conditions can arise in hydrolysis, see Process 6). As for aerobic growth with RBCOD, ammonia (Process 3) or nitrate (Process 4) can serve as nitrogen source for cell synthesis; this is accommodated through switching functions. Further switching functions in both Processes 3 and 4 ensure that the anoxic growth rates decrease to zero at low nitrate concentrations.

Table 2.4: Matrix representation of IAWPRC Task Group model

j	COMPOUND i — PROCESS	1 Z_{BH}	2 Z_{BA}	3 Z_E	4 Z_1	5 S_{erm}	6 N_{obp}	7 S_{bs}	8 N_a	9 N_{o3}	10 N_{obs}	11 A_{lk}	12 S_{us}	13 0	PROCESS RATES, ρ_j
1	Aerobic growth of Z_{BH} with N_a	1						- $f_{ZB,N}$				- $f_{ZB,N}/14$			$\frac{1-f_{ZH}}{Y_{ZH}}$ $\hat{\mu}_H \left[\begin{array}{c c} S_{bs} & H_Air \\ \hline K_{SH} + S_{bs} & \eta_S \end{array} \right] N_a / \text{Limit}$
2	Aerobic growth of Z_{BA} with N_{o3}	1						- $f_{ZB,N}$				$f_{ZB,N}/14$			$\frac{1-f_{ZH}}{Y_{ZH}}$ $\hat{\mu}_H \left[\begin{array}{c c} S_{bs} & H_Air \\ \hline K_{SH} + S_{bs} & \eta_S \end{array} \right] N_{o3} / \text{Limit}$
3	Anoxic growth of Z_{BH} with N_a	1						- $f_{ZB,N}$				$f_{ZB,N}/14$			$\frac{1-f_{ZH}}{Y_{ZH}}$ $\hat{\mu}_H \left[\begin{array}{c c} S_{bs} & H_Air \\ \hline K_{SH} + S_{bs} & \eta_S \end{array} \right] N_a / \text{Limit}$
4	Anoxic growth of Z_{BA} with N_{o3}	1						- $f_{ZB,N}$				$f_{ZB,N}/14$			$\frac{1-f_{ZH}}{Y_{ZH}}$ $\hat{\mu}_H \left[\begin{array}{c c} S_{bs} & H_Air \\ \hline K_{SH} + S_{bs} & \eta_S \end{array} \right] N_{o3} / \text{Limit}$
5	Death of Z_{BH}	-1													$b_H Z_{BH}$
6	Hydrolysis of S_{erm}							$f_{ZB,N}$							$\rho_6 (N_{obp} / S_{erm})$
7	Hydrolysis of N_{obp}							$-f_E f_{ZE,N}$							$K_R N_{obp} Z_{BH}$
8	Ammonification of N_{obs}								-1						$N_{obp} (N_{obp} / S_{erm})$
9	Aerobic growth of Z_{BA}								$-f_{ZB,N}/14$						$\frac{1-f_{ZH}}{Y_{ZH}}$ $\hat{\mu}_A \left[\begin{array}{c c} N_a & H_Air \\ \hline K_{SA} + N_a & \eta_S \end{array} \right] Z_{BA}$
10	Death of Z_{BA}	-1							$f_{ZB,N}$						$b_A Z_{BA}$
															KEY
															$A^* = \frac{1-f_{ZH}}{14+2.86 Y_{ZH}} - f_{ZB,N} / 14$
															$B^* = \frac{1-f_{ZH}}{2.86 Y_{ZH}} - f_{ZB,N}$
															$C^* = \frac{1-f_{ZH}}{14+2.86 Y_{ZH}} + f_{ZB,N} / 14$

Table 2.5: Default values for kinetic, stoichiometric and switching function constants in the IAWPRC Task Group model

SYMBOL	VALUE	UNITS
Kinetic parameters (20°C)		
$\hat{\mu}_H$	2,4 - 5,0	d^{-1}
K_{SH}	5,0	$g \text{ COD } m^{-3}$
K_H	2,03	$g \text{ COD } (g \text{ cell COD} \cdot d)^{-1}$
K_X	0,027	$g \text{ COD } (g \text{ cell COD})^{-1}$
b_H	0,62	d^{-1}
K_R	0,032	$m^3 (g \text{ cell COD} \cdot d)^{-1}$
$\hat{\mu}_A$	0,2 - 0,75	d^{-1}
K_{SA}	1,0	$g \text{ NH}_3\text{-N } m^{-3}$
b_A	0,04	d^{-1}
η_S	0,33	-
η_G	1,00	-
Stoichiometric parameters		
Y_{ZH}	0,666	$g \text{ cell COD } (g \text{ COD utilized})^{-1}$
Y_{ZA}	0,15	$g \text{ cell COD } (g \text{ N utilized})^{-1}$
f_E	0,08	-
$f_{ZB,N}$	0,068	$g \text{ N } (g \text{ COD})^{-1} \text{ in active mass}$
$f_{ZE,N}$	0,068	$g \text{ N } (g \text{ COD})^{-1} \text{ in endogenous mass}$
Switching function parameters		
K_{OH}	0,002	$g \text{ O}_2 \text{ } m^{-3}$
K_{OA}	0,002	$g \text{ O}_2 \text{ } m^{-3}$
K_{HA}	0,01	$g \text{ NH}_3\text{-N } m^{-3}$
K_{NO}	0,1	$g \text{ NO}_3\text{-N } m^{-3}$
Arrhenius temperature dependency constants		
$K_{i,T} = K_{i,20} \theta^{(T-20)}$		
where $K_{i,T} = K_i$ at $T^\circ\text{C}$ $\theta = \text{Arrhenius constant}$		
$\hat{\mu}_H$	1,200	-
K_{SH}	1,000	-
K_H	1,080	-
K_X	0,910	-
b_H	1,029	-
K_R	1,029	-
$\hat{\mu}_A$	1,123	-
K_{SA}	1,123	-
b_A	1,029	-

Process 5 *Death of heterotrophs*: The process is modelled according to the death-regeneration hypothesis. That is, the heterotrophic organism mass dies at a certain rate; a portion of the material from death is unbiodegradable and adds to the unbiodegradable endogenous residue while the remainder adds to the pool of SBCOD. Nitrogen associated with the SBCOD becomes available as particulate organic nitrogen. The process of organism death is assumed to continue under aerobic, anoxic and anaerobic conditions.

Process 6 "Hydrolysis" of slowly biodegradable COD (SBCOD): SBCOD enmeshed in the sludge mass is broken down extracellularly, with the products of breakdown adding to the pool of RBCOD available to the organisms for growth (Processes 1, 2, 3 and 4). This "hydrolysis" process is modelled on the basis of Levenspiel's surface reaction kinetics, and occurs only under aerobic or anoxic conditions; the rate of hydrolysis under anoxic conditions is reduced compared to the rate under aerobic conditions by multiplying the aerobic hydrolysis rate by the factor η_s under anoxic conditions. Hydrolysis does not occur under anaerobic conditions; a switching function ensures that the hydrolysis process only operates if oxygen or nitrate is present.

Process 7 "Hydrolysis" of particulate organic nitrogen: Biodegradable particulate organic nitrogen is broken down to soluble organic nitrogen at a rate defined by the hydrolysis reaction for SBCOD (Process 6 above). The product of breakdown adds to the pool of soluble organic nitrogen.

Process 8 Ammonification of soluble organic nitrogen: Biodegradable soluble organic nitrogen is converted to free and saline ammonia, a process mediated by the active heterotrophs. Hydrogen ions consumed in the conversion process results in an alkalinity change.

Process 9 Aerobic growth of autotrophs: In this process ammonia is oxidized to nitrate via a single step resulting in production (growth) of autotroph active mass and giving rise to an associated oxygen demand. The process requires the presence of oxygen; a switching function ensures that the process only operates if oxygen is present. This process has a marked effect on the alkalinity and the total oxygen demand; the effect on total MLVSS is small as the yield of autotrophic nitrifiers is low. As with the growth of heterotrophs, ammonia nitrogen is incorporated in the new cells and the alkalinity is affected.

Process 10 Death of autotrophs: The process parallels that for heterotrophs (Process 5).

IAWPRC system model

The process model of the compounds presented above defines the behaviour at a single point in a system. To obtain the response of the system a number of factors need to be incorporated. The reader is referred to the previous section "UCTOLD system model" where consideration is given to these factors, and conditions for application of the UCT model are set out; these apply also to the IAWPRC model.

IAWPRC system model solution

The same solution techniques and algorithms employed in the UCTOLD program are used in the IAWPRC program; details of these are set out in Billing (1987) and Billing and Dold (1988a, b and c).

INFLUENT WASTEWATER CHARACTERISTICS

Carbonaceous material

Characterization of the carbonaceous material in the influent is in terms of the chemical oxygen demand (COD). For use in the models it is necessary to specify the magnitudes of the various fractions of the influent COD. (Details of the symbol system used in this manual are given in Appendix D). Research by the UCT Group has indicated a division shown diagrammatically in Fig 2.2.

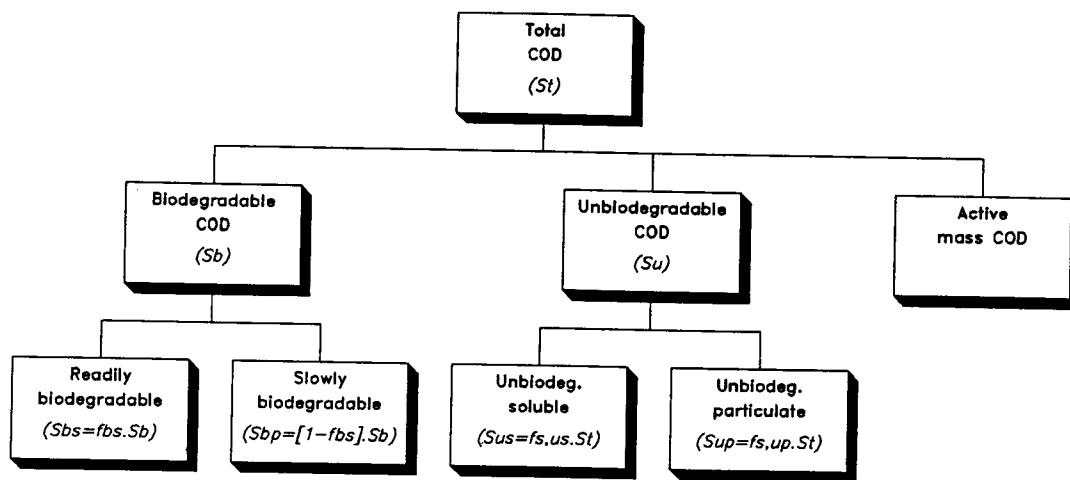


Fig 2.2: Division of the influent COD into its constituent fractions.

Biodegradable and unbiodegradable fractions

The first division of the influent COD (S_{ti}) is into biodegradable COD (S_{bi}) and unbiodegradable COD (S_{ui}). Each of these fractions is subdivided further into two sub-fractions:

Unbiodegradable sub-fractions: The influent unbiodegradable COD (S_{ui}) is divided into two fractions, unbiodegradable soluble COD (S_{us}) and unbiodegradable particulate COD (S_{up}). Both are hypothesized to be unaffected by biological action in the system. The S_{us} passes out in the secondary settling tank overflow; the S_{up} is enmeshed in the sludge mass and accumulates in the system as inert VSS (Z_I in COD units). At steady state the mass of S_{up} entering the system in the influent will be balanced by the mass of Z_I leaving via the sludge wastage stream. From a mass balance, the mass of Z_I in the system will equal the influent mass of S_{up} per day multiplied by the system sludge age.

Biodegradable sub-fractions: The influent biodegradable COD (S_{bi}) is divided into two fractions, readily biodegradable COD (RBCOD, S_{bs}) and slowly biodegradable COD (SBCOD, S_{bp}). The RBCOD is hypothesized to consist of simple soluble molecules that can be absorbed readily by the organism and metabolized for energy and synthesis, whereas the SBCOD is assumed to be made up of particulate/colloidal/complex organic molecules that require extracellular enzymatic breakdown prior to absorption and utilization.

Quantifying the division

From practical considerations, the division of the influent wastewater COD into fractions is conventionally defined by the fractional constants, $f_{S, us}$, $f_{S, up}$ and f_{bs} :

$f_{S, us}$ = fraction of the total influent COD which is unbiodegradable soluble;

$f_{S, up}$ = fraction of the total influent COD which is unbiodegradable particulate;

f_{bs} = fraction of the biodegradable influent COD which is readily biodegradable.

Using these fractional constants the division of the influent COD into the various sub-fractions may be expressed as follows:

$$S_{usi} = f_{S, us} \cdot S_{ti} \quad (2.1)$$

$$S_{upi} = f_{S, up} \cdot S_{ti} \quad (2.2)$$

The biodegradable influent COD (S_{bi}) is given by the difference of the total influent COD (S_{ti}) and the sum of S_{usi} and S_{upi} :

$$\begin{aligned} S_{bi} &= S_{ti} - (S_{usi} + S_{upi}) \\ &= S_{ti} (1 - f_{S, us} - f_{S, up}) \\ &= S_{bsi} + S_{bpi} \end{aligned} \quad (2.3)$$

where

$$S_{bsi} = f_{bs} \cdot S_{bi} \quad (2.4)$$

$$S_{bpi} = (1 - f_{bs}) \cdot S_{bi} \quad (2.5)$$

To specify the wastewater fully, values must be assigned to the total influent COD concentration (S_{ti}) and the fractional constants, $f_{S, us}$, $f_{S, up}$ and f_{bs} . The magnitudes of these constants will vary from influent to influent, and differ for a raw and a primary settled wastewater. In the program, default values are provided for raw and settled wastewaters; these are approximate average values observed for municipal wastewaters in South Africa. Experimental procedures for estimating these fractional constants are set out by Ekama, Dold and Marais (1986) and are reviewed in Chapter 6.

The IAWPRC Task Group proposed a further influent COD fraction, the COD of active aerobic organisms present in the influent. This COD fraction is shown in Fig 2.2 and incorporated in both models. In the models, quantification of this COD fraction (S_{ZBi}) is via the fractional constant $f_{S, ZB}$ where,

$$S_{ZBi} = f_{S, ZB} \cdot S_{ti}$$

For municipal wastewaters in South Africa it appears that the fractional constant $f_{S, ZB}$ can be taken as zero as the sewers generally are anaerobic. However, in cold temperate climates and with sewer systems that are aerated the influent active organism COD fraction may be significant. At present its magnitude can be assessed only by simulation, comparing the predicted response with the experimental response on laboratory-scale units treating the influent (Sollfrank and Gujer, 1991). Should the influent active organism COD fraction be significant, it is subtracted from the influent total COD and adds to the active organism mass in the reactor.

The remaining influent COD is divided into the biodegradable/unbiodegradable fractions as discussed above.

Nitrogenous material

Characterization of the nitrogenous material in the influent is in terms of the total Kjeldahl nitrogen (TKN). It is necessary to specify the magnitudes of the various fractions of the influent TKN. Research by the UCT Group has indicated a division shown diagrammatically in Fig 2.3.

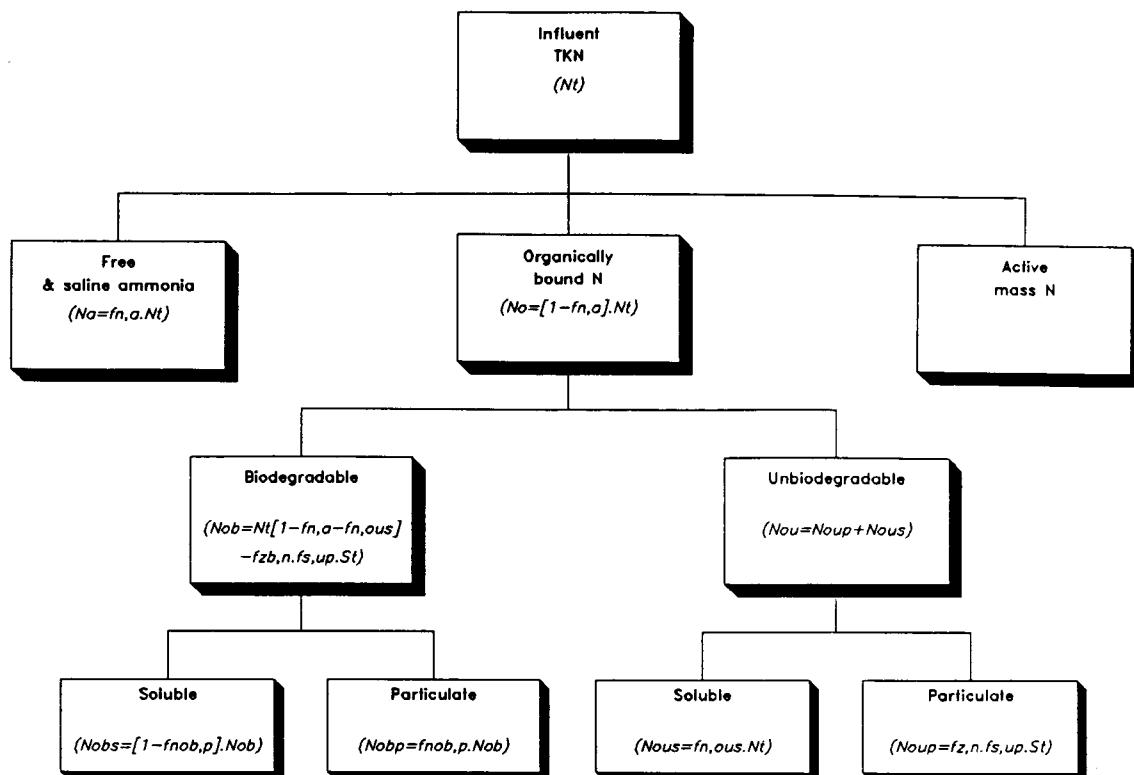


Fig 2.3: Division of the influent TKN into its constituent fractions.

Free and saline ammonia and organically bound fractions

The first subdivision of the influent TKN (N_{ti}) is into free and saline ammonia (N_{ai}) and organically bound N (N_{oi}). The influent organically bound nitrogen (N_{oi}) is divided further into two sub-fractions, unbiodegradable (N_{oui}) and biodegradable (N_{obi}).

Unbiodegradable organic nitrogen: The influent unbiodegradable organic nitrogen (N_{oui}) has two forms, unbiodegradable soluble (N_{ousi}) and unbiodegradable particulate (N_{oupi}). The unbiodegradable organic nitrogen forms are hypothesized to be unaffected by biological action in the system. The soluble unbiodegradable organic nitrogen passes out in the secondary settling tank overflow. The particulate unbiodegradable organic nitrogen is associated with the unbiodegradable particulate COD in the influent and leaves the system via the sludge wastage stream.

Biodegradable organic nitrogen: The influent biodegradable organic nitrogen (N_{obi}) is in two forms, soluble (N_{obsi}) and particulate (N_{obpi}).

Quantifying the division

Again, from practical considerations the various nitrogen components of the influent wastewater TKN are defined by the fractional constants, $f_{N,a}$, $f_{N,ous}$ and $f_{Nob,p}$:

$f_{N,a}$ = fraction of the total influent TKN which is free and saline ammonia;

$f_{N,ous}$ = fraction of the total influent TKN which is organic unbiodegradable soluble;

$f_{Nob,p}$ = fraction of the organic biodegradable N which is particulate.

Using the fractional constants the division of the influent total TKN (N_{ti}) into the various components may be expressed as follows:

$$N_{ai} = f_{N,a} \cdot N_{ti} \quad (2.6)$$

$$N_{ousi} = f_{N,ous} \cdot N_{ti} \quad (2.7)$$

The influent unbiodegradable particulate organic nitrogen (N_{oupi}) is associated with the influent unbiodegradable particulate COD (S_{upi}), and is expressed as follows:

$$N_{oupi} = f_{Z,N} \cdot f_{S,up} \cdot S_{ti} \quad (2.8)$$

where $f_{Z,N}$ = fraction of VSS (COD units) which is N.

The influent biodegradable organic nitrogen (N_{obi}) is given by the difference of the total influent TKN (N_{ti}) and the sum of N_{ai} , N_{ousi} and N_{oupi} :

$$\begin{aligned} N_{obi} &= N_{ti} - N_{ai} - N_{ousi} - N_{oupi} \\ &= N_{ti} (1 - f_{N,a} - f_{N,ous}) - f_{Z,N} \cdot f_{S,up} \cdot S_{ti} \end{aligned} \quad (2.9)$$

The soluble (N_{obsi}) and particulate (N_{obpi}) influent biodegradable organic nitrogen concentrations are respectively:

$$N_{obsi} = (1 - f_{Nob,p}) N_{obi} \quad (2.10)$$

$$N_{obpi} = f_{Nob,p} \cdot N_{obi} \quad (2.11)$$

To specify the wastewater fully, values must be assigned to the total influent TKN concentration (N_{ti}) and the fractions $f_{N,a}$, $f_{N,ous}$ and $f_{Nob,p}$. The magnitudes of the fractions will vary from influent to influent, and will differ for an unsettled and a primary settled wastewater. In the program default values are provided for raw and settled wastewaters; these are approximate average values observed for municipal wastewaters in South Africa. Procedures for the determination of these values are set out in Chapter 6.

Following the IAWPRC recommendations, an influent biological (active) mass nitrogen fraction (N_{ZBi}) is included in both models,

$$N_{ZBi} = f_{ZB,N} \cdot S_{ZBi}$$

where $f_{ZB,N}$ = fraction of biological (active) mass which is nitrogen.

Quantification of this nitrogen fraction depends on the influent biological (active) mass, which can be determined only by trial and error simulations, see earlier.

CHAPTER 3

INSTALLING THE PROGRAMS

THE SUPPLIED DISKS

Three 5½ inch floppy disks will be found on the inside of the front cover of the manual. Two of the floppy disks, labelled 'UCTOLD Listed Version' and 'IAWPRC Listed Version', contain listings of the two computer programs; the programs are written using Borland's Turbo Pascal version 4.0 and can be listed with the Borland compiler/editor. Also, alterations to the programs can be made using this compiler/editor. [Should the user make any alterations, the authors request that details of these alterations be forwarded to them for possible incorporation in future versions of the programs.]

The third floppy disk, labelled "Distribution disk" contains compiled versions of the two computer programs, UCTOLD and IAWPRC. This chapter contains instructions on the installation and use of the two activated sludge system simulation programs supplied on the distribution disk.

IMPORTANT NOTE !!

No attempt should be made to run the programs directly from the distribution disk. The instructions in this Chapter should be followed to set up the programs. Users are advised, for their own protection, to make a back-up copy of the distribution disk and to store the original. Instructions on how to make a back-up disk follow in the section below.

BACK-UP COPIES

The distribution disk is formatted for a standard 5½ inch disk, 360K disk drive, and can be read by an IBM PC or compatible. The following procedure can be used to make a back-up copy of the distribution disk:

- Find a new (or unused) floppy disk.
- Boot up your computer.
- At the system prompt type **diskcopy A: B:** and press <Enter>. The message **Insert source diskette into drive A:** will be displayed on the screen. Remove any disk from drive A and replace it with the distribution disk.

- If your system has two floppy disk drives, the screen will say **Insert destination diskette into drive B:**. In that case remove any disk from drive B, replacing it with the blank disk. If your system has only one floppy drive then you will be swapping disks in drive A. Remember that the distribution disk is the **source** disk and the blank disk is the **destination** disk.
- Now press <Enter>. The computer will start reading from the source disk in drive A.
- If you have a two-drive system the computer will then write to the destination disk in drive B and continue reading from drive A and writing to drive B until copying is complete. If you have a one-drive system you will be asked to alternatively put the destination disk and the source disk in drive A until copying is finished.

FILES ON THE DISTRIBUTION DISK

The distribution disk contains the following four files:

UCTOLD.EXE
IAWPRC.EXE
SQ555.DAT
RETRIEVE.EXE

The files **UCTOLD.EXE** and **IAWPRC.EXE** are the two executable program files. **SQ555.DAT** is a data file containing a diurnal influent pattern. This data set can be used as an example. **RETRIEVE.EXE** is the program used to convert data files generated by the simulation programs into a format which can be imported into a spreadsheet package (see **Appendix A**).

SYSTEM REQUIREMENTS

The programs will run on an IBM PC or compatible machine using DOS 3.0 or greater. The amount of RAM memory in the machine will determine the size of system which can be simulated using the programs. With 256K of memory, systems with only one or two reactors can be simulated. The maximum number of reactors increases to twelve with 640K of memory. When using the programs the maximum allowable number of reactors is determined automatically by the program, depending on the amount of memory detected in the particular computer. It is possible that the maximum allowable number of reactors will be reduced if memory resident utilities, such as menu operating programs, have been loaded.

The programs will detect whether or not a graphics adapter is resident in the computer and select the appropriate screen driver automatically. The graphics adapters which can be detected are CGA, EGA, VGA, ATT, PC3270 and Hercules. If a colour card is resident then the programs output will appear in various colours on the screen. In the section of the programs where dynamic system response is simulated one of the options is to display results graphically. If the computer does not have graphics capabilities then a message to this effect is displayed on the screen should this option be selected.

When graphs are displayed on the screen the user may elect to obtain a printed copy of the graph. Graphs can be printed on a 9-pin Epson-compatible dot matrix printer with graphics capabilities; a range of Epson-compatible dot matrix printers has been used to produce graphical output successfully.

The programs use space in "high" memory to store data. It is possible that problems may be encountered when executing the programs if memory-resident utilities such as spelling checkers have been loaded into memory.

The speed of execution of the simulation programs is dependent on the type of computer used. As a guideline the following execution times were measured when running the program **IAWPRC** on a 10-MHz IBM AT compatible, for a two-reactor contact stabilization system subjected to a square wave influent loading pattern.

Steady state solution: 18 seconds.

Dynamic solution: 10 minutes to simulate the performance over five 24-hour cycles, i.e. 1 minute per cycle per reactor.

This example is a particularly "difficult" one from a numerical point of view for two reasons; (1) the difference in reactor sizes demands a large number of iterations to converge to the steady state solution and necessitates small integration steps, and (2) the sudden changes in the influent pattern compounds the problem of small integration steps. Execution times should be considerably shorter for problems with more standard reactor configurations and less discontinuous influent patterns, and for more advanced computers.

SETTING UP ON A FLOPPY DISK SYSTEM

The two programs, **UCTOLD** and **IAWPRC**, take up most of the space on the distribution disk - approximately 330K of the available 360K. This does not leave much space for storing data files generated by the user. It is therefore suggested that separate floppy disks be set up for *each* program. The procedure outlined below should be followed:

For the **UCTOLD** program:

- Place the distribution disk in drive A.
- Place a blank formatted disk labelled **UCTOLD** in drive B.
- At the DOS prompt on the screen (probably A:> or B:>) type the following instructions (pressing <Enter> at the end of each line):

```
copy a:uctold.exe b:  
copy a:retrieve.exe b:  
copy a:sq555.dat b
```

For the **IAWPRC** program:

- Place the distribution disk in drive A.
- Place a blank formatted disk labelled **IAWPRC** in drive B.

- At the DOS prompt on the screen (probably A:> or B:>) type the following instructions (pressing <Enter> at the end of each line):

```
copy a:iawprc.exe b:  
copy a:retrieve.exe b:  
copy a:sq555.dat b:
```

SETTING UP ON A HARD DISK SYSTEM

The most convenient method for running the programs on a hard disk system is to execute each program from its own subdirectory. Typically these would be called UCTOLD and IAWPRC. The procedure outlined below would then be followed:

- Assuming that the hard disk is designated as drive C, type the following commands (pressing <Enter> at the end of each line):

```
c:  
cd c:\  
mkdir uctold  
mkdir iawprc
```

If the hard disk is not designated as drive C, replace C by the relevant designation code.

- Place the distribution disk in the disk drive (usually drive A).
- Change to the subdirectory UCTOLD by entering the command

```
cd c:\uctold
```

- At the DOS prompt on the screen (C:> or C:\UCTOLD>) type the following instructions (pressing <Enter> at the end of each line):

```
copy a:uctold.exe  
copy a:retrieve.exe  
copy a:sq555.dat
```

- Change to the subdirectory IAWPRC by entering the command

```
cd c:\iawprc
```

- At the DOS prompt on the screen (C:> or C:\IAWPRC>) type the following instructions (pressing <Enter> at the end of each line):

```
copy a:iawprc.exe  
copy a:retrieve.exe  
copy a:sq555.dat
```

CHAPTER 4

RUNNING THE PROGRAMS

STARTING PROGRAM EXECUTION

In **Chapter 3**, procedures were described to set up the programs for execution on a floppy drive and a hard drive system. In this Chapter execution of the programs is described for the UCTOLD program. If the IAWPRC program is to be run, then substitute IAWPRC for UCTOLD.

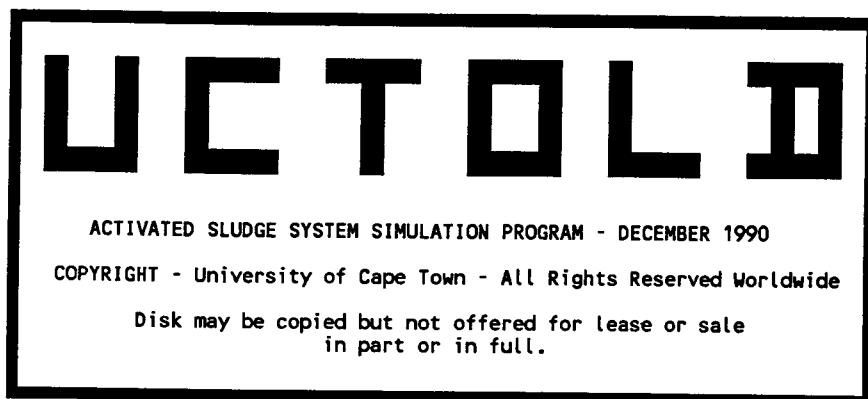
Floppy disk system

- Boot up the computer from a DOS disk in drive A:
- Remove the DOS disk from drive A: and replace with disk labelled UCTOLD (see **Chapter 3**)
- To initiate execution of the program, at the DOS prompt A:> the user must type

UCTOLD

and then press the carriage return key (<RETURN>, <C/R>, <ENTER> key on different keyboards).

- The program will be loaded into memory from disk, after which the title page will appear on the screen as shown below.



Depts Chemical/Civil Eng.
University of Cape Town
Rondebosch 7700 South Africa

Program written by P Dold,
A Billing, M Wentzel,
G Ekama and G Marais.

Hit key to continue...

Hard disk system

- Boot up the system from the hard disk
- At the DOS prompt C:> change to the subdirectory UCTOLD (see Chapter 3) by entering the command

cd c:\uctold

- To initiate execution of the program, at the DOS prompt (either C:> or C:\UCTOLD>) type

UCTOLD

and press the carriage return key

- The program will be loaded into memory from the hard disk, after which the title page will appear on the screen as shown above.

Once the title page appears on the screen any key may be pressed to continue execution of the program

INTERACTIVE DATA INPUT BY THE USER

The activated sludge simulation program is "menu driven". That is, the user selects a desired program option from a list of possible options displayed on the screen. In this program an option is selected by moving a shaded block (or "highlight") on the screen to cover the appropriate option and then pressing the <RETURN> key on the keyboard. (Details of how to move the highlight between options are given later.) This approach should be familiar to users of many commercial software packages and is adopted to simplify program operation and to minimize the amount of typing by the user. Even though the program is "menu driven" the user nevertheless is required to input certain information from the keyboard such as reactor volumes, COD concentrations, the response to queries (usually Yes/No), and so on. The actions required from the user to input this information should be self-evident. However, to obviate any confusion, a brief instruction on keyboard input follows before program operation is demonstrated.

Keyboard data input typed in by the user falls into three categories:

- **Single characters:** At a number of stages the user must respond to a query printed on the screen. For example, whether or not a set of data must be listed by a printer. In response to these queries a single alphabetical character must be pressed on the keyboard. For example if the query were as follows:

Print data? Y/N...

the user merely has to press either the Y or N key to respond. It is not necessary to press the <RETURN> key after typing the letter Y or N. Furthermore, the program is case-insensitive; that is, either upper- or lower-case letters may be typed (Y or y / N or n in this case).

- **Numerical data:** In many instances the user is required to input numerical data; for example, a reactor number or volume. To enter these data the user types in the appropriate value and then presses the <RETURN> key. The Backspace key may be used to delete typing errors before the <RETURN> key is pressed.
- **File names:** Diurnal influent patterns and diurnal response results may be stored on disk for subsequent use. To input a file name the user types in the alphanumeric string and then presses the <RETURN> key. The maximum number of characters allowed in a file name is eight. If the user attempts to enter a file name with more than eight characters only the first eight characters will be assigned to the file name. The files containing diurnal influent patterns and diurnal results are automatically given the extension .DAT and .DID, respectively. When entering a file name it is not necessary to type in the extension.

These instructions apply to data input throughout the program. In the demonstration of program operation which follows the instructions will not be repeated at each point where input by the user is required. For example, the instructions may state that "the user must enter the COD concentration". This implies that the user must type in the value and then press the <RETURN> key.

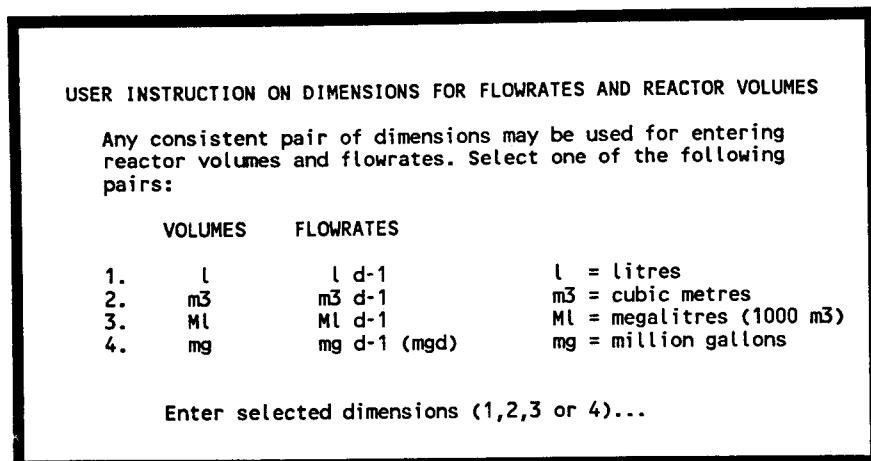
The user will find that it is very difficult to upset program operation when inputting information. Protection against typing incorrect keys is built into the program wherever possible. Here are three examples:

- If either a Y or an N is expected by the program any other key pressed by the user is ignored.
- If a numerical value is to be entered all keys other than those in the set [0,1,...,8,9] (and the decimal point for non-integer values) are ignored if pressed.
- If the user is required to enter a reactor number when there are, say, three reactors in the configuration only the 1, 2 or 3 keys will be accepted as input.

UNITS FOR REACTOR VOLUMES AND FLOWRATES

Concentration units of g m^{-3} (mg l^{-3}) are used throughout the program. In the case of reactor volumes and flowrates, the user may select one of four possible sets of consistent dimensions. For each set the volumetric quantity is the same (either litres, cubic metres, megalitres or million gallons) and the flowrates are specified as the volumetric quantity per day.

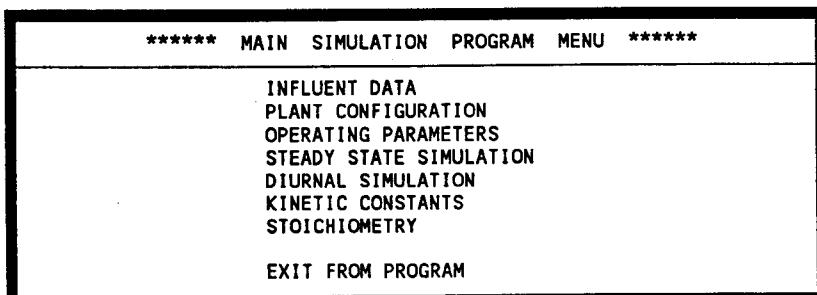
When the title page is visible and any key is pressed, the program advances and the window below will appear on the screen.



To select the appropriate units the user must enter either 1, 2, 3 or 4 as indicated on the screen. The selected units will be used when the program prints information or prompts the user for volumes and flow rates. After the units have been selected, the program automatically advances to the main menu.

THE MAIN MENU

The main program menu is as follows



Press <Arrows> or <SpaceBar> to move selection

Press <Return> to select option

Eight options, including the option to exit from the program, appear in the upper window of the main menu screen. An option is selected by moving the highlighted block¹ to that option and pressing the <RETURN> key. The cursor (-) blinks alongside the highlighted option. The highlighted block may be moved between options by pressing the "up arrow" (\uparrow) or "down arrow" (\downarrow) keys or by pressing the spacebar (this scrolls the highlight downwards). Brief instructions on how to move between options and select an option are shown in the lower window on the screen.

¹In this manual the relevant highlighted option will be indicated by a pointer in the printout of the program screen.

Three options necessarily must be executed before the response of a system can be simulated: **INFLUENT DATA**, **PLANT CONFIGURATION** and **OPERATING PARAMETERS**. If the user attempts to execute the options **STEADY STATE SIMULATION** or **DIURNAL SIMULATION** before the necessary data have been supplied a message such as that shown below will be flashed on the screen indicating which data are required. The main menu will then appear with the appropriate option highlighted.

First specify plant CONFIGURATION....

Once the **INFLUENT DATA**, **PLANT CONFIGURATION** and **OPERATING PARAMETERS** options have been executed the user may select the **STEADY STATE SIMULATION** and then the **DIURNAL SIMULATION** options in that order. In the simulations, default values for the kinetic and stoichiometric constants will be used unless changes have been made to these constants via the **KINETIC CONSTANTS** or **STOICHIOMETRY** options.

The **KINETIC CONSTANTS** option can be selected only if the plant operating temperature has been specified (in the **OPERATING PARAMETERS** option). This is to allow calculation of the values of the constants at the operating temperature based on the values at the reference temperature of 20°C.

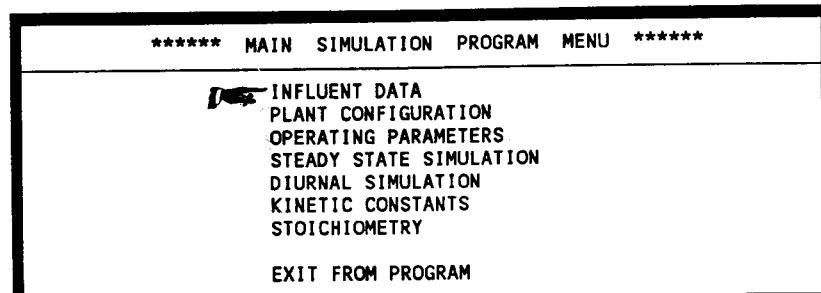
In the remainder of this Chapter, operation of the program is demonstrated using the UCTOLD program as an example. Each of the options in the main menu will be covered in turn with a detailed explanation of all data input options, sub-menus and so on. The instructions for each main menu option will commence on a new page for ease of reference.

INFLUENT DATA

The program requires the influent wastewater COD and TKN concentrations and the influent flowrate. There are a number of options for inputting these data:

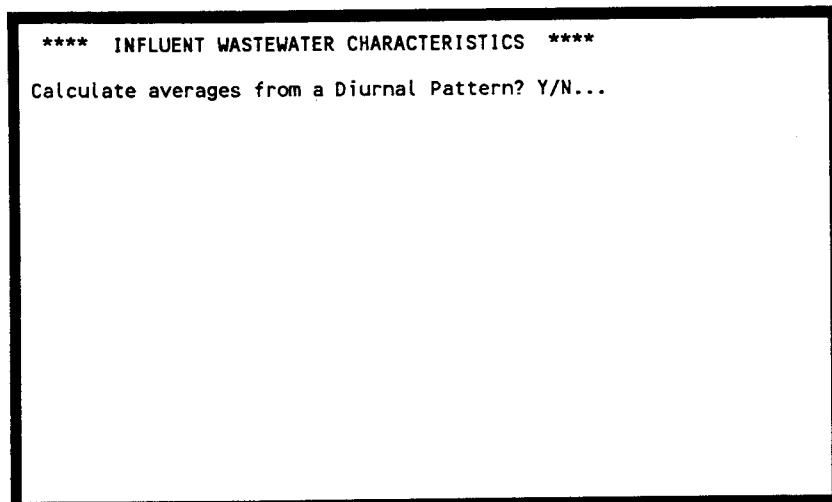
- If the user wishes to analyze only steady state behaviour then the average influent values may be input directly from the keyboard.
- If the user wishes to analyze diurnal behaviour, then the time-varying influent flow and concentration data must be supplied; the data can be input either from the keyboard or loaded from a disk file. Once the diurnal data have been entered the average influent flowrate and COD and TKN concentrations are computed.
- If the user wishes to analyze steady state behaviour, but the average influent values are calculated from a diurnal pattern, data input is as for the diurnal case.

When the user has selected the set of units for reactor volumes and flowrates the main menu appears with the **INFLUENT DATA** option highlighted as shown below.



Press <Arrows> or <SpaceBar> to move selection
Press <Return> to select option

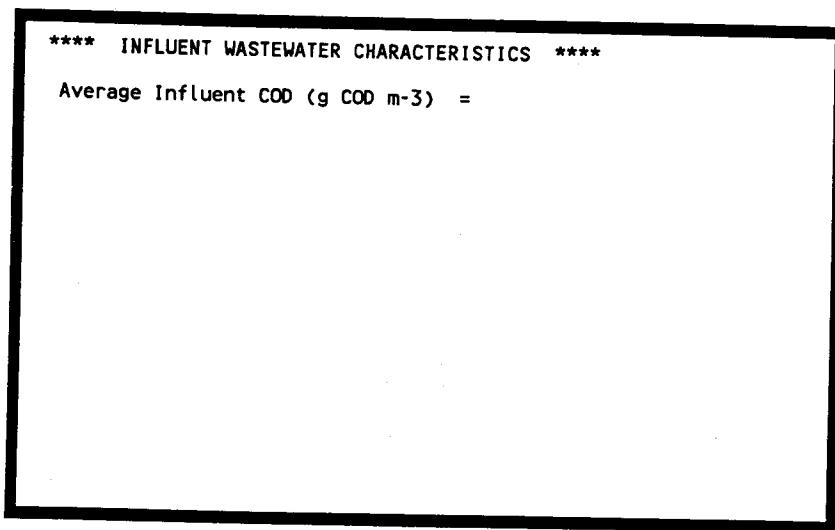
If the **INFLUENT DATA** option is selected from the main menu a window will appear on the screen as follows



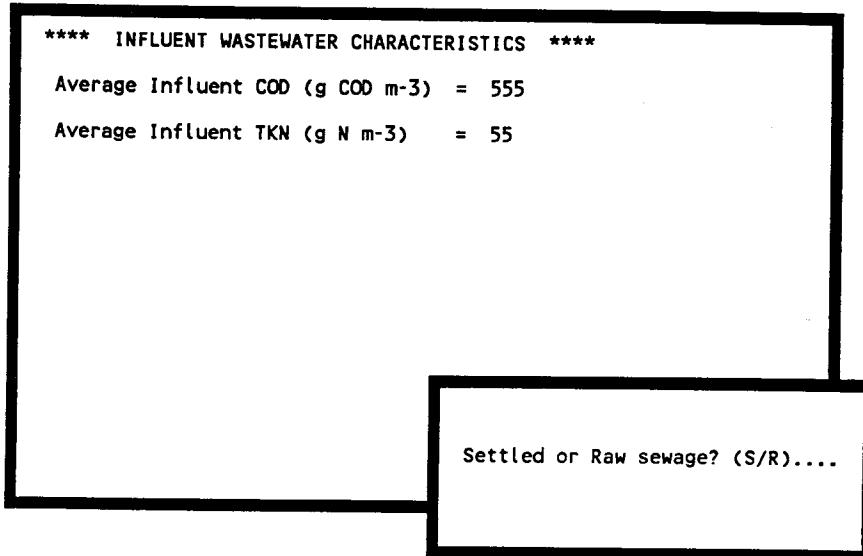
If Y is entered continue on page 4.10; if N, continue overleaf.

Entering steady state influent data

If only steady state behaviour is to be analyzed, and the average influent and concentrations are known, then the user presses the **N** key. The following will appear



The user is prompted to enter the average influent COD concentration, thereafter the average influent TKN concentration. Once both values have been entered a second window appears on the screen towards the lower right corner.



Default values for the characteristics of raw and settled sewage are provided in the program. These are average values for the various COD and TKN fractions encountered with South African municipal wastewaters. The user makes the appropriate selection by entering **S** or **R** for settled or raw sewage, respectively. The screen will appear as follows with the selected values of the fractions as well as the average influent COD and TKN concentrations and a default value for the influent alkalinity appearing in the main window. A legend explaining the meaning of the fractional values is shown in a window at the lower left of the screen.

**** WASTEWATER CHARACTERISTICS ****		
Sti(avg)	g COD m-3	555.000
Nti(avg)	g N m-3	55.000
Fbs	g COD g-1 COD	0.200
Fs,us	g COD g-1 COD	0.050
Fs,up	g COD g-1 COD	0.130
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

RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH3/NH4
 Fnob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
to move selection

 Hit <Return> to enter
new value for
selected constant

Changes to any of the values (influent COD, TKN and alkalinity as well as the sewage fractions) can be made at this stage. Any updated data will remain current during execution of the program, unless changed again. When the program execution is halted and then is re-run, the original default values will appear.

Instructions for changing any of the data are provided in the window at the lower right of the screen. To update a value the highlighted block must be moved from RETURN TO MENU to the value which is to be changed. This is achieved by pressing the "up arrow" (\uparrow) or "down arrow" (\downarrow) keys or by pressing the spacebar (this scrolls the highlight from the top downwards). When the highlight appears on the value to be changed the user presses the <RETURN> key, and is prompted for a new value as shown below. On typing the new value and pressing the <RETURN> key the screen is updated and the highlight reverts to the RETURN TO MENU position.

**** WASTEWATER CHARACTERISTICS ****		
Sti(avg)	g COD m-3	555.000
Nti(avg)	g N m-3	55.000
Fbs	g COD g-1 COD	0.200
Fs,us	g COD g-1 COD	0.050
Fs,up	g COD g-1 COD	0.130
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

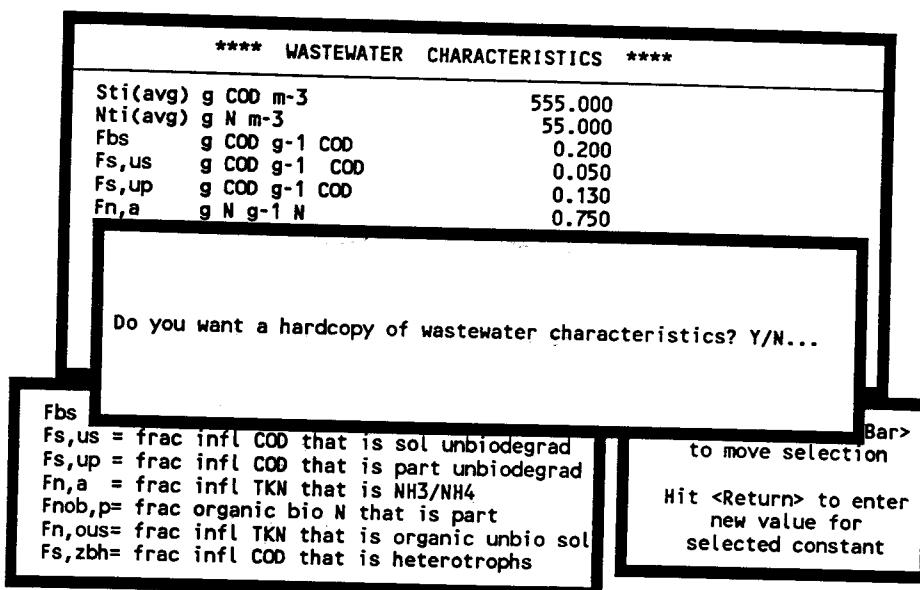
RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH3/NH4
 Fnob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

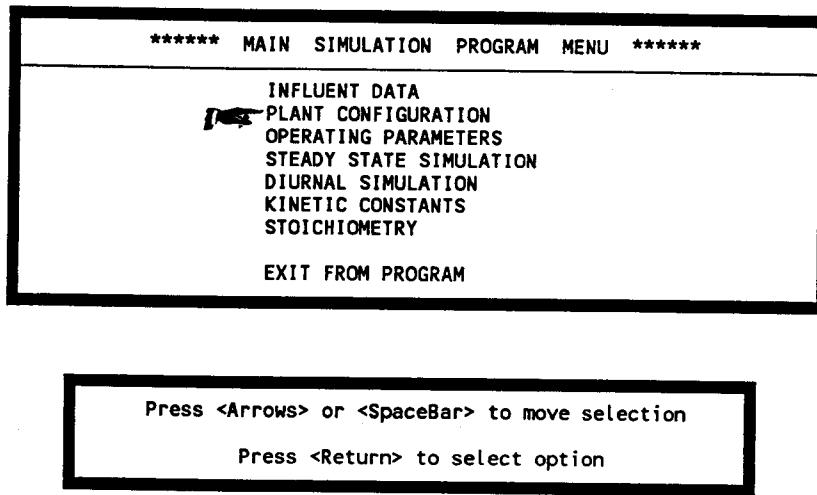
Hit <Arrows>/<SpaceBar>
to move selection

 Hit <Return> to enter
new value for
selected constant

When the user is satisfied with the influent data the <RETURN> key must be pressed with the highlight in the RETURN TO MENU position. Before the main menu is re-listed a new window appears at the centre of the screen as shown below.



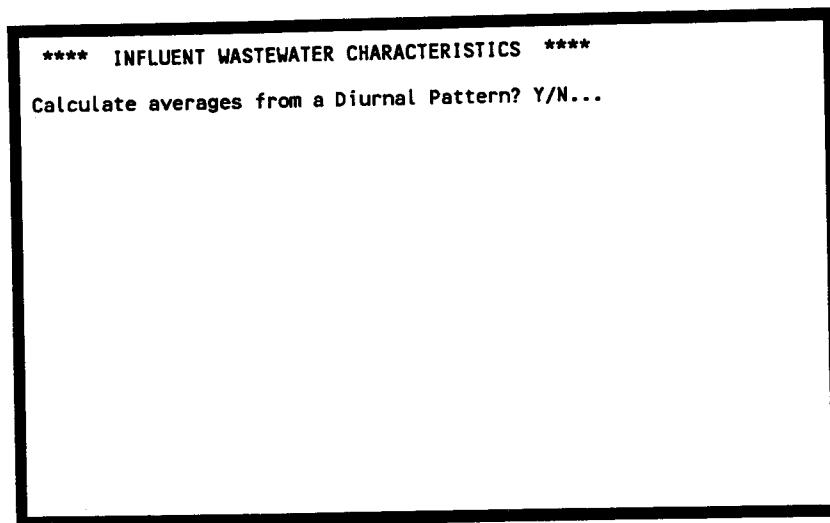
When a printer is attached to the computer the user may respond by entering Y; else N is entered to proceed. If Y is entered there will be a short delay (of a few seconds) while data are sent to the printer. At a later stage, directly after simulating either the steady state or diurnal response, it is again possible to obtain a printout of the sewage characteristics. After entering Y or N the program reverts to the main menu and the highlight appears on the PLANT CONFIGURATION option as shown below.



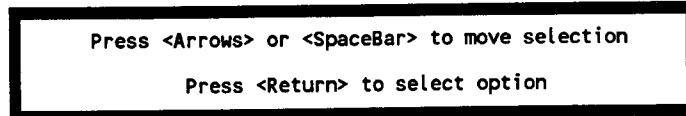
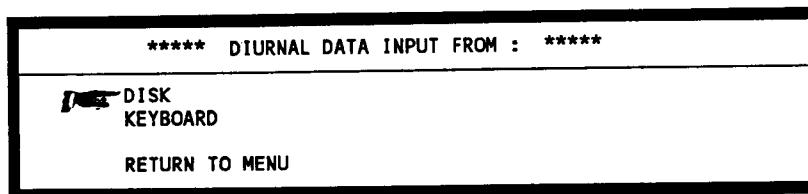
Instructions for entering PLANT CONFIGURATION data commence on Page 4.21.

Entering a diurnal influent pattern

When the INFLUENT DATA option is first selected from the main menu the user is required to specify whether or not a diurnal influent pattern is required, as shown in the following window.



The procedure to follow when **N** is entered was explained in the previous section Entering steady state influent data. If the **Y** key is pressed the following window will appear.



If one or more diurnal influent patterns have already been stored on disk one of these may be retrieved by selecting the DISK option. This option is outlined in the next section Retrieving a diurnal pattern from disk on Page 4.16.

If diurnal data are to be input for the first time or if a new diurnal pattern is to be input then the KEYBOARD option must be selected. The following instruction on the format of the diurnal data then appears on the screen.

CREATING DATA FOR DYNAMIC ANALYSIS

To utilise the program for the simulation of dynamic process response it is necessary first to set up arrays which contain the time-varying values of the influent FLOWRATE, COD and TKN. The program requires 12 sets of values; that is, two-hourly values. These values can be stored on the working disk drive once the user is satisfied.

** Hit any key to continue...

Program execution is advanced by pressing any key as instructed. A new screen appears with a main window and an input window as shown below. The user is prompted to input twelve sets of data (influent flowrate and concentrations of COD and TKN) as requested in the input window at the lower right of the screen. These are the average values for each of the twelve two-hour intervals, starting with the first interval at 0h00. Each time interval extends from the given time for the next two hours. For example, data for time 0h00 applies for the period 0h00 to 2h00.

***** DIURNAL INPUT PATTERN *****

Record No	Time (h)	Flow($m^3 d^{-1}$)	COD ($g m^{-3}$)	TKN ($g m^{-3}$)

Time (hours) = 0h00 :

Flowrate (m³ d⁻¹) =

As each set of flowrate, COD and TKN is completed, the set appears in the main window. For example, when six sets have been input the screen may be as follows.

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow(m ³ d ⁻¹)	COD (g m ⁻³)	TKN (g m ⁻³)
1	0.0	0.0	555.0	55.0
2	2.0	0.0	555.0	55.0
3	4.0	0.0	555.0	55.0
4	6.0	0.0	555.0	55.0
5	8.0	22.0	555.0	55.0
6	10.0	22.0	555.0	55.0

Time (hours) = 12h00 ;

Flowrate (m³ d⁻¹) =

When all twelve sets of data have been entered the weighted mean values are calculated and appear in the main window at the lower left as shown below. For this case a square wave influent pattern has been set up. The flowrate is $22 \text{ m}^3 \text{ d}^{-1}$ for a period of 12 hours (6 intervals of 2 hours starting at 08h00 and ending at 20h00; note that record number 10 with time 18.0 applies for the period 18h00 to 20h00) with no flow for the remainder of the diurnal cycle. The concentrations of COD (gCOD m^{-3}) and TKN (gN m^{-3}) are intended to be constant at 555 and 55, respectively. However, an error appears in the sixth record where the TKN has been entered incorrectly as 44 gN m^{-3} .

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow($\text{m}^3 \text{ d}^{-1}$)	COD (g m^{-3})	TKN (g m^{-3})
1	0.0	0.0	555.0	55.0
2	2.0	0.0	555.0	55.0
3	4.0	0.0	555.0	55.0
4	6.0	0.0	555.0	55.0
5	8.0	22.0	555.0	55.0
6	10.0	22.0	555.0	44.0
7	12.0	22.0	555.0	55.0
8	14.0	22.0	555.0	55.0
9	16.0	22.0	555.0	55.0
10	18.0	22.0	555.0	55.0
11	20.0	0.0	555.0	55.0
12	22.0	0.0	555.0	55.0

** Calculated Mean Values : Change any values? Y/N....

Flowrate = 11.0	Change any values? Y/N....
COD = 555.0	
TKN = 53.2	

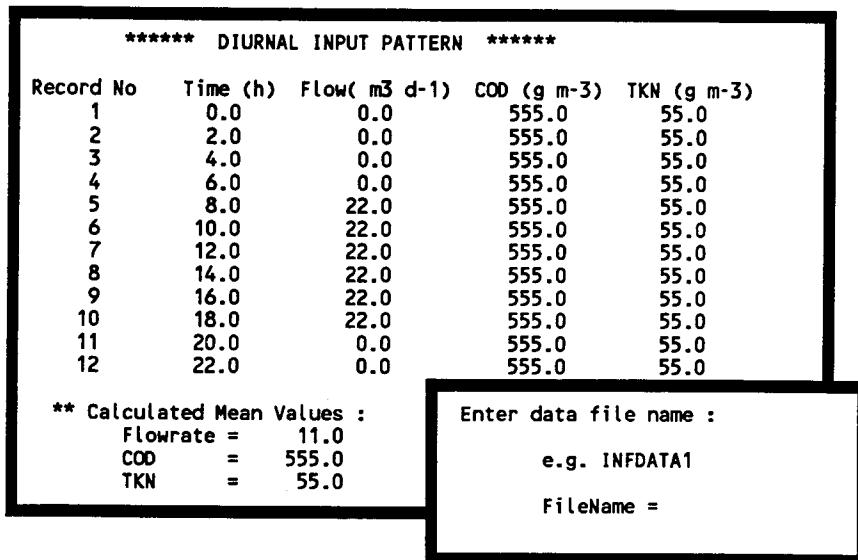
After all the data have been entered corrections can be made by entering a Y at the prompt in the input window. The record number (6 here) is entered. The user is prompted to enter all three values for that record. The mean influent values are recalculated and the screen is updated. When the data are correct the user advances the program by responding with an N to the request for changes. The message in the input window will change as follows.

