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AEROBIC DIGESTION OF WASTE ACTIVATED SLUDGE
FROM BIOLOGICAL NUTRIENT REMOVAL
ACTIVATED SLUDGE SYSTEMS

BY

MICHAEL KIDANE MEBRAHTU

A thesis submitted in partial fulfilment of the requirement for the degree of Master of Science
in Civil Engineering

University of Cape Town
Faculty of Engineering and the Built Environment
Department of Civil Engineering

January 2007
DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree in any other university. All sources of information have been acknowledged.

Michael Kidane Mebrahtu

Feb. 16, 2007
Date
DEDICATION

This work is dedicated to my family for their love.
ACKNOWLEDGEMENT

First and foremost, I thank the Almighty God, Jehovah, for enabling me to finish this work in time.

I wish to express my heartfelt gratitude to the Postgraduate Funding Office of the University of Cape Town and Water Research Commission (WRC) for sponsoring my MSc. program.

I thank my supervisors, Prof. G. A. Ekama and Prof. M. C. Wentzel for their guidance, invaluable input and advice.

I am indebted to Dr. S. W. Sötemann for his help during the simulation process.

I acknowledge the assistance and co-operation of Mr. M. T. Lakay and Mr. H. Mafungwa of the Water Research Laboratory of the Department of Civil Engineering of the University of Cape Town.

My special thanks go to the stuff of the Work Shop of the Department of Civil Engineering of the University of Cape Town for their assistance and co-operation.
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<td>Anaerobic Digestion Model</td>
</tr>
<tr>
<td>ANO</td>
<td>Autotrophic nitrifying organisms</td>
</tr>
<tr>
<td>AOB</td>
<td>Ammonia oxidizing bacteria</td>
</tr>
<tr>
<td>AS</td>
<td>Activated sludge</td>
</tr>
<tr>
<td>ASM</td>
<td>Activated sludge model</td>
</tr>
<tr>
<td>AVSS</td>
<td>Active volatile suspended solids</td>
</tr>
<tr>
<td>BRM</td>
<td>Batch Reactor model</td>
</tr>
<tr>
<td>BEPR</td>
<td>Biological excess phosphorus removal</td>
</tr>
<tr>
<td>BNR</td>
<td>Biological nutrient removal</td>
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<td>BOD₅</td>
<td>Biochemical oxygen demand</td>
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<td>bVSS</td>
<td>Biodegradable volatile suspended solids</td>
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<td>Completely mixed aerobic digester</td>
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<td>COD</td>
<td>Chemical oxygen demand</td>
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<tr>
<td>DO</td>
<td>Dissolved oxygen</td>
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<tr>
<td>DSVI</td>
<td>Diluted sludge volume index</td>
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<td>Free and saline ammonia</td>
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<td>IDS</td>
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<td>IWA</td>
<td>International Water Association</td>
</tr>
<tr>
<td>MB</td>
<td>Mass balance</td>
</tr>
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<td>Membrane</td>
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<td>Mixed liquor suspended solids</td>
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<tr>
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<td>Mixed liquor volatile suspended solids</td>
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<tr>
<td>ND</td>
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<tr>
<td>NDBEPR</td>
<td>Nitrification denitrification biological excess phosphorus removal</td>
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<tr>
<td>NOB</td>
<td>Nitrate oxidizing bacteria</td>
</tr>
<tr>
<td>OHO</td>
<td>Ordinary heterotrophic organisms</td>
</tr>
<tr>
<td>OP</td>
<td>Ortho phosphate</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
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<tr>
<td>OP&lt;sub&gt;t&lt;/sub&gt;</td>
<td>Ortho phosphate concentration at time t</td>
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<tr>
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<td>Oxygen utilized</td>
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<tr>
<td>PVC</td>
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<tr>
<td>RAS</td>
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<td>RBCOD</td>
<td>Readily biodegradable chemical oxygen demand</td>
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<td>rpm</td>
<td>Revolutions per minute</td>
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<td>SB</td>
<td>Sewage batch</td>
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<td>Specific oxygen utilization rate</td>
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<td>TSS</td>
<td>Total suspended solids</td>
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<td>UCT</td>
<td>University of Cape Town</td>
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<tr>
<td>UCTPHO</td>
<td>University of Cape Town model</td>
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<tr>
<td>VFA</td>
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<td>WAS</td>
<td>Waste activated sludge</td>
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<td>WRC</td>
<td>Water Research Commission</td>
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<td>WWTP</td>
<td>Wastewater treatment plant</td>
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<td>Anaerobic oxic</td>
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<tr>
<td>b_H</td>
<td>d⁻¹</td>
<td>OHO endogenous respiration rate</td>
</tr>
<tr>
<td>b_H'</td>
<td>d⁻¹</td>
<td>Death rate of OHOs</td>
</tr>
<tr>
<td>b_HT</td>
<td>d⁻¹</td>
<td>OHO endogenous respiration rate at temperature T</td>
</tr>
<tr>
<td>b_G</td>
<td>d⁻¹</td>
<td>Death rate of PAOs</td>
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<tr>
<td>b_G20</td>
<td>d⁻¹</td>
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<tr>
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<td></td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>C₅H₇NO₂</td>
<td></td>
<td>Component formula of an activated sludge cell</td>
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<td></td>
<td></td>
<td>Fraction of degradable active biomass in the influent that appears as degradable active biomass in the effluent</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f</td>
<td></td>
<td>Fraction of active volatile material degraded</td>
</tr>
<tr>
<td>f_ac</td>
<td></td>
<td>Fraction of acetate with respect to RBCOD</td>
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<td>f_GTe</td>
<td>mgPAOTSS mgTSS⁻¹</td>
<td>Effluent active fraction of the PAOTSS</td>
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<td>f_GTi</td>
<td>mgPAOTSS mgTSS⁻¹</td>
<td>Initial/influent active fraction of the PAOTSS</td>
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<tr>
<td>f_HTe</td>
<td>mgOHOTSS mgTSS⁻¹</td>
<td>Effluent active fraction of the OHOTSS</td>
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<td>Initial/influent active fraction of the OHOTSS</td>
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<tr>
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<tr>
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<td>mgOHOVSS mgVSS⁻¹</td>
<td>Initial/influent active fraction of the OHOVSS</td>
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<tr>
<td>f_T</td>
<td>mgTSS mgTSS⁻¹</td>
<td>TSS active fraction</td>
</tr>
<tr>
<td>f_Te</td>
<td>mgTSS mgTSS⁻¹</td>
<td>Effluent TSS active fraction</td>
</tr>
<tr>
<td>f_Ti</td>
<td>mgTSS mgTSS⁻¹</td>
<td>Initial/influent TSS active fraction</td>
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<td>f_V</td>
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<td>VSS active fraction</td>
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<tr>
<td>f_Ve</td>
<td>mgVSS mgVSS⁻¹</td>
<td>Effluent VSS active fraction</td>
</tr>
<tr>
<td>f_Vi</td>
<td>mgVSS mgVSS⁻¹</td>
<td>Initial/influent VSS active fraction</td>
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\( f_{\text{hs}} \) Fraction of biodegradable soluble COD with respect to biodegradable COD
\( f_{\text{cv}} \) mgCOD mgVSS\(^{-1}\) COD/VSS ratio
\( f_{\text{cvH}} \) mgCOD mgOHOVSS\(^{-1}\) COD/VSS ratio for OHOs
\( f_{\text{cvG}} \) mgCOD mgPAOVSS\(^{-1}\) COD/VSS ratio for PAOs
\( f_{\text{eG}} \) Endogenous residue of the PAOs
\( f_{\text{eG}'} \) Unbiodegradable VSS in PAOs
\( f_{\text{eH}} \) Endogenous residue of the OHOs
\( f_{\text{eH}'} \) Unbiodegradable VSS in OHOs
\( \text{Fe(NH}_4\text{)_2(SO}_4\text{)}_2 \) Ferrous ammonium sulphate
\( f_G \) Fraction of the endogenous residue of the PAOs
\( f_{G\text{Vr}} \) \% Fraction of PAOVSS removed at time t
\( f_H \) Fraction of the endogenous residue of the OHOs
\( f_{H\text{Vr}} \) \% Fraction of OHOVSS removed at time t
\( f_i \) mgVSS mgTSS\(^{-1}\) VSS/TSS ratio
\( f_{ie} \) mgVSS mgTSS\(^{-1}\) Effluent VSS/TSS ratio
\( f_{ii} \) mgVSS mgTSS\(^{-1}\) Influent VSS/TSS ratio
\( f_{i\text{OHO}} \) mgISS mgOHOVSS\(^{-1}\) Inorganic suspended solids content of OHOs
\( f_{i\text{PAO}} \) mgISS mgPAOVSS\(^{-1}\) Inorganic suspended solids content of PAOs
\( f_{i\text{PAOBN}} \) mgISS mgPAOVSS\(^{-1}\) P content of PAO cell mass
\( f_n \) mgN mgVSS\(^{-1}\) Nitrogen content of the VSS
\( f_p \) mgP mgVSS\(^{-1}\) Phosphorus content of the VSS
\( f_{pG} \) mgP mgVSS\(^{-1}\) Phosphorus content of the OHOs
\( f_{PH} \) mgP mgVSS\(^{-1}\) Phosphorus content of the PAOs
\( f_{S\text{up}} \) mgCOD mgCOD\(^{-1}\) Fraction of unbiodegradable particulate COD
\( f_{S\text{us}} \) mgCOD mgCOD\(^{-1}\) Fraction of unbiodegradable soluble COD
\( f_T \) Fraction of nondegradable active TSS unaffected by digestion
\( f_{Trt} \) \% Fraction of total suspended solids removed at time t
\( f_{Ts} \) \% Fraction of solids removed (with respect to TSS)
\( f_{Vr} \) \% Fraction of volatile suspended solids removed
\( f_{Vrt} \) \% Fraction of volatile suspended solids removed at time t
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ABSTRACT

Waste activated sludge (WAS) is a biological sludge that contains biodegradable and non-biodegradable volatile suspended solids (VSS) and non-volatile inorganic suspended solids (ISS). Stabilization for safe disposal of the WAS is a process of paramount importance at wastewater treatment plants (WWTPs). Hence, aerobic digestion of the WAS from biological nutrient removal (BNR) activated sludge (AS) systems was carried out under batch conditions to (1) measure changes in nitrogen and phosphorus concentrations in solid and liquid phases during aerobic batch digestion tests (2) simulate the parent system with Activated Sludge Model No. 2 (ASM-2) in AQUASIM computer program to obtain the initial conditions for batch test simulation (3) simulate the batch aerobic digestion process with ASM-2 and compare with experimental data (4) develop VSS-based and total suspended solids (TSS) (with the addition of ISS to the VSS-based) batch reactor and steady state models for aerobic digestion of nitrification denitrification biological excess phosphorus removal (NDBEPR) WAS based on the individual biomass die-off rates of phosphorus accumulating organisms (PAOs) and ordinary heterotrophic organisms (OHOs), and (5) evaluate the ASM-2 simulation results with steady state aerobic batch digestion model.

The aerobically digested WAS was harvested from a University of Cape Town (UCT) configuration membrane (MBR) system which was fed raw wastewater taken from the Mitchell’s plain WWTP in Cape Town (South Africa) which treats primarily domestic wastewater. The MBR UCT system, which had 140 l d⁻¹ of influent flow and 20 days sludge age, comprised an anaerobic-anoxic-aerobic sequence of reactors with volumes of 25, 19 and 35 l respectively with mixed liquor recycled from the anoxic to anaerobic, and aerobic to anoxic reactors at ratios of 1:1 and 3:1 of the influent flow respectively. The batch aerobic digestion reactor was a 5 l cylindrical Perspex vessel with graduations for measuring the level of the sludge in the reactor. The concentration of the dissolved oxygen (DO) in the reactor was automatically controlled, within the range of 2 to 5 mgO l⁻¹, by a DO controller/oxygen utilization rate (OUR) meter which also concomitantly measures the OUR. Eight aerobic digestion batch tests (BT) with detention times ranging from 6 to 25 days were carried out at regulated pH (7.20) and temperature (20°C).

The sewage batch (SB) average results of the parent system and the batch digestion results were both simulated with ASM-2 in the computer program AQUASIM. The predicted results
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of the parent system provided initial condition input data for the batch test simulations with ASM-2. The batch test simulation results were then compared with those measured. The ISS model, developed by Ekama and Wentzel (2004) was incorporated into the ASM-2. The ASM-2 was calibrated by using the measured SB average data of the MBR UCT system and COD, N and P mass balances of the simulated results were checked. Moreover, based on the aerobic digestion steady state model (SSM) of Marais and Ekama (1976), VSS-based and TSS (adding ISS to the VSS-based) batch reactor and steady state models for aerobic digestion of WAS from BEPR AS systems were developed.

During the aerobic digestion process the VSS, TSS and COD concentrations decreased whereas the P release increased almost linearly with time. For all the batch tests the ISS decreased with some undulations, especially at the beginning of the digestion period. The appearance of nitrate on the second day of digestion indicated the immediate commencement of nitrification and the low FSA concentrations, well below 1 mg l⁻¹, maintained during the end of the digestion period showed the occurrence of complete nitrification. The release of ortho phosphate (OP) into the bulk liquid was directly related to the initial concentration of the suspended solids. Curiously, significantly less P was released to the bulk liquid than expected from the P content of the polyphosphate accumulating organisms (PAOs) in the concentrated TSS batch tests than in the diluted one. This indicated the mineral precipitation of P was taking place in the concentrated TSS batch tests, which was confirmed with supplementary experiments.

For the batch aerobic digestion, generally, the measured COD concentrations dropped faster than those simulated with ASM-2. With regard to the OUR there was marked deviation of the predicted from the measured values. Similar trends of decrease of VSS and TSS concentrations with retention time were observed with ASM-2 and the batch reactor model (BRM). Except for the slightly higher levels of nitrate computed with the BRM, the increase in nitrate concentrations as simulated with ASM-2 and computed with BRM was almost the same during the aerobic digestion process. The endogenous respiration (b) rates of the OHOs and PAOs determined from the computed OUR using the BRM were 0.23 and 0.04 d⁻¹ respectively.

The almost identical TKN reductions with respect to VSS destruction and TSS reduction and linear increase in nitrate concentration with cumulative total oxygen utilized during the
CHAPTER 1
INTRODUCTION

1.1 General

Wastewater is basically the water supply of the community after it has been used in a variety of applications. Wastewater is a combination of the liquid or water-carried wastes removed from residences, institutions, and commercial and industrial establishments. Wastewater is a highly turbid liquid, consisting of a dilute complex mixture of mineral and organic matter in many forms, including: (a) large and small particles of solid matter floating and in suspension, (b) substances in true solution, and (c) extremely finely divided ‘colloidal’ substances between these two categories.

Wastewater contains living organisms such as bacteria, viruses and protozoa; it is an excellent medium for the development of bacteria, containing several million per millilitre. The organic substances present in wastewater include carbohydrates, lignins, fats, soaps and synthetic detergents, and proteins. Ammonia and ammonium salts are always present, some derived from the decomposition of urine. In addition, untreated wastewater contains numerous pathogenic micro-organisms that dwell in the human intestinal tract. Wastewater also contains nutrients, such as nitrogen and phosphorus, which can stimulate the growth of aquatic plants, and may contain potentially toxic compounds that may damage the receiving water courses.

When wastewater or other organic wastes are discharged to a watercourse there is a reduction in the concentration of dissolved oxygen in the receiving water owing to its utilization by bacteria in the presence of organic matter. The bacteria utilize this organic matter as food for their growth, causing it to be broken down into simpler organic and inorganic compounds and development of disease vectors. The objectionable character of sewage is, mainly, due to the presence of organic matter which, in the absence of dissolved oxygen, soon putrefies, with the formation of foul-smelling compounds. If the organic pollution load is sufficiently great, the stream may lose all its dissolved oxygen resulting in putrefaction and foul odours due to liberation of hydrogen sulphide gas.
If pollution of these watercourses is to be avoided so that they can be used for their many requirements, then the organic matter in sewage must be converted to stable substances permitting a reasonably clean effluent to be discharged. To protect public health and the environment, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment and disposal into the environment becomes a necessity.

The treatment of wastewater produces a significant quantity of residual suspended solids that must be further processed prior to disposal. Invariably, the processing stages involve the separation of liquids from the suspended solids and, in doing so; change the characteristics of the residual matter. Furthermore, processing changes the solids/water mixture to cakes of high concentration and, ultimately, to minimal moisture content at the ultimate solids concentration. The constituents removed in wastewater treatment plants (WWTPs) include screenings, grit, scum and sludge. The solids in the waste sludge flow represent the unbiodegradable organics and the net growth of biological cells that have been synthesized in the utilization of the incoming organic material to the WWTP.

The objective of the WWTP, therefore, is to convert the wastewater into a stable sludge for disposal and an effluent suitable for discharge to the local watercourse. The amount and quality of the sludges produced depend entirely on the origin of the wastewater, the type of treatment plant and, perhaps even more important, on the method of plant operation. The whole treatment plant must be operated efficiently and without nuisance or offense to surrounding public and land uses.

Generally, the liquid part of sewage can be treated satisfactorily. Of the constituents removed from the wastewater at the different stages, biosolids (primary and/or secondary sludges) are by far the largest in volume and mass, and its stabilization and disposal present perhaps the most complex problem and high operation cost in the whole WWTP.

The complexity of dealing with the produced and wasted sludge arises from (1) the composition of the sludge in that it mainly consists of the substances responsible for the offensive character of untreated wastewater; (2) the decomposing nature, depending on its active fraction, of the organic matter contained in the waste activated sludge (WAS); and (3) the fact that the greater part of the WAS is organic matter.
The WAS is a biological sludge that contains biodegradable and non-biodegradable volatile suspended solids (VSS) and non-volatile inorganic suspended solids (ISS). Its characteristics differ greatly from primary sludge (PS) and so, too, does its behaviour. The VSS fraction of untreated WAS ranges from 60 to 80 percent without primary clarification at the WWTP and from 75 to 85 percent with primary clarification.

Waste activated sludges are treated to (1) reduce pathogens (disinfection), (2) eliminate offensive odours, and (3) inhibit, reduce, or eliminate the potential for putrefaction by oxidizing the biodegradable organics (stabilization). The success in achieving these objectives is related to the effects of the stabilization operation or process on the volatile or organic fraction of the suspended solids. Die-off of pathogens, release of odours, and putrefaction occur when micro-organisms are allowed to flourish in the biodegradable organic fraction of the sludge. The means to eliminate these nuisance conditions is mainly related to the biological reduction of the biodegradable organic content of the sludge to render them unsuitable for further growth of the micro-organisms. In addition to the health and aesthetic reasons, stabilization is also used for organic solids reduction with or without energy recovery.

The principal methods used for stabilization of sludge are (1) alkaline stabilization, usually with lime; (2) anaerobic digestion; (3) aerobic digestion, and (4) composting. Digestion is a commonly used biological process for the stabilization of sludges from WWTPs and trickling filters.

Aerobic digestion is the aerobic biological stabilization of wastewater sludge. During aerobic digestion the biodegradable organics of the biomass are utilized with oxygen because the wastewater organics have been completely degraded. This ‘auto’ biodegradation can be visualized in two ways. The first way is as endogenous respiration in which micro-organisms metabolize their own cellular mass when the external substrate available is inadequate. In this model, as the biodegradable portion of organic part of sludge continuously decrease, a living cell consumes its own protoplasm and cellular matter in order to obtain the energy required for the metabolism. Through this endogenous respiration process, the mass of biodegradable solids decreases resulting in the required stabilization of the WAS.
The second way of visualizing the ‘auto’ oxidation of biomass biodegradable organics is as death-regeneration. In this model, a fraction of the live cells die and release the biodegradable organics to the bulk liquid. The remaining live organisms use these biodegradable organics in normal growth process of anabolism (cell mass generation) and catabolism (energy generation) as they would any biodegradable organics. Fewer new cells grow due to the catabolic energy loss resulting in oxygen utilization for growth. Provided the correct endogenous respiration or death rates and unbiodegradable residue fractions are chosen for each model, both models give the same results. Generally, the endogenous respiration model is used in steady state activated sludge (AS) and aerobic digestion models (ADMs) because it leads to simpler equations. The death-regeneration model is incorporated into activated sludge simulation models, such as activated sludge model No. 1 (ASM-1) and ASM-2 (Henze et al., 1987, 1995).

Advantages of aerobic digestion as compared to anaerobic digestion are:

(a) Volatile solids reduction in a well-operated aerobic digester can be equal to that obtained anaerobically,
(b) Low chemical oxygen demand (COD) concentration in supernatant liquor
(c) Production of an odourless, humus-like, biologically stable digested sludge
(d) Operation is relatively easy with low operational problems
(e) Lower capital cost
(f) Suitability for digesting nutrient-rich WAS

The major disadvantages of the aerobic digestion process are:

(a) Requirement of high power cost associated with supplying the required oxygen, and

(b) Non-recovery of energy in methane to reduce power consumption at the WWTP.

Though the basic composition of the sludge remains relatively unchanged, the bio-oxidation that occurs during aerobic digestion changes the characteristics of the treated sludges affecting its characteristics such as volatile suspended solids to total suspended solids (VSS/TSS) ratio and dewaterability.
Important parameters for measuring the degree of aerobic (or anaerobic) treatment for sludge stability are:

- Odour production – in addition to hydrogen sulphide, many other chemicals either in or produced by sludge may create odours.
- Reduction in volatile suspended solids (e.g., > 38% VSS removal)
- Change in the rate of oxygen utilization by aerobic organisms as an indication of aerobic activity (e.g., < 1.0 mgO gVSS\(^{-1}\) h\(^{-1}\))
- COD of the supernatant
- Dewaterability

1.2 Rationale for the Study

The AS process is widely used to treat various organic wastewaters. However, the materials removed during treatment process are often left in a sludge, which must be further treated before disposal. Waste activated sludges from biological nutrient removal (BNR) plants, even those with extended aeration, are not stable enough to be dewatered and disposed of into the environment. Stabilization for safe disposal of the WAS, therefore, is a process of paramount importance at WWTPs.

With the recent goals on developing simulation models for the whole WWTP, including the sludge stabilization systems (Copp et al., 2003), it is necessary to know how nitrogen (N) and phosphorus (P) are released from WAS under aerobic (and anaerobic) digestion conditions, in particular the P from biological excess phosphorus removal (BEPR) sludges.

Research into aerobic digestion of fully aerobic or N removal system WAS showed that the N release could be modelled as a co-process of the endogenous respiration or death regeneration models (e.g. Warner et al., 1985); as the biodegradable organics of the biomass was degraded so its N and P components added to the bulk liquid N and P concentrations. In biological excess phosphorus removal, the process of P release under anaerobic conditions is much faster than the die-off or endogenous respiration rates of the phosphorus accumulating organisms (PAOs). Does this also apply to aerobic conditions? In this respect, the ASM-2 model kinetics may not apply because under aerobic digestion conditions, the PAOs receive no influent biodegradable organics. Under these prolonged substrate limited conditions do
their die-off and P-release rates change? The objectives of this thesis is to examine these questions and to investigate whether or not the BEPR/PAO kinetics in the ASM-2 can also be used for modelling aerobic digestion of WAS from BEPR plants, as ASM-1 can be used for modelling aerobic digestion of WAS from fully aerobic or nitrification-denitrification (ND) plants.

1.3 Objectives of the Study

The objectives of the study are to:

- conduct aerobic digestion batch tests on WAS harvested from a parent laboratory scale nitrification-denitrification biological excess phosphorus removal (NDBEPR) system,
- measure changes in nitrogen and phosphorus concentrations in solid and liquid phases during aerobic batch digestion tests,
- simulate the parent system with ASM-2 in AQUASIM computer program to obtain the initial conditions for batch test simulation,
- simulate the batch aerobic digestion process with ASM-2 and compare with experimental data,
- develop VSS-based and TSS (with the addition of ISS to the VSS-based) batch reactor and steady state models for aerobic digestion of NDBEPR WAS based on the individual biomass die-off rates of PAOs and ordinary heterotrophic organisms (OHOs), and
- evaluate the ASM-2 simulation results with steady state aerobic batch digestion model.
CHAPTER 2
LITERATURE REVIEW

2.1 General Description

For fully aerobic or N removal AS, aerobic digestion of the WAS is nothing more than a continuation of the AS process. Aerobic digestion is a metabolic process in which "endogenous" respiration prevails over biosynthesis activity of micro-organisms because of the almost complete exhaustion of the influent wastewater food supply. Once the external wastewater source of organic material has been exhausted, the micro-organisms will enter into endogenous respiration where cellular material is oxidized to satisfy the energy of maintenance, i.e., energy for life support requirement. Due to the presence of a heterogeneous population of micro-organisms and an extremely complex ecosystem, various microbial species may serve as food sources for other members of the population (Adam et al., 1974). Under these conditions, whether they are visualized as endogenous respiration or death regeneration, the concentration of biomass will continuously decrease and the remaining portion will present such a low utilizable energy content as to be considered biologically stable and suitable for disposal in the environment.

One of the major objectives of wastewater treatment is the removal of solids that otherwise might damage the water quality in the recipient water body. These solids are generally referred to as sludge and exist in many forms and various quantities. Obviously the amount and quality of sludge depends entirely on the origin of the waste, the type of treatment plant and, perhaps even more important, on the method of plant operation.

In spite of many research works conducted, no uniform parameter has been found to determine unequivocally the degree of stabilization and digestion time (Barbusinski and Koscielniak, 1997). The stability of the sludge required at a particular installation depends on the method of ultimate disposal and the local restraints on disposal (Ahlberg and Boyko, 1972).
2.2 Stoichiometry

Aerobic digestion is similar to the AS process. For an unlimited supply of usable organics and nutrients, the micro-organisms undergo log growth and the activity of the organism per unit mass is at a maximum. As the supply of available substrate becomes limiting the micro-organisms begin to consume their own protoplasm to obtain energy for cell maintenance reactions. During this phase, the organisms' activity becomes less than maximum resulting in declining growth. When energy is obtained from cell tissue the micro-organisms are said to be in the endogenous phase. Cell tissue is oxidized aerobically to carbon dioxide, water and ammonia.

The oxidation of biomass VSS to carbon dioxide and water through microbial metabolism, during the aerobic digestion process can, generally, be represented by the following equation:

\[
\text{Volatile suspended solids + Oxygen} \rightarrow \text{Micro-organisms} \rightarrow \text{Nutrients} \\
\text{CO}_2 + \text{H}_2\text{O} + \text{NH}_3
\]  

(2.1)

In the above equation the heterotrophic micro-organisms both participate and are produced in the reaction.

Actually, only about 75 to 80 percent of the cell tissue can be oxidized; the remaining 20 to 25 percent is composed of inert components and organic compounds that are not biodegradable. Non-biodegradable VSS, called endogenous residue, will remain in the final product from aerobic digestion.

The basic principle of aerobic sludge digestion is usually illustrated as follows:

\[
\text{Sludge cells} + \text{O}_2 \rightarrow \text{non-degradable cell material} + \text{CO}_2 + \text{H}_2\text{O} + \text{NH}_3
\]  

(2.2)

Considering the biomass wasted to a digester and the formula \(C_5H_7NO_2\) represents cell mass of micro-organisms, the stoichiometry of Equation (2.2), when applied to the degradable portion of the sludge, will be:
\[ C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_3 \] (2.3)

During the AS process the influent nitrogen is either incorporated into the AS, or escapes as nitrogen gas to the environment, or exits through the effluent as nitrate or ammonia. Most of the nitrogen in the WAS is organically bound in the sludge cells, though a significant amount of nitrogen may also be present as ammonia and nitrate. During aerobic digestion several different biologically mediated reactions may take place changing the forms of nitrogen both in solid form and in solution. The important reactions are ammonification, nitrification, and denitrification. Ammonification is the change from organic nitrogen to ammonium. Nitrification describes the biological oxidation of ammonium to nitrate; and denitrification describes the reduction of nitrate or nitrite to nitrogen gas. Sometimes denitrification may be encountered during aerobic digestion due to under aeration where some organisms are at zero dissolved oxygen (DO) concentration.

In the process of aerobic digestion, endogenous hydrolysis causes the release of nitrogen contained in the AS mass into the bulk liquid as organic nitrogen. The organic nitrogen is, then converted to ammonia. This ammonification process is expressed as follows,

\[ C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_4^+ + OH^- + H_2O \] (2.4)

where \( C_5H_7NO_2 \) is the component formula of an activated sludge cell.