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow($\text{m}^3 \text{ d}^{-1}$)	COD (g m^{-3})	TKN (g m^{-3})
1	0.0	0.0	555.0	55.0
2	2.0	0.0	555.0	55.0
3	4.0	0.0	555.0	55.0
4	6.0	0.0	555.0	55.0
5	8.0	22.0	555.0	55.0
6	10.0	22.0	555.0	55.0
7	12.0	22.0	555.0	55.0
8	14.0	22.0	555.0	55.0
9	16.0	22.0	555.0	55.0
10	18.0	22.0	555.0	55.0
11	20.0	0.0	555.0	55.0
12	22.0	0.0	555.0	55.0

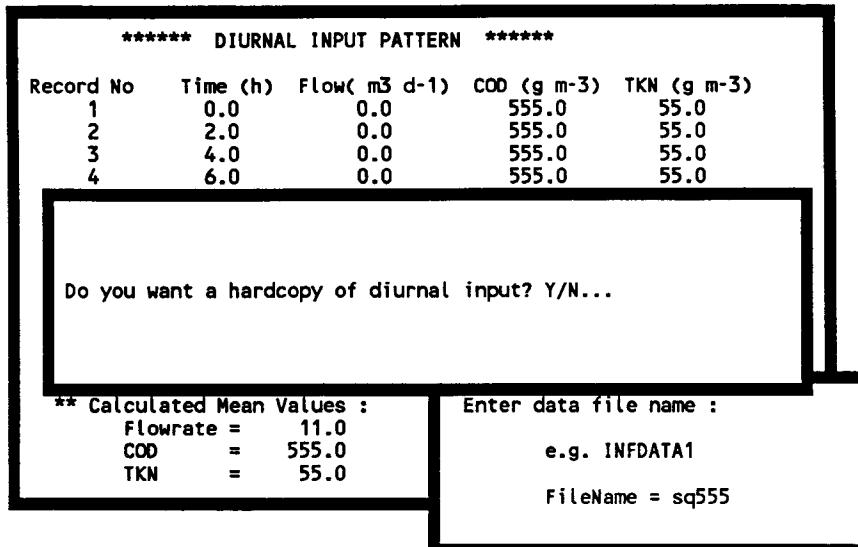
** Calculated Mean Values : Do you wish to store these data on disk ? Y/N....

Flowrate = 11.0	Do you wish to store these data on disk ? Y/N....
COD = 555.0	
TKN = 55.0	

The diurnal pattern may be stored on disk for later use. When the user wishes to store the influent pattern Y is entered at the prompt and a name is requested as shown below.



Once a name has been entered (maximum of 8 characters) the data are stored on disk. The data are stored in a file of the specified name with the extension .DAT on the disk (and in the directory) from where the program was executed. Once the data have been stored a window appears at the centre of the screen as shown below.



The user is prompted to enter Y to obtain a printout of the diurnal influent pattern. After the Y or N key is pressed the screen will appear as follows.

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow(m ³ d ⁻¹)	COD (g m ⁻³)	TKN (g m ⁻³)
1	0.0	0.0	555.0	55.0
2	2.0	0.0	555.0	55.0
3	4.0	0.0	555.0	55.0
4	6.0	0.0	555.0	55.0

Do you want a hardcopy of diurnal input? Y/N...

** Calculated Mean Values :
 Flowrate = 11.0
 COD = 555.0
 TKN = 55.0

Settled or Raw sewage? (S/R)....

The user must specify whether raw or settled sewage characteristics are to be selected. Once the R or the S key is pressed the list of wastewater characteristics will appear on the screen as shown below. The values for the average influent COD and TKN concentration are those calculated from the diurnal influent pattern, and the values for the constants are default values obtained for South African municipal wastewaters.

**** WASTEWATER CHARACTERISTICS ****	
Sti(avg) g COD m ⁻³	555.000
Nti(avg) g N m ⁻³	55.000
Fbs g COD g ⁻¹ COD	0.200
Fs,us g COD g ⁻¹ COD	0.050
Fs,up g COD g ⁻¹ COD	0.130
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

 RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH₃/NH₄
 Fnob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
 to move selection

Hit <Return> to enter
 new value for
 selected constant

Changes can be made to the default values where appropriate by following the instructions in the lower right window. This procedure has been outlined in the previous section Entering steady state influent data. When the user is satisfied with the influent data the <RETURN> key must be pressed with the highlight in the RETURN TO MENU position. Before the main menu is re-listed a new window appears at the centre of the screen as shown overleaf.

***** WASTEWATER CHARACTERISTICS *****		
Sti(avg) g COD m ⁻³	555.000	
Nti(avg) g N m ⁻³	55.000	
Fbs g COD g ⁻¹ COD	0.200	
Fs,us g COD g ⁻¹ COD	0.050	
Fs,up g COD g ⁻¹ COD	0.130	
Fn,a g N g ⁻¹ N	0.750	

Do you want a hardcopy of wastewater characteristics? Y/N...

Fbs
Fs,us = frac infl COD that is sol unbiodegrad
Fs,up = frac infl COD that is part unbiodegrad
Fn,a = frac infl TKN that is NH3/NH4
Fnob,p= frac organic bio N that is part
Fn,ous= frac infl TKN that is organic unbio sol
Fs,zbh= frac infl COD that is heterotrophs

Bar>
to move selection
Hit <Return> to enter
new value for
selected constant

When a printer is attached to the computer the user may respond by entering **Y**; else an **N** is entered to proceed. If a **Y** is entered there will be a short delay (of a few seconds) while data are sent to the printer. At a later stage, directly after simulating either the steady state or diurnal response, it is again possible to obtain a printout of the sewage characteristics. After entering **Y** or **N** the program returns to the main menu with the highlight appearing on the **PLANT CONFIGURATION** option as shown below.

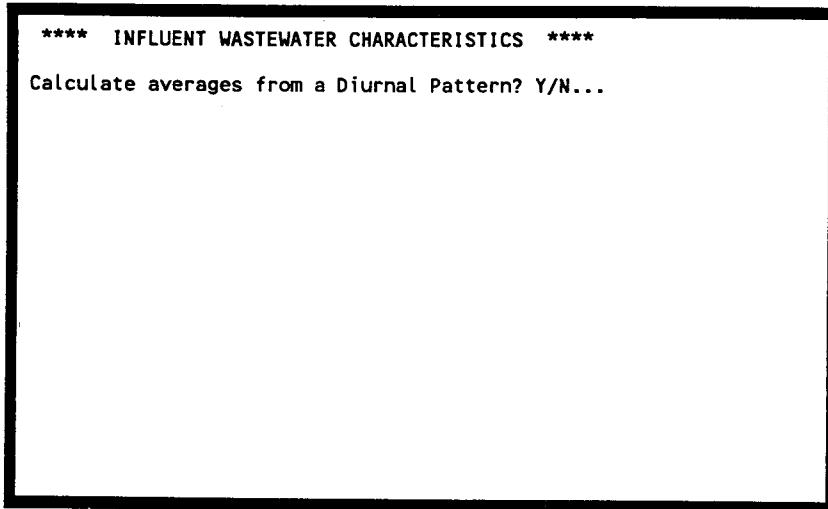
***** MAIN SIMULATION PROGRAM MENU *****	
INFLUENT DATA	
PLANT CONFIGURATION	
OPERATING PARAMETERS	
STEADY STATE SIMULATION	
DIURNAL SIMULATION	
KINETIC CONSTANTS	
STOICHIOMETRY	
EXIT FROM PROGRAM	

Press <Arrows> or <SpaceBar> to move selection
Press <Return> to select option

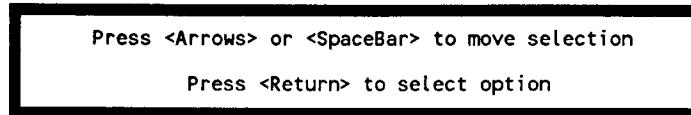
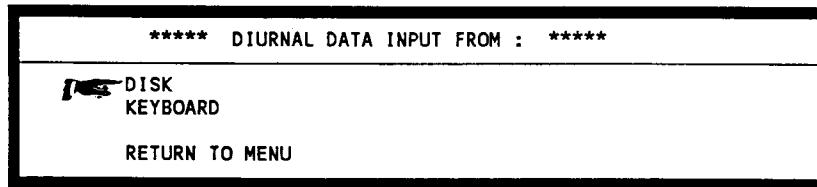
Instructions for entering **PLANT CONFIGURATION** data commence on page 4.21.

Retrieving a diurnal pattern from disk

When the **INFLUENT DATA** option is first selected from the main menu the user is required to specify whether or not a diurnal influent pattern is required in the following window.

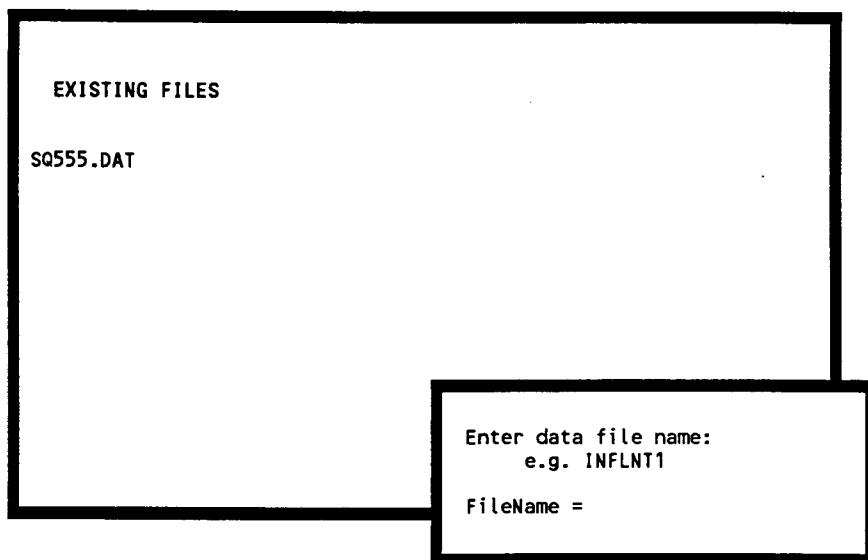


The procedure to follow when an **N** is entered was explained in the earlier section Entering steady state influent data. If the **Y** key is pressed the following window will appear.



If diurnal data are to be input for the first time or if a new diurnal pattern is to be input then the **KEYBOARD** option must be selected. The procedure to follow in this case is outlined in the previous section Entering a diurnal influent Pattern.

If one or more diurnal influent patterns have already been stored on disk one of these may be retrieved by selecting the **DISK** option. As an example, the following may appear on the screen.



The names of all the stored influent data files are listed in three columns in the main window. The user is prompted to enter the name of the file to be retrieved. It is not necessary to type the extension **.DAT**.

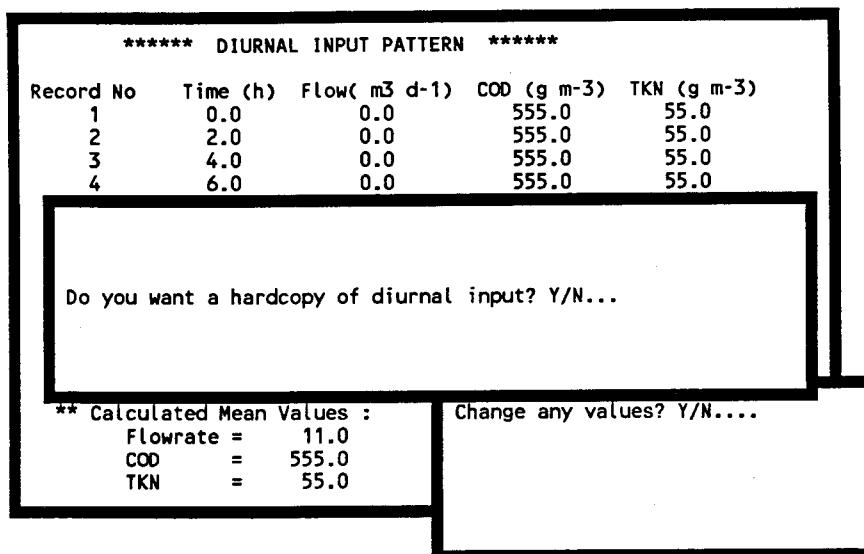
The diurnal data are displayed in the same format as in the previous section Entering a diurnal influent pattern. An example is shown below. Changes to the data can be made, and the modified data stored if desired, as described in that section. Thereafter the user must specify whether raw or settled sewage characteristics are to be selected, and changes made to the default values as appropriate according to the procedure outlined in the section Entering steady state influent data. Finally, the user can obtain a printout if required before returning to the main menu. The procedure to follow once a data file has been retrieved is very similar to that presented in the previous section. However, the procedure is now outlined for the sake of completeness.

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow(m ³ d ⁻¹)	COD (g m ⁻³)	TKN (g m ⁻³)
1	0.0	0.0	555.0	55.0
2	2.0	0.0	555.0	55.0
3	4.0	0.0	555.0	55.0
4	6.0	0.0	555.0	55.0
5	8.0	22.0	555.0	55.0
6	10.0	22.0	555.0	55.0
7	12.0	22.0	555.0	55.0
8	14.0	22.0	555.0	55.0
9	16.0	22.0	555.0	55.0
10	18.0	22.0	555.0	55.0
11	20.0	0.0	555.0	55.0
12	22.0	0.0	555.0	55.0

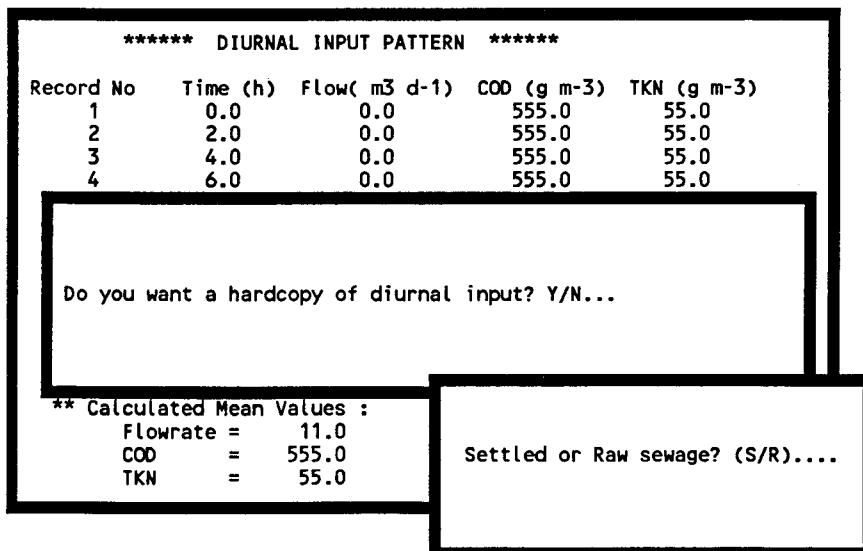
** Calculated Mean Values :
 Flowrate = 11.0
 COD = 555.0
 TKN = 55.0

Change any values? Y/N....

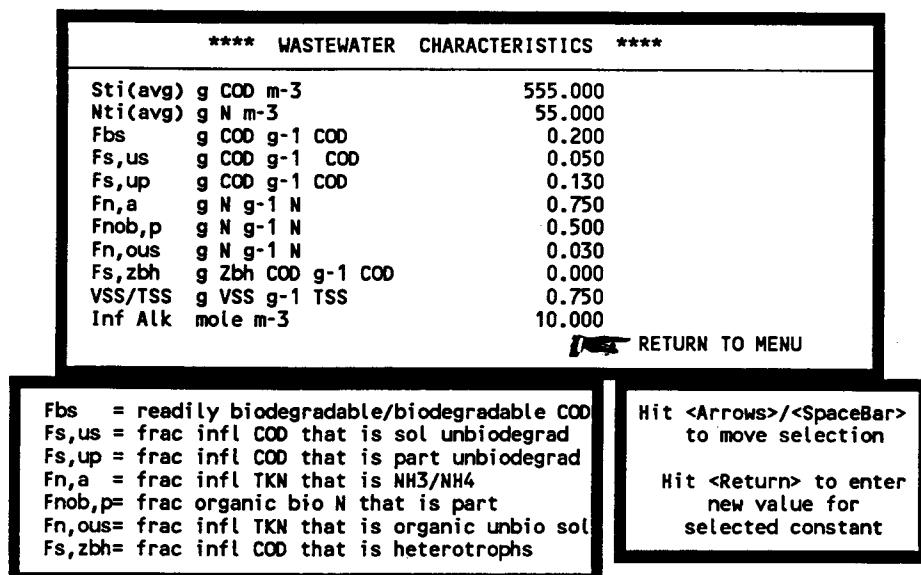
Changes can be made by entering a Y at the prompt in the input window. The record number is entered and the user is prompted to enter all three values for that record. The mean influent values are recalculated and the screen is updated. When no more changes are required, an N is entered and a window appears at the centre of the screen as shown below.



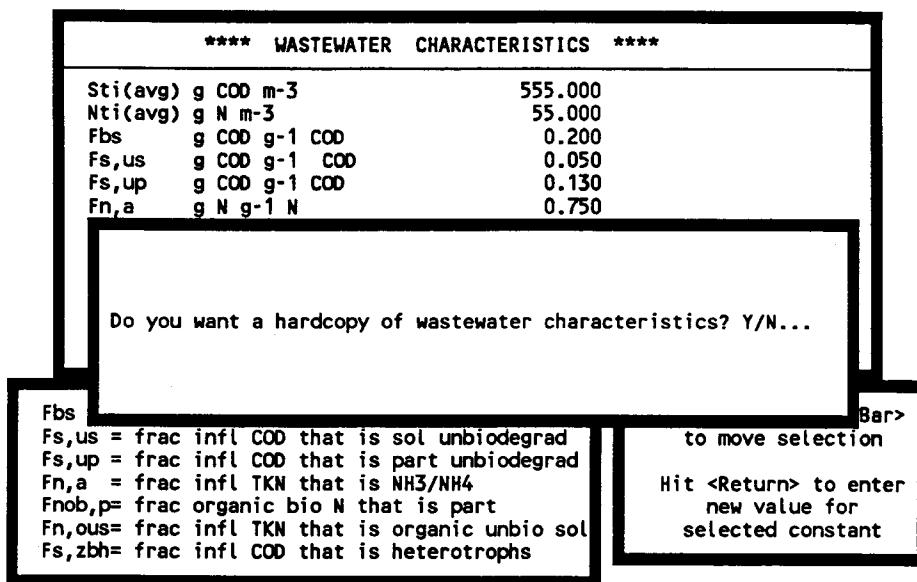
The user is prompted to enter a Y to obtain a printout of the diurnal influent pattern. After the Y or N key is pressed the screen will appear as follows.



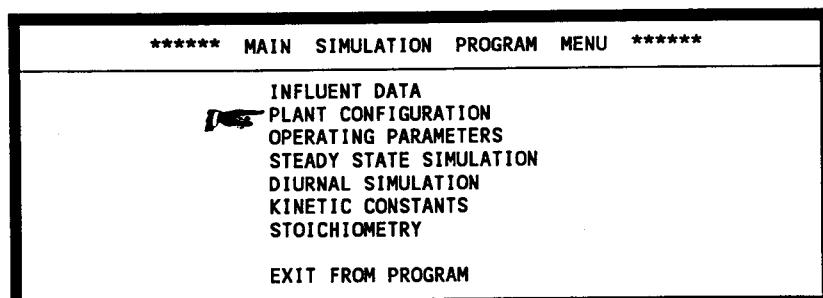
The user must specify whether raw or settled sewage characteristics are to be selected. Once the R or the S key is pressed the list of wastewater characteristics will appear on the screen as shown below. The values for the average influent COD and TKN concentration are those calculated from the diurnal influent pattern and the values of the constants are default values obtained for South African municipal wastewaters.



Changes can be made to the default values as appropriate by following the instructions in the lower right window. This procedure has been outlined in the previous section Entering steady state influent data. When the user is satisfied with the influent data the RETURN TO MENU option is selected. Before the main menu is re-listed a new window appears at the centre of the screen as shown below.



When a printer is attached to the computer the user may respond by entering **Y**; else an **N** is entered to proceed. If a **Y** is entered there will be a short delay (of a few seconds) while data are sent to the printer. At a later stage, directly after simulating either the steady state or diurnal response, it is again possible to obtain a printout of the sewage characteristics. After entering **Y** or **N** the program returns to the main menu with the highlight appearing on the **PLANT CONFIGURATION** option as shown overleaf.

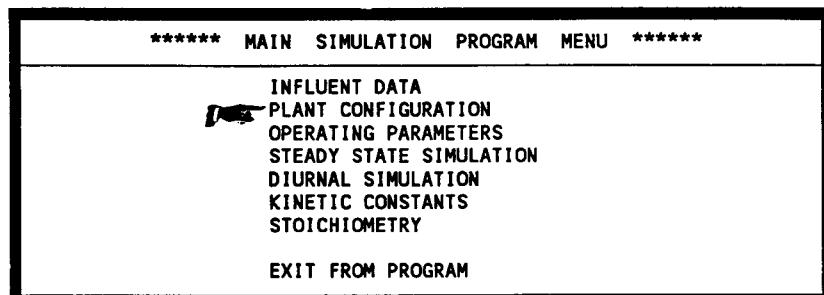


Press <Arrows> or <SpaceBar> to move selection

Press <Return> to select option

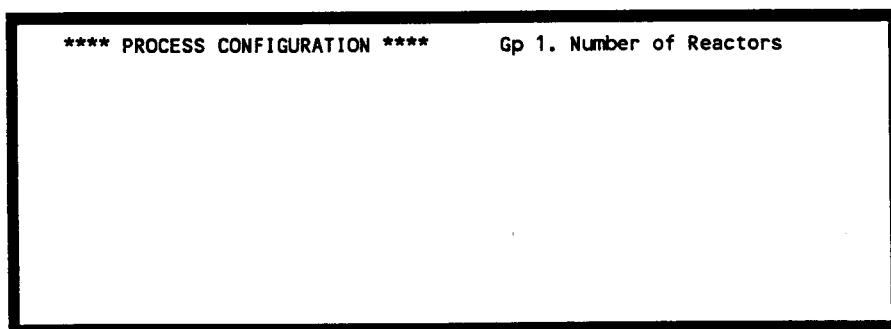
PLANT CONFIGURATION

When the user has completed the input of influent data the main menu appears with the **PLANT CONFIGURATION** option highlighted.



Press <Arrows> or <SpaceBar> to move selection
 Press <Return> to select option

On pressing the <RETURN> key to select the **PLANT CONFIGURATION** option the following screen appears.



Number of reactors (max 12) =

In the input window at the lower right of the screen the user is prompted to enter the number of completely mixed reactors in the system; the maximum allowable number is indicated and has been calculated by the program from the amount of memory available. Thereafter input from the user is dependent on whether one or more reactors are specified. For multiple reactor configurations continue on Page 4.25.

Single reactor configuration

Once the number of reactors has been specified (1 here) the user is prompted to input the reactor volume as shown below. The units of volume (selected earlier) appear in the input window as a reminder.

**** PROCESS CONFIGURATION ****	Gp 1. Number of Reactors = 1
Gp 2. Reactor Vols,m ³	
No. 1:	

Enter reactor volume(s) - m ³ :
Reactor No. 1 =

When the volume of the reactor has been entered the screen will appear as shown below. In an activated sludge system with only one reactor all of the influent necessarily must enter this reactor and the reactor must be aerated. A default dissolved oxygen (DO) concentration of 3 gO m⁻³ (mgO l⁻¹) is assumed.

**** PROCESS CONFIGURATION ****	Gp 1. Number of Reactors = 1	
Gp 2. Reactor Vols,m ³	Gp 3. Feed Fraction	Gp 4. Aeration/DDO
No. 1: 7.00	1.00	3.0

Do you wish to change any parameters?
Y/N....

The user may change the data by following the instructions in the input window. If a change is to be made and the Y key is pressed the input window will appear as follows.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 1	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	7.00	1.00	3.0

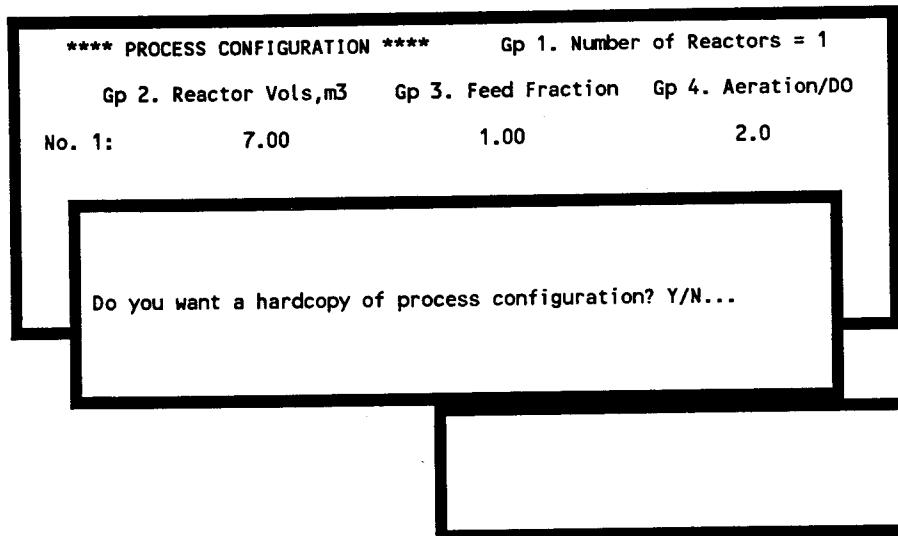
Do you wish to change any parameters?
In which group? 1,2,...,4

The user must specify in which group of data the change is required. For example, if a change is desired in the DO concentration the 4 key is pressed, and the user is prompted for a new DO value in the input window as follows.

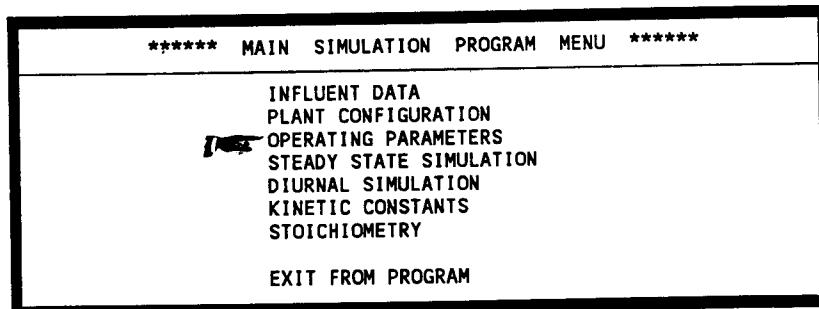
**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 1	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	7.00	1.00	3.0

Aerated reactor DO setpoints:
e.g. 3 (g O m⁻³)
Reactor No. 1 : DO setpoint =

When no more changes are required to the data and an N is entered at the prompt a window will appear at the centre of the screen as follows.



If a printer is attached to the computer the user may respond by pressing the Y key to obtain a printout of the configuration data; else an N is entered. At a later stage, directly after simulating either the steady state or diurnal response, there is another opportunity to print the configuration data. After entering Y or N the program returns to the main menu with the highlight on the OPERATING PARAMETERS option as shown below.



Press <Arrows> or <SpaceBar> to move selection
Press <Return> to select option

Multiple reactor configuration

If there is more than one reactor in the system the user may wish to specify that the feed is split between reactors, that certain reactors are unaerated, and that mixed liquor recycles are included. The convention for numbering reactors is that the last reactor is the one preceding the settling tank, and flow is sequential from reactor to reactor by number; that is, from Reactor 1 to 2 to 3 and so on. Examples of reactor numbering for different configurations are illustrated in Appendix C.

When two or more reactors are specified the user is prompted to input the reactor volumes sequentially. For example, if two reactors have been specified and the first reactor volume has been entered as 2 m³ the screen will appear as follows.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2
Gp 2. Reactor Vols,m ³		
No. 1:	2.00	
No. 2:		

Enter reactor volume(s) - m ³ :	
Reactor No. 2 =	

Once all the reactor volumes have been specified (2 and 5 m³ in this case) the screen will be similar to that shown below.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2
Gp 2. Reactor Vols,m ³ Gp 3. Feed Fraction		
No. 1:	2.00	
No. 2:	5.00	

Fractional influent distribution:	
Fraction to Reactor No. 1 =	

The influent flow may be split between reactors. The user is prompted to enter the fraction fed to each reactor sequentially. Input continues until either the sum of the fractions equals one or the fraction to the second last reactor is specified (the remainder is assumed to enter the last reactor).

When the feed distribution has been entered the screen may appear as follows.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	2.00	1.00	Aerated
No. 2:	5.00		Aerated

Reactor aeration pattern:
Make any changes? Y/N.....

Initially it is assumed that all reactors are aerated. To change the status of a reactor between aerated and unaerated the user enters a Y at the prompt. The user is then prompted to enter the number of the reactor to change in the input window as shown below.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	2.00	1.00	Aerated
No. 2:	5.00		Aerated

Reactor aeration pattern:
Change Reactor No.

The screen is updated to reflect the change in aeration pattern. This procedure is repeated until the user is satisfied with the aeration pattern. When no more changes are required the N key is pressed and the user is prompted to enter the DO concentration in the aerated reactors sequentially. For example, in the two reactor case if the first reactor is unaerated, the following will appear.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	2.00	1.00	Unaerated
No. 2:	5.00		Aerated

Aerated reactor DO setpoints:
e.g. 3 (g O m⁻³)
Reactor No. 2 : DO setpoint =

When all the DO concentrations have been input the screen appears as shown below and the user specifies whether or not there are any mixed liquor recycles between reactors. A maximum of two recycles (A and B) other than the return activated sludge (RAS) recycle may be specified.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	2.00	1.00	Unaerated
No. 2:	5.00		3.0
Gp 5. Recycles: Use to include/remove mixed liquor recycles.			

Any inter-reactor mixed liquor
recycles? Y/N....

If the **Y** key is pressed details for the A recycle are requested. The user first enters the number of the reactor from which the recycle is taken (as shown below), and then the number of the reactor to which the recycle is pumped.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	2.00	1.00	Unaerated
No. 2:	5.00		3.0
Gp 5. Recycles: Use to include/remove mixed liquor recycles.			

A recycle : Out of Reactor No.

When this information has been supplied the screen is updated and the user specifies whether or not a second recycle is required as shown below.

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	2.00	1.00	Unaerated
No. 2:	5.00		3.0
Gp 5. Recycles: Use to include/remove mixed liquor recycles.			
A recycle : Out of Reactor No.2 Into Reactor No.1			

Another mixed liquor recycle?

Y/N....

If a **Y** is pressed data for the B recycle are requested in the same format as for the A recycle.

If any mixed liquor recycles have been specified the user is prompted to input the number of the reactor to which the RAS recycle is directed in the screen shown below. Had no recycles been specified the program would automatically assume that the RAS recycle is pumped to the first reactor.

```
**** PROCESS CONFIGURATION ****      Gp 1. Number of Reactors = 2
Gp 2. Reactor Vols,m3    Gp 3. Feed Fraction   Gp 4. Aeration/DO
No. 1:          2.00           1.00           Unaerated
No. 2:          5.00
Gp 5. Recycles: Use to include/remove mixed liquor recycles.
A recycle : Out of Reactor No.2
            Into Reactor No.1
```

RAS recycle from settler to
Reactor No.

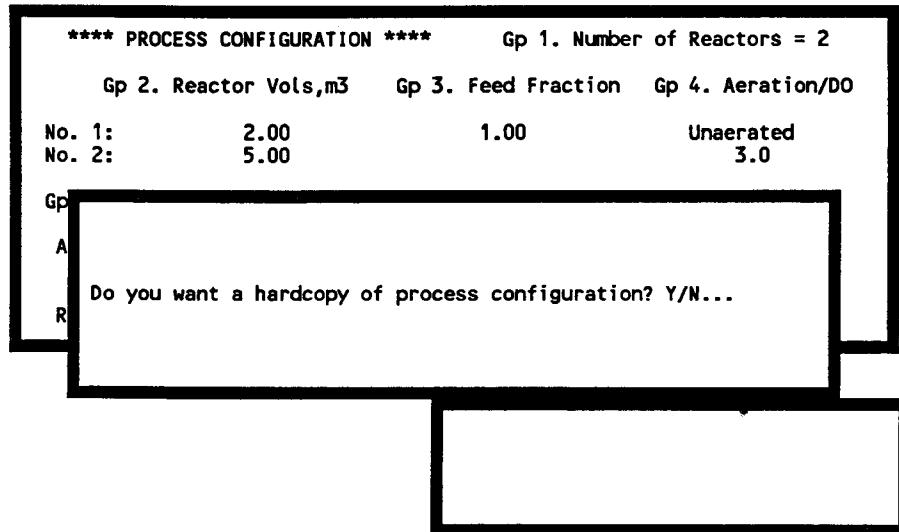
This completes the data input for **PLANT CONFIGURATION**. The user can make changes to the data by entering a **Y** at the prompt as shown below. The procedure for making changes has been outlined for the single reactor case earlier.

```
**** PROCESS CONFIGURATION ****      Gp 1. Number of Reactors = 2
Gp 2. Reactor Vols,m3    Gp 3. Feed Fraction   Gp 4. Aeration/DO
No. 1:          2.00           1.00           Unaerated
No. 2:          5.00           3.0
Gp 5. Recycles: Use to include/remove mixed liquor recycles.
A recycle : Out of Reactor No.2
            Into Reactor No.1
RAS recycle to Reactor No.1
```

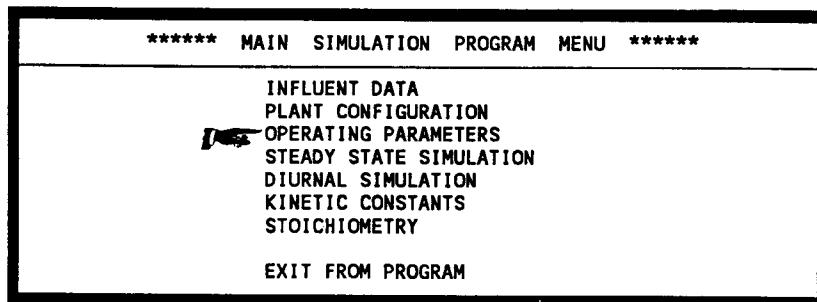
Do you wish to change any parameters?

Y/N....

When no more changes are required to the data and an **N** is entered at the prompt a window will appear at the centre of the screen as follows.



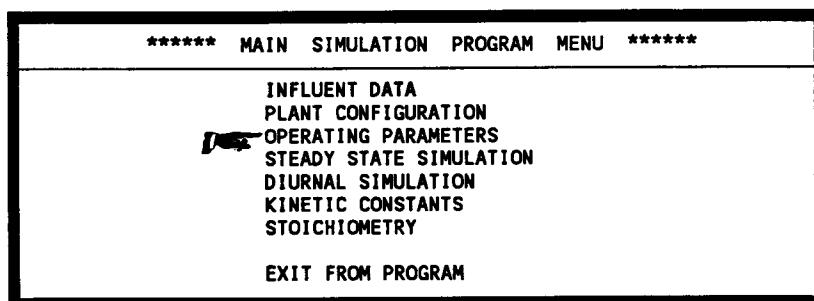
If a printer is attached to the computer the user may respond by pressing the **Y** key to obtain a printout of the configuration data; else an **N** is entered. At a later stage, directly after simulating either the steady state or diurnal response, there is another opportunity to print the configuration data. After entering **Y** or **N** the program returns to the main menu with the highlight on the **OPERATING PARAMETERS** option as shown below.



Press <Arrows> or <SpaceBar> to move selection
Press <Return> to select option

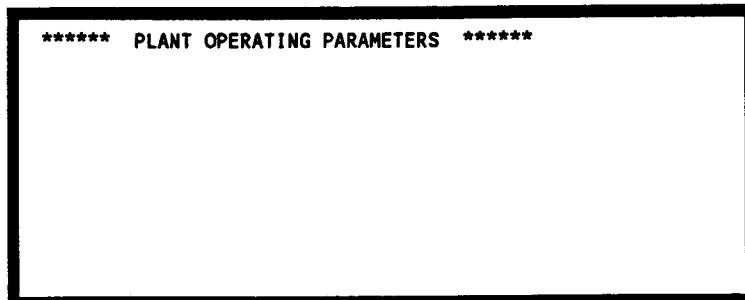
OPERATING PARAMETERS

Once the system configuration data have been entered the main menu reappears with the **OPERATING PARAMETERS** option highlighted.



Press <Arrows> or <SpaceBar> to move selection
Press <Return> to select option

On pressing the <RETURN> key to select the **OPERATING PARAMETERS** option the following screen appears.



Operating sludge age (SRT) of plant (days) =

The user is prompted to enter the sludge age (SRT) of the plant in the input window at the lower right of the screen as shown above. The sludge age appears in the main window and the user is prompted to input the temperature within the plant (not ambient) in °C as shown overleaf.

***** PLANT OPERATING PARAMETERS *****			
1 SRT (total)	d	=	5.0

Operating temperature of plant (degC) =

If a diurnal influent pattern has been set up in the **INFLUENT DATA** option the average influent flowrate will appear automatically in the main window immediately after the temperature is entered, as shown below. The user is then prompted to enter the RAS recycle flowrate in the input window. However, if average influent COD and TKN concentrations were entered in the **INFLUENT DATA** option then the user is prompted to enter the average influent flowrate before the RAS recycle flowrate.

***** PLANT OPERATING PARAMETERS *****			
1 SRT (total)	d	=	5.0
2 Process Temperature	degC	=	22.0
Flow rates:			
3 Influent flow	m ³ d ⁻¹	=	11.0

RAS-recycle Flow (m ³ d ⁻¹) =
--

If the mixed liquor recycles have been specified in the **PLANT CONFIGURATION** option the user is prompted to enter the appropriate flow rates. The mixed liquor recycle flowrates are assumed to be constant irrespective of any variation in the influent flowrate. For the two reactor example discussed earlier the screen would appear as follows.

***** PLANT OPERATING PARAMETERS *****

1 SRT {total}	d	=	5.0
2 Process Temperature	degC	=	22.0
Flow rates:			
3 Influent flow	m ³ d ⁻¹	=	11.0
4 RAS recycle flow	m ³ d ⁻¹	=	11.0

A recycle Flow (m³ d⁻¹) =

This completes the input of data for the **OPERATING PARAMETERS** option. The user may make changes to the data by following the instructions in the input window as shown below.

***** PLANT OPERATING PARAMETERS *****

1 SRT {total}	d	=	5.0
2 Process Temperature	degC	=	22.0
Flow rates:			
3 Influent flow	m ³ d ⁻¹	=	11.0
4 RAS recycle flow	m ³ d ⁻¹	=	11.0
5 A-recycle flow	m ³ d ⁻¹	=	33.0

Do you wish to change any parameters?

Y/N....

If a change is to be made and the **Y** key is pressed the user is prompted to specify in which group of data the change is required, as follows.

```
***** PLANT OPERATING PARAMETERS *****
1 SRT {total}      d      =      5.0
2 Process Temperature degC   =    22.0
Flow rates:
3 Influent flow   m3 d-1 =    11.0
4 RAS recycle flow m3 d-1 =    11.0
5 A-recycle flow   m3 d-1 =   33.0
```

Do you wish to change any parameters?

In which group? 1,2,...,5

For example, if a change is desired in the RAS recycle rate the 4 key is pressed, and the user is prompted for a new flowrate value in the input window as shown below.

```
***** PLANT OPERATING PARAMETERS *****
1 SRT {total}      d      =      5.0
2 Process Temperature degC   =    22.0
Flow rates:
3 Influent flow   m3 d-1 =    11.0
4 RAS recycle flow m3 d-1 =    11.0
5 A-recycle flow   m3 d-1 =   33.0
```

RAS-recycle Flow (m3 d-1) =

The main window is updated to reflect the new value and the user is prompted for more changes. When no more changes are required the N key is pressed at the prompt and a new window appears at the centre of the screen as follows.

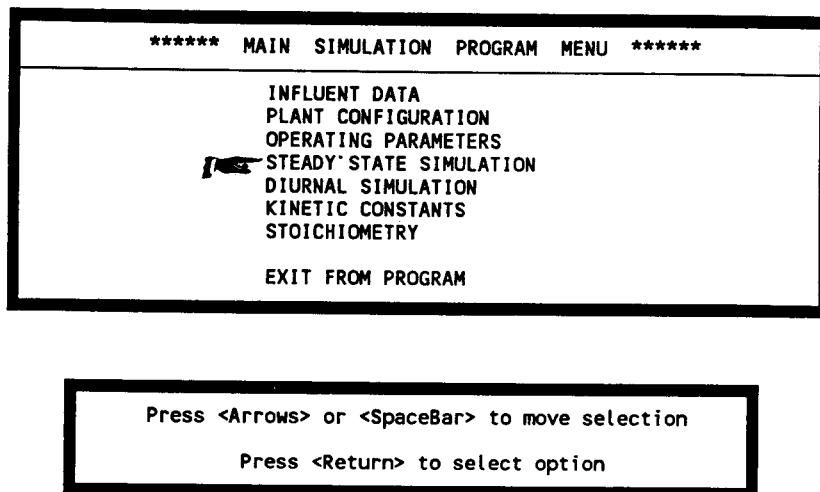
***** PLANT OPERATING PARAMETERS *****				
1	SRT {total}	d	=	5.0
2	Process Temperature	degC	=	22.0
Flow rates:				
3	Influent flow	m ³ d ⁻¹	=	11.0
4				
5				
Do you want a hardcopy of operating conditions? Y/N...				

If a printer is attached to the computer a printout of the operating parameters may be obtained by entering a **Y**; else an **N** is entered to proceed. At a later stage, directly after simulating either the steady state or diurnal response, there is another opportunity to obtain a printout of the operating parameters. After entering **Y** or **N** the program reverts to the main menu with the highlight on the **STEADY STATE SIMULATION** option as shown below.

***** MAIN SIMULATION PROGRAM MENU *****	
INFLUENT DATA	
PLANT CONFIGURATION	
OPERATING PARAMETERS	
STEADY STATE SIMULATION	
DIURNAL SIMULATION	
KINETIC CONSTANTS	
STOICHIOMETRY	
EXIT FROM PROGRAM	
Press <Arrows> or <SpaceBar> to move selection	
Press <Return> to select option	

STEADY STATE SIMULATION

Once the **INFLUENT DATA**, **PLANT CONFIGURATION** and **OPERATING PARAMETERS** options have been executed the main menu reappears with the **STEADY STATE SIMULATION** option highlighted as shown below. The user may press the <RETURN> key to initiate the steady state calculation. In this case default values for the kinetic and stoichiometric constants are used in the simulation. Under certain circumstances the user may wish to make changes to the kinetic and stoichiometric constants prior to the steady state calculation via the main menu **KINETIC CONSTANTS** or **STOICHIOMETRY** options, see later.



When the **STEADY STATE SIMULATION** option is selected the program first calculates the mixed liquor wastage rate required for the selected reactor volumes and specified sludge age. The sludge wastage stream is assumed to be withdrawn from the last reactor in the series; that is, the reactor preceding the settling tank. If the solids concentration is approximately constant from reactor to reactor, calculation of the wastage rate is a trivial problem. However, if there are appreciable differences in solids concentration between reactors an iterative calculation procedure must be employed. These differences occur in systems where the influent does not enter the first reactor (such as the contact stabilization process) or where the RAS recycle is not pumped to the first reactor (such as the UCT process). To cover all possibilities the iterative procedure always is used in the program. During the calculation a line of data relating to the solids distribution is printed on the screen at each iteration as shown below. These data are of no concern to the user, but provide an indication that calculation is continuing.

Iterative Wastage Rate Calculation	Wastage rate
785.71 785.71	1.400

Wastage rate = 1.400

When the calculation is completed the required wastage rate is displayed on the screen for a few seconds. There is no need for the user to note this value because it can be printed, if required, together with the operating parameters after completing the steady state calculation.

Calculation of the steady state solution commences once the wastage rate has been determined. Because calculation of the steady state response involves solution of a set of nonlinear algebraic equations an iterative procedure is utilized. Starting from an empirical estimate of the solution the estimates are improved until the solution is reached. During calculation, the concentrations of eight compounds are printed on the screen at each iteration together with an error factor, MaxF. When the system comprises more than one reactor, five of the concentration values are for selected compounds in the first reactor and three for compounds in the last reactor, as shown in the example below.

Zbh	First Reactor				Last Reactor				MaxF
	Zba	Sads	Sbs	No3	Sbs	Na	No3		
1039.38	34.93	103.94	18.20	0.00	1.00	0.50	38.92	1.000E+10	
1020.84	31.10	120.62	0.18	0.02	0.01	1.21	6.79	1.487E+03	
1024.43	31.67	81.49	0.99	0.17	0.01	1.74	6.82	7.411E+02	
1022.74	31.62	87.84	0.01	0.53	0.00	1.87	7.17	9.772E+02	
1021.51	31.61	89.68	0.41	1.52	0.00	1.87	8.15	1.899E+02	
1019.97	31.59	92.97	0.38	2.78	0.00	1.87	9.41	3.456E+01	
1019.68	31.59	93.60	0.39	3.01	0.00	1.87	9.65	3.194E-01	

If there is only one reactor in the system the eight parameters are compound concentrations from that reactor. During the solution procedure each of the concentrations converges to its steady state value. The solution is accepted as satisfactory when the error factor, MaxF, in the right-hand-most column decreases to less than 10^{-3} .

When the steady state solution is found the results appear on the screen. An example of the results format is shown below for a two reactor system where the first reactor is unaerated and where the UCTOLD model has been used to simulate system behaviour. In the first column the model compounds are listed together with seven additional parameters of interest. These are the volatile and total settleable solids concentrations; oxygen utilization rates for heterotrophs, autotrophs (nitrifiers), and the total; the denitrification rate; and the TKN concentration. The influent concentrations of the model compounds are listed under the title INPUT. The values of all parameters in each reactor are listed below the corresponding reactor number under the title REACTOR. Units for each parameter are shown at the right-hand side.

COMPOUND	INPUT	REACTOR	
		1	2
Zbh (hetero.)	= 0.0 1019.7 1043.7 g COD m-3		
Zba (autotrophs)	= 0.0 31.6 32.5 g COD m-3		
Ze (endog.)	= 0.0 267.8 272.8 g COD m-3		
Zi (prt unb COD)	= 72.1 566.9 566.9 g COD m-3		
Sads (adsorb.COD)	= 0.0 93.6 31.8 g COD m-3		
Senm (enmesh COD)	= 364.1 14.1 4.1 g COD m-3		
Nobp (prt bio N)	= 3.6 3.6 2.0 g N m-3		
Sbs (sol bio COD)	= 91.0 0.4 0.0 g COD m-3		
Na (ammonia N)	= 41.3 9.4 1.9 g N m-3		
Nobs (sol org N)	= 3.6 1.1 1.6 g N m-3		
No3 (nitrate N)	= 0.0 3.0 9.6 g N m-3		
Alkalinity	= 10.0 7.5 6.5 mole m-3		
Sus (sol unb COD)	= 27.7 27.7 27.7 g COD m-3		
Volatile SS	= 1347.1 1318.7 g VSS m-3		
Total SS	= 1796.1 1758.3 g TSS m-3		
OUR heterotrophs	= 0.0 19.8 g O2 m-3 h-1		
OUR autotrophs	= 0.0 13.5 g O2 m-3 h-1		
OUR total	= 0.0 33.3 g O2 m-3 h-1		
Denit. rate	= 5.4 0.0 g NO3-N m-3 h-1		
TKN	= 12.1 5.1 g N m-3		

*** Hit any key to continue...

When the results have been viewed any key may be pressed to advance the program. A window appears at the centre of the screen as shown below.

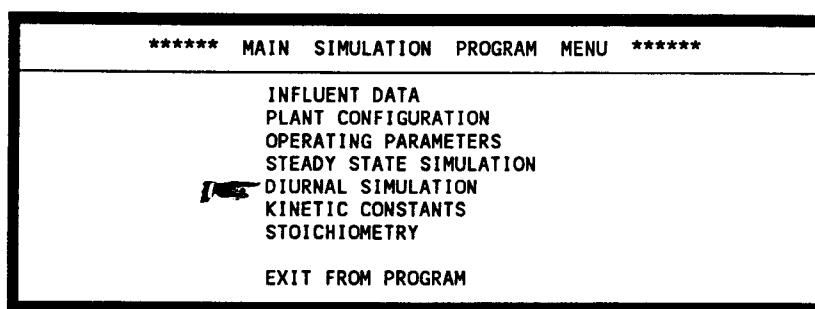
COMPOUND	INPUT	REACTOR	
		1	2
Zbh (hetero.)	=	0.0	1019.7 1043.7 g COD m ⁻³
Zba (autotrophs)	=	0.0	31.6 32.5 g COD m ⁻³
Ze (endog.)	=	0.0	267.8 272.8 g COD m ⁻³
Zi (prt unb COD)	=	72.1	566.9 566.9 g COD m ⁻³
Sads (adsorb.COD)	=	0.0	93.6 31.8 g COD m ⁻³
Senm (enmesh COD)	=	364.1	14.1 4.1 g COD m ⁻³
Nobp (prt bio N)	=	3.6	3.6 2.0 g N m ⁻³
Sbs (so			
Na (amm			
Nobs (s			
No ₃ (ni			
Alkalini	Do you want a hardcopy of steady state results ? Y/N...		
Sus (so			
Volatile			
Total S			
OUR heterotrophs	=	0.0	19.8 g O ₂ m ⁻³ h ⁻¹
OUR autotrophs	=	0.0	13.5 g O ₂ m ⁻³ h ⁻¹
OUR total	=	0.0	33.3 g O ₂ m ⁻³ h ⁻¹
Denit. rate	=	5.4	0.0 g NO ₃ -N m ⁻³ h ⁻¹
TKN	=	12.1	5.1 g N m ⁻³

*** Hit any key to continue...

If a printer is attached to the computer the user may obtain a printout of the steady state results by entering a **Y** at the prompt; else an **N** is entered. After the **Y** or **N** key has been pressed the user may then elect to print one or more of the following sets of data:

- wastewater characteristics
- plant configuration data
- operating data
- kinetic constants
- stoichiometric constants

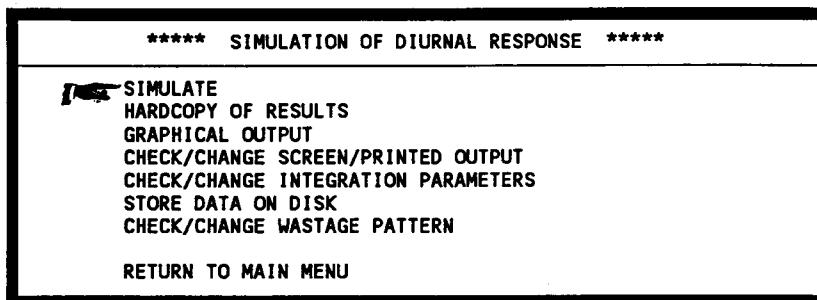
When the user has responded to the requests for printed output the main menu appears with the **DIURNAL SIMULATION** option highlighted as shown below.



Press <Arrows> or <SpaceBar> to move selection
 Press <Return> to select option

DIURNAL SIMULATION

When the **DIURNAL SIMULATION** option is selected from the main menu a window will appear with a sub-menu as shown below.



Eight options, including one to return to the main menu, appear in the upper window of the diurnal sub-menu screen. An option is selected in the same manner as for the main menu by moving the highlighted block to that option and pressing the **<RETURN>** key. The cursor (-) blinks alongside the highlighted option. The highlighted block may be moved between options by pressing the "up arrow" (\uparrow) or "down arrow" (\downarrow) keys or by pressing the **spacebar** (this scrolls the highlight downwards). Brief instructions on how to move between options and select an option are shown in the lower window on the screen.

Three options necessarily can be selected only once the **SIMULATE** option has been executed: **HARDCOPY OF RESULTS**, **GRAPHICAL OUTPUT** and **STORE DATA ON DISK**. If the user attempts to select one of these options before the **SIMULATE** option is executed the message shown below will be flashed on the screen indicating that the **SIMULATE** option should first be executed. The menu will then reappear with the **SIMULATE** option highlighted.



In the remainder of this section each of the diurnal sub-menu options is demonstrated. Each of the options will be covered in turn with a detailed explanation of all data input options, any sub-menus and so on. The instructions for each diurnal simulation menu option will commence on a new page for ease of reference.

Simulate

When the **SIMULATE** option is selected the program commences computing the response of the system under the diurnal influent pattern. It is assumed that the diurnal pattern is repeated continuously. In this situation the true solution is one where the response of the system is repeated identically from 24-hour cycle to 24-hour cycle. That is, the concentration of each compound (in a given reactor) is the same at a given time from cycle to cycle. Also the concentration of each compound (in a given reactor) will be the same at the start and end of a cycle (0h00 and 24h00). Because the concentrations of the compounds at the start of the cycle are not known before commencing the calculation it is necessary to estimate these. The initial estimates are taken as the steady state solution. Starting from these values the response of the system is simulated by integrating forward in time. The process continues for cycle after cycle until the values of certain parameters are close to equal at the start and end of a cycle. When the differences in the magnitudes of these "end" values are within specified limits the response is accepted as being sufficiently close to the true solution.

The screen is cleared when the **SIMULATE** option is first selected. An integration time monitor appears towards the base of the screen as shown below.

Integration time = 1.25

The magnitude displayed by the time counter shows the current position of computation in the cycle and increases from 0.0 to 24.0. The function of the timer is merely as an indicator to the user. The rate at which the counter is incremented is not necessarily constant. This is because a variable steplength algorithm is used for the integration.

Some intermediate results are displayed on the screen when the end of the first 24-hour cycle is reached as shown in the example below. These are the values of ten parameters in the last reactor of the configuration at two-hourly intervals as calculated during the previous cycle. Control of which ten parameters are displayed is discussed in the section Check/change screen/printed output later. The integration time in the current cycle appears at the base of the screen.