The ammonium is oxidized to nitrite or nitrate by nitrifying bacteria. The biological nitrification of ammonium by ammonia oxidizing bacteria (AOB) is considered a two-step reaction. The first step involves oxidation of ammonium to nitrite by AOB, while the second step is oxidation of nitrite to nitrate by nitrate oxidizing bacteria (NOB). Both of these groups are autotrophic, deriving energy for metabolism from inorganic nitrogen. These two-step reactions of nitrification of released ammonia nitrogen are described as:

\[ NH_4^+ + \frac{3}{2}O_2 \rightarrow NO_2^- + 2H^+ + H_2O \] (2.5)

\[ NO_2^- + \frac{1}{2}O_2 \rightarrow NO_3^- \] (2.6)
2.4

The net stoichiometric relationship for the oxidation of ammonium to nitrate by autotrophic nitrifying bacteria can be represented by the sum of Equations (2.5 and 2.6),

\[ NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \] (2.7)

In the aquatic environment of an aerobic digester the production of free hydrogen ions generally results in reaction with bicarbonate ions (Bishop and Farmer, 1978). Equation (2.7) can be modified to show this:

\[ NH_4^+ + 2O_2 + 2HCO_3^- \rightarrow NO_3^- + 2CO_2 + 3H_2O \] (2.8)

The overall equation with complete nitrification:

\[ C_5H_7NO_2 + 7O_2 \rightarrow 5CO_2 + HNO_3 + 3H_2O \] (2.9)

With complete nitrification/denitrification:

\[ C_5H_7NO_2 + 5.75O_2 \rightarrow 5CO_2 + 3.5H_2O + 0.5N_2 \] (2.10)

As given by Equations (2.7) to (2.9), the conversion of organic nitrogen to nitrate, results in an increase in the concentration of hydrogen ions. For every molecule of nitrate (\(NO_3^-\)) formed from soluble ammonia (\(NH_4^+\)) two molecules of \(H^+\) are generated. Hence, approximately 7 kg of alkalinity, expressed as CaCO₃, is destroyed per each kg N of \(NH_4^+\) oxidized. As a result, the pH decreases. In the absence of sufficient buffering capacity, if the pH drops too low, nitrification is inhibited and eventually may stop. Moreover, if the DO concentration is kept very low (less than 1 mg l⁻¹) nitrification will not occur.

Thus, the theoretical oxygen demand for the aerobic sludge digestion process can be determined from Equation (2.3) as follows:

\[ C_5H_7NO_2 = (5*12) + (7*1) + (2*16) = 113 \text{ g organisms (VSS)} \]

Oxygen utilized, \(5O_2 = (5*2*16) = 160 \text{ g oxygen (COD)} \)
Therefore, \( 1 \text{ g VSS} = (160/113) = 1.42 \text{ g COD} \)

Hence, theoretically, the aerobic sludge digestion process requires approximately 1.42 g O to oxidize 1 g of cell material (VSS). The theoretical oxygen demand to oxidize 1 g VSS would be 1.98 g O (COD) with complete nitrification, and 1.77 g O (COD) with complete nitrification and denitrification. From the stoichiometric relations it can be seen that \( H^+ \) is consumed and released resulting in pH changes during digestion (Brink et al., 2006). This aspect is discussed in detail in Section 2.3.1.

### 2.3 Factors Affecting Digestion Kinetics

Like any other biological process, the kinetics of aerobic digestion process is influenced by a number of factors as discussed below.

#### 2.3.1 pH

pH is one of the most important parameters affecting the stoichiometry and kinetics of the biological aerobic digestion process. A pH close to a neutral level (pH = 7) provides a good environment for the oxidative micro-organisms, thus enhancing aerobic digestion efficiency through enhanced endogenous metabolism (Anderson and Mavinic, 1984). Moreover, keeping the pH at \(~7.20\) provides the optimum nitrification rate, which is expected to fall in the range of 7 to 8 (Ekama, 2005). Hence to provide a better environment for microbial metabolism, monitoring and regulating the pH has become one of the main parameters of concern during aerobic digestion process.

In their study of aerobic digestion of non-BEPR WAS with pH control, Anderson and Mavinic (1984) observed a trend of increase in digestion efficiency with pH increase to 7.0. When investigating the fate of nitrogen during aerobic digestion, Mavinic and Koers (1982) reported that a pH as low as 4.0 did not seem to impede the nitrification or denitrification processes. In their examination of the effects of detention time and pH on the performance of continuous flow aerobic digestion, Randall et al. (1974) reported that a pH of 6.5 gave the maximum value of decay coefficient, followed in order by values of 8.0, 5.0, and 3.5.
However, at pH values less than 5.7, Randall et al. (1969) experienced retardation of biological activity in some of their aerobic digesters. Moore (1970) evaluated the effect of pH on aerobic digestion of WAS and stated that the aerobic digestion efficiency, as measured by solids reduction, was relatively insensitive to different test pH conditions (3.5, 5.0, 7.0, and 9.0) but was always greater in pH-controlled units. Coackley et al. (1966), however, noted that pH values less that 4.0 would inhibit the microbial activity.

2.3.2 Temperature

Temperature will affect the biological system in two ways: first, temperature will affect the enzymatic reactions that are responsible for the reductions of VSS; second, the temperature will influence the diffusion of substrate to the organisms (Eikum et al., 1974).

The effect of temperature on the decay coefficient usually has been represented by a modified Arrhenius relationship (Grady and Lim, 1980):

\[ k_i = k_2 \theta^{(T_1 - T_2)} \]  

(2.11)

where

\( k_1 \) and \( k_2 \) = reaction rate coefficients at temperature \( T_1 \) and \( T_2 \) respectively; and

\( \theta \) = thermal coefficient.

Marais and Ekama (1976) reported that the temperature dependency of the OHO endogenous respiration rate, \( b_H \) could be expressed in terms of a simplified Arrhenius equation:

\[ b_{HT} = b_{H20} \theta^{(T - 20)} \]  

(2.12)

where

\( b_{HT} \) = value at \( t^\circ C \)

\( b_{H20} \) = value at \( 20^\circ C = 0.24 \) mgOHOVSS mgOHOVSS\(^{-1}\) d\(^{-1}\)

\( \theta \) = constant = 1.029

\( t \) = temperature in degree C
That is,

\[ b_{HT} = 0.24 \left(1.029\right)^{(T-20)} \]

Randall et al. (1975) stated that an Arrhenius relationship might not be valid above 20°C, whereas Matsch and Drnevich (1977) verified this relationship up to about 60°C with acclimated systems. In their study of aerobic digestion of WAS at low temperatures, Mavinic and Koers (1979) observed that temperature had a significant effect on oxygen uptake at all sludge ages and VSS reduction increased with increasing temperature. While Marais and Ekama (1976) worked in the temperature range 8 to 20°C, van Haandel et al. (1998) worked in the temperature range 20 to 30°C and confirmed that \( b_{H20} = 0.24 \text{ d}^{-1} \) but found a slightly higher temperature sensitivity coefficient, \( \theta = 1.04 \).

### 2.3.3 Initial concentration of suspended solids

The effect of the initial concentration of suspended solids on the kinetics of aerobic digestion is mainly related to its influence on oxygen transfer rate.

The extent to which the oxygen mass transfer rate, \( k_La \) value of an aeration system is influenced by the presence of dissolved or suspended solids is generally expressed in terms of a factor, \( \alpha \), defined as follows:

\[ \alpha = \frac{k_La_{(s)}}{k_La_{(w)}} \]  

(2.13)

where \( k_La_{(s)} \) relates to the aqueous suspension and \( k_La_{(w)} \) relates to distilled water or tap water.

The presence of solids in suspension may affect oxygen transfer through (Casey and Karmo, 1974):

- their influence on the bulk characteristics of the air-water mixture, i.e. on its effective density and viscosity
- their effect on air-water interface conditions
Quoting on the work of Rogers and Vernimmen (1964) on the influence of suspensions of diatomaceous earth, AS, ferric hydroxide and aluminium hydroxide on the rate of oxygen transfer in aeration columns, Casey and Karmo (1974) stated that AS was found to reduce the rate of oxygen transfer with increasing solids concentration up to about 2.5 g l\(^{-1}\), at which the value of \(\alpha\) was about 0.4; at higher concentrations the effect became less marked. This solids concentration and \(\alpha\) values are very low compared with the solids concentration considered in the membrane (MBR) University of Cape Town (UCT) system which is about 7, 13 and 15 g l\(^{-1}\) in the anaerobic, anoxic and aerobic reactors, respectively, with \(\alpha\) value of 0.75. On their work of the influence of suspended solids on oxygen transfer in aeration systems Casey and Karmo (1974) noted that non-flocculent suspensions within concentration range of 0 – 10 g l\(^{-1}\) had a negligible influence on the overall transfer coefficient. However, organic flocculent suspensions (i.e. AS and synthetic suspensions) had a significant effect on oxygen transfer rate.

An inverse relationship has been observed in several studies between initial solids concentration and the first-order decay coefficient, \(k_d\) (Reynolds, 1973; Ganczarczyk et al., 1980; d’Antonio and Gigliani, 1984; Krishnamoorthy and Loehr, 1989; and Khalili et al., 2000).

Randal et al. (1969) carried out laboratory batch digestion tests on non-BEPR WAS having initial suspended solids concentrations in the ranges of 11,000 – 26,000 mg l\(^{-1}\) and reported that the rate of destruction of sludge solids by aerobic digestion increased with the increase in solids concentration. When conducting aerobic stabilization of non-BEPR WAS, Abramov (1975) associated a more concentrated sludge with somewhat lower VSS degradation rate, while sludge concentrations from 7,500 – 20,000 mg l\(^{-1}\) did not affect the first-order decay coefficient.

Since increasing the sludge age increases the nonactive volatile solids accumulation in the AS system, Upadhyaya and Eckenfelder (1975) indicated that an increase in mixed liquor volatile suspended solids (MLVSS) could cause a decrease in AS active mass, even under conditions of similar sludge ages. In their study of aerobic digestion of thickened non-BEPR WAS to determine reaction rate constants, D’Antonio, (1983) observed that the destruction rate constant values decreased as the initial solids concentration increased. For the same duration, less concentrated sludges exhibited higher VSS percent destructions than did the more
thickened samples; however, at the end of the test, the latter reached higher destruction values with longer aeration periods. Moreover, he reported the need for longer digestion time for sludges with higher initial concentration of solids.

2.3.4 Sludge Age (in Prior Activated Sludge Process)

Owing to the different substrate types on which the activated sludges were grown, various studies on the influence of sludge age in prior AS process on the kinetics of aerobic digestion showed differing results. Generally, the unbiodegradable VSS fraction of the WAS generated from AS process with longer sludge ages will be higher as a result of the accumulation of biologically inert volatile matter (endogenous residue). Hence increasing the sludge age increases the inert volatile solids accumulation in the system because in effect the endogenous process has continued for longer in the AS reactor at longer sludge ages.

In their study of aerobic digestion of non-BEPR WAS, Reece et al. (1979) found that the solids retention time (SRT) at which the sludge was grown did not significantly affect the first order rate constant. Hence, they concluded that the degradable solids in an AS grown at a long SRT could be destroyed just as rapidly as those in a sludge grown at a short SRT.

A decrease of the first order decay coefficient with an increase in prior sludge age have been reported by Abramov (1975), Krishnamoorthy and Loehr (1989), and Goodman and Englande (1974). However, Marais and Ekama (1976) showed that, while the decay rate constant, \( k_b \), based on VSS, decreases with parent system sludge age, the endogenous respiration rate, \( b_t \), based on ordinary heterotrophic organisms volatile suspended solids (OHOVSS), is not affected by sludge age.

2.3.5 Type of Sludge and Detention Time

Matsch and Drnevich (1977) stated that the rate of digestion is a function of the past history of the sludge and that, in general, WAS will require less time to digest aerobically than PS. This is because in the WAS the external substrate is almost completely exhausted, especially for long sludge ages, as a result the micro-organisms will 'immediately' undergo an endogenous mass loss, perceived as endogenous respiration or death-regeneration, with the
lysis of cell material to obtain the energy required for maintenance. The presence of external substrate in the PS enhances growth of the micro-organisms thereby delaying the endogenous mass loss of the micro-organisms until the depletion of the external substrate. Ganczarczyk et al. (1980) noted that the decay coefficients of WAS were, in general, lower than those of PS.

In their study of the variations in sludge metabolic activity and viable micro-organism percentage as a function of growth rate, Weddle and Jenkins (1971) observed that metabolic activity was directly proportional to the number of viable micro-organisms present in the system. Similarly, when investigating the microbial activity in aerobic sludge digestion, Droste and Sanchez (1983) noted that the rate of substrate removal and the decrease of endogenous mass were ultimately dependent on the active cell mass concentration within the reactor.

In their study of aerobic stabilization of primary and mixed primary chemical (alum) sludge, Eikum et al. (1974) reported a decrease in the rate of reduction of volatile organic solids as the detention time in the reactor increased. Similarly, when conducting aerobic digestion of non-BEPR WAS at low temperatures, Koers and Mavinic, (1977) noted a decrease of biodegradability of digested sludge with increased in detention time. In their evaluation of the aerobic digestion of WAS at variable temperature and loading rates, Mavinic and Koers (1979), however, observed increase of VSS reduction with increasing detention time.

Rich (1982) observed that the magnitude of the decay coefficient was dependent on the aeration period used to determine its value, while Abramov (1975) observed that DO concentrations of 1.0 – 8.5 mg l\(^{-1}\) did not affect the value of the decay coefficient.

From the above, the sludge type, its microbial content, the physiological condition, characteristics of the influent wastewater where the sludge is grown, the concentration of nutrients, and mixing affect the kinetics of sludge digestion.

2.4 Transformations of Nutrients during Aerobic Digestion

The nitrogen and phosphorus entering a biological nutrient removal plant either are in solution or associated with the suspended and colloidal solids. While portions of the feed
nitrogen and phosphorus are removed during primary sedimentation, the rest enters the BNR reactor. During aerobic digestion, nitrogen and phosphorus are released from the decomposed sludge biomass.

Most research to date on aerobic digestion has been concerned with the rate and extent of solids reduction, and the effect of digestion on the settleability and drainability of sludges. In only a few cases have researchers reported data concerning the fate of nutrients during digestion. It is, generally, concluded that aerobic digestion produces a supernatant substantially lower in nitrogen and phosphorus than supernatant produced from anaerobic digestion (Bishop and Farmer, 1978).

2.4.1 Nitrogen

Eckenfelder (1956) was one of the first to investigate the changes in nutrient forms during aerobic digestion process. He noted an increase in soluble nitrogen at approximately stoichiometric ratio to the sludge oxidized.

When evaluating the fate of nutrients during aerobic digestion of non-BEPR WAS, Bishop and Farmer (1978) noted that, as much as 41% of the nitrogen in the feed sludge remained in the supernatant of the digested sludge, while the percentage of nitrogen in the sludge solids remained fairly constant. The percentage of nitrogen released to the liquid phase was roughly equivalent to the percentage of VSS destroyed.

Mavinic and Koers (1982) stated that, in the absence of organic N in the supernatants, and the constant organic nitrogen content of the cell mass, the volatile solids destruction, in aerobic digestion, results in almost 100 percent mineralization of organic nitrogen to ammonia in solution. Moreover, they reported that the organic nitrogen content for the digested sludges and feed sludges was practically constant, with an overall value of 0.08 gN gVSS⁻¹. Hence they concluded that the amount of nitrogen converted from the solid phase to the liquid phase in aerobically digested AS should then be proportional to the amount of VSS destroyed.

In their study of aerobic digestion of non-BEPR WAS with different initial solids concentrations, Ganczarczyk et al. (1980) observed that the rate and degree of nitrification
were lower for sludges having higher solids concentration. Based on these observations together with those made on pH changes during aerobic digestion they suggested that there was some inhibition of nitrification during the digestion of the more concentrated sludges or that a simultaneous denitrification occurred. From Ganczarczyk et al. (1980) above, such differences are possible and appear to be associated with the N content of the aerobically digested organics. If the organics are largely proteins then a high bulk liquid ammonia concentration will be observed, if largely carbohydrates, then a low bulk liquid ammonia concentration will be observed. Aerobic digestion models can take this into account through the N content \( f_n \) of the biodegradable organics. Matsuda et al. (1988) studied the behaviour of nitrogen during aerobic digestion of BEPR WAS with continuous and intermittent aeration and pH range of 4 to 6 for detention time of 30 days. In their aerobic batch digestion of BEPR WAS, Matsuda et al. (1988) noted an almost linear decrease of TKN from about 560 to 225 mgN l\(^{-1}\), while the corresponding increase of nitrate (NO\(_3\)) and ammonia (NH\(_4\)) was up to 175 and 125 mg l\(^{-1}\) with 30 days of detention time respectively. The high ammonia concentration Matsuda et al. (1988) obtained at the end of their 30 days of aerobic digestion, however, casts doubt on the existence of complete nitrification. In the aerobic digestion test of WAS from three BNR plants (Anglesea, Ballarat South and Bendigo) with continuous and intermittent aeration for 7 days of detention time, Tonkovic (1999) observed that a significant reduction of organic nitrogen, particularly with continuous aeration, with 23, 8 and 27% destruction of organic nitrogen and 6, 0 and 14% of overall nitrogen removal respectively. For the BEPR WAS with 14% total nitrogen removal, Tonkovic (1999) asserted that there was occurrence of a significant simultaneous nitrification and denitrification.

### 2.4.2 Phosphorus

In the BEPR system the influent phosphorus is mainly incorporated into the AS via the BEPR process mediated by the PAOs while the rest exits through the effluent as orthophosphate (OP). Normal biological uptake during the AS process usually accounts for a removal of only about 20% of the total phosphorus (TP) in the plant influent. BEPR seeks to increase this to 100%. Aerobic and ND activated sludge contains approximately 2% to 3% phosphorus on a dry weight basis (Bishop and Farmer, 1978). The enhanced PAO cultures of Wentzel et al. (1988) contained 0.38 mgP mgPAOVSS\(^{-1}\) or equivalently 30 to 35% P biomass or 300 to 350 mgP gVSS\(^{-1}\) at 10 to 20 days sludge age. In the NDBEPR system with real wastewater the
PAOs are diluted into the 2 to 3% P OHOs and unbiodegradable VSS organics with the result that the P VSS content of NDBEPR systems varies between 5 to 15% P depending on the P removal. Whatever the P content, aerobic digestion of NDBEPR WAS can result in 3 to 5 times more P being released to the bulk liquid. Most of this will be released as OP from the internally stored polyphosphate (PP) of the PAOs. During the aerobic digestion process, through endogenous hydrolysis the solid phase phosphorus of the WAS is solubilized into organic phosphorus, and the organic phosphorus does change into ortho phosphate (OP).

Because the PAO PP is stabilized with cations such as magnesium, potassium and calcium, during the aerobic digestion process these cations are released as a result of solids degradation. If the combined molar concentration of magnesium (Mg$^{2+}$), ammonium (NH$_4^+$) and phosphate (PO$_4^{3-}$) exceeds the solubility product, $K_{sp}$ of struvite, then struvite precipitation occurs. Struvite is magnesium ammonium phosphate (MgNH$_4$PO$_4$), which forms a hard crystalline deposit blocking aerators, pipes and pumps of sludge treatment facilities. The formation of struvite can be represented as:

$$Mg^{2+} + NH_4^+ + PO_4^{3-} + 6H_2O \leftrightarrow MgNH_4PO_4\cdot6H_2O$$ (2.14)

The approximate minimum concentration required for struvite precipitation to occur is at a molar ratio of Mg:NH$_4$:PO$_4$ of 1:1:1, i.e. at concentrations of 27 mg l$^{-1}$ Mg$^{2+}$, 20 mg l$^{-1}$ NH$_4^+$ and 106 mg l$^{-1}$ PO$_4^{3-}$. Struvite precipitation is highly pH dependent. As the pH increases from 7 to 9 the percent of total ammoniacal nitrogen present as NH$_4^+$ decreases from 99 to 64% while the fraction of total PO$_4$P present as the PO$_4^{3-}$ anion increases 250 fold (Stum and Morgan, 1970). In this respect nitrification during aerobic digestion of BEPR WAS is beneficial because it keeps the free ammonia concentration very low and so reduces the potential to precipitate struvite. The problem associated with struvite precipitation is most pronounced in anaerobic digestion process.

During the aerobic digestion of non-BEPR WAS, Irgens and Halvorson (1965) observed very low levels of phosphorus in aerobic digester supernatant. In their study of aerobic digestion of both primary and mixed sludges, Eikum, et al. (1975) found no significant solubilization of solid phase phosphorus. However, when tracking nutrient changes during aerobic digestion
of non-BEPR WAS, Bishop and Farmer (1978) stated that 37% of the phosphorus in the feed sludge remained in the supernatant of the digested sludge. Moreover, they noted that the phosphorus was released in approximately a stoichiometric ratio to the volatile solids destroyed, producing a stabilized sludge with a phosphorus content of about 2% of the suspended solids.

Matsuda et al. (1988) studied the behaviour of phosphorus during aerobic digestion of BEPR WAS with continuous and intermittent aeration and pH range of 4 to 6 for detention time of 30 days. They observed a decrease of TSS and VSS with detention time while the fixed suspended solids (FSS) were roughly constant (1000 – 3000 mg l\(^{-1}\)), and the reduction rate of VSS was proportional to biodegradable volatile suspended solids (bVSS) with a rate constant of about 0.15 d\(^{-1}\). They also noted that the concentration of phosphorus in liquid phase increased considerably and stated that biomass with low phosphorus content are decomposed in the first stage of aerobic digestion and that with high phosphorus content are decomposed thereafter. The percentage of biomass phosphorus of the total phosphorus (TP) decreased from 99 to 30%. The OP concentration increased from 2 to 45 mg l\(^{-1}\), i.e., showing an increase of 70% in 30 days of detention time. Moreover, they observed that after 30 days of digestion 30% of the initial VSS and 40% of the initial TSS remained. From this it can be seen that the 70% increase of the liquid phase phosphorus was accompanied by 70% decrease of VSS, indicating that the P release during the digestion process was as a result of VSS degradation.

Tonkovic (1999) undertook aerobic digestion of WAS from three BNR and four conventional plants with continuous and intermittent aeration for 7 days of detention time. He stated that the VSS content of the BNR sludges from treatment plants with relatively long sludge ages was high, while plants with a lower operating sludge age produced less stable sludges having a high VSS/TSS ratio and a high specific oxygen utilization rate (SOUR) value. Besides, he noted that intermittent aeration resulted in slightly greater VSS destruction than continuous aeration. For the WAS harvested from three BNR plants (Anglesea, Ballarat South and Bendigo) with continuous aeration, the COD/VSS ratio decreased from 1.40, 1.44 and 1.31 mgCOD mgVSS\(^{-1}\) to 1.23, 1.36 and 1.13 mgCOD mgVSS\(^{-1}\) respectively, during the 7 days of aerobic digestion. For these three BNR plants, the VSS/TSS ratio changed from initial values of 0.59, 0.73 and 0.81 mgVSS mgTSS\(^{-1}\) to final values of 0.63, 0.70 and 0.78 mgVSS mgTSS\(^{-1}\) respectively. The final SOUR values of these BNR sludges after 7 days of digestion
were 0.9, 3.0 and 1.5 mgO (gTSS.h)$^{-1}$. Moreover, Tonkovic (1999) stated that intermittent aeration reduced phosphorus leaching by 50% or more, and biosolids from BNR treatment plants operating under long sludge ages leached very little phosphorus even under continuous aeration conditions. He ascribed this to the phosphorus being in a mineralized form contained within the lysed cell wall or as inorganic granules (polymer metal phosphorus complexes) within the cell proper.

Ju et al. (2005) conducted aerobic batch digestion tests of secondary sludges from a conventional and BNR WWTPs. From the conventional plant, they harvested fresh sludge from the returned activated sludge (RAS) of a secondary clarifier and digested the sludge within one hour of harvesting. The conventional WWTP, which used aeration ditches for the secondary biological treatment to remove ammonium and organic substances, had an average influent flow of ~3000-3500 l s$^{-1}$ (70-80 mgd) with biochemical oxygen demand (BOD$_5$), TSS and total kjeldahl nitrogen (TKN) concentrations of 100-110, 160 and 20 mg l$^{-1}$ respectively. The BOD$_5$ of the influent to the secondary treatment was 70-90 mg l$^{-1}$. The BNR WWTP, of an anaerobic/oxic (A/O) ditch process that consisted of a three-stage anaerobic selector (including a RAS denitrification stage and two subsequent anaerobic stages) and a single oxidation ditch, had a design capacity of 1.75 mgd (77 l s$^{-1}$). The typical influent TSS and TKN concentrations were 350 mg l$^{-1}$ and 40 mg l$^{-1}$ respectively. The sludge harvested from the BNR plant was shipped to the laboratory where the aerobic batch digestion tests were conducted. To remedy the extensive P release encountered in the anaerobic conditions during the shipment, samples of WAS and of the influent to the secondary treatment were shipped separately in ice packs. The sludge was reacclimatized in the laboratory using a sequential batch operation to simulate the plant condition. The sludge was mixed with the influent water at a ratio of 1:2 (the average ratio used in the plant) and the resultant mixed liquor was subjected to 1.5 h of gentle mixing without aeration, 26 h of aeration and 7 h of sludge settling. The settled sludge was then remixed with the influent sample from the BNR plant and the cycle of acclimation repeated. The sludge was acclimatized for 3-5 cycles before being collected for the digestion tests. The WAS from the conventional and BNR plants were batch digested under a combination of low aeration (DO: 0.8-2 mgO l$^{-1}$), high aeration (DO: 3-4 mgO l$^{-1}$) and cyclic aeration, and without and with pH control (@ 5.0, 5.5, 6.5, 6.8, and 7.0) in six runs at a room temperature (22 ± 2°C).
Ju et al. (2005) observed appreciable amounts of phosphorus release into the water along with the sludge digestion. Generally, they noted that the OP concentrations of the BNR WAS (60 – 130 mg l\(^{-1}\)) were higher than that of the conventional WAS (20 – 80 mg l\(^{-1}\)). For the conventional WAS, the OP concentrations under fully aerobic conditions with initial phosphorus content of the TSS \((P/TSS)_{i}\) of 2% and pH of 7.0 and 7.5 were \(~29.9\) and \(~28.8\) mgOP l\(^{-1}\) respectively, at the end of 16 days of detention time. For the BNR WAS, the OP concentrations under fully aerobic conditions with \((P/TSS)_{i}\) of \(~3.6\)% and pH of 6.5 was 82.4 mgOP l\(^{-1}\) while that with \((P/TSS)_{i}\) of \(~7.3\)% and pH of 7.0 was 102.9 mgOP l\(^{-1}\). Besides, they reported that the initial phosphorus content of the TSS were higher for the BNR WAS (6 – 7%) than those of the conventional WAS (2 – 3.5%), and that the OP concentrations of the low DO (0.8 – 2 mgO l\(^{-1}\)) and intermittent aeration were comparable, and were lower than those of the fully aerobic (DO of 3 – 4 mgO l\(^{-1}\)). The reaction rate constants, \(k_{d}\), they obtained were lower for the conventional WAS (0.006 – 0.024 h\(^{-1}\)) than for the BNR WAS (0.002 – 0.008 h\(^{-1}\)), while for the BNR WAS at pH of 7.20 the \(k_{d}\) was 0.008 h\(^{-1}\). For the conventional WAS, they stated that the pH decreased with increased DO, due to nitrification, and increased with decreasing DO, due to slower nitrification and occurrence of denitrification, in that the supernatant phosphorus profiles mirrored the profiles of the pH change. The formation of inorganic phosphorus precipitates they ascribed to the effect of pH. Moreover, they asserted that the P release from organic phosphorus was accompanied with VSS degradation.

2.5 Historical Developments

In view of WAS being predominantly biological solids, the most important reaction controlling the digestion of organic solids would be the microbial decay. It has been shown that the rate and extent of biological stabilization in aerobic digesters are significantly influenced by the operation conditions such as mixing rate, aeration time, reactor temperature, mean residence time of sludge, and oxygen uptake rate (Khalili et al., 2000).

The rate at which biodegradable volatile solids are oxidized is a function of many factors such as (Kambhu and Andrews, 1969):

1. Concentration of biodegradable volatile solids
2. Temperature
3. Mixing
4. Oxygen transfer rate
5. Composition of solids
6. Concentration of nutrients
7. Concentration of micro-organisms
8. Type of micro-organisms
9. Physiological condition of micro-organisms

A number of batch aerobic digestion tests have been carried out to determine the reaction rate constant, $k_d$ mgVSS$^{-1}$ mgVSS$^{-1}$ d$^{-1}$. As a result, varying values of reaction rate constants have been reported, in particular lower rates at longer sludge ages. For example, Krishnamoorthy and Loehr (1989) obtained values of decay coefficients for WAS ranging from 0.016 to 0.426 day$^{-1}$. Moreover, Mavinic and Koers (1979) reported that the endogenous decay rates based on VSS were not adequately described by a single $k_d$ value. Instead, they found that two $k_d$ values better fitted their data. These global (VSS specific) reaction rate constants, however, do not explicitly portray the decay rate of the OHOs which form part of the VSS. The unbiodegradable components of the VSS clearly can not be degraded further.

Marais and Ekama (1976) found the decay rate for OHOs, $b_H$, to be 0.24 d$^{-1}$ at 20°C. This rate is specific to the OHO biomass and has units mgOHOVSSdegraded (mgOHOVSSpresent)$^{-1}$ d$^{-1}$. From a number of tests on sludge samples from plants with sludge ages ranging from 2.5 to 20 days, but at the same temperatures, they found that $b_H$ is constant and independent of sludge age. This resolved the long discussion in the literature in the 1970s on the variation of $k_d$ with sludge age; while $k_d$ based on VSS changes, $b_H$ based on only the OHO part of the VSS does not. This, therefore, opened the way for developing general AS simulation models. Repeating the tests at 14°C and 8°C, they showed that $b_H$ is not very temperature sensitive, i.e. $b_{HT} = 0.24 (1.029)^{(T-20)}$. Van Haandel et al. (1998) provided independent validation of a constant $b_H$ value with sludge age and determined $b_{HT} = 0.24 (1.04)^{(T-20)}$ over the 20 to 30°C temperature range.

Dold et al. (1980) developed the death regeneration approach to modelling OHO loss. In this approach some OHOs actually die and lyse their biodegradable organics (which are slowly biodegradable particulate organics, SBCOD) to the bulk liquid. The surviving OHOs utilize this SBCOD as they would any SBCOD from the influent wastewater. They showed that
identical simulation results are obtained for the endogenous respiration and death-regeneration approaches if

\[
b'_{H} = b_{H} \frac{(1-f_{eh}f_{cv}Y_{H})}{(1-f_{cv}Y_{H})} \tag{2.15}\]

\[
f'_{eh} = f_{eh} \frac{(1-f_{cv}Y_{H})}{(1-f_{eh}f_{cv}Y_{H})} \tag{2.16}\]

where

\(b_{H}\) = OHO endogenous respiration rate (d\(^{-1}\))
\(= 0.24\) at 20°C

\(b'_{H}\) = OHO death rate (d\(^{-1}\))
\(= 0.62\) at 20°C

\(f_{eh}\) = endogenous residue of OHOs
\(= 0.20\) in endogenous respiration model

\(f'_{eh}\) = unbiodegradable VSS in OHOs
\(= 0.92\) in death regeneration model

\(Y_{H}\) = OHO yield coefficient
\(= 0.45\) mgVSS mgCOD\(^{-1}\)

\(f_{cv}\) = OHO COD/VSS ratio
\(= 1.48\) mgCOD mgVSS\(^{-1}\)

Van Haandel et al. (1981) extended the model of Dold et al. (1980) to include biological denitrification. With some further modifications to the kinetic equations describing the enmeshment, hydrolysis and utilization of SBCOD this model was adopted by the International Water Association (IWA) as ASM-1 (Henze et al., 1987). Warner et al. (1986) applied the ND simulation model of van Haandel et al. (1981) and a steady state simplification of it, to anoxic-aerobic digestion and found that these models predicted the behaviour of the system very well. The recommended air off time for complete N removal in the intermittently aerated digester was 50% of the time in 4 to 6 hour cycles. Apart from N removal this mode of operation also obviated the need for lime addition to control pH (Warner et al., 1985).
To include BEPR by PAOs into ASM-1, Wentzel et al. (1988) developed and tested enhanced PAO cultures in laboratory scale 3-stage Bardenpho and UCT BNR systems. These enhanced PAO cultures exhibited predominantly aerobic P uptake BEPR, and had negligibly little capacity for denitrification. From aerobic digestion batch tests on sludge harvested from these systems, they determined the PAO endogenous respiration rate at 20°C, $b_{O_{2}}$ to be 0.04 mgPAOVSS mgPAOVSS$^{-1}$ d$^{-1}$. This is very low – 1/6th of the OHOs. Due to the complexities and uncertainties of what happens to the internally stored substrate (polyhydroxyalkanoates, PHAs) and polyphosphate (PP) during death regeneration, the net effect endogenous respiration approach was maintained. The loss of PAO biomass results in a release of P to the bulk liquid but because the $b_{O_{2}}$ rate is so slow, this release of P is small relative to the P uptake resulting from replenishment of internally stored PP chains in the “surviving” and newly grown PAO biomass. However, under aerobic digestion conditions in the absence of PHA formation and growth, the P release due to endogenous respiration will cause significant increase in bulk liquid P concentration.

The kinetics of P release, P uptake, growth and endogenous respiration of PAOs were included in the ND model of van Haandel et al. (1981) to form The University of Cape Town (UCT) model (UCTPHO, Wentzel et al., 1992). The details of this model are described by Wentzel et al. (1988, 1992); suffice to say that the BEPR kinetics of these models are based exclusively an aerobic P uptake PAO behaviour. The aerobic P uptake BEPR kinetics were also included into ASM-1 to form ASM-2 (Henze et al., 1995). This ASM-2 model will form the modelling basis of this investigation on aerobic digestion of BEPR WAS. A review of the Dold et al. (1980), van Haandel et al. (1981) and ASM-1 and ASM-2 simulation models is given by Hu et al. (2003) and is, therefore, not repeated here.

### 2.6 Steady State Models of Aerobic Digestion

During aerobic sludge stabilization, the biodegradable organic matter is stabilized to a point that it can be safely discharged to the environment. Generally, a significant percentage (40 to 60%) of the original organic residue remains after biological degradation (Higgins et al.,

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* It is suspected that the same complexities faced the developers of ASM-3 which considers that all substrate is first internally stored before utilization, and so applied the net effect endogenous respiration to OHOs, instead of death-regeneration model of biomass loss.
1982) since all the organic matter in wastewater sludges is ordinarily not susceptible to total oxidation.

Since the extent of the organic solid removal and effectiveness of aerobic digestion are controlled by the kinetics of the biological processes, most of the studies have attempted to identify the best proper kinetics of biodegradation for aerobic digesters. Consequently, there has been considerable interest in the development of kinetic equations that can be used to determine the reactor-residence times required to achieve a desired degree of solids destruction.

With the introduction of a term for the inert organic residue by Eckenfelder et al. (1961), most of the studies have concluded that the rate of destruction of biomass may be expressed as a first order function of the concentration of biodegradable biomass present. The first-order decay coefficient is recognized as a "pseudo-constant" whose value is affected by many factors.

Four models have been proposed to describe the kinetic behaviour of aerobic digestion of non-BEPR WAS: Adams et al. (1974), Marais and Ekama (1976), Benefield and Randall (1978), and Ekama et al. (2006).

2.6.1 Model of Adams, Eckenfelder and Stein (1974)

Adams et al. (1974) considered digestion of biological sludge only, that is, sludges derived from wastage of mixed liquor from the AS process, and sludges naturally wasted from trickling filters. This is the classical \( k_d \) model which considers a certain fraction of the measured VSS to be biodegradable. It does not include endogenous residue generation during aerobic digestion and so is not a true AS model derivative. The model assumes that only the VSS content of the sludge will decrease during digestion without loss of non-volatile (inorganic) suspended solids (ISS). Interestingly Ekama et al. (2006) show that the assumption of constant ISS during digestion is not correct (see below).
Based on observations of Eckenfelder and Ford (1970) and Benedek \textit{et al.} (1972), Adams \textit{et al.} (1974) approximated the destruction of volatile degradable organics in batch-fed reactors or continuously-fed plug flow systems by first order kinetics as follows\textsuperscript{b}:

\[
\frac{X_{dt}}{X_{di}} = e^{-k_d t}
\]  

(2.17)

where:

\( X_{dt} \) = degradable VSS remaining after batch aeration time, \( t \) (mg l\(^{-1}\))
\( X_{di} \) = initial degradable VSS at time, \( 0 \) (mg l\(^{-1}\))
\( k_d \) = batch reaction rate for degradable VSS destruction (day\(^{-1}\))
\( t \) = time of aeration (days)

Therefore, under batch conditions, the degradable VSS at time \( t \) will be:

\[
X_{dt} = X_{di} e^{-k_d t}
\]  

(2.18)

By incorporating the non-degradable residue, \( X_n \) they expressed the degradable VSS, \( X_{db} \), as a function of total VSS, \( X_i \):

\[
X_{dt} = (X_e - X_n)
\]  

(2.19a)

\[
X_{di} = (X_{di} - X_n)
\]  

(2.19b)

where:

\( X_e \) = effluent total VSS remaining at time, \( t \) (mg l\(^{-1}\))
\( X_i \) = influent total VSS at time, \( 0 \) (mg l\(^{-1}\))
\( X_n \) = non-degradable portion of VSS, assumed constant throughout the aeration period (mg l\(^{-1}\))

Modifying Equation (2.17) to consider total VSS rather than degradable VSS by incorporating Equations (2.19a) and (2.19b):

\textsuperscript{b} For the sake of uniformity of notation the symbolic representations used by the authors is altered
\[
\frac{(X_c - X_n)}{(X_i - X_n)} = e^{-k_d t}
\] (2.20)

The value of \(X_n\) was taken as that of the remaining VSS corresponding to that of zero degradable VSS value during the process of batch digestion.

Once the value of \(X_n\) is obtained, subtracting \(X_n\) from each \(X_c\) value at different specific times of the digestion process will give an estimate of the concentration of biodegradable material at the corresponding times. Plotting the \(\log_{10}\) of \(X_c\) versus detention time would yield an approximate straight line with the intercept on the \(\log_{10}\) axis giving an estimate of \(X_i\), and the slope an estimate of \(k_d\), i.e.

\[
k_d = 2.303 \times (\text{slope}).
\]

2.6.2 Model of Marais and Ekama (1976)

The aerobic digestion model of Marais and Ekama (1976) is a particular application of their steady state model (SSM) for the AS process under purely aerobic conditions without influent feed. It is different to the Adams et al. (1974) model in that it included endogenous residue generation during digestion and in this respect is a true AS model derivative for aerobic digestion.

Based on the sub-division of the waste activated sludge fed into the aerobic digester into inert and active microbial masses, Marais and Ekama (1976) developed their aerobic digestion theory with the following four behavioural patterns:

(i) Inert volatile material comprising endogenous residue and unbiodegradable particulate organics from the AS system, \(X_1\) (mgVSS l\(^{-1}\)), is unaffected by digestion

(ii) Active volatile material (OHOs), \(X_a\) (mgAVSS l\(^{-1}\)), degrade at a specific endogenous respiration or mass loss rate of \(b_{1h}\) in accordance with:

\[
\frac{dX_a}{dt} = -b_{1h} X_a
\] (2.21)
(iii) A fraction of the active material that is degraded, \( f \), remains as endogenous residue, \( X_e \) (mgVSS l\(^{-1}\))

\[
\frac{dX_e}{dt} = f(-\frac{dX_a}{dt}) = fbHX_a
\]  

(2.22)

(iv) The balance of the active material from (iii) above, (1-\( f \))\( X_a \) is utilized as substrate and oxidized with oxygen as electron acceptor. The COD (oxygen) equivalent of the VSS oxidized is \( f_{e\nu} = 1.48 \) mgCOD mgVSS\(^{-1}\). Hence the oxygen demand for endogenous respiration,

\[
O_e = f_{e\nu} \Delta VSS = f_{e\nu} (1 - f)bHX_a
\]  

(2.23)

During the aerobic batch digestion, the VSS at time \( t \) is

\[
X_{Vt} = X_{at} + X_{a} + X_{lt}
\]  

(2.24)

\( X_I \) remains constant and equal to \( X_{ii} \), where as \( X_a \) and \( X_e \) are altered during the digestion process.

Equation (2.21) has the solution

\[
X_{at} = X_{at}e^{-bHt}
\]  

(2.25)

From every unit of \( X_a \) that disappears, \( f \) units of \( X_e \) are generated, i.e.

\[
X_{et} = f(X_{at} - X_{at})
\]  

(2.26)

Substituting \( X_{at} \) from Equation (2.25) into Equation (2.26)

\[
X_{et} = fX_{at}(1 - e^{-bHt})
\]  

(2.27)

The VSS at any time \( t \), \( X_{Vt} \) is given by
\[ X_{t} = X_{at} + X_{ct} + X_{lt} \]
\[ = X_{at}e^{-b_{lt}t} + fX_{at}(1 - e^{-b_{lt}t}) + X_{lt} \]
\[ = X_{at}(1 - f)e^{-b_{lt}t} + fX_{at} + X_{lt} \]  

(2.28)

Rearranging and taking the natural log results in

\[ \log_{10}(X_{t} - fX_{at} - X_{lt}) = \log_{10}[X_{at}(1 - f)] - b_{lt}\log_{10}e \]  

(2.29)

In an aerobic batch digestion as the test proceeds \( X_{at} \) decreases and \( X_{ct} \) increases at \( f \) (0.2) times the rate of decrease of \( X_{at} \) until eventually at \( t = \infty \), \( X_{at} = 0 \) and \( X_{ct} = fX_{at} \), and \( X_{Vt} = X_{ct} + X_{lt} = X_{ct} \)

Marais and Ekama (1976) proposed that a value of \( X_{ct} \) (= \( fX_{at} + X_{lt} \)) be estimated and subtracted from \( X_{Vt} \) and the difference plotted on \( \log_{10}(X_{Vt} - X_{ct}) \) versus digestion time. If the value of \( X_{ct} \) is selected too large the plot curves downwards, if too small it curves upwards and a lower linear least square regression coefficient would be obtained compared with the correct \( X_{ct} \) which gives a straight line and minimizes the correlation coefficient (\( R^2 \)). The slope of the line gives \( b_{lt} \) and \( X_{at} \) is determined from the intercept on the vertical axis.

For the determination of \( X_{at} \), citing the difficulty of measuring the mixed liquor volatile suspended solids (MLVSS) accurately, especially for sludges from plants with long sludge ages, Marais and Ekama (1976) proposed using the oxygen utilization rate (OUR).

The OUR for endogenous respiration, \( O_e \) is given by Equation (2.23). Substituting \( X_{at} \) from Equation (2.25) into Equation (2.23) gives

\[ O_e = f_{cv}(1 - f)b_{lt}X_{at}e^{-b_{lt}t} \quad (mgO \cdot l^{-1} \cdot d^{-1}) \]  

(2.30)

where \( f_{cv} = COD/VSS \) ratio = 1.48 mgCOD mgVSS\(^{-1}\).

Hence, a plot of \( \log_{10}(O_e) \) versus time will give a linear line with the slope giving \( b_{lt} \), i.e.
\[ b_H = 2.303 \times \text{slope} \]

And the intercept on the \( O_c \) axis (i.e. at \( t = 0 \)) is the value \( f_c (1 - f) b_H X_{ai} \). Hence, \( X_{ai} \) is determined from

\[ X_{ai} = \frac{\text{Intercept}}{f_c (1 - f) b_H} \quad \text{(2.31)} \]

Marais and Ekama (1976) concluded that the OUR approach, as compared with using the VSS, is particularly useful because OUR can be measured much more accurately than VSS and can be automated with an online DO controller/OUR meter. Moreover, the batch volume does not decrease by sampling but evaporation water loss needs to be replaced daily.

Determination of \( b_H \) and \( X_{ai} \) by the OUR procedure requires that the value of \( f \) and \( f_c \) be known. They, therefore, adopted a mean measured value of 1.48 mgCOD mgVSS\(^{-1}\) for \( f_c \) and 0.2 for \( f \) based on the findings of McKinney and Symons (1964).

With the occurrence of complete nitrification, they accounted the oxygen demand for nitrification by observing that a fraction, \( f_n \) with regard to the biodegradable material, i.e. \( (1 - f) \), is nitrogen released as ammonia and available for nitrification. This nitrogen fraction is then nitrified with the corresponding oxygen demand for nitrification. The nitrification oxygen demand is, then, given by

\[ O_n = 4.57 f_n (1 - f) b_H X_{ai} \quad \text{(mgO l\(^{-1}\) d\(^{-1}\})} \quad \text{(2.32)} \]

Substituting for \( X_{ai} \) from Equation (2.25)

\[ O_n = 4.57 f_n (1 - f) b_H X_{ai} e^{-b_H t} \quad \text{(mgO l\(^{-1}\) d\(^{-1}\})} \quad \text{(2.33)} \]

where

\[ f_n = \text{fraction of nitrogen in the active mass} = 0.10 \text{ (mgN mgVSS}^{-1}) \]

\[ 4.57 = \text{mass of oxygen required to nitrify 1 mg NH}_3\text{ to NO}_3\text{-N} \]
The total oxygen demand at time \( t \), \( O_{T_t} \) in a batch digester is therefore given by the sum of the carbonaceous and nitrification oxygen requirements

\[
O_{T_t} = O_c + O_n = f_{c_v} (1 - f) b_H X_{a_t} e^{-b_H t} + 4.57 f_s (1 - f) b_H X_{a_t} e^{-b_H t} = (f_{c_v} + 4.57 f_s)(1 - f) b_H X_{a_t} e^{-b_H t}
\]  \( \text{(2.34)} \)

From Equation (2.33) it can be seen that nitrification does not affect the \( b_H \) determination because the slope of the \( \log_{10}(O_{T_t}) \) versus time remains unchanged, but the intercept on the vertical axis has increased. Nevertheless, the actual OHO concentration, \( X_{a_t} \) can still be calculated from Equation (2.33).

The increase in the nitrate concentration in the digester as a result of complete nitrification is given by

\[
\Delta N_{a_t} = (X_{a_t} - X_{a_i})(1 - f) f_s \quad \text{(mgN l}^{-1})
\]  \( \text{(2.35)} \)

Substituting for \( X_{a_t} \) from Equation (2.25) into Equation (2.34) and simplifying yields

\[
\Delta N_{a_t} = X_{a_i} (1 - e^{-b_H t})(1 - f) f_s \quad \text{(mgN l}^{-1})
\]  \( \text{(2.36)} \)

Similarly, the phosphorus released through endogenous respiration, in the batch digester, will be

\[
\Delta P_{s_t} = X_{a_i} (1 - e^{-b_H t})(1 - f) f_p \quad \text{(mgP l}^{-1})
\]  \( \text{(2.37)} \)

where \( f_p = \text{fraction of phosphorus in the active mass (mgP mgVSS}^{-1}) \)

Utilization of the model for design hinges upon knowing the active and inert fractions of the feed sludge into the aerobic digester. This was obtained from the influent wastewater characteristics and design parameters of the AS system from which the WAS was harvested and their steady state AS model, of which the aerobic digester model is a subset. Marais and Ekama (1976) formulated, under steady state conditions, the following equation for the determination of the active fraction of the sludge,
\[
X_a = \frac{Y_H \{ S_u (1 - f_{S_{up}}) - S_{be} \} R_s}{(1 + b_H R_s)} \frac{R_s}{R_h} \text{ mgHOVSS l}^{-1}
\]

(2.38)

where

\[Y_H\] = growth yield coefficient (mgAVSS mgCOD\(^{-1}\) utilized)
\[S_u\] = influent COD (mgCOD l\(^{-1}\))
\[S_{be}\] = effluent biodegradable COD, which is assumed zero (mgCOD l\(^{-1}\))
\[f_{S_{us}}\] = unbiodegradable soluble COD fraction (mgCOD mgCOD\(^{-1}\))
\[f_{S_{up}}\] = unbiodegradable particulate COD fraction (mgCOD mgCOD\(^{-1}\))
\[R_s\] = sludge age, in days
\[R_h\] = hydraulic retention time, in days

The endogenous residue is given by

\[
X_e = f b_H R_s X_a \text{ mgHOVSS l}^{-1}
\]

(2.39)

and inert fraction is

\[
X_i = X_h \frac{R_s}{R_h} = \frac{f_{S_{up}} S_H R_s}{f_{cr} R_h} \text{ mgVSS l}^{-1}
\]

(2.40)

The total VSS content of the sludge will, then, be

\[
X_v = X_a + X_e + X_i
\]

(2.41)

Substituting for \(X_a\), \(X_e\) and \(X_i\) from Equations (2.38, 2.39 and 2.40) into Equation (2.41) and rearranging yields

\[
X_v = \frac{Y_H \{ S_u (1 - f_{S_{us}}) - S_{be} \} R_s}{(1 + b_H R_s)} \frac{R_s}{R_h} + f b_H R_s \left( \frac{Y_H \{ S_u (1 - f_{S_{us}}) - S_{be} \} R_s}{(1 + b_H R_s)} \frac{R_s}{R_h} + f_{S_{up}} S_H R_s \frac{R_s}{R_h} \right) \text{ mgVSS l}^{-1}
\]

(2.42)
Simplifying and rearranging Equation (2.42) yields

\[ X_v = \frac{S_{li}}{R_h} \left( \frac{(1 - f_{S^{'}, \text{us}} - f_{S^{'}, \text{up}})Y_H R_i}{(1 + b_H R_i)} \right) \left( 1 + \frac{f_{S^{'}, \text{up}}}{f_{cv}} R_i \right) \text{ mgVSS l}^{-1} \]  

(2.43)

The OHO active fraction with respect to the VSS ($f_{a,v}$) is defined as

\[ f_{a,v} = \frac{X_a}{X_v} \]  

(2.44)

and

\[ \frac{1}{f_{a,v}} = \frac{X_v}{X_a} \]  

(2.45)

Hence from Equations (2.38) and (2.43):

\[ \frac{1}{f_{a,v}} = \frac{S_{li}}{R_h} \left( \frac{(1 - f_{S^{'}, \text{us}} - f_{S^{'}, \text{up}})Y_H R_i}{(1 + b_H R_i)} \right) \left( 1 + \frac{f_{S^{'}, \text{up}}}{f_{cv}} R_i \right) \left[ \frac{1}{Y_H \left( \frac{S_{li}(1 - f_{S^{'}, \text{us}} - f_{S^{'}, \text{up}} - S_{be})}{(1 + b_H R_i)} \right) R_i} \right] \]  

(2.46)

Simplifying and rearranging Equation (2.46) yields

\[ \frac{1}{f_{a,v}} = (1 + b_H R_i) \left( 1 + \frac{(1 + b_H R_i)f_{S^{'}, \text{up}}}{f_{cv}Y_H (1 - f_{S^{'}, \text{us}} - f_{S^{'}, \text{up}})} \right) \]  

(2.47)

2.6.3 Model of Benefield and Randall (1978)

Owing to the reported decrease in fixed (inorganic) suspended solids (ISS) during digestion of WAS by Randall et al. (1975), Benefield and Randall (1978) developed a model, based on TSS, for aerobic digestion process.

With the following assumptions:

(1) the TSS are composed of an active fraction and an inactive fraction;
(2) the inactive fraction of the influent TSS in nondegradable, that is, material which cannot be oxidized or solubilised through microbial activity;

(3) the active fraction of the influent TSS is composed of nondegradable and degradable fractions where degradable describes material which can be oxidized or solubilised through microbial activity;

(4) only the degradable active fraction of the total suspended solids decreases during digestion

they developed the following relationships:

\[ X_{\text{Te}} = X_{\text{Ti}} + X_{\text{Taoi}} - f_T X_{\text{Te}} X_{\text{Ti}} = X_{\text{Tae}} X_{\text{Te}} \]  \hspace{1cm} (2.48)

\[ f_T X_{\text{Taoi}} + DX_{\text{Taoi}} X_{\text{Ti}} = X_{\text{Tae}} X_{\text{Te}} \]  \hspace{1cm} (2.49)

\[ X_{\text{Taoi}} X_{\text{Ti}} = X_{\text{Tai}} X_{\text{To}} \]  \hspace{1cm} (2.50)

\[ X_{\text{Taoi}} X_{\text{Ti}} + X_{\text{Taoi}} X_{\text{Ti}} = X_{\text{Tai}} X_{\text{Ti}} \]  \hspace{1cm} (2.51)

\[ X_{\text{Tai}} X_{\text{Te}} + X_{\text{Tai}} X_{\text{Ti}} = X_{\text{Ti}} \]  \hspace{1cm} (2.52)

\[ X_{\text{Tae}} X_{\text{Te}} + X_{\text{Tae}} X_{\text{Te}} = X_{\text{Te}} \]  \hspace{1cm} (2.53)

where

\[ X_{\text{Ti}} \] = TSS concentration in influent to digester

\[ X_{\text{Te}} \] = TSS concentration in effluent from digester

\[ X_{\text{Tai}} \] = active fraction of the TSS concentration in the influent

\[ X_{\text{Taoi}} \] = fraction of the TSS concentration in the influent which is inactive

\[ X_{\text{Tadi}} \] = degradable portion of active fraction of the TSS concentration in the influent

\[ X_{\text{Taoi}} \] = nondegradable portion of active fraction of the TSS concentration in the influent

\[ X_{\text{Taoi}} \] = nondegradable portion of the inactive fraction of the TSS concentration in the influent

\[ X_{\text{Tae}} \] = active fraction of the TSS concentration in the effluent

\[ X_{\text{Tae}} \] = fraction of the TSS concentration in the effluent which is inactive

\[ f_T \] = fraction of nondegradable active biomass in the influent that passes through the digestion process and appears as active nondegradable biomass in the effluent

\[ D \] = fraction of degradable active biomass in the influent that appears as degradable active biomass in the effluent

\(^c\) For the sake of uniformity of notation the symbolic representations used by the authors is altered
\( K_d \) = decay rate of the degradable fraction of the active biomass approximated from the decrease in TSS

\( t_d \) = digestion time

Defining \( K_d \) as the active degradable biomass lost per unit time of active degradable biomass in the system:

\[
\text{Active degradable biomass lost through microbial activity} = K_d t_d \left( D X_{T_{adi}} X_{T_i} \right)
\]

\[
= X_{T_{adi}} X_{T_i} - D X_{T_{adi}} X_{T_i}
\]  

(2.54)

which reduces to

\[
K_d t_d = \frac{(1-D)}{D}
\]  

(2.55)

Equation (2.47) can be rearranged into the form

\[ X_{T_{adi}} X_{T_i} - f_T X_{T_{adi}} X_{T_i} = X_{T_{ne}} X_{T_e} - X_{T_{adi}} X_{T_i} \]  

(2.56)

Substituting for \( f_T X_{T_{adi}} X_{T_i} \) in Equation (2.48) from Equation (2.49) gives

\[ X_{T_{adi}} X_{T_i} - (X_{T_{ne}} X_{T_e} - D X_{T_{adi}} X_{T_i}) = X_{T_{ne}} X_{T_e} - X_{T_{adi}} X_{T_i} \]  

(2.57)

A further substitution can be made for \( X_{T_{adi}} X_{T_i} \) from Equation (2.51) and for \( X_{T_{adi}} X_{T_i} \) from Equation (2.50):

\[ X_{T_{adi}} X_{T_i} - X_{T_{adi}} X_{T_i} - X_{T_{ne}} X_{T_e} + D X_{T_{adi}} X_{T_i} = X_{T_{ne}} X_{T_e} - X_{T_{adi}} X_{T_i} \]  

(2.58)

Rearranging, this expression can be written as

\[ (X_{T_{adi}} + X_{T_{ne}}) X_{T_i} + X_{T_{adi}} X_{T_i} (D - 1) = (X_{T_{ne}} + X_{T_{ne}}) X_{T_e} \]  

(2.59)
From Equations (2.52) and (2.53) we see that

\[
(X_{Ta} + X_{Ta}) = X_{Te} + X_{Te} = 1
\]  
(2.60)

Thus, Equation (2.59) can be expressed as

\[
X_{Ta} + X_{Ta}X_{Te} (D - 1) = X_{Te}
\]  
(2.61)

or

\[
(1 - D) = \frac{X_{Ta} - X_{Te}}{X_{Ta}X_{Te}}
\]  
(2.62)

Substituting for \(1-D\) from Equation (2.55) into Equation (2.62) and solving for \(t_d\) yields

\[
t_d = \frac{(X_{Ta} - X_{Te})}{K_d DX_{Ta}X_{Ta}}
\]  
(2.63)

With the findings of Kountz and Forney (1959) that approximately 77 percent of a biological cell is degradable, Equation (2.63) can be modified as

\[
t_d = \frac{(X_{Ta} - X_{Te})}{K_d 0.77 DX_{Ta}X_{Ta}}
\]  
(2.64)

The applicability of this TSS based aerobic digestion model to experimental data under completely mixed aerobic digestion conditions that are from sources other than Benefield and Randall (1978) was not explored in this review. This is because recently Ekama and Wentzel (2004) extended the steady state VSS based AS model to include the ISS and hence also the TSS for aerobic and N removal systems (based on OHOs) and BEPR systems (based on PAOs). This model extension is reviewed below because Ekama et al. (2006) used it to develop a TSS based aerobic digestion model for aerobic and N removal WAS (including OHOs only). This ISS AS model has not been applied to aerobic digestion of BEPR system WAS. This aspect will be explored in this investigation.
2.6.4 Aerobic Digestion Model of Ekama, Wentzel and Sötemann (2006)

Ekama and Wentzel (2004) developed a predictive model of the ISS concentration in the activated sludge reactor. This model is an extension of the Wentzel et al. (1990) VSS and COD based AS model for NDBEPR systems and considers accumulation of influent ISS in the reactor in proportion to sludge age and an OHO and PAO biomass ISS content. This biomass ISS content is not real, it consists of dissolved intracellular inorganics which precipitate in the drying step of the VSS-TSS test procedure. The OHO and PAO ISS content (\( f_{\text{OHO}} \) and \( f_{\text{PAO}} \)) were found to be

\[
\begin{align*}
  f_{\text{OHO}} &= 0.15 \text{ mgISS mgOHOVSS}^{-1} \\
  f_{\text{PAO}} &= f_{\text{PAOBM}} + 3.286(f_{\text{XBGP}} - f_{\text{XBGPBM}}) \\
  f_{\text{XBGP}} &= f_{\text{XBGPBM}} + f_{\text{XBGP}} \\
  f_{\text{XBGPBM}} &= 0.03 \text{ mgP mgPAOVSS}^{-1} \\
  f_{\text{PAOBM}} &= 0.15 \text{ mgISS mgPAOVSS}^{-1} \text{ (without polyphosphate)}
\end{align*}
\]  

where

- \( f_{\text{OHO}} \) = inorganic suspended solids content of OHO cell mass (mgISS mgOHOVSS\(^{-1}\))
- \( f_{\text{PAO}} \) = inorganic suspended solids content of PAOs (mgISS mgPAOVSS\(^{-1}\))
- \( f_{\text{PAOBM}} \) = ISS content of PAO cell mass (mgISS mgPAOVSS\(^{-1}\))
- \( f_{\text{XBGP}} \) = total P content of PAOs (mgP mgPAOVSS\(^{-1}\))
- \( f_{\text{XBGPBM}} \) = P content of the PAO cell mass (mgP mgPAOVSS\(^{-1}\))
- \( f_{\text{XBGP}} \) = polyphosphate content of PAOs (mgPP mgPAOVSS\(^{-1}\))
- 3.286 = ISS content of the PAO intracellular polyphosphate (mgISS mgPP\(^{-1}\))

The model was validated with experimental data from 21 investigations collected over 15 years on 30 aerobic and anoxic-aerobic ND AS systems and 18 NDBEPR systems operated on artificial and real wastewater and at sludge ages from 3 to 20 days.