***** DIURNAL RESPONSE RESULTS *****

Reactor 2		Cycle number 1								
TIME	Zbh	Zba	Sads	Senm	VSS	Sbs	Na	No3	TKN	Ot
0.0	1043.7	32.5	31.8	4.1	1318.7	0.0	1.9	9.6	5.1	33.3
2.0	1040.0	32.7	14.5	3.4	1306.4	-0.0	0.6	10.5	3.8	20.2
4.0	1021.6	32.8	10.3	3.4	1294.2	-0.0	0.4	10.9	3.5	15.6
6.0	1000.7	32.9	9.6	3.3	1282.7	-0.0	0.3	11.2	3.3	14.1
8.0	979.9	33.0	9.4	3.4	1271.5	-0.0	0.3	11.3	3.2	13.4
10.0	970.7	32.7	42.7	5.1	1286.7	0.0	2.9	9.7	5.8	37.1
12.0	977.6	32.3	69.5	5.4	1305.9	0.0	4.6	8.5	7.6	42.2
14.0	988.6	32.0	89.4	5.5	1323.2	0.0	5.5	8.0	8.6	44.4
16.0	1001.2	31.7	105.2	5.6	1339.0	0.0	6.1	7.8	9.3	45.6
18.0	1015.1	31.4	117.7	5.6	1353.5	0.0	6.6	7.8	9.8	46.5
20.0	1029.7	31.2	127.5	5.6	1366.9	0.0	6.9	7.7	10.1	47.2
22.0	1059.2	31.6	67.4	3.6	1346.9	-0.0	1.8	10.5	5.3	38.5
24.0	1068.8	31.8	20.8	3.4	1324.8	-0.0	0.6	11.1	4.4	23.6

Integration time = 1.25

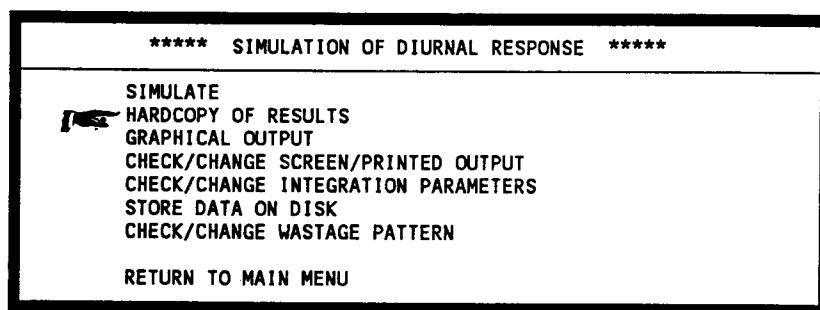
At the end of each cycle the most recent results are displayed in the format shown above. If the computation is progressing satisfactorily the difference between the values of each parameter at the start and end of the cycle should get smaller from cycle to cycle. When the difference is judged by the program to be sufficiently small the results of the current cycle are accepted as the diurnal solution and integration is terminated. An example of the screen output at this point is shown below.

***** DIURNAL RESPONSE RESULTS *****

Reactor 2		Cycle number 7								
TIME	Zbh	Zba	Sads	Senm	VSS	Sbs	Na	No3	TKN	Ot
0.0	1084.9	30.1	20.0	3.4	1331.5	-0.0	0.8	11.5	4.6	24.5
2.0	1068.1	30.4	11.2	3.4	1317.5	-0.0	0.6	12.4	3.9	18.3
4.0	1046.5	30.6	10.1	3.4	1305.4	-0.0	0.4	13.0	3.4	15.3
6.0	1024.8	30.7	9.8	3.4	1293.7	-0.0	0.3	13.3	3.3	14.2
8.0	1003.5	30.7	9.5	3.4	1282.2	-0.0	0.3	13.4	3.3	13.7
10.0	993.4	30.4	42.6	5.1	1296.8	0.0	3.1	11.2	6.0	36.6
12.0	999.9	30.1	68.4	5.3	1315.2	0.0	5.0	9.3	8.0	41.6
14.0	1010.6	29.9	86.8	5.4	1331.5	0.0	6.1	8.1	9.2	43.8
16.0	1022.6	29.6	102.0	5.4	1346.7	0.0	6.9	7.6	10.0	45.1
18.0	1035.1	29.4	114.9	5.4	1360.7	0.0	7.4	7.4	10.6	46.0
20.0	1048.4	29.1	125.1	5.5	1373.7	0.0	7.8	7.3	11.0	46.8
22.0	1077.3	29.6	65.1	3.6	1353.5	-0.0	2.7	10.2	6.3	39.9
24.0	1085.5	30.0	20.0	3.4	1331.7	-0.0	0.9	11.5	4.7	24.7

*** Dynamic solution reached...Hit any key to continue...

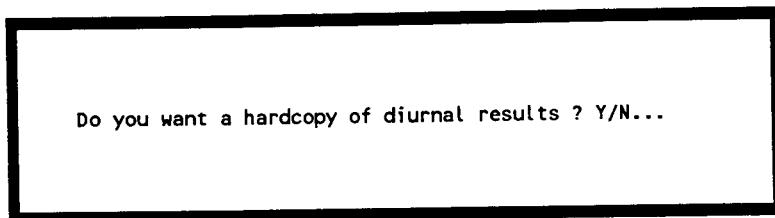
If a key is pressed the program returns to the diurnal sub-menu with the **HARDCOPY OF RESULTS** option highlighted as shown below.



Press <Arrows> or <SpaceBar> to move selection
Press <Return> to select option

Hard copy of results

When the **HARDCOPY OF RESULTS** option is selected from the diurnal sub-menu the window shown below appears on the screen.



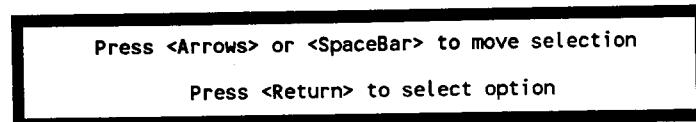
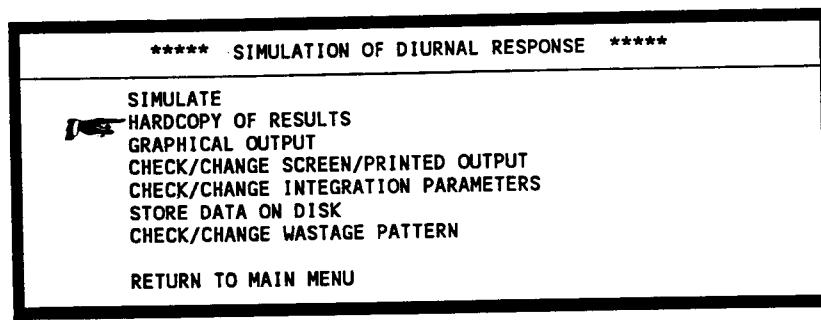
If a printer is attached to the computer the user may press the **Y** key to obtain a printout of some of the diurnal results; else an **N** is entered. The results which are printed are the values, for each reactor, of ten selected parameters at intervals over the 24-hour cycle. An example of a portion of the output for *one of the reactors* is shown below.

***** DIURNAL RESPONSE RESULTS *****										
Reactor 2		Cycle number 7								
TIME	Zbh	Zba	Sads	Senm	VSS	Sbs	Na	No3	TKN	Ot
0.0	1084.9	30.1	20.0	3.4	1331.5	-0.0	0.8	11.5	4.6	24.5
0.3	1083.6	30.2	17.6	3.4	1329.4	-0.0	0.8	11.6	4.6	23.4
0.5	1082.0	30.2	15.8	3.4	1327.5	-0.0	0.8	11.7	4.5	22.4
0.8	1080.1	30.2	14.5	3.3	1325.7	-0.0	0.8	11.8	4.4	21.5
1.0	1077.9	30.3	13.5	3.3	1324.0	-0.0	0.8	11.9	4.3	20.8
1.3	1075.6	30.3	12.6	3.4	1322.3	-0.0	0.8	12.1	4.2	20.1
1.5	1073.2	30.3	12.0	3.4	1320.7	-0.0	0.7	12.2	4.1	19.4
1.8	1070.7	30.4	11.5	3.4	1319.1	-0.0	0.7	12.3	4.0	18.8
2.0	1068.1	30.4	11.2	3.4	1317.5	-0.0	0.6	12.4	3.9	18.3
2.3	1065.5	30.4	10.9	3.4	1316.0	-0.0	0.6	12.5	3.8	17.8
2.5	1062.8	30.5	10.7	3.4	1314.4	-0.0	0.6	12.6	3.7	17.3
2.8	1060.1	30.5	10.6	3.3	1312.9	-0.0	0.5	12.7	3.7	16.9
3.0	1057.4	30.5	10.5	3.3	1311.4	-0.0	0.5	12.8	3.6	16.5
3.3	1054.7	30.5	10.3	3.3	1309.9	-0.0	0.5	12.9	3.6	16.2
3.5	1052.0	30.5	10.2	3.4	1308.4	-0.0	0.4	12.9	3.5	15.9
3.8	1049.2	30.6	10.1	3.4	1306.9	-0.0	0.4	13.0	3.5	15.6
4.0	1046.5	30.6	10.1	3.4	1305.4	-0.0	0.4	13.0	3.4	15.3
4.3	1043.8	30.6	10.0	3.4	1303.9	-0.0	0.4	13.1	3.4	15.1
4.5	1041.0	30.6	10.0	3.3	1302.5	-0.0	0.4	13.1	3.4	14.9
4.8	1038.3	30.6	10.0	3.3	1301.0	-0.0	0.3	13.1	3.4	14.8
5.0	1035.6	30.6	10.0	3.3	1299.5	-0.0	0.3	13.2	3.3	14.7
5.3	1032.9	30.6	9.9	3.3	1298.1	-0.0	0.3	13.2	3.3	14.5
5.5	1030.2	30.6	9.8	3.4	1296.6	-0.0	0.3	13.2	3.3	14.4
5.8	1027.5	30.7	9.8	3.4	1295.1	-0.0	0.3	13.2	3.3	14.3
6.0	1024.8	30.7	9.8	3.4	1293.7	-0.0	0.3	13.3	3.3	14.2
6.3	1022.1	30.7	9.7	3.4	1292.2	-0.0	0.3	13.3	3.3	14.1
6.5	1019.5	30.7	9.7	3.4	1290.8	-0.0	0.3	13.3	3.3	14.0
6.8	1016.8	30.7	9.7	3.4	1289.4	-0.0	0.3	13.3	3.3	14.0
7.0	1014.1	30.7	9.7	3.3	1287.9	-0.0	0.3	13.3	3.3	13.9
7.3	1011.5	30.7	9.7	3.3	1286.5	-0.0	0.3	13.4	3.3	13.9
7.5	1008.8	30.7	9.7	3.3	1285.1	-0.0	0.3	13.4	3.3	13.8
7.8	1006.2	30.7	9.6	3.3	1283.6	-0.0	0.3	13.4	3.3	13.8
8.0	1003.5	30.7	9.5	3.4	1282.2	-0.0	0.3	13.4	3.3	13.7
8.2	1000.4	30.7	11.2	4.2	1282.0	0.0	0.5	13.2	3.5	17.0
8.5	997.7	30.7	15.2	4.7	1283.1	0.0	0.8	13.0	3.8	22.0
8.8	995.8	30.7	20.0	4.8	1285.0	0.0	1.2	12.7	4.2	26.2
9.0	994.5	30.6	24.9	4.9	1287.1	0.0	1.6	12.4	4.6	29.4
9.2	993.7	30.6	29.7	4.9	1289.5	0.0	2.0	12.1	5.0	31.9
9.5	993.4	30.5	34.2	5.0	1291.9	0.0	2.4	11.8	5.4	33.8
9.7	993.3	30.5	38.5	5.0	1294.4	0.0	2.7	11.5	5.7	35.3
10.0	993.4	30.4	42.6	5.1	1296.8	0.0	3.1	11.2	6.0	36.6
10.2	993.8	30.4	46.5	5.1	1299.3	0.0	3.4	10.9	6.4	37.6
10.5	994.3	30.4	50.1	5.1	1301.7	0.0	3.6	10.6	6.6	38.5
10.7	995.0	30.3	53.6	5.2	1304.0	0.0	3.9	10.4	6.9	39.2
11.0	995.8	30.3	56.8	5.2	1306.3	0.0	4.1	10.1	7.2	39.8
11.3	996.7	30.2	59.9	5.2	1308.6	0.0	4.4	9.9	7.4	40.4
11.5	997.7	30.2	62.9	5.2	1310.8	0.0	4.6	9.7	7.6	40.8
11.7	998.7	30.2	65.7	5.2	1313.0	0.0	4.8	9.5	7.8	41.3
12.0	999.9	30.1	68.4	5.3	1315.2	0.0	5.0	9.3	8.0	41.6

The selection of the ten parameters which appear in the table of results can be modified via the **CHECK/CHANGE SCREEN/PRINTED OUTPUT** option. The procedure for modifying the selection is discussed later.

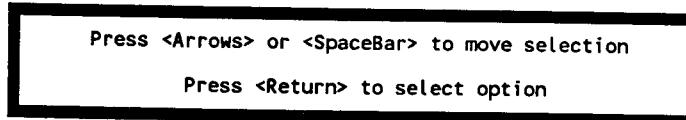
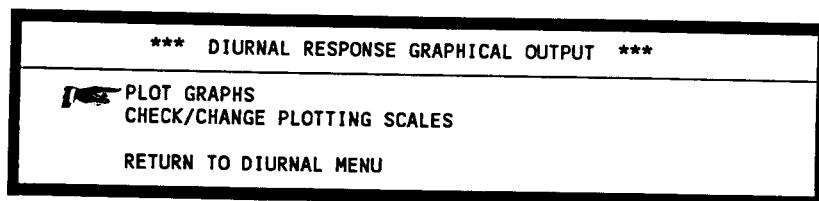
In the example above the results are printed at intervals of 15 minutes; for illustrative purposes, only the first 12 hours of the 24 hour cycle are shown that is, there are 49 sets of values. The printing interval is set equal to the *data interval* which appears in the **CHECK/CHANGE INTEGRATION PARAMETERS** sub-menu discussed later. At this point it suffices to note that intervals of 10, 15 or 30 minutes can be selected. The default value is 15 minutes.

The printing of results may take several minutes depending on printer speed, data interval and the number of reactors. When the program is ready to continue after the last set of data has been sent to the printer the diurnal sub-menu will appear on the screen with the highlight on the **HARDCOPY OF RESULTS** option as shown below.



Graphical output

When the **GRAPHICAL OUTPUT** option is selected from the diurnal sub-menu the following sub-menu appears on the screen. The user may select between plotting graphical results on the screen (and possibly on a printer) and changing the graph plotting scales.



If the **PLOT GRAPHS** option is selected three windows appear on the screen as shown below. The upper right window indicates the variable to be plotted **versus** time over the 24-hour cycle; plots of this variable in each reactor will be obtained. A list of eighteen possible plotting variables appears in a window at the left. The number of variables in this window differs for IAWPRC and UCTOLD.

POSSIBLE OUTPUT PARAMETERS	
1	Zbh (hetero.) g COD m ⁻³
2	Zba (autotrophs) g COD m ⁻³
3	Ze (endog.) g COD m ⁻³
4	Zi (prt unb COD) g COD m ⁻³
5	Sads (adsorb.COD) g COD m ⁻³
6	Senn (ennmesh COD) g COD m ⁻³
7	Nobp (prt bio N) g N m ⁻³
8	Sbs (sol bio COD) g COD m ⁻³
9	Na (ammonia N) g N m ⁻³
10	Nobs (sol org N) g N m ⁻³
11	No ₃ (nitrate N) g N m ⁻³
12	Alkalinity mole m ⁻³
13	Sus (sol unb COD) g COD m ⁻³
14	OUR carb g O ₂ m ⁻³ h ⁻¹
15	OUR nitr g O ₂ m ⁻³ h ⁻¹
16	OUR tot g O ₂ m ⁻³ h ⁻¹
17	Volatile solids g VSS m ⁻³
18	TKN g N m ⁻³

If the user wishes to change the variable to be plotted, a **Y** is entered at the prompt and the user must respond to the query in the lower right window, as follows.

POSSIBLE OUTPUT PARAMETERS

1 Zbh (hetero.)	g COD m-3
2 Zba (autotrophs)	g COD m-3
3 Ze (endog.)	g COD m-3
4 Zi (prt unb COD)	g COD m-3
5 Sads (adsorb.COD)	g COD m-3
6 Senm (enmesh COD)	g COD m-3
7 Nobp (prt bio N)	g N m-3
8 Sbs (sol bio COD)	g COD m-3
9 Na (ammonia N)	g N m-3
10 Nobs (sol org N)	g N m-3
11 No3 (nitrate N)	g N m-3
12 Alkalinity	mole m-3
13 Sus (sol unb COD)	g COD m-3
14 OUR carb	g O ₂ m-3 h-1
15 OUR nitr	g O ₂ m-3 h-1
16 OUR tot	g O ₂ m-3 h-1
17 Volatile solids	g VSS m-3
18 TKN	g N m-3

SELECTED PLOTTING OUTPUTS

Ot in all reactors

Change this selection? Y/N...
Change to Parameter No.

If the user wishes to view a plot of, say, the ammonia concentration instead of the total oxygen utilization rate then a 9 would be entered at the prompt. The selected option will change in the upper right window as follows.

POSSIBLE OUTPUT PARAMETERS

1 Zbh (hetero.)	g COD m-3
2 Zba (autotrophs)	g COD m-3
3 Ze (endog.)	g COD m-3
4 Zi (prt unb COD)	g COD m-3
5 Sads (adsorb.COD)	g COD m-3
6 Senm (enmesh COD)	g COD m-3
7 Nobp (prt bio N)	g N m-3
8 Sbs (sol bio COD)	g COD m-3
9 Na (ammonia N)	g N m-3
10 Nobs (sol org N)	g N m-3
11 No3 (nitrate N)	g N m-3
12 Alkalinity	mole m-3
13 Sus (sol unb COD)	g COD m-3
14 OUR carb	g O ₂ m-3 h-1
15 OUR nitr	g O ₂ m-3 h-1
16 OUR tot	g O ₂ m-3 h-1
17 Volatile solids	g VSS m-3
18 TKN	g N m-3

SELECTED PLOTTING OUTPUTS

Na in all reactors

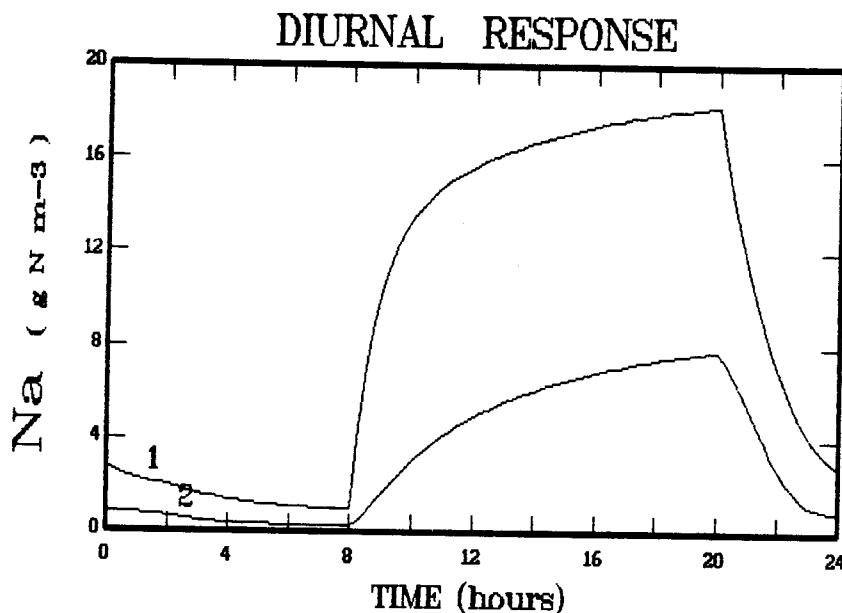
Change this selection? Y/N...

Once the desired plotting parameter has been selected the user enters an N at the prompt in the lower right window. If the computer does not have graphics facilities the message shown below is flashed on the screen. Thereafter the program will return to the diurnal sub-menu.

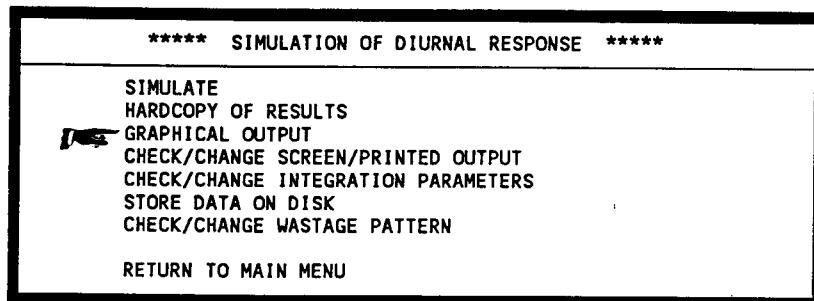
Graphics error

You probably have no graphics card!

If the computer has graphics facilities a plot of the response of the selected parameter over the 24-hour cycle will appear on the screen. An example plot is shown below.



Once the user has viewed the plot a copy of the graph may be generated on a printer by entering a Y at the prompt. This option should be used only when a 9-pin Epson-compatible dot matrix printer is being used. Once a Y or an N has been entered the diurnal menu will reappear with the GRAPHICAL OUTPUT option highlighted.



Press <Arrows> or <SpaceBar> to move selection
Press <Return> to select option

If the **CHECK/CHANGE PLOTTING SCALES** option is selected from the sub-menu of the **GRAPHICAL OUTPUT** option shown above, changes can be made to default values of the maximum plotting range for the parameters. Two windows appear on the screen as shown below. The possible plotting variables are listed in a window to the left of the screen together with the current values of the maxima of the graphs for the corresponding variables. The list will differ for IAWPRC and UCTOLD.

MAXIMUM PLOTTING RANGES		
1 Zbh (hetero.)	g COD m-3	4000
2 Zba (autotrophs)	g COD m-3	400
3 Ze (endog.)	g COD m-3	4000
4 Zi (prt unb COD)	g COD m-3	4000
5 Sads (adsorb.COD)	g COD m-3	400
6 Serm (enmesh COD)	g COD m-3	1000
7 Nobp (prt bio N)	g N m-3	100
8 Sbs (sol bio COD)	g COD m-3	20
9 Na (ammonia N)	g N m-3	40
10 Nobs (sol org N)	g N m-3	20
11 No3 (nitrate N)	g N m-3	50
12 Alkalinity	mole m-3	20
13 Sus (sol unb COD)	g COD m-3	100
14 OUR carb	g O2 m-3 h-1	100
15 OUR nitr	g O2 m-3 h-1	100
16 OUR tot	g O2 m-3 h-1	100
17 Volatile solids	g VSS m-3	10000
18 TKN	g N m-3	50

Alter any ranges ? Y/N...

The user must enter either a Y or an N at the prompt in the window to the right depending on whether or not a change must be made to any of the maximum plotting values. If a Y is entered the window on the right will change as follows.

MAXIMUM PLOTTING RANGES		
1 Zbh (hetero.)	g COD m-3	4000
2 Zba (autotrophs)	g COD m-3	400
3 Ze (endog.)	g COD m-3	4000
4 Zi (prt unb COD)	g COD m-3	4000
5 Sads (adsorb.COD)	g COD m-3	400
6 Serm (enmesh COD)	g COD m-3	1000
7 Nobp (prt bio N)	g N m-3	100
8 Sbs (sol bio COD)	g COD m-3	20
9 Na (ammonia N)	g N m-3	40
10 Nobs (sol org N)	g N m-3	20
11 No3 (nitrate N)	g N m-3	50
12 Alkalinity	mole m-3	20
13 Sus (sol unb COD)	g COD m-3	100
14 OUR carb	g O2 m-3 h-1	100
15 OUR nitr	g O2 m-3 h-1	100
16 OUR tot	g O2 m-3 h-1	100
17 Volatile solids	g VSS m-3	10000
18 TKN	g N m-3	50

Alter any ranges ? Y/N...

Change Scale No.

The number of the parameter for which the scale must change is entered at the prompt. If, say, a 9 is entered (for the parameter ammonia here) the user is prompted to enter a new maximum plotting range for this parameter as shown below.

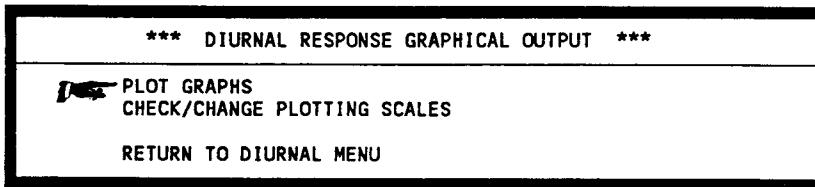
MAXIMUM PLOTTING RANGES		
1 Zbh (hetero.)	g COD m-3	4000
2 Zba (autotrophs)	g COD m-3	400
3 Ze (endog.)	g COD m-3	4000
4 Zi (prt unb COD)	g COD m-3	4000
5 Sads (adsorb.COD)	g COD m-3	400
6 Semm (enmesh COD)	g COD m-3	1000
7 Nobp (prt bio N)	g N m-3	100
8 Sbs (sol bio COD)	g COD m-3	20
9 Na (ammonia N)	g N m-3	40
10 Nobs (sol org N)	g N m-3	20
11 No3 (nitrate N)	g N m-3	50
12 Alkalinity	mole m-3	20
13 Sus (sol unb COD)	g COD m-3	100
14 OUR carb	g O2 m-3 h-1	100
15 OUR nitr	g O2 m-3 h-1	100
16 OUR tot	g O2 m-3 h-1	100
17 Volatile solids	g VSS m-3	10000
18 TKN	g N m-3	50

Alter any ranges ? Y/N...

Change Scale No. 9

New Na max. range =

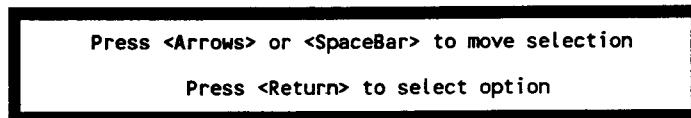
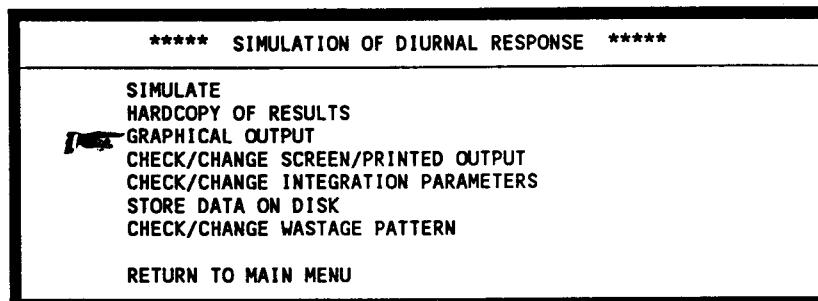
When the new value is entered the appropriate maximum plotting range is updated in the window to the left. The user is then prompted for more changes to the maximum plotting ranges. If an N is entered the graphics sub-menu reappears with the **PLOT GRAPHS** option highlighted as shown below.



Press <Arrows> or <SpaceBar> to move selection

Press <Return> to select option

When the user has finished viewing the graphs the **RETURN TO DIURNAL MENU** option is selected. The program returns to the diurnal sub-menu with the **GRAPHICAL OUTPUT** option highlighted as shown below.



*The diurnal response patterns shown in the plots are constructed by joining data points at intervals with straight lines. If the intervals are short then the graph will mimic the response closely. The interval between data points is equal to the data interval which appears in the **CHECK/CHANGE INTEGRATION PARAMETERS** sub-menu discussed later. At this point it suffices to note that intervals of 10, 15 or 30 minutes can be selected. The default value is 15 minutes.*

Check/change screen/printed output

The response of ten parameters is listed either on the screen during computation of the diurnal response (**SIMULATE** option) or by the printer when the option **HARDCOPY OF RESULTS** is selected from the diurnal sub-menu. This is the maximum number that can be listed conveniently on the screen or on 80 column printer paper. The ten selected output variables may be modified via the **CHECK/CHANGE SCREEN/PRINTED OUTPUT** option.

If the **CHECK/CHANGE SCREEN/PRINTED OUTPUT** option is selected from the diurnal sub-menu three windows appear on the screen as shown below. The upper right window lists the ten current output variables. A list of eighteen possible output variables appears in a window at the left. The number of variables in this window differs for **IAWPRC** and **UCTOLD**.

POSSIBLE OUTPUT PARAMETERS	
1	Zbh (hetero.) g COD m-3
2	Zba (autotrophs) g COD m-3
3	Ze (endog.) g COD m-3
4	Zi (prt unb COD) g COD m-3
5	Sads (adsorb.COD) g COD m-3
6	Serm (enmesh COD) g COD m-3
7	Nobp (prt bio N) g N m-3
8	Sbs (sol bio COD) g COD m-3
9	Na (ammonia N) g N m-3
10	Nobs (sol org N) g N m-3
11	No3 (nitrate N) g N m-3
12	Alkalinity mole m-3
13	Sus (sol unb COD) g COD m-3
14	OUR carb g O2 m-3 h-1
15	OUR nitr g O2 m-3 h-1
16	OUR tot g O2 m-3 h-1
17	Volatile solids g VSS m-3
18	TKN g N m-3

SELECTED OUTPUTS	
1	Zbh
2	Zba
3	Sads
4	Serm
5	VSS
6	Sbs
7	Na
8	No3
9	TKN
10	Ot

Change any of the above ? Y/N...

The selected output variables can be changed one at a time. If a **Y** is entered at the prompt the user must respond to the query in the window to the lower right as shown below.

POSSIBLE OUTPUT PARAMETERS	
1	Zbh (hetero.) g COD m-3
2	Zba (autotrophs) g COD m-3
3	Ze (endog.) g COD m-3
4	Zi (prt unb COD) g COD m-3
5	Sads (adsorb.COD) g COD m-3
6	Serm (enmesh COD) g COD m-3
7	Nobp (prt bio N) g N m-3
8	Sbs (sol bio COD) g COD m-3
9	Na (ammonia N) g N m-3
10	Nobs (sol org N) g N m-3
11	No3 (nitrate N) g N m-3
12	Alkalinity mole m-3
13	Sus (sol unb COD) g COD m-3
14	OUR carb g O2 m-3 h-1
15	OUR nitr g O2 m-3 h-1
16	OUR tot g O2 m-3 h-1
17	Volatile solids g VSS m-3
18	TKN g N m-3

SELECTED OUTPUTS	
1	Zbh
2	Zba
3	Sads
4	Serm
5	VSS
6	Sbs
7	Na
8	No3
9	TKN
10	Ot

Change any of the above ? Y/N...

Remove Selection No.

If the user wishes to output, say, the oxygen utilization rate for nitrification (O_n) instead of the TKN concentration, then a 9 would be entered at the prompt to designate the selected variable to be removed. The user is then prompted to enter the number of the replacement variable, 15 here, in the lower right window as shown below.

POSSIBLE OUTPUT PARAMETERS	
1	Zbh (hetero.) g COD m ⁻³
2	Zba (autotrophs) g COD m ⁻³
3	Ze (endog.) g COD m ⁻³
4	Zi (prt unb COD) g COD m ⁻³
5	Sads (adsorb.COD) g COD m ⁻³
6	Senn (ennmesh COD) g COD m ⁻³
7	Nobp (prt bio N) g N m ⁻³
8	Sbs (sol bio COD) g COD m ⁻³
9	Na (ammonia N) g N m ⁻³
10	Nobs (sol org N) g N m ⁻³
11	No3 (nitrate N) g N m ⁻³
12	Alkalinity mole m ⁻³
13	Sus (sol unb COD) g COD m ⁻³
14	OUR carb g O ₂ m ⁻³ h ⁻¹
15	OUR nitr g O ₂ m ⁻³ h ⁻¹
16	OUR tot g O ₂ m ⁻³ h ⁻¹
17	Volatile solids g VSS m ⁻³
18	TKN g N m ⁻³

SELECTED OUTPUTS	
1	Zbh
2	Zba
3	Sads
4	Senn
5	VSS
6	Sbs
7	Na
8	No3
9	TKN
10	Ot

Change any of the above ? Y/N...

Remove Selection No. 9

Replace with Parameter No.

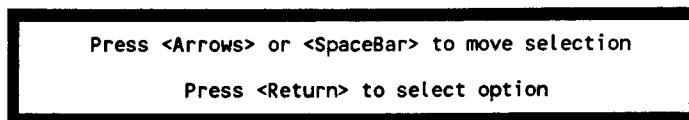
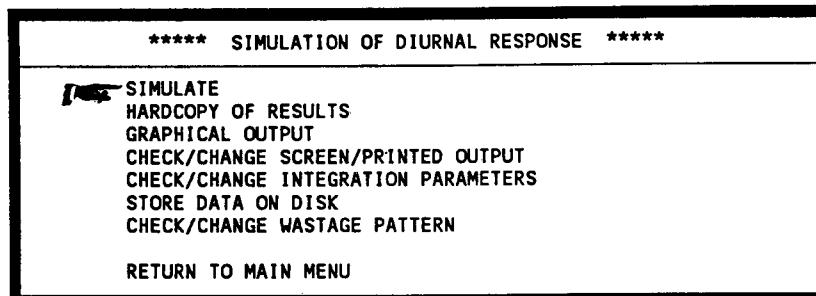
The list of selected output variables is updated to reflect the change as shown below, and the user is prompted for more changes as shown below. These ten parameters will be listed either during computation of the diurnal response (SIMULATE option) or when the option HARDCOPY OF RESULTS is selected from the diurnal sub-menu.

POSSIBLE OUTPUT PARAMETERS	
1	Zbh (hetero.) g COD m ⁻³
2	Zba (autotrophs) g COD m ⁻³
3	Ze (endog.) g COD m ⁻³
4	Zi (prt unb COD) g COD m ⁻³
5	Sads (adsorb.COD) g COD m ⁻³
6	Senn (ennmesh COD) g COD m ⁻³
7	Nobp (prt bio N) g N m ⁻³
8	Sbs (sol bio COD) g COD m ⁻³
9	Na (ammonia N) g N m ⁻³
10	Nobs (sol org N) g N m ⁻³
11	No3 (nitrate N) g N m ⁻³
12	Alkalinity mole m ⁻³
13	Sus (sol unb COD) g COD m ⁻³
14	OUR carb g O ₂ m ⁻³ h ⁻¹
15	OUR nitr g O ₂ m ⁻³ h ⁻¹
16	OUR tot g O ₂ m ⁻³ h ⁻¹
17	Volatile solids g VSS m ⁻³
18	TKN g N m ⁻³

SELECTED OUTPUTS	
1	Zbh
2	Zba
3	Sads
4	Senn
5	VSS
6	Sbs
7	Na
8	No3
9	On
10	Ot

Change any of the above ? Y/N...

Once the desired set of ten output parameters has been selected and no more changes are required the user enters an N at the prompt in the lower right window. The diurnal sub-menu will re-appear as shown below.



Check/change integration parameters

When the **CHECK/CHANGE INTEGRATION PARAMETERS** option is selected from the diurnal menu the following list of three parameters appears on the screen.

**** INTEGRATION PARAMETERS ****	
% Accuracy (0.01 to 1.0)	0.500
Theta (0.5 to 0.8)	0.700
Data interval (10,15 or 30 mins)	15.000
RETURN TO MENU	

Hit <Arrows> or <SpaceBar> to move selection
Hit <Return> to enter new value for selected constant

Default values for the three constants are provided in the program. These will appear in the list unless changes have already been made by the user during the current execution of the program. A short explanation of the function of the constants, and reasons for why the user may wish to alter the values, now follows.

% Accuracy and Theta

The first two parameters, *% Accuracy* and *Theta*, are utilized in the diurnal simulation by the integration algorithm in the automatic steplength adjustment procedure. *% Accuracy* relates to a limiting value for the integration error at each step. *Theta* is a safety factor limit the increase in steplength from one step to the next. Default values are provided in the program. These have been found suitable for most situations, and lead to acceptably short simulation times. It is likely that most users will have no need to adjust the values. However, under certain circumstances the integration algorithm may encounter difficulties when using the default values and adjustments must be made.

Problems with the integration algorithm usually manifest themselves in two ways. Firstly, a large number of cycles are required to converge to the solution in the **SIMULATE** option, well in excess of the usual two to five cycles. Secondly, in the graphical output certain parameters (typically soluble COD and oxygen utilization rate) may exhibit small oscillations ("noise" or "spikiness") over a part of the diurnal cycle instead of a smooth change with time.

The problems usually occur in simulation of systems where there is a large difference in size between reactors or where there are very large changes in the influent flow. The solution normally lies in decreasing the parameter *% Accuracy* from the default of 0.5 to 0.1 or perhaps even smaller. Decreasing the parameter *Theta* from 0.7 to 0.6 or 0.5 can also improve performance of the integration algorithm. However, decreasing the parameters leads to longer simulation times as the integration is more rigorous.

Data interval

While simulating the response of a system it is necessary to store values of parameters at intervals over the diurnal cycle. This allows the user to print results and plot graphs of the response after the simulation has been completed.

The parameter *Data interval* specifies the time (in minutes) between values which are stored in memory. For example, with the default *Data interval* of 15 minutes there will be 97 discrete values of each parameter stored representing the response of the system over the cycle from 0h00 to 24h00.

The reason for reducing the *Data interval* to 10 minutes usually is to allow the response of rapidly-changing parameters to be tracked accurately. The penalty for reducing the *Data interval* is that the maximum allowable integration steplength may be constrained so as to store data at the correct times where otherwise a longer steplength may have been used. This will result in an increased simulation time.

The user should note that if the "Data interval" is changed then the program requires that the SIMULATE option must be executed before attempting to print or plot data.

Changes to any of the values can be made by the user. Any updated data will remain current during execution of the program, unless changed again. When execution is terminated and the program is re-run the original default values will appear.

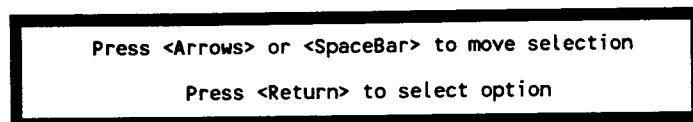
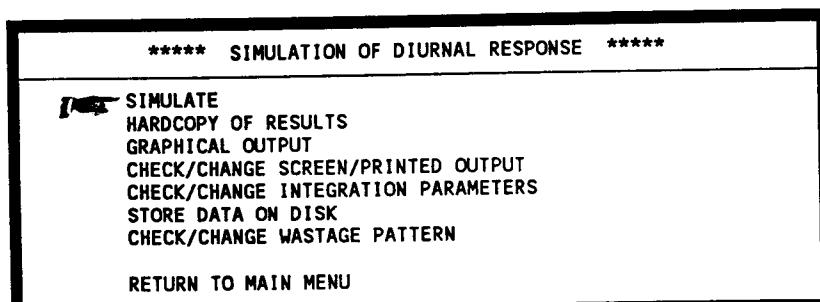
Instructions for changing any of the data are provided in the window at the bottom of the screen. To update a value the highlighted block must be moved from RETURN TO MENU to the value which is to be changed. This is achieved by pressing the "up arrow" (\uparrow) or "down arrow" (\downarrow) keys or by pressing the spacebar (this scrolls the highlight from the top downwards). When the highlight appears on the value to be changed the user presses the <RETURN> key, and is prompted for a new value as shown below. On entering the new value the screen is updated and the highlight reverts to the RETURN TO MENU position.

**** INTEGRATION PARAMETERS ****		
% Accuracy (0.01 to 1.0)	0.500	
Theta (0.5 to 0.8)	0.700	New value =
Data interval (10,15 or 30 mins)	15.000	
RETURN TO MENU		

Hit <Arrows> or <SpaceBar> to move selection

Hit <Return> to enter new value for selected constant

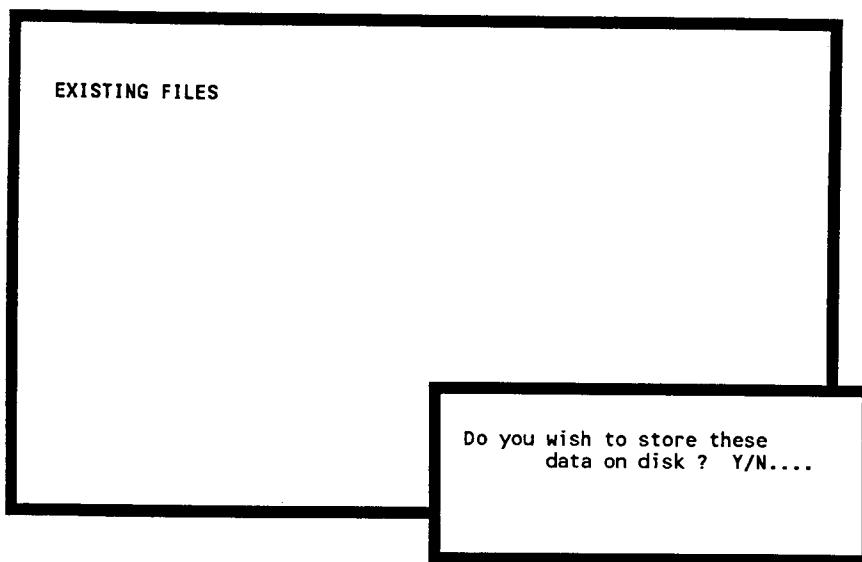
When the RETURN TO MENU option is selected the diurnal sub-menu reappears with the highlight on the SIMULATE option as shown below.



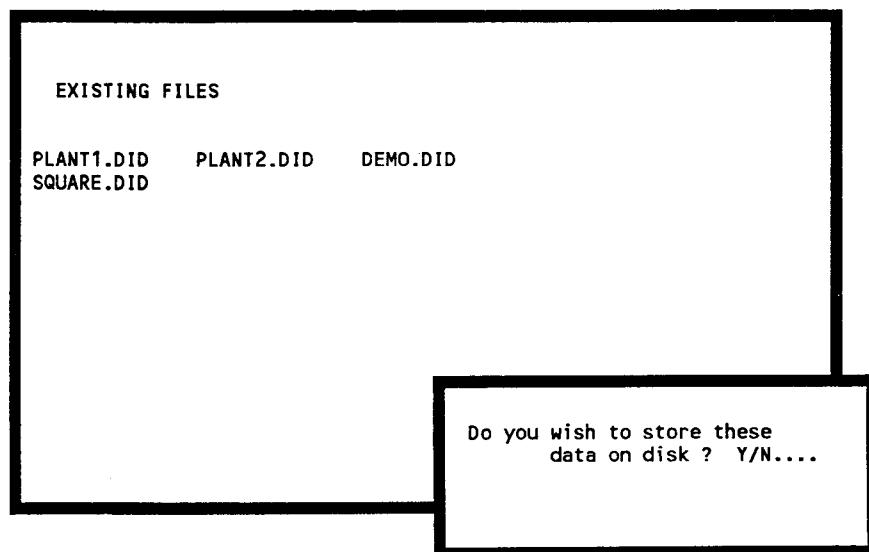
Store data on disk

The user may wish to store the results of a diurnal simulation on disk for off-line processing. For example, to allow a package such as *Lotus 1-2-3* access to the data.

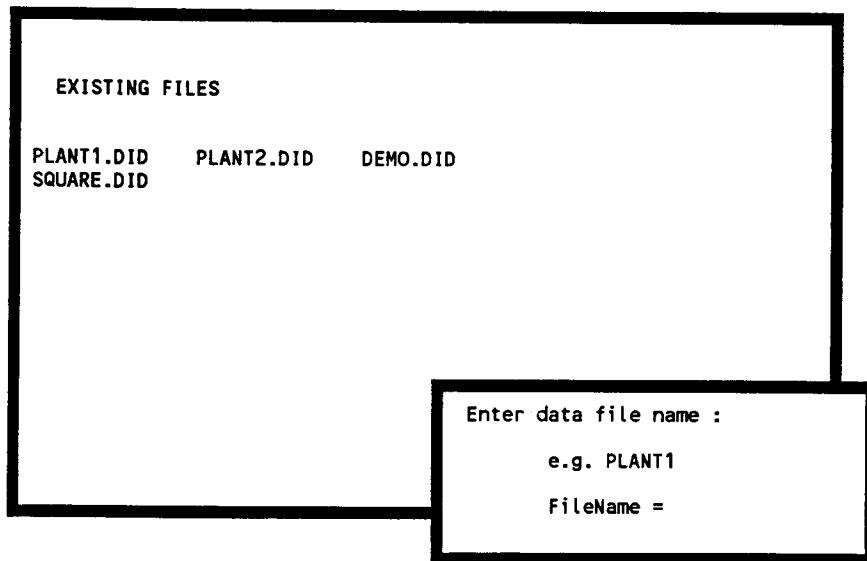
When the option **STORE DATA ON DISK** is selected from the diurnal sub-menu for the first time two windows appear on the screen as shown below. The main window will not list any existing files as none have been created.



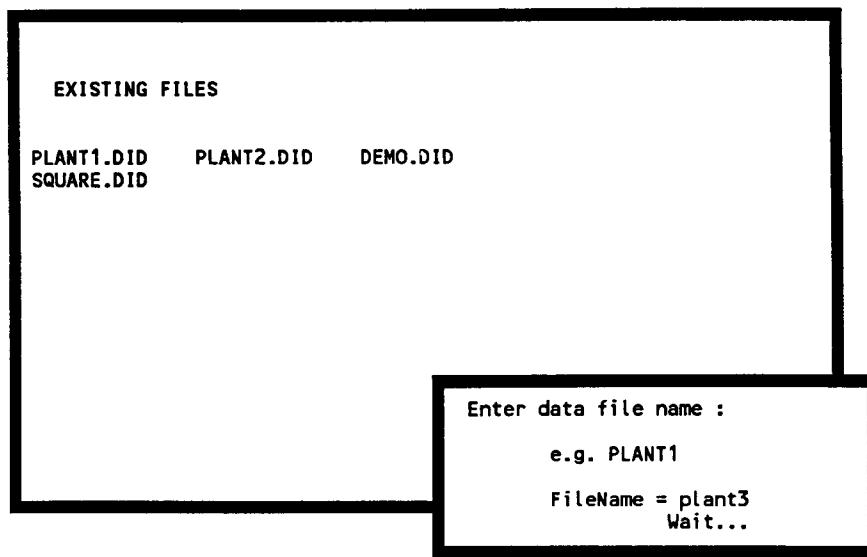
If the data have been stored on disk prior to selecting the **STORE DATA ON DISK** option then the names of all existing diurnal data files will be listed in three columns in the main window. The files are given the extension .DID. For example, the screen may appear as follows.



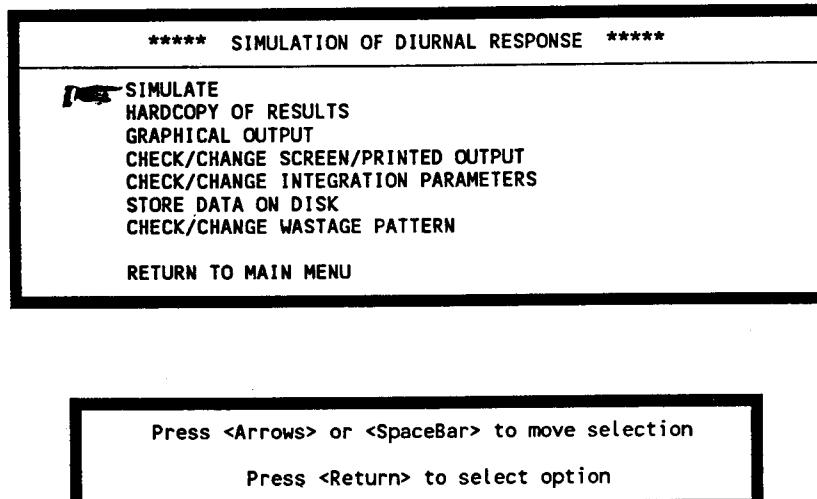
In the input window at the lower right the user enters a Y if the data are to be stored on disk. If an N is entered the program returns to the diurnal sub-menu. When a Y is entered at the prompt the user is requested to enter a file name in the input window as shown below. It is not necessary to type the extension .DID after the file name.



The data are stored in a file of the specified name with the extension .DID on the disk (and in the directory) from where the program was executed. The user must wait for a few seconds while the data are being written to disk before continuing with program operation. During this delay the screen will appear as follows.



When the data have been written to disk the diurnal sub-menu reappears with the highlight on the **SIMULATE** option as shown below.



The data are stored in a Turbo Pascal *file of reals*. The size of the data file is different for **IAWPRC** or **UCTOLD** and is dependant on the number of reactors in the configuration and the *Data interval*. For example, with **UCTOLD** eighteen parameters are stored for each reactor. Therefore with a two reactor system simulated with a *Data interval* of 15 minutes (97 values for the 24-hour cycle), noting that 6 bytes are used to store each real value, the size of the data file will be

$$2 \cdot 18 \cdot 97 \cdot 6 = 20\,952 \text{ bytes.}$$

Details of the code used to write the data to disk are presented in Appendix A. This will enable the user to write a program to extract the data. The program **RETRIEVE** on the distribution disk can be used for creating a text file which can be imported into *Lotus 1-2-3* or Borland's *Quattro*.

Check/change wastage pattern

The **average** mixed liquor wastage rate required to establish the specified sludge age is calculated in the steady state section of the program. However, a number of situations may arise where the wastage rate at stages during the 24-hour cycle should not necessarily equal the average value. For example:

- In certain cases the user may wish to specify that wastage only takes place over a part of the cycle. A facility is included in the program to allow the wastage pattern over the 24-hour cycle to be manipulated. It is assumed that wastage is either on or off during each of 12 two-hour intervals. This corresponds to the division of the influent pattern. The wastage rate is the same over intervals when wastage occurs (and otherwise zero) and is such that the correct volume of mixed liquor is removed per day.
- Depending on the diurnal influent pattern situations may arise when the flow into the plant over one or more two-hour intervals is less than the average wastage rate. In this case the reactor volume will decrease and accordingly the wastage rate over such an interval should be reduced and the rate increased over another interval(s) where the influent flow is higher. In the program, before simulation of the diurnal response is started, the influent pattern is checked against the wastage rate. Adjustments are made to the waste pattern by switching wastage on or off during each of the 12 two-hour intervals in the cycle.

When the **CHECK/CHANGE WASTAGE PATTERN** option is selected from the diurnal sub-menu the screen will appear in a form similar to that shown below. This is the wastage pattern set up by the program and is in this case for the configuration used to illustrate program operation so far. That is, a two-reactor system with volumes of 2 and 5 m³ operated at a sludge age of 5 days. The average wastage rate is $(2+5)/5 = 1.40 \text{ m}^3 \text{ d}^{-1}$. The influent flow follows a square wave pattern with flow for 12 hours between 06h00 and 18h00 and no flow for the remainder of the cycle.

***** SLUDGE WASTAGE PATTERN *****				
Record No	Time (h)	Wastage On	Waste Flow (m ³ d ⁻¹)	
1	0.0	No	0.00	
2	2.0	No	0.00	
3	4.0	No	0.00	
4	6.0	No	0.00	
5	8.0	Yes	2.80	
6	10.0	Yes	2.80	
7	12.0	Yes	2.80	
8	14.0	Yes	2.80	
9	16.0	Yes	2.80	
10	18.0	Yes	2.80	
11	20.0	No	0.00	
12	22.0	No	0.00	

** Mean wastage rate =
1.40 m³/d

Switch any on/off? Y/N....

Because there is no influent flow for six of the 12 two-hour intervals the wastage must be switched off during these intervals. For the remaining six intervals the wastage rate must be set at twice the average value (i.e. $2,80 \text{ m}^3 \text{ d}^{-1}$). The average appears at the lower left of the main window.

If the user wishes to make a change to the wastage pattern as defined in the main window a Y is entered at the prompt in the input window at the lower right of the screen. The user is then prompted to enter the number of the record where the wastage is to be changed from on to off or *vice versa* as shown below.

***** SLUDGE WASTAGE PATTERN *****				
Record No	Time (h)	Wastage On	Waste Flow (m ³ d ⁻¹)	
1	0.0	No	0.00	
2	2.0	No	0.00	
3	4.0	No	0.00	
4	6.0	No	0.00	
5	8.0	Yes	2.80	
6	10.0	Yes	2.80	
7	12.0	Yes	2.80	
8	14.0	Yes	2.80	
9	16.0	Yes	2.80	
10	18.0	Yes	2.80	
11	20.0	No	0.00	
12	22.0	No	0.00	

** Mean wastage rate = 1.40 m³/d

Change in Record No.

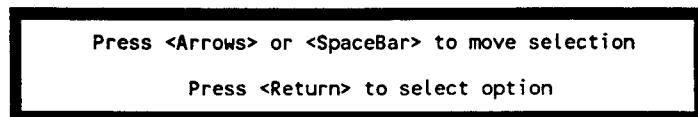
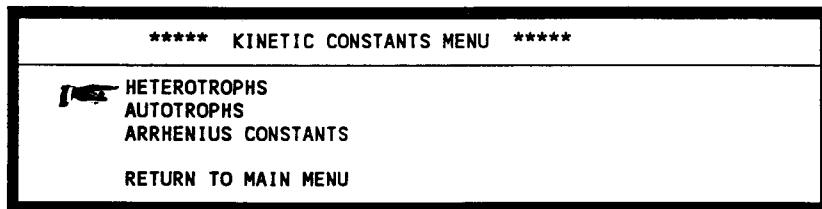
When no more changes to the pattern are required the user enters an N at the prompt in the input window and the diurnal sub-menu re-appears with the highlight on the SIMULATE option as shown below.

***** SIMULATION OF DIURNAL RESPONSE *****	
 SIMULATE	
HARDCOPY OF RESULTS	
GRAPHICAL OUTPUT	
CHECK/CHANGE SCREEN/PRINTED OUTPUT	
CHECK/CHANGE INTEGRATION PARAMETERS	
STORE DATA ON DISK	
CHECK/CHANGE WASTAGE PATTERN	
RETURN TO MAIN MENU	

Press <Arrows> or <SpaceBar> to move selection
 Press <Return> to select option

KINETIC CONSTANTS

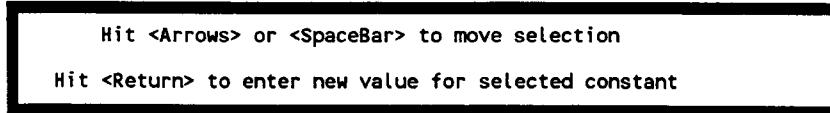
When the **KINETIC CONSTANTS** option is selected from the main menu a sub-menu appears on the screen as shown below:



The user may view and/or change the values of the kinetic constants for either the heterotrophs or the autotrophs, and the Arrhenius temperature dependency constants for certain of the kinetic constants. The appropriate set of constants is selected by moving the highlight to the desired option and pressing the <RETURN> key. For example, when the **HETEROTROPHS** option is selected when utilizing the UCTOLD model the screen will appear as shown below. *The displayed data are the default values of the constants at 20° C.*

**** HETEROTROPHS ****		
Mue max	d-1	3.200
Ks COD	(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
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
Ks NH3	(Kna) g N m-3	0.010
Adsorption rate	(Ka) g-1 COD m3 d-1	0.170

RETURN TO MENU



Default values for the kinetic constants and their temperature dependency constants are provided in the program. These will appear in the list unless changes have already been made by the user during the current execution of the program. The values are averages obtained in simulation of the observed response of a range of system configurations over a range of operating conditions.

Changes to any of the values can be made at this stage. Any updated data will remain current during execution of the program, unless changed again. When execution is terminated and the program is re-run the original default values will appear.

Instructions for changing any of the data are provided in the window at the bottom of the screen. To update a value the highlighted block must be moved from **RETURN TO MENU** to the value which is to be changed. This is achieved by pressing the "up arrow" (\uparrow) or "down arrow" (\downarrow) keys or by pressing the **spacebar** (this scrolls the highlight from the top downwards). When the highlight appears on the value to be changed the user presses the <RETURN> key, and is prompted for a new value as shown below. On entering the new value the screen is updated and the highlight reverts to the **RETURN TO MENU** position.

***** HETEROTROPHS *****		
Mue max	d-1	3.200
Ks COD	(Ksh) g COD m ⁻³	5.000
Ks O ₂	(Koh) g O ₂ m ⁻³	0.002
B decay	(bh) d-1	0.620
Neta (growth)		0.330
Ks N _{O3}	(Kno) g N m ⁻³	0.100
Hydrolysis rate	(Kmp) d-1	1.350 New value =
Ks hydrolysis	(Ksp) g COD g ⁻¹ COD	0.027
Ammonification	(Kr) m ³ g ⁻¹ COD d-1	0.032
Ks NH ₃	(Kna) g N m ⁻³	0.010
Adsorption rate	(Ka) g ⁻¹ COD m ³ d-1	0.170
RETURN TO MENU		

Hit <Arrows> or <SpaceBar> to move selection
Hit <Return> to enter new value for selected constant

If the highlight is in the **RETURN TO MENU** position and the **RETURN** key is pressed the kinetic constants sub-menu will re-appear as shown below.

***** KINETIC CONSTANTS MENU *****	
	HETEROTROPHS
	AUTOTROPHS
	ARRHENIUS CONSTANTS
RETURN TO MAIN MENU	

Press <Arrows> or <SpaceBar> to move selection
Press <Return> to select option

The user may either select one of these options or return to the main menu. When the user elects to return to the main menu the following window appears on the screen.

Do you want a hardcopy of kinetic constants? Y/N...

If a printer is attached to the computer the user may obtain a printout of all the kinetic and temperature dependency constants by entering a Y; else the N key is pressed. At a later stage, directly after simulating either the steady state or diurnal response, there is another opportunity to obtain a listing of the constants. After entering a Y or an N the program returns to the main menu with the highlight on the **STEADY STATE SIMULATION** option as shown below.

***** MAIN SIMULATION PROGRAM MENU *****

INFLUENT DATA
PLANT CONFIGURATION
OPERATING PARAMETERS
~~STEADY STATE SIMULATION~~
DIURNAL SIMULATION
KINETIC CONSTANTS
STOICHIOMETRY

EXIT FROM PROGRAM

Press <Arrows> or <SpaceBar> to move selection

Press <Return> to select option

STOICHIOMETRY

The user may view and/or change the values of the stoichiometric constants by selecting the **STOICHIOMETRY** option from the main menu and pressing the <RETURN> key. When utilizing the UCTOLD model the screen will appear as follows.

***** 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	
[] RETURN TO MENU				

Hit <Arrows> or <SpaceBar> to move selection Hit <Return> to enter new value for selected constant

Default values for the stoichiometric constants are provided in the program as is the case with the kinetic constants. These will be displayed unless changes have already been made by the user during the current execution of the program. The values are averages obtained in simulation of the observed response of a range of system configurations over a range of operating conditions.

Changes to any of the values can be made at this stage by following the procedure outlined in the window towards the base of the screen. Any updated data will remain current during execution of the program, unless changed again. When execution is terminated and the program is re-run the original default values will appear.

Instructions for changing any of the data are provided in the window at the bottom of the screen. To update a value the highlighted block must be moved from **RETURN TO MENU** to the value which is to be changed. This is achieved by pressing the "up arrow" (\uparrow) or "down arrow" (\downarrow) keys or by pressing the spacebar (this scrolls the highlight from the top downwards). When the highlight appears on the value to be changed the user presses the <RETURN> key, and is prompted for a new value as shown below. On entering the new value the screen is updated and the highlight reverts to the **RETURN TO MENU** position.

**** 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	New value =
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	
RETURN TO MENU				

Hit <Arrows> or <SpaceBar> to move selection

Hit <Return> to enter new value for selected constant

When no more changes are required and the user elects to return to the main menu the following window appears on the screen.

**** 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	
Do you want a hardcopy of stoichiometric constants? Y/N...				
Hit <Arrows> or <SpaceBar> to move selection				
Hit <Return> to enter new value for selected constant				

If a printer is attached to the computer the user may obtain a printout of the stoichiometric constants by entering a Y; else the N key is pressed. At a later stage, directly after simulating either the steady state or diurnal response, there is another opportunity to obtain a listing of the constants. After entering a Y or an N the program returns to the main menu with the highlight on the STEADY STATE SIMULATION option as shown overleaf.

***** MAIN SIMULATION PROGRAM MENU *****

INFLUENT DATA
PLANT CONFIGURATION
OPERATING PARAMETERS
 STEADY STATE SIMULATION
DIURNAL SIMULATION
KINETIC CONSTANTS
STOICHIOMETRY

EXIT FROM PROGRAM

Press <Arrows> or <SpaceBar> to move selection

Press <Return> to select option

CHAPTER 5

APPLICATION AND VERIFICATION

INTRODUCTION

In Chapter 2 the origins and key features of the two general activated sludge models included in the simulation package (UCTOLD and IAWPRC) were described briefly. In this Chapter the predictive power of the two models will be evaluated. To test the predictive power of the two models, data sets for a number of activated sludge systems were selected from the experimental database generated over the past 20 years at UCT; the responses of the selected systems were simulated using both models, and the predictions compared to the experimental data. In the simulations, the values for the kinetic and stoichiometric constants were the default values listed in Chapter 2, Tables 2.2 and 2.5, unless explicitly stated otherwise. The screens in the computer programs of the default values are as follows:

For UCTOLD, heterotroph kinetic (at 20° C) and Arrhenius temperature constants,

***** HETEROTROPHS *****		
Mue max	d-1	3.200
Ks COD	(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
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
Ks NH3	(Kna) g N m-3	0.010
Adsorption rate	(Ka) g-1 COD m3 d-1	0.170

RETURN TO MENU

Hit <Arrows> or <SpaceBar> to move selection
Hit <Return> to enter new value for selected constant

** ARRHENIUS TEMP CONSTANTS (Thetas ref 20C) **	
Mue max hetero	1.200
Ksh	1.000
B endogenous hetero (Bh)	1.029
Kmp hydrolysis	1.080
Ksp hydrol. half-sat.	0.910
Kr	1.029
Mue max auto	1.123
Ksa	1.123
B endogenous auto (Ba)	1.029
Ka adsoption rate	1.029

RETURN TO MENU

Hit <Arrows> or <SpaceBar> to move selection
Hit <Return> to enter new value for selected constant

For IAWPRC, heterotroph kinetic (at 20°C) and Arrhenius temperature constants,

**** HETEROtROPHS ****		
Mue max	d-1	3.200
Ks COD	(Ksh) g COD m-3	5.000
Ks O2	(Koh) g O2 m-3	0.002
B decay	(bh) d-1	0.620
Neta (solubilization)		0.330
Neta (growth)		1.000
Ks NO3	(Kno) g N m-3	0.100
Hydrolysis rate	(Kh) d-1	2.030
Ks hydrolysis	(Kx) 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

[RETURN TO MENU](#)

Hit <Arrows> or <SpaceBar> to move selection

Hit <Return> to enter new value for selected constant

** ARRHENIUS TEMP CONSTANTS (Thetas ref 20C) **	
Mue max hetero	1.200
Ksh	1.000
B endogenous hetero (Bh)	1.029
Kh hydrolysis	1.080
Kx hydrol. half-sat.	0.910
Kr	1.029
Mue max auto	1.123
KnH	1.123
B endogenous auto (Ba)	1.029

[RETURN TO MENU](#)

Hit <Arrows> or <SpaceBar> to move selection

Hit <Return> to enter new value for selected constant

For UCTOLD and IAWPRC, the autotroph kinetic (at 20°C) and the stoichiometric constants are the same,

**** AUTOTROPHS ****		
Mue max auto	d-1	0.450
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

[RETURN TO MENU](#)

Hit <Arrows> or <SpaceBar> to move selection

Hit <Return> to enter new value for selected constant

**** 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	

RETURN TO MENU

Hit <Arrows> or <SpaceBar> to move selection
 Hit <Return> to enter new value for selected constant

The constants characterizing the influent wastewater were determined separately for each system (for procedures see **Chapter 6**) and are listed where appropriate. The following systems were simulated:

- Aerobic completely mixed reactor systems with constant or cyclic flow and load.
- Aerobic batch tests, with and without nitrification.
- Anoxic/aerobic systems with plugflow primary and secondary anoxic reactors and constant flow and load.
- Anoxic/aerobic systems with completely mixed in-series reactors and constant or cyclic flow and load.
- Contact-stabilization systems with constant or cyclic flow and load.

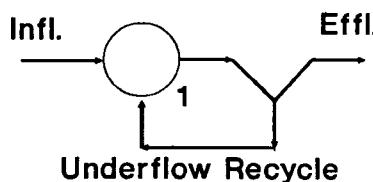
The results obtained for selected typical examples of these simulations are described below.

AEROBIC COMPLETELY MIXED REACTOR SYSTEMS

Simulations were undertaken of aerobic systems with constant and cyclic flow and load influents.

Constant flow and load

Single completely mixed aerobic reactor



5.4

The system received unsettled municipal wastewater from Cape Flats, Cape Town, South Africa as influent (Arkley and Marais, 1981). Wastewater characteristics and configuration and operational data as input to the programs were as follows:

***** WASTEWATER CHARACTERISTICS *****	
Sti(avg) g COD m ⁻³	502.000
Nti(avg) g N m ⁻³	50.100
Fbs g COD g ⁻¹ COD	0.240
Fs,us g COD g ⁻¹ COD	0.080
Fs,up g COD g ⁻¹ COD	0.130
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	0.000
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

RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH3/NH4
 Fnob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
 to move selection

 Hit <Return> to enter
 new value for
 selected constant

***** PROCESS CONFIGURATION *****		Gp 1. Number of Reactors = 1
Gp 2. Reactor Vols, l	Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1: 10.00	1.00	3.0

Do you wish to change any parameters?
Y/N....

***** PLANT OPERATING PARAMETERS *****				
1 SRT {total}	d	=	20.0	
2 Process Temperature	degC	=	20.0	
Flow rates:				
3 Influent flow	l d-1	=	10.0	
4 RAS recycle flow	l d-1	=	40.0	

Do you wish to change any parameters?
Y/N....

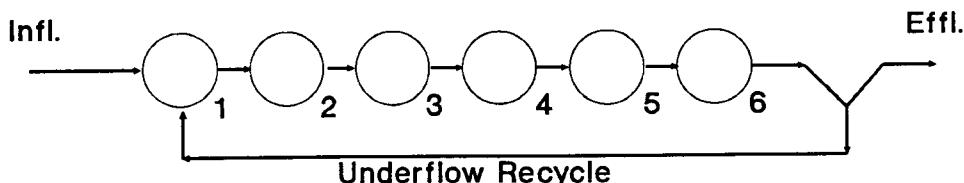
All kinetic and stoichiometric constants were the default values.

The responses predicted by the two models, UCTOLD and IAWPRC, are compared in Table 5.1 with the measured response; evidently good agreement is obtained with both models.

Table 5.1: Comparison of measured and predicted results for completely mixed aerobic single reactor system receiving unsettled wastewater as influent.

Parameter	Reactor			Effluent		
	Measured	UCTOLD	IAWPRC	Measured	UCTOLD	IAWPRC
Nitrate (mgN/l)	39,1	37,6	37,6	39,0	37,6	37,6
VSS (mgVSS/l)	2050	2174	2168	-	-	-
OUR (mgO/l/h)	19,2	20,0	20,0	-	-	-
TKN (mgN/l)	-	-	-	1,5	1,7	1,7
COD (mgCOD/l)	-	-	-	39,3	40,3	41,5

6 in-series completely mixed aerobic reactors



The system received unsettled municipal wastewater from Cape Flats, Cape Town, South Africa as influent (Ekama and Marais, 1979). Data input to the programs was as follows:

**** WASTEWATER CHARACTERISTICS ****	
Sti(avg) g COD m ⁻³	429.000
Nti(avg) g N m ⁻³	37.000
Fbs g COD g ⁻¹ COD	0,190
Fs,us g COD g ⁻¹ COD	0,080
Fs,up g COD g ⁻¹ COD	0,130
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

RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH3/NH4
 Fnob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
to move selection

Hit <Return> to enter
new value for
selected constant

***** PROCESS CONFIGURATION *****		Gp 1. Number of Reactors = 6	
Gp 2. Reactor Vols, l		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	2.00	1.00	3.0
No. 2:	2.00		3.0
No. 3:	2.00		3.0
No. 4:	2.00		3.0
No. 5:	2.00		3.0
No. 6:	2.00		3.0

Gp 5. Recycles: Use to include/remove mixed liquor recycles.
RAS recycle to Reactor No.1

Do you wish to change any parameters?
 Y/N.....

***** PLANT OPERATING PARAMETERS *****				
1 SRT {total}	d	=	10.0	
2 Process Temperature	degC	=	20.0	
Flow rates:				
3 Influent flow	l d-1	=	36.0	
4 RAS recycle flow	l d-1	=	72.0	

Do you wish to change any parameters?
 Y/N.....

The value for the autotroph maximum specific growth rate ($\hat{\mu}_A$) had to be increased, from the default value of 0,45/d to 0,65/d. Also, since in the system pH = 6,05, the autotroph kinetic constants had to be adjusted (WRC, 1984), as follows:

$$\begin{aligned}
 \hat{\mu}_A &= \hat{\mu}_A (\text{pH} = 7,2) \cdot (2,35)^{(7,2-7,2)} \\
 &= 0,65 \cdot (2,35)^{(6,05-7,2)} \\
 &= 0,243 /d
 \end{aligned} \tag{5.1}$$

$$\begin{aligned}
 K_{SA} &= K_{SA} (\text{pH} = 7,2) \cdot (2,35)^{(7,2-\text{pH})} \\
 &= 1,0 \cdot (2,35)^{(7,2-6,05)} \\
 &= 2,67 \text{ mgN/l}
 \end{aligned} \tag{5.2}$$

All other stoichiometric and kinetic constants used in the simulations were the default values. The predicted and measured results are compared in Fig 5.1(a,b,c,d and e); good agreement is obtained with both models.

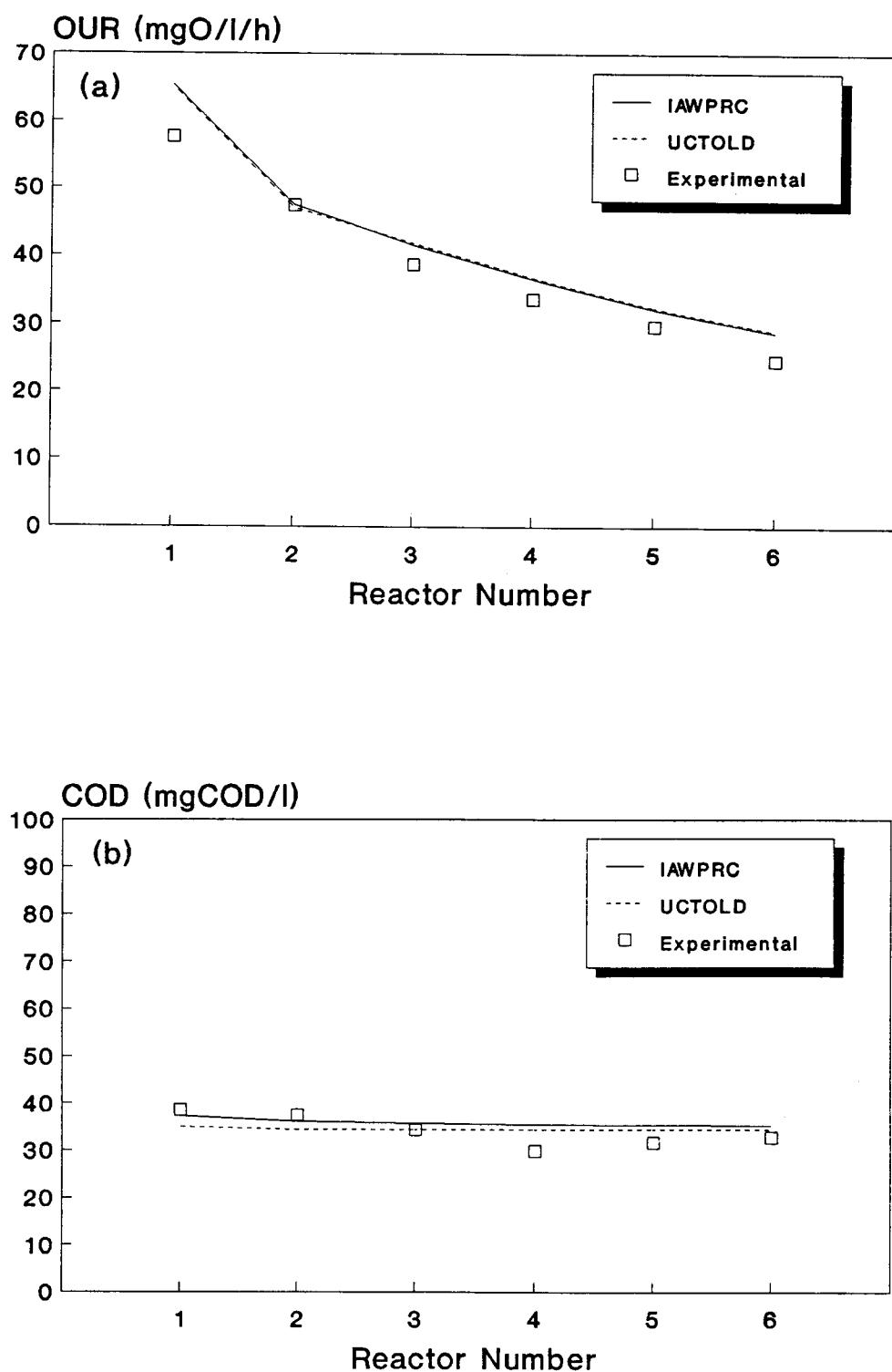


Fig 5.1: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate profiles for 6 in-series reactor completely aerobic system under constant flow and load; predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979). Continued overleaf.....

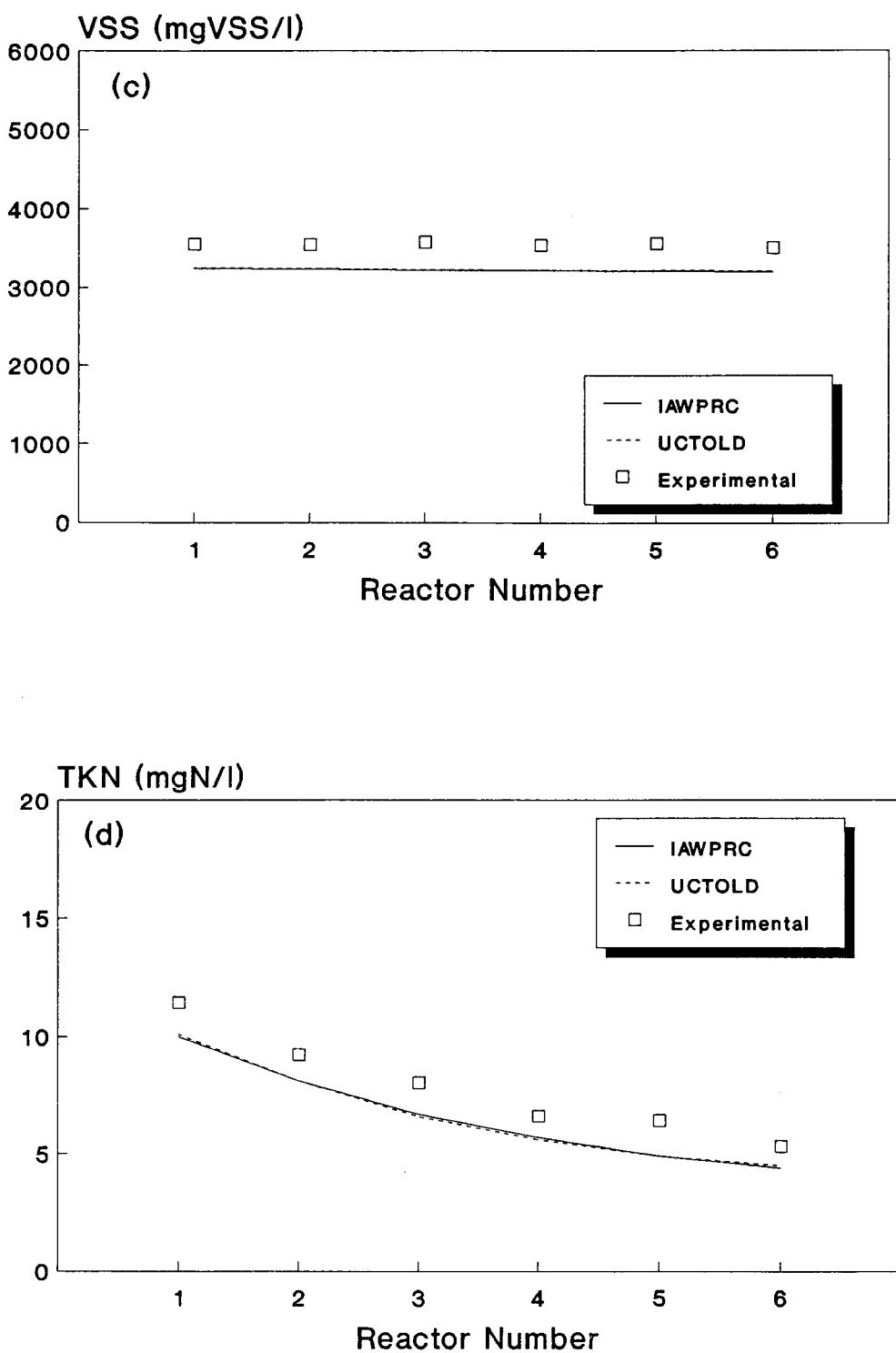


Fig 5.1: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate profiles for 6 in-series reactor completely aerobic system under constant flow and load; predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979). Continued overleaf.....

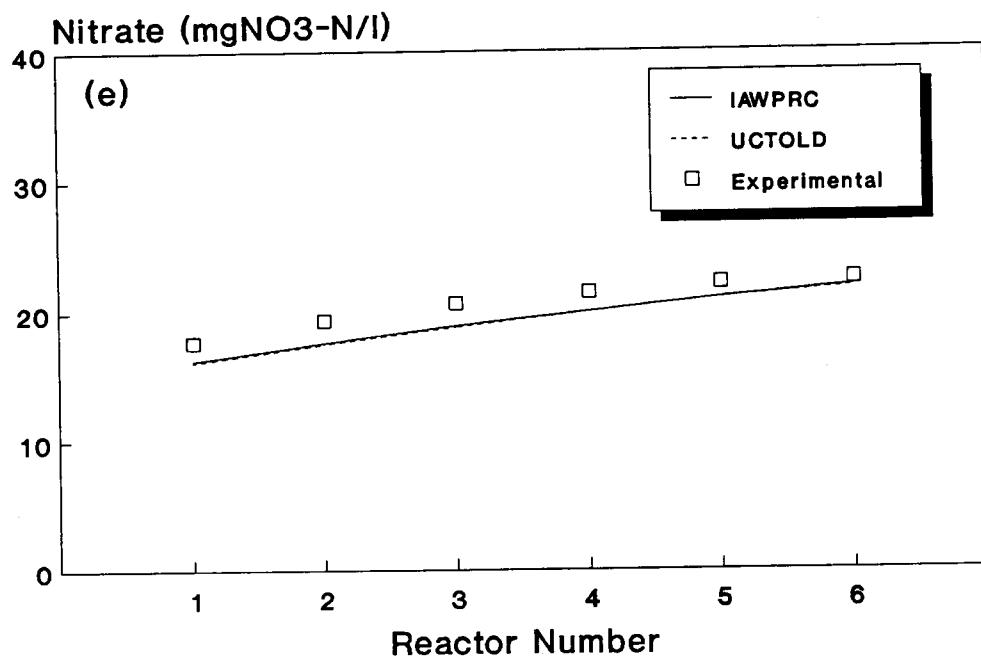
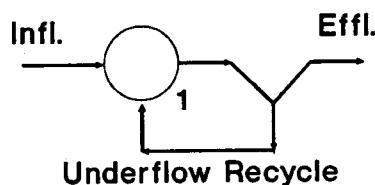


Fig 5.1: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate profiles for 6 in-series reactor completely aerobic system under constant flow and load; predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979).

Cyclic flow and load

Completely mixed single reactor aerobic systems receiving cyclic flow and load influent and operated at sludge ages of 2,5 and 20 days (Ekama and Marais, 1979) were simulated. In both systems, unsettled municipal wastewater from Cape Flats, Cape Town, South Africa, served as influent.



Sludge age 2,5 days

The cyclic flow and load input data were as follows:

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow(l d-1)	COD (g m-3)	TKN (g m-3)
1	0.0	0.0	515.0	45.8
2	2.0	36.0	515.0	45.8
3	4.0	36.0	515.0	45.8
4	6.0	36.0	515.0	45.8
5	8.0	36.0	515.0	45.8
6	10.0	36.0	515.0	45.8
7	12.0	36.0	515.0	45.8
8	14.0	0.0	515.0	45.8
9	16.0	0.0	515.0	45.8
10	18.0	0.0	515.0	45.8
11	20.0	0.0	515.0	45.8
12	22.0	0.0	515.0	45.8

** Calculated Mean Values : Change any values? Y/N....

Flowrate = 18.0
COD = 515.0
TKN = 45.8

Wastewater characteristics and configuration and operational data input were as follows:

**** WASTEWATER CHARACTERISTICS ****	
Sti(avg) g COD m-3	515.000
Nti(avg) g N m-3	45.800
Fbs g COD g-1 COD	0.190
Fs,us g COD g-1 COD	0.080
Fs,up g COD g-1 COD	0.130
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	0.000
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

RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH3/NH4
 Fnob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
to move selection

Hit <Return> to enter
new value for
selected constant

**** PROCESS CONFIGURATION **** Gp 1. Number of Reactors = 1

Gp 2. Reactor Vols, l Gp 3. Feed Fraction Gp 4. Aeration/DO

No. 1: 6.73 1.00 3.0

Do you wish to change any parameters?

Y/N....

***** PLANT OPERATING PARAMETERS *****				
1 SRT (total)	d	=	2.5	
2 Process Temperature	degC	=	20.0	
Flow rates:				
3 Influent flow	l d-1	=	18.0	
4 RAS recycle flow	l d-1	=	18.0	

Do you wish to change any parameters?

Y/N....

Sludge wastage to maintain the sludge age took place continuously during the feed on period, as follows:

***** SLUDGE WASTAGE PATTERN *****				
Record No	Time (h)	Wastage On	Waste Flow (l d-1)	
1	0.0	No	0.00	
2	2.0	Yes	5.38	
3	4.0	Yes	5.38	
4	6.0	Yes	5.38	
5	8.0	Yes	5.38	
6	10.0	Yes	5.38	
7	12.0	Yes	5.38	
8	14.0	No	0.00	
9	16.0	No	0.00	
10	18.0	No	0.00	
11	20.0	No	0.00	
12	22.0	No	0.00	

** Mean wastage rate = 2.69 l/d

Switch any on/off? Y/N....

The value for $\hat{\mu}_A$ had to be increased to 0,65/d. Also, since in the system pH = 7,0, the autotroph kinetic constants had to be adjusted (WRC, 1984) using Eqs (5.1) and (5.2) to give:

$$\begin{aligned}\hat{\mu}_A &= 0.65 \cdot (2,35)^{(7,0-7,2)} \\ &= 0,548 /d\end{aligned}$$

$$\begin{aligned}K_{SA} &= 1,0 \cdot (2,35)^{(7,2-7,0)} \\ &= 1,186 \text{ mgN/l}\end{aligned}$$

The values for all other kinetic and stoichiometric constants were the default values.

The predicted and measured results are compared in Fig 5.2(a,b,c,d and e); good agreement is obtained with both models. This system can be used to determine the influent readily biodegradable COD concentration, see Chapter 6 for a detailed description of the test.

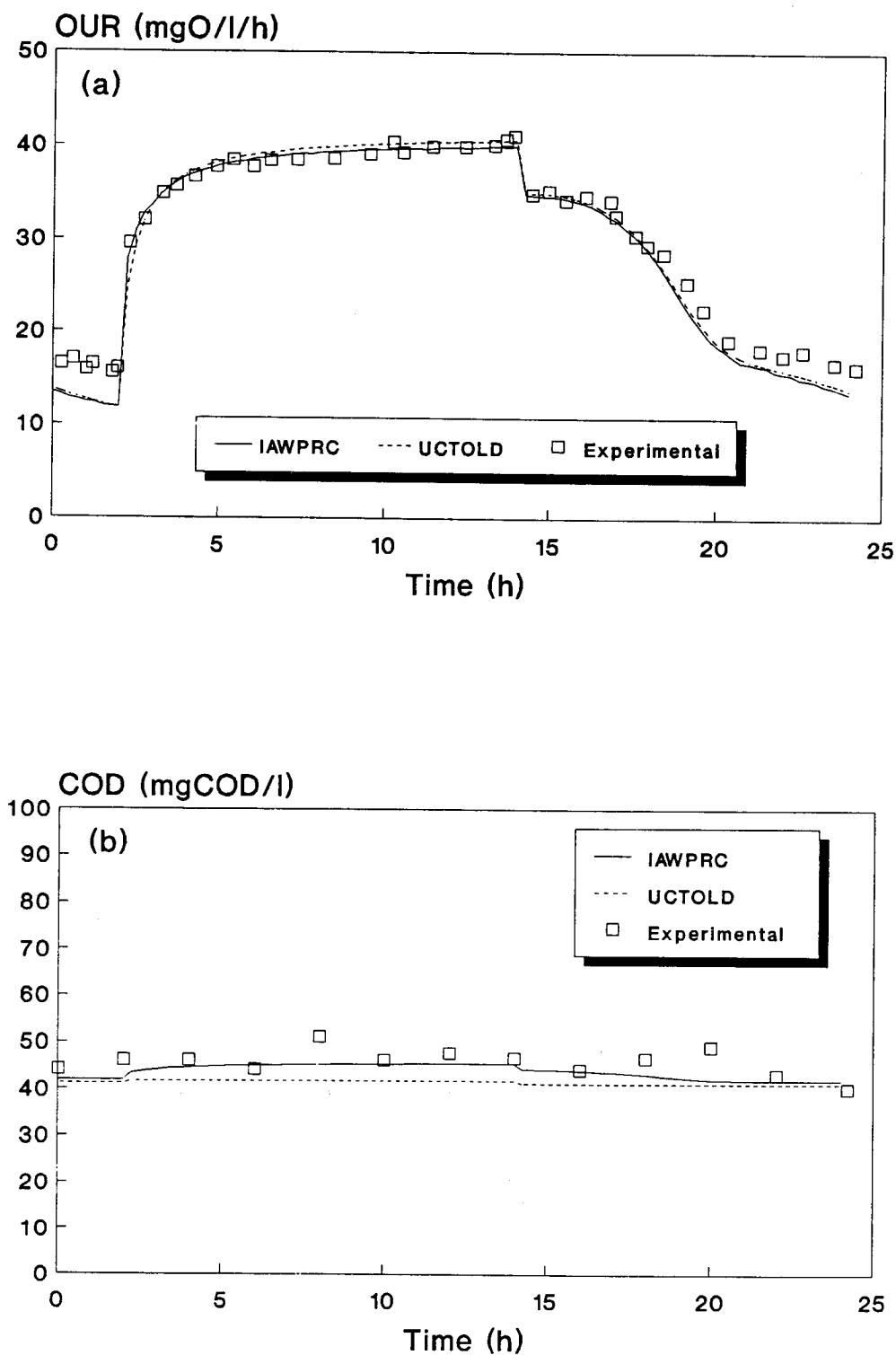


Fig 5.2: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for single reactor completely aerobic system operated at 2,5d sludge age under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979). Continued overleaf.....

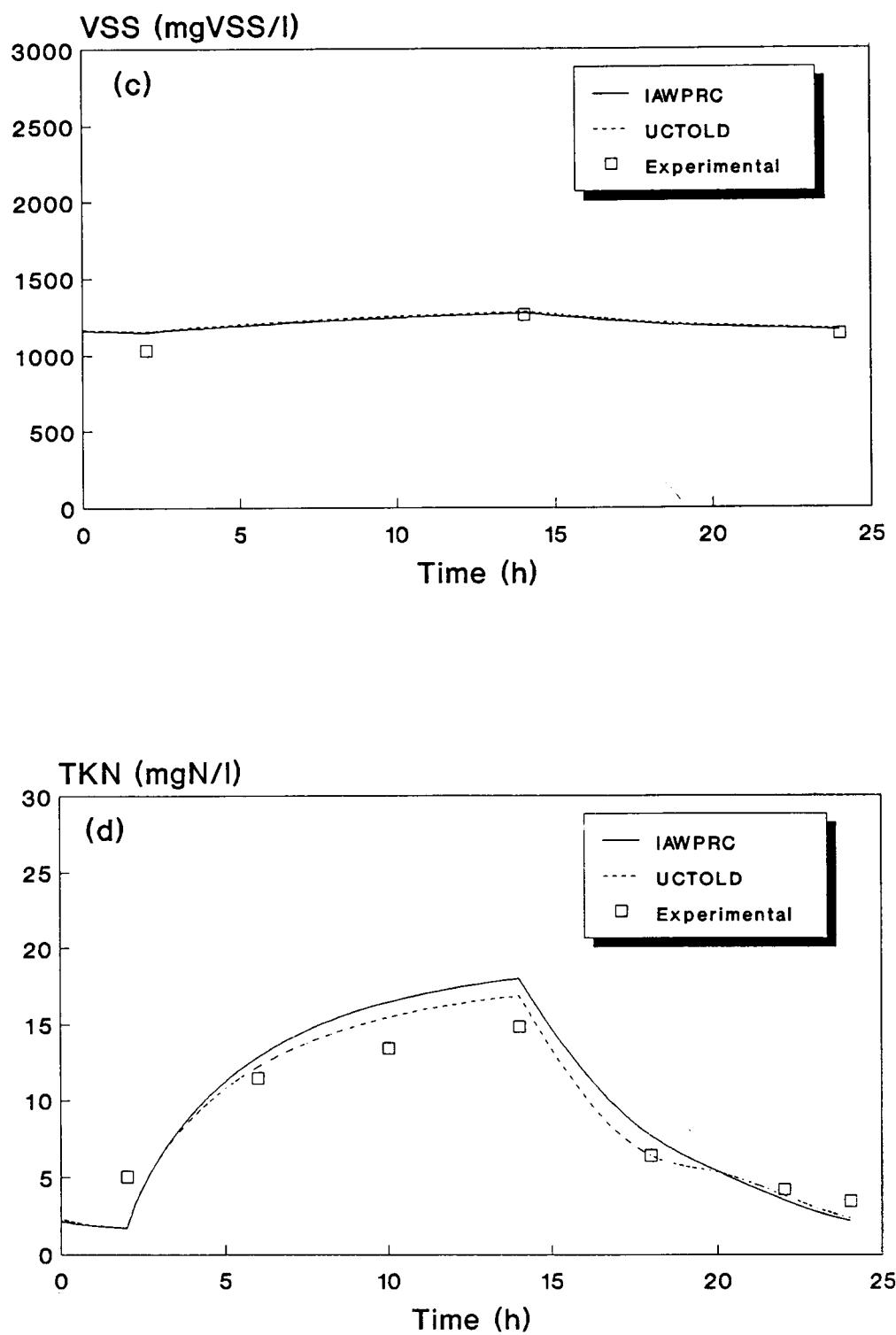


Fig 5.2: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for single reactor completely aerobic system operated at 2.5d sludge age under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979). Continued overleaf.....

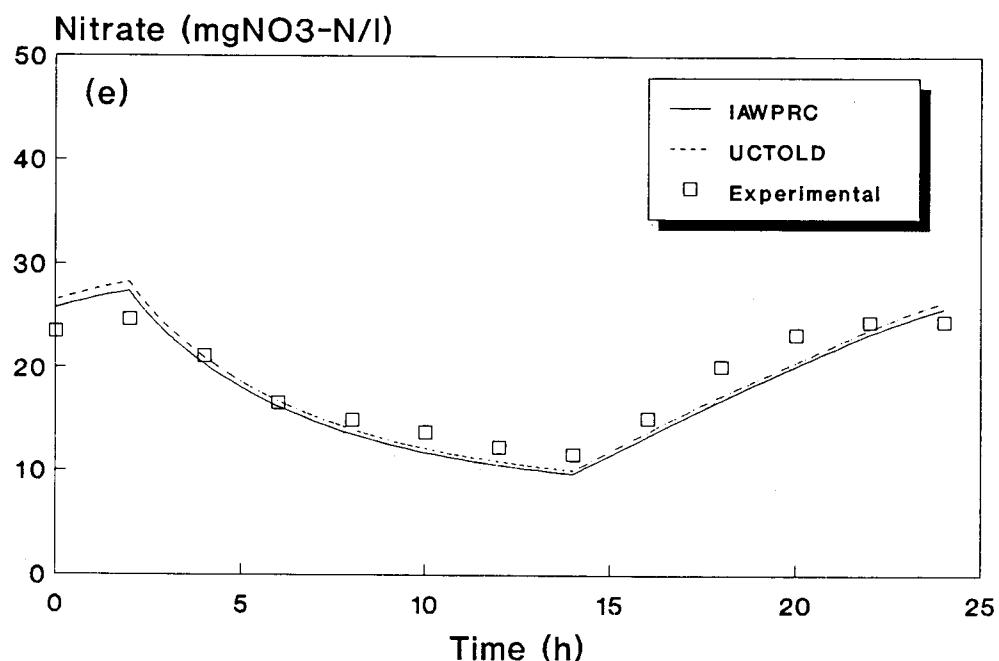


Fig 5.2: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for single reactor completely aerobic system operated at 2.5d sludge age under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979).

Sludge age 20 days

The cyclic flow and load input data were as follows:

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow(l d-1)	COD (g m-3)	TKN (g m-3)
1	0.0	0.0	515.0	44.1
2	2.0	28.0	515.0	44.1
3	4.0	28.0	515.0	44.1
4	6.0	28.0	515.0	44.1
5	8.0	28.0	515.0	44.1
6	10.0	28.0	515.0	44.1
7	12.0	28.0	515.0	44.1
8	14.0	0.0	515.0	44.1
9	16.0	0.0	515.0	44.1
10	18.0	0.0	515.0	44.1
11	20.0	0.0	515.0	44.1
12	22.0	0.0	515.0	44.1

** Calculated Mean Values :
 Flowrate = 14.0
 COD = 515.0
 TKN = 44.1

Change any values? Y/N....

Sewage characteristics and configuration and operational data input were as follows:

***** WASTEWATER CHARACTERISTICS *****		
Sti(avg) g COD m ⁻³	515.000	
Nti(avg) g N m ⁻³	44.100	
Fbs g COD g ⁻¹ COD	0.190	
Fs,us g COD g ⁻¹ COD	0.080	
Fs,up g COD g ⁻¹ COD	0.130	
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	0.000	
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	

RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH3/NH4
 Fnob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
to move selection

Hit <Return> to enter
new value for
selected constant

***** PROCESS CONFIGURATION *****		Gp 1. Number of Reactors = 1
Gp 2. Reactor Vols, l	Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1: 12.00	1.00	3.0

Do you wish to change any parameters?
Y/N....

***** PLANT OPERATING PARAMETERS *****				
1 SRT {total}	d	=	20.0	
2 Process Temperature	degC	=	20.0	
 Flow rates: 3 Influent flow l d ⁻¹ = 14.0				
4 RAS recycle flow	l d ⁻¹	=	14.0	

Do you wish to change any parameters?
Y/N....

Sludge wastage to maintain the sludge age took place continuously during the feed on period, as follows:

***** SLUDGE WASTAGE PATTERN *****				
Record No	Time (h)	Wastage On	Waste Flow (l d-1)	
1	0.0	No	0.00	
2	2.0	Yes	1.20	
3	4.0	Yes	1.20	
4	6.0	Yes	1.20	
5	8.0	Yes	1.20	
6	10.0	Yes	1.20	
7	12.0	Yes	1.20	
8	14.0	No	0.00	
9	16.0	No	0.00	
10	18.0	No	0.00	
11	20.0	No	0.00	
12	22.0	No	0.00	

** Mean wastage rate = 0.60 l/d

Switch any on/off? Y/N....

The value for $\hat{\mu}_A$ had to be increased to 0,75/d. Also, since in the system pH = 5,5, the autotroph kinetic constants had to be adjusted (WRC, 1984) using Eqs (5.1) and (5.2), to give:

$$\begin{aligned}\hat{\mu}_A &= 0,75 \cdot (2,35)^{(5,5-7,2)} \\ &= 0,175 /d\end{aligned}$$

$$\begin{aligned}K_{SA} &= 1,0 \cdot (2,35)^{(7,2-5,5)} \\ &= 4,27 \text{ mgN/l}\end{aligned}$$

The values used in the simulation for all other kinetic and stoichiometric constants were the default values. The predicted and measured results are compared in Figs 5.3(a,b,c,d and e); good agreement is obtained with both models.

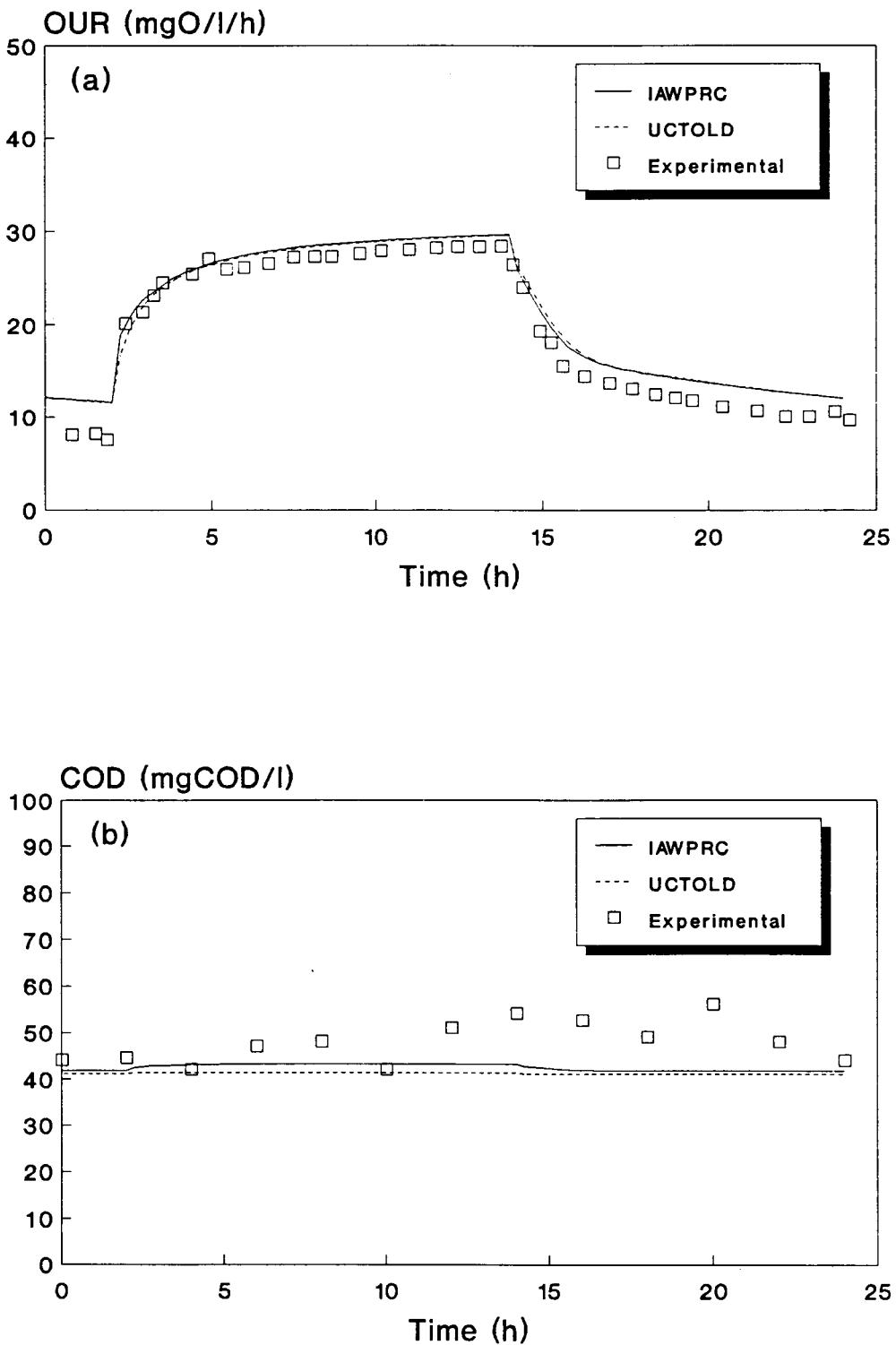


Fig 5.3: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for single reactor completely aerobic system operated at 20d sludge age under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979). Continued overleaf.....

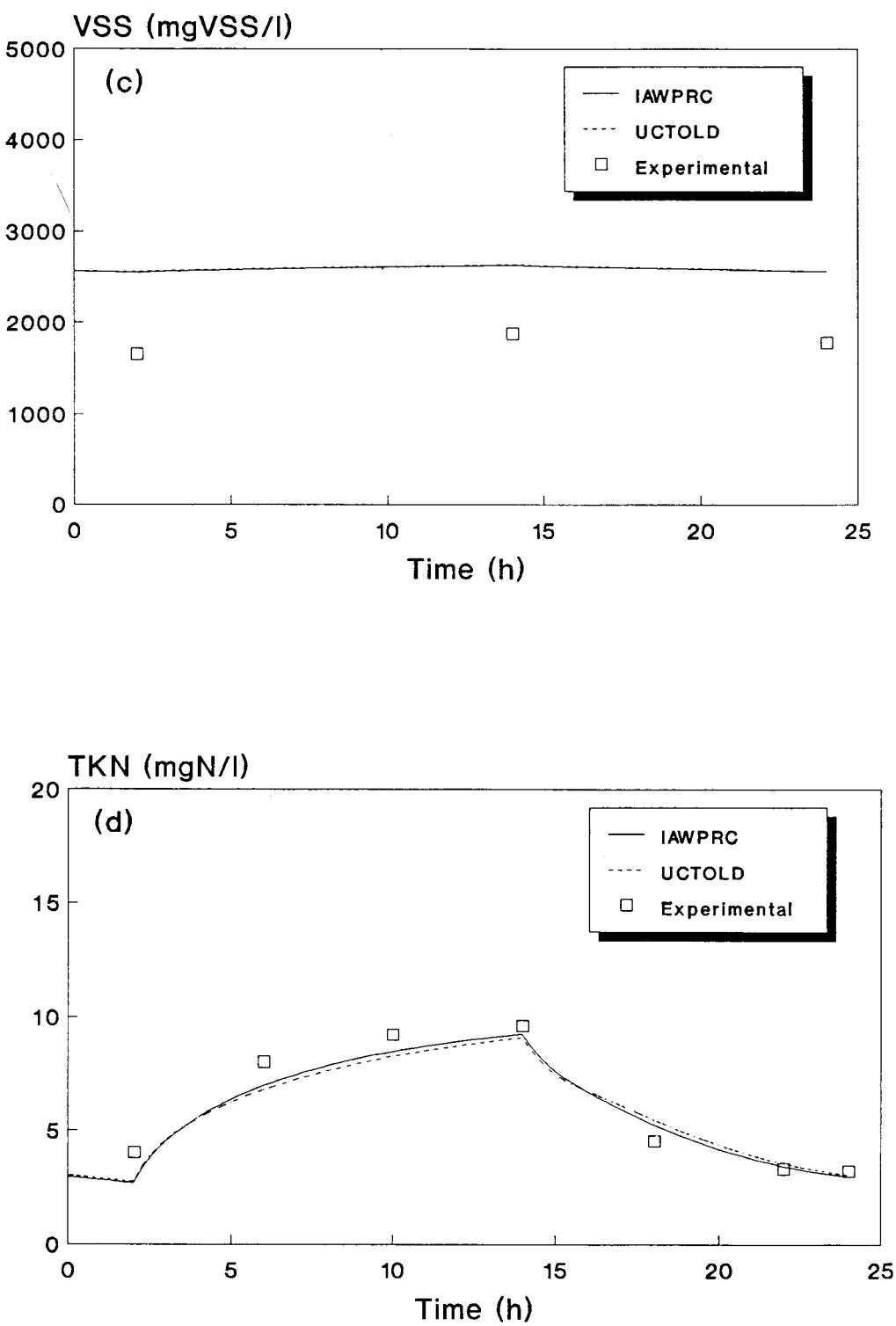


Fig 5.3: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for single reactor completely aerobic system operated at 20d sludge age under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979). Continued overleaf.....

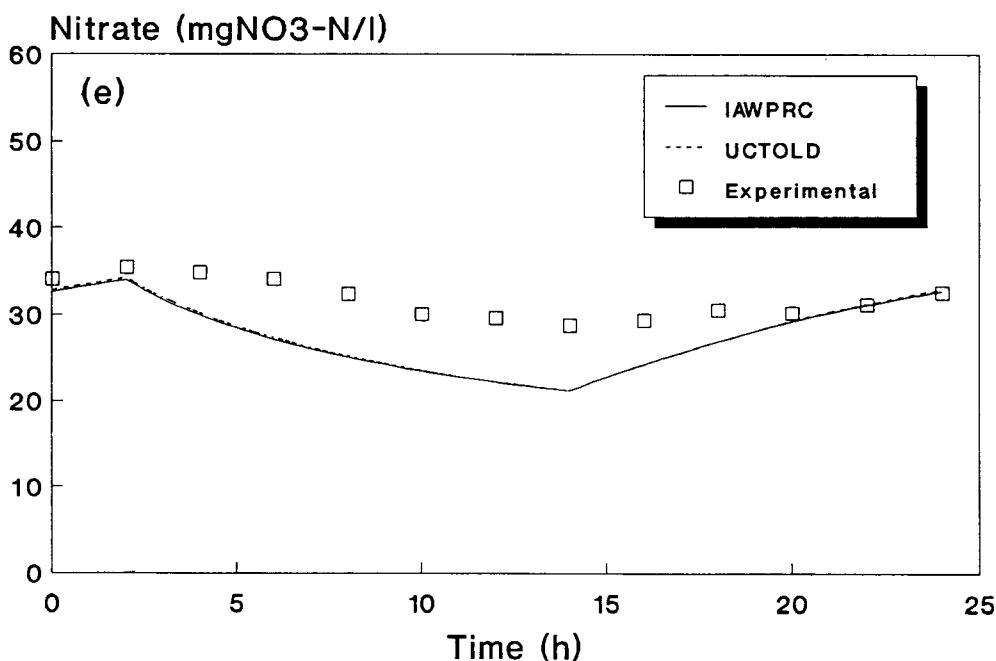


Fig 5.3: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for single reactor completely aerobic system operated at 20d sludge age under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, experimental data from Ekama and Marais (1979).

AEROBIC BATCH TESTS

To perform the aerobic batch test, mixed liquor from an operating aerobic or anoxic/aerobic activated sludge system (parent system) is combined with a quantity of the same wastewater that serves as influent to the parent system, the mixture is aerated, and the response of various parameters monitored with time (see Chapter 6 for details on test procedures). These batch tests can be conducted with nitrification present or with nitrification inhibited by addition of thiourea, or a similar compound. Simulations of batch tests with nitrification, and with nitrification inhibited, were undertaken. The simulations were conducted using batch versions of the two models; the batch programs are not included in the simulation package and the simulations are merely to illustrate additional model verification.

In simulation of the batch tests, the initial mixed liquor constituent fractions (active mass, endogenous mass, etc.) were calculated from the parent system parameters (sludge age, influent COD, etc.) using the steady state theory (WRC, 1984; Chapter 6) or the UCTOLD/IAWPRC computer programs. The constituent fractions of the wastewater had been determined separately (for procedures see

Chapter 6). The combination of mixed liquor and wastewater constituent fractions in the batch test gives the initial starting condition (i.e. at time = 0) and serves as input to the batch program.

From the batch test simulations three aspects of importance became apparent:

- (1) To obtain the same simulated oxygen utilization rates (OUR) using the IAWPRC Task Group and UCT models, the input value for the heterotroph maximum specific growth rate on RBCOD ($\hat{\mu}_H$) differs. This is so because in the IAWPRC Task Group model growth occurs only with RBCOD, and the OUR associated with this growth (plus any nitrification OUR) gives rise to the observed OUR; in the UCT model growth occurs both on RBCOD and SBCOD and the growth processes on these two substrate types are independent and, consequently, the summation of the OUR associated with the respective growth processes on RBCOD and SBCOD (plus any nitrification OUR) gives rise to the observed OUR, see Chapters 2 and 6.
- (2) In both models variation in the reactor configuration of, and load pattern on, the parent system from which the mixed liquor is taken for the batch test, can give rise to markedly different $\hat{\mu}_H$ values. Such differences in $\hat{\mu}_H$ were noted previously in investigations into sludge bulking and were linked to stimulation of a "selector effect" (Jenkins *et al.*, 1984; Still *et al.*, 1986; Gabb *et al.*, 1989). In contrast an important conclusion from the batch simulations is that the maximum specific rate of SBCOD hydrolysis appears to be independent of reactor configuration and load pattern, and can be accepted as constant.
- (3) In both models it was necessary to change the maximum specific growth rate for the autotrophs ($\hat{\mu}_A$) when simulating batch tests with different influents and/or batch tests with mixed liquor drawn from different systems in order to predict correctly the nitrate-time profiles. In some of the simulations described earlier, the value for $\hat{\mu}_A$ also had to be changed from the default value and from system to system. This behaviour had been noted previously where it was concluded that the value for $\hat{\mu}_A$ is dependent on the specific wastewater (WRC, 1984) and on the reactor configuration and load pattern (Still *et al.*, 1986). (For more detailed discussion, see Chapter 6.)

The variability in $\hat{\mu}_H$ and $\hat{\mu}_A$ necessitates that values for these constants be determined for each batch test, by using the procedures set out in Chapter 6. Accordingly, values for these two constants will be given where appropriate for each simulation described below.

Batch test with nitrification

One example of an aerobic batch test with nitrification was selected from a number of similar tests. In this test, mixed liquor was drawn from the parent system (anoxic/aerobic fill and draw, sludge age = 20d, reactor volume = 10ℓ, feed = 7500 mgCOD/d unsettled municipal wastewater) and mixed with unsettled municipal wastewater from Mitchell's Plain, South Africa to give the initial starting conditions as follows:

For UCTOLD

For IAWPRC

INITIAL CONCENTRATIONS

```
*****
1 Zbh (hetero.) = 460.00 g COD m-3
2 Ze (endog.) = 442.00 g COD m-3
3 Zba (autotrophs) = 25.40 g COD m-3
4 Sads (adsorb COD) = 5.00 g COD m-3
5 Semm (enmesh COD) = 173.96 g COD m-3
6 Zi (prt unb COD) = 17.44 g COD m-3
7 Znd (prt bio N) = 1.77 g N m-3
8 Sbs (sol bio COD) = 9.16 g COD m-3
9 Na (ammonia N) = 14.17 g N m-3
10 Nobp (sol org N) = 1.77 g N m-3
11 No3 (nitrate N) = 9.40 g N m-3
12 Alkalinity = 7.50 mole m-3
13 Sus (sol unb COD) = 17.44 g COD m-3
```

Do you wish to change any values?...Y/N

INITIAL CONCENTRATIONS

```
*****
1 Zbh (hetero.) = 460.00 g COD m-3
2 Ze (endog.) = 442.00 g COD m-3
3 Zba (autotrophs) = 25.40 g COD m-3
4 Semm (enmesh COD) = 173.96 g COD m-3
5 Zi (prt unb COD) = 17.44 g COD m-3
6 Nobp (prt bio N) = 1.77 g N m-3
7 Sbs (sol bio COD) = 9.16 g COD m-3
8 Na (ammonia N) = 14.17 g N m-3
9 Nobs (sol org N) = 4.56 g N m-3
10 No3 (nitrate N) = 9.40 g N m-3
11 Alkalinity = 7.50 mole m-3
12 Sus (sol unb COD) = 17.44 g COD m-3
```

Do you wish to change any values?...Y/N

For the simulations, $\hat{\mu}_H = 5$ and $4.3/d$ for IAWPRC and UCTOLD respectively, and $\hat{\mu}_A = 0.29/d$ for both models. All other kinetic and stoichiometric constants were the default values. The predicted and measured OUR and concentration time profiles are compared in Fig 5.4(a,b and c); good agreement is obtained.

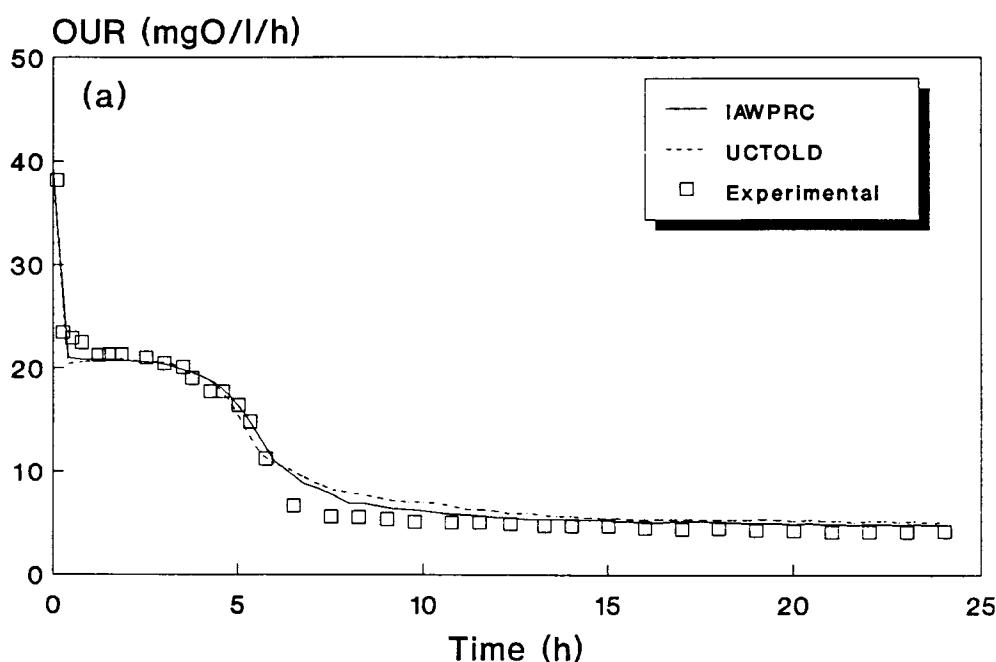


Fig 5.4: Predicted and experimental (a) OUR, (b) nitrate, and (c) TKN time profiles for aerobic batch test with nitrification; predictions using batch versions of UCTOLD and IAWPRC programs with default value for SBCOD hydrolysis half saturation constant (K_{SP} UCTOLD; K_X IAWPRC). Continued overleaf.....