Ekama et al. (2006) included in the ISS model the steady state AS model for OHOs only and applied it to aerobic digestion of ND system WAS to produce a TSS based aerobic digester model using influent and effluent active fractions with respect to TSS as inputs. They also reworked the VSS based aerobic digester model of Marais and Ekama (1976) in terms of influent and effluent active fractions with respect to VSS. The model shows a decrease in ISS
with digestion time as OHO biomass decreases, as noted and modelled in a different way by Benefield and Randall (1978).

In the interest of brevity the derivation of these models are not presented here; the equations for the single reactor flow through aerobic digester are given in Table 2.1 (Ekama et al., 2006).

As part of their SSM validation Ekama et al. (2006) also incorporated the OHO based ISS model into ASM-1. They found that the ASM-1 model predictions matched very closely the prediction of the SSM and the experimental data of van Haandel et al. (1998).

As indicated above, Ekama et al. (2006) applied their VSS-TSS aerobic digester models only to WAS from ND AS systems. They did not develop a OHO and PAO based steady state aerobic digestion model in terms of VSS and TSS applicable to NDBEPR system WAS. A SSM for aerobic digestion of NDBEPR sludge, therefore, does not exist. It is the intention in this investigation to develop such a model by considering the endogenous respiration process of PAOs. To provide a theoretical modelling basis to interpret experimental aerobic digestion data of NDBEPR WAS, the ISS model for OHOs and PAOs (Equation 2.65 and 2.66) will be integrated into ASM-2 in this investigation. The ISS ASM-2 model will then be used to simulate the parent NDBEPR system from which WAS will be harvested for batch aerobic digestion tests, and the batch digestion tests themselves.
Table 2.1. Equations of the steady state aerobic digestion model of Ekama, Wentzel and Söteman (2006)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model in terms of VSS</th>
<th>Model in terms of TSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent active fraction ($f_{viv}$, $f_{ini}$)</td>
<td>$\beta = \frac{1}{f_{viv}} - (1 - f_{EH}) \ldots$ (1)</td>
<td>$\delta = \frac{1}{f_{ini}} - (1 - f_{IOHO}) \ldots$ (11)</td>
</tr>
<tr>
<td>Effluent active fraction ($f_{ave}$, $f_{ste}$)</td>
<td>$\alpha = \frac{1}{f_{ave}} - (1 - f_{EH}) \ldots$ (2)</td>
<td>$\gamma = \frac{1}{f_{ste}} - (1 - f_{IOHO}) \ldots$ (12)</td>
</tr>
<tr>
<td>Retention time ($R_h$, d)</td>
<td>$R_h = \frac{1}{b_{HT}} \left[ \frac{\alpha}{\beta} - 1 \right] \ldots$ (3)</td>
<td>$R_h = \frac{\gamma - \delta}{b_{HT}(\delta + f_{EH})} \ldots$ (13)</td>
</tr>
<tr>
<td>Effluent active fraction ($f_{ave}$, $f_{ste}$)</td>
<td>$\alpha = \beta(1 + b_{HT} R_h) \ldots$ (4)</td>
<td>$\gamma = \delta + b_{HT} R_h (\delta + f_{EH}) \ldots$ (14)</td>
</tr>
<tr>
<td>Fraction of solids removed ($f_{viv}$, $f_{ste}$)</td>
<td>$f_{viv} = f_{ini}(1 - f_{EH})(1 - \frac{\beta}{\alpha}) \ldots$ (5)</td>
<td>$f_{ste} = 1 - \frac{f_{ini}}{f_{viv}(1 + b_{HT} R_h)} \ldots$ (15)</td>
</tr>
<tr>
<td>Organic oxygen demand (kgO/d)</td>
<td>$V_d O_n = f_{viv} f_{ste} Q_r X_m \ldots$ (6)</td>
<td>$V_d O_n = f_{ini} Q_r X_m f_{ste} (1 - f_{EH})/(1 + f_{IOHO} - f_{EH}) \ldots$ (16)</td>
</tr>
<tr>
<td>Nitrification oxygen demand (kgO/d)</td>
<td>$V_d O_n = 4.57 f_{viv} f_{ste} Q_r X_m \ldots$ (7)</td>
<td>$V_d O_n = 4.57 f_{ini} Q_r X_m f_{ste} (1 - f_{EH})/(1 + f_{IOHO} - f_{EH}) \ldots$ (17)</td>
</tr>
<tr>
<td>Total oxygen demand (kgO/d)</td>
<td>$V_d O_{ti} = (f_{viv} + 4.57 f_{ini}) f_{ste} Q_r X_m \ldots$ (8)</td>
<td>$V_d O_{ti} = (f_{ini} + 4.57 f_{ini}) Q_r X_m f_{ste} (1 - f_{EH})/(1 + f_{IOHO} - f_{EH}) \ldots$ (18)</td>
</tr>
<tr>
<td>Effluent ammonia concentration (mgN/l)</td>
<td>$N_{eH} = N_{ste} = f_{viv} X_m f_{ste} \ldots$ (9a &amp; 9b)</td>
<td>$N_{eH} = N_{ste} = f_{ini} X_m f_{ste} (1 - f_{EH})/(1 + f_{IOHO} - f_{EH}) \ldots$ (19a &amp; 19b)</td>
</tr>
<tr>
<td>Effluent ortho-P concentration (mgP/l)</td>
<td>$P_{eH} = f_{viv} X_m f_{ste} \ldots$ (10)</td>
<td>$P_{eH} = f_{ini} X_m f_{ste} (1 - f_{EH})/(1 + f_{IOHO} - f_{EH}) \ldots$ (20)</td>
</tr>
<tr>
<td>VSS/TSS ratio</td>
<td>$f_{viv} = \frac{f_{ini}}{f_{viv}} \ldots$ (21)</td>
<td>$f_{ini} = \frac{f_{viv}}{f_{ini}} \ldots$ (22)</td>
</tr>
</tbody>
</table>

Notes: (1) For known influent active fraction ($f_{viv}$, $f_{ini}$) if (i) effluent active fraction is specified (i.e. a level of sludge stability), then use Eqs. 2 or 12 to calculate $\alpha$ or $\gamma$ and Eqs. 3 or 13 to calculate the required retention time ($R_h$) or (ii) if $R_h$ is known, then use Eqs. 4 or 14 to calculate $\alpha$ or $\gamma$ and Eqs. 2 or 12 to calculate the resulting effluent active fraction.

(2) Symbols: $f_{viv}$, $f_{ini}$, $f_{ave}$, $f_{ste}$ = active fraction with respect to VSS (script v) and TSS (script i) for the influent (script i) and effluent (script e) sludges, $f_{viv}$, $f_{ste}$ = fraction of VSS (script v) and TSS (script i) solids removed; $f_{ini}$, $f_{ste}$ = VSS/TSS ratio of the influent (script i) and effluent (script e) solids; $V_d =$ digester volume; $Q_r =$ influent flow; $O_n$, $O_{ti}$ and $O_{r}$ = organic, nitrification and total oxygen utilization rates – mgO/L.d$^\dagger$; $f_{EH}$ and $b_{HT}$ = biodegradable fraction and endogenous respiration rate of the OHOs in the endogenous respiration model (i.e. 0.20 and 0.24 d$^\dagger$ at 20°C); $f_{IOHO}$ = ISS content of the OHOs = 0.15 mgISS mgOHO/VSS$^\dagger$; $N_{ste}$ and $P_{ste}$ are the effluent ammonia (no nitrification, $N_{ste} = 0$), nitrate (complete nitrification, $N_{ste} = 0$) and phosphorus concentrations.
2.7 Model Validation

2.7.1 VSS-based

The models of Adams et al. (1974) and of Marais and Ekama (1976) are VSS-based, while the model of Ekama et al. (2006) is both VSS and TSS based. However, under batch conditions the models of Marais and Ekama (1976) and the VSS-based model of Ekama et al. (2006) are similar. Therefore, the results of the model of Marais and Ekama (1976) will apply to the VSS-based model of Ekama et al. (2006). The data of Adams et al. (1974) will be used for comparative validation of these models.

Table 2.2. Comparison of experimental batch aerobic digestion data of Adams et al. (1974) with the equivalent values computed with the models of Adams et al. (1974) and of Marais and Ekama (1976)

<table>
<thead>
<tr>
<th>Retention Time (d)</th>
<th>VSS Remaining (mgVSS l⁻¹)</th>
<th>Degradable VSS Remaining (mgVSS l⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experiment</td>
<td>Adam's (Xₚ=1760)</td>
</tr>
<tr>
<td>0</td>
<td>6115.00</td>
<td>6115.00</td>
</tr>
<tr>
<td>1</td>
<td>4220.00</td>
<td>4024.93</td>
</tr>
<tr>
<td>3</td>
<td>2770.00</td>
<td>3184.68</td>
</tr>
<tr>
<td>5</td>
<td>2510.00</td>
<td>2656.14</td>
</tr>
<tr>
<td>7</td>
<td>2280.00</td>
<td>2323.69</td>
</tr>
<tr>
<td>9</td>
<td>1975.00</td>
<td>2114.57</td>
</tr>
<tr>
<td>11</td>
<td>2105.00</td>
<td>1983.03</td>
</tr>
<tr>
<td>13</td>
<td>1925.00</td>
<td>1900.29</td>
</tr>
<tr>
<td>15</td>
<td>1760.00</td>
<td>1848.24</td>
</tr>
<tr>
<td>17</td>
<td>1775.00</td>
<td>1815.51</td>
</tr>
</tbody>
</table>

The models of Adams et al. (1974) and of Marais and Ekama (1976) are similar. The main difference lies in the way the Xₚ and Xₑ are determined. In the model of Adams et al. (1974) Xₚ is estimated as the VSS remaining at the end of ‘complete’ digestion of the degradable VSS. In the model of Marais and Ekama (1976) Xₑ is computed as the sum of the Xᵢᵢ (influent inert material) and the Xₑ (unbiodegradable residue accumulated during the digestion process). Apart for this difference in the calculation of the Xₚ and Xₑ, the simulated concentrations of the two models were equivalent.
2.7.2 TSS-based

The model of Benefield and Randall (1978) is TSS-based. Under batch conditions, unlike that of the model of Adams et al. (1974), the model of Benefield and Randall (1978) does not give a fixed unbiodegradable TSS except for the inclusion of the findings of Kountz and Forney where approximately 77 percent of a biological cell is degradable. Moreover, the model of Benefield and Randall (1978) considers, under completely mixed aerobic digester conditions, only the influent and effluent TSS with their respective various components. Though the model assumes that a portion of the active influent TSS is nondegradable, it does not assign a quantitative value to this nondegradable active TSS nor does it account for a generation of inert TSS (endogenous residue) concentration during aerobic digestion. Hence, determination of instantaneous TSS concentrations (TSS at time t) is not possible even if an assumed active fraction of the effluent TSS is assigned. As the model of Benefield and Randall (1978) cannot be employed under aerobic batch conditions its validation cannot be performed.

The model of Ekama et al. (2006) is both VSS and TSS based. These VSS and TSS based models were validated with aerobic digester data of van Haandel et al. (1998) and a very good correlation was obtained between predicted and measured results (Ekama et al., 2006)

2.8 Closure

In this chapter the aerobic digestion process as mediated by the OHOs, PAOs and ANOs was described. The stoichiometric relations of the occurring biological process, the factors affecting the processes and the transformations occurring during the aerobic digestion process were explained. The historical development of understanding, explaining and representing the aerobic digestion process were presented. The refinement, through time, of the reaction rate constants and the specific death rate were addressed. Representation of the decay rate during the aerobic digestion process in terms of endogenous respiration and death regeneration models were discussed. Moreover, the historical development and comparison of the existing steady state aerobic digestion models were presented. Except for the different ways of determining the Xn (Adam et al.) and Xc (Marais and Ekama), the models of Adams, Eckenfelder and Stein (1974) and of Marais and Ekama (1976) are similar. Application of the
model of Benefield and Randall (1978) under aerobic batch digestion can not be realized since the model does not assign a quantitative value to the nondegradable active TSS though the model assumes that a portion of the active influent TSS is nondegradable; nor does the model of Benefield and Randall (1978) account for a generation of inert TSS (endogenous residue) concentration during aerobic digestion. From this review, pH and temperature have a major influence on the aerobic digestion process. Especially in the aerobic digestion of BEPR WAS, it became clear that pH change can result in precipitation of inorganic phosphorus. Hence, this study of aerobic digestion of BEPR WAS was conducted with controlled pH (7.20) and complete nitrification to keep the ammonia concentration low, to control inorganic phosphorus precipitation, and in a temperature-controlled laboratory (at 20°C), for optimum biological activity. Most of the aerobic digestion studies are conducted on non-BEPR WAS which in turn shows the necessity of conducting aerobic digestion of BEPR WAS.
CHAPTER 3

EXPERIMENTAL SET UP AND PROCEDURES

3.1 Experimental set up

3.1.1 Parent system

The generator reactor (parent system) from which the WAS that was tested under aerobic digestion conditions was harvested is a UCT configuration membrane (MBR) bioreactor BNR system. The influent raw wastewater fed to the MBR UCT system was collected from the Mitchell’s Plain WWTP in Cape Town (South Africa) which treats primarily domestic wastewater, with a small (< 10%) industrial component. The MBR UCT system was fed 800 mgCOD l⁻¹ raw wastewater supplemented with 200 mgCOD l⁻¹ sodium acetate (to increase the biological P removal) and ammonium chloride and di-hydrogen potassium orthophosphate to increase the COD, TKN and phosphorus to 1000 mgCOD l⁻¹, 100 mgN l⁻¹ and 40 mgP l⁻¹ respectively.

The MBR UCT system comprised an anaerobic-anoxic-aerobic sequence of reactors with volumes of 25, 19 and 35 l and mass fractions of 0.126, 0.279 and 0.595 respectively (Figure 3.1). The system had a 20 days sludge age, was fed 140 l d⁻¹ influent flow and 2.9 l d⁻¹ waste sludge was taken directly from the aerobic reactor for sludge age control. Mixed liquor was recycled from the anoxic to anaerobic, and aerobic to anoxic reactors at ratios of 1:1 and 3:1 of the influent flow respectively. The mixed liquor suspended solids (MLSS) and MLVSS concentrations in the aerobic reactor were around 16800 mgTSS l⁻¹ and 13600 mgVSS l⁻¹ respectively, with lower concentrations in the anoxic and anaerobic reactors due to the lower concentration inflows to these reactors.

As the name implies, the MBR UCT system was equipped with five double-sided Kubota® panel membranes with total surface area of 0.586 m² acting as solid-liquid separators. The membranes were submerged in the aerobic reactor and scoured by a coarse bubble aeration system which also supplied the required oxygen demand for the biological reactions. The effluent flow through the membranes was collected via flexible silicone tubing connected to
the membrane outlets, into a common rigid polyvinyl chloride (PVC) pipe that exited through the reactor sidewall.

The sewage feed was collected from the WWTP in 2 m³ batches, trucked to the laboratory, macerated and stored in 400 l stainless steel drums refrigerated at 4°C. A sewage batch served as feed for approximately two weeks. Daily the raw sewage in one of the stainless steel tanks was thoroughly mixed, then the required volume withdrawn via a valve outlet pipe at the bottom of each tank and strained through a 1mm mesh. The appropriate volume of the screened sewage was then poured into a 200 l plastic drum where it was mixed with a tablespoon of sodium bicarbonate. The required volumes of sodium acetate, di-hydrogen potassium orthophosphate and ammonium chloride solutions were then added, and the volume made up to the required amount with tap water so that the final COD concentration was as close as possible to the target 800 mgCOD l⁻¹. Once the feed mix had been prepared in this manner, after taking a 200 ml sample, it was poured into the feed tank of the MBR UCT system. The feed bucket was maintained upright in a chest refrigerator at about 4 to 8°C and its content was gently stirred at about 10 rpm by paddle mixer to prevent sedimentation of particulates. The wastewater feed was continuously pumped for 24 h through an outlet at the bottom of the feed tank via silicon tubing.

Figure 3.1. Schematic diagram of the MBR UCT system
As part of a different research project the MBR UCT system was tested every 2\textsuperscript{nd} day for all the required parameters such as influent, reactor and effluent COD, VSS, TSS, TKN, FSA, TP, OP, nitrite, nitrate, oxygen utilization rate (OUR), diluted sludge volume index (DSVI). The data collected in this way was averaged over a sewage batch (SB). The SB averages reflected the system performance over that SB. For details see du Toit \textit{et al.} (2006). The SB average influent COD, TKN, FSA, TP, OP and measured readily biodegradable COD (RBCOD\textsuperscript{*}) concentrations and the system operating parameters constituted the input to ASM-2 simulation model to simulate the system performance. In the simulation model a number of influent wastewater characteristics and kinetic constants were adjusted so that the predicted performance matched that measured in the MBR UCT system. This was done for the SBs during which batch aerobic digestion tests were conducted to determine the theoretical initial concentrations for the batch tests. The batch tests themselves were also simulated with the calibrated ASM-2 model to compare predicted results with those measured in the batch tests. This procedure is described in greater detail below.

3.1.2 Batch aerobic reactor

The batch aerobic digestion reactor was a 5 l cylindrical Perspex vessel with graduations for measuring the level of the sludge in the reactor. The bottom of the reactor had a hole for coupling a tube for aeration. The removable top lid of the reactor had a hole for inserting DO and pH probes and for taking samples. The sludge was continuously mixed by paddle agitators driven by an electric motor mounted on top of the lid. The concentration of the DO in the reactor was controlled within the range of 2 to 5 mgO l\textsuperscript{-1} by a DO controller/OUR meter. Low-pressure compressed air was used for aeration. The air was humidified by passing it through a flask partially filled with water and entered the reactor via a diffuser stone placed at the bottom of the reactor. The air supply was automatically switched on by the DO controller/OUR meter when the DO concentration drops below 2 and switches off when it reached 5 mgO l\textsuperscript{-1}.

The DO concentration, and concomitantly the OUR was measured continuously and automatically using a YSI Model 5739 DO probe and HiTech MicroSystem DO and OUR

* Measured with a dedicated square wave fed RBCOD AS system fed the same wastewater and with floc-filtered influent and effluent COD concentrations (see du Toit \textit{et al.}, 2006)
meter. The OUR is calculated with a statistical linear least-square regression analysis on the accumulated data pairs of DO and time during air-off period. The DO data stored in the DO and OUR meter over 24 h together with the OUR values and corresponding correlation coefficients were downloaded with a cable connection to a personal computer (PC) and copied into a spreadsheet program for further analysis.

The schematic set-up of the batch aerobic digestion reactor is given in Figure 3.2.

![Figure 3.2. Schematic diagram of the batch aerobic digester reactor](image)

### 3.2 Experimental Procedures

Eight aerobic digestion batch tests (BT) with detention times ranging from 6 to 25 days were carried out at 20°C. For the first six batch tests, 5 l of undiluted sludge was harvested from the aerobic reactor of the MBR UCT system and aerobically digested for about 20 days. These six batch test (BT-1 to BT-6) were done when the MBR UCT system was fed SBs 1, 2, 2, 5, 26, and 28. The last two batch tests, i.e. BT-7, with undiluted aerobic reactor sludge and
BT-8, with diluted aerobic reactor sludge, were done simultaneously during SB 30 to compare the effect of the initial concentration of the WAS on the aerobic digestion kinetics. These two batch tests had a volume of 3 l each. The source WAS for these two batch tests was taken as a single volume of sludge from the MBR UCT system. BT-7 was fed 3 l of undiluted sludge while 0.6 l of undiluted sludge diluted 5 times, i.e. 0.6 l of WAS plus 2.4 l of distilled water was fed into BT-8.

For batch tests 1, 2 and 3 the sludge harvested from the MBR UCT system was collected over several days and stored in a cold room at 4°C. Before feeding into the aerobic batch reactors, the harvested sludge was brought to a room temperature (20°C) by placing the container with the WAS in a warm water bath. After reaching 20°C the temperature was maintained at 20°C because the batch tests were conducted in the temperature-controlled laboratory of the Water Research Group at UCT. For batch tests 4, 5 and 6, only freshly harvested sludge was fed into the aerobic reactors. Similarly, only freshly wasted sludge was used for the last two batch tests 7 and 8.

Evaporation loss in the batch tests was minimized by using humidified air and was determined by measuring the level of the sludge in the reactor each day. The evaporation loss was then compensated by adding an equivalent amount of distilled water to the reactor. By regularly cleaning and brushing the sludge that got stuck on the side wall of the reactor, all the contents of the reactor was kept in solution/suspension during the batch tests.

At the beginning of each day during the batch test, 150 ml of sample was taken from the batch reactor for analysis. Prior to taking the sample, pH was measured and if below 7.2 adjusted to 7.2. This was done by adding a measured amount of sodium bicarbonate (NaHCO₃) from a prepared stock solution. The volume, and therefore, the concentration of the sodium bicarbonate added were recorded. The pH was measured with a calibrated pH probe immersed in the aerated sludge mass.

A sample was taken daily from the batch reactor. A drop of polyelectrolyte flocculant (1 g l⁻¹) was added to the samples to make subsequent filtering easier. The sample taken was centrifuged at 3500 rpm for 10 min. All the supernatant was retained for further analysis. Part of the supernatant was filtered through 0.45μm membrane filters for filtered-sample analysis and the rest was used for unfiltered-sample analysis. The filtered and unfiltered sample
volumes remaining after performing some analysis were preserved by adding one drop of mercuric chloride (8 g l⁻¹) and kept in a cold room at 4°C.

After centrifugation, the centrifuged solids were placed in a crucible by rinsing all the solids content of the centrifuge tube into a crucible for VSS and TSS analysis. Before use, empty crucibles were cleaned, dried, labelled and weighed on an airtight digital scale with 0.1 mg resolution. The crucibles with solids were put in an oven for 12 hrs at 110°C. After removal from the oven, the crucibles containing the dried solids were put in a dessicator to cool down. The crucibles were weighed and incinerated in an oven for 20 min at 600°C. Thereafter, the crucibles were returned to the dessicator and their weights taken after cooling. From these measurements the VSS and TSS concentrations were calculated.

The COD, FSA, TKN, TP, OP, nitrite and nitrate analyses were carried out using standard procedures as set out in the Laboratory Procedures – Wastewater treatment laboratory manual (Lakay et al., 2000) and Standard Methods (1995).

For filtered and unfiltered COD analyses, 10 ml duplicate samples of each were used with a pair of flasks with 10 ml distilled water serving as blanks. Into each 250 ml Erlenmeyer flask were added 10 ml of distilled water, approximately 0.04 mg of mercuric sulphate (HgSO₄) powder, 5 ml of potassium dichromate (K₂Cr₂O₇) with normality of 0.25N and 15 ml of concentrated sulphuric acid (H₂SO₄) (37.52N, as supplied at 1840 g l⁻¹) with predissolved AgSO₄. Following thorough mixing the flasks were placed on a heating pad for 2 hrs. Once they were cooled off, approximately 80 ml of distilled water was poured through the top opening of the condenser tubes to rinse the side walls. After adding 2 drops of ferroin indicator, each flask was titrated with standardized 0.05N ferrous ammonium sulphate (Fe(NH₄)₂(SO₄)₂). The COD concentration was calculated from the average of the sample and blank titration volumes. For high COD concentrations such as unfiltered samples, the samples were first diluted into the range of the above COD procedure (0 – 1000 mgCOD l⁻¹).

For FSA and TKN analyses, 10 ml of filtered and unfiltered samples, respectively, were pipetted into 100 ml bulb TKN flasks. For TKN analysis, after adding 2 glass beads, 10 ml distilled water and a 10 ml of digestion mix into each flask, they were placed on a heating pad and boiled until the samples were clear (~2 hrs) and thereafter allowed to cool. After this digestion step, the flasks were fitted to a steam distillation unit. To each bulb flask about 10
ml of distilled water was added to dissolve the sediment. For FSA analysis the flasks were fitted into a distillation unit after the addition of filtered sample and 10 ml of distilled water. Conical flasks with 25 ml of boric acid (H₃BO₃) solution were placed at the receiving ends of the steam distillation apparatus. After adding 7 ml of 1N sodium hydroxide (NaOH), the contents of the bulb flasks were boiled until the volume of the conical flasks with boric acid reached about 50 ml. After steam distillation the conical flasks with boric acid were titrated with standard 0.001N sulphuric acid solution. The FSA and TKN concentrations were calculated from the titrant volumes. For high TKN and FSA concentrations, the samples were appropriately diluted so that the titrant volume would not exceed 50 ml.

Nitrite and nitrate analysis were done on a Technicon Auto Analyzer, in accordance with the testing procedure given in Technicon Auto-Analyser Methodology (Industrial Methods 33-69W), with the nitrate reduction to nitrite and formation of a soluble pink dye which is measured colorimetrically representing the original nitrite present plus that formed from nitrate. The filtered samples were appropriately diluted to ensure the nitrite and nitrate samples fell into the 0 to 2 mgN l⁻¹. The diluted samples were put in the auto analyser together with nine evenly spaced standards of nitrite and nitrate concentration solutions. Taking due account of the dilutions, the concentrations of the samples were determined from the plotted graphs in comparison with the standards.

For TP and OP analyses, 10 ml of unfiltered and filtered samples, respectively, were used. In separate boiling tubes 20 ml of distilled water, 20 ml of standard solutions of 5, 10, 15, 20 and 25 ppm, and 10 ml of sample and 10 ml of distilled water were pipetted. Into each tube 5 ml of potassium persulphate solution and 5 ml sulphuric acid solution were added. After closing with aluminium foil, the tubes were placed in a hot water bath (96°C) for 1h. After cooling down the samples were filtered and 5 ml of filtrate was placed in smaller tubes to which 5 ml of vanadomolybdate solution was added. The tubes were covered with ‘parafilm’ plastic and shaken for thorough mixing. After 20 minutes for colour development the samples were analysed with a UNICAM 8625 UV/VIS spectrometer at microwave length of 470 μm.

The inorganic carbon system alkalinity (H₂CO₃⁻) analyses were carried out using the 5 pH point titration procedure of Moosbrugger et al. (1992). A beaker containing 10 ml of filtered sample diluted to 50 ml with distilled water was placed on a slow magnetic stirrer. A
calibrated pH probe was dipped into the solution. After recording the initial pH and temperature, the sample was titrated from its initial pH to four further pH points symmetrically spaced about the $H_2CO_3^- - HCO_3^-$ and $HA^- - A^-_C$ pK values, with dosing increments of 0.02 ml of titrant (hydrochloric acid). The pH, temperature and dosage of titrant added were recorded at each pH point. The alkalinity (and volatile fatty acids, VFA, which was zero) of the sample was computed by inserting the recorded pHs, temperature and titrant volumes into the computer program TITRA5.

The calcium and magnesium analyses were carried out in the Laboratory of the Department of Chemical Engineering to the University of Cape Town using atomic adsorption spectroscopy analysis with atomic-adsorption spectrometer Varian AA 110 Model.

3.3 Modelling and Simulation

The SB average results of the parent system and the batch digestion results were both simulated with ASM-2 in the computer program AQUASIM. All the compounds and system descriptions required by ASM-2, such as the measured characteristics of the influent, sizes of the anaerobic, anoxic and aerobic reactors, mixed liquor recycle ratios, along with the process configuration, of the MBR UCT system were written into the AQUASIM computer program. The ASM-2 simulated values were then compared with the measured mixed liquor, waste and effluent concentrations of the various parameters of the MBR UCT system. Some kinetic and stoichiometric constants were modified to achieve the best correlation between predicted and measured results (see below). The predicted results of the parent system provided initial condition input data for the batch test simulations with ASM-2. The batch test simulation results were then compared with those measured.

3.3.1 Model description

The mathematical description of the ASM-2 is presented in a matrix format in Appendix C1. The matrix contains fifteen compounds of interest and seventeen processes. The symbols of the compounds are placed on the head of the matrix identified with index “i” for the range of the compounds, i.e., 1 through 15. The biological processes occurring in the system, identified with the index “j”, are listed on the left end column of the matrix. The
mathematical formulations of the process rates (denoted by $r_j$) are described on the right end column of the matrix. Along with the units of measurement, the compounds of interest are defined in their respective column at the bottom of the matrix. It is noteworthy to mention that all the compounds are measured in COD units, including the sludge organic solids, resulting in the ease of conservation, rate tracking and calculation.

The intersection of a pertinent compound (i) with a process (j) signifies the stoichiometric coefficient, denoted by $v_{ij}$. A specific stoichiometric coefficient could have a positive or negative sign depending on whether it represents growth/production or death/consumption, respectively. This, therefore, signifies the behaviour at a single point in the system. The matrix format enables the presentation of the lengthy and separate equations describing biological processes in a compact form and easy visualization of the flow and interaction of the different compounds and rates.

The different components of the VSS, TSS, COD, nitrogen, phosphorus and oxygen constitute the fifteen compounds. Similarly, the different processes of the OHOs, PAOs and autotrophic nitrifying organisms (ANOs) associated with growth and death, along with the hydrolysis of the particulate biodegradable substrate make up the seventeen processes of the ASM-2 model.

3.3.2 Inclusion of the ISS model into the ASM-2

In contrast to organic models, predictive models for the reactor ISS, and hence the TSS (TSS = VSS + ISS) concentrations have not been included in simulation models (Ekama and Wentzel, 2004). In ASM-1 the ISS is empirically calculated from an assumed VSS/TSS ratio, without inclusion of a fundamentally based predictive model for the accumulation of ISS in the reactor. The principle of Gujer (1993), i.e. calculating TSS from stoichiometric TSS/COD ratios for the individual mixed liquor organic compounds, is employed in ASM-2. Hence, the TSS concentration is computed via stoichiometric TSS/COD ratios for the active biomass (for OHO, PAO and ANO), $i_{\text{TSSBM}} = 0.90 \text{ mgTSS mgCOD}^{-1}$, for slowly biodegradable particulate substrate, $i_{\text{TSSXs}} = 0.75 \text{ mgTSS mgCOD}^{-1}$, for unbiodegradable (inert) organic matter, $i_{\text{TSSXi}} = 0.75 \text{ mgTSS mgCOD}^{-1}$ and for the polyphosphate (PP) content of the PAOs 3.23, mgISS (mgP-PP)$^{-1}$ (Henze et al., 2000). The difference between TSS and VSS is then the ISS. The
model has no provision for including the ISS concentration in the influent. Therefore, the ISS model, developed by Ekama and Wentzel (2004), which recognizes influent and OHO and PAO biomass ISS, was incorporated into the ASM-2 to replace the TSS/COD ratios.

The ISS model of Ekama and Wentzel (2004) was reviewed in Chapter 2 and is readily incorporated into ASM-2. The influent ISS, $X_{iss}$ accumulation in the reactor is proportional to sludge age ($R_s$) and inversely proportional to average nominal hydraulic retention time ($R_h$), the OHO ISS contribution is proportional to the OHO biomass concentration ($f_{OHO} = 0.15 \text{ mgISS mgOHOVSS}^{-1}$ or $0.10 \text{ mgISS mgOHOCOD}^{-1}$) and the PAO ISS contribution is proportional to the PAO biomass concentration (also $0.10 \text{ mgISS mgPAOCOD}^{-1}$) and the PAO P content ($f_{XBGP}$), which is obtained in the model from the simulated BEPR behaviour.

3.3.3 Model calibration

The ASM-2 was calibrated by using the measured SB average data of the MBR UCT system. First, the predicted P removal for the measured influent RBCOD concentration was reconciled with that measured. For all the SBs, the predicted P removal was higher than that measured. Because the P uptake behaviour in MBR UCT system was predominantly aerobic, as in the ASM-2 model, the predicted P removal was higher because (i) the P content of the PAO is higher than that measured due to a higher P uptake to poly-$\beta$-hydroxybutyrate (PHB) utilized (P uptake/PHB) ratio or (ii) the PAO concentration was lower because they did not take up all the influent RBCOD in the anaerobic reactor. So to match the predicted P removal to that measured for (i) the rate constant for storage of poly-P ($q_{pp}$) was decreased and for (ii) the anaerobic RBCOD fermentation rate ($q_{fe}$) was decreased. Both options were simulated. Once the predicted and measured P removal matched by adjusting $q_{pp}$ or $q_{fe}$, the unbiodegradable particulate COD fraction ($f_{S_{up}}$) was varied until the predicted VSS matched that measured. Some very minor adjustment of $q_{pp}$ and $q_{fe}$ was required to rematch the predicted and measured P removal because $f_{S_{up}}$ has a very small influence on P removal. Once the measured and predicted VSS matched, the influent ISS concentration was adjusted until the predicted and measured TSS matched. The infrequently measured influent ISS concentration matched this calibrated values quite closely. Once calibrated in this way, COD, N and P mass balances of the simulated results were checked.
Based on the average SB influent values, COD, N and P mass balances of the simulated values of the MBR UCT system were found to range from 99.8 to 100.5, 99.8 to 100.0 and 99.9 to 100.2%, respectively (Appendix A3 to A11), which is acceptable and an indication that the model was giving consistent and reliable results. Since the aerobic digestion tests were carried on the sludge harvested from the MBR UCT system, no further calibration was done on the ASM-2 model for simulating the aerobic batch digestion tests.

For the aerobic batch digestion simulations, the measured initial concentrations were taken as the initial values for simulation. For model parameters with no corresponding measured values, such as the concentration of poly phosphate (PP), the fraction of SBCOD, etc., the initial concentrations of the particulate components were determined from the ratios of the predicted VSS and TSS concentrations to the initial measured batch test concentrations. These ratios reflected the degree of dilution/concentration that took place between harvesting the sludge from the MBR UCT system and filling the batch reactor. The initial dissolved concentrations were not changed from those measured, or in the absence of measured data, those simulated for the particular SB were used. The batch test predicted and measured data were plotted graphically for each batch and evaluated. This is presented in Chapter 5.
CHAPTER 4

DEVELOPMENT OF BATCH REACTOR AND STEADY STATE MODELS FOR AEROBIC DIGESTION OF WAS FROM BEPR AS SYSTEMS

4.1 Batch Aerobic Digester (Batch Reactor Model)

4.1.1 VSS based

Based on the model of Marais and Ekama (1976), a VSS-based batch reactor model (BRM) for aerobic batch digestion of WAS from BEPR AS systems was developed.

In the development of the model the following assumptions were made:

(i) Inert volatile material, \( X_I \) (mgVSS l\(^{-1}\)) is unaffected by digestion

(ii) The active OHOs, \( X_H \) (mgAOHOVSS l\(^{-1}\)) degrade at a specific endogenous respiration or mass loss rate of \( b_H \) in accordance with:

\[
\frac{dX_H}{dt} = -b_H X_H \tag{4.1}
\]

where \( b_H = 0.24 \) day\(^{-1}\) at 20°C

(iii) A fraction of the active OHOs that is degraded, \( f_H \) remains as endogenous residue, \( X_{eH} \) (mgVSS l\(^{-1}\))

\[
\frac{dX_{eH}}{dt} = f_H \left( -\frac{dX_H}{dt} \right) = f_H b_H X_H \tag{4.2}
\]

(iv) The active PAOs, \( X_G \) (mgAPAOVSS l\(^{-1}\)) degrade at a specific endogenous respiration or mass loss rate of \( b_G \) in accordance with:

\[
\frac{dX_G}{dt} = -b_G X_G \tag{4.3}
\]
(v) A fraction of the active PAOs that is degraded, $f_G$, remains as endogenous residue, $X_{eG}$ (mgVSS l$^{-1}$)

$$\frac{dX_{eG}}{dt} = f_G (\frac{dX_G}{dt}) = f_G b_G X_G$$  \hfill (4.4)

(vi) The balance of the active OHOs and PAOs from (iii) and (v) above, i.e. $(1 - f_H)b_H X_H$ and $(1 - f_G)b_G X_G$ are utilized catabolically as substrate and oxidized with oxygen as electron acceptor,

$$\frac{dOU_H}{dt} = O_{eH} = f_{eH} (1 - f_H)b_H X_H \quad (\text{mgO l}^{-1} \text{d}^{-1})$$  \hfill (4.5)

$$\frac{dOU_G}{dt} = O_{eG} = f_{eG} (1 - f_G)b_G X_G \quad (\text{mgO l}^{-1} \text{d}^{-1})$$  \hfill (4.6)

$$O_e = O_{eH} + O_{eG} \quad (\text{mgO l}^{-1} \text{d}^{-1})$$  \hfill (4.7)

where

$X_H$ = Concentration of active OHOs (mg l$^{-1}$)

$X_{eH}$ = Concentration of endogenous residue of the OHOs (mg l$^{-1}$)

$b_H$ = OHOs endogenous respiration rate, (day$^{-1}$)

$f_H$ = Fraction of endogenous residue of the OHOs

$f_{eH}$ = COD/VSS ratio of the OHOs (mgCOD mgOHOVS$^{-1}$)

$O_{eH}$ = OUR at any time t associated with the OHOs (mgO l$^{-1}$ d$^{-1}$)

$OU_H$ = Oxygen utilized by the OHOs (mgO d$^{-1}$)

$X_G$ = Concentration of active PAOs (mg l$^{-1}$)

$X_{eG}$ = Concentration of endogenous residue of the PAOs (mg l$^{-1}$)

$b_G$ = PAOs endogenous respiration rate, (day$^{-1}$)

$f_G$ = Fraction of endogenous residue of the PAOs

$f_{eG}$ = COD/VSS ratio of the PAOs (mgCOD mgPAOVSS$^{-1}$)

$O_{eG}$ = OUR at any time t associated with the PAOs (mgO l$^{-1}$ d$^{-1}$)

$OU_G$ = Oxygen utilized by the PAOs (mgO d$^{-1}$)

$O_e$ = OUR for endogenous respiration (mgO l$^{-1}$ d$^{-1}$)
During the aerobic batch digestion, the VSS at time \( t \), \( X_{VIS} \) is

\[
X_{VIS} = X_{H} + X_{G} + X_{eH} + X_{eG} + X_{I} \tag{4.8}
\]

where

\( X_{H} \) = Concentration of active OHOs at time \( t \) (mg l\(^{-1}\))

\( X_{G} \) = Concentration of active PAOs at time \( t \) (mg l\(^{-1}\))

\( X_{eH} \) = Concentration of endogenous residue of the OHOs at time \( t \) (mg l\(^{-1}\))

\( X_{eG} \) = Concentration of endogenous residue of the PAOs at time \( t \) (mg l\(^{-1}\))

\( X_{I} \) = Concentration of inert material at time \( t \) (mg l\(^{-1}\))

The inert material, \( X_{I} \) remains constant and equal to the influent inert material, \( X_{H} \) whereas \( X_{H}, X_{G}, X_{eH} \) and \( X_{eG} \) are altered during the digestion process.

The degradation of the active OHO-VSS, \( X_{H} \) is given by Equation (4.1) which has the solution

\[
X_{H} = X_{H0} e^{-b_{H}t} \tag{4.9}
\]

where \( X_{H0} \) = Initial concentration of active OHOs (mg l\(^{-1}\))

From every unit of \( X_{H} \) that disappears, \( f_{H} \) units of \( X_{eH} \) are generated, i.e.

\[
X_{eH} = f_{H} (X_{H} - X_{H0}) \tag{4.10}
\]

where \( f_{H} = 0.20 \)

Substituting from Equation (4.9) into Equation (4.10) and simplifying yields

\[
X_{eH} = f_{H} X_{H0} (1 - e^{-b_{H}t}) \tag{4.11}
\]

The degradation of the active PAO-VSS, \( X_{G} \) is given by Equation (4.3) which has the solution
\[ X_{Gi} = X_{Gi}e^{-b_{Gi}t} \]  
(4.12)

where \( X_{Gi} \) = Initial concentration of active PAOs (mg l\(^{-1}\))

From every unit of \( X_G \) that disappears, \( f_G \) units of \( X_{eG} \) are generated, i.e.

\[ X_{eG} = f_G (X_{Gi} - X_{Gi}) \]  
(4.13)

where \( f_G = 0.25 \)

Substituting from Equation (4.12) into Equation (4.13) and simplifying yields

\[ X_{eG} = f_G X_{Gi} (1-e^{-b_{Gi}t}) \]  
(4.14)

Hence, the total concentration of the endogenous residue at time \( t \), \( X_{ei} \) in the batch aerobic digester is given by

\[ X_{ei} = X_{eh} + X_{eG} = f_H X_{eh} (1-e^{-b_{eh}t}) + f_G X_{Gi} (1-e^{-b_{Gi}t}) \]  
(4.15)

The VSS concentration at any time \( t \), \( X_{Vt} \) in the batch aerobic digester is given by Equation (4.8). Substituting from Equations (4.9), (4.12) and (4.15) into Equation (4.8) yields

\[ X_{Vt} = X_{eh}e^{-b_{eh}t} + X_{Gi}e^{-b_{Gi}t} + f_H X_{eh} (1-e^{-b_{eh}t}) + f_G X_{Gi} (1-e^{-b_{Gi}t}) + X_{hl} \]  
(4.16)

Simplifying and rearranging Equation (4.16) yields

\[ X_{Vt} = X_{hl}(f_{hl} + (1-f_{hl})e^{-b_{hl}t}) + X_{Gi}(f_G + (1-f_G)e^{-b_{Gi}t}) + X_{hl} \]  
(4.17)

The change (reduction) in VSS concentration at any time \( t \), \( \Delta X_{Vt} \) is given by

\[ \Delta X_{Vt} = X_{Vt} - X_{Vt} \]  
(4.18)
where $X_{vi}$ = Initial concentration of the VSS (mg l$^{-1}$)

Substituting from Equation (4.17) into Equation (4.18) yields

$$\Delta X_{vi} = (X_{mi} + X_{gi} + X_{ni}) - \left[ X_{mi} \{ f_H + (1-f_H) e^{-b_{H1}t} \} + X_{gi} \{ f_G + (1-f_G) e^{-b_{G1}t} \} + X_{ni} \right] \quad (4.19)$$

Simplifying and rearranging Equation (4.19) yields

$$\Delta X_{vi} = \{ X_{mi} (1-f_H)(1-e^{-b_{H1}t}) \} + \{ X_{gi} (1-f_G)(1-e^{-b_{G1}t}) \} \quad (4.20)$$

The fraction of VSS removed (VSS destruction) at any time $t$, $f_{vn}$ is given by

$$f_{vn} = \frac{\Delta X_{vi}}{X_{vi}} \quad (4.21)$$

Substituting from Equation (4.20) into Equation (4.21) yields

$$f_{vn} = \frac{X_{mi} (1-f_H)(1-e^{-b_{H1}t}) + X_{gi} (1-f_G)(1-e^{-b_{G1}t})}{X_{vi}} \quad (4.22)$$

If $\frac{X_{mi}}{X_{vi}} = f_{aHvi}$ (initial active fraction of the OHOVSS) and $\frac{X_{gi}}{X_{vi}} = f_{aGvi}$ (initial active fraction of the PAOVSS), then

$$f_{vn} = f_{aHvi} (1-f_H)(1-e^{-b_{H1}t}) + f_{aGvi} (1-f_G)(1-e^{-b_{G1}t}) \quad (4.23)$$

The concentration of the organic N released into the bulk liquid as ammonia and subsequently nitrified to nitrate is equal to the N content of the VSS concentration removed.

Accepting the N content of the OHO and PAOVSS to be $f_a$, the nitrate concentration in the batch aerobic digester at any time $t$ will be
\[ N_{nt} = f_n X_{vi} f_{nt} \quad \text{(mgNO}_3\text{-N l}^{-1}) \]  \hspace{1cm} (4.24)

where \( f_n = 0.10 \text{ mgN mgVSS}^{-1} \)

Substituting from Equation (4.22) into Equation (4.24) yields

\[ N_{nt} = f_n X_{vi} \frac{X_{lh}(1 - f_{nt})(1 - e^{-b_n t}) + X_{G}(1 - f_{G})(1 - e^{-b_G t})}{X_{vi}} \quad \text{(mgNO}_3\text{-N l}^{-1}) \]  \hspace{1cm} (4.25)

Simplifying and rearranging Equation (4.25) yields

\[ N_{nt} = f_n \left\{ X_{lh}(1 - f_{nt})(1 - e^{-b_n t}) + X_{G}(1 - f_{G})(1 - e^{-b_G t}) \right\} \quad \text{(mgNO}_3\text{-N l}^{-1}) \]  \hspace{1cm} (4.26)

The concentration of the P released into the bulk liquid appearing as OP is the sum of the P contents of the OHOs and PAOs removed.

The OHOVSS removed, \( f_{HVnt} \) at time \( t \) will be

\[ f_{HVnt} = \frac{\Delta X_{ht}}{X_{vi}} = \frac{X_{hi} - X_{ht}}{X_{vi}} \]  \hspace{1cm} (4.27)

Substituting from Equation (4.9) into Equation (4.27) and simplifying yields

\[ f_{HVnt} = \frac{\Delta X_{ht}}{X_{vi}} = \frac{X_{hi} - (X_{hi} e^{-b_n t})}{X_{vi}} = f_{sHV}(1-e^{-b_n t}) \]  \hspace{1cm} (4.28)

and the PAOVSS removed, \( f_{GVnt} \) at time \( t \) will be

\[ f_{GVnt} = \frac{\Delta X_{Gt}}{X_{vi}} \]  \hspace{1cm} (4.29)

Substituting from Equation (4.12) into Equation (4.29) and simplifying yields
\[ f_{GV,t} = \frac{\Delta X_{G,i}}{X_{Vi}} = \frac{X_{G,i} - (X_{G,i}e^{-b_{i,t}})}{X_{Vi}} = f_{aGV,i}(1 - e^{-b_{i,t}}) \] (4.30)

Accepting the P content of the OHOs to be \( f_{p,h} \), the contribution of the OP concentration of the OHOs in the batch aerobic digester at any time \( t \) will be

\[ P_{slh} = f_{p,h} X_{Vi} f_{GV,t} \] (mgOP l\(^{-1}\)) (4.31)

Substituting from Equation (4.28) into Equation (4.31) yields

\[ P_{slh} = f_{p,h} f_{ahVi} X_{Vi} (1 - e^{-b_{i,t}}) \] (mgOP l\(^{-1}\)) (4.32)

where \( f_{p,h} = 0.03 \text{ mgP mgOHOVSS}^{-1} \) (Wentzel et al., 1990)

Accepting the P content of the PAOs to be \( f_{p,G} \), the contribution of the OP concentration of the PAOs in the batch aerobic digester at any time \( t \) will be

\[ P_{sgl} = f_{p,G} X_{Vi} f_{GV,t} \] (mgOP l\(^{-1}\)) (4.33)

Substituting from Equation (4.30) to Equation (4.33) yields

\[ P_{sgl} = f_{p,G} f_{aGV,i} X_{Vi} (1 - e^{-b_{i,t}}) \] (mgOP l\(^{-1}\)) (4.34)

where \( f_{p,G} = 0.38 \text{ mgP mgPAOVSS}^{-1} \) (Wentzel et al., 1990)

Therefore, the total OP concentration in the batch aerobic digester at any time \( t \) will be

\[ P_{sl} = P_{slh} + P_{sgl} = f_{p,h} f_{ahVi} X_{Vi} (1 - e^{-b_{i,t}}) + f_{p,G} f_{aGV,i} X_{Vi} (1 - e^{-b_{i,t}}) \] (mgOP l\(^{-1}\)) (4.35)

The OUR at any time \( t \) associated with the OHOs, \( O_{lh} \) in the batch aerobic digester is
Substituting from Equation (4.9) into Equation (4.36) yields

\[ O_{ht} = \frac{1}{24} (1 - f_{ht}) f_{vht} b_{ht} X_{ht} e^{-h_{ht} t} \quad \text{(mgO l}^{-1} \text{ h}^{-1}) \] (4.37)

The OUR at any time \( t \) associated with the PAOs, \( O_{Gt} \) in the batch aerobic digester is

\[ O_{Gt} = \frac{1}{24} (1 - f_{G}) f_{vG} b_{G} X_{Gt} e^{-b_{G} t} \quad \text{(mgO l}^{-1} \text{ h}^{-1}) \] (4.38)

Substituting from Equation (4.12) into Equation (4.38) yields

\[ O_{Gt} = \frac{1}{24} (1 - f_{G}) f_{vG} b_{G} X_{Gt} e^{-b_{G} t} \quad \text{(mgO l}^{-1} \text{ h}^{-1}) \] (4.39)

The carbonaceous (endogenous respiration) OUR at any time \( t \), \( O_{ct} \) in the batch aerobic digester is the sum of the OUR of the OHOs and the PAOs, i.e.

\[ O_{ct} = O_{ht} + O_{Gt} \quad \text{(mgO l}^{-1} \text{ h}^{-1}) \] (4.40)

Hence,

\[ O_{ct} = \frac{1}{24} [\{(1 - f_{ht})(f_{vht} b_{ht} X_{ht} e^{-h_{ht} t})\} + \{(1 - f_{G})(f_{vG} b_{G} X_{Gt} e^{-b_{G} t})\}] \quad \text{(mgO l}^{-1} \text{ h}^{-1}) \] (4.41)

With the occurrence of complete nitrification, the nitrification OUR in the batch aerobic digester at any time \( t \), \( O_{nt} \) is

\[ O_{nt} = \frac{4.57}{24} f_{n} \{ (1 - f_{ht})(b_{ht} X_{ht} e^{-h_{ht} t}) + (1 - f_{G})(b_{G} X_{Gt} e^{-b_{G} t}) \} \quad \text{(mgO l}^{-1} \text{ h}^{-1}) \] (4.42)
where 4.57 = mgO required per mgNH\textsubscript{4}-N nitrified to NO\textsubscript{3}-N

The total OUR, with complete nitrification, in the batch aerobic digester at any time t, \( O_n \) will, then, be the sum of the carbonaceous and nitrification OUR, i.e.

\[
O_n = O_c + O_n\text{'}, \quad \text{(mgO l}^{-1}\text{ h}^{-1})
\]

(4.43)

Substituting from Equation (4.41) and (4.42) into Equation (4.43) yields

\[
O_n = \frac{1}{24} \left[ \left( (1 - f_H) (f_{cvH} b_H X_{Hh} e^{-b_H t}) \right) + \left( (1 - f_G) (f_{cvG} b_G X_{Gh} e^{-b_G t}) \right) \right] + \frac{4.57}{24} f_n \left( (1 - f_H) (b_H X_{Hn} e^{-b_H t}) + (1 - f_G) (b_G X_{Gn} e^{-b_G t}) \right)
\]

(4.44)

(mgO l\textsuperscript{-1} h\textsuperscript{-1})

Simplifying and rearranging Equation (4.44) yields

\[
O_n = \frac{1}{24} \left[ \left( f_{cvH} + 4.57 f_n \right) (1 - f_H) (X_{Hh} b_H e^{-b_H t}) + \left( f_{cvG} + 4.57 f_n \right) (1 - f_G) (X_{Gh} b_G e^{-b_G t}) \right]
\]

(4.45)

(mgO l\textsuperscript{-1} h\textsuperscript{-1})

If \( \frac{X_{Hh}}{X_{vi}} = f_{uHvi} \) (initial active fraction of the OHOVSS) and \( \frac{X_{Gi}}{X_{vi}} = f_{uGvi} \) (initial active fraction of the PAOVSS), then

\[
\frac{O_n}{X_{vi}} = \frac{1}{24} \left[ \left( f_{cvH} + 4.57 f_n \right) (1 - f_H) f_{uHvi} b_H e^{-b_H t} + \left( f_{cvG} + 4.57 f_n \right) (1 - f_G) f_{uGvi} b_G e^{-b_G t} \right]
\]

(4.46)

(mgO [mgVSS.l.h]^{-1})

where \( \frac{O_n}{X_{vi}} \) is the total OUR per influent VSS into the aerobic digester.

Similarly, multiplying both sides of Equation (4.45) by the volume of the digester and 24 hrs per day and noting that \( \frac{M X_{Hh}}{M X_{vi}} = f_{uHvi} \) and \( \frac{M X_{Gi}}{M X_{vi}} = f_{uGvi} \) results in
\[
\frac{MO}{MX} = (f_{vH} + 4.57 f_u)(1 - f_{H})(f_{uH} b_H e^{-k_{H}}) + (f_{vG} + 4.57 f_u)(1 - f_{G})(f_{uG} b_G e^{-k_{G}})
\]

(4.47) (kgO kgVSS\(^{-1}\) day\(^{-1}\))

where \(\frac{MO}{MX}\) is the mass of oxygen required per day per kgVSS sludge load per day.