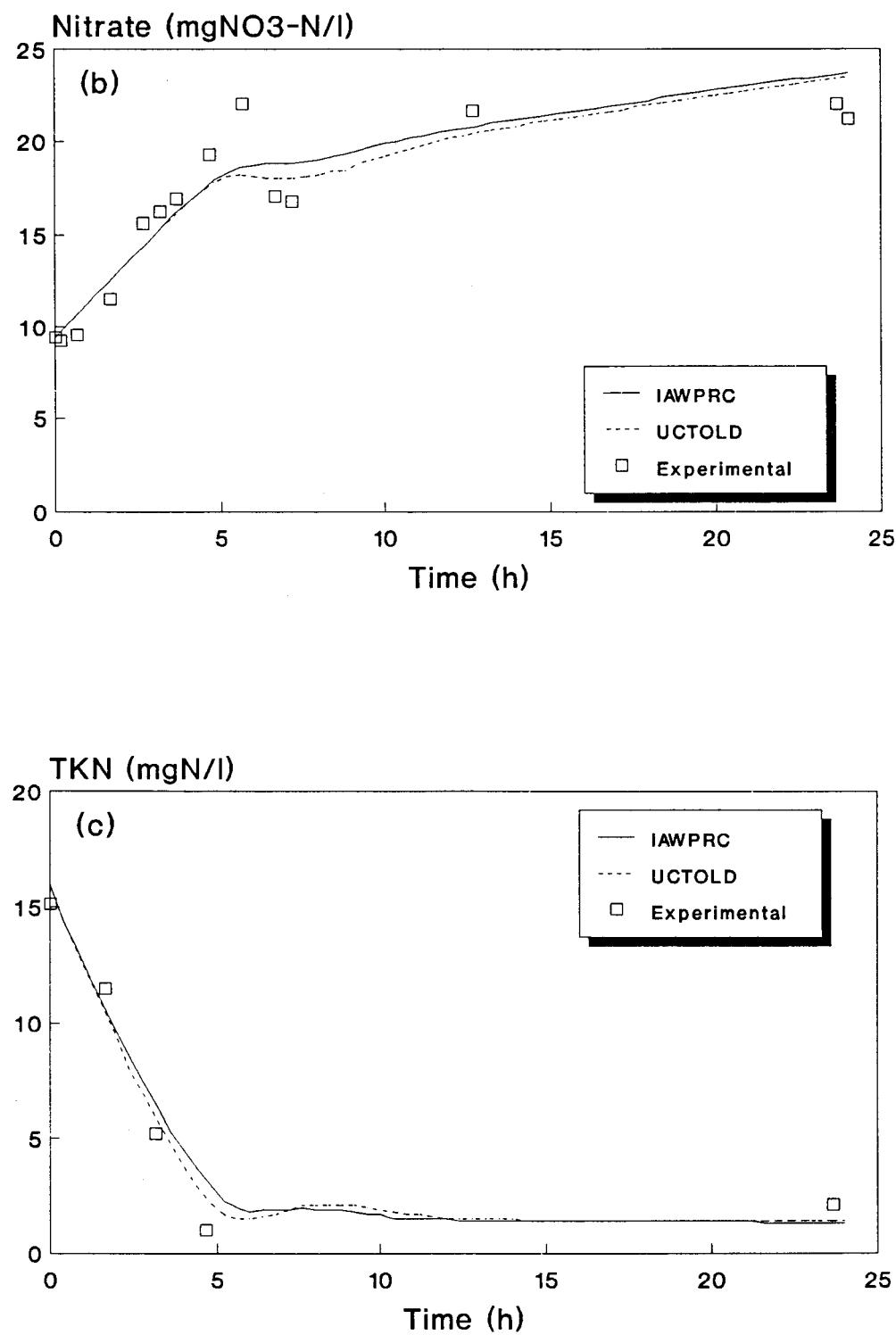


Fig 5.4: Predicted and experimental (a) OUR, (b) nitrate, and (c) TKN time profiles for aerobic batch test with nitrification; predictions using batch versions of UCTOLD and IAWPRC programs with default value for SBCOD hydrolysis half saturation constant (K_{SP} UCTOLD; K_X IAWPRC).

Batch tests with nitrification inhibition

In this series of aerobic batch tests nitrification was inhibited by addition of 20 mg thiourea per litre of batch volume. In an example of one such test, mixed liquor was drawn from the parent system (completely aerobic system with selector reactor, sludge age = 20d, total reactor volume = 15ℓ - selector reactor volume = 0,3ℓ and main reactor volume = 14,7ℓ, feed = 30 ℓ/d at 350 mgCOD/ℓ) and mixed with settled municipal wastewater from Mitchell's Plain, South Africa to give initial conditions as follows:

For UCTOLD

INITIAL CONCENTRATIONS	
1 Zbh (hetero.)	= 379.00 g COD m ⁻³
2 Ze (endog.)	= 353.00 g COD m ⁻³
3 Zba (autotrophs)	= 0.00 g COD m ⁻³
4 Sads (adsorb COD)	= 5.00 g COD m ⁻³
5 Serm (enmesh COD)	= 220.33 g COD m ⁻³
6 Zi (prt unb COD)	= 8.94 g COD m ⁻³
7 Znd (prt bio N)	= 2.25 g N m ⁻³
8 Sbs (sol bio COD)	= 35.87 g COD m ⁻³
9 Na (ammonia N)	= 24.90 g N m ⁻³
10 Nobp (sol org N)	= 2.25 g N m ⁻³
11 No ₃ (nitrate N)	= 10.00 g N m ⁻³
12 Alkalinity	= 7.50 mole m ⁻³
13 Sus (sol unb COD)	= 32.77 g COD m ⁻³

For IAWPRC

INITIAL CONCENTRATIONS	
1 Zbh (hetero.)	= 379.00 g COD m ⁻³
2 Ze (endog.)	= 353.00 g COD m ⁻³
3 Zba (autotrophs)	= 0.00 g COD m ⁻³
4 Serm (enmesh COD)	= 220.33 g COD m ⁻³
5 Zi (prt unb COD)	= 8.94 g COD m ⁻³
6 Nobp (prt bio N)	= 2.25 g N m ⁻³
7 Sbs (sol bio COD)	= 35.87 g COD m ⁻³
8 Na (ammonia N)	= 24.90 g N m ⁻³
9 Nobp (sol org N)	= 2.25 g N m ⁻³
10 No ₃ (nitrate N)	= 10.00 g N m ⁻³
11 Alkalinity	= 7.50 mole m ⁻³
12 Sus (sol unb COD)	= 32.77 g COD m ⁻³

Do you wish to change any values?...Y/N

Do you wish to change any values?...Y/N

In the simulations $\hat{\mu}_H = 3,0$ and 1,6/d for IAWPRC and UCTOLD respectively, and $\hat{\mu}_A = 0/d$ for both models due to nitrification inhibition. All other kinetic and stoichiometric constants were assigned the default values. The predicted and measured OUR-time profiles are compared in Fig 5.5; gross differences between the predicted and measured OUR responses are evident. It was hypothesized that the thiourea exerts some inhibitory influence on the heterotrophic population. This inhibition appeared to be most evident in the rate of hydrolysis/utilization of SBCOD. Accordingly, a study was made on the effect of changing the rate constants associated with SBCOD hydrolysis/utilization on the model predictions. This showed that the value for the maximum specific hydrolysis rate ($K_H = 2,0/d$, IAWPRC; $K_{MP} = 1,35/d$ UCTOLD) could be retained, but the hydrolysis half saturation constant (K_X , IAWPRC; K_{SP} , UCTOLD) needed to be increased, from 0,027 to 0,15 mgCOD/mgCOD, for both models. With only this change the OUR responses in the batch tests with nitrification inhibition were closely simulated by both models, see Fig 5.6. Using the increased value for the hydrolysis half saturation constant in the models, simulations of the spectrum of system configurations and operating conditions gave poor fits of the predicted responses to the measured response; as an example, the batch test with nitrification was simulated using the increased hydrolysis half saturation constant, see Fig 5.7. Evidently thiourea exerts a significant influence on the hydrolysis kinetic rate, and that this can be accommodated in the structure of the two models by increasing the magnitude of one constant, the half saturation constant for hydrolysis. Inhibition of heterotrophs by thiourea had been noted previously at the University of Cape Town, in investigations into biological phosphorus removal (Wentzel *et al.*, 1988) and has been substantiated subsequently where it was observed that addition of 120 mg thiourea/ℓ batch volume (6 times normal concentration) completely inhibited heterotrophic activity.

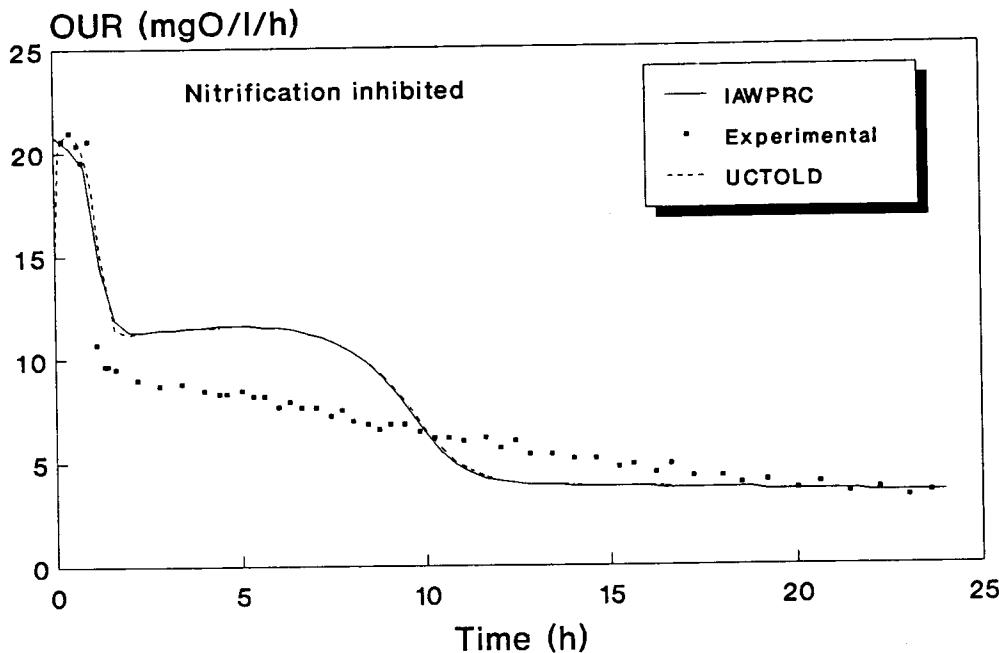


Fig 5.5: Predicted and experimental OUR-time profiles for aerobic batch test with nitrification inhibited by addition of 20 mg thiourea/l batch volume; predictions using batch versions of UCTOLD and IAWPRC programs with default value for SBCOD hydrolysis half saturation constant (K_{SP} UCTOLD; K_X IAWPRC).

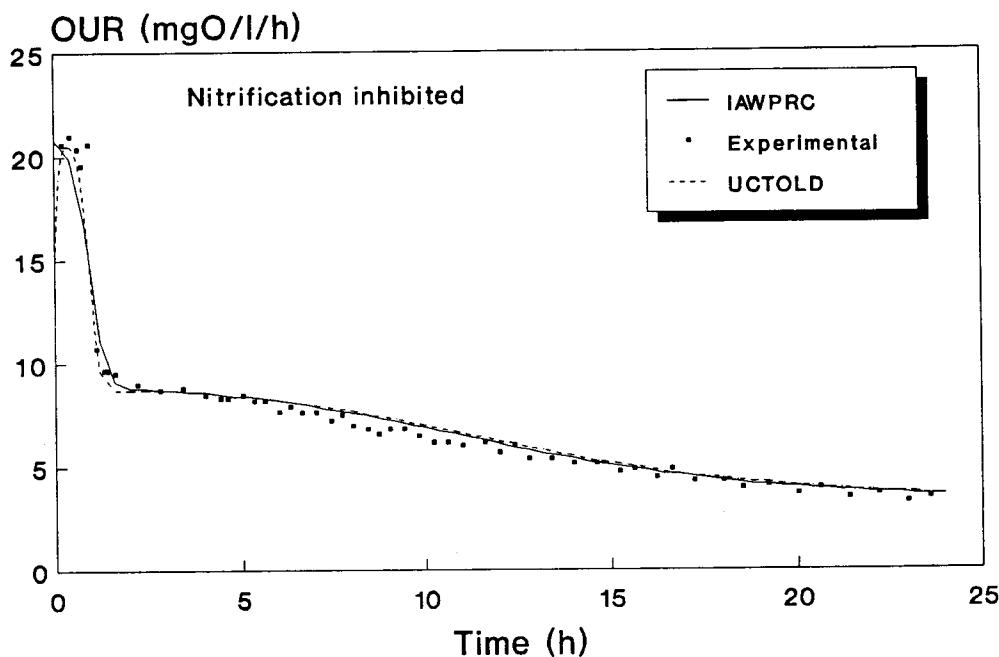


Fig 5.6: Predicted and experimental OUR-time profiles for aerobic batch test with nitrification inhibited by addition of 20 mg thiourea/l batch volume; predictions using batch versions of UCTOLD and IAWPRC programs with the SBCOD hydrolysis half saturation constant (K_{SP} UCTOLD; K_X IAWPRC) increased from the default value of 0,027 to 0,15 mgCOD/mgCOD (see Fig 5.5 for simulations with the default value for this constant).

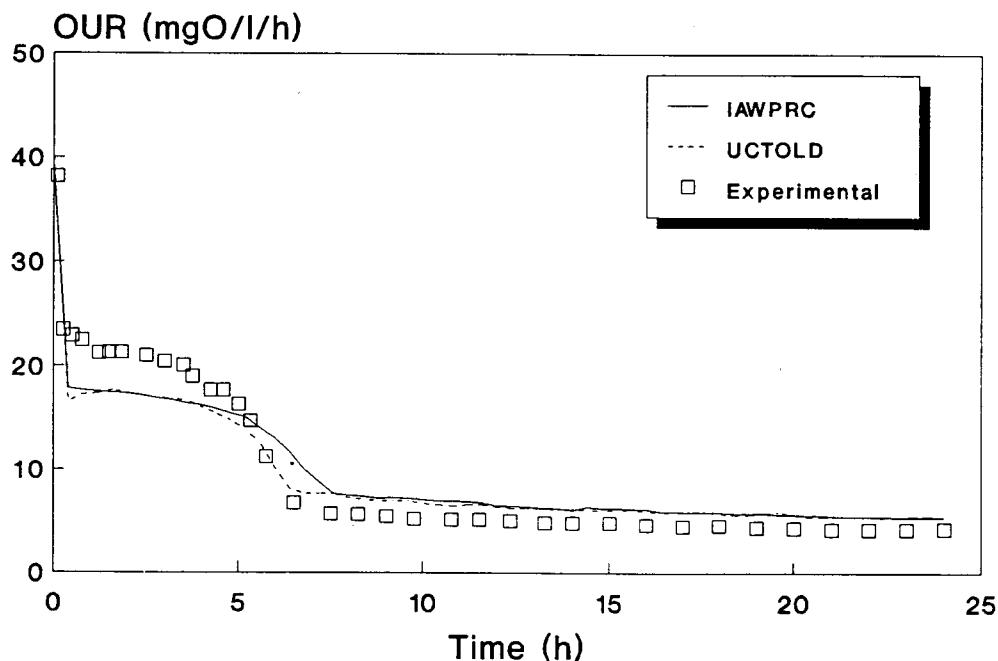


Fig. 5.7: Predicted and experimental OUR-time profiles for aerobic batch test with nitrification; predictions using batch versions of UCTOLD and IAWPRC programs with the SBCOD hydrolysis half saturation constant increased from the default value of 0,027 to 0,015 mgCOD/mgCOD (see Fig 5.4 for simulations with the default value for this constant).

ANOXIC/AEROBIC SYSTEMS – PLUGFLOW ANOXIC REACTORS

In nitrification/denitrification systems, Stern and Marais (1974) had shown that in plugflow anoxic reactors upstream of the aerobic reactor (primary anoxic reactor) denitrification took place in two linear phases, a rapid first phase which persisted for a short period then terminated and a second slow phase which continued for the retention time in the reactor. In plugflow anoxic reactors downstream of the aerobic reactor (secondary anoxic reactor), only one linear denitrification phase was operative, at a slow rate of about two thirds that of the slow second rate in the primary anoxic reactor. Stern and Marais concluded that the three denitrification phases can be expressed by:

$$\Delta N = K X_{BH} \Delta R$$

where K = specific denitrification rate constant per unit active mass per unit time
 X_{BH} = heterotroph biological active mass concentration
 ΔR = actual reaction time
 ΔN = nitrate reduction per unit volume

From the experimental data available, van Haandel *et al.* (1981) evaluated the mean values for the specific denitrification rate constants, K , for the three denitrification phases (K_1 , K_2 and K_3 respectively) for various sludge ages and temperatures; values for K_2 and K_3 are listed in Table 5.2.

The denitrification behaviour in plugflow primary and secondary anoxic reactors was simulated for a range of sludge ages and temperatures using IAWPRC and UCTOLD with the default values for the kinetic and stoichiometric constants. In the simulations, plugflow conditions were approximated by incorporating a series of small completely mixed reactors. As an example, input data for the simulation of the K₂ specific denitrification rate constant at 20°C and 20 days sludge age were as follows:

**** WASTEWATER CHARACTERISTICS ****		
St _i (avg)	g COD m ⁻³	500.000
Nt _i (avg)	g N m ⁻³	100.000
F _b s	g COD g ⁻¹ COD	0.200
F _{s,us}	g COD g ⁻¹ COD	0.050
F _{s,up}	g COD g ⁻¹ COD	0.130
F _{n,a}	g N g ⁻¹ N	0.750
F _{nob,p}	g N g ⁻¹ N	0.500
F _{n,ous}	g N g ⁻¹ N	0.000
F _{s,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

RETURN TO MENU

F_bs = readily biodegradable/biodegradable COD
 F_{s,us} = frac infl COD that is sol unbiodegrad
 F_{s,up} = frac infl COD that is part unbiodegrad
 F_{n,a} = frac infl TKN that is NH₃/NH₄
 F_{nob,p}= frac organic bio N that is part
 F_{n,ous}= frac infl TKN that is organic unbio sol
 F_{s,zbh}= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
 to move selection

 Hit <Return> to enter
 new value for
 selected constant

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 6	
Gp 2. Reactor Vols, l		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	1.00	1.00	Unaerated
No. 2:	2.00		Unaerated
No. 3:	2.00		Unaerated
No. 4:	2.00		Unaerated
No. 5:	2.00		Unaerated
No. 6:	10.00		3.0

Gp 5. Recycles: Use to include/remove mixed liquor recycles.

RAS recycle to Reactor No.1

Do you wish to change any parameters?
Y/N....

***** PLANT OPERATING PARAMETERS *****				
1 SRT (total)	d	=	20.0	
2 Process Temperature	degC	=	20.0	
Flow rates:				
3 Influent flow	l d ⁻¹	=	15.0	
4 RAS recycle flow	l d ⁻¹	=	15.0	

Do you wish to change any parameters?

.Y/N....

In the simulations, the value for the constant defining the specific denitrification rate for the rapid first phase denitrification in the primary anoxic reactor (K_1) was not evaluated; this rate is linked to the utilization of RBCOD and, as shown in the previous section, the rate is dependent on the system configuration and load pattern through variation in $\hat{\mu}_H$.

The specific denitrification rates, K_2 and K_3 , predicted in the simulations for a range of sludge ages and temperatures are listed in Table 5.2, together with the experimentally observed values; good agreement is obtained with both models.

Table 5.2: Experimentally observed and simulated specific denitrification rate constants K_2 and K_3 for various temperatures and sludge ages.

Temp. (° C)	Sludge Age (d)	Specific denitrification rate constant (mgN/mg X_{BH} /d)					
		Experimental		UCTOLD		IAWPRC	
		K_2	K_3	K_2	K_3	K_2	K_3
15	20	0,0464	0,0461	0,0486	0,0464	0,0495	0,0465
20	10	0,0681	0,0535	0,0703	0,0595	0,0709	0,0572
	20	0,0681	0,0535	0,0681	0,0581	0,0681	0,0568
	30	0,0681	0,0535	0,0681	0,0554	0,0681	0,0558

ANOXIC/AEROBIC SYSTEMS - BATCH DIGESTION

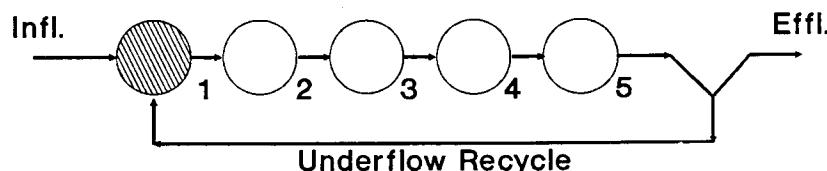
In anoxic/aerobic batch digestion of waste activated sludge, Warner *et al.* (1984) found that the denitrification rate observed (K_4) is lower than that in the secondary anoxic reactor (K_3). From simulations of this system using the UCT model with the default constants in a specialized digester program, Warner *et al.* concluded that the model predicts accurately both the aerobic and anoxic/aerobic digestion behaviour under both steady state and dynamic loading conditions, i.e. the model predicts correctly the lower K_4 denitrification behaviour in anoxic/aerobic batch digestion. The two computer programs included in the simulation package (UCTOLD and IAWPRC) are not set up for the batch digestion system and therefore cannot be used to simulate it; the reader is referred to Warner *et al.* (1983) for details on development of specialized digester programs.

ANOXIC/AEROBIC SYSTEMS – COMPLETELY MIXED REACTORS

Anoxic/aerobic completely mixed in-series reactor systems under constant and cyclic flow and load conditions were simulated.

Constant flow and load

The experimental data were obtained from a pilot-scale investigation at Daspoort Sewage Works, Pretoria, South Africa (van Haandel *et al.*, 1981). The influent was settled municipal wastewater and the reactor configuration was an anoxic reactor in series with four aerobic reactors.



Data input to the program was as follows:

***** WASTEWATER CHARACTERISTICS *****	
St _i (avg) g COD m ⁻³	477.000
Nt _i (avg) g N m ⁻³	45.100
F _b s g COD g ⁻¹ COD	0.240
F _{s,us} g COD g ⁻¹ COD	0.040
F _{s,up} g COD g ⁻¹ COD	0.040
F _{n,a} g N g ⁻¹ N	0.830
F _{nob,p} g N g ⁻¹ N	0.500
F _{n,ous} g N g ⁻¹ N	0.000
F _{s,zbh} g Zbh COD g ⁻¹ COD	0.000
VSS/TSS g VSS g ⁻¹ TSS	0.830
Inf Alk mole m ⁻³	10.000
RETURN TO MENU	

F_bs = readily biodegradable/biodegradable COD
 F_{s,us} = frac infl COD that is sol unbiodegrad
 F_{s,up} = frac infl COD that is part unbiodegrad
 F_{n,a} = frac infl TKN that is NH₃/NH₄
 F_{nob,p}= frac infl organic bio N that is part
 F_{n,ous}= frac infl TKN that is organic unbio sol
 F_{s,zbh}= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
to move selection

 Hit <Return> to enter
new value for
selected constant

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 5	
Gp 2. Reactor Vols,m ³		Gp 3. Feed Fraction	Gp 4. Aeration/DO
No. 1:	5.00	1.00	Unaerated
No. 2:	5.00		3.0
No. 3:	5.00		3.0
No. 4:	5.00		3.0
No. 5:	5.00		3.0

Gp 5. Recycles: Use to include/remove mixed liquor recycles.

RAS recycle to Reactor No.1

Do you wish to change any parameters?
Y/N....

***** PLANT OPERATING PARAMETERS *****			
1 SRT {total}	d	=	18.0
2 Process Temperature	degC	=	21.6
Flow rates:			
3 Influent flow	m ³ d ⁻¹	=	40.0
4 RAS recycle flow	m ³ d ⁻¹	=	120.0

Do you wish to change any parameters?
Y/N....

All values for the kinetic and stoichiometric constants were the default values except the maximum specific growth rate for the autotrophs (μ_A) which was 0,31/d.

The predicted and measured results are compared in Fig 5.8(a,b,c,d,e and f); good agreement is obtained with both models for all the parameters in each reactor.

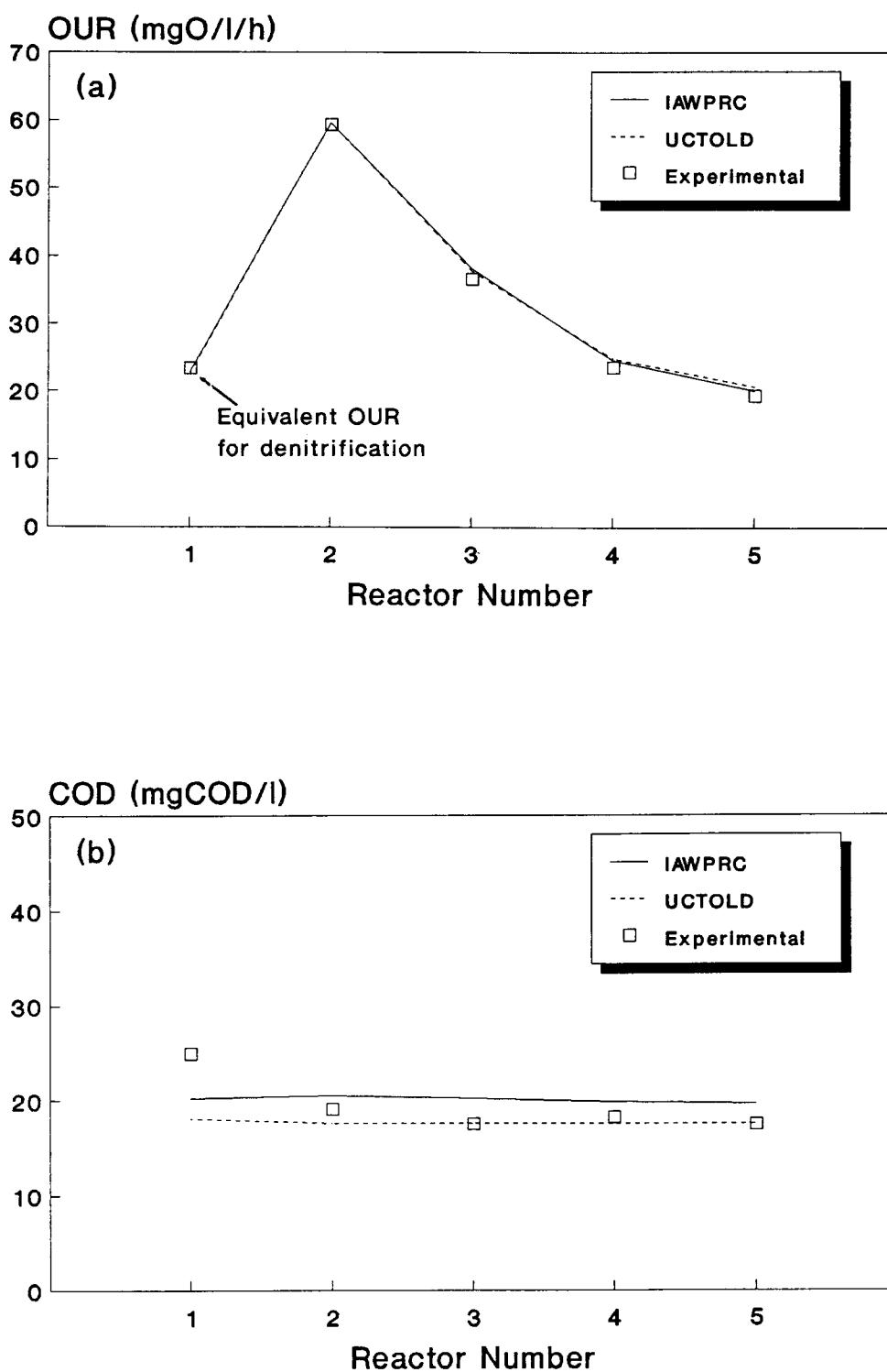


Fig 5.8: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, (e) ammonia, and (f) nitrate profiles for in-series anoxic/4 aerobic reactor system under constant flow and load; predictions using UCTOLD and IAWPRC, data from van Haandel *et al.* (1981). Continued overleaf.....

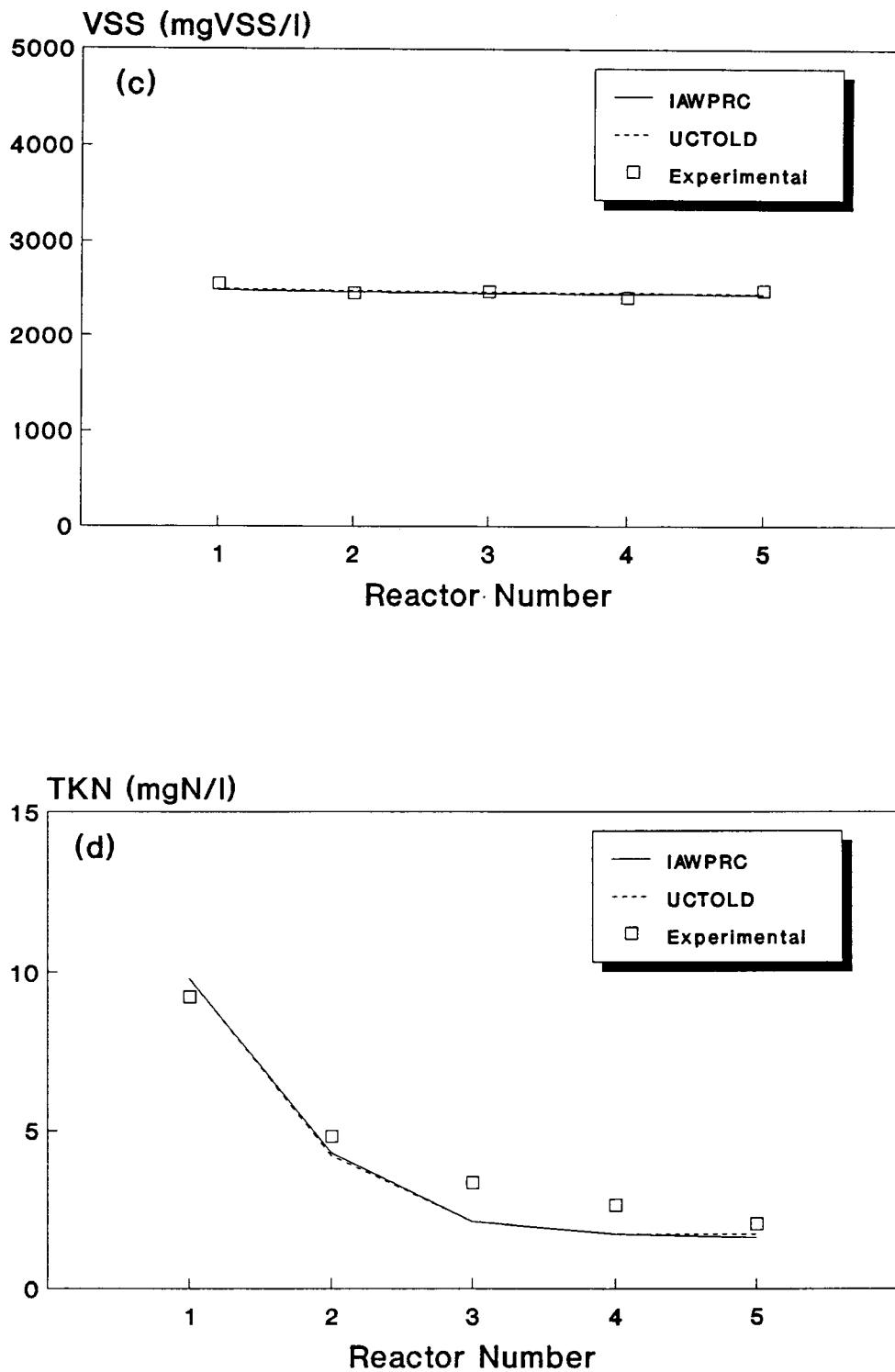


Fig 5.8: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, (e) ammonia, and (f) nitrate profiles for in-series anoxic/4 aerobic reactor system under constant flow and load; predictions using UCTOLD and IAWPRC, data from van Haandel *et al.* (1981). Continued overleaf.....

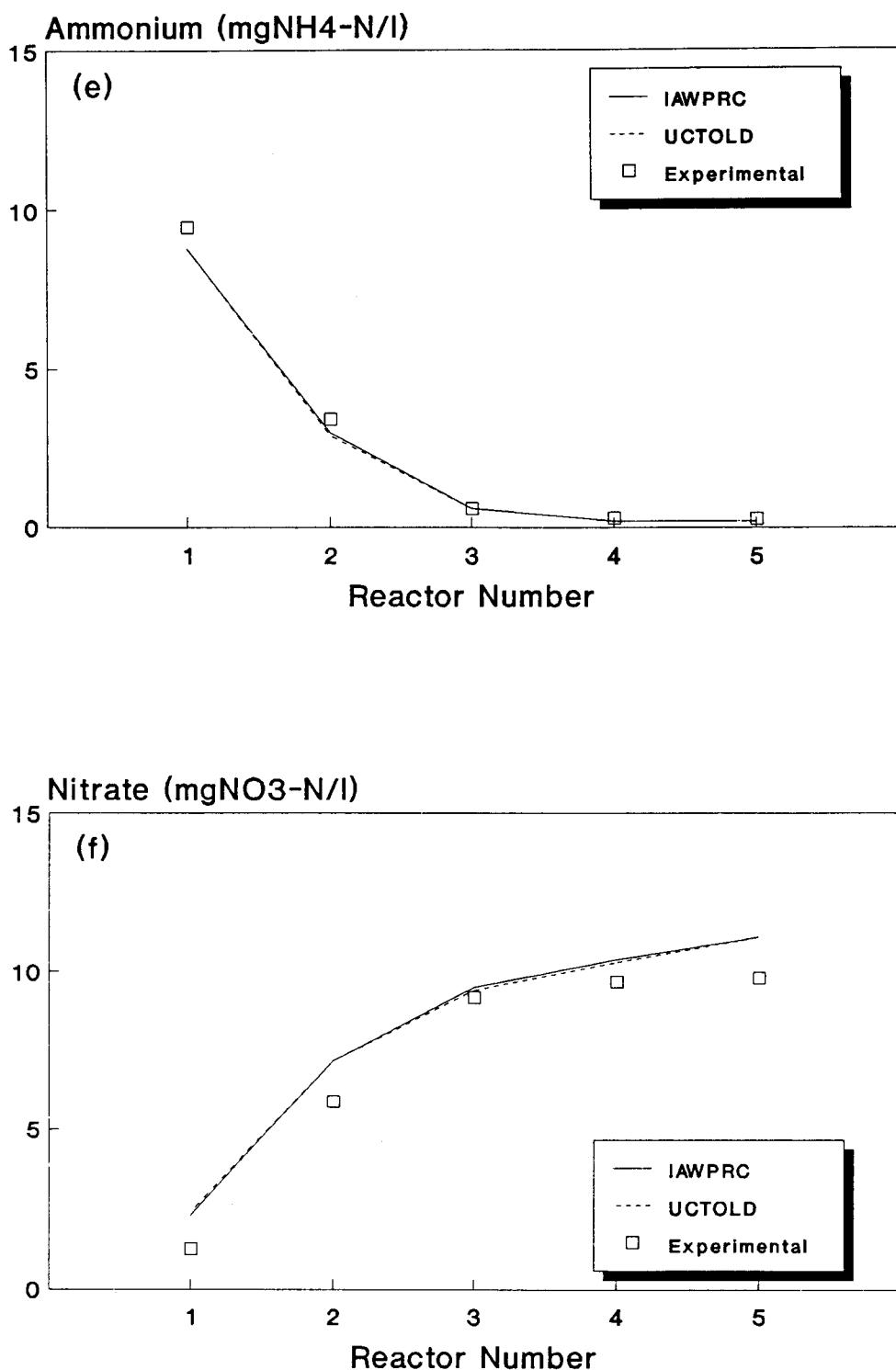
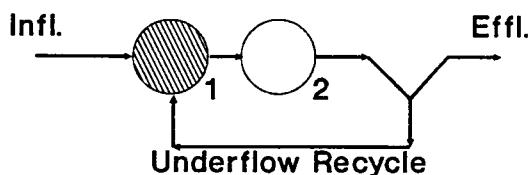


Fig 5.8: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, (e) ammonia, and (f) nitrate profiles for in-series anoxic/4 aerobic reactor system under constant flow and load; predictions using UCTOLD and IAWPRC, data from van Haandel *et al.* (1981).

Cyclic flow and load

At laboratory-scale, Wilson and Marais (1976) tested a two in-series reactor anoxic/aerobic system under cyclic flow and load using settled municipal wastewater from Athlone, Cape Town, South Africa as influent.



The cyclic flow and load input data were as follows:

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow(l d-1)	COD (g m-3)	TKN (g m-3)
1	0.0	0.0	570.0	54.0
2	2.0	30.0	570.0	54.0
3	4.0	30.0	570.0	54.0
4	6.0	30.0	570.0	54.0
5	8.0	30.0	570.0	54.0
6	10.0	30.0	570.0	54.0
7	12.0	30.0	570.0	54.0
8	14.0	0.0	570.0	54.0
9	16.0	0.0	570.0	54.0
10	18.0	0.0	570.0	54.0
11	20.0	0.0	570.0	54.0
12	22.0	0.0	570.0	54.0

** Calculated Mean Values : Change any values? Y/N....

Flowrate = 15.0
COD = 570.0
TKN = 54.0

Wastewater characteristics and configuration and operational data input were as follows:

**** WASTEWATER CHARACTERISTICS ****	
Sti(avg)	g COD m-3
Nti(avg)	g N m-3
Fbs	g COD g-1 COD
Fs,us	g COD g-1 COD
Fs,up	g COD g-1 COD
Fn,a	g N g-1 N
Fnob,p	g N g-1 N
Fn,ous	g N g-1 N
Fs,zbh	g Zbh COD g-1 COD
VSS/TSS	g VSS g-1 TSS
Inf Alk	mole m-3
RETURN TO MENU	
Fbs = readily biodegradable/biodegradable COD Fs,us = frac infl COD that is sol unbiodegrad Fs,up = frac infl COD that is part unbiodegrad Fn,a = frac infl TKN that is NH3/NH4 Fn,nob,p= frac organic bio N that is part Fn,ous= frac infl TKN that is organic unbio sol Fs,zbh= frac infl COD that is heterotrophs	
Hit <Arrows>/<SpaceBar> to move selection Hit <Return> to enter new value for selected constant	

***** PROCESS CONFIGURATION ***** Gp 1. Number of Reactors = 2

 Gp 2. Reactor Vols, l Gp 3. Feed Fraction Gp 4. Aeration/DO

No. 1:	1.00	1.00	Unaerated
No. 2:	6.40		3.0

Gp 5. Recycles: Use to include/remove mixed liquor recycles.

RAS recycle to Reactor No.1

Do you wish to change any parameters?

Y/N....

***** PLANT OPERATING PARAMETERS *****

1 SRT (total)	d	=	20.0
2 Process Temperature	degC	=	20.0

Flow rates:

3 Influent flow	l d-1	=	15.0
4 RAS recycle flow	l d-1	=	22.5

Do you wish to change any parameters?

Y/N....

Sludge wastage to maintain the sludge age took place continuously during the feed on period, as follows:

***** SLUDGE WASTAGE PATTERN *****			
Record No	Time (h)	Wastage On	Waste Flow (l d-1)
1	0.0	No	0.00
2	2.0	Yes	0.74
3	4.0	Yes	0.74
4	6.0	Yes	0.74
5	8.0	Yes	0.74
6	10.0	Yes	0.74
7	12.0	Yes	0.74
8	14.0	No	0.00
9	16.0	No	0.00
10	18.0	No	0.00
11	20.0	No	0.00
12	22.0	No	0.00

** Mean wastage rate = 0.37 l/d

Switch any on/off? Y/N....

Values for all the kinetic and stoichiometric constants were the default values, except for $\hat{\mu}_A$ which was 0.17/d.

The predicted and measured results are compared in Fig 5.9(a,b,c,d and e); good agreement is obtained.

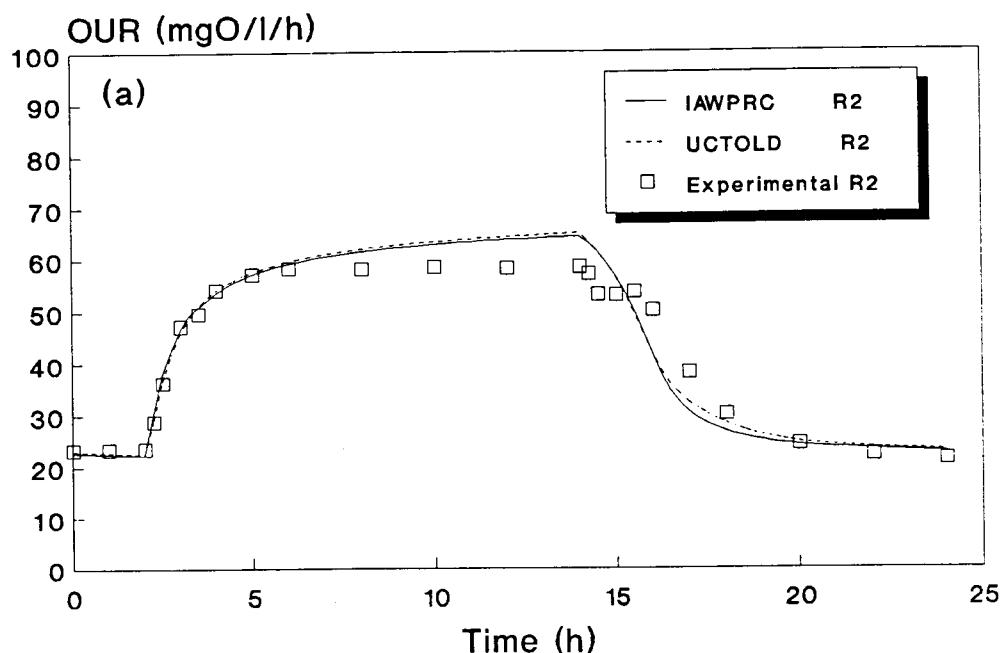


Fig 5.9: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for in-series anoxic (R1)/aerobic (R2) reactor system under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, data from Wilson and Marais (1976). Continued overleaf.....

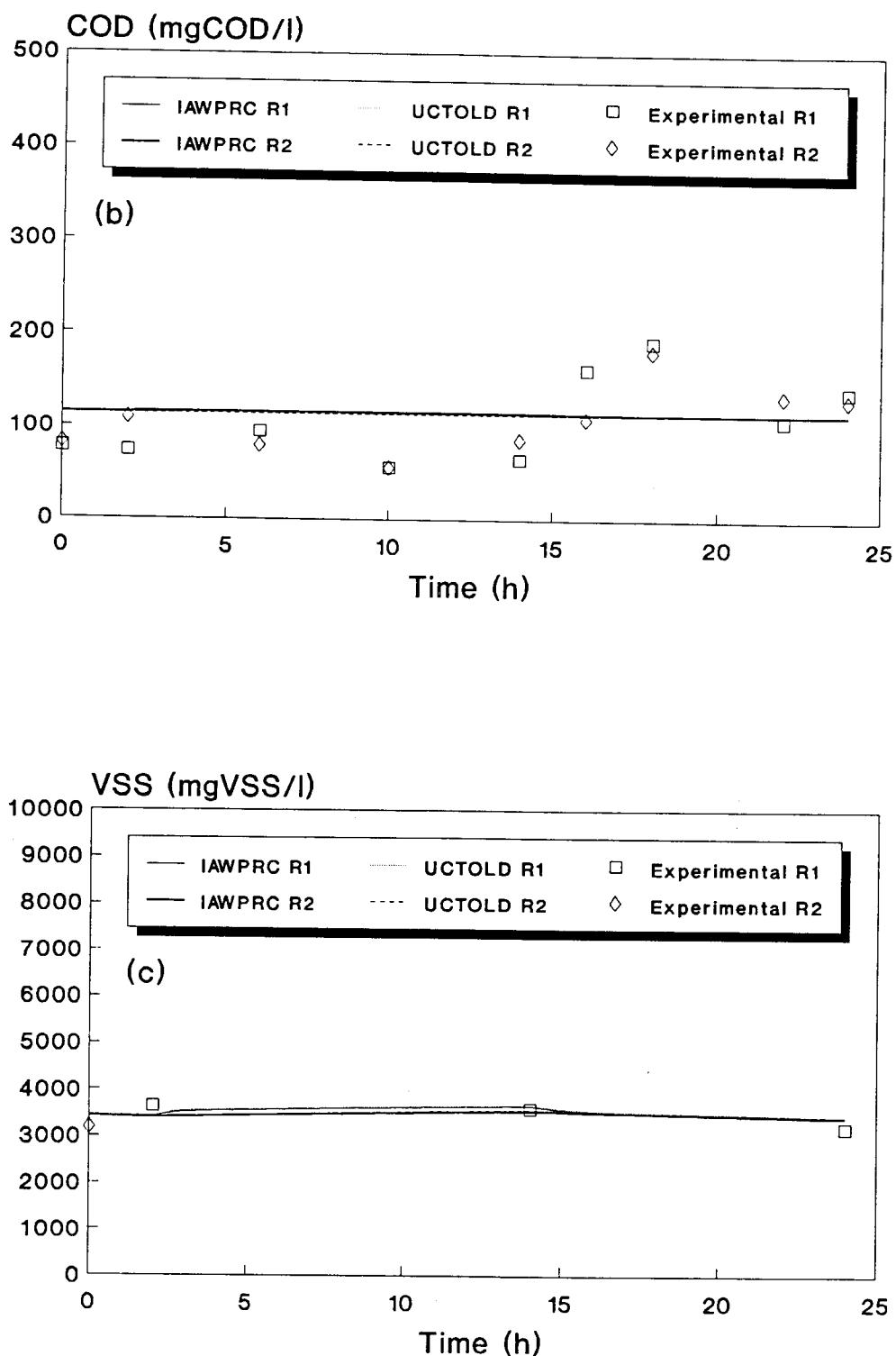


Fig 5.9: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for in-series anoxic (R1)/aerobic (R2) reactor system under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, data from Wilson and Marais (1976). Continued overleaf.....

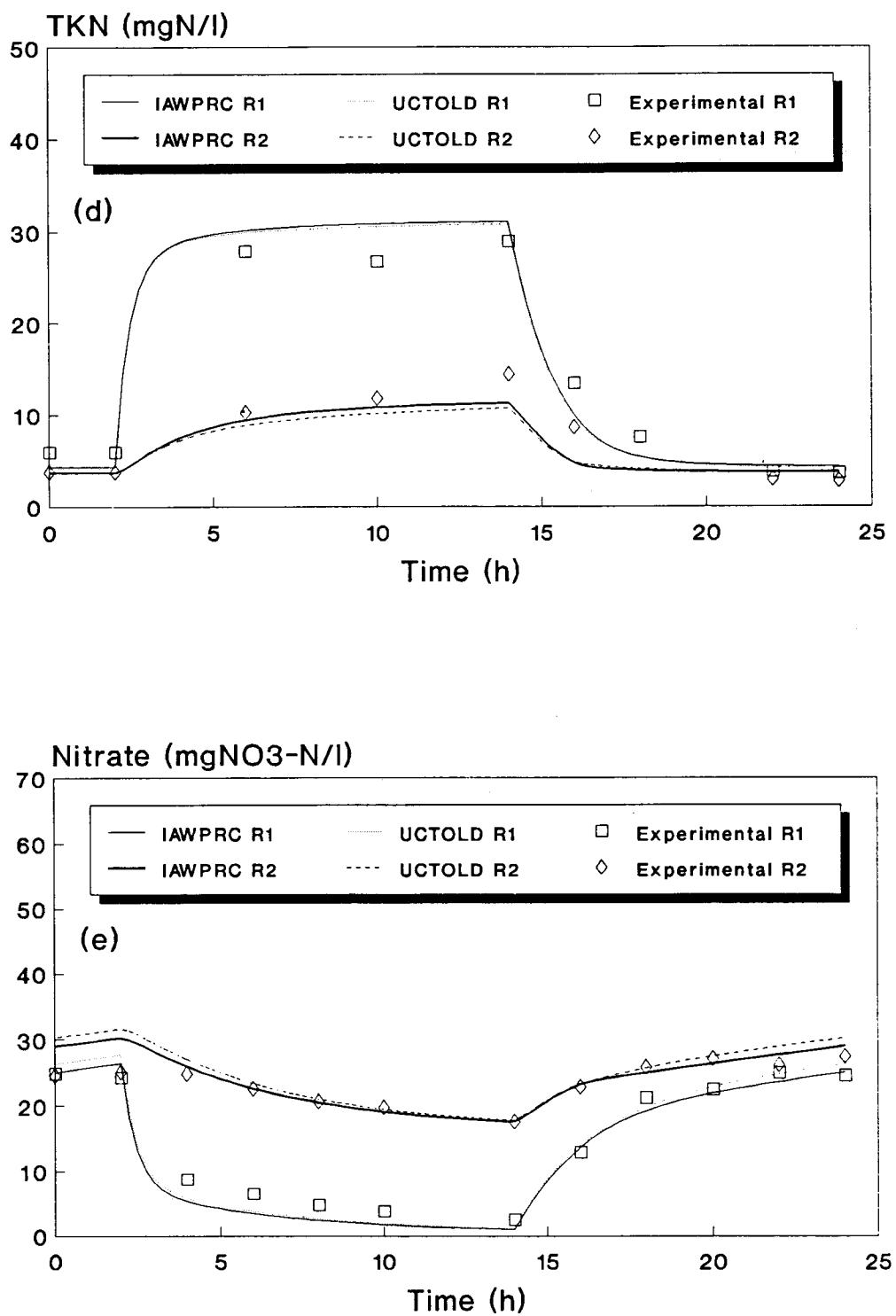
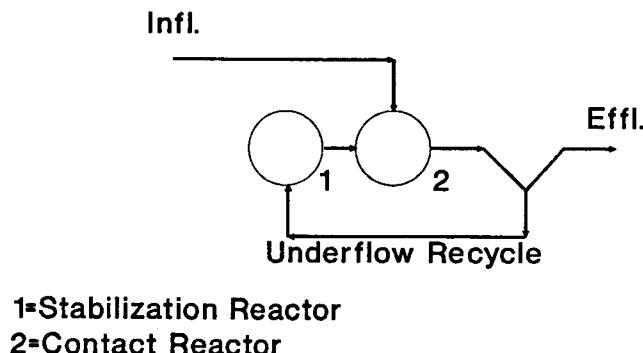


Fig 5.9: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for in-series anoxic (R1)/aerobic (R2) reactor system under cyclic flow and load (feed 12h on, 12h off); predictions using UCTOLD and IAWPRC, data from Wilson and Marais (1976).

CONTACT-STABILIZATION SYSTEM

A laboratory-scale investigation of the contact-stabilization system under constant and cyclic flow and load was conducted by Alexander, Ekama and Marais (1980) using unsettled wastewater from Cape Flats, Cape Town, South Africa.



Constant flow and load

Contact-stabilization systems at 6 and 10 days sludge age were operated. Data input for the 6 day sludge age system was as follows:

***** WASTEWATER CHARACTERISTICS *****	
St _i (avg)	g COD m ⁻³
Nt _i (avg)	g N m ⁻³
F _{bs}	g COD g ⁻¹ COD
F _{s,us}	g COD g ⁻¹ COD
F _{s,up}	g COD g ⁻¹ COD
F _{n,a}	g N g ⁻¹ N
F _{n,ob,p}	g N g ⁻¹ N
F _{n,ous}	g N g ⁻¹ N
F _{s,zbh}	g Zbh COD g ⁻¹ COD
VSS/TSS	g VSS g ⁻¹ TSS
Inf Alk	mole m ⁻³
	512.000
	56.000
	0.230
	0.100
	0.130
	0.750
	0.500
	0.030
	0.000
	0.750
	10.000

RETURN TO MENU

F_{bs} = readily biodegradable/biodegradable COD
 F_{s,us} = frac infl COD that is sol unbiodegrad
 F_{s,up} = frac infl COD that is part unbiodegrad
 F_{n,a} = frac infl TKN that is NH₃/NH₄
 F_{n,ob,p}= frac organic bio N that is part
 F_{n,ous}= frac infl TKN that is organic unbio sol
 F_{s,zbh}= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
 to move selection

 Hit <Return> to enter
 new value for
 selected constant

**** PROCESS CONFIGURATION ****		Gp 1. Number of Reactors = 2
Gp 2. Reactor Vols, l		Gp 3. Feed Fraction Gp 4. Aeration/DO
No. 1:	12.30	0.00 3.0
No. 2:	2.00	1.00 3.0
Gp 5. Recycles: Use to include/remove mixed liquor recycles.		
RAS recycle to Reactor No.1		

Do you wish to change any parameters?
Y/N....

***** PLANT OPERATING PARAMETERS *****.				
1 SRT (total)	d	=	6.0	
2 Process Temperature	degC	=	20.0	
Flow rates:				
3 Influent flow	l d-1	=	36.0	
4 RAS recycle flow	l d-1	=	72.0	

Do you wish to change any parameters?
Y/N....

Data input for the 10 day sludge age system was as follows:

**** WASTEWATER CHARACTERISTICS ****	
Sti(avg) g COD m ⁻³	496.000
Nti(avg) g N m ⁻³	47.000
Fbs g COD g ⁻¹ COD	0.230
Fs,us g COD g ⁻¹ COD	0.100
Fs,up g COD g ⁻¹ COD	0.130
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

RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH3/NH4
 Fn,ob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
to move selection

Hit <Return> to enter
new value for
selected constant

**** PROCESS CONFIGURATION **** Gp 1. Number of Reactors = 2

Gp 2. Reactor Vols, l Gp 3. Feed Fraction Gp 4. Aeration/DO

No. 1:	12.30	0.00	3.0
No. 2:	2.00	1.00	

Gp 5. Recycles: Use to include/remove mixed liquor recycles.

RAS recycle to Reactor No.1

Do you wish to change any parameters?

Y/N....

***** PLANT OPERATING PARAMETERS *****

1 SRT {total}	d	=	10.0
2 Process Temperature	degC	=	20.0

Flow rates:

3 Influent flow	l d-1	=	24.0
4 RAS recycle flow	l d-1	=	48.0

Do you wish to change any parameters?

Y/N....

With regard to the kinetic and stoichiometric constants, $\hat{\mu}_A = 0,66/d$ and $0,50/d$ for the 6 and 10 day sludge age systems respectively were necessary. The value of one other constant had to be changed from the default value – the half saturation constant for RBCOD (K_{S_H}) had to be increased, from 5 to 110 mgCOD/l for UCTOLD and from 5 to 50 mgCOD/l for IAWPRC. The reasons for this change are detailed in the next section dealing with the contact-stabilization system under cyclic flow and load.

The predicted and simulated results are compared in Table 5.3.

Table 5.3: Comparison of measured and predicted results for contact stabilization system at 6 and 10 days sludge age receiving unsettled wastewater as influent.