**Steady State BEPR model of Wentzel et al. (1990)**

Wentzel et al. (1990) developed a steady state BEPR model as a simplification of their kinetic model. Though the models apply strictly for enhanced cultures of polyP and non polyP organisms, with modification application is made for mixed cultures. For model development see Wentzel et al. (1990). The diagrammatic representation is given in Figure 4.1.

![Diagram](attachment:image.png)

**Figure 4.1. The UCT system**

Hence, from the equations developed by Wentzel et al. (1990) for biological excess phosphorus removal – steady state process design, the biological active mass of the PAOs
generated in the BEPR AS system, the WAS of which becomes the influent active PAO mass to the aerobic digester, is given by

$$MX_G = \frac{Y_G MS_{seq} R_s}{(1 + b_G R_s)} \text{ mgPAOVSS}$$

(4.48)

And

$$MS_{seq} = MS_{CON} + Q_i S_{bsai} \text{ mgPAOVSS}$$ (4.49)

$$MS_{CON} = Q_i [S'_{bsfi} - (1 + r) S_{bsfi}]$$ (4.50)

$$S'_{bsfi} = S_{bsfi} - 8.6 (r NO_{3r} + NO_{3i}) - 3.0 (r O_r + O_i)$$ (4.51)

$$S_{bsfi} = \frac{S'_{bsfi} / (1 + r)}{[1 + K_C T \frac{f_{se}}{N_r} \left( \frac{MX_H}{Q_i \sqrt{1 + r}} \right)]^n}$$ (4.52)

$$\frac{MX_H}{Q_i} = \left[ S_{bsfi} - (1 + r) S_{bsfi} + S_{bsai} \right] Y_H R_s$$ (4.53)

where

- $MX_G$ = Biological active mass of the PAOs generated in the BEPR AS system (mgPAOVSS)
- $Y_G$ = PAOs yield (mgPAOVSS mgCOD$^{-1}$)
- $MS_{seq}$ = Mass of substrate sequestered by the PAOs in the anaerobic reactor (mgCOD d$^{-1}$)
- $R_s$ = Sludge age of the BEPR AS system
- $MS_{CON}$ = Fermentable RBCOD (F-RBCOD) converted to SCFA
- $Q_i$ = Influent average dry weather flow to BEPR system (1 day$^{-1}$)
- $S_{bsai}$ = SCFA in the influent (mgCOD l$^{-1}$)
- $S'_{bsfi}$ = F-RBCOD available for conversion per litre of influent (mgCOD l$^{-1}$)
- $S_{bsfi}$ = RBCOD concentration leaving the n$^{th}$ anaerobic reactor in the series of N anaerobic reactors (mgCOD l$^{-1}$)
- $S_{bsfi}$ = Influent F-RBCOD concentration (mgCOD l$^{-1}$)
- $r$ = Recycle ratio to the anaerobic reactor with respect to the influent flow of the
BEPR AS system

\[ \text{NO}_3^r = \text{Nitrate recycled to the anaerobic reactor of the BEPR AS system} \]

\[ \text{NO}_3^i = \text{Nitrate in the influent to the anaerobic reactor of the BEPR AS system} \]

\[ \text{O}_r = \text{Oxygen recycled to the anaerobic reactor of the BEPR AS system} \]

\[ \text{O}_i = \text{Oxygen in the influent to the anaerobic reactor of the BEPR AS system} \]

\[ 0.86 = \text{Mass of COD removed per unit nitrate denitrified in synthesis (mgCOD mgNO}_3^-\text{N}^{-1}) \]

\[ 3.0 = \text{Mass of COD removed per unit oxygen utilized (mgCOD mgO}^{-1}) \]

\[ K_{CT} = \text{First order rate constant for conversion of F-RBCOD to SCFA RBCOD at temperature T (0.06 day}^{-1} \text{ at 20}^\circ\text{C}) \]

\[ f_{xa} = \text{Anaerobic mass fraction} \]

\[ N_r = \text{Total number of anaerobic reactors of equal volume in series } n = 1, 2, \ldots, N \]

\[ MX_H = \text{Active mass of the OHOs generated in the BEPR AS system, forming the influent mass of active OHOs to the aerobic digester (mgOHO)} \]

\[ Y_H = \text{OHOs yield (mgAOHOVSS mgCOD}^{-1}) \]

Equations (4.52 and 4.53) are solved simultaneously to calculate the concentration of F-RBCOD, leaving the last anaerobic reactor (\( N_r \)) with the following iterative steps (Wentzel et al., 1990):

- Assume \( S_{\text{bas}N} = 0 \text{ mgCOD l}^{-1} \)
- Calculate \( MX_{iV}/Q \) using Equation (4.53)
- Using the calculated value of \( MX_{iV}/Q \), calculate \( S_{\text{bas}N} \) using Equation (4.52)
- Recalculate \( MX_{iV}/Q \) using the calculated value of \( S_{\text{bas}N} \)
- Repeat the last two steps until \( S_{\text{bas}N} \) and \( MX_{iV}/Q \) remain constant.

The endogenous mass of the PAOs generated in the AS system, the WAS of which forms part of the influent organic inert material to the aerobic digester is given by

\[ MX_{eG} = f_{eG} b_G MX_G R_i \text{ mgVSS} \]  

(4.54)

Determining the biological active mass of the OHOs generated in the AS system, the WAS of which becomes the influent active OHO mass to the aerobic digester, from the equation developed by Marais and Ekama (1976) for steady state AS process design:
\[ MX_H = \frac{Y_H MS_H R_s}{(1 + b_H R_s)} \text{ mgPAOVSS} \quad (4.55) \]

And

\[ MS_H = MS_{bi} - MS_{seq} \text{ mgPAOVSS} \quad (4.56) \]
\[ MS_{bi} = MS_u (1 - f_{S_{up}} - f_{S_{up'}}) \quad (4.57) \]

where

\[ MS_H = \text{Mass of biodegradable substrate available to OHOs (mgCOD day}^{-1}) \]
\[ MS_{bi} = \text{Mass of biodegradable substrate in the influent (mgCOD day}^{-1}) \]

From the equation developed by Marais and Ekama (1976), the endogenous mass of the OHOs generated in the AS system, the WAS of which forms part of the influent organic inert material to the aerobic digester, \( MX_{eh} \):

\[ MX_{eh} = f_{eh} b_H MX_H R_i \text{ mgVSS} \quad (4.58) \]

The WAS of the inert mass, which exits the BEPR AS system unaltered (Marais and Ekama, 1976), forms part of the influent organic inert material to the aerobic digester:

\[ MX_I = f_{S_{up}} Q_i S_{ii} R_i / f_{cvH} \text{ mgVSS} \quad (4.59) \]

where

\[ S_{ii} = \text{Influent COD to the BEPR AS system} \]
\[ f_{cvH} = \text{COD/VSS ratio of the OHOs} \]

Therefore, the influent active OHO mass into the aerobic digester is given by the sum of the influent OHOs and PAOs:

\[ MX_{hi} = \frac{MX_H}{R_s} \text{ mgVSS} \quad (4.60) \]

And the influent active PAO mass into the aerobic digester is given by
4.14

\[ MX_{Gi} = \frac{MX_{Gi}}{R_i} \quad \text{mgVSS} \quad (4.61) \]

Hence, the influent active VSS mass into the aerobic digester is given by the sum of the influent OHOs and PAOs:

\[ MX_{vi} = MX_{hi} + MX_{Gi} \quad \text{mgVSS} \quad (4.62) \]

And the influent organic inert mass into the aerobic digester is given by the sum of the endogenous masses of the OHOs and PAOs generated in the BEPR AS system and the inert mass:

\[ MX_{hi} = \frac{1}{R_i} (MX_{eh} + MX_{eG} + MX_i) \quad \text{mgVSS} \quad (4.63) \]

From the MBR UCT system (Figure 3.1) using Equations (4.48 to 4.63) and the constants listed in Table 4.1, the active OHO and PAO concentrations in the MBR UCT system were determined. From these computed OHOVSS, PAOVSS, OHO and PAO endogenous and organic inert material concentrations in the parent system (with 20 days of sludge age), the influent active fractions of the VSS (f_{vi}), PAOVSS (f_{Gvi}) and OHOVSS (f_{Hvi}) into the aerobic batch digester were 37.6, 25.7 and 11.9% respectively. These active fractions were comparable to the simulated values computed with ASM-2 (see Chapter 5). Based on these influent active VSS, OHOVSS and PAOVSS fractions into the aerobic batch digester, the concentrations of the active VSS, OHOVSS and PAOVSS and the corresponding endogenous residue concentrations, the effluent active VSS, OHOVSS and PAOVSS fractions, the fraction of VSS, OHOVSS and PAOVSS removed, the effluent nitrate and total OP concentrations along with P release from the OHOs and PAOs, and the carbonaceous, nitrification and total oxygen demands of the aerobic batch digester were computed using the developed Equations (4.9 – 4.45) for hydraulic retention times ranging from 0 – 30 days (Figures 4.1a and b to 4.3a and b).
Figure 4.1a and b. Active OHOVSS, endogenous residue of the OHOs and inert material concentration, and active PAOVSS, endogenous residue of the PAOs and inert material concentration during aerobic digestion.

Table 4.1. Constants used in the determination of the influent active fractions of the OHOVSS, PAOVSS and VSS from the MBR UCT system for aerobic batch digestion.

<table>
<thead>
<tr>
<th>Constant</th>
<th>Value</th>
<th>Unit</th>
<th>Constant</th>
<th>Value</th>
<th>Unit</th>
<th>Constant</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_{cVH}</td>
<td>1.48</td>
<td>mgCOD mgVSS(^{-1})</td>
<td>f_{bs}</td>
<td>0.46</td>
<td>mgCOD l(^{-1})</td>
<td>NO(_3)(_r)</td>
<td>1.00</td>
<td>mgN l(^{-1})</td>
</tr>
<tr>
<td>f_{cG}</td>
<td>1.48</td>
<td>mgCOD mgVSS(^{-1})</td>
<td>f_{S\text{up}}</td>
<td>0.20</td>
<td>mgCOD l(^{-1})</td>
<td>NO(_3)(_i)</td>
<td>0.00</td>
<td>mgN l(^{-1})</td>
</tr>
<tr>
<td>b(_H)</td>
<td>0.24</td>
<td>day(^{-1})</td>
<td>f_{Sus}</td>
<td>0.04</td>
<td>mgCOD l(^{-1})</td>
<td>O(_r)</td>
<td>0.00</td>
<td>mgO l(^{-1})</td>
</tr>
<tr>
<td>b(_G)</td>
<td>0.04</td>
<td>day(^{-1})</td>
<td>Y(_H)</td>
<td>0.45</td>
<td>day(^{-1})</td>
<td>O(_i)</td>
<td>0.00</td>
<td>mgO l(^{-1})</td>
</tr>
<tr>
<td>f(_n)</td>
<td>0.10</td>
<td>mgN mgVSS(^{-1})</td>
<td>Y(_G)</td>
<td>0.45</td>
<td>day(^{-1})</td>
<td>f_{sa}</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>f_{eH}</td>
<td>0.20</td>
<td></td>
<td>Q(_i)</td>
<td>140</td>
<td>l day(^{-1})</td>
<td>K(_CT)</td>
<td>0.06</td>
<td>day(^{-1})</td>
</tr>
<tr>
<td>f_{eG}</td>
<td>0.25</td>
<td></td>
<td>S(_i)</td>
<td>944</td>
<td>mgCOD l(^{-1})</td>
<td>N(_r)</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>f_{ph}</td>
<td>0.03</td>
<td>mgP mgOHOVSS(^{-1})</td>
<td>R(_s)</td>
<td>20.00</td>
<td>day</td>
<td>n</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>f_{pg}</td>
<td>0.38</td>
<td>mgP mgPAOVSS(^{-1})</td>
<td>r</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The concentrations of oxygen and nitrate in the influent to the MBR UCT system were assumed to be zero. Moreover, the nitrate concentration in the recycle flow to the anaerobic reactor and the fraction of the WAS with respect to the total VSS in the MBR UCT system were taken as 1.0 mg l\(^{-1}\) and 0.20 respectively. An average value of influent COD concentration of 944 mgCOD l\(^{-1}\) was used.
Figure 4.2a and b. Active VSS, total endogenous residue and inert material concentrations, and active effluent fractions of the OHOVSS, PAOVSS and total VSS (%) and fractions of OHOVSS, PAOVSS and total VSS removed(%) during aerobic digestion.

Figure 4.3a and b. Mass of effluent nitrate and phosphorus release from the OHOs and PAOs, and mass of carbonaceous, nitrification and total oxygen demand during aerobic batch digestion.

4.1.2 Adding the ISS and TSS to the aerobic batch reactor model (BRM)

Based on the models of Marais and Ekama (1976) and Ekama et al. (2006), a TSS (VSS + ISS) batch reactor model (BRM) with predicted ISS for the aerobic batch digestion of WAS from BEPR AS systems was developed.
In the development of adding the ISS concentration to the BRM, the following assumptions from the ISS model of Ekama and Wentzel (2004) were added:

(a) Precipitation of minerals in the biological reactor (unless stimulated by chemical precipitant dosing) and dissolution of influent ISS, are considered negligible

(b) The OHOs and the PAOs contain inorganic dissolved solids (IDS) as part of their cell contents which, when sludge samples are dried and incinerated in the TSS-VSS test procedure, precipitate as inorganic solids. Additionally, the PAOs take up IDS and store it as counter ions associated with polyphosphates (PP, see Chapter 5, Section 5.2.6.2). Because of their negligible contribution (< 2%) the IDS content of the ANOs is neglected

(c) Slowly biodegradable particulate substrate and endogenous residue do not contain an inorganic component

(d) The P content of the remaining live PAOs remains constant during digestion (an aspect that was investigated in this research – see Chapter 5, Section 5.2.6)

The TSS (TSS = VSS + ISS) in the aerobic batch reactor, $X_T$ at time $t$ is

$$X_T = X_v + X_{i,OHO} + X_{i,PAO} + X_{i,ot}$$

(4.64)

where

$X_{i,OHO}$ = Concentration of active OHOs at time $t$ (mgOHOVSS l$^{-1}$)

$X_{i,PAO}$ = Concentration of active PAOs at time $t$ (mgPAOVSS l$^{-1}$)

$X_{e,OHO}$ = Concentration of endogenous residue of the OHOs at time $t$ (mgVSS l$^{-1}$)

$X_{e,PAO}$ = Concentration of endogenous residue of the PAOs at time $t$ (mgVSS l$^{-1}$)

$X_{i,ot}$ = Concentration of inert organic material in the WAS (originating from the unbiodegradable organics from the influent plus the endogenous residue concentrations of the OHOs and PAOs from the AS system) at time $t$ (mgVSS l$^{-1}$)

$X_{i,ot}$ = Concentration of inert inorganic material originating from the influent at time $t$ (mgTSS l$^{-1}$)

$f_{OHO}$ = Inorganic suspended solids content of OHO cell mass (0.15 mgISS mgOHOVSS$^{-1}$)

$f_{PAO}$ = Inorganic suspended solids content of PAOs (mgISS mgPAOVSS$^{-1}$)

And
\[ f_{\text{PAO}} = f_{\text{PAO}BM} + 3.286(f_{\text{XBGP}} - f_{\text{XBGP}BM}) \] (2.64)

\[ f_{\text{XBGP}} = f_{\text{XBGP}BM} + f_{\text{XBGP}PP} \] (2.65)

where

\[ f_{\text{PAO}BM} = \text{ISS content of PAO cell mass (0.15 mgISS mgPAO VSS}^{-1}) \]

\[ f_{\text{XBGP}} = \text{Total P content of PAOs (mgP mgPAO VSS}^{-1}) \]

\[ f_{\text{XBGP}PP} = \text{PP content of PAOs (0.03 mgP mgPAO VSS}^{-1}) \]

3.286 = ISS mass of the PAO intracellular PP (mgISS mgPP-P}^{-1})

The inert organic material \((X_i)\), which is the unbiodegradable particulate organics from the influent and the endogenous residue of the OHOs and PAOs from the AS system, and the inorganic material \((X_{io})\) originating from the influent, remain constant and equal to the digester influent inert material, \(X_{ii}\) and \(X_{ioi}\) respectively, whereas \(X_{He}, X_{Ge}, X_{eH}\) and \(X_{eG}\) are altered during the digestion process.

\[ X_{ii} = X_{ie} \] (4.65)

\[ X_{ioi} = X_{ioe} \] (4.66)

where

\(X_i\) = concentration of inert organic material, subscripts ‘i’ and ‘e’ refer to influent and effluent (mgISS l}^{-1})

\(X_{io}\) = concentration of inert inorganic material, subscripts ‘i’ and ‘e’ refer to influent and effluent (mgISS l}^{-1})

The degradation of the active OHOVSS, \(X_{Hi}\) is given by Equation (4.1) which has the solution

\[ X_{Hi} = X_{Hi}e^{-hu_t} \] (4.9)

where \(X_{Hi}\) = Initial concentration of active OHOs (mg l}^{-1})

From every unit of \(X_{ii}\) that disappears, \(f_{ii}\) units of \(X_{eH}\) are generated, i.e.
\[ X_{\text{eth}} = f_H X_{\text{th}} (1-e^{-b_H t}) \] (4.11)

The degradation of the active PAOVSS, \(X_G\) is given by Equation (4.3) which has the solution

\[ X_{G_t} = X_{G_i} e^{-b_G t} \] (4.12)

where \(X_{G_i}\) = Initial concentration of active PAOs (mg l\(^{-1}\))

From every unit of \(X_G\) that disappears, \(f_G\) units of \(X_{\text{eth}}\) are generated, i.e.

\[ X_{\text{eth}} = f_G X_{G_t} (1-e^{-b_G t}) \] (4.14)

The total endogenous residue concentration at time \(t\), \(X_{\text{et}}\) in the batch aerobic digester is given by Equation (4.15). Hence the VSS concentration at time \(t\), \(X_{V_1}\) is given by Equation (4.16) and after substitution and simplification by Equation (4.17). From the above, it is clear that the decrease in VSS with time is identical to that developed above in Section 4.1.1. The calculation of the ISS and, therefore, TSS simply adds these two parameters to the VSS model.

The TSS concentration at any time \(t\), \(X_{T_1}\) in the batch aerobic digester is given by Equation (4.64). Substituting from Equation (4.9), (4.11), (4.12), and (4.14) into Equation (4.64) yields

\[ X_{T_1} = X_{\text{et}} + X_{\text{Gt}} e^{-b_G t} + f_H X_{\text{th}} (1-e^{-b_H t}) + f_G X_{G_t} (1-e^{-b_G t}) + X_H + f_{\text{iOHO}} (X_{\text{et}} e^{-b_H t}) + f_{\text{iPAO}} (X_{G_t} e^{-b_G t}) + X_{\text{iot}} \] (4.67)

Simplifying and rearranging Equation (4.67) yields

\[ X_{T_1} = X_{\text{et}} \{f_H + (1-f_H + f_{\text{iOHO}}) e^{-b_H t}\} + X_{G_t} \{f_G + (1-f_G + f_{\text{iPAO}}) e^{-b_G t}\} + X_H + X_{\text{iot}} \] (4.68)

The change (reduction) in TSS concentration at any time \(t\), \(\Delta X_{T_1}\), is given by

\[ \Delta X_{T_1} = X_{T_1} - X_{T_1} \] (4.69)
where $X_{Ti} = \text{Initial concentration of the TSS (mg l}^{-1})$

Substituting from Equation (4.68) into Equation (4.69) yields

$$\Delta X_{T} = (X_{HI} + X_{GI} + X_{Hi} + X_{HI}f_{iOHO} + X_{GI}f_{PAO} + X_{bi}) - [X_{HI}(1 - f_{H} + f_{iOHO}e^{-b_Ht}) + X_{GI}(1 - f_{G} + f_{PAO}e^{-b_Gt})]$$  

(4.70)

Simplifying and rearranging Equation (4.70) yields

$$\Delta X_{T} = X_{HI}(1 - f_{H} + f_{iOHO})(1 - e^{-b_Ht}) + X_{GI}(1 - f_{G} + f_{PAO})(1 - e^{-b_Gt})$$  

(4.71)

The fraction of total solids removed (TSS decrease) at any time $t$, $f_{TrT}$ is given by

$$f_{TrT} = \frac{\Delta X_{T}}{X_{Ti}}$$  

(4.72)

Substituting from Equation (4.71) into Equation (4.72) yields

$$f_{TrT} = \frac{X_{HI}(1 - f_{H} + f_{iOHO})(1 - e^{-b_Ht}) + X_{GI}(1 - f_{G} + f_{PAO})(1 - e^{-b_Gt})}{X_{Ti}}$$  

(4.73)

If $\frac{X_{HI}}{X_{Ti}} = f_{aHTi}$ (initial active fraction of the OHO with respect to TSS) and $\frac{X_{GI}}{X_{Ti}} = f_{aGti}$ (initial active fraction of the PAO with respect to TSS), then

$$f_{TrT} = f_{aHT}(1 - f_{H} + f_{iOHO})(1 - e^{-b_Ht}) + f_{aGti}(1 - f_{G} + f_{PAO})(1 - e^{-b_Gt})$$  

(4.74)

Recalling that $X_{Ti} = X_{VI} + X_{HI}f_{iOHO} + X_{GI}f_{PAO} + X_{bi}$, the TSS concentration at time $t$, $X_{Ti}$ is, then, given by

$$X_{Ti} = (1 - f_{TrT})X_{Ti}$$  

(4.75)
The computation of the VSS components of the parent system (MBR UCT system) generating influent WAS to the aerobic batch digester is outlined in Section 4.1.1. The influent ISS concentration fed to the aerobic batch digester is equal to the ISS concentration in the WAS from the MBR UCT system. This ISS concentration is calculated from the ISS model of Ekama and Wentzel (2004) for BEPR AS systems viz.

\[ MX_{lo} = Q_i X_{loi} R_s + f_{iOHO} MX_{Hi} + f_{iPAO} MX_{Gi} \]  
\[ \text{(mgISS)} \]  
\[ (4.76) \]

where

- \( MX_{lo} \) = Mass of ISS in the BEPR AS system (mgISS)
- \( Q_i \) = Influent average dry weather flow to BEPR AS system (l day\(^{-1}\))
- \( X_{loi} \) = Influent ISS concentration (mgISS l\(^{-1}\))
- \( R_s \) = Sludge age of BEPR AS system (d)
- \( MX_{H} \) = Mass of OHOs in the BEPR AS system (mgOHOVSS)
- \( MX_{G} \) = Mass of PAOs in the BEPR AS system (mgPAOVSS)
- \( f_{iOHO} \) = ISS content of the OHOs (0.15 mgISS mgOHOVSS\(^{-1}\))
- \( f_{iPAO} \) = fiPAOBM+3.286(f\(_{XBGP}\)-f\(_{XBGPMB}\)) (see Equation 2.64 and 2.65 above)

Hence, the mass of ISS into the aerobic digester, \( MX_{loi} \) is

\[ MX_{loi} = \frac{MX_{lo}}{R_s} \]  
\[ \text{(mgISS)} \]  
\[ (4.77) \]

Based on the average simulated values of the influent ISS (\( X_{loi} \)) to the MBR UCT system, concentration of influent ISS of 3.5 mgISS l\(^{-1}\) and a polyphosphate (PP) content of the PAOs of 0.30 mgPP mgPAOVSS\(^{-1}\) was applied in the ISS model of Ekama and Wentzel (2004) for BEPR AS systems. Therefore, employing Equations (2.64 and 2.65) an ISS content of PAOs, \( f_{iPAO} \) of 1.14 mgISS mgPAOVSS\(^{-1}\) was obtained. These ISS components and the VSS components computed in Section 4.1.1 were added into the BEPR model of Wentzel et al. (1990) to give the ISS and TSS concentrations in the WAS of the MBR UCT system, from which were obtained the total (OHO + PAO) (\( f_{aTi} \)), OHO (\( f_{aHTi} \)) and PAO (\( f_{aGti} \)) active fractions with respect to TSS in the aerobic digester feed. The total (\( f_{aTi} \)), PAO (\( f_{aGti} \)) and OHO (\( f_{aHTi} \)) active fractions with respect to TSS were 28.4, 19.4 and 9.0% respectively. From
these influent active fractions the effluent active fractions of TSS, OHOs and PAOs with respect to TSS, and the fractions of TSS, OHOs and PAOs removed with respect to TSS were computed using the developed Equations (4.64 to 4.75) for hydraulic retention times ranging from 0 – 30 days (Figures 4.4 and 4.5).

Figure 4.4a and b. TSS, endogenous residue, organic and inorganic inert material concentrations during aerobic digestion (endogenous residue and organic inert material concentrations magnified in Figure 4.4b).

Figure 4.5. Fractions of TSS, OHOs and PAOs removed with respect to TSS (%), and active effluent fractions of TSS, OHOs and PAOs with respect to TSS (%) and during aerobic digestion.
The comparison of the predicted values with the steady state model and ASM-2 with those measured is done in Chapter 5.

### 4.2 Completely Mixed Aerobic Digester (Steady State Model)

Now the steady state model (SSM) for the single completely mixed aerobic digester (CMAD) will be developed because in practice, aerobic digesters are usually of the flow through type consisting of one or more digesters in series.

#### 4.2.1 VSS based model

A diagrammatic representation of a flow through CMAD with the VSS-based components of the influent and effluent flows is given in Figure 4.6.