Parameter	Sample Point	Sludge age : 6d			Sludge age : 10d		
		Measured	UCTOLD	IAWPRC	Measured	UCTOLD	IAWPRC
COD (mgCOD/l)	Contact	62	69	79	52	65	76
	Effluent	90	69	79	61	65	76
	Stabil.	54	53	62	42	51	59
TKN (mgN/l)	Contact	11	14	14	11	11	11
	Effluent	15	14	14	12	11	11
	Stabil.	1,7	3,5	3,5	4,8	3,1	3,1
NO ₃ (mgN/l)	Contact	27	28	28	22	24	24
	Effluent	27	28	28	23	24	24
	Stabil.	36	38	38	29	32	32
MLVSS (mgVSS/l)	Contact	1301	1540	1513	1478	1466	1439
	Stabil.	1772	2185	2148	2073	2080	2043
OUR (mgO/l/h)	Contact	61	61	59	42	43	41
	Stabil.	32	35	34	21	23	22

Cyclic flow and load

A contact-stabilization system under cyclic flow and load was operated at a sludge age of 5,8 days. The cyclic flow and load input data were as follows:

***** DIURNAL INPUT PATTERN *****				
Record No	Time (h)	Flow(l d-1)	COD (g m-3)	TKN (g m-3)
1	0.0	18.0	500.0	46.0
2	2.0	54.0	500.0	46.0
3	4.0	54.0	500.0	46.0
4	6.0	54.0	500.0	46.0
5	8.0	54.0	500.0	46.0
6	10.0	54.0	500.0	46.0
7	12.0	54.0	500.0	46.0
8	14.0	18.0	500.0	46.0
9	16.0	18.0	500.0	46.0
10	18.0	18.0	500.0	46.0
11	20.0	18.0	500.0	46.0
12	22.0	18.0	500.0	46.0

** Calculated Mean Values :
 Flowrate = 36.0
 COD = 500.0
 TKN = 46.0

Change any values? Y/N....

Wastewater characteristics and configuration and operational data input were as follows:

**** WASTEWATER CHARACTERISTICS ****	
Sti(avg) g COD m-3	500.000
Nti(avg) g N m-3	46.000
Fbs g COD g-1 COD	0.230
Fs,us g COD g-1 COD	0.100
Fs,up g COD g-1 COD	0.130
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

RETURN TO MENU

Fbs = readily biodegradable/biodegradable COD
 Fs,us = frac infl COD that is sol unbiodegrad
 Fs,up = frac infl COD that is part unbiodegrad
 Fn,a = frac infl TKN that is NH3/NH4
 Fnob,p= frac organic bio N that is part
 Fn,ous= frac infl TKN that is organic unbio sol
 Fs,zbh= frac infl COD that is heterotrophs

Hit <Arrows>/<SpaceBar>
to move selection

 Hit <Return> to enter
new value for
selected constant

***** PROCESS CONFIGURATION ***** Gp 1. Number of Reactors = 2

Gp 2. Reactor Vols, l Gp 3. Feed Fraction Gp 4. Aeration/DO

No. 1:	12.30	0.00	3.0
No. 2:	2.00	1.00	3.0

Gp 5. Recycles: Use to include/remove mixed liquor recycles.

RAS recycle to Reactor No.1

Do you wish to change any parameters?

Y/N....

***** PLANT OPERATING PARAMETERS *****

1 SRT {total}	d	=	5.8
2 Process Temperature	degC	=	20.0

Flow rates:

3 Influent flow	l d-1	=	36.0
4 RAS recycle flow	l d-1	=	72.0

Do you wish to change any parameters?

Y/N....

Sludge wastage to maintain the sludge age took place continuously over a 24 hour period from the contact reactor, as follows:

***** SLUDGE WASTAGE PATTERN *****

Record No	Time (h)	Wastage On	Waste Flow (l d-1)
1	0.0	Yes	3.42
2	2.0	Yes	3.42
3	4.0	Yes	3.42
4	6.0	Yes	3.42
5	8.0	Yes	3.42
6	10.0	Yes	3.42
7	12.0	Yes	3.42
8	14.0	Yes	3.42
9	16.0	Yes	3.42
10	18.0	Yes	3.42
11	20.0	Yes	3.42
12	22.0	Yes	3.42

** Mean wastage rate =

3.42 l/d

Switch any on/off? Y/N....

In the simulation, $\hat{\mu}_A = 0.55/d$. The value of one other constant had to be changed from the default value – the half saturation constant for RBCOD ($K_{S\text{H}}$) had to be increased, from 5 to 110 for UCTOLD and from 5 to 50 mgCOD/l IAWPRC. This increase was necessary in order to give reasonable predictions of the soluble COD (< 0.45 µm) in the contact reactor. No explanation for the increase is apparent at this stage – it is not certain whether the structure of the model is inadequate to accommodate the contact-stabilization system, or whether the increase in $K_{S\text{H}}$ reflects a change in behaviour of the heterotrophic population when placed in the contact-stabilization environment in which the COD loading rate in the contact reactor is high. Accepting the increase in $K_{S\text{H}}$, predicted and measured results are compared in Fig 5.10(a,b,c,d and e); reasonable agreement is obtained.

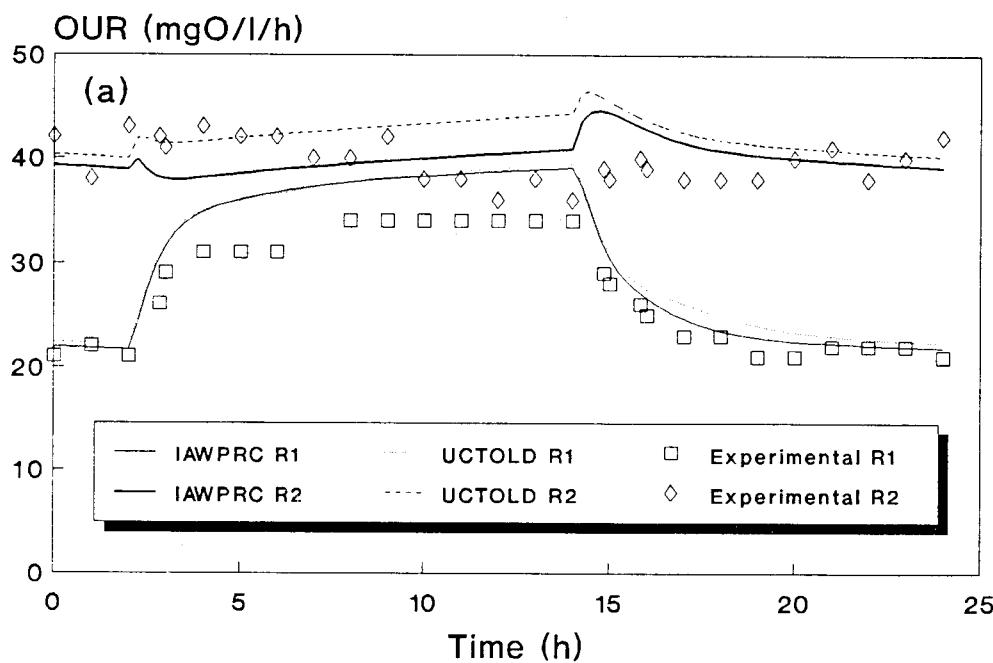


Fig 5.10: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for in-series aerobic contact (R2)-stabilization (R1) system under cyclic flow and load (feed 12h at 54l/d, 12h at 18l/d); predictions using UCTOLD and IAWPRC, data from Alexander *et al.* (1980). Continued overleaf.....

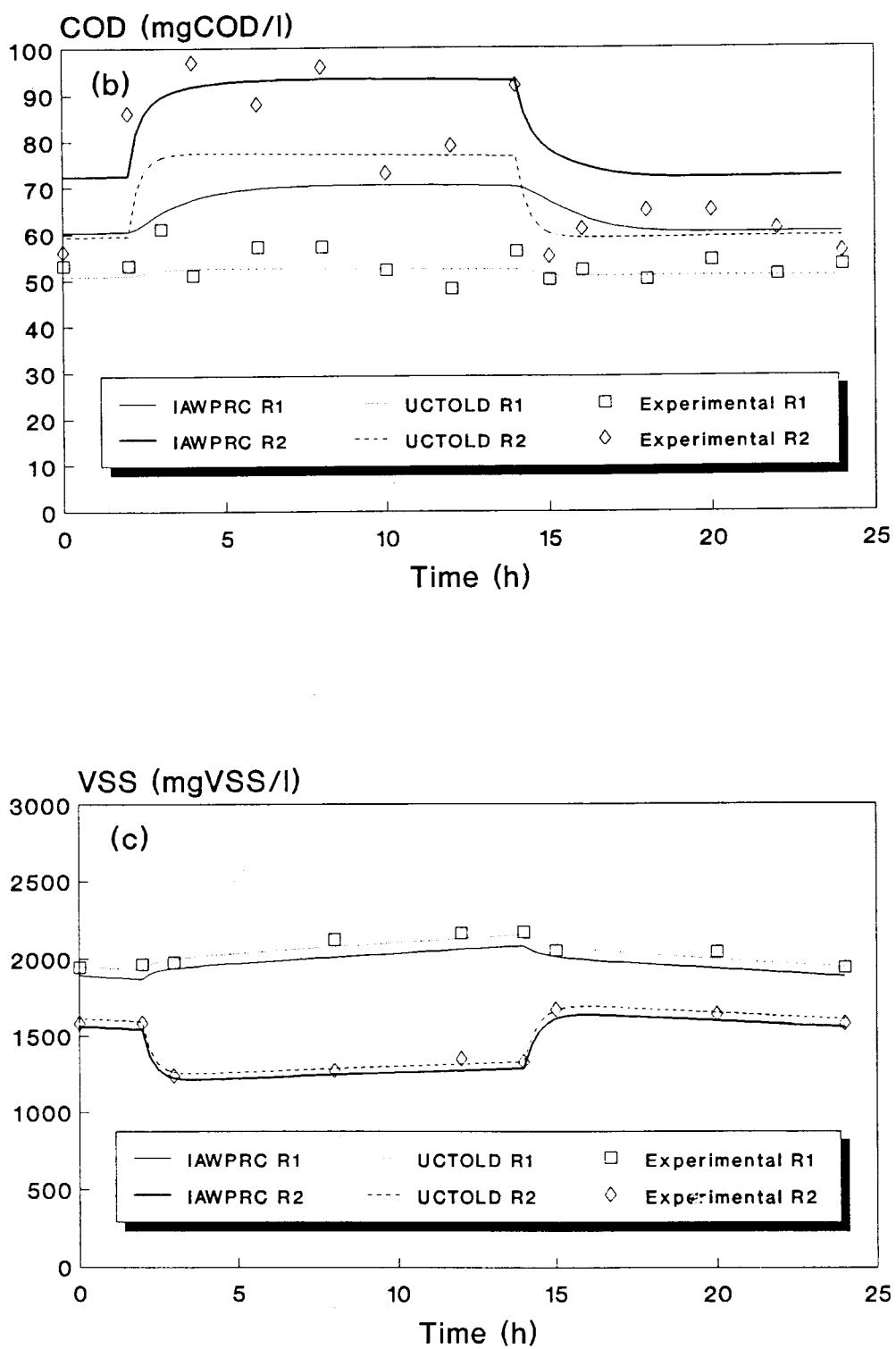


Fig 5.10: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for in-series aerobic contact (R2)-stabilization (R1) system under cyclic flow and load (feed 12h at 54 l/d , 12h at 18 l/d); predictions using UCTOLD and IAWPRC, data from Alexander *et al.* (1980). Continued overleaf.....

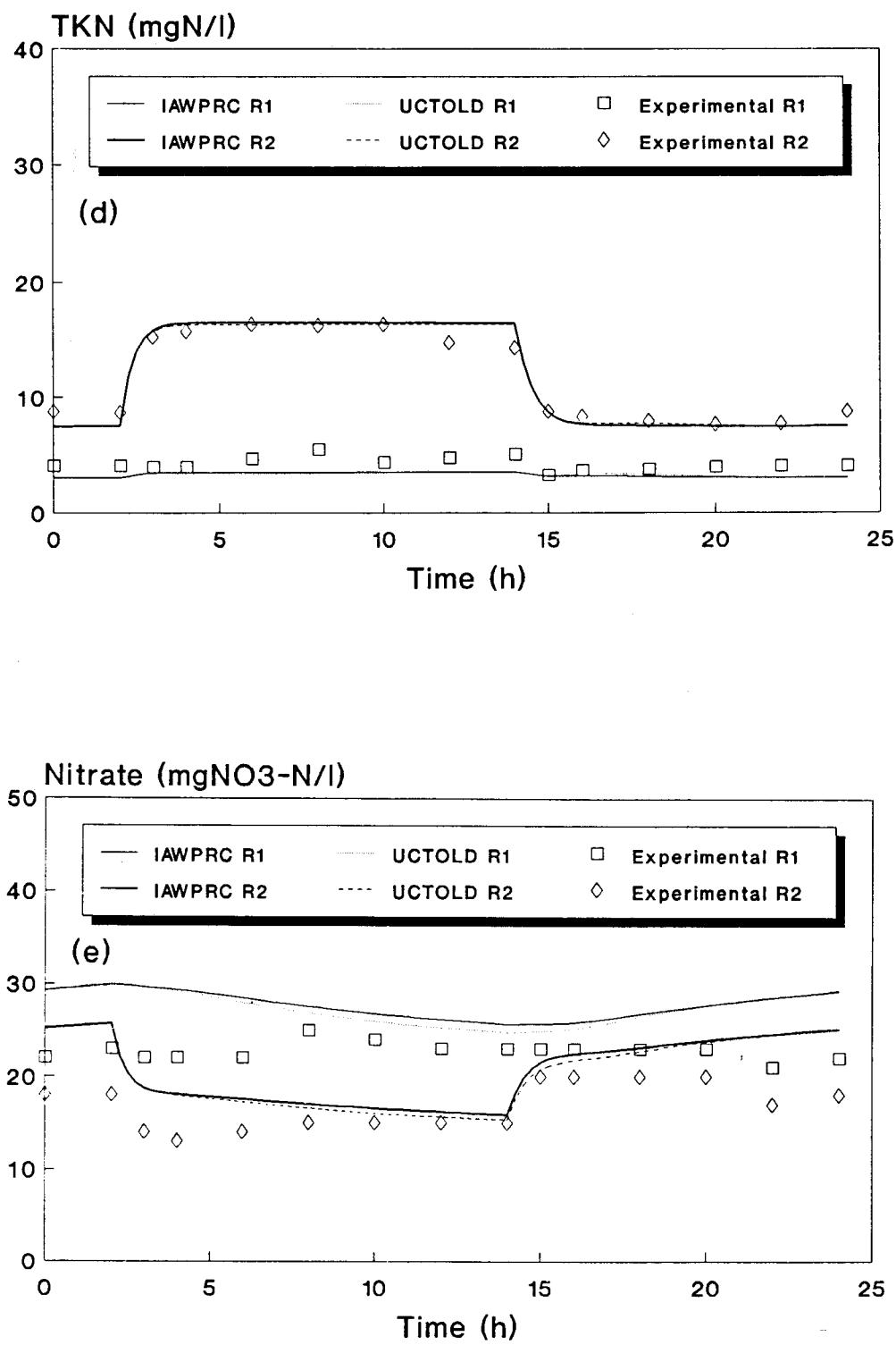
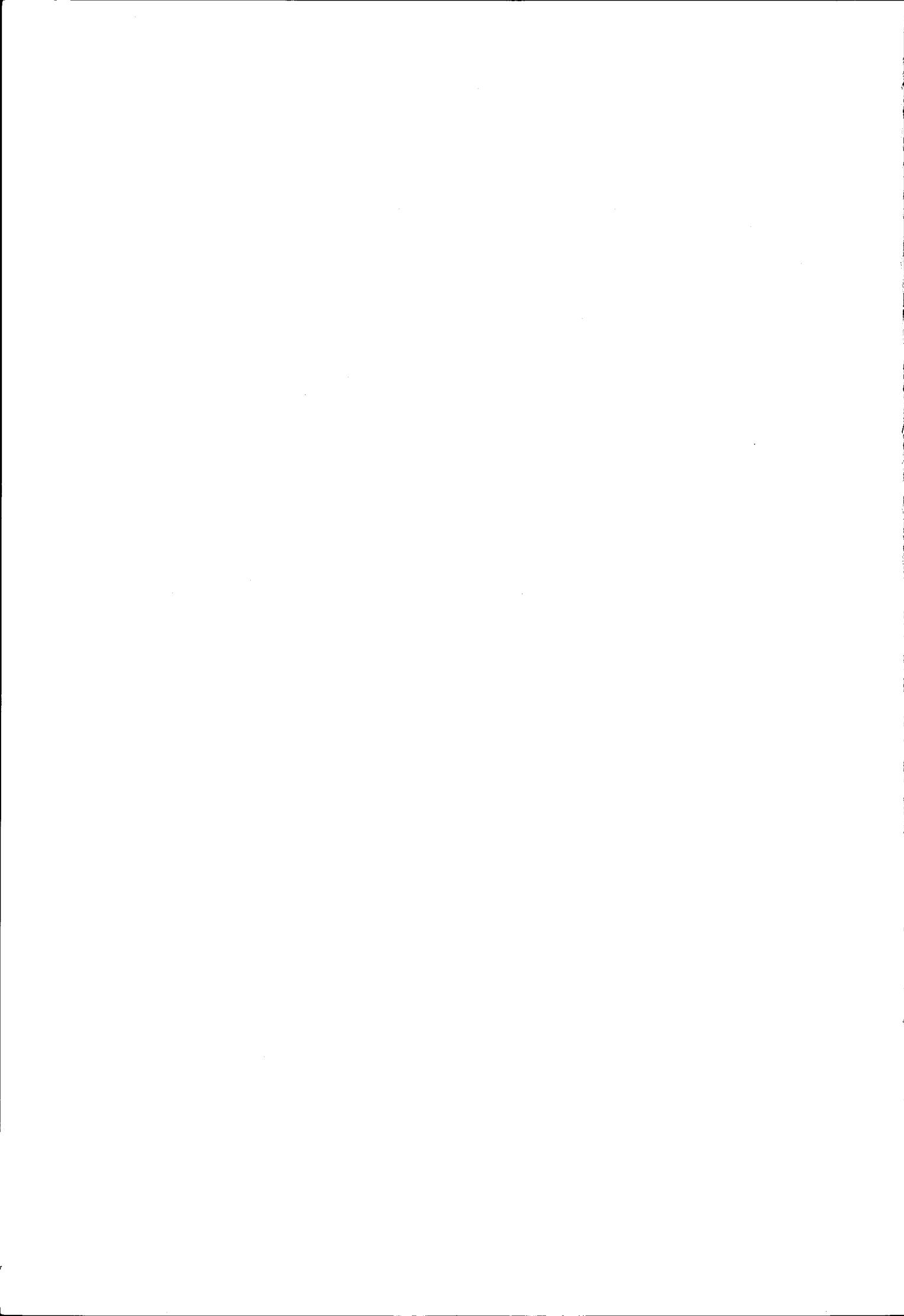


Fig 5.10: Predicted and experimental (a) OUR, (b) COD, (c) VSS, (d) TKN, and (e) nitrate time profiles for in-series aerobic contact (R2)-stabilization (R1) system under cyclic flow and load (feed 12h at 54ℓ/d, 12h at 18ℓ/d); predictions using UCTOLD and IAWPRC, data from Alexander *et al.* (1980).

CONCLUSIONS

From the simulations in this Chapter using the two models:

- Both models provide reasonable descriptions of the response of a wide range of systems and accordingly both can be accepted as adequate.
- Without further information it is not possible to pass judgement as to which model is to be preferred.
- For simulation of all systems, except for contact-stabilization systems and batch tests with nitrification inhibition, the default values for the kinetic and stoichiometric constants can be accepted with the exception of $\hat{\mu}_H$ and $\hat{\mu}_A$; $\hat{\mu}_H$ and $\hat{\mu}_A$ have been found to change with certain reactor configurations (e.g. selectors, plugflow) and influent load patterns (e.g. on-off feed pattern), $\hat{\mu}_A$ has been found to be dependent on characteristics of the wastewater feed also. (Procedures to determine these constants are set out in Chapter 6).
- For simulations of the contact-stabilization system, and batch tests in which nitrification has been inhibited by addition of thiourea, adjustment of a single constant is required in each case, the half saturation constant for RBCOD for the contact-stabilization system, and the half saturation constant for SBCOD hydrolysis for the batch test in which nitrification is inhibited.



CHAPTER 6

DETERMINATION OF MODEL CONSTANTS

INTRODUCTION

In the two general models, values for a number of constants defining the influent wastewater COD and TKN characteristics and the biological kinetics and stoichiometry need to be known. In the programs, UCTOLD and IAWPRC, default values have been assigned to these constants. For the constants defining the influent wastewater COD and TKN characteristics, the default values are averages determined for South African municipal wastewaters; for the kinetic and stoichiometric constants, the default values have been determined by direct measurement and by simulation of the responses measured for a wide range of experimental activated sludge systems.

In this chapter guidance is given for the determination of the influent wastewater COD and TKN characteristics, and on the kinetic and stoichiometric constants which appear to change with different wastewaters and/or systems.

INFLUENT COD CHARACTERISTICS

Knowledge of the influent COD characteristics is of importance in determining carbonaceous oxygen demand, sludge production, denitrification and effluent COD.

The influent COD characteristics can differ greatly between wastewaters. It was shown in Chapter 2 that the COD of wastewaters can be divided into two main fractions, unbiodegradable and biodegradable (Fig 6.1).

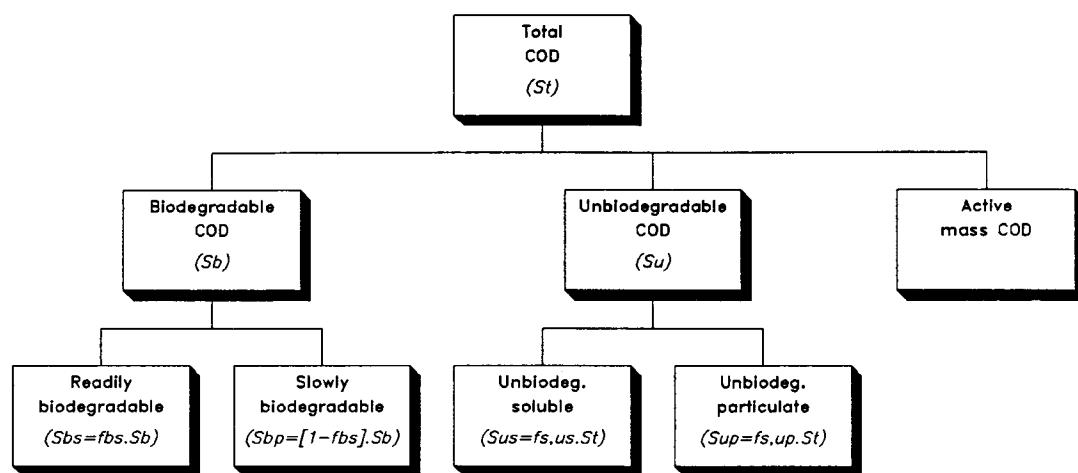


Fig 6.1: Division of influent COD into its constituent fractions

The unbiodegradable COD has two sub-fractions; (1) unbiodegradable particulate (UPCOD) and (2) unbiodegradable soluble (USCOD). The biodegradable COD also has two sub-fractions; (3) slowly biodegradable (SBCOD) and (4) readily biodegradable (RBCOD), this latter subdivision is made on the basis of *biological response*, not on physical separation. Procedures are presented for determining RBCOD, USCOD, UPCOD; subtraction of these three COD fractions from the total COD gives the SBCOD. Following the IAWPRC recommendations, an additional influent COD fraction is included in the models, that of influent biological (active) mass, see Fig 6.1. However, this COD fraction can be determined only by trial and error fitting of simulated to experimental data (Chapter 2) and accordingly procedures for its determination are not included in this Chapter.

Determination of readily biodegradable COD (RBCOD)

The method recommended and presented below for determining RBCOD is the flow through activated sludge system method. (Batch test methods also are available for determining RBCOD, see later).

Basis of test

In experimental investigations into the dynamic response of activated sludge systems (Ekama and Marais, 1979; Dold *et al.*, 1980), it was found that in aerobic completely mixed single reactor systems at short sludge ages (1,5–3,0d) under daily cyclic square wave loading conditions (feed 12h on, 12h off) there was a precipitous drop in the oxygen utilization rate on termination of the feed period (Fig 6.2). This behaviour was hypothesized to be due to the RBCOD in the influent – during the feed period the RBCOD is utilized at a very high rate and virtually completely; at feed termination addition of RBCOD also ceases causing a concomitant precipitous drop in the OUR. Measurement of the drop in OUR at feed termination therefore provides a means for estimating the mass concentration of RBCOD in the influent.

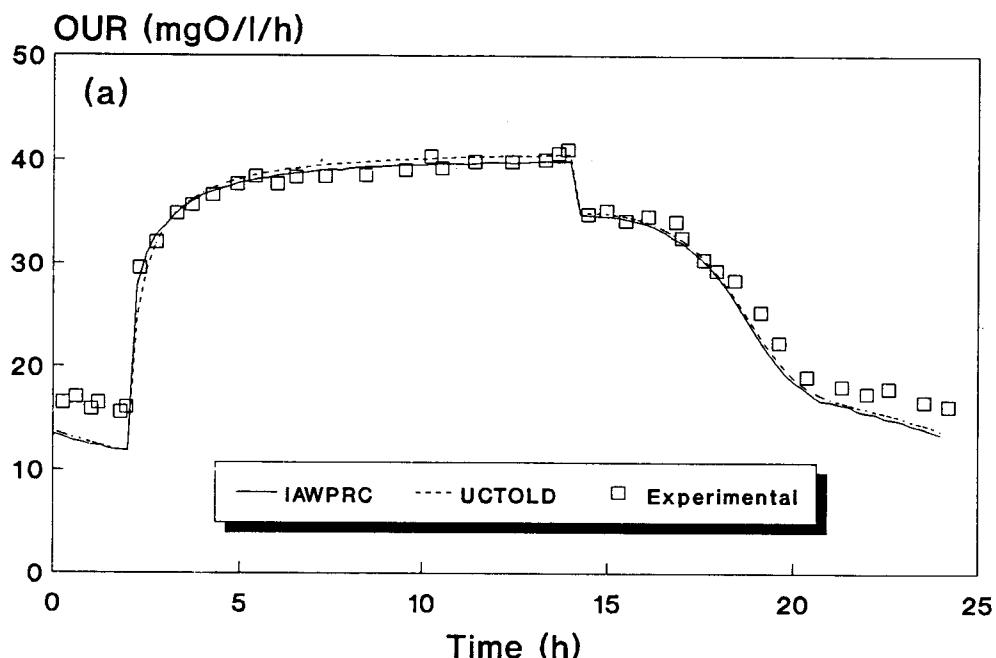


Fig 6.2: OUR-time profile in single reactor completely aerobic system at 2,5d sludge age under daily cyclic square wave loading (feed 12h on, 12h off); note precipitous drop in OUR on feed termination.

Experience with the test, and with theoretical modelling exercises, is that in order to obtain a clear definition of the precipitous drop in OUR, a short sludge age and a daily cyclic square wave loading pattern (feed 12h on, 12h off) must be imposed. A sludge age of 1,5 to 3d usually is satisfactory; for the purpose of the test knowledge of the exact sludge age is not essential, the only requirement being that a clear definition of the precipitous OUR drop is exhibited experimentally.

Experimental set up

A single aerobic reactor completely mixed independently of aeration, a settler, feed and underflow recycle pump channels, and an oxygen meter connected to a strip chart recorder, are required (see Fig 6.3).¹

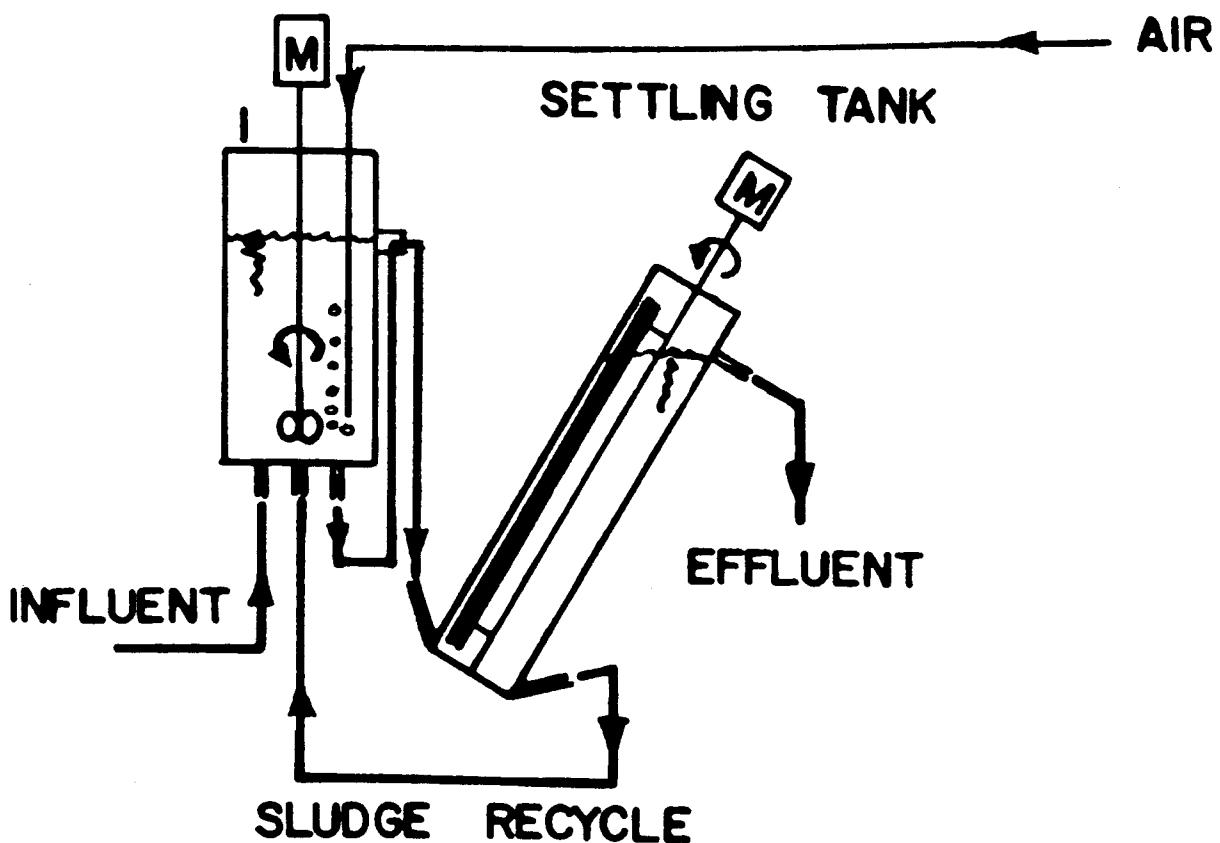


Fig 6.3: Sideview of experimental set-up for RBCOD determination.

¹Details of reactor, settler and pumps can be obtained on request from Water Research Group, Dept. Civil Engineering, University of Cape Town, Rondebosch 7700, South Africa.

In the set up and operation of the system, the following points warrant notice:

Inlets and outlets from aeration reactor: All streams to and from the reactor should enter the reactor below the liquid surface, preferably at the reactor bottom as shown in Fig 6.3; surface outlets are to be avoided as these may block and/or filter out to a degree particulate material in the effluent flow.

Feed: A batch of the wastewater to be tested sufficient for 1–2 weeks feed to the system should be collected; this is to overcome acclimatization problems and to ensure steady state is maintained. The wastewater batch must be stored at 4°C in stainless steel or plastic tanks to minimize RBCOD utilization during storage. Daily, the wastewater in the storage vessel is thoroughly mixed. It has been found that mixing can be best achieved by using a flat round disk attached at right angles to a long rod; by picking up and pushing down the rod mixing is readily achieved without significant dissolved oxygen (DO) entrainment. A volume of the mixed wastewater is drawn off and diluted with tap water to the desired feed COD concentration; this is placed in a feed reservoir also at 4°C. The contents of the feed reservoir should be mechanically mixed slowly and gently in order to keep particulate matter in suspension, but to limit DO entrainment. Covering the reservoir contents by a floating disk effectively restricts DO entrainment. Daily the reservoir and feed pipes must be cleaned in boiling water. Also, once a week the cleaned feed pipes are dumped in a hypochlorite solution. These procedures are necessary to prevent growth of *Sphaerotilus natans* on the walls of the influent feed line. These organisms readily proliferate in this substrate rich low DO environment. If this proliferation is not controlled, the mixed liquor in the reactors is continuously seeded with *S.natans* which may give rise to bulking (Gabb *et al.*, 1989).

Temperature: The system should be operated at a constant temperature, preferably in a temperature controlled room, at say 20°C. With the cyclic feeding pattern temperature changes may take place in the aerobic reactor due to the low temperature of the feed; these can be overcome by passing the feed through a coil in a warm water bath prior to discharge to the aerobic reactor.

Sludge age control: It is strongly recommended that the sludge age is established by hydraulic control. In this procedure, to maintain the sludge age at the desired value the appropriate mass of mixed liquor must be wasted every day. If the reactor liquid volume is say 10ℓ and the desired sludge age 2.5 d then $10/2.5 = 4\ell$ of mixed liquor must be wasted from the reactor daily and the volume wasted replaced with effluent. With such a large volume fraction to be wasted, wasting should be done at least 2 times/day, in this case 2ℓ in the morning and 2ℓ in the afternoon, say. Sludge wastage during the feed period should always take place at least about 4 hours before a RBCOD test is done in order that the OUR has time to regain steady state. Prior to each sludge wastage the stirrer blades and the walls of the reactor must be thoroughly brushed to dislodge adhering biological growth. (About every 2 weeks the mixed liquor must be emptied and stored under aeration while the reactor, settling tank and connecting tubing are thoroughly scrubbed in boiling water). Under no circumstances should the MLVSS (or MLSS) concentration *per se* be controlled by say, adjusting sludge wastage; this creates considerable uncertainty in the system sludge age.

Suggested loading rate: The COD load on the reactor should be such that the OUR (excluding nitrification which may or may not occur at the short sludge age depending on the maximum specific growth rate of the autotrophs, $\hat{\mu}_A$) is greater than 25 mgO/ℓ/h. This can be achieved if the feed rate, COD feed concentration

and reactor volume are such that the load during the feed period is greater than 2400 mgCOD/l reactor liquid volume/day. Thus, if the feed concentration is about 350 mgCOD/l and reactor liquid volume is 10ℓ , the feed flow rate Q prior to feed termination should be greater than $2400 \cdot 10 / 350 = 68.5 \ell/\text{d}$.

Reactor oxygen concentration: The dissolved oxygen (DO) concentration in the reactor must be maintained at a level that does not inhibit the biological processes, $1 < \text{DO} < 3 \text{ mgO/l}$. Fine bubble aeration is preferable, to improve oxygen dissolution. Aeration and mixing must be independent so that during air off periods the mixed liquor is kept in suspension.

Nitrification: The degree of nitrification which takes place in the unit does not affect the RBCOD determination. The reason for this is that at the short sludge age at which the determination is done, the oxygen utilization for *nitrification* is the same before and after feed termination, due to the high ammonia concentration in the reactor and effluent. If the ammonia concentration in the reactor and effluent before and after feed termination is low ($< 5 \text{ mgN/l}$), the change in the oxygen utilization rate for nitrification may lead to errors in the RBCOD determination. In this case it is necessary to reduce the sludge age or supplement the feed with ammonia.

System start up

From start up, operate the unit under constant flow and load conditions for at least 3 sludge ages to allow the unit to reach steady state – steady state is achieved when the day to day oxygen consumption rate and reactor MLVSS concentration show approximately steady values. Although not essential to obtain the correct RBCOD fraction, it is advisable to do COD and N mass balances on the steady state data (method given below) to give an indication of the accuracy and reliability of the experimental measurements. When steady state is achieved switch the unit over to daily cyclic square wave loading conditions by discharging the daily volume of feed over say 12 hours instead of 24. (Keep the feed volume and COD concentration constant; simply increase the flow rate). Operate the unit under square wave conditions for about 2 sludge ages. Note that now the oxygen consumption rate will vary over the day but the MLVSS concentration should not change significantly.

Should the influent composition change substantially, or if, for example, glucose is added to influent, the system must be run for a further 2 sludge ages before RBCOD measurements commence. Experience has shown that with change of substrate, even if readily biodegradable, an appreciable time may elapse before organisms adapt to the new substrate.

RBCOD measurement

The RBCOD concentration is determined from the oxygen utilization rate (OUR) drop at feed termination. This OUR drop is measured as follows:

- (1) At some time at least 6 hours after commencing the feed, measure the OUR by raising the DO to about 6 mgO/l , switching off the air supply only, and monitoring the rate of decrease of DO on a recorder until the DO reaches 1 mgO/l , whereupon the air is switched on again. Repeat measurement of the OUR every 20 to 30 minutes for about 2 hours before the feed is terminated.
- (2) Switch off the *feed and underflow recycle* to the reactor and again raise the DO to about 6 mgO/l . About 1 to 2 minutes after the feed has been stopped again measure the OUR, and every 20 to 30 minutes for about 2 hours thereafter. The underflow recycle must be switched off otherwise the sludge in the settling tank is added to the reactor disturbing the "steady state" VSS

prior to feed termination, which leads to slightly too high OUR's after feed termination.

- (3) Plot OUR for the periods of about 2 hours before and after the feed was terminated. Estimate the average OUR before and after the feed termination.

Instead of manually determining the OUR, as described above, an electronic automatic system has been developed at the University of Cape Town (Randall *et al.*, 1991). This system performs all the manual functions, i.e. switches the air on and off between selected lower and upper DO concentration limits; during the air off period it stores the DO-time values, discards those values close to the upper DO limit and via linear regression fits the best straight line to the remaining DO-time values, the slope of which defines the OUR. The OUR's determined in this manner are stored and can be reproduced off-line on a computer.

From the measurements, the following information is used to calculate the concentration of RBCOD in the influent feed:

$$\begin{aligned} Q &= \text{feed flow rate } (\ell/d) \text{ during the feed-on period} \\ V_p &= \text{reactor volume } (\ell) \\ \text{OUR}_b &= \text{average OUR before feed termination } (\text{mgO}/\ell/h) \\ \text{OUR}_a &= \text{average OUR after feed termination } (\text{mgO}/\ell/h) \\ S_{ti} &= \text{total influent COD concentration of feed } (\text{mgCOD}/\ell) \\ \Delta \text{OUR} &= (\text{OUR}_b - \text{OUR}_a) \text{ (mgO}/\ell/h) \end{aligned}$$

The influent RBCOD concentration (S_{bsi}) is given by

$$S_{bsi} = (\Delta \text{OUR} \cdot V_p \cdot 24) / (Q \cdot 0,334) \quad (\text{mgCOD}/\ell) \quad (6.1)$$

where

$$\begin{aligned} 24 &= \text{number of hours per day} \\ 0,334 &= \text{conversion factor for COD to oxygen. This factor implies that for every unit of COD utilized by the micro-organisms, 0,334 units of COD are passed to the electron acceptor oxygen and therefore reflects oxygen consumption; the remaining 0,666 units of COD are converted to new organism mass (see WRC, 1984).} \end{aligned}$$

Wtong As input to the computer programs the fractional constant f_{bs} is required which is the fraction of influent RBCOD (S_{bsi}) with respect to the influent biodegradable COD (S_{bi}), and is given by

$$\begin{aligned} f_{bs} &= S_{bsi} / S_{bi} \\ &= S_{bsi} / [S_{ti} (1 - f_{S, us} - f_{S, up})] \quad (6.2) \end{aligned}$$

where

$$\begin{aligned} f_{S, us} &= \text{fraction of total COD which is unbiodegradable soluble} \\ f_{S, up} &= \text{fraction of total COD which is unbiodegradable particulate} \end{aligned}$$

Procedures for determining $f_{S, us}$ and $f_{S, up}$ are given below.

Example calculation

The following data were obtained from an experimental unit operated on primary settling tank effluent at the Goudkoppies plant, South Africa,

$$\begin{aligned}
 Q &= 50 \text{ l/d} \text{ for period prior to feed termination} \\
 V_p &= 7,5 \text{ l} \\
 OUR_b &= 24,1 \text{ mgO/l/h} \\
 OUR_a &= 20,1 \text{ mgO/l/h} \\
 S_{ti} &= 370 \text{ mgCOD/l} \\
 \Delta OUR &= 24,1 - 20,1 = 4,0 \text{ mgO/l/h}
 \end{aligned}$$

From Eq (6.1),

$$\begin{aligned}
 S_{bsi} &= (4,0 \cdot 7,5 \cdot 24) / (50 \cdot 0,334) \\
 &= 43,1 \text{ mgCOD/l}
 \end{aligned}$$

Now, $f_{S,us}$ and $f_{S,up}$ were determined independently (for method see below) to give values of 0,09 and 0,04 respectively. Accordingly, from Eq (6.2)

$$\begin{aligned}
 f_{bs} &= 43,1 / [370(1 - 0,09 - 0,04)] \\
 &= 0,13 \text{ mgCOD/mgCOD}.
 \end{aligned}$$

Determination of unbiodegradable soluble and particulate COD (USCOD and UPCOD)

With regard to the unbiodegradable COD fractions, even though these are presumed to be unaffected by biological action, determination of USCOD and UPCOD is important for accurate description of the activated sludge system; the former passes out with the effluent as soluble COD, whereas the latter is enmeshed in the sludge mass, accumulates in the system and is removed via the daily waste sludge. Accordingly, the USCOD fraction sets the lowest filtered effluent COD concentration the system can attain (provided unbiodegradable soluble COD is not generated in the system to any significant degree, see later) and the UPCOD fraction affects the sludge production. Measurement of USCOD is direct; UPCOD can be estimated only via the hypothesized model and in this regard it has meaning only in terms of the model structure.

Experimental set up

Two laboratory-scale activated sludge systems are set up to operate at two different sludge ages longer than 5 days – say 10 and 20 days. Each system consists of a single fully aerobic reactor completely mixed by an independent mechanical mixer, a settler and feed and underflow recycle pumps (as for the RBCOD measurement unit). In the set up and operation of the systems the procedures set out above for determination of RBCOD (i.e. brushing of reactors, daily cleaning of feed tubes, etc.) should be followed with the following alterations and additions:

Feed: Collection and storage of the feed is as for the RBCOD system described above. Each of the systems must be fed a constant mass of COD each day at a constant flow rate over the day. The daily volume of feed multiplied by the selected COD concentration gives the mass of COD fed per day.

Sludge age control: As with the RBCOD system, the sludge age is set by hydraulic control, e.g. for 10 and 20 days sludge age, every day 1/10th and 1/20th of the reactor volume respectively is abstracted. In time, the reactor MLVSS concentration will reach a steady state value corresponding to the set sludge age and the mass of COD fed per day.

Unlike the flow through activated sludge system for RBCOD determination, knowledge of the exact sludge age is essential in determining UPCOD. Accordingly, one needs to take care that additional losses of sludge are duly

accounted for. In an experimental investigation usually the mass of VSS in the settling tank is small and the mass lost in the effluent is negligible. Under such conditions hydraulic control gives the correct sludge age. If the mass of sludge in the settling tank is found to be significant, this mass needs to be added to that in the reactor to give the ***total mass of VSS in the system***. If the concentration of VSS in the effluent (measured directly or calculated from the difference between the unfiltered and filtered COD concentrations divided by the COD/VSS ratio) is significant, then the VSS mass lost via the effluent (concentration times effluent flow) needs to be added to the VSS mass abstracted from the reactor to give the ***total VSS mass wasted and lost from the system per day***. From the total mass of VSS in the system and the total mass of VSS wasted and lost per day, a revised value of the sludge age can be calculated, i.e.

$$\text{Sludge age} = \frac{\text{total VSS mass in system}}{\text{total VSS mass wasted and lost per day}} \quad (\text{d}) \quad (6.3)$$

To minimize wall growth in the system, which also will influence the sludge age, about every 2 weeks the mixed liquor must be emptied and stored under aeration while the reactor, settling tank and connecting tubing are thoroughly scrubbed in boiling water.

Reactor MLSS concentration and volume requirements: It is recommended that the experimental systems are operated with reactor mixed liquor suspended solids (MLSS) concentrations of approximately 4000 mgMLSS/l ($\approx 3000 \text{ mgMLVSS/l}$); higher concentrations may give rise to difficulties in sludge settling, aeration and mixed liquor recycling, while lower concentrations make reliable measurements difficult. The reactor volume is set to give the selected MLSS concentration; the reactor volume is determined by diluting the ***mass*** of MLSS expected for the sludge age and influent COD mass loading per day, to the selected MLSS concentration. From WRC (1984), to give the selected MLSS concentration of 4000 mgMLSS/l at sludges of 10 and 20 days, the reactor volume requirements are approximately 0,9 and 1,5 l/gCOD load respectively for raw wastewater and 0,4 and 0,6 l/gCOD load respectively for settled wastewater.

As an example, if 10 l/d of raw wastewater with a COD of 500 mg/l is fed to the two experimental systems at 10 and 20 days sludge age then the required reactor volumes (V_p) are:

$$\begin{aligned} 10 \text{ days: } V_p &= 0,9 \cdot 10 \cdot 500 / 1000 = 4,5\ell \\ 20 \text{ days: } V_p &= 1,5 \cdot 10 \cdot 500 / 1000 = 7,5\ell \end{aligned}$$

Parameter measurement

Once steady state has been achieved, usually after 2 to 3 sludge ages, the following parameters must be measured regularly over a further 2 to 3 sludge ages; filtered ($0,45 \mu\text{m}$) and unfiltered influent COD and TKN; filtered and unfiltered effluent COD and TKN; filtered effluent ammonia and nitrate; reactor MLSS and MLVSS; the COD/VSS and TKN/VSS ratios of the VSS and the oxygen utilization rate (OUR) in the reactor. The operation and control of these plants and the procedures for measuring the cited parameters, in particular the oxygen utilization rate, must be done with the utmost care. Practical details of these tests are set out at length by Marais and Ekama (1976).

Calculation of USCOD

From extensive experimental enquiry at the University of Cape Town, it became clear that for municipal-type wastes the filtered effluent COD is virtually constant

for all sludge ages longer than about 3 days. This was found to be so not only under constant flow and load conditions, but also under daily cyclic loading conditions. Furthermore, from measured oxygen utilization rates (OUR), at sludge ages greater than 5 days at 20°C, it was found that virtually all the biodegradable COD (both soluble and particulate) is utilized in the system; this behaviour has been reflected in numerous computer simulations of a wide range of experimental systems. Accordingly, for the experimental systems recommended above, operated at sludge ages of 10 to 20 days at 20°C, the effluent (soluble) biodegradable COD concentration can be assumed to be zero. Furthermore, the organisms in the experimental systems do not generate unbiodegradable COD to any significant degree (Dold *et al.*, 1986). Therefore, it can be accepted that the filtered effluent COD is due entirely to the USCOD in the influent and, in the two experimental systems, the USCOD is given by the COD of the filtered effluent (0.45 µm filter). This COD concentration divided by the influent total COD (TCOD) gives the fractional constant $f_{S,us}$ required in the programs, i.e.

$$f_{S,us} = \text{USCOD/TCOD} = S_{usi}/S_{ti} \quad (6.4)$$

Estimation of UPCOD

The influent UPCOD is estimated by comparing MLVSS concentrations measured for the two experimental systems, with MLVSS concentrations predicted by the two models, as follows:

The experimental system set-ups serve as input to the program. Simulations are run for a range of $f_{S,up}$ values; the $f_{S,up}$ value which gives the predicted MLVSS closest to that measured at both sludge ages is the estimated $f_{S,up}$ for that wastewater.

Provided that good COD and N mass balances (for determination see later) are obtained (95 to 105%) for the experimental systems, the $f_{S,up}$ determined above can be checked as follows:

Compare the *predicted* oxygen utilization rate (OUR) for the carbonaceous material against the *measured* OUR for carbonaceous material. If nitrification takes place, the measured OUR must be corrected to give the OUR for carbonaceous material only by deducting the OUR for nitrification. Provided a good N balance is obtained (>95%, i.e. no inadvertent denitrification in system) the OUR for nitrification (OUR_n) can be calculated from the measured effluent nitrate concentration (N_{o3e}) less the influent nitrate concentration (N_{o3i}), i.e.

$$\text{OUR}_n = 4.57 \cdot (N_{o3e} - N_{o3i}) \cdot Q / (24 \cdot V_p) \quad (\text{mgO}/\ell/\text{h}) \quad (6.5)$$

where

4.57 = mg oxygen required to nitrify 1 mgN nitrate (mgO/mgN)
 V_p = reactor liquid volume (ℓ)

[In the above equation (6.5) nitrite is not included; in completely aerobic systems the nitrite concentration usually is small and can be neglected.]

Hence, the measured OUR for carbonaceous material (OUR_c) is given by

$$\text{OUR}_c = \text{OUR}_m - \text{OUR}_n \quad (\text{mgO}/\ell/\text{h}) \quad (6.6)$$

where

OUR_m = measured OUR $(\text{mgO}/\ell/\text{h})$

These calculations only apply if there is no denitrification in the experimental systems. Also, the OUR is relatively insensitive to variations in $f_{S, up}$ so that accurate and reliable measurements are essential; these can be checked by COD and N mass balances, see below.

In utilizing the procedure above to determine $f_{S, up}$, the values of the kinetic/stoichiometric constants Y_{Z_N} , b_N , f_E and f_{cv} can influence the predicted MLVSS and hence the estimated value of $f_{S, up}$; values for these constants therefore must be known. The default values for these constants supplied in the programs can be accepted as adequate; these values have been obtained from extensive research enquiry. Should the values for the constants require calibration, the reader is referred to Marais and Ekama (1976), WRC (1984) and Ekama *et al.* (1986).

Mass balances

The accuracy of the values for UPCOD ($f_{S, up}$) determined via the procedures set out above hinges around the acceptable accuracy of the experimental data. Acceptability is checked by calculating N and COD mass balances over the experimental system. In the N balance, the influent TKN must be accounted for (to within 95 to 105%) by the sum of the mass of effluent TKN and nitrate, and the mass of N abstracted with the waste sludge. Similarly, the influent COD must be accounted for (to within 95 to 105%) by the sum of the masses of effluent COD, carbonaceous oxygen demand and COD of the waste sludge. For the two experimental systems described earlier, the methods for calculating N and COD mass balances are given below:

N balance:

- (1) Mass of N in the sludge wasted per day (ΔMN_X) is given by the TKN/VSS ratio times the mass of VSS wasted from the reactor per day, i.e.

$$\Delta MN_X = f_{X, N} \cdot q \cdot X_v = f_{X, N} \cdot V_p \cdot X_v / R_s \quad (\text{mgN/d}) \quad (6.7)$$

where

q	= wastage flow rate	(ℓ/d)
X_v	= reactor VSS concentration	(mgVSS/ℓ)
V_p	= reactor liquid volume	(ℓ)
R_s	= sludge age	(d)
$f_{X, N}$	= TKN/VSS	(mgN/mgVSS)
	= fraction of VSS which is N	$\approx 0.1 \text{ mgN/mgVSS}$.

- (2) Mass of TKN-N in the effluent (MN_{te}) is given by

$$MN_{te} = Q \cdot N_{te} \quad (\text{mgN/d}) \quad (6.8)$$

where

Q	= influent flow rate	(ℓ/d)
N_{te}	= effluent TKN concentration	(mgN/ℓ)

In Eq (6.8), the influent flow rate, not the effluent flow rate, is used. The effluent flow rate is less than the influent flow rate by the sludge waste flow rate; soluble TKN equal in concentration to the effluent TKN also leaves the system via the sludge waste flow. Using the influent flow rate takes this into account. Also, in Eq (6.8), if N_{te} is the filtered value, then in Eq (6.7) the value for the sludge age must be adjusted to take due account of the VSS in the effluent, see Eq (6.3). Alternatively, if N_{te} is the unfiltered value then the value for the sludge age need not be adjusted.

- (3) Mass of nitrate generated in the system (MN_{o_3}) is given by

$$MN_{o_3} = Q \cdot N_{o_3e} - Q \cdot N_{o_3i} \quad (\text{mgN/d}) \quad (6.9)$$

where

N_{o_3e} = effluent nitrate concentration (mgN/l)

N_{o_3i} = influent nitrate concentration (mgN/l)

From Eqs (6.7 to 6.9) the N balance is given by

$$N_{bal} (\%) = 100 \cdot (\Delta MN_X + MN_{te} + MN_{o_3}) / MN_{ti} \quad (6.10)$$

where

MN_{ti} = influent TKN mass (mgN/d)

$= Q \cdot N_{ti}$ (mgN/d) (6.11)

N_{ti} = influent TKN concentration (mgN/l)

The experimental data can be considered acceptable if the N balance is in the range 95 to 105%. If the N balance does not fall within this range, the source of error should be identified in the experimental system, sample handling or analysis techniques, and the test repeated.

COD balance:

- (1) The COD of the sludge mass wasted per day ($MCOD_w$) is given by the COD/VSS ratio (f_{cv}) times the mass of VSS wasted per day, i.e.

$$MCOD_w = f_{cv} \cdot q \cdot X_v = f_{cv} \cdot V_p \cdot X_v / R_s \quad (\text{mgCOD/d}) \quad (6.12)$$

where

f_{cv} = COD/VSS ratio of the sludge $\approx 1,48 \text{ mgCOD/mgVSS}$.

- (2) The COD mass in the effluent (MS_{te}) is given by

$$MS_{te} = Q \cdot S_{te} \quad (\text{mgCOD/d}) \quad (6.13)$$

where

Q = influent flow rate (l/d)

S_{te} = effluent COD concentration (mgCOD/l) .

In Eq (6.13), if S_{te} is the filtered value, then in Eq (6.12) the value for the sludge age must be adjusted to take due account of the VSS in the effluent, see Eq (6.3). Alternatively, if S_{te} is the unfiltered value then the sludge age need not be adjusted.

- (3) The COD recovered from the oxygen demand must take due account of the oxygen demand for nitrification. Provided the N balance is acceptable, the oxygen demand for nitrification (MO_n) is given by

$$MO_n = 4,57 \cdot MN_{o_3} \quad (\text{mgO/d}) \quad (6.14)$$

where

MN_{o_3} = mass of nitrate generated per day, Eq (6.9) (mgN/d)

4,57 = mass of oxygen utilized per ammonia nitrified (mgO/mgN) .

From the measured OUR ($\text{mgO}/\ell/\text{h}$) the oxygen demand for carbonaceous material (MO_c) is given by

$$\text{MO}_c = (\text{OUR})_M \cdot V_p \cdot 24 - \text{MO}_n \quad (\text{mgO}/\text{d}) \quad (6.15)$$

where

$$(\text{OUR})_M = \text{measured OUR} \quad (\text{mgO}/\ell/\text{h}).$$

From Eqs (6.12 to 6.15), the COD balance is given by

$$\text{COD}_{\text{bal}} (\%) = 100 \cdot (\text{MCOD}_w + \text{MS}_{te} + \text{MO}_c) / \text{MS}_{ti} \quad (6.16)$$

where

$$\begin{aligned} \text{MS}_{ti} &= \text{total mass of COD fed to system} \quad (\text{mgCOD}/\text{d}) \\ &= Q \cdot S_{ti} \\ S_{ti} &= \text{influent COD concentration} \quad (\text{mgCOD}/\ell). \end{aligned} \quad (6.17)$$

As with the N balance, the COD balance also should be at least 95 to 105% for the experimental data to be acceptable for aerobic systems². From Eq (6.15) it can be seen that errors in the N balance are carried through to the COD balance via the oxygen demand for nitrification. Consequently both N and COD balances should be adequate for the data to be acceptable. Generally, greater difficulty is found in achieving good COD balances than N balances: Likely sources of error in the COD balance arise from loss of COD in the feed bucket before discharge to the system, incorrect determination of the OUR and/or errors in the measurement of the influent COD; a likely source of error in the N balance arises in aerobic systems from unintentional denitrification in the experimental set-up.

In the calculation of the mass balances only 3 stoichiometric constants are required, *viz* COD/VSS ratio (f_{cv}), TKN/VSS ratio ($f_{X,N}$) and 4.57 mgO required per mgNO₃-N generated by nitrification. The first two of these constants can be directly measured in the investigation. The latter is a theoretical value but it has been experimentally verified and shown to be sufficiently accurate for all purposes. Consequently in the mass balances a minimum of theoretical assumptions are applied – the data are checked on the basis of continuity and conservation of mass principles which do not invoke theoretical relationships depicting the activated sludge system kinetics. Only with acceptable mass balances are the data adequate to calculate reliably kinetic and sewage characteristic constants within the framework of the theoretical model. *To obtain acceptable N and COD mass balances, the experimental investigation must be conducted with an uncompromising vigilance, a strict discipline and attention to detail in every operational procedure; if these are lax or neglected, the results will be largely useless.*

INFLUENT TKN CHARACTERISTICS

Knowledge of influent TKN characteristics is of importance in determining nitrification oxygen demand, nitrification capacity and effluent TKN. As with the COD, the influent TKN also is subdivided into different fractions. In Chapter 2 it was shown that the TKN of wastewaters can be divided in two main fractions (Fig 6.4), (1) free and saline ammonia and organically bound N. The organically bound

²Difficulties may be encountered in obtaining good COD balances in systems with large unaerated mass fractions (Arkley and Marais, 1981; Warburton *et al.*, 1991). In contrast, good N balances have been obtained consistently in all types of systems.