![Diagram of CMAD](image)

Figure 4.6. Diagrammatic representation of the single completely mixed aerobic digester

From the mass balance of the active organisms over the flow through completely mixed system and accepting as discussed earlier that the OHOs and PAOs act independently (see Equation 4.81 below),

$$V_d \frac{d}{dt}(X_H + X_G) = (X_{H_0} + X_{G_0})Q_d dt - (X_{H_e} + X_{G_e})Q_e dt - (b_H X_H + b_G X_G) dt V_d \tag{4.78}$$
where
\[ V_d = \text{Volume of the aerobic digester} \]
\[ Q_i = \text{Influent WAS into the aerobic digester} \]
\[ Q_e = \text{Effluent WAS from the aerobic digester} \]
\[ X_H = \text{Concentration of the active OHOs, subscripts ‘i’ and ‘e’ refer to influent and effluent} \]
\[ X_G = \text{Concentration of the active PAOs, subscripts ‘i’ and ‘e’ refer to influent and effluent} \]
\[ b_H = \text{OHOs endogenous respiration rate (day}^{-1}\text{)} \]
\[ b_G = \text{PAOs endogenous respiration rate (day}^{-1}\text{)} \]

Dividing both sides of Equation (4.78) by \( V_d dt \) and noting that \( Q_i = Q_e \) and \( Q_i/V_d = R_h \) yields

\[
\frac{d(X_H + X_G)}{dt} = \frac{1}{R_h} (X_{Hi} + X_{Gi}) - \frac{1}{R_h} (X_{He} + X_{Ge}) - (b_H X_H + b_G X_G)
\]

(4.79)

where \( R_h \) = hydraulic retention time (for CMAD the hydraulic retention time and the sludge age, \( R_s \) are equal) (days)

Setting the transient \( d(X_H + X_G)/dt = 0 \) results in

\[
0 = \frac{1}{R_h} (X_{Hi} + X_{Gi}) - \frac{1}{R_h} (X_{He} + X_{Ge}) - (b_H X_H + b_G X_G)
\]

(4.80)

From the definition of completely mixed conditions, \( X_H \) (in the digester) = \( X_{He} \) (in the effluent) and \( X_G = X_{Ge} \) and simplifying Equation (4.80) yields

\[
X_{Hi} + X_{Gi} = X_{He} (1 + b_H R_h) + X_{Ge} (1 + b_G R_h)
\]

(4.81)

From Equation (4.81) the following relationships can be developed because \( X_{Hi} \) and \( X_{Gi} \) degrade independently\(^6\), each according to its own endogenous respiration rate,

\(^6\) Independent digestion of the OHOs and PAOs is assumed in this steady state model. This assumption also applies to the simulation models like ASM-2, because in these models mass loss of PAOs is dealt with an endogenous respiration (i.e. net effect) not death generation as for OHOs. In the
\[ X_{ii} = X_{ihe}(1 + b_{ii}R_{h}) \]  
\[ X_{Gi} = X_{Ge}(1 + b_{Gi}R_{h}) \]  
(4.82)  
(4.83)

From the mass balance of the endogenous residue over the flow through completely mixed system, noting that there is no \( X_e \) in the influent but it is included in \( X_i \) of the influent,

\[ X_{ehe} = X_{ehe} + X_{eGe} = f_{eii}(X_{ii} - X_{ihe}) + f_{eGi}(X_{Gi} - X_{Ge}) \]  
(4.84)

where

- \( X_{ehe} \) = Concentration of the endogenous residue of the OHOs in the effluent (mg l\(^{-1}\))
- \( X_{eGe} \) = Concentration of the endogenous residue of the PAOs in the effluent (mg l\(^{-1}\))
- \( f_{eii} \) = Fraction of endogenous residue of the OHOs
- \( f_{eGi} \) = Fraction of endogenous residue of the PAOs

Substituting from Equations (4.82) and (4.83) into Equation (4.84) and simplifying yields

\[ X_{ehe} = X_{ehe} + X_{eGe} = f_{eii}X_{ihe}b_{ii}R_{h} + f_{eGi}X_{Ge}b_{Gi}R_{h} \]  
(4.85)

Similarly, from Equation (4.85) the following relationships can be developed

\[ \frac{X_{ehe}}{X_{ihe}} = f_{eii}b_{ii}R_{h} \]  
(4.86)

\[ \frac{X_{eGe}}{X_{Ge}} = f_{eGi}b_{Gi}R_{h} \]  
(4.87)

The inert material (unbiodegradable VSS) is not affected by digestion, therefore,

\[ X_{ii} = X_{ie} \]  
(4.88)

endogenous respiration model, the PAOs do not release biodegradable organics to the bulk liquid – all PAO biodegradable organics are utilized catabolically by the PAOs themselves with the electron (COD) all passed to oxygen. The PAOs, therefore, do not release biodegradable organics to the bulk liquid for the OHOs to use; with the result they are modelled to operate independently. In reality this may not be the case where biodegradable PAO organics are utilized to grow new OHOs.
where $X_i$ = concentration of inert material, subscripts ‘i’ and ‘e’ refer to influent and effluent (mg l$^{-1}$)

The influent VSS concentration is given by

$$X_{vi} = X_{hi} + X_{gi} + X_{li}$$

(4.89)

The effluent VSS concentration is given by

$$X_{ve} = X_{he} + X_{ge} + X_{eh} + X_{eh} + X_{ke}$$

(4.90)

The digester influent active fraction of the sludge, $f_{a vi}$ is given by

$$f_{a vi} = \frac{X_{hi} + X_{gi}}{X_{hi} + X_{gi} + X_{li}} = \frac{X_{hi}}{X_{hi} + X_{gi} + X_{li}} + \frac{X_{gi}}{X_{hi} + X_{gi} + X_{li}}$$

(4.91)

where

$$\frac{X_{hi}}{X_{hi} + X_{gi} + X_{li}} = f_{a hi}, \text{ influent active fraction of the OHOVSS}$$

(4.92)

$$\frac{X_{gi}}{X_{hi} + X_{gi} + X_{li}} = f_{a gi}, \text{ influent active fraction of the PAOVSS}$$

(4.93)

Hence, the digester influent active fraction (with respect to VSS) is the sum of the OHO and PAO active influent fractions,

$$f_{a vi} = f_{a hi} + f_{a gi}$$

(4.94)

Simplifying and rearranging Equation (4.92) yields
\[
\frac{1}{f_{\text{aIVI}}} - 1 = \frac{X_{\text{Gi}}}{X_{\text{Hii}}} + \frac{X_{\text{le}}}{X_{\text{He}}(1 + b_H R_h)}
\] (4.95)

Substituting from Equations (4.82), (4.83) and (4.88) into Equation (4.95) yields

\[
\frac{1}{f_{\text{aIVI}}} - 1 = \frac{X_{\text{Ge}}(1 + b_G R_h)}{X_{\text{Hie}}(1 + b_H R_h)} + \frac{X_{\text{le}}}{X_{\text{He}}(1 + b_H R_h)}
\] (4.96)

Simplifying and rearranging Equation (4.96) yields

\[
\frac{X_{\text{le}}}{X_{\text{He}}} = \left(\frac{1}{f_{\text{aIVI}}} - 1\right)(1 + b_H R_h) - \frac{X_{\text{Ge}}}{X_{\text{He}}}(1 + b_G R_h)
\] (4.97)

Simplifying and rearranging Equation (4.93) yields

\[
\frac{1}{f_{\text{aIVI}}} - 1 = \frac{X_{\text{Hii}}}{X_{\text{Gl}}} + \frac{X_{\text{Hii}}}{X_{\text{Gl}}}
\] (4.98)

Substituting from Equations (4.82), (4.83) and (4.88) into Equation (4.98) yields

\[
\frac{1}{f_{\text{aIVI}}} - 1 = \frac{X_{\text{Hie}}(1 + b_H R_h)}{X_{\text{Ge}}(1 + b_G R_h)} + \frac{X_{\text{le}}}{X_{\text{Ge}}(1 + b_G R_h)}
\] (4.99)

Simplifying and rearranging Equation (4.99) yields

\[
\frac{X_{\text{le}}}{X_{\text{Ge}}} = \left(\frac{1}{f_{\text{aIVI}}} - 1\right)(1 + b_G R_h) - \frac{X_{\text{Hie}}}{X_{\text{Ge}}}(1 + b_H R_h)
\] (4.100)

The digester effluent active fraction of the sludge, \(f_{\text{aVe}}\) is given by

\[
f_{\text{aVe}} = \frac{X_{\text{Hie}} + X_{\text{Ge}}}{X_{\text{Hie}} + X_{\text{Ge}} + X_{\text{cile}} + X_{\text{cGe}} + X_{\text{le}}}
\]

\[
= \frac{X_{\text{Hie}}}{X_{\text{Hie}} + X_{\text{Ge}} + X_{\text{cile}} + X_{\text{cGe}} + X_{\text{le}}} + \frac{X_{\text{Gl}}}{X_{\text{Hie}} + X_{\text{Ge}} + X_{\text{cile}} + X_{\text{cGe}} + X_{\text{le}}}
\] (4.101)
where

\[
\frac{X_{\text{HHe}}}{X_{\text{HHe}} + X_{\text{Ge}} + X_{\text{ele}} + X_{\text{eGe}} + X_{\text{He}}} = f_{\text{aHVe}}, \text{ active fraction of the effluent}
\]  \hspace{1cm} (4.102)

**OHOVSS**

\[
\frac{X_{\text{GI}}}{X_{\text{HHe}} + X_{\text{Ge}} + X_{\text{ele}} + X_{\text{eGe}} + X_{\text{He}}} = f_{\text{aGVe}}, \text{ active fraction of the effluent}
\]  \hspace{1cm} (4.103)

**PAOVSS**

Hence, the digester effluent active fraction (with respect to VSS) is the sum of the OHO and PAO active effluent fractions,

\[
f_{\text{aVe}} = f_{\text{aHVe}} + f_{\text{aGVe}}
\]  \hspace{1cm} (4.104)

Simplifying and rearranging Equation (4.102) yields

\[
\frac{1}{f_{\text{aHVe}}} - 1 = \frac{X_{\text{Ge}}}{X_{\text{HHe}}} + \frac{X_{\text{ele}}}{X_{\text{HHe}}} + \frac{X_{\text{eGe}}}{X_{\text{HHe}}} + \frac{X_{\text{He}}}{X_{\text{HHe}}}
\]  \hspace{1cm} (4.105)

Substituting from Equations (4.85), (4.86) and (4.97) into Equation (4.105) yields

\[
\frac{1}{f_{\text{aHVe}}} - 1 = \frac{X_{\text{Ge}}}{X_{\text{HHe}}} + f_{\text{ehbH}} R_h + \frac{X_{\text{Ge}}}{X_{\text{HHe}}} f_{\text{ehbGe}} R_h + \left(\frac{1}{f_{\text{aHVi}}} - 1\right)(1 + b_h R_h) - \frac{X_{\text{Ge}}}{X_{\text{HHe}}} (1 + b_G R_h)
\]  \hspace{1cm} (4.106)

Simplifying and rearranging Equation (4.106) yields

\[
\frac{1}{f_{\text{aHVe}}} - 1 = \frac{X_{\text{Ge}}}{X_{\text{HHe}}} \left\{ (f_{\text{eGe}} - 1)b_G R_h \right\} + f_{\text{ehbH}} R_h + \left(\frac{1}{f_{\text{aHVi}}} - 1\right)(1 + b_h R_h) - \frac{X_{\text{Ge}}}{X_{\text{HHe}}} (1 + b_G R_h)
\]  \hspace{1cm} (4.107)

Assigning
\[ \alpha_n = \frac{1}{f_{aIVi}} - (1 - f_{eII}) \]  
(4.108)

\[ \beta_n = \frac{1}{f_{aIVe}} - (1 - f_{eII}) \]  
(4.109)

Equation (4.107) can be simplified and rearranged as

\[ \frac{X_{Ge}}{X_{He}} = \frac{\beta_n - \alpha_n (1 + b_n R_h)}{(f_e - 1)b_G R_h} \]  
(4.110)

Simplifying and rearranging Equation (4.103) yields

\[ \frac{1}{f_{aGve}} - 1 = \frac{X_{He}}{X_{Ge}} + \frac{X_{eHe}}{X_{Ge}} + \frac{X_{eGe}}{X_{Ge}} + \frac{X_{Ge}}{X_{Ge}} \]  
(4.111)

Substituting from Equations (4.85), (4.87) and (4.100) into Equation (4.111) yields

\[ \frac{1}{f_{aGve}} - 1 = \frac{X_{He}}{X_{Ge}} \frac{f_{eII} b_H R_h + f_{eG} b_G R_h + \left( \frac{1}{f_{aGVI}} - 1 \right) (1 + b_G R_h)}{X_{Ge}} - \frac{X_{He}}{X_{Ge}} (1 + b_H R_h) \]  
(4.112)

Simplifying and rearranging Equation (4.112) yields

\[ \frac{1}{f_{aGve}} - 1 = \frac{X_{He}}{X_{Ge}} \left( f_{eII} - 1 \right) b_H R_h + f_{eG} b_G R_h + \left( \frac{1}{f_{aGVI}} - 1 \right) (1 + b_G R_h) \]  
(4.113)

Substituting from Equations (4.110) into Equation (4.113) yields

\[ \frac{1}{f_{aGve}} - 1 = \frac{(f_{eG} - 1)b_G R_h}{\beta_n - \alpha_n (1 + b_H R_h)} \left( f_{eII} - 1 \right) b_H R_h + f_{eG} b_G R_h + \left( \frac{1}{f_{aGVI}} - 1 \right) (1 + b_G R_h) \]  
(4.114)

Assigning
\[ \alpha_G = \frac{1}{f_{g V_i}} - (1 - f_{i G}) \]  
\[ \beta_G = \frac{1}{f_{g V_e}} - (1 - f_{i G}) \]  

Equation (4.114) can be simplified and rearranged as

\[ R_h^2 \{ (1 - f_{e H} - f_{e G} + f_{e H} f_{e G}) b_h b_G \} + R_h (\alpha_H \beta_G b_h + \alpha_G b_G) + \{ \beta_G (\alpha_H - \beta_H) + \alpha_G \} = 0 \]  

(4.117)

This is a quadratic equation of the form

\[ aR_h^2 + bR_h + c = 0 \]

where

\[ a = (1 - f_{e H} - f_{e G} + f_{e H} f_{e G}) b_h b_G \]
\[ b = \alpha_H \beta_G b_h + \alpha_G b_G \]
\[ c = \beta_G (\alpha_H - \beta_H) + \alpha_G \]

By employing the solution for the quadratic equation

\[ R_h = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

and substituting the values, the required hydraulic retention time, \( R_h \) is determined.

The fraction of VSS removed, \( f_{Vr} \), is defined as the ratio of VSS mass degraded, \( Q_i(X_{Vi} - X_{Ve}) \) to the influent VSS mass, i.e.,

\[ f_{Vr} = \frac{Q_i X_{Vi} - Q_e X_{Ve}}{Q_i X_{Vi}} \]  

(4.118)
Noting that $Q_t = Q_e$, Equation (4.118) can be reduced to

$$f_{vr} = \frac{X_{vl} - X_{ve}}{X_{vl}} \quad (4.119)$$

Substituting from Equations (4.89) and (4.90) into Equation (4.119)

$$f_{vr} = \frac{(X_{Hi} + X_{Gi} + X_{Hi}) - (X_{He} + X_{Ge} + X_{Ge} + X_{He})}{X_{vl}} \quad (4.120)$$

Noting that $X_{Hi} = X_{He}$ and rearranging Equation (4.120) yields

$$f_{vr} = \frac{(X_{Hi} - X_{He} - X_{Ge}) + (X_{Gi} - X_{Ge} - X_{Ge})}{X_{vl}} = \frac{(X_{Hi} - X_{He} - X_{Ge})}{X_{vl}} + \frac{(X_{Gi} - X_{Ge} - X_{Ge})}{X_{vl}} \quad (4.121)$$

Substituting from Equations (4.82), (4.83) and (4.85) into Equation (4.121) yields

$$f_{vr} = \frac{(X_{Hi} - (X_{Hi}/(1 + R_h b_H))) - f_{eh} R_h b_H (X_{Hi}/(1 + R_h b_H)))}{X_{vl}} + \frac{(X_{Gi} - (X_{Gi}/(1 + R_k b_G))) - f_{eh} R_k b_G (X_{Gi}/(1 + R_k b_G)))}{X_{vl}} \quad (4.122)$$

Simplifying and rearranging Equation (4.122) yields

$$f_{vr} = f_{ahvi} \frac{(1 - f_{eh}) b_H R_h}{(1 + b_H R_h)} + f_{aGvi} \frac{(1 - f_{eg}) b_G R_h}{(1 + b_G R_h)} \quad (4.123)$$

The concentration of the organic N released into the bulk liquid as ammonia and subsequently nitrified to nitrate, like that of the aerobic batch digestion, will be proportional to the N content of the VSS concentration removed. (It is accepted that the OHOs and PAOs have the same N content, $f_n$.)
Accepting the N content of the VSS to be \( f_n \), the nitrate concentration generated in the aerobic digester will be

\[
N_{nc} = f_n X_{vi} f_{vr}
\]  
(4.124)

where \( f_n = 0.10 \) mgN mgVSS\(^{-1}\)

Noting that \( f_{ahvi} = \frac{X_{hi}}{X_{vi}} \) and \( f_{aGvi} = \frac{X_{Gl}}{X_{vi}} \), and substituting from Equation (4.123) into Equation (4.124) yields

\[
N_{nc} = f_n \left\{ X_{hi} \left( \frac{1 - f_{eh}}{1 + b_H R_h} \right) + X_{Gl} \left( \frac{1 - f_{eg}}{1 + b_G R_h} \right) \right\}
\]  
(4.125)

Similarly, the OP concentration in the bulk liquid of the aerobic digester will be equivalent to the P contents of the OHOs and PAOs removed. Accepting the P content of the OHOs and the PAOs to be \( f_{pH} \) and \( f_{pG} \) respectively, the OP concentration in the aerobic digester will be

\[
P_{pe} = f_{pH} X_{vi} f_{hvi} + f_{pG} X_{vi} f_{gvi}
\]  
(4.126)

Noting that \( f_{ahvi} = \frac{X_{hi}}{X_{vi}} \) and \( f_{aGvi} = \frac{X_{Gl}}{X_{vi}} \), and substituting from Equation (4.123) into Equation (4.126) yields

\[
P_{pe} = f_{pH} X_{hi} \left( \frac{1 - f_{eh}}{1 + b_H R_h} \right) + f_{pG} X_{Gl} \left( \frac{1 - f_{eg}}{1 + b_G R_h} \right)
\]  
(4.127)

The carbonaceous (endogenous respiration) OUR in the aerobic digester is given by

\[
O_e = \frac{1}{24} \left\{ f_{vch} \frac{X_{chi} b_H}{1 + b_H R_h} + f_{vCG} \frac{X_{chi} b_G}{1 + b_G R_h} \right\} \quad (\text{mgO} \ l^{-1} \ h^{-1})
\]  
(4.128)
where
\[ f_{\text{cVI}} = \text{COD/VSS ratio of the OHOs (mgCOD mgOHOVSS}^{-1}) \]
\[ f_{\text{cV}} = \text{COD/VSS ratio of the PAOs (mgCOD mgPAOVSS}^{-1}) \]

Multiplying both sides of Equation (4.128) by 24 hour per day and by the volume of the digester, \( V_d \) and noting that \( V_dQ_d = MO_c \), i.e. the mass carbonaceous oxygen demand per day (kgO day\(^{-1}\)), and \( V_dX_{\text{HI}} = Q_dX_{\text{HI}}R_h = MX_{\text{HI}} \) and \( V_dX_{\text{GI}} = Q_dX_{\text{GI}}R_h = MX_{\text{GI}} \) where \( MX_{\text{HI}} \) and \( MX_{\text{GI}} \) is the mass of active OHOVSS and PAOVSS load on the digester per day, yields

\[
MO_c = f_{\text{cVI}} \frac{(1 - f_{\text{cVI}})MX_{\text{HI}}b_{\text{HI}}R_h}{(1 + b_{\text{HI}}R_h)} + f_{\text{cV}} \frac{(1 - f_{\text{cV}})MX_{\text{GI}}b_{\text{GI}}R_h}{(1 + b_{\text{GI}}R_h)} \quad \text{(kgO day}^{-1}) \tag{4.129}
\]

Noting that \( MX_{\text{HI}} = f_{\text{cVI}}MX_{\text{VI}} \) and \( MX_{\text{GI}} = f_{\text{cV}}MX_{\text{VI}} \) and dividing Equation (4.129) by \( MX_{\text{VI}} \) yields the mass oxygen required per day per kgVSS sludge load on the digester per day,

\[
\frac{MO_c}{MX_{\text{VI}}} = f_{\text{cVI}} \frac{(1 - f_{\text{cVI}})b_{\text{HI}}R_h}{(1 + b_{\text{HI}}R_h)} + f_{\text{cV}} \frac{(1 - f_{\text{cV}})b_{\text{GI}}R_h}{(1 + b_{\text{GI}}R_h)} \quad \text{(kgO kgVSS}^{-1}) \tag{4.130}
\]

Comparing Equation (4.123) with Equation (4.130) shows that \( MO_c/MX_{\text{VI}} \) is equal to the fractions of the OHOVSS and PAOVSS removed multiplied by their respective COD/VSS ratios showing, from a COD mass balance point of view, that the COD of the VSS degraded is equal to the carbonaceous oxygen demand.

With the occurrence of complete nitrification, the nitrification OUR, \( O_n \) in the aerobic digester will be

\[
O_n = \frac{4.57}{24} f_a \left\{ \frac{(1 - f_{\text{cVI}})X_{\text{HI}}b_{\text{HI}}}{(1 + b_{\text{HI}}R_h)} + \frac{(1 - f_{\text{cV}})X_{\text{GI}}b_{\text{GI}}}{(1 + b_{\text{GI}}R_h)} \right\} \quad \text{(mgO l}^{-1} \text{h}^{-1}) \tag{4.131}
\]

where 4.57 = mgO required per mgNH\(_4\)-N nitrified to NO\(_3\)-N.

Similarly, the mass nitrification oxygen demand per day,
\[ MO_n = 4.57f_n \left( \frac{(1-f_{cel})MX_h b_{lh} R_h}{(1+b_{lh} R_h)} \right) + \frac{(1-f_{cel})MX_h b_{lh} R_h}{(1+b_{lh} R_h)} \] (kgO day\(^{-1}\))  

(4.132)

The total OUR, with complete nitrification, in the aerobic digester, \( O_T \) will be the sum of the carbonaceous and nitrification OUR, i.e.

\[ O_T = O_c + O_n \] (mgO l\(^{-1}\) h\(^{-1}\))  

(4.133)

Substituting from Equation (4.128) and (4.131) into Equation (4.133) yields

\[ O_T = \frac{1}{24} \left\{ f_{cG} \left( \frac{(1-f_{cel})X_h b_{lh}}{1+b_{lh} R_h} \right) + f_{cG} \left( \frac{(1-f_{cel})X_h b_{lh}}{1+b_{lh} R_h} \right) + 4.57f_n \left( \frac{(1-f_{cel})X_h b_{lh}}{1+b_{lh} R_h} \right) \right\} \] (mgO l\(^{-1}\) h\(^{-1}\))  

(4.134)

Simplifying and rearranging Equation (4.134) yields

\[ O_T = \frac{1}{24} \left\{ (f_{cG} + 4.57f_n) \left( \frac{(1-f_{cel})X_h b_{lh}}{1+b_{lh} R_h} \right) + (f_{cG} + 4.57f_n) \left( \frac{(1-f_{cel})X_h b_{lh}}{1+b_{lh} R_h} \right) \right\} \] (mgO l\(^{-1}\) h\(^{-1}\))  

(4.135)

And the total oxygen demand per day:

\[ MO_T = \left\{ (f_{cG} + 4.57f_n) \left( \frac{(1-f_{cel})MX_h b_{lh}}{1+b_{lh} R_h} \right) + (f_{cG} + 4.57f_n) \left( \frac{(1-f_{cel})MX_h b_{lh}}{1+b_{lh} R_h} \right) \right\} \] (kgO day\(^{-1}\))  

(4.136)

The determination of the active VSS, OHOVSS, PAOVSS and inert organic material concentrations in the parent system is done in Section 4.1.1. From these concentrations the influent active VSS, OHOVSS and PAOVSS fractions and concentrations and the concentration of the inert organic material into the CMAD were computed using Equations
The influent active fractions of the VSS ($f_{aV}$), PAOVSS ($f_{aG}$) and OHOVSS ($f_{aH}$) into the aerobic batch digester were 37.6, 25.7 and 11.9% respectively. Based on these influent active VSS, OHOVSS and PAOVSS fractions the effluent active VSS, OHOVSS and PAOVSS fractions and concentrations, the fractions of VSS removed, the effluent nitrate and OP concentrations, and the carbonaceous, nitrification and total oxygen demands in the CMAD were computed using the developed Equations (4.81 – 4.136) for hydraulic retention times ranging from 0 – 30 days (Figures 4.7a and b, and 4.8a and b).

Figure 4.7a and b. Effluent active fractions of the OHOVSS, PAOVSS and VSS (in percentage), and effluent AOOHSS and APAOVSS concentrations and fractions of VSS removed for single CMAD.
Figure 4.8a and b. Mass of carbonaceous, nitrification and total oxygen demand, and mass of effluent nitrate and phosphorus for single CMAD

4.2.2 Adding ISS and TSS to the VSS model

Adding the ISS and, therefore, the TSS concentration to the VSS-based SSM (i.e. TSS = VSS + ISS) follows a similar pattern to that given in Section 4.1.2.

The influent TSS concentration to the single CMAD, $X_{Ti}$ is given by

$$X_{Ti} = X_{Vt} + X_{Hi}f_{iOHO} + X_{Gi}f_{iPAO} + X_{loi} \tag{4.137}$$

And the effluent TSS concentration is given by

$$X_{Te} = X_{Ve} + X_{He}f_{iOHO} + X_{Ge}f_{iPAO} + X_{loe} \tag{4.138}$$

The inert organic material ($X_i$), which is the unbiodegradable particulate organics from the influent and the endogenous residue of the OHOs and PAOs from the AS system, and the inorganic material ($X_{lo}$) originating from the influent, remain constant and equal to the digester influent inert material, $X_{II}$ and $X_{lo}$, therefore,
\[ X_{bi} = X_{ir} \]  

\[ X_{io} = X_{io} \]  

where

\[ X_i \] = concentration of inert organic material, subscripts ‘i’ and ‘e’ refer to influent and effluent (mgISS l⁻¹)  

\[ X_{io} \] = concentration of inert inorganic material, subscripts ‘i’ and ‘e’ refer to influent and effluent (mgISS l⁻¹) 

The digester influent active fraction of the sludge (with respect to TSS), \( f_{aTi} \) is given by

\[
f_{aTi} = \frac{X_{Hi} + X_{Gi}}{X_{Hi} + X_{Gi} + X_h + X_{Hi} f_{iOHO} + X_{Gi} f_{iPAO} + X_{io}} + \frac{X_{Hi}}{X_{Hi} + X_{Gi} + X_{li} + X_{Hi} f_{iOHO} + X_{Gi} f_{iPAO} + X_{io}} + \frac{X_{Gi}}{X_{Hi} + X_{Gi} + X_{li} + X_{Hi} f_{iOHO} + X_{Gi} f_{iPAO} + X_{io}} \tag{4.140}
\]

where

\[
\frac{X_{Hi}}{X_{Hi} + X_{Gi} + X_h + X_{Hi} f_{iOHO} + X_{Gi} f_{iPAO} + X_{io}} = f_{aHTi}, \text{ active fraction of the influent OHO with respect to TSS} \tag{4.141}
\]

\[
\frac{X_{Gi}}{X_{Hi} + X_{Gi} + X_{li} + X_{Hi} f_{iOHO} + X_{Gi} f_{iPAO} + X_{io}} = f_{aGTi}, \text{ active fraction of the influent PAO with respect to TSS} \tag{4.142}
\]

Hence, the influent active fraction (with respect to TSS), \( f_{aTi} \) is given by the sum of the OHO and PAO active fractions (with respect to TSS),

\[
f_{aTi} = f_{aHTi} + f_{aGTi} \tag{4.143}
\]

Simplifying and rearranging Equation (4.141) results in
\[ \frac{1}{f_{atTi}} - 1 - f_{iOHO} = \frac{X_{Ga}(1 + f_{iPAO})}{X_{Hi}} + \frac{X_{Li} + X_{lci}}{X_{Hi}} \]  \hspace{1cm} (4.144)

Substituting from Equations (4.82), (4.83), (4.88) and (4.140) into Equation (4.144) yields

\[ \frac{1}{f_{atTi}} - 1 - f_{iOHO} = \frac{X_{Ge}}{X_{He}} \frac{(1 + f_{iPAO})(1 + b_{i} R_{h})}{(1 + b_{Hi} R_{h})} + \frac{X_{Le} + X_{lce}}{X_{He}(1 + b_{Hi} R_{h})} \]  \hspace{1cm} (4.145)

Simplifying and rearranging Equation (4.145) yields

\[ \frac{X_{Le} + X_{lce}}{X_{He}} = \left( \frac{1}{f_{atTi}} - 1 - f_{iOHO} \right) \frac{(1 + b_{Hi} R_{h})}{(1 + f_{iPAO})(1 + b_{i} R_{h})} - \frac{X_{Ge}}{X_{He}} \frac{(1 + f_{iPAO})(1 + b_{i} R_{h})}{(1 + b_{Hi} R_{h})} \]  \hspace{1cm} (4.146)

Substituting from Equations (4.83), (4.82), (4.88) and (4.140) into Equation (4.144) yields

\[ \frac{1}{f_{atTi}} - 1 - f_{iPAO} = \frac{X_{Hi}}{X_{Gi}} \frac{(1 + f_{iPAO})(1 + b_{i} R_{h})}{X_{Ge}} + \frac{X_{Li} + X_{lpi}}{X_{Gi}} \]  \hspace{1cm} (4.147)

Simplifying and rearranging Equation (4.147) yields

\[ \frac{1}{f_{atTi}} - 1 - f_{iPAO} = \frac{X_{He}}{X_{Ge}} \frac{(1 + f_{iPAO})(1 + b_{i} R_{h})}{(1 + b_{Hi} R_{h})} + \frac{X_{Le} + X_{lce}}{X_{Ge}(1 + b_{Hi} R_{h})} \]  \hspace{1cm} (4.148)

Simplifying and rearranging Equation (4.148) yields

\[ \frac{X_{Le} + X_{lce}}{X_{Ge}} = \left( \frac{1}{f_{atTi}} - 1 - f_{iPAO} \right) \frac{(1 + b_{Hi} R_{h})}{(1 + f_{iPAO})(1 + b_{i} R_{h})} - \frac{X_{He}}{X_{Ge}} \frac{(1 + f_{iPAO})(1 + b_{i} R_{h})}{(1 + b_{Hi} R_{h})} \]  \hspace{1cm} (4.149)