N has two subfractions, biodegradable and unbiodegradable; each of these is further subdivided into particulate and soluble subfractions to give (2) biodegradable particulate organic N (BPON), (3) biodegradable soluble organic N (BSON), (4) unbiodegradable particulate organic N (UPON) and (5) unbiodegradable soluble organic N (USON). Following the IAWPRC recommendations, an influent biological (active) mass N fraction is included in both models, see Fig 6.4. However, quantification of this fraction is via the influent biological (active) mass COD fraction which can be determined only by trial and error fitting of simulated to experimental data (see Chapter 2). Accordingly, procedures to determine this N fraction are not included in the discussion below.

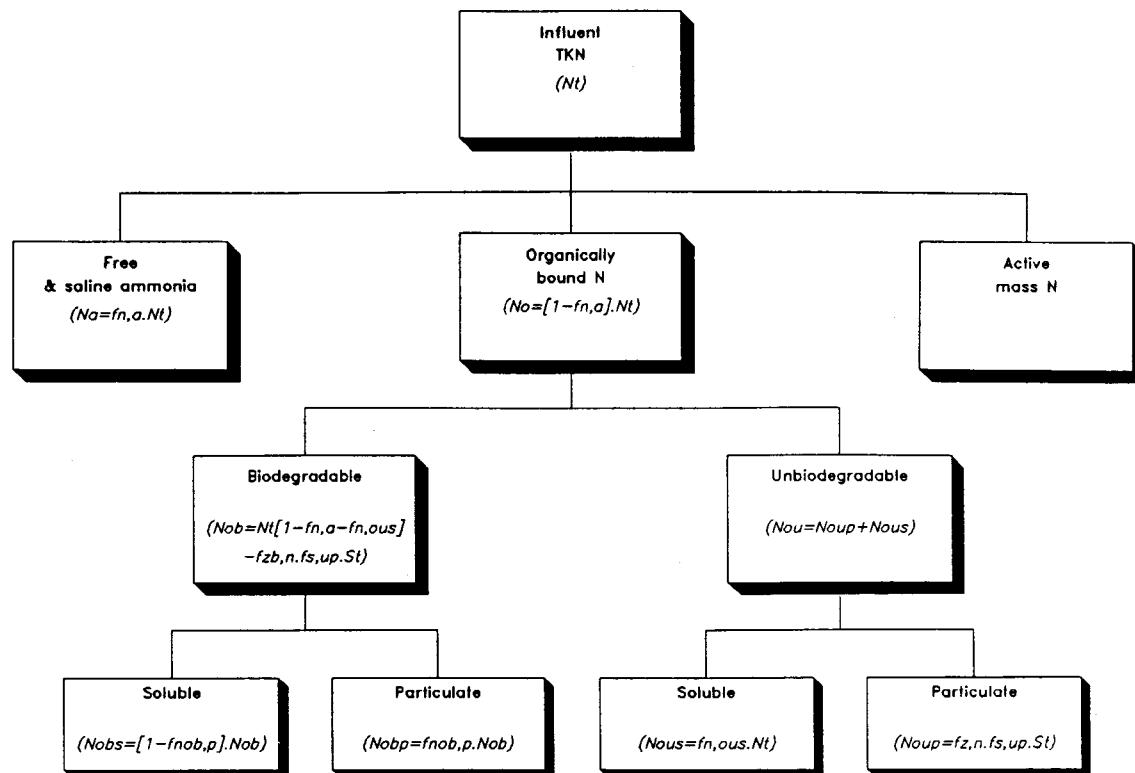


Fig 6.4: Division of the influent TKN into its constituent fractions.

With regard to quantification of the other influent N fractions, the free and saline ammonia (N_{a,i}) is measured directly by the test bearing this name; the total organic N_{o,i} is found from the difference between the measured influent TKN (N_{t,i}) and free and saline ammonia (N_{a,i}) concentrations. Difficulties in quantification arise when subdividing the total organic N (N_{o,i}) into its four subfractions, BPON, BSON, UPON and USON (see Fig 6.4). Accurate measures of the magnitudes of these fractions can be obtained only by comparing the observed response of laboratory-scale systems (such as those described in the previous section 'Determination of unbiodegradable soluble and particulate COD') with that predicted by the two models. From a large number of such comparisons for systems operated within the range of sludge ages 2 to 30d under cyclic and steady state in the temperature range 12 to 25°C, it would appear that subdivision of the total organic N into four subfractions is necessary in the models to obtain consistent correlation between observation and prediction. However, the magnitudes of the two unbiodegradable organic N fractions, UPON and USON, are small and the

relative subdivision of the biodegradable organic N into the two subfractions, BPON and BSON, does not exert significant influence on the model's predictions. It is not necessary therefore to have accurate measures for the magnitudes of UPON and USON or for the subdivision of the biodegradable organic N into soluble (BSON) and particulate (BPON) fractions. Accordingly, for most applications the default values for the constants defining the total organic N fractions ($f_{N,ous}$, $f_{N,ob,p}$) can be accepted as adequate. However, should it prove necessary, the magnitudes of the total organic N fractions can be estimated from measurements made on the laboratory-scale systems described in the previous section 'Determination of unbiodegradable soluble and particulate COD', provided acceptable COD and N balances have been obtained.

UPON

In the models UPON in the influent (N_{oup_i}) is expressed in terms of UPCOD in the influent (S_{up_i}), i.e.

$$N_{oup_i} = f_{Z,N} \cdot S_{up_i} \quad (6.18)$$

where

$$\begin{aligned} f_{Z,N} &= \text{TKN/COD ratio of MLVSS (mgN/mgCOD)} \\ &= f_{cv} \cdot f_{X,N} \\ f_{X,N} &= \text{TKN/VSS ratio of MLVSS (mgN/mgVSS)} \\ &= \approx 0,1 \text{ mgN/mgVSS} \\ f_{cv} &= \text{COD/VSS ratio of MLVSS (mgCOD/mgVSS)} \\ &= \approx 1,48 \text{ mgCOD/mgVSS} \end{aligned}$$

From experimental data on the TKN/COD ratio of the mixed liquor volatile suspended solids (MLVSS) in the biological reactor, our experience is that the TKN/COD ratio remains substantially the same irrespective of the sludge age from 3 to 30d despite the fact that the various MLVSS components (active, endogenous and inert fractions) change with sludge age. Hence, it would seem reasonable to accept that the TKN/COD ratio of the inert fraction of the MLVSS (and therefore of UPCOD) is equal to that of the other MLVSS fractions. The TKN/COD ratio for MLVSS, from extensive experimental measurements has a mean value of 0,068 mgN/mgCOD. The value for the TKN/COD ratio in a particular investigation can be checked by direct measurement of the TKN and COD of the MLVSS in the two experimental systems. If necessary, the computer program input constants for the TKN/COD ratio, $f_{ZB,N}$ and $f_{ZE,N}$, can be adjusted to reflect the measured TKN/COD ratio.

USON

An estimate of USON in the influent (N_{ous_i}) can be obtained from the filtered ($<0,45\mu\text{m}$) effluent total TKN of the two experimental systems. The filtered effluent total TKN (N_{te}) contains three soluble N fractions, USON, BSON and free and saline ammonia. The effluent free and saline ammonia (N_{ae}) can be measured directly by the test bearing this name. (The N_{ae} very likely will be small so that reliable measurement of this parameter may not be possible; if $N_{ae} < 1,0 \text{ mgN/l}$ then accept $N_{ae} = 0,5 \text{ mgN/l}$). From numerous simulations, for sludge ages > 5 days and temperature = 20°C the effluent BSON (N_{obse}) can be accepted to be $1,5 \text{ mgN/l}$. Accordingly, the effluent USON (N_{ouse}) is given by

$$N_{ouse} = N_{te} - N_{ae} - 1,5 \quad (6.19)$$

Since USON is unbiodegradable and soluble, the influent concentration will equal the effluent concentration, i.e.

$$N_{ousi} = N_{ouse} \quad (6.20)$$

As input to the computer programs, the fractional constant $f_{N,ous}$ defines the influent USON where

$$f_{N,ous} = N_{ousi}/N_{ti} \quad (6.21)$$

BSON

An estimate of BSON in the influent (N_{obsi}) can be obtained from the filtered ($<0,45\mu m$) *influent* TKN. The filtered influent TKN contains three soluble N fractions, free and saline ammonia, USON and BSON. The influent free and saline ammonia (N_{ai}) can be measured by the test bearing this name and the influent USON (N_{ousi}) has been estimated in the previous section. The filtered influent TKN remaining can be assigned to the influent BSON (N_{obsi}) fraction, i.e.

$$N_{obsi} = \text{filtered influent TKN} - N_{ai} - N_{ousi} \quad (6.22)$$

The input required for the computer programs is the fractional constant $f_{N_{ob},p}$ which defines the influent BSON in terms of the influent biodegradable organic N (N_{obi}), i.e.

$$N_{obi} = N_{ti} - N_{ai} - N_{ousi} - N_{oupi} \quad (6.23)$$

and

$$f_{N_{ob},p} = 1 - N_{obsi}/N_{obi}$$

BPON

The influent BPON (N_{obpi}) is given by the influent TKN remaining after all the other TKN fractions have been estimated, i.e.

$$N_{obpi} = N_{ti} - N_{ai} - N_{obsi} - N_{ousi} - N_{oupi} \quad (6.24)$$

N_{obpi} is not required as input to the computer programs, but is calculated automatically by the programs from the influent TKN fractions given.

Revised estimates for organic N fractions

In the procedures described above to estimate the various organic N fractions, initially it was assumed that the effluent BSON (N_{obsi}) was $1,5 \text{ mgN/l}$, see Eq (6.19). A revised estimate for this parameter can be obtained by inputting the initial estimates for the various TKN fractions (as determined above) into the computer programs and simulating the two experimental systems. The predicted value for the effluent BSON is accepted, and the various organic N fractions recalculated via the procedures detailed above. This process is repeated until the predicted effluent BSON is the same for two successive simulations.

KINETIC AND STOICHIOMETRIC CONSTANTS

In Chapter 2, the kinetic and stoichiometric constants for the two models are listed together with the default values included in the programs. These default values have been obtained from extensive research enquiry, and have been consistently corroborated in application of the models to simulate data obtained from a range of experimental systems (see Chapter 5 for examples). Therefore, we believe the quoted default values constitute reliable average values for normal application of the models to systems treating municipal-type wastes. *However, it should be noted that these values are for temperature = 20°C and pH = 7,2 to 8,5.* Adjustment of the values for the operational temperature of the activated sludge system to be simulated is computed automatically by the programs from the input temperature and the default Arrhenius temperature constants; adjustment for pH is not computed (refer WRC, 1984 for details on adjusting the values for pH). Furthermore, from experience it has been found that the values for some of the constants change for different wastewaters and/or system configurations and load patterns. In this regard four constants have been found to change:

- (1) The maximum specific growth rate of the heterotrophs on RBCOD ($\hat{\mu}_H$) is dependent on the system configuration and load pattern (Ekama *et al.*, 1986, Gabb *et al.*, 1989). For most applications of the models the value for this constant has little influence on the models predictions – the rate of growth on RBCOD usually is limited by the rate at which RBCOD enters the system with the influent and not by the kinetics of utilization. However, the value has significance in that it sets the denitrification rate for RBCOD in *batch* denitrification which forms the basis in design to fix the minimum size for a primary anoxic reactor (WRC, 1984). Also, $\hat{\mu}_H$ is implicated in the phenomenon of sludge bulking by certain filamentous organisms.³
- (2) The maximum specific growth rate of the autotrophs ($\hat{\mu}_A$) is dependant on the wastewater (WRC, 1984) and on the system configuration and load pattern (Still *et al.*, 1986). Again, for most applications of the models the absolute value for this constant has little influence on the models predictions provided the value selected falls in the range 0,2–0,8/d and the system nitrifies completely at the lowest temperature. However, the value for this constant has significance in design in that it influences the minimum sludge age for complete nitrification (WRC, 1984).
- (3) Change in the value of the half saturation constant for heterotrophic RBCOD utilization (K_{S_H}) has been found necessary in simulations of the contact-stabilization system, from $K_{S_H} = 5$ to 110 mgCOD/l for UCTOLD and from $K_{S_H} = 5$ to 50 mgCOD/l for IAWPRC (see Chapter 5 for details). However, whether this change is a true reflection of the behaviour of the organisms in a contact-stabilization system is not certain. In all other situations investigated, the default value for K_{S_H} was found to be adequate, so that an independent determination of this constant is not necessary.

³In investigations into sludge bulking at the University of Cape Town, it has been found that the value for $\hat{\mu}_H$ has no significance in bulking by low F/M filaments, but may be of importance for bulking due to other filamentous organisms (Gabb *et al.*, 1991).

- (4) Change in the value for the SBCOD hydrolysis rate half saturation constant (K_{SP} for UCTOLD and K_x for IAWPRC) has been found necessary in simulations of batch tests in which nitrification has been inhibited by addition of thiourea (see Chapter 5). The constant needed to be changed from 0,027 to 0,15 mgCOD/mgCOD for both models. However, in all other situations investigated, the default value of 0,027 mgCOD/mgCOD was found to be adequate, so that independent determination of this constant probably is not necessary.

From the above, variability in $\hat{\mu}_H$ and $\hat{\mu}_A$ indicate that these two constants should be determined before model application if a sensitivity analysis shows that the values for the constants have kinetic influence, i.e. if variation in $\hat{\mu}_H$ of 1 to 6/d and $\hat{\mu}_A$ of 0,2 to 0,8/d significantly influence the model predictions.

Measurement of $\hat{\mu}_H$ and $\hat{\mu}_A$

The constants $\hat{\mu}_H$ and $\hat{\mu}_A$ are quantified by means of aerobic batch tests. In this test a volume of wastewater is mixed with a volume of mixed liquor in an aerated and stirred batch reactor, and the OUR and nitrate responses monitored with time. Three important aspects must be noted in obtaining wastewater and mixed liquor for the batch test:

- (1) Because $\hat{\mu}_A$ is dependant on the wastewater, the wastewater added to the batch test must be the same as that fed to the system (to be simulated using the computer programs).
- (2) Because $\hat{\mu}_H$ and $\hat{\mu}_A$ are dependant on the system configuration and load pattern, the mixed liquor added to the batch test must be drawn from the system to be simulated, or from a pilot-scale/laboratory-scale replica of the system; it is not possible to use mixed liquor drawn from a different laboratory-scale system (such as those detailed in the previous section) because the values for $\hat{\mu}_H$ and $\hat{\mu}_A$ may differ from those in the system to be simulated. Also, using mixed liquor and wastewater from the same system will overcome acclimatization problems. (If a pilot-scale/laboratory-scale replica of the system is operated, it must be fed the same wastewater as the system.)
- (3) The ***mixed liquor must not be drawn from a biological excess phosphorus removal system*** – in the aerobic batch test, on addition of the wastewater, the organisms mediating biological excess phosphorus removal (polyP organisms) will take up some of the RBCOD and store it as PHB (Wentzel *et al.*, 1989), and in this manner interfere with the response of the heterotrophs.

Basis of Test

With the correct selection of the volumes of wastewater and mixed liquor (see later), on mixing in the aerated, stirred batch reactor, the OUR remains constant at a plateau for a period of up to 3 hours depending on the wastewater RBCOD fraction, whereafter the OUR drops precipitously, then levels off at a second plateau, see Fig 6.5. This OUR-time profile is made up of the OUR's for nitrification and for carbonaceous material utilization.

If the ammonia concentration is greater than about 2 times the half saturation constant for the nitrification (in the Monod formulation for the growth rate of the

nitrifying autotrophs, Chapter 2), the nitrification will take place at a maximum (and constant) rate. Consequently, if adequate ammonia is available at the start of the batch test, and since the half saturation constant for the autotrophs is relatively small ($K_{SA} = 1.0 \text{ mgN/l}$), the nitrification rate will remain at a maximum and constant value over the test period giving rise to a constant nitrification OUR (Fig 6.5, Area 3) and a linear increase in the nitrate concentration (Fig 6.6). Since the nitrification rate is at a maximum and approximately constant, $\hat{\mu}_A$ can be determined from the nitrate concentration profile. If inadequate ammonia-N is present, the observed OUR will exhibit a second drop to a third plateau level and the nitrate concentration profile will reflect this decrease in nitrification rate – in this case it is necessary to redo the test supplementing the wastewater with ammonia-N.

Superimposed on the constant nitrification OUR is the OUR due to carbonaceous material utilization [Fig 6.5, Area 1 + Area 2(a and b)] which gives rise to the variation in the observed OUR with time. The interpretation of the carbonaceous OUR-time profile differs in terms of the UCT and IAWPRC Task Group models:

UCT model: In the UCT model, RBCOD and SBCOD are utilized independently but simultaneously by the heterotrophs for growth; RBCOD is directly absorbed and utilized while SBCOD is adsorbed extra cellularly, hydrolysed to smaller units which then are utilized directly (Chapter 2). The summation of the OUR's associated with RBCOD and SBCOD growth gives rise to the observed carbonaceous OUR. At the start of the batch test both RBCOD and SBCOD are present, and are utilized independently for growth, with associated OUR's (Fig 6.5, Area 1 for RBCOD, Area 2a for SBCOD). The OUR is constant over the initial period because the RBCOD and SBCOD concentrations are sufficiently high to ensure that RBCOD utilization and SBCOD hydrolysis/utilization rates are close to their respective maxima. Once the influent RBCOD is depleted, the OUR drops to the second plateau which is due to the maximum hydrolysis/utilization of SBCOD only (Fig 6.5, Area 2b). The magnitude of the drop in OUR is proportional to the heterotroph maximum specific growth rate on RBCOD, $\hat{\mu}_H$, and can be used to obtain an estimate for this constant (Fig 6.5). Also, the area under the OUR-time plot associated with RBCOD (Fig 6.5, Area 1) can be used to calculate the wastewater RBCOD concentration.

IAWPRC Task Group model: In the IAWPRC Task Group model only RBCOD is utilized for growth, the SBCOD is hydrolysed to RBCOD (Chapter 2). Therefore, the carbonaceous OUR is due only to that OUR associated with RBCOD utilization. In the batch test the initial high OUR is a consequence of the utilization of RBCOD derived from the influent (Fig 6.5, Area 1) and from hydrolysis of SBCOD (Fig 6.5, Area 2a). The OUR is constant over this period because the concentration of RBCOD is so high that the growth rate of the heterotrophs is at a maximum ($\hat{\mu}_H$) in accordance with the Monod kinetics for growth on RBCOD (see Chapter 2). Because of the saturation condition it is possible to estimate $\hat{\mu}_H$ from the initial high OUR (Fig 6.5) and to estimate the influent RBCOD concentration from the area under the high OUR plateau (Fig 6.5, Area 1). Once the RBCOD in the influent is depleted, the OUR drops to the second plateau level, which is associated with the utilization of RBCOD generated from hydrolysis of SBCOD (Fig 6.5, Area 2b).

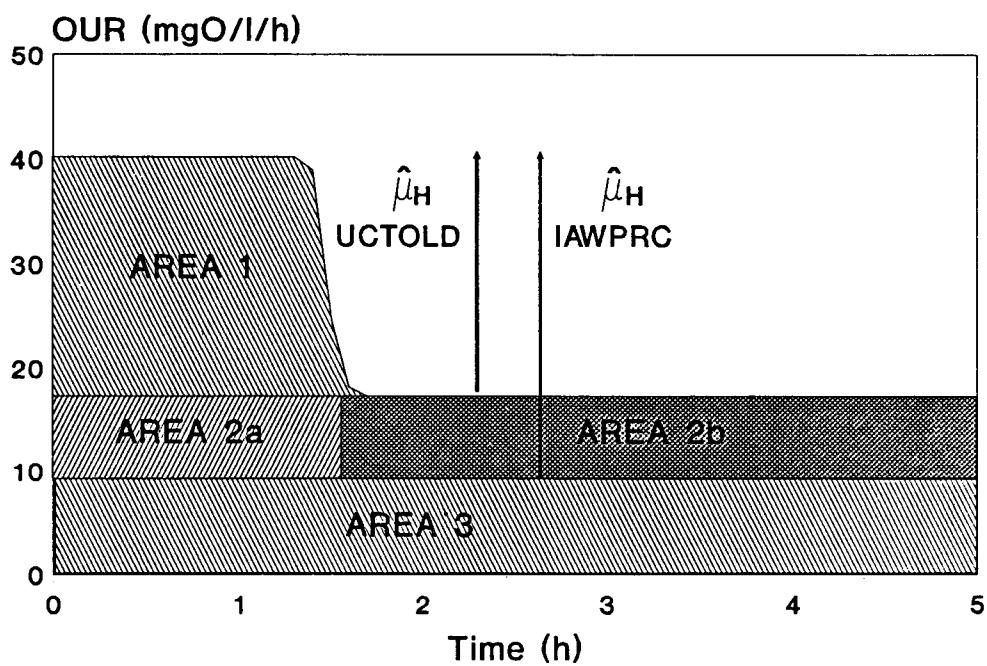


Fig 6.5: OUR-time profile for aerobic batch test with nitrification; see Fig 6.6 for nitrate-time profile.

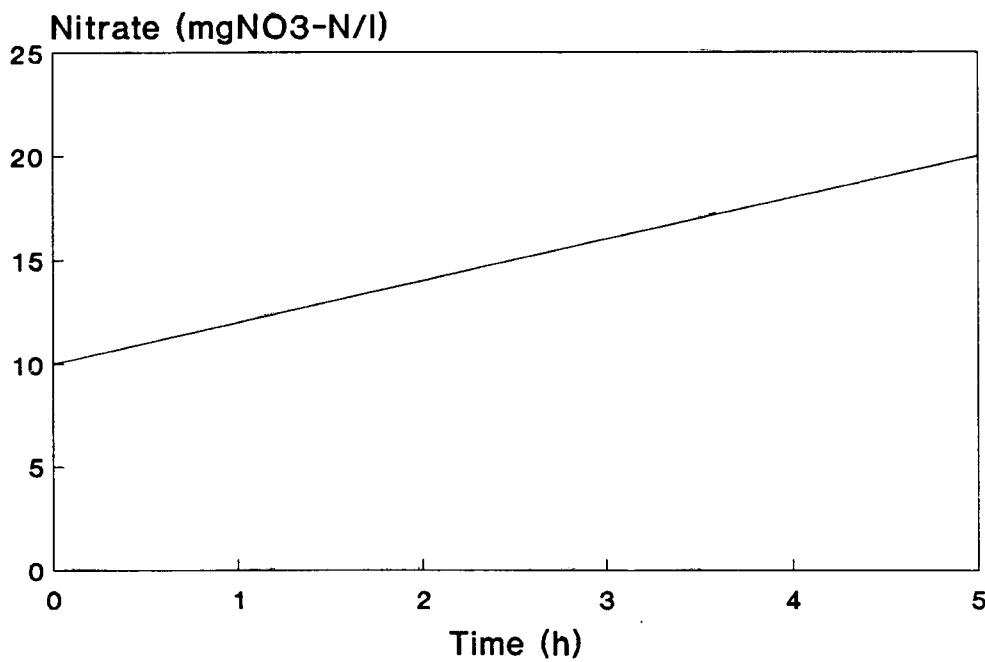


Fig 6.6: Nitrate-time profile for aerobic batch test with nitrification; see Fig 6.5 for OUR-time profile.

Aerobic batch test method

Taking note of the considerations above, a preselected volume of mixed liquor (V_{ml}) of known MLVSS concentration (X_v) is placed in an aerated, stirred batch reactor. A preselected volume of wastewater (V_{ww}) of known characteristics (for procedures to characterize the wastewater see earlier) is added. From immediately after mixing, the OUR is measured approximately every 5 to 10 minutes for at least about 4 to 5 hours using the technique described previously for RBCOD measurement. Also, periodically samples are extracted from the batch reactor, biological activity terminated immediately by adding a drop of $HgCl_2$ solution (8,6g $HgCl_2/l$), the samples filtered ($0,45\mu m$) and nitrate measurements made on the filtrate. The temperature and pH in the batch reactor must be monitored; pH must be maintained in the region 7,2 to 7,5 and temperature ($T^\circ C$) kept constant in the range 14 to 22° C. In selection of V_{ww} and V_{ml} the following warrants attention:

COD loading rate: The mass of COD (i.e. $V_{ww}S_{ti}$ where S_{ti} = total COD concentration of the undiluted wastewater) with respect to the mass of VSS (i.e. $V_{ml}X_v$) mixed in the batch test is known as the COD loading rate (LR). The LR established in the batch test should be such that the OUR response is well defined and allows (1) the initial peak OUR to be readily determined (to estimate $\hat{\mu}_H$ in the IAWPRC Task Group model), (2) the magnitude of the precipitous drop in OUR to be clear (to estimate $\hat{\mu}_H$ in the UCT model) and (3) the area under the initial peak OUR (Fig 6.5, Area 1) to be accurately estimated (to calculate RBCOD). For the *same wastewater volume* changing the LR does not change the **magnitude** of Area 1, which is a function only of the mass of RBCOD in the wastewater sample, but it does change the **shape** of Area 1: If LR is too low (i.e. a higher mixed liquor volume), the shape is tall and narrow because the RBCOD is utilized very quickly, and too few OUR measurements can be taken to give reasonable surety of the initial high OUR; if LR is too high (i.e. a lower mixed liquor volume), the shape is low and wide and it is difficult to establish the magnitude of the drop in OUR (see Fig 6.7).

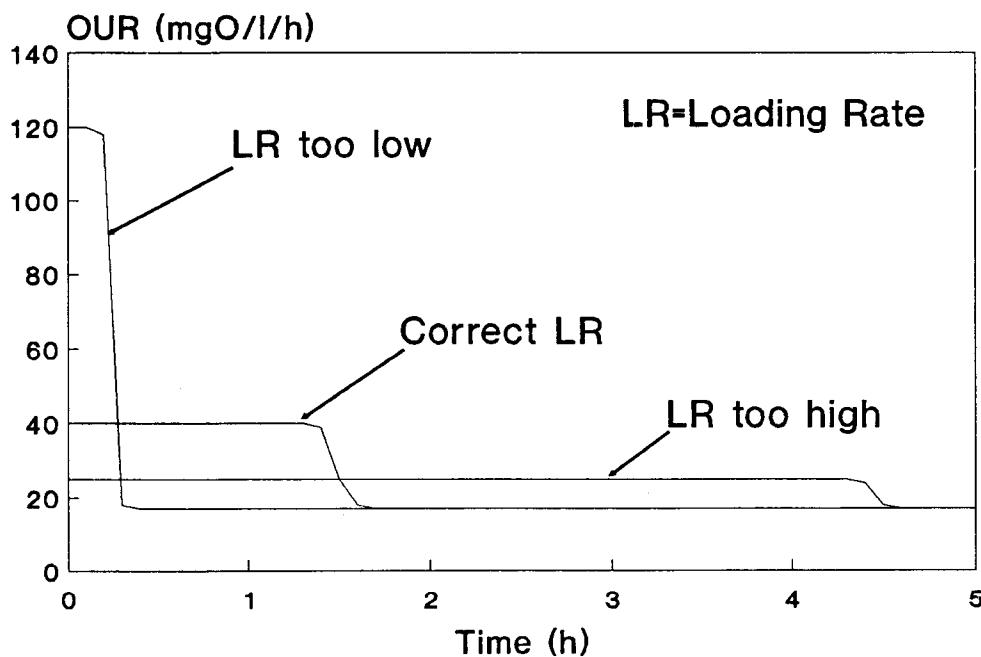


Fig 6.7: OUR-time profile for aerobic batch test to show the effect of loading rate on the shape of the OUR-time response.

Ideally the step change in OUR should take place 1 to 2 hours after the start of the test. This can be achieved by setting LR at 1,0 to 1,2 times the estimated heterotroph (active) biological mass fraction of the VSS, $f_{X,BH}$, i.e.

$$LR = (1,0 \text{ to } 1,2) \cdot f_{X,BH} \quad (\text{mgCOD/mgVSS}) \quad (6.25)$$

The value for $f_{X,BH}$ is a function of the sludge age (R_s) of the system from which the mixed liquor is obtained and can be *estimated roughly* as follows (Ekama *et al.*, 1986):

$$f_{X,BH} = 1,41 \cdot (R_s)^{-0,53} \text{ for raw wastewater} \quad (6.26a)$$

and

$$f_{X,BH} = 1,57 \cdot (R_s)^{-0,43} \text{ for settled wastewater} \quad (6.26b)$$

(Although the two equations above provide a rough estimate for $f_{X,BH}$, they are not sufficiently accurate to be used to estimate $\hat{\mu}_H$, as described later).

Selection of the appropriate LR is complicated by the fact that $\hat{\mu}_H$ varies for different system configurations and load patterns (Still *et al.*, 1986; Gabb *et al.*, 1989). Variation in $\hat{\mu}_H$ will result in different OUR-time response profiles for different mixed liquors even though the LR is kept constant. The equations above, therefore, provide only an initial estimate for the correct LR, the best value for this ratio can be determined only by trial and error.

Note that if the LR in a batch test is "excessively" high the kinetic response of the organisms deviates from the pattern described above. The maximum OUR during the period when RBCOD is present increases with time until the RBCOD is depleted giving a "saw tooth" appearance instead of a flat plateau.

Maximum OUR: The maximum OUR in the test should be at a value that can be measured conveniently and accurately, i.e. at values which allow the DO concentration to be raised quickly. From experience, a convenient OUR is about 30 to 40 mgO/l/h. The OUR is governed by the active mass concentration in the batch test, which in turn is related to the heterotroph biological mass fraction ($f_{X,BH}$) and the MLVSS concentration. The MLVSS concentration in the batch test ($X_v BT$), to give an OUR of 30 to 40 mgO/l/h, can be estimated from

$$X_v BT = (300 \text{ to } 400) / f_{X,BH} \quad (\text{mgVSS/l batch volume}) \quad (6.27)$$

where the value for $f_{X,BH}$ can be estimated from Eq (6.26).

It may not be possible to attain the MLVSS in the batch test in this range especially when the wastewater COD concentration is low; for these feed concentrations, lower MLVSS concentrations will be obtained in which event OUR's lower than 30 mgO/l/h will be measured.

Calculation procedure

For estimation of $\hat{\mu}_A$, $\hat{\mu}_H$ and RBCOD, the MLVSS fractions of the parent system mixed liquor need to be determined.

Parent system MLVSS fractions: From the steady state theory (WRC, 1984) the various MLVSS fractions can be calculated as follows:⁴

- Heterotroph biological (active) mass

$$MX_{BH} = \frac{MS_{ti} \cdot (1 - f_{S, us} - f_{S, up}) \cdot Y_{XH} \cdot R_s}{(1 + b_{HT}^* \cdot R_s)} \quad (6.28a)$$

where

$$MX_{BH} = \text{Heterotroph biological (active) mass in system (mgAVSS)} \\ = V \cdot X_{BH} \quad (6.28b)$$

V = System volume

X_{BH} = Heterotroph biological (active) mass concentration (mgAVSS/ℓ)

MS_{ti} = Mass of COD load per day (mgCOD/d)

= Q · S_{ti} (6.28c)

Q = Influent flow rate (ℓ/d)

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

f_{S, us} = Fraction of influent COD which is unbiodegradable soluble

f_{S, up} = Fraction of influent COD which is unbiodegradable particulate

Y_{XH} = Heterotroph specific yield in VSS units (0,45 mgAVSS/mgCOD)

R_s = Sludge age (d)

b_{HT}^{*} = specific heterotroph endogenous mass loss rate⁵ at temperature T°C

= 0,24 · (1,029)^(T-20) (/d) (6.28d)

- Endogenous mass

$$MX_E = f_E^* \cdot b_{HT}^* \cdot R_s \cdot MX_{BH} \quad (6.29a)$$

where

$$MX_E = \text{Endogenous mass in system (mgEVSS)} \\ = V \cdot X_E \quad (6.29b)$$

X_E = Endogenous mass concentration (mgEVSS/ℓ)

f_E^{*} = Fraction of biological (active) mass which is unbiodegradable particulate according to endogenous mass loss approach (0,2 mgEVSS/mgAVSS)

⁴To regularize the symbol system the symbols used in this manual are not exactly the same as those used in WRC (1984); the reader is referred to Appendix D for details on the symbol system. Also, in the models described in Chapter 2, MLVSS is expressed in terms of COD units. In this Chapter MLVSS is expressed directly as VSS as this parameter is more practical to measure. To differentiate between these units, the symbol Z is used for COD units and the symbol X for VSS units, where Z = f_{cv}X and f_{cv} = COD/VSS ratio of the MLVSS.

⁵The specific endogenous mass loss rate (b_E^{*}) used in this Chapter is not the same as the specific death rate (b_H) used in the models (see Chapter 2). However, under steady state conditions, applying the death-regeneration approach will give nett active mass loss identical to the endogenous mass loss approach. The endogenous mass loss approach is used here in preference to the death-regeneration approach because the calculation procedures are simpler.

- Inert mass

$$MX_I = f_{S, up} \cdot MS_{ti} \cdot R_s / f_{cv} \quad (6.30a)$$

where

$$\begin{aligned} MX_I &= \text{Inert mass in system} && (\text{mgIVSS}) \\ &= V \cdot X_I \\ X_I &= \text{Inert mass concentration} && (\text{mgIVSS}/\ell) \\ f_{cv} &= \text{COD/VSS ratio of MLVSS} && (1,48 \text{ mgCOD/mgVSS}) \end{aligned} \quad (6.30b)$$

- MLVSS

$$MX_v = MX_{BH} + MX_E + MX_I \quad (6.31a)$$

where

$$\begin{aligned} MX_v &= \text{mass of volatile suspended solids in system} && (\text{mgVSS}) \\ &= V \cdot X_v \\ X_v &= \text{Volatile suspended solids concentration} && (\text{mgVSS}/\ell) \end{aligned} \quad (6.31b)$$

- Ratio heterotroph biological (active) mass/MLVSS

$$f_{X, BH} = MX_{BH} / MX_v \quad (6.32)$$

- Autotroph biological (active) mass

$$MX_{BA} = \frac{MN_{o_3} \cdot Y_{XA} \cdot R_s}{(1 + b_{AT} \cdot R_s)} \quad (6.33a)$$

where

$$\begin{aligned} MX_{BA} &= \text{Autotroph biological (active) mass} && (\text{mgVSS}) \\ &= V \cdot X_{BA} \end{aligned} \quad (6.33b)$$

$$X_{BA} = \text{Autotroph biological (active) mass concentration} & (\text{mgVSS}/\ell)$$

$$MN_{o_3} = \text{Mass of nitrate generated per day} & (\text{mgN/d})$$

$$= MN_{ti} - MN_{te} - \Delta MN_x \quad (6.33c)$$

$$MN_{ti} = \text{Influent TKN mass load} & (\text{mgN/d}) \quad (6.33d)$$

$$= Q \cdot N_{ti}$$

$$N_{ti} = \text{Influent TKN concentration} & (\text{mgN}/\ell)$$

$$MN_{te} = \text{Effluent TKN mass} & (\text{mgN/d})$$

$$= Q \cdot N_{te} \quad (6.33e)$$

$$N_{te} = \text{Effluent TKN concentration} & (\text{mgN}/\ell)$$

$$\Delta MN_x = \text{Mass of N required for sludge production} & (\text{mgN/d})$$

$$= \frac{f_{X, N} \cdot MX_v}{R_s} \quad (6.33f)$$

$$f_{X, N} = \text{Fraction of volatile solids which is nitrogen} & (0,1 \text{ mgN/mgVSS})$$

$$Y_{XA} = \text{Autotroph specific yield} & (0,1 \text{ mgVSS/mgN})$$

$$b_A = \text{Autotroph specific endogenous mass loss rate at temperature } T^\circ C$$

$$= 0,04 \cdot (1,029)^{(T-20)} & (/d) \quad (6.33g)$$

- Ratio autotroph biological (active) mass/MLVSS

$$f_{X, BA} = MX_{BA} / MX_v \quad (6.34)$$

Calculation of $\hat{\mu}_A$: For both models

$$\frac{dN_{O_3}}{dt} = \frac{1}{Y_{XA}} \cdot \frac{dX_{BA}}{dt} = \frac{1}{Y_{XA}} \cdot \frac{\hat{\mu}_A \cdot N_a}{K_{SA} + N_a} \cdot X_{BA} \quad (6.35)$$

where

$$\frac{dN_{O_3}}{dt} = \text{Rate of change in nitrate concentration (mgN/l/d)}$$

$$\frac{dX_{BA}}{dt} = \text{Rate of change in autotroph concentration (mgVSS/l/d)}$$

$$N_a = \text{Ammonia-N concentration (mgN/l)}$$

$$K_{SA} = \text{Half saturation coefficient (mgN/l)}$$

In the batch test $N_a \gg K_{SA}$, $X_{BA} = X_{BA}BT$ and temperature = $T^\circ C$, therefore

$$\frac{dN_{O_3}}{dt} \approx \frac{1}{Y_{XA}} \hat{\mu}_{AT} \cdot X_{BA}BT \quad (6.36)$$

and

$$\hat{\mu}_{AT} \approx \frac{dN_{O_3}}{dt} \cdot \frac{Y_{XA}}{f_{X, BA} \cdot X_v BT} \quad (6.37a)$$

where

$$\hat{\mu}_{AT} = \text{Maximum specific growth rate of autotrophs at } T^\circ C \text{ (/d)}$$

$$X_v BT = \text{MLVSS concentration in the batch test (mgVSS/l)}$$

$$= X_v \cdot V_{ml} / (V_{ml} + V_{ww}) \quad (6.37b)$$

$$X_v = \text{MLVSS concentration of mixed liquor added to the batch test (mgVSS/l)}$$

Since in the batch test the nitrification rate virtually is constant, dN_{O_3}/dt can be approximated by $\Delta N_{O_3}/\Delta t$ which is the slope of the nitrate concentration time profile.

As input to the computer programs the value of $\hat{\mu}_A$ at $20^\circ C$ is required. This is calculated from the value measured at $T^\circ C$ ($\hat{\mu}_{AT}$) as follows:

$$\hat{\mu}_{A20} = \hat{\mu}_{AT} \cdot \frac{1}{1,123(T-20)} \quad (6.37c)$$

Calculation of $\hat{\mu}_H$: For both models

$$\frac{dX_{BH}}{dt} = Y_{XH} \cdot \frac{dS_{bs}}{dt} = \frac{Y_{XH}}{(1 - f_{cv} \cdot Y_{XH})} \cdot OUR_R \cdot 24 \quad (6.38)$$

and

$$\frac{dX_{BH}}{dt} = \frac{\hat{\mu}_H \cdot S_{bs}}{K_{SH} + S_{bs}} \cdot X_{BH} \quad (6.39)$$

where

$\frac{dX_{BH}}{dt}$ = Rate of synthesis of heterotroph biological (active) mass from RBCOD
(mgVSS/ ℓ/d)

$\frac{dS_{bs}}{dt}$ = Rate of change of RBCOD concentration (mgCOD/ ℓ/d)

OUR_R = Oxygen utilization rate for RBCOD utilization (mgO/ ℓ/h)
 K_{SH} = Half saturation coefficient (mgCOD/ ℓ)

Hence,

$$\frac{\hat{\mu}_H \cdot S_{bs}}{K_{SH} + S_{bs}} \cdot X_{BH} = \frac{Y_{XH}}{(1 - f_{cv} \cdot Y_{XH})} \cdot OUR_R \cdot 24$$

However, in the batch test during the initial peak OUR , $S_{bs} \gg K_{SH}$, $X_{BH} = X_{BH}BT$ and temperature = $T^\circ C$, therefore

$$\hat{\mu}_{HT} = \frac{Y_{XH} \cdot OUR_R \cdot 24}{(1 - f_{cv} \cdot Y_{XH}) \cdot X_{BH}BT} = \frac{Y_{XH} \cdot OUR_R \cdot 24}{(1 - f_{cv} \cdot Y_{XH}) \cdot f_{X,BH} \cdot X_v BT} \quad (6.40)$$

where

$\hat{\mu}_{HT}$ = Maximum specific growth rate of heterotrophs at $T^\circ C$ (/d)

In Eq (6.40), the OUR_R term is the OUR associated with utilization of RBCOD. In terms of the UCT model, this is obtained from the magnitude of the drop in the measured OUR when the RBCOD is depleted (see earlier and Fig 6.5). In terms of the IAWPRC Task Group model, this is obtained from the initial OUR minus the OUR for nitrification, (see Fig 6.5), i.e. for the IAWPRC model

$$OUR_R = Peak\ OUR - OUR_n \quad (mgO/\ell/h) \quad (6.41a)$$

where

OUR_n = OUR for nitrification

$$= 4.57 \frac{dN_{o_3}}{dt} \quad (mgO/\ell/h) \quad (6.41b)$$

As noted earlier, dN_{O_3}/dt can be approximated by $\Delta N_{O_3}/\Delta t$ which is the slope of the nitrate concentration time profile.

As input to the computer programs the value of $\hat{\mu}_H$ at 20°C is required. This is calculated from the value measured at T°C ($\hat{\mu}_{HT}$) as follows:

$$\hat{\mu}_{H20} = \hat{\mu}_{HT} \cdot \frac{1}{1,20(T-20)} \quad (6.42)$$

Calculation of RBCOD: The RBCOD concentration in the wastewater added to the batch test (S_{bsi}) can be estimated from the area under the peak OUR (Fig 6.5, Area 1).

$$S_{bsi} = \{ 1/(1-f_{cv} \cdot Y_{XH}) \} \cdot MO \cdot (V_{m1} + V_{ww}) / V_{ww} \quad (\text{mgCOD}/\ell) \quad (6.43a)$$

where

$$\begin{aligned} MO &= \text{Mass of oxygen utilized in RBCOD consumption (i.e. Fig 6.5, Area 1)} \\ &= \Delta \text{OUR} \cdot t \quad (\text{mgO}/\ell) \end{aligned} \quad (6.43b)$$

$$\begin{aligned} \Delta \text{OUR} &= \text{Magnitude of drop in OUR from 1st to 2nd plateau } (\text{mgO}/\ell/\text{h}) \\ t &= \text{Time 1st plateau lasts } (\text{h}) \end{aligned}$$

Also,

$$f_{ts} = S_{bsi} / S_{ti} \quad (6.44)$$

where

$$\begin{aligned} f_{ts} &= \text{Fraction of substrate total COD which is RBCOD} \\ S_{ti} &= \text{Total COD concentration of wastewater added to the batch test} \\ &= (\text{mgCOD}/\ell) \end{aligned}$$

and

$$f_{bs} = S_{bsi} / S_{ti} (1 - f_{S, us} - f_{S, up}) \quad (6.45)$$

where

$$f_{bs} = \text{fraction of biodegradable COD that is RBCOD.}$$

Example calculation

Mixed liquor for the batch test was obtained from an intermittently fed fill-and-draw system operated at 20°C and with sludge age of 20 days. The volume of the reactor was 10ℓ and every day the system received 7500 mgCOD of Mitchell's Plain, South Africa, raw wastewater, which gave an influent TKN of 650 mgN/d. For the batch test, 10ℓ of mixed liquor with MLVSS = 2725 mgVSS/ℓ were drawn from the system and settled to 3.75ℓ with MLVSS = $2725 \cdot 10 / 3.75 = 7267$ mgVSS/ℓ. The mixed liquor was mixed with 6.25ℓ of Mitchell's Plain raw wastewater of 1159 mgCOD/ℓ and an aerobic batch test conducted at 20°C. The OUR, nitrate and TKN concentration time profiles are shown overleaf in Fig 6.8(a,b and c).

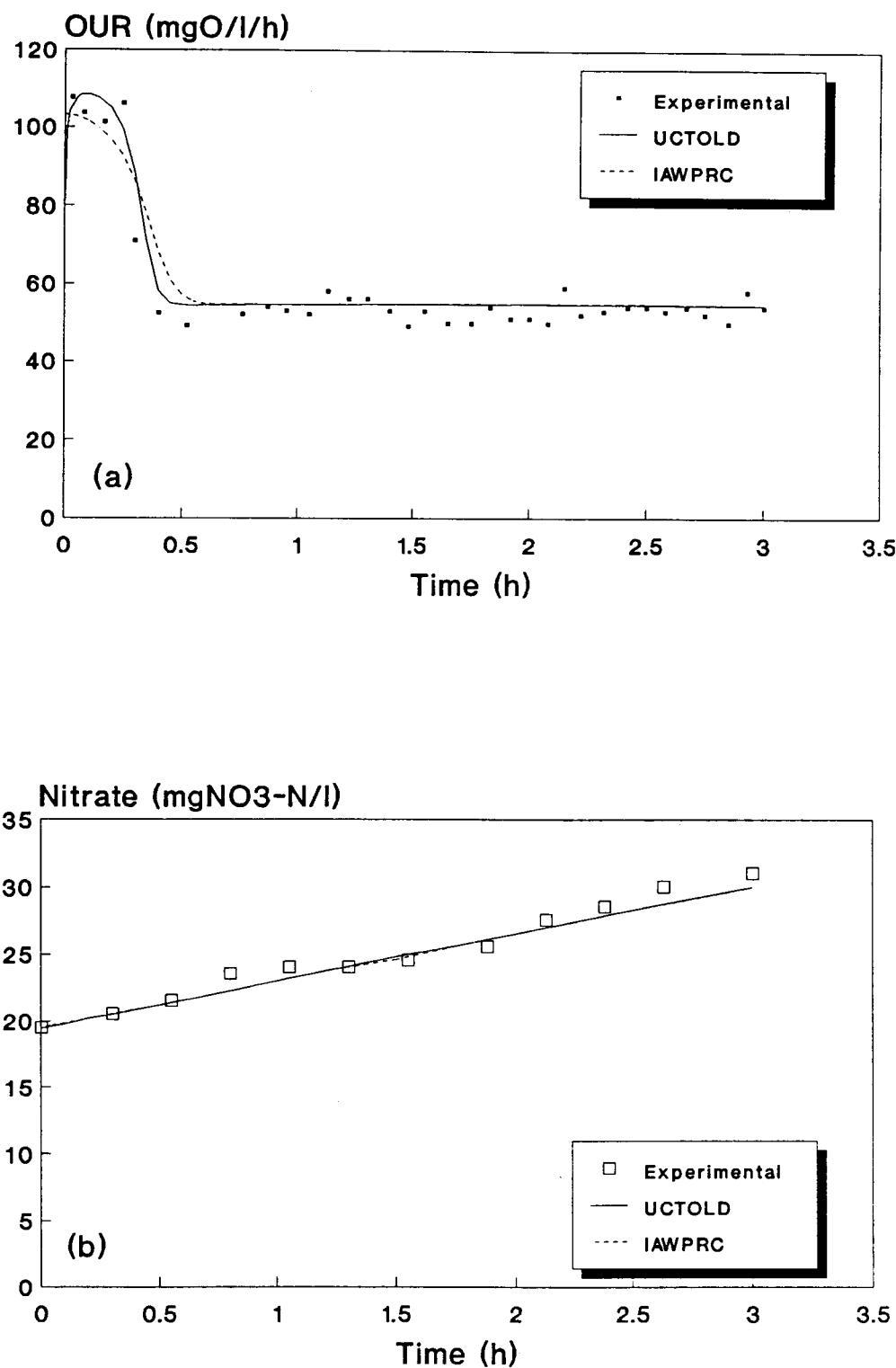


Fig 6.8: Predicted and experimental (a) OUR, (b) nitrate, and (c) TKN time profiles in an aerobic batch test; predictions using batch versions of the UCTOLD and IAWPRC programs. Continued overleaf.....

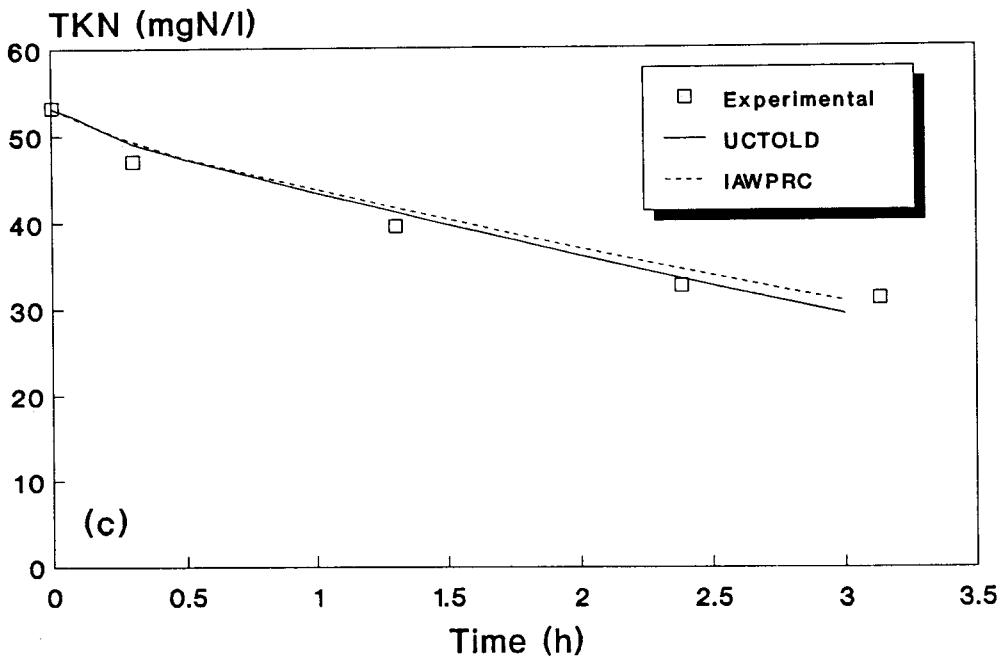


Fig 6.8: Predicted and experimental (a) OUR, (b) nitrate, and (c) TKN time profiles in an aerobic batch test; predictions using batch versions of the UCTOLD and IAWPRC programs.

For this batch test,

$$\begin{aligned}
 V_{ml} &= 3,75\ell \\
 V_{ww} &= 6,25\ell \\
 X_v^{BT} &= 7267 \cdot 3,75 / (3,75 + 6,25) = 2725 \text{ mgVSS}/\ell \\
 S_{ti} &= 1159 \text{ mgCOD}/\ell
 \end{aligned}$$

The wastewater had been characterized previously using the procedures set out earlier, to give $f_{S, us} = 0,08$ and $f_{S, up} = 0,08$.

Parent system MLVSS fractions:

- From Eq (6.28)

$$\begin{aligned}
 MX_{BH} &= \frac{7500 (1 - 0,08 - 0,08) \cdot 0,45 \cdot 20}{(1 + 0,24 \cdot 20)} \\
 &= 9776 \text{ mgAVSS} \\
 X_{BH} &= 9776 / 10 = 978 \text{ mgAVSS}/\ell
 \end{aligned}$$

- From Eq (6.29)

$$\begin{aligned} MX_E &= 0,2 \cdot 0,24 \cdot 20 \cdot 9776 \\ &= 9385 \text{ mg EVSS} \end{aligned}$$

$$X_E = 9385/10 = 939 \text{ mgEVSS}/\ell$$

- From Eq (6.30)

$$\begin{aligned} MX_I &= 0,08 \cdot 7500 \cdot 20 / 1,48 \\ &= 8108 \text{ mgIVSS} \end{aligned}$$

$$X_I = 8108/10 = 811 \text{ mgIVSS}/\ell$$

- From Eq (6.31)

$$\begin{aligned} MX_v &= 9776 + 9385 + 8108 \\ &= 27269 \text{ mgVSS} \end{aligned}$$

$$X_v = 27269/10 = 2727 \text{ mgVSS}/\ell \text{ (measured to be } 2725 \text{ mgVSS}/\ell)$$

- From Eq (6.32)

$$f_{X, BH} = 9776/27269 = 0,359$$

- From Eq (6.33c) and from the measured effluent TKN mass (MN_{te}) of 30 mgN/d

$$\begin{aligned} MN_{o3} &= 650 - 30 - 0,1 \cdot \frac{27269}{20} \\ &= 484 \text{ mgN/d} \end{aligned}$$

- From Eq (6.33a)

$$\begin{aligned} MX_{BA} &= \frac{484 \cdot 0,1 \cdot 20}{1+0,04 \cdot 20} \\ &= 538 \text{ mgVSS} \end{aligned}$$

$$X_{BA} = 538/10 = 53,8 \text{ mgVSS}/\ell$$

- From Eq (6.34)

$$f_{X, BA} = 538/27269 = 0,02$$

Calculation of $\hat{\mu}_A$:

- From Fig 6.8b, the slope of the nitrate concentration time profile $\Delta N_{o3}/\Delta t$ is $(32-20,5)/3,13 = 3,674 \text{ mgN}/\ell/\text{h} = 88,2 \text{ mgN}/\ell/\text{d}$. From Eq (6.37 a and b)

$$\hat{\mu}_{AT} = 88,2 \cdot \frac{0,1}{0,02 \cdot 2725} = 0,16/\text{d}$$

- From Eq (6.37c), adjusting $\hat{\mu}_{AT}$ to 20°C,

$$\begin{aligned}\hat{\mu}_{A20} &= 0,16 \cdot \frac{1}{1,123(20-20)} \\ &= 0,16 /d\end{aligned}$$

Calculation of $\hat{\mu}_H$:

- In terms of the UCT model, from Fig 6.8a $OUR_R = 116 - 52 = 64 \text{ mgO}/\ell/\text{h}$. In terms of the IAWPRC Task Group model, from Fig 5.8a and Eq (6.41)

$$\begin{aligned}OUR_R &= 116 - 4,57 \cdot 3,67 \\ &= 99 \text{ mgO}/\ell/\text{h}\end{aligned}$$

- From Eq (6.40), for the UCT model

$$\begin{aligned}\hat{\mu}_{HT} &= \frac{0,45 \cdot 64 \cdot 24}{(1-1,48 \cdot 0,45) \cdot 0,359 \cdot 2725} \\ &= 2,12/d\end{aligned}$$

- From Eq (6.42), adjusting $\hat{\mu}_{HT}$ to 20°C, for the UCT model,

$$\begin{aligned}\hat{\mu}_{H20} &= 2,12 \cdot \frac{1}{1,20(20-20)} \\ &= 2,12 /d\end{aligned}$$

- From Eq (6.40), for the IAWPRC Task Group model,

$$\begin{aligned}\hat{\mu}_{HT} &= \frac{0,45 \cdot 99 \cdot 24}{(1-1,48 \cdot 0,45) \cdot 0,359 \cdot 2725} \\ &= 3,27/d\end{aligned}$$

- From Eq (6.42), adjusting $\hat{\mu}_{HT}$ to 20°C, for the IAWPRC Task Group model,

$$\begin{aligned}\hat{\mu}_{H20} &= 3,27 \cdot \frac{1}{1,20(20-20)} \\ &= 3,27 /d\end{aligned}$$

Calculation of RBCOD:

- From Eq (6.43b)

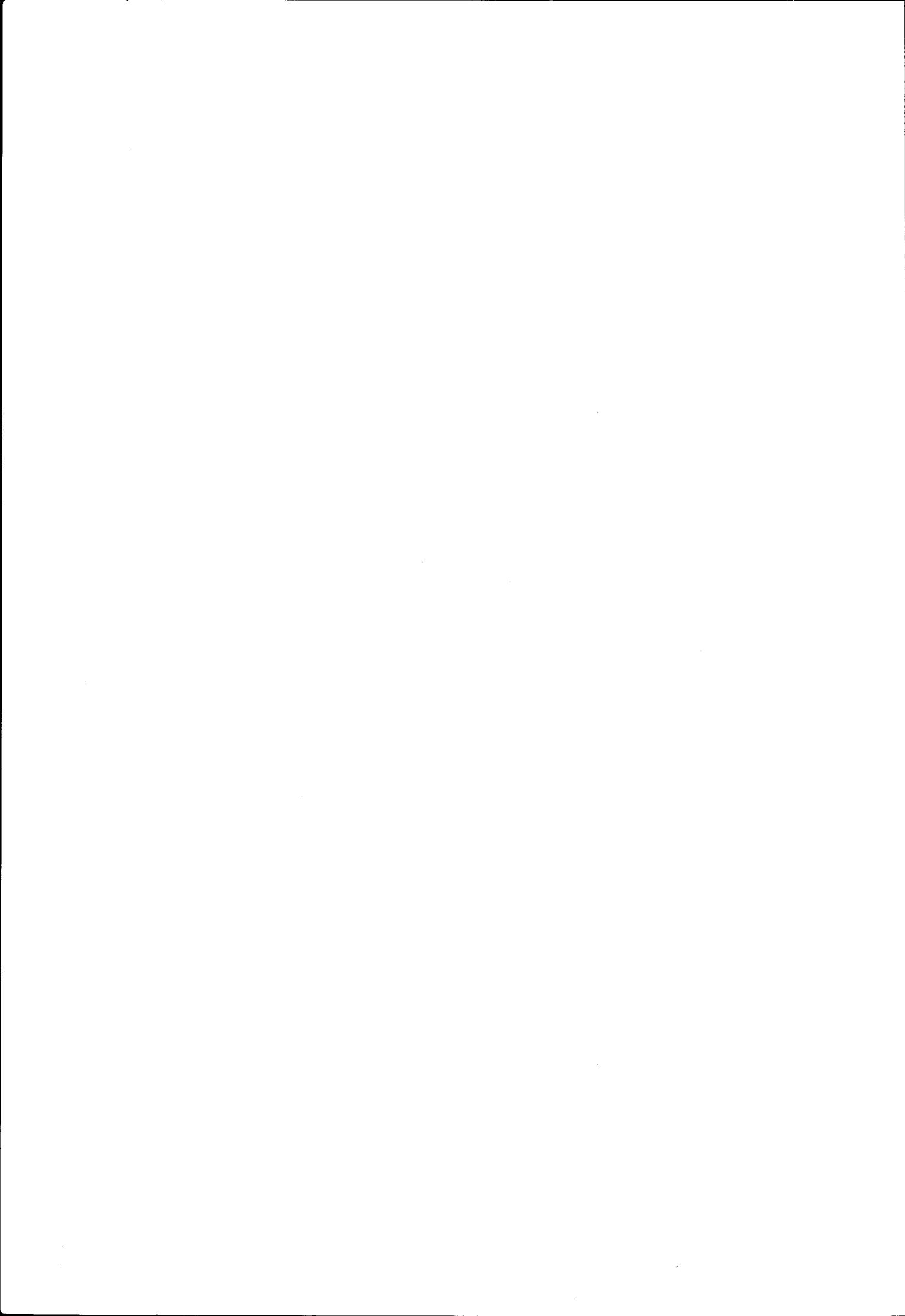
$$MO = 64 \cdot 0,25 = 16 \text{ mgO/l}$$

- From Eq (6.43a)

$$\begin{aligned} S_{bsi} &= \frac{1}{(1-1,48 \cdot 0,45)} \cdot 16 \cdot (3,75+6,25)/6,25 \\ &= 76,7 \text{ mgCOD/l} \end{aligned}$$

- From Eq (6.45)

$$\begin{aligned} f_{bs} &= 76,7/1159(1 - 0,08 - 0,08) \\ &= 0,08 \end{aligned}$$



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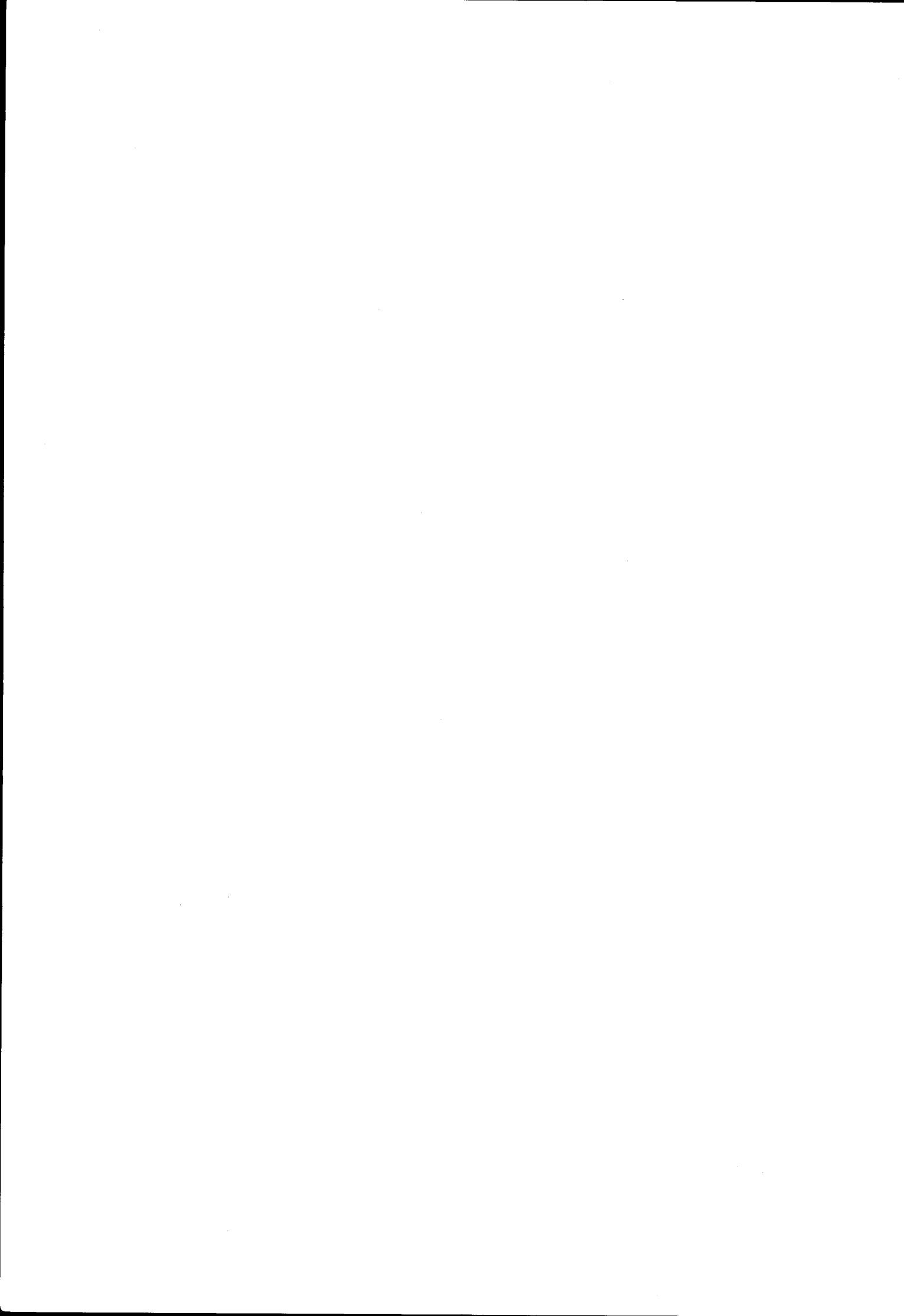
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APPENDIX A

RETRIEVAL OF DIURNAL RESPONSE DATA

INTRODUCTION

One of the options in the diurnal sub-menu, **STORE DATA ON DISK**, allows the user to record the diurnal simulation results in a data file on disk. The purpose of this option is to enable off-line processing of the diurnal simulation results. For example, the user may wish to use a spreadsheet package such as *Lotus 1-2-3* or Borland's *Quattro* to plot results in a specific format. This Appendix explains the format of the data file and lists the parameters stored for the two programs **UCTOLD** and **IAWPRC**.

The program **RETRIEVE** on the "Distribution disk" may be used to set up the data for off-line processing. Instructions on the use of the program also are provided in this Appendix.

The data are stored by the simulation programs in a Turbo Pascal *file of reals* with the extension **.DID**; the file name is specified by the user. The file consists of sets of values of the diurnal response parameters (concentrations), in each reactor, at each *Data interval* over the twenty four hour cycle. The number of sets of data depends on the *Data interval* used in the simulation (either 10, 15 or 30 minutes). For example, if the *Data interval* is set at 30 minutes in the simulation then $24 \cdot 60 / 30 + 1 = 49$ sets of values evenly spaced in time (every 30 minutes) from 0 to 24 hours will be stored. The default value for *Data Interval* is 15 minutes.

The number of diurnal response parameters (concentrations) differs for the two simulation programs; eighteen for **UCTOLD** and seventeen for **IAWPRC**. The parameters are listed separately below. For each program the size of the data file can be calculated as a check by the user, knowing the number of reactors (*r*), the *Data interval* (*d*), and that 6 bytes are used to store each real value. For example, if **UCTOLD** is used to simulate a two reactor system and the *Data interval* is set at 30 minutes, the size of the file will be

$$r \cdot 18 \cdot (24 \cdot 60/d + 1) \cdot 6 = 2 \cdot 18 \cdot 49 \cdot 6 = 10584 \text{ bytes}$$

This should correspond exactly to the file size obtained when the files on the disk are listed with the *dir* command in DOS.

PARAMETERS FOR UCTOLD

Concentrations of the following parameters are stored by the program **UCTOLD**

1. Z_{BH}	- active heterotrophic biomass	(g COD m^{-3})
2. Z_{BA}	- active autotrophic biomass	(g COD m^{-3})
3. Z_E	- endogenous mass	(g COD m^{-3})
4. Z_I	- inert mass	(g COD m^{-3})
5. S_{ads}	- adsorbed slowly biodegradable substrate	(g COD m^{-3})
6. S_{enm}	- enmeshed slowly biodegradable substrate	(g COD m^{-3})

7.	N_{obp}	- nitrogen organic biodegradable particulate	(g N m ⁻³)
8.	S_{bs}	- soluble readily biodegradable substrate	(g COD m ⁻³)
9.	N_a	- ammonia nitrogen	(g N m ⁻³)
10.	N_{obs}	- nitrogen organic biodegradable soluble	(g N m ⁻³)
11.	N_{o3}	- nitrate nitrogen	(g N m ⁻³)
12.	Alk	- $H_2CO_3^*$ alkalinity	(moles m ⁻³)
13.	S_{us}	- soluble unbiodegradable substrate	(g COD m ⁻³)
14.	O_c	- carbonaceous oxygen utilization rate	(g O ₂ m ⁻³ h ⁻¹)
15.	O_n	- nitrification oxygen utilization rate	(g O ₂ m ⁻³ h ⁻¹)
16.	O_t	- total oxygen utilization rate	(g O ₂ m ⁻³ h ⁻¹)
17.	X_v	- volatile settleable solids (VSS)	(g VSS m ⁻³)
18.	N_t	- total Kjeldahl nitrogen (TKN)	(g N m ⁻³)

PARAMETERS FOR IAWPRC

Concentrations of the following parameters are stored by the program IAWPRC:

1.	Z_{BH}	- active heterotrophic biomass	(g COD m ⁻³)
2.	Z_{BA}	- active autotrophic biomass	(g COD m ⁻³)
3.	Z_E	- endogenous mass	(g COD m ⁻³)
4.	Z_I	- inert mass	(g COD m ⁻³)
5.	S_{enm}	- enmeshed slowly biodegradable substrate	(g COD m ⁻³)
6.	N_{obp}	- nitrogen organic biodegradable particulate	(g N m ⁻³)
7.	S_{bs}	- soluble readily biodegradable substrate	(g COD m ⁻³)
8.	N_a	- ammonia nitrogen	(g N m ⁻³)
9.	N_{obs}	- nitrogen organic biodegradable soluble	(g N m ⁻³)
10.	N_{o3}	- nitrate nitrogen	(g N m ⁻³)
11.	Alk	- $H_2CO_3^*$ alkalinity	(moles m ⁻³)
12.	S_{us}	- soluble unbiodegradable substrate	(g COD m ⁻³)
13.	O_c	- carbonaceous oxygen utilization rate	(g O ₂ m ⁻³ h ⁻¹)
14.	O_n	- nitrification oxygen utilization rate	(g O ₂ m ⁻³ h ⁻¹)
15.	O_t	- total oxygen utilization rate	(g O ₂ m ⁻³ h ⁻¹)
16.	X_v	- volatile settleable solids (VSS)	(g VSS m ⁻³)
17.	N_t	- total Kjeldahl nitrogen (TKN)	(g N m ⁻³)

STRUCTURE OF THE DATA FILE

The Turbo Pascal code which writes the diurnal response results to the disk file is as follows:

```

for k := 1 to LastReactor do
  for j := 0 to DataPerDay do
    for i := 1 to NoDiVars do
      write (DATfile, Response [k]^ [i,j]) ;
  
```

where

$DATfile$ = Turbo Pascal file of reals
 $LastReactor$ = number of reactors in system
 $DataPerDay$ = index of last point at which data are stored in 24 hour cycle
 $= 24 \cdot 60 / Data\ interval$ ($Data\ interval = 10, 15$ or 30 minutes)
 $NoDiVars$ = number of diurnal response parameters
 $Response$ = three-dimensional array of concentration values

The data structure *Response* is an array of pointers to two dimensional matrices that store the concentration values for each reactor. The range of the two dimensional arrays is [1..*NoDiVars*,0..*DataPerDay*]. For example, if a *Data interval* of 30 minutes has been used in the simulation (and hence *DataPerDay* is 48) the matrix for a particular reactor may be visualized as follows:

$$\left[\begin{array}{ccccccc} (Z_{BH})_0 & (Z_{BA})_0 & \cdot & \cdot & \cdot & \cdot & (X_v)_0 & (N_t)_0 \\ (Z_{BH})_1 & (Z_{BA})_1 & \cdot & \cdot & \cdot & \cdot & (X_v)_1 & (N_t)_1 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ (Z_{BH})_{47} & (Z_{BA})_{47} & \cdot & \cdot & \cdot & \cdot & (X_v)_{47} & (N_t)_{47} \\ (Z_{BH})_{48} & (Z_{BA})_{48} & \cdot & \cdot & \cdot & \cdot & (X_v)_{48} & (N_t)_{48} \end{array} \right]$$

The complete data file will consist of a set of such matrices, one for each reactor sequentially from the first to *LastReactor*. Each entry is a real number.

PROGRAM RETRIEVE FOR RETRIEVING DATA

The program **RETRIEVE** can be used to convert a data file with the extension **.DID** into a text file with the extension **.PRN** which is suitable for importing into a spread sheet package such as *Lotus 1-2-3*. The **.PRN** file is assigned the same name as the **.DID** file.

The program is executed by typing **RETRIEVE** at the DOS prompt. The program operates on files in the current directory of the logged drive. The user is then prompted to enter the name of the **.DID** file, the *Data interval* used in the simulation (10, 15 or 30 minutes), and the program used to create the data (**UCTOLD** or **IAWPRC**). The program then converts the selected data file with extension **.DID** into a text file with extension **.PRN**.

The **.PRN** file is made up of a set of blocks of concentration values for each reactor. The blocks are stacked vertically and are separated by a blank line. Each block consists of (*DataPerDay* + 1) lines. Each line consists of an integer denoting the reactor number, the corresponding time in the 24-hour cycle, followed by either 17 (**IAWPRC**) or 18 (**UCTOLD**) concentration values. The first line of the file provides headings for each column of values.

The **.PRN** file is loaded into the spreadsheets *Lotus 1-2-3* and Borland's *Quattro* by selecting following sequences of commands:

Lotus 1-2-3:

File
Import
Numbers

Quattro:

File
Import
Comma & " " Delimited File

In the case of *Lotus 1-2-3* the message **Part of file is missing** will appear at the lower left of the screen. However, the spreadsheet will appear intact when the **<Enter>** is pressed.

A.4

An example of how a part of a spreadsheet appears on the screen is shown below:

1	A REACTOR	B TIME	C Var 1	D Var 2	E Var 3	F Var 4	G Var 5	H Var 6
3	1	0	1067.343	29.873	265.214	566.893	46.858	3.574
4	1	0.25	1067.597	29.919	265.817	566.893	42.102	3.574
5	1	0.5	1067.379	29.962	266.417	566.893	38.068	3.584
6	1	0.75	1066.728	30.004	267.014	566.893	34.694	3.603
7	1	1	1065.693	30.045	267.609	566.893	31.903	3.636
8	1	1.25	1064.33	30.084	268.201	566.893	29.737	3.557
9	1	1.5	1062.682	30.122	268.792	566.893	27.988	3.497
10	1	1.75	1060.8	30.158	269.381	566.893	26.557	3.484
11	1	2	1058.729	30.193	269.967	566.893	25.402	3.492
12	1	2.25	1056.51	30.227	270.552	566.893	24.479	3.506
13	1	2.5	1054.174	30.259	271.136	566.893	23.738	3.525
14	1	2.75	1051.749	30.289	271.717	566.893	23.139	3.551
15	1	3	1049.254	30.318	272.297	566.893	22.648	3.585
16	1	3.25	1046.706	30.345	272.875	566.893	22.334	3.536
17	1	3.5	1044.114	30.37	273.452	566.893	22.089	3.49
18	1	3.75	1041.498	30.393	274.027	566.893	21.86	3.481
19	1	4	1038.861	30.415	274.6	566.893	21.65	3.495
20	1	4.25	1036.209	30.436	275.172	566.893	21.468	3.512

A1: ' REACTOR
14-Mar-91 02:00 PM

READY

Using the spreadsheet package, the simulated data can be processed and plotted in a variety of ways. Also, any experimental data can be entered into the spreadsheet and plotted on the same graphs as the simulated data and more than one set of simulated data can be loaded into the spreadsheet and plotted on the same graph for comparison.

LISTING OF PROGRAM RETRIEVE

A listing of the program RETRIEVE, written in Turbo Pascal Version 4.0, can be found on the floppy disks labelled "UCTOLD Listed Version" and "IAWPRC Listed Version":

APPENDIX B

MODEL REPRESENTATION IN MATRIX FORMAT

INTRODUCTION

The two activated sludge system models included in the simulation package were presented in Chapter 2. In presenting the models, each was set out in matrix format. This Appendix provides a background and explanation of the use of the matrix format in the context of biological reactions (biological processes). A simple example is used to illustrate the technique.

MATHEMATICAL DESCRIPTION OF A MODEL

A comprehensive mathematical model for the simulation of biological system behaviour must account for a large number of reactions between a large number of components (*compounds*). In this manual, the reactions are referred to as *processes*, where processes act on certain *compounds* in the *system*, and convert these to other compounds. The set of distinct biological processes and the manner in which these act on the group of compounds constitute the biological or *process model*. The model should quantify, for each process, both the kinetics (rate-concentration dependence) and the stoichiometry (effect on the masses of compounds involved).

MATRIX METHOD FOR MODEL REPRESENTATION

An important part of biological modelling is that representation of the process model is clear and flexible. One convenient method of presentation is the matrix format.

The matrix method for model presentation described here is based on an approach used widely in chemical engineering kinetic modelling. In the context of biological systems, the method has been recommended by the IAWPRC Task Group on Mathematical Modelling in Wastewater Treatment. The matrix representation ensures clarity in presenting the processes in the model, their kinetics and their stoichiometric interactions with the compounds. In addition, it allows easy comparison of different models, and facilitates transforming the model into a computer program.

Setting up the matrix (process model)

Table B.1 presents, in matrix format, the essential components of a simple Monod-Herbert process model for aerobic microbial growth on a soluble substrate, accompanied by endogenous mass loss.

Table B.1: Monod-Herbert process model in matrix format.

COMPOUND i → ↓ j PROCESS	1 Z_{BH}	2 S_{bs}	3 0	PROCESS RATE, ρ_j
1 GROWTH	1	$-1/Y_{ZH}$	$-(1-Y_{ZH})/Y_{ZH}$	$\hat{\mu}_H \frac{S_{bs}}{K_{SH} + S_{bs}} Z_{BH}$
2 DECAY	-1			$b_H Z_{BH}$
OBSERVED CONVERSION RATES, $M L^{-3} T^{-1}$	$r_i = \sum \gamma_{ij} \rho_j$			
	HETROTROPH BIOMASS $M (COD) L^{-3}$	SOLUBLE SUBSTRATE $M (COD) L^{-3}$	OXYGEN $M (-COD) L^{-3}$	

The matrix is represented by a number of columns and rows; one column for each compound and one row for each process. The first step in setting up the matrix is to identify the compounds of relevance in the model. The Monod-Herbert model quantifies the growth of the heterotrophic biomass compound (Z_{BH} , COD units) at the expense of the soluble substrate compound (S_{bs}). By keeping track of Z_{BH} and S_{bs} , it is possible to calculate the oxygen requirement, in this fashion oxygen (O) can be included as a third compound (noting that oxygen has units of negative COD). The compounds are presented as symbols across the top of the table, and are defined (with dimensions) at the bottom of the corresponding matrix columns. The index i is assigned to the range of compounds. In this case, i ranges from 1 to 3 for the three compounds considered in this simple model.

The second step in developing the matrix is to identify the biological processes occurring in the system. These are conversions or transformations which affect the compounds considered in the model. Only two processes take place in this simple model – aerobic growth of organisms at the expense of soluble substrate, and endogenous mass loss. These are itemized one below the other at the left of the matrix. The index j is assigned to the range of processes. In this case, j can assume only a value of 1 or 2.

The process rates are formulated mathematically and are recorded down the right-hand side of the matrix in the appropriate row. These are given the symbol ρ_j with j denoting the index of the biological process.

Along each process row the stoichiometric coefficient for conversion from one compound to another is inserted so that each compound column lists the stoichiometric coefficients for the processes that influence that compound. The stoichiometric coefficients are given the symbol ν_{ij} where i denotes the index of the

compound and j the index of the process. In our example for process 1, (aerobic growth of heterotrophs) the compound heterotrophic biomass (Z_{BH}) increases (+1), the compound soluble substrate (S_{bs}) decreases ($-1/Y_{ZH}$) and the compound oxygen (O) decreases $[-(1-Y_{ZH})/Y_{ZH}]$.

The sign convention used in the matrix for each compound *per se* is "negative for consumption" and "positive for production". Cognizance must be taken of the units used in the rate equations for the processes. For example, the rate equation for the process aerobic growth of heterotroph biomass, ρ_1 , is written as a biomass growth rate (not as a substrate utilization rate) and has units of (mg cell COD growth)/(mg substrate COD utilized) $^{-1}d^{-1}$. The stoichiometric values are thus normalized with respect to the heterotroph biomass concentration (Z_{BH}), i.e. the stoichiometric coefficients for Z_{BH} and S_{bs} are 1 and $-1/Y_{ZH}$ respectively, not Y_{ZH} and -1 .

The stoichiometric coefficients, ν_{ij} , are greatly simplified by working in consistent units; in the example above, the compounds are expressed as COD equivalents. Provided consistent units are used, continuity may be checked from the stoichiometric parameters by moving across any row of the matrix. With consistent units, the sum of the stoichiometric coefficients must be zero (noting that oxygen is equivalent to negative COD). (In the matrices for UCTOLD and IAWPRC models, Chapter 2, the compound alkalinity is included. This compound does not constitute a part of the mass balance for the selected process and therefore must not be included in the continuity check.)

System model

The process model of the compounds, processes and rates presented in Table B.1 defines the behaviour at a single point in a system. To obtain the response of any system, the mass transport terms (e.g. mass flows and compounds into, and out of, each reactor) must be integrated with the process model, to give the *system model*. This is accomplished by setting up mass balance equations. An important benefit of the matrix representation is that it allows rapid and easy recognition of the fate of each compound, which aids in the preparation of the system mass balance equations.

The fundamental equation for a mass balance within any defined system boundary is:

$$\left\{ \begin{array}{l} \text{Rate} \\ \text{of} \\ \text{accumulation} \end{array} \right\} = \left\{ \begin{array}{l} \text{Rate} \\ \text{of} \\ \text{Input} \end{array} \right\} - \left\{ \begin{array}{l} \text{Rate} \\ \text{of} \\ \text{Output} \end{array} \right\} + \left\{ \begin{array}{l} \text{Rate of} \\ \text{Production} \\ \text{by Reaction} \end{array} \right\} \quad (\text{B.1})$$

The *input* and *output* terms are *transport terms* and depend upon the physical characteristics of the system being modelled. The *production by reaction* term (usually denoted by r_i for compound i) often is made up of a number of processes. In the matrix format, this information is obtained by summing the products of the stoichiometric coefficients, ν_{ij} , and the process rate expression, ρ_j , for the compound i being considered in the mass balance, i.e. moving down the matrix column for the specific compound i and accumulating the product of ν_{ij} and ρ_j :

$$r_i = \sum_j \nu_{ij} \rho_j \quad (\text{B.2})$$

For example, from Table B.1, the rate of reaction for the compound $i = 1$, heterotrophic biomass (Z_{BH}) at a point in the system would be:

$$r_1 = \frac{\hat{\mu}_H S_{bs}}{(K_{SH} + S_{bs})} Z_{BH} - b_H Z_{BH} \quad (B.3)$$

Similarly for the compound $i = 2$, soluble substrate (S_{bs}):

$$r_2 = -\frac{1}{Y_{ZH}} \frac{\hat{\mu}_H S_{bs}}{(K_{SH} + S_{bs})} Z_{BH} \quad (B.4)$$

and for compound $i = 3$, dissolved oxygen (O):

$$r_3 = -\frac{(1-Y_{ZH})}{Y_{ZH}} \frac{\hat{\mu}_H S_{bs}}{(K_{SH} + S_{bs})} Z_{BH} - b_H Z_{BH} \quad (B.5)$$

To create the mass balance for any compound within a given system boundary (e.g. a completely mixed reactor), the conversion rate, r_i , would be multiplied by the reactor volume and added to the appropriate advective terms, i.e. input and output masses (where each mass is given by concentration times flow in or out of the system) for the particular system; this mass balance is not shown here as the system is not defined.

The rate of production by reaction, r_i , may be of interest on its own. For example, Eq (B.5) defines the "rate of production" of O ; therefore $-r_3$ defines the oxygen utilization rate at a point within the system. This parameter often is of interest in aerobic systems.

Switching functions

At this point, it is worth introducing an aspect of the kinetic expressions which often is useful and which is incorporated in the models presented in Chapter 2, namely *switching functions*. Consider the aerobic growth of biomass; in Table B.1 the Monod growth rate equation has been used:

$$\rho_1 = \frac{\hat{\mu}_H S_{bs}}{(K_{SH} + S_{bs})} Z_{BH} \quad (B.6)$$

In an environment where the dissolved oxygen concentration (O) is zero (or perhaps close to zero), the rate of this aerobic process also should be zero. Mathematically, this can be achieved by multiplying the Monod rate expression by a "switching" factor which is zero when O is zero, and unity when the environment is "fully" aerobic. Experience has shown that a switching function formulation that is very flexible and useful is one that takes the same form as the Monod formulation. For example, the switching function for oxygen is:

$$\frac{O}{(K_0 + O)} \quad (B.7)$$

where K_0 = switching constant of small magnitude (say 0.1 mgO l^{-1})

The selection of a small value for K_0 means that the value of the switching function decreases from near-unity to zero at very low O values, i.e. when the DO value decreases below about 0.2 mgO l^{-1} . However, the function is mathematically continuous, which helps to eliminate problems of numerical instability in simulating system behaviour; such problems can arise if the rate is switched "on" and "off" discontinuously.

On incorporating the switching function the process rate equation then becomes:

$$\rho_1 = \frac{\hat{\mu}_H S_{bs}}{(K_{SH} + S_{bs})} \frac{O}{(K_0 + O)} Z_{BH} \quad (\text{B.8})$$

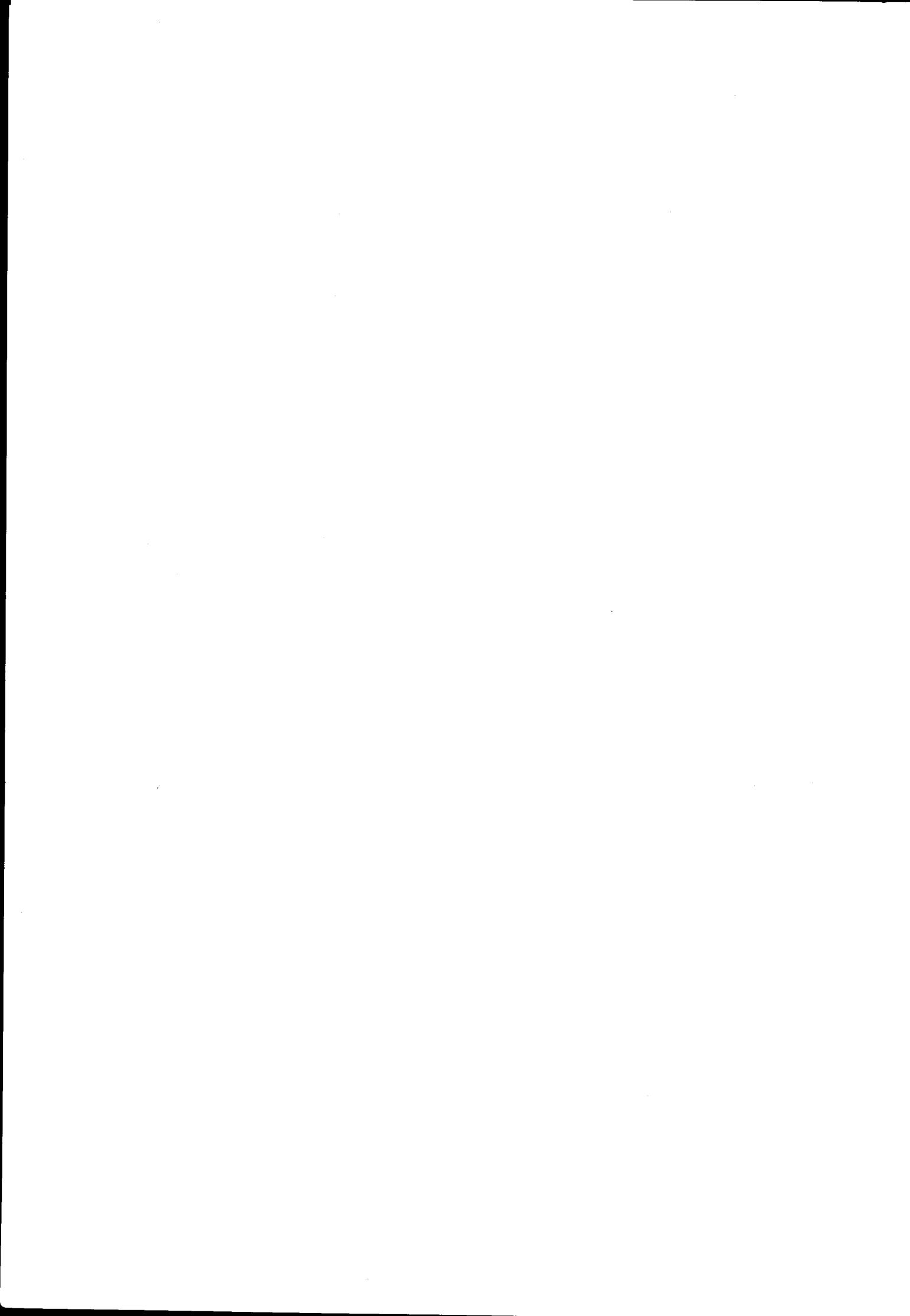
With the switching function operating on the Monod growth rate equation, when O is zero the value of the switching function is zero, and the process rate, ρ_1 , will be zero. However, if O is say 1 mgO l^{-1} then the value of the switching function is close to unity (i.e. "fully" aerobic) and the process rate will be given by the Monod growth rate equation. In this way, the process of aerobic growth is switched "on" or "off" automatically by the model depending on the dissolved oxygen concentration.

In certain situations, the switching "off" of one process may be linked to the switching "on" of another. If, for example, the oxygen input to a nitrifying activated sludge system were terminated periodically, there would be a switch from aerobic to anoxic growth. The latter process is governed by kinetic and stoichiometric expressions which differ from those for the aerobic growth process. To account for this phenomenon in a single model, the rate equations for aerobic and anoxic growth can be multiplied by the appropriate switching functions as follows:

$$\rho_{\text{aerobic}} = \rho_{\text{aerobic}} \frac{O}{(K_0 + O)} \quad (\text{B.9})$$

$$\begin{aligned} \rho_{\text{anoxic}} &= \rho_{\text{anoxic}} \left\{ 1 - \frac{O}{(K_0 + O)} \right\} \\ &= \rho_{\text{anoxic}} \frac{K_0}{(K_0 + O)} \end{aligned} \quad (\text{B.10})$$

In this instance, it is apparent that the selection of K_0 will influence the point at which there is a switch from aerobic to anoxic growth, and *vice versa*. That is, K_0 now influences the model predictions and is not only serving a mathematical objective. Therefore, whenever switching functions are used, care should be taken in the selection of the magnitude of the switching constant (K_0 here) to ensure that the model predictions are not incorrectly biased.



APPENDIX C

REACTOR NUMBERING CONVENTION

The structure of the computer programs requires that the reactors in the system configuration are numbered using a defined procedure. This procedure should be followed when entering the **PLANT CONFIGURATION** data.

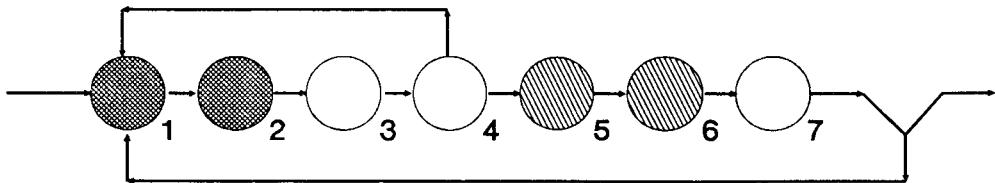
The reactor numbering procedure is as follows:

- *Draw the number of reactors in the system in a linear sequence following the stream of flow from reactor to reactor.*
- *The secondary clarifier is positioned at the downstream end of the reactor sequence.*
- *Number the reactors in descending order backwards, assigning the reactor immediately upstream of the clarifier with the highest number in the sequence. The reactor furthest upstream of the clarifier will then be assigned as number 1. The program assumes that inter-reactor flow passes sequentially from reactor to reactor (starting at No. 1) towards the clarifier without bypassing any reactor in the sequence.*
- *The mixed liquor recycles can have any reactor as point of origin but must discharge into a reactor upstream of the point of origin; that is, the reactor number of the point of origin must be greater than the reactor number of the point of discharge.*
- *The influent flow can discharge into any reactor in the series, or be split between a number of reactors.*
- *The program allows simulation of systems with reactors in the underflow (RAS) recycle provided these reactors are at the start of the reactor sequence. The program cannot simulate systems with reactors between the point of origin and discharge of the mixed liquor recycles, i.e. no reactors are allowed in the mixed liquor recycles.*

Some examples illustrating the reactor numbering convention are set out below.

1. 4-STAGE BARDENPHO SYSTEM

This nitrification/denitrification (ND) system has 4 zones. Assuming that the system has been designed to comprise 2 reactors for each zone with the exception of the final reaeration zone, there is a total of 7 reactors in the series. Set up the 7 reactors in a linear sequence and number the reactors backwards from reactor 7 immediately upstream of the clarifier.



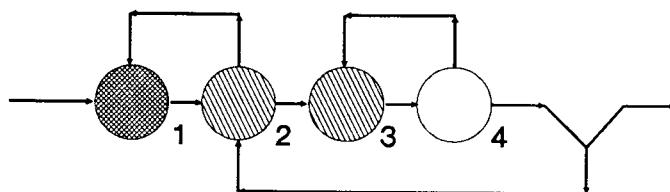
The sequence of reactors comprising the 4 zones is:

- | | |
|-----------------------|--------------------|
| primary anoxic zone | - reactors 1 and 2 |
| main aeration zone | - reactors 3 and 4 |
| secondary anoxic zone | - reactors 5 and 6 |
| re-aeration zone | - reactor 7. |

In the 4-stage Bardenpho system the influent and clarifier underflow (RAS recycle) discharge to the start of the primary anoxic zone, i.e. reactor 1. The mixed liquor recycle has its point of origin at the end of the main aeration zone (reactor 4) and its point of discharge at the start of the primary anoxic zone (reactor 1).

2. MODIFIED UCT SYSTEM

This nitrification/denitrification/biological excess phosphorus removal (NDBEPR) system has 3 zones, anaerobic, primary anoxic, aerobic but the primary anoxic zone is divided in two. Therefore, for modelling purposes the system is comprised of 4 zones. Assuming there is one reactor for each zone, number these backwards from the clarifier as follows:



The sequence of reactors comprising the 4 zones is:

- | | |
|-------------------------|-------------|
| anaerobic zone | - reactor 1 |
| 1st primary anoxic zone | - reactor 2 |
| 2nd primary anoxic zone | - reactor 3 |
| aeration zone | - reactor 4 |

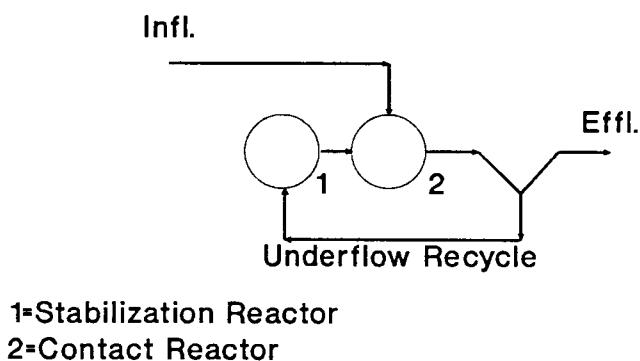
In the modified UCT system the underflow is discharged to the 1st primary anoxic zone (reactor 2) and the influent flow to the anaerobic zone (reactor 1). There are two mixed liquor recycles; one from the aerobic zone (reactor 4) to the 2nd primary anoxic zone (reactor 3) [a-recycle], and one from the 1st primary anoxic zone (reactor 2) to the anaerobic zone (reactor 1) [b- or r-recycle].

Note: With NDBEPR systems, the UCTOLD and IAWPRC programs give only approximate estimates of the nitrification, denitrification and oxygen demand, and, do not give any estimates of phosphorus removal, see "Scope of Models".

3. CONTACT STABILIZATION SYSTEM

In the first two examples the reactor numbering sequence is straightforward and does not differ from the way these systems usually are presented schematically. With the contact stabilization system the program reactor numbering sequence results in a configuration which may appear different from the usual schematic representation of the system.

The contact stabilization system has 2 zones, a contact reactor and a stabilization reactor. Assuming there is one reactor for each zone, number these backwards from the clarifier as follows:



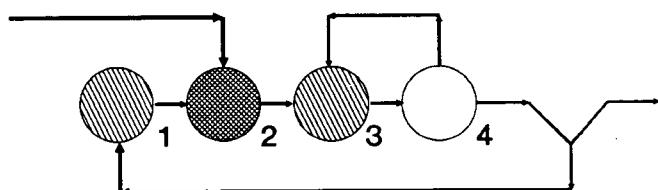
In the contact stabilization system there are no mixed liquor recycle flows – only an influent and an underflow stream (RAS recycle). The influent is discharged to the contact reactor which is directly upstream of the clarifier (reactor 2). The underflow discharges to the stabilization reactor (reactor 1). Hence the sequence of reactors comprising the 2 zones is:

stabilization reactor	- reactor 1
contact reactor	- reactor 2

From the example of the contact stabilization system, it is apparent that by discharging the influent into a reactor with a sequence number greater than 1, modelling of systems with reactors "in" the underflow from the clarifier is possible. This approach is used for the Johannesburg system.

4. JOHANNESBURG (JHB) SYSTEM

This system is a nitrification/denitrification/biological excess phosphorus removal one with anaerobic, primary anoxic and aerobic zones and includes an additional anoxic zone in the underflow recycle. Assuming there is one reactor for each zone, number the 4 reactors in a linear sequence backwards from the clarifier as follows:



The sequence of reactors comprising the 4 zones is:

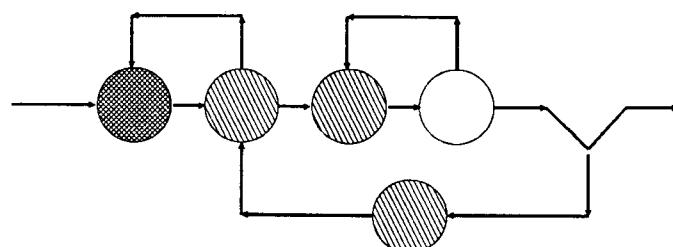
underflow anoxic zone	- reactor 1
anaerobic zone	- reactor 2
primary anoxic zone	- reactor 3
aeration zone	- reactor 4

In the Johannesburg system the underflow is discharged to the anoxic zone in the underflow stream (reactor 1). The discharge from this zone passes to the next reactor in the sequence (reactor 2); this is the anaerobic zone. The influent flow also discharges into the anaerobic zone (reactor 2). There is one mixed liquor recycle (a-recycle) in the system, from the aerobic zone (reactor 4) to the primary anoxic zone (reactor 3).

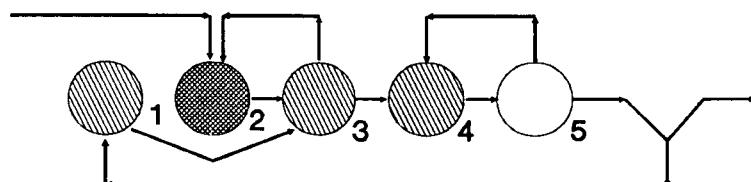
Note: The restrictions set out in the section on the modified UCT system above apply also to the Johannesburg system.

5. INADMISSIBLE CONFIGURATIONS

In general, if the outflow of a reactor/s in the underflow (usually reactor 1 or perhaps 1 and 2 in the sequence) discharges to a reactor with the next number in the sequence then the system can be simulated by the programs. This is demonstrated in the contact stabilization and Johannesburg system examples. However, if the outflow of the reactor/s in the underflow does not discharge to the reactor with the next sequence number, but to a reactor with a greater number, *the system cannot be simulated*. An example of such a case would be a 5-zone JHB/UCT combination system shown below:



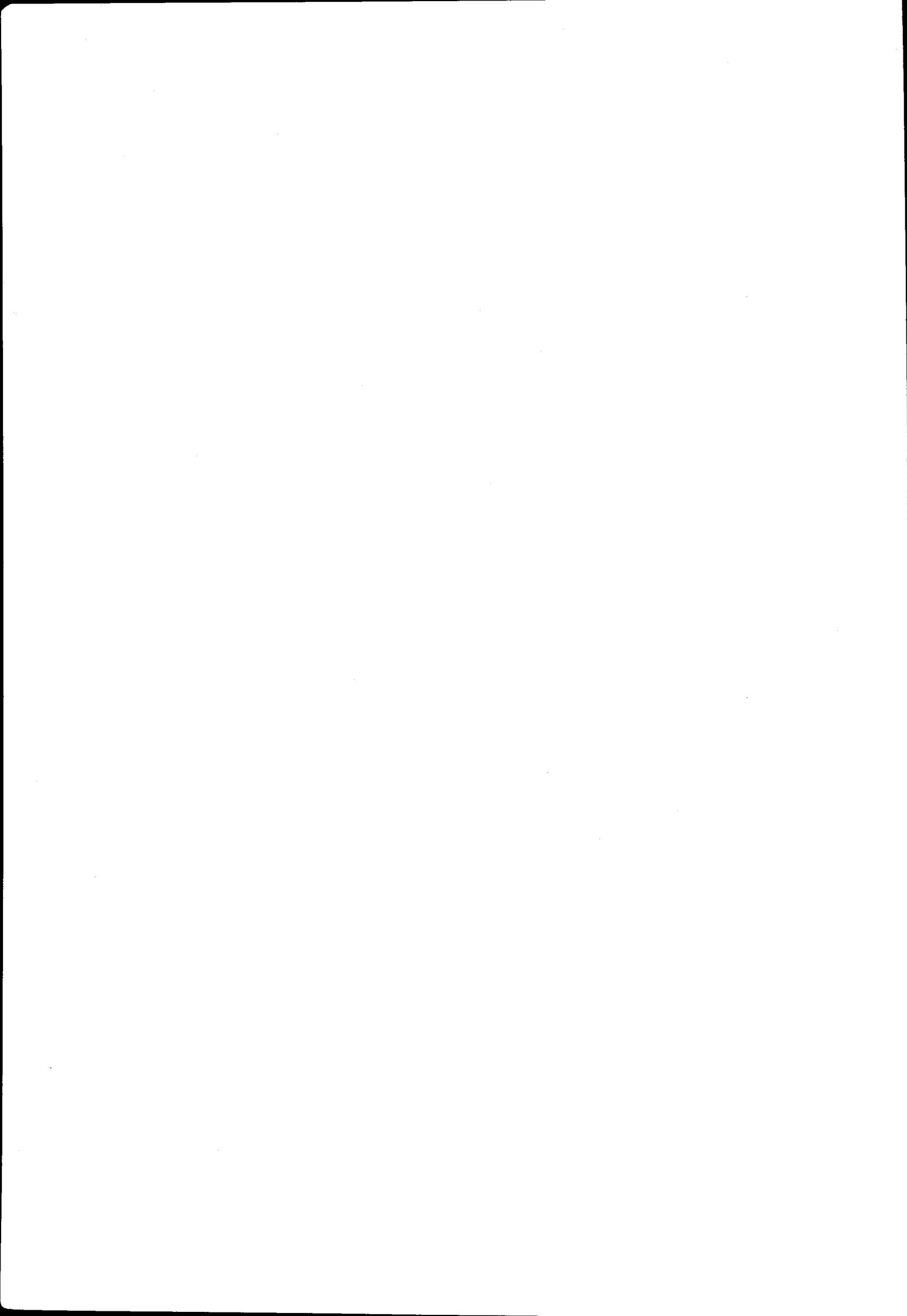
Assuming one reactor per zone, drawing the 5 reactors in a linear sequence and numbering backwards from the clarifier yields:



The reactor immediately upstream of the clarifier is the aerobic zone (reactor 5). Continuing upstream from the aerobic zone, the next three reactors will be the 2nd and 1st primary anoxic reactors and the anaerobic reactor respectively, i.e. reactors 4, 3 and 2 respectively. Reactor 1 therefore must be the anoxic reactor in the underflow. However, discharge from this underflow anoxic reactor (reactor 1) must pass to the 1st primary anoxic zone (reactor 3); this would involve bypassing reactor 2 in the sequence. This is not possible with the structure of the programs – the outflow from reactor 1 can only be discharged to reactor 2. Consequently, the JHB/UCT type system, or any system where the outflow of a reactor does not pass directly to the next reactor in the sequence, cannot be simulated by the programs.

CAUTION

Simulations of the nitrification/denitrification/biological excess phosphorus removal (NDBEPR) system configurations (modified UCT and Johannesburg used as examples above) will be approximate only. These systems are configured to give biological excess phosphorus removal (BEPR) in addition to nitrification/denitrification (ND). However, the UCT and IA WPRC models do not incorporate the processes and compounds for BEPR. Also, the simulated nitrification, denitrification and oxygen demands are approximations only, although usually not greatly different from the observed behaviour.



APPENDIX D

SYMBOL SYSTEM

At the University of Cape Town (UCT) the first activated sludge model (a steady state model) was developed in 1969. Thereafter a series of models were developed, sequentially incorporating nitrification, denitrification, bisubstrate concept and death-regeneration (see Chapter 2). With each extension, the symbols previously defined had to be critically re-examined for consistency and for easy recognition.

With recent developments in the models, some new symbols had to be identified and, for consistency, some of the previous symbols had to be modified. Also, the symbol system had to be regularized to make provision for easy incorporation of future developments in the models, e.g. incorporation of biological excess phosphorus removal. The total list of revised symbols, and what they represent, is given in Table D.1.

Also given in Table D.1 are the equivalent symbols recommended by the IAWPRC task group. The reader will note that the symbols proposed by the UCT group are not the same as those recommended by the IAWPRC task group - the basis for naming the symbols differs sharply between the two symbol systems:

In the UCT symbol system, subdivision of the compounds is on the basis of substrate (S), volatile mass (X-VSS units or Z-COD units), nitrogen (N), phosphorus (P) and oxygen (O). In the IAWPRC symbol system, subdivision of the compounds is on the basis of particulate (X) or soluble (S).

Irrespective of the merits of the two symbol systems, the UCT symbol system has been used because we believe it more readily allows recognition of the meaning of the symbols, and the symbols can be readily related to those used in publications by the UCT group over the past 20 years.

Table D.1: General UCT symbol system, updated to include biological excess phosphorus removal, with IAWPRC symbol equivalent.

UCT SYMBOL SYSTEM		IAWPRC
Symbol	Description	Equivalent
MAIN SYMBOLS		
S	Substrate	X or S
X	Volatile solids in VSS units	X
Z	Volatile solids in COD units	X
N	Nitrogen	X or S
P	Phosphorus	X or S
O	Oxygen	S_0
f	Fractional contents	f
M	Mass	-
SUBSCRIPTS		
B	Biological (active) mass	B
E	Endogenous mass	E
I	Inert mass	I
H	Heterotrophs	H
A	Autotrophs (nitrifiers)	A
G	PolyP organisms	-
b	Biodegradable	-
u	Unbiodegradable	-
p	Particulate	-
s	Soluble	-
o	Organic (nitrogen)	-
a	Ammonia	-
i	Influent	-
e	Effluent	-
t	Total	-
FRACTIONAL CONSTANTS		
$f_{X,YZ}$	Fraction of X which is YZ	i
$f_{XY,Z}$	Fraction of XY which is Z	

Table D.1: (Continued)

UCT SYMBOL SYSTEM		IAWPRC
Symbol	Description	Equivalent
COMPOUNDS		
S	Substrate	
S_u	Unbiodegradable	-
S_{up}	Unbiodegradable, particulate	X_I
S_{us}	Unbiodegradable, soluble	S_I
S_b	Biodegradable	-
S_{bs}	Biodegradable, readily (soluble)	S_S
$S_{bs, a}$	Biodegradable, readily (soluble), acetate	-
$S_{bs, c}$	Biodegradable, readily (soluble), complex	-
S_{bp}	Biodegradable, slowly (particulate)	X_S
S_{ads}	Adsorbed	-
S_{enm}	Enmeshed	X_S
S_{phb}	Stored PHB	-
Z	Volatile solids (COD units)*	
Z_B	Biological (active) mass	-
Z_{BH}	Biological (active) mass, Heterotrophs	$X_{B, H}$
Z_{BA}	Biological (active) mass, Autotrophs	$X_{B, A}$
Z_{BG}	Biological (active) mass, PolyP organisms	-
Z_E	Endogenous mass	X_E
Z_I	Inert mass	X_I
Z_V	Total volatile solids (COD units)	X_V
	$= Z_B + Z_E + Z_I + (S_{ads} + S_{enm})$	
	$= X_V \cdot f_{cv}$	

* Following the IAWPRC task group proposals volatile solids are expressed in COD units. The symbol X is substituted for Z if VSS units are used.

Table D.1: (Continued)

UCT SYMBOL SYSTEM		IAWPRC
Symbol	Description	Equivalent
N		
N	Nitrogen	
N_o	Organic	—
N_{ou}	Organic, unbiodegradable	—
N_{oup}	Organic, unbiodegradable, particulate	X_{NI}
N_{ous}	Organic, unbiodegradable, soluble	—
N_{ob}	Organic, biodegradable	—
N_{obp}	Organic, biodegradable, particulate	—
N_{obs}	Organic, biodegradable, soluble	S_{ND}
N_a	Ammonia	S_{NH}
N_{o3}	Nitrate	S_{NO}
N_z	Nitrogen in volatile solids	—
N_{ZB}	Nitrogen in volatile solids, biological (active) mass	—
N_{ZE}	Nitrogen in volatile solids, endogenous mass	—
N_{ZI}	Nitrogen in volatile solids, inert mass	—
P		
Phosphorus		
P_p	Particulate	X_P
P_s	Soluble	S_P
P_z	Phosphorus in volatile solids	—
P_{zb}	Phosphorus in volatile solids, biological (active) mass	—
P_{ze}	Phosphorus in volatile solids, endogenous mass	—
P_{zi}	Phosphorus in volatile solids, inert mass	—
P_{polyP}	Stored polyphosphate	—

Table D.1: (Continued)

UCT SYMBOL SYSTEM		IAWPRC
Symbol	Description	Equivalent
f	FRACTIONAL CONTENTS	
Substrate		
$f_{S,}$	Fraction of substrate, which is	
$f_{S, u}$	unbiodegradable	-
$f_{S, us}$	unbiodegradable, soluble	-
$f_{S, up}$	unbiodegradable, particulate	-
$f_{S, b}$	biodegradable	-
$f_{S, bs}$	biodegradable, readily (soluble)	-
$f_{S, bsa}$	biodegradable, readily (soluble), acetate	-
$f_{S, bsc}$	biodegradable, readily (soluble), complex	-
$f_{S, bp}$	biodegradable, slowly (particulate)	-
$f_{S, ZBH}$	biological active mass, heterotrophs	-
f_{bs}	Fraction of biodegradable substrate which is readily biodegradable	-
Volatile solids (COD units)		
$f_{Z,}$	Fraction of volatile solids, which is	
$f_{Z, B}$	biological (active) mass	-
$f_{Z, BH}$	biological (active) mass, heterotrophs	-
$f_{Z, BA}$	biological (active) mass, autotrophs	-
$f_{Z, BG}$	biological (active) mass, polyP organisms	-
$f_{Z, E}$	endogenous mass	-
$f_{Z, I}$	inert mass	-

** Little information is available in the literature on the subscripts for fractional contents, using the IAWPRC symbol system.

Table D.1: (Continued)

Symbol	UCT SYMBOL SYSTEM Description	IAWPRC Equivalent
Nitrogen		
$f_{\underline{N}}$,	Fraction of nitrogen, which is	
$f_{N, o}$	organic	-
$f_{N, ou}$	organic, unbiodegradable	-
$f_{N, ous}$	organic, unbiodegradable, soluble	-
$f_{N, oup}$	organic, unbiodegradable, particulate	-
$f_{N, ob}$	organic, biodegradable	-
$f_{N, obs}$	organic, biodegradable, soluble	-
$f_{N, obp}$	organic, biodegradable, particulate	-
$f_{N, a}$	ammonia	-
$f_{Nob, p}$	Fraction of organic biodegradable nitrogen which is particulate	-
Phosphorus		
$f_{\underline{P}}$,	Fraction of phosphorus, which is	
$f_{P, p}$	particulate	-
$f_{P, s}$	soluble	-

Table D.1: (Continued)

UCT SYMBOL SYSTEM		IAWPRC
Symbol	Description	Equivalent
Nitrogen content		
$f_{,N}$	Fraction of ".....", which is nitrogen	
$f_{Z,N}$	volatile solids (COD units)	-
$f_{ZB,N}$	volatile solids (COD units), biological active mass	i_{XBN}
$f_{ZE,N}$	volatile solids (COD units), endogenous mass	i_{XEN}
$f_{ZI,N}$	volatile solids (COD units), inert mass	-
Phosphorus content		
$f_{,P}$	Fraction of ".....", which is phosphorus	
$f_{Z,P}$	volatile solids (COD units)	-
$f_{ZB,P}$	volatile solids (COD units), biological (active) mass	i_{XBP}
$f_{ZE,P}$	volatile solids (COD units), endogenous mass	i_{XEP}
$f_{ZI,P}$	volatile solids (COD units), inert mass	-
Endogenous residue		
f_E	Fraction of the organism that remains as unbiodegradable residue	f_E
Special fractional contents		
f_{cv}	COD/VSS ratio	
f_i	MLVSS/MLSS ratio	
f_{ns}	Influent TKN/COD concentration ratio	

Table D.1: (Continued)

UCT SYMBOL SYSTEM		IAWPRC
Symbol	Description	Equivalent
CONSTANTS***		
Y	<u>True specific yield (COD units)</u>	Y
Y_{ZH}	Heterotrophs	Y_H
Y_{ZA}	Autotrophs	Y_A
$\hat{\mu}$	<u>Maximum specific growth rate</u>	μ_{\max}
$\hat{\mu}_H$	Heterotrophs	$\hat{\mu}_H$
$\hat{\mu}_A$	Autotrophs	$\hat{\mu}_A$
K_S	<u>Monod half saturation coefficient</u>	K_S
K_{SH}	Heterotrophs	K_{SH}
K_{SA}	Autotrophs	K_{SA}
R_h	Hydraulic retention time	Θ
R_s	Sludge age - solids retention time	Θ_c
Q	Flow rate	Q
V	Volume	V

*** Only constants common to both bacterial populations are given. A number of constants exist specific to each population. Constants used in this manual are given in the list of symbols, and in the relevant chapters.