The digester effluent active fraction of the sludge (with respect to TSS), \( f_{aTe} \) is given by
\[ f_{aTe} = \frac{X_{He} + X_{Ge}}{X_{He} + X_{Ge} + X_{elHe} + X_{eGe} + X_{le} + X_{He}f_{iOHO} + X_{Ge}f_{iPAO} + X_{lo}} = \]

\[ \frac{X_{He} + X_{Ge} + X_{elHe} + X_{eGe} + X_{le} + X_{He}f_{iOHO} + X_{Ge}f_{iPAO} + X_{lo}}{X_{He} + X_{Ge} + X_{elHe} + X_{eGe} + X_{le} + X_{He}f_{iOHO} + X_{Ge}f_{iPAO} + X_{lo}} \]

(4.150)

where

\[ \frac{X_{He}}{X_{He} + X_{Ge} + X_{elHe} + X_{eGe} + X_{le} + X_{He}f_{iOHO} + X_{Ge}f_{iPAO} + X_{lo}} = f_{aHTe}, \text{ active} \]  

(4.151)

fraction of the effluent OHO with respect to TSS

\[ \frac{X_{Ge}}{X_{He} + X_{Ge} + X_{elHe} + X_{eGe} + X_{le} + X_{He}f_{iOHO} + X_{Ge}f_{iPAO} + X_{lo}} = f_{aGTe}, \text{ active} \]  

(4.152)

fraction of the effluent PAO with respect to TSS

Hence, the effluent active fraction of the sludge (with respect to TSS), \( f_{aTe} \) is given by the sum of the OHO and PAO effluent active fractions (with respect to TSS),

\[ f_{aTe} = f_{aHTe} + f_{aGTe} \]  

(4.153)

Simplifying and rearranging Equation (4.151) yields

\[ \frac{1}{f_{aHTe}} - 1 - f_{iOHO} = \frac{X_{Ge}(1 + f_{iPAO})}{X_{He}} + \frac{X_{elHe}}{X_{He}} + \frac{X_{eGe}}{X_{He}} + \frac{X_{le} + X_{lo}}{X_{He}} \]  

(4.154)

Substituting from Equations (4.86), (4.87) and (4.146) into Equation (4.154) yields

\[ \frac{1}{f_{aHTe}} - 1 - f_{iOHO} = \frac{X_{Ge}(1 + f_{iPAO})}{X_{He}} + f_{eh}b_{R_h} + \frac{X_{Ge}f_{G}b_{G}R_{k}}{X_{He}} + \]

\[ \{(\frac{1}{f_{aHTi}} - 1 - f_{iOHO})(1 + b_{R_k}) - \frac{X_{Ge}}{X_{He}}(1 + f_{iPAO})(1 + b_{G}R_{k})\} \]  

(4.155)

Simplifying and rearranging Equation (4.155) yields
\[ \frac{1}{f_{\text{GeTe}}} - 1 - f_{\text{iOHO}} = f_{\text{eG}} b_H R_h + \frac{X_{\text{Ge}}}{X_{\text{He}}} (f_{\text{eG}} - 1 - f_{\text{iPAO}}) b_G R_h + \frac{1}{f_{\text{eTi}}} - 1 - f_{\text{iOHO}} (1 + b_H R_h) \]  

(4.156)

Assigning

\[ \delta_H = \frac{1}{f_{\text{eTi}}} - 1 - f_{\text{iOHO}} \]

(4.157)

\[ \gamma_H = \frac{1}{f_{\text{GeTe}}} - 1 - f_{\text{iOHO}} \]

(4.158)

Equation (4.156) can be simplified as

\[ \frac{X_{\text{Ge}}}{X_{\text{He}}} = \frac{\gamma_H - \delta_H (1 + b_H R_h) - f_{\text{eG}} b_H R_h}{(f_{\text{eG}} - 1 - f_{\text{iPAO}}) b_G R_h} \]

(4.159)

Simplifying and rearranging Equation (4.152) yields

\[ \frac{1}{f_{\text{eGTe}}} - 1 - f_{\text{iPAO}} = \frac{X_{\text{He}} (1 + f_{\text{iOHO}})}{X_{\text{Ge}}} + \frac{X_{\text{eGe}}}{X_{\text{Ge}}} + \frac{X_{\text{eHe}}}{X_{\text{Ge}}} + \frac{X_{\text{He}}}{X_{\text{Ge}}} + \frac{X_{\text{He}}}{X_{\text{Ge}}} \]

(4.160)

Substituting from Equations (4.86), (4.87) and (4.149) into Equation (4.160) yields

\[ \frac{1}{f_{\text{eGTe}}} - 1 - f_{\text{iPAO}} = \frac{X_{\text{He}} (1 + f_{\text{iOHO}})}{X_{\text{Ge}}} + f_{\text{eG}} b_G R_h + \frac{X_{\text{He}}}{X_{\text{Ge}}} f_{\text{eG}} b_H R_h + \]

\[ \{ \frac{1}{f_{\text{eGTe}}} - 1 - f_{\text{iPAO}} (1 + b_G R_h) - \frac{X_{\text{He}}}{X_{\text{Ge}}} (1 + f_{\text{iOHO}}) (1 + b_H R_h) \} \]

(4.161)

Simplifying and rearranging Equation (4.161) yields

\[ \frac{1}{f_{\text{eGTe}}} - 1 - f_{\text{iPAO}} = f_{\text{eG}} b_G R_h + \frac{X_{\text{He}}}{X_{\text{Ge}}} (f_{\text{eG}} - 1 - f_{\text{iOHO}}) b_H R_h + \frac{1}{f_{\text{eGTe}}} - 1 - f_{\text{iPAO}} (1 + b_G R_h) \]

(4.162)
Substituting from Equations (4.159) into Equation (4.162) yields

\[
\frac{1}{f_{\text{GTe}}} - 1 - f_{\text{PAO}} = f_{\text{G}} b_G R_h + \left( \frac{(f_{\text{G}} - 1 - f_{\text{PAO}}) b_G R_h}{\gamma_H - \delta_H (1 + b_H R_h) - f_{\text{eh}} b_H R_h} \right) (f_{\text{eh}} - 1 - f_{\text{IOHO}}) b_H R_h + \\
\left( \frac{1}{f_{\text{GTi}}} - 1 - f_{\text{PAO}} \right) (1 + b_G R_h)
\]

(4.163)

Assigning

\[
\delta_G = \frac{1}{f_{\text{GTi}}} - 1 - f_{\text{PAO}}
\]

(4.164)

\[
\gamma_G = \frac{1}{f_{\text{GTe}}} - 1 - f_{\text{PAO}}
\]

(4.165)

Equation (4.163) can be simplified as

\[
\gamma_G = f_{\text{G}} b_G R_h + \left( \frac{(f_{\text{G}} - 1 - f_{\text{PAO}}) b_G R_h}{\gamma_H - \delta_H (1 + b_H R_h) - f_{\text{eh}} b_H R_h} \right) (f_{\text{eh}} - 1 - f_{\text{IOHO}}) b_H R_h + \delta_G (1 + b_G R_h)
\]

(4.165)

Simplifying and rearranging Equation (4.165) yields a quadratic equation of the form of

\[
ar_h^2 + b_r + c = 0
\]

(4.166)

where

\[
a = b_h b_G \{ \delta_H f_{\text{G}} + f_{\text{eh}} (\delta_G + f_{\text{G}}) - (f_{\text{eh}} - 1 - f_{\text{IOHO}}) (f_{\text{G}} - 1 - f_{\text{PAO}}) \}
\]

\[
b = b_h (\delta_G - \gamma_G) (f_{\text{eh}} + \delta_H) + b_G \{ \gamma_H \delta_G + f_{\text{G}} (\delta_H - \gamma_H) \}
\]

\[
c = (\gamma_H - \delta_H) (\gamma_G - \delta_G)
\]

By employing the solution for the quadratic equation
\[ R_h = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

and substituting the values, the required hydraulic retention, \( R_h \) time is determined.

The fraction of TSS removed, \( f_{Tr} \) is defined as the ratio of TSS mass degraded, \( Q_i (X_{Ti} - X_{Te}) \) to the influent TSS mass, i.e.,

\[ f_{Tr} = \frac{Q_i X_{Ti} - Q_e X_{Te}}{Q_i X_{Ti}} \quad (4.167) \]

where, \( X_T \) = TSS concentration, subscripts ‘i’ and ‘e’ refer to influent and effluent (mg l\(^{-1}\))

Noting that \( Q_i = Q_e \), Equation (4.167) can be reduced to

\[ f_{Tr} = \frac{X_{Ti} - X_{Te}}{X_{Ti}} \quad (4.168) \]

Noting that \( X_{li} = X_{le} \) and \( X_{loi} = X_{loe} \) and substituting from Equations (4.137) and (4.138) into Equation (4.168) yields

\[ f_{Tr} = \frac{(X_{Hi} + X_{Gi} + X_{Hi}f_{OHO} + X_{Gi}f_{PAO}) - (X_{He} + X_{Ge} + X_{eHe} + X_{eGe} + X_{He}f_{OHO} + X_{Ge}f_{PAO})}{X_{Ti}} \quad (4.169) \]

Simplifying and rearranging Equation (4.169) yields

\[ f_{Tr} = \frac{X_{Hi}(1 + f_{OHO}) - X_{He}(1 + f_{OHO}) - X_{eHe} + X_{Gi}(1 + f_{PAO}) - X_{Ge}(1 + f_{PAO}) - X_{eGe}}{X_{Ti}} \quad (4.170) \]

Substituting from Equations (4.82), (4.83), (4.86) and (4.87) into Equation (4.170) yields
\[ f_{tr} = \frac{X_{Hi} \left( 1 + f_{iOHO} \right) - X_{Hi} \left( 1 + f_{iPAO} \right)}{X_{ni} \left( 1 + b_H R_H \right)} - X_{Hi} f_{eh} b_H R_H + \]

\[ X_{Gi} \left( 1 + f_{iPAO} \right) \frac{X_{Gi} \left( 1 + f_{iPAO} \right)}{X_{ni} \left( 1 + b_G R_G \right)} X_{Gi} f_{eg} b_G R_H \]

Substituting from Equation (4.82) and (4.83) into Equation (4.171) yields

\[ f_{tr} = \frac{X_{Hi} \left( 1 + f_{iOHO} \right) - X_{Hi} \left( 1 + f_{iOHO} \right)}{X_{ni} \left( 1 + b_H R_H \right)} - \frac{X_{Hi}}{X_{ni} \left( 1 + b_H R_H \right)} f_{eh} b_H R_H + \]

\[ X_{Gi} \left( 1 + f_{iPAO} \right) \frac{X_{Gi} \left( 1 + f_{iPAO} \right)}{X_{ni} \left( 1 + b_G R_G \right)} X_{Gi} f_{eg} b_G R_H \]

(4.172)

Simplifying and rearranging Equation (4.172) yields

\[ f_{tr} = f_{aH NI} \left( (1 + f_{iOHO}) \left( 1 - \frac{1}{(1 + b_H R_H)} \right) - \frac{f_{eh} b_H R_H}{(1 + b_H R_H)} \right) + \]

\[ f_{aG NI} \left( (1 + f_{iPAO}) \left( 1 - \frac{1}{(1 + b_G R_G)} \right) - \frac{f_{eg} b_G R_H}{(1 + b_G R_G)} \right) \]

(4.173)

where

\[ \frac{X_{Hi}}{X_{ni}} = f_{aH NI}, \text{ active fraction of the influent OHOTSS (with respect to TSS)} \]

\[ \frac{X_{Gi}}{X_{ni}} = f_{aG NI}, \text{ active fraction of the influent PAOTSS (with respect to TSS)} \]

The determination of the influent VSS, AOHOVSS, APAOVSS and inert organic material concentrations is done in Section 4.1.1. And the computation of the components of the ISS
CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

In this chapter the experimental batch test results are evaluated. First, the trends measured in the batch tests are qualitatively discussed. This is followed by quantitative modelling of the batch test results with batch reactor, steady state and ASM-2 simulation models.

5.2 The Experimental Data – Observed Trends

5.2.1 Batch test initial conditions

Batch Test No.1 (BT-1), BT-3, BT-4 and BT-6 were run until the digestion processes were complete, i.e., until the OUR in the reactor was almost zero and no further decrease in VSS was observed. BT-2 and BT-5 were interrupted due to failure of the motor for mixing the sludge. BT-7 and BT-8 were run simultaneously until the digestion processes of BT-8, which was fed with diluted WAS, was complete.

The experimental conditions of the aerobic digestion of WAS along with the measured initial concentrations of VSS, TSS, TKN and COD in the batch reactor are given in Table 5.1.
Table 5.1. Experimental conditions for the aerobic batch digestion of WAS

<table>
<thead>
<tr>
<th>Date</th>
<th>Batch Test No.</th>
<th>Batch of Source Sludge</th>
<th>Operation Time of Parent System</th>
<th>Detention Time of Batch Test (days)</th>
<th>Initial Conditions of the Batch Reactor (@ 20°C and pH controlled @ ~7.20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar 14-25, 2005</td>
<td>BT-1</td>
<td>SB-1</td>
<td>Mar 05-18, 2005</td>
<td>12</td>
<td>12983</td>
</tr>
<tr>
<td>Apr 01-25, 2005</td>
<td>BT-3</td>
<td>SB-2</td>
<td>Mar 19-Apr 04, 2005</td>
<td>25</td>
<td>14300</td>
</tr>
<tr>
<td>May 19-June 09, 2005</td>
<td>BT-4</td>
<td>SB-5</td>
<td>May 16-31, 2005</td>
<td>21</td>
<td>13401</td>
</tr>
<tr>
<td>Mar 25-Apr 04, 2006</td>
<td>BT-5</td>
<td>SB-26</td>
<td>Mar 24-Apr 07, 2006</td>
<td>11</td>
<td>14647</td>
</tr>
<tr>
<td>May 06-20, 2006</td>
<td>BT-6</td>
<td>SB-28</td>
<td>Apr 24- May 06, 2006</td>
<td>15</td>
<td>13189</td>
</tr>
<tr>
<td>June 05-13, 2006</td>
<td>BT-7</td>
<td>SB-30</td>
<td>June 04-17, 2006</td>
<td>9</td>
<td>15558</td>
</tr>
<tr>
<td>June 05-13, 2006</td>
<td>BT-8</td>
<td>SB-30</td>
<td>June 04-17, 2006</td>
<td>9</td>
<td>2985</td>
</tr>
</tbody>
</table>

During the aerobic batch digestion process, an average of 38 ml per day evaporation loss was observed, which was made up with distilled water.

5.2.2 pH and Alkalinity

At the beginning of the batch test the pH values for all the tests were above 7.35. However, within four days of the commencement of digestion the pH started to decrease below 7.2, thereby necessitating the addition of sodium bicarbonate. The decrease in pH necessitating the addition of increased amounts of sodium bicarbonate indicated increased nitrification activity of the sludge biomass which produces hydrogen ions resulting in the consumption of alkalinity. After the addition of increasing amounts of sodium bicarbonate during the early period of the digestion, the amount of sodium bicarbonate added was reduced as the decrease in pH declined.

In keeping the pH at ~7.20, the addition of measured amounts of sodium bicarbonate along with the resulting change in alkalinity is shown in Figure 5.1a and b. The cumulative
5.3

Consumption of alkalinity increased sharply after the fourth day of digestion for all the batch tests. Following a logarithmic trend, this change in alkalinity consumption became very low at the end of the digestion period.

Figure 5.1a and b. Total sodium bicarbonate added and cumulative consumption of alkalinity while regulating the pH @ 7.20

The trends of increase of both the total addition of NaHCO₃ and the cumulative consumption of alkalinity were similar, except that the cumulative consumption of alkalinity was of a higher scale. This was expected as the addition of NaHCO₃ is making up for the alkalinity consumed due to the production of hydrogen ions as a result of nitrification. The higher scale of the cumulative consumption of alkalinity over the total addition of NaHCO₃ is a consequence of the initial alkalinity present in the WAS prior to the drop of pH to just below 7.20.

5.2.3 VSS, ISS and TSS

The initial VSS concentration for all the batch tests ranged from 12500 to 14300 mg l⁻¹. As shown in Figure 5.2a, apart for some fluctuation, the VSS decreased almost linearly. For BT-3 and BT-4, the VSS concentration decreased from initial values of 14300 and 13400 mg l⁻¹ to 7125 and 8772 mg l⁻¹, with 50.2 and 34.5% VSS reductions in 25 and 21 days of aeration time respectively. Similarly, 39.3 and 25.5% VSS reductions were obtained for BT-5 and BT-
6 with aeration times of 11 and 14 days respectively. The highest percentage VSS destruction was obtained with the longest aeration time (BT-3), as expected from theory, followed by that of the shortest aeration time (BT-5), which is not expected from theory.

Figure 5.2a and b. Reduction of VSS and TSS versus percentage VSS destruction and TSS reduction obtained during the aerobic digestion of WAS

For BT-3 and BT-4, the TSS concentration decreased from initial values of 17420 and 16630 mg l\(^{-1}\) to 8970 and 11280 mg l\(^{-1}\), with 48.5 and 32.2% TSS reductions respectively. Similarly, TSS reductions of 37.3 and 29.6% were obtained for BT-5 and BT-6 when the TSS concentration dropped from initial values of 18380 and 17540 mg l\(^{-1}\) to 11520 and 12350 mg l\(^{-1}\) respectively (Figure 5.2b).

Both VSS and TSS decreased approximately linearly during the aerobic digestion process. Except for the magnitudes of the initial concentrations of the VSS and TSS, the trend and rate of decrease of both the VSS and TSS were similar. Generally, the percentages of VSS destruction were slightly higher than the percentages of TSS reduction, except for BT-6 where the percentage of VSS destruction was slightly lower than the percentages of TSS reduction (Figure 5.2a and b). In their aerobic digestion of non-BEPR WAS Khalili et al. (2000) reported a slightly higher VSS removal efficiency than that for the TSS. Moreover, Al-Ghusain et al. (2002) observed VSS and TSS removal efficiencies of 42.7 and 37.4% respectively.
For all the batch tests the ISS decreased with some undulations, especially at the beginning of the digestion period (Figure 5.3a). For BT-4, the ISS decreased linearly from an initial concentration of 3591 mgISS l\(^{-1}\) to a final value of 2509 mgISS l\(^{-1}\) with 43.1% ISS reduction in 21 days of aeration time. After an initial increase, the ISS concentration of BT-2 decreased to a final value equivalent to the initial ISS concentration. For the rest of the batch tests, after an initial increase, the ISS concentration decreased almost linearly during the digestion process. The highest decrease in ISS concentration was for BT-3 where the ISS decreased from an initial concentration of 3122 mgISS l\(^{-1}\) to a final value of 1845 mgISS l\(^{-1}\) with 69.2% ISS reduction in 25 days of aeration time. With 33.8% ISS reduction BT-1 exhibited the lowest ISS reduction from an initial concentration of 3836 mgISS l\(^{-1}\) to a final value of 2867 mgISS l\(^{-1}\) in 8 days of aeration time. This observed decrease of ISS concentration during digestion is in keeping with the ISS model of Ekama and Wentzel (2004) that for a decrease in biomass VSS, a commensurate decrease in biomass ISS also takes place. Although in their aerobic batch digestion of BNR WAS Matsuda et al. (1988) reported that the values of the fixed suspended solids (FSS, i.e. ISS) were roughly constant throughout their aerobic digestion tests, in their aerobic digestion of non-BEPR WAS Randall et al. (1975) and Reece et al. (1979) reported that the FSS decreased during aerobic batch digestion.

As shown in Figure 5.3b, apart from some fluctuations especially for BT-5 and BT-6 the VSS/TSS ratio remained almost constant during the aerobic digestion tests. The average VSS/TSS ratio for BT-1 to BT-6 was 0.78 mgVSS mgTSS\(^{-1}\) with a standard deviation of 0.016. For SBs of the parent system where the WAS was harvested for these six batch tests, the average VSS/TSS ratio in the anaerobic, anoxic and aerobic reactors were 0.83, 0.81 and 0.80 mgVSS mgTSS\(^{-1}\) respectively, with standard deviations of 0.01. The average VSS/TSS ratio of the MBR UCT system for all the SBs from March 2005 to May 2006 in the anaerobic, anoxic and aerobic reactors were 0.82, 0.80 and 0.79 mgVSS mgTSS\(^{-1}\) with standard deviations of 0.01, 0.01 and 0.02 respectively. Because of P release, the VSS/TSS ratio is higher in the anaerobic reactor and lower in the aerobic reactor due to P uptake. The average VSS/TSS ratio for the batch tests, however, was slightly lower than that of the parent system.
Figure 5.3a and b. ISS concentration and the VSS/TSS ratio of the WAS during the aerobic digestion process

For BT-7 and BT-8, operated simultaneously with undiluted and diluted WAS, the percentage VSS destructions were similar. With 23.4% VSS destruction, the VSS of the diluted WAS decreased uniformly from an initial VSS concentration of 2985 mg l\(^{-1}\) to a final value of 2287 mg l\(^{-1}\). During the same period of aeration time, the VSS of the undiluted WAS decreased from an initial concentration of 15560 mg l\(^{-1}\) to 11510 mg l\(^{-1}\) which is a 26.0% VSS destruction (Figure 5.4).

Figure 5.4. Comparison of the concentration of VSS and percentage VSS destruction for BT-7 (undiluted WAS) and BT-8 (diluted WAS)
Theoretically, multiplying the diluted WAS by the factor of dilution, i.e. bringing it back to its undiluted state, would make it equivalent to the undiluted WAS. In doing so, as shown in Figure 5.4, apart from a small discrepancy, the reduction in VSS of the 5 times multiplied diluted WAS was close to that of the undiluted WAS.

5.2.4 COD

Like the VSS, the total (unfiltered) COD concentration decreased almost linearly for all the batch tests (Figure 5.5a). The total COD decreased from initial values of 19350 and 19180 mgCOD l\(^{-1}\) to 9840 and 11880 mgCOD l\(^{-1}\) for BT-3 and BT-4 respectively. The highest and the lowest COD reduction obtained, with detention times of 23 and 10 days, were 49.1 and 34.7% for BT-3 and BT-5 respectively. Within 20 and 14 days of digestion period BT-4 and BT-6 had COD reductions of 38.1 and 36.1% respectively.

![Figure 5.5a and b. Decrease in total COD along with the percentage total-COD reduction achieved and concentration of soluble (filtered) COD during the aerobic digestion process](image)

On average, for all the batch tests, similar or slightly higher percentage of total COD reduction was achieved to that of the percentage VSS destruction. The total COD reductions obtained were 36.1, 38.1 and 49.1% for BT-6, BT-4, and BT-3 respectively. Moreover, the aeration times for BT-6, BT-4 and BT-3 were 11, 24 and 25 days respectively. Like the VSS, the highest percentage COD reduction was obtained with the longest detention time (BT-3)
but, unlike the VSS, the lowest percentage total COD reduction was obtained with the shortest detention time (BT-5), as expected from theory.

![Figure 5.6. COD/VSS ratio of the WAS during the aerobic digestion process](image)

Higgins et al. (1982) indicated that the order of removal efficiency would be higher for COD than for VSS, which indicated that the COD/VSS ratio decreases with digestion retention time. The results of this study, however, showed this conclusion not to be true. In fact, the removal efficiency of VSS was slightly higher than that of the COD, indicating a slight increase in COD/VSS ratio of the remaining solids.

The soluble (filtered) COD is unaffected by the digestion process and its value was expected to remain constant and low throughout the digestion process. However, as shown in Figure 5.5b, the filtered COD was observed to increase very slightly (relative to total COD) with variation between minimum and maximum values of 52 and 125 mg l⁻¹. A similar generation of a soluble endogenous ‘residue’, ascribed to a high specificity of the micro-organism population, was observed by Wentzel et al. (1988) in their enhanced PAO BEPR cultures. The PAO release of unbiodegradable soluble organics was not included in the UCTPHO and ASM-2 OHO and PAO mixed culture models because it was assumed that the OHOs would be able to utilize these soluble organics released by the PAOs, i.e. these organics are only unbiodegradable to themselves. These batch tests validate this assumption considering an average increase of only ~30 mgCOD l⁻¹ of soluble unbiodegradable organics from a total COD reduction of ~10000 mgCOD l⁻¹ which is only ~0.3% and can be considered negligible.
Figure 5.7a and b. Ratios of COD reduction/VSS reduction and %COD reduction/%VSS reduction of the WAS during the aerobic digestion process.

Generally, during the digestion process the COD/VSS ratio of the remaining sludge mass fluctuated between minimum and maximum values of 1.33 and 1.47 mgCOD mgVSS\(^{-1}\) (Figure 5.6). For BT-3, while the initial and final values of the COD/VSS were the same, i.e. 1.39 mgCOD mgVSS\(^{-1}\), the intermittent values oscillated between minimum and maximum values of 1.33 and 1.47 mgCOD mgVSS\(^{-1}\) respectively. For BT-4, the COD/VSS ratio decreased from an initial value of 1.47 to a final value of 1.39 mgCOD mgVSS\(^{-1}\). Besides, the COD/VSS ratio fluctuated between 1.09 and 1.23 mgCOD mgVSS\(^{-1}\), and 1.15 and 1.39 mgCOD mgVSS\(^{-1}\), for BT-5 and BT-6 respectively.
Figure 5.8. Statistical plot for the measured average COD/VSS ratio for BT-1 to BT-6.

The lowest average COD/VSS ratio was obtained for BT-5 (1.16 mgCOD mgVSS\(^{-1}\) with standard deviation of 0.050), while BT-4 exhibited the highest average COD/VSS ratio of 1.50 mgCOD mgVSS\(^{-1}\) with standard deviation of 0.063 (Figure 5.8). The COD/VSS ratio for BT-3 and BT-6 were 1.26 and 1.39 mgCOD mgVSS\(^{-1}\) with standard deviations of 0.034 and 0.083 respectively. An average COD/VSS ratio of 1.36 mgCOD mgVSS\(^{-1}\) with a standard deviation of 0.113 was obtained for all the six batch tests. This average value is lower than the accepted value of 1.48 mgCOD mgVSS\(^{-1}\). Besides, for the parent system for all the SBs from March 2005 to May 2006 and for SBs where the WAS was harvested for these six batch tests, the average COD/VSS ratios in the aerobic reactor were 1.40 and 1.35 mgCOD mgVSS\(^{-1}\) with standard deviations of 0.12 and 0.15 respectively (du Toit et al., 2006), which are equivalent to the average value for the batch tests. Though no adequate explanation could be given, the very high concentrations of the waste activated sludges considered might have contributed to the deviation of the average COD/VSS ratio obtained in this study (1.36 mgCOD mgVSS\(^{-1}\)) from the conventionally accepted or standard value of 1.48 mgCOD mgVSS\(^{-1}\).
Table 5.2. Comparison of the measured average remaining, removed and percentage reductions of COD to VSS ratios

<table>
<thead>
<tr>
<th>Type</th>
<th>Batch Test Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BT-1</td>
</tr>
<tr>
<td>COD/VSS</td>
<td>1.40</td>
</tr>
<tr>
<td>COD Removed /VSS Removed</td>
<td>0.94</td>
</tr>
<tr>
<td>%COD Reduction / %VSS Destruction</td>
<td>0.71</td>
</tr>
<tr>
<td>Percentage increase of COD Removed /VSS Removed over %COD Reduction /%VSS Destruction</td>
<td>32.43</td>
</tr>
</tbody>
</table>

As shown in Figure 5.7a and b, the COD removed/VSS destroyed ratio fluctuated between minimum and maximum values of 0.27 (BT-2) and 2.4 (BT-6) while the %COD reduction/%VSS destruction ratio fluctuated between minimum and maximum values of 0.20 (BT-2) and 1.87 (BT-6). Except for the scale, the trends of fluctuation of the COD removed/VSS destroyed and %COD reduction/%VSS destruction ratios were exactly the same. Both COD removed/VSS destroyed and %COD reduction/%VSS destruction ratios showed, with undulations, an increasing trend with digestion aeration times except for BT-4 and BT-6 where the undulating increase was preceded with an initial decrease at the beginning of the digestion test.

The COD removed/VSS destroyed ratios were higher than those of the %COD reduction/%VSS destruction ratios by 32.4, 38.1, 38.7, 46.7, 13.9 and 30.4% for BT-1, BT-2, BT-3, BT-4, BT-5 and BT-6 respectively (Table 5.2). Interestingly, the percentage increase of the COD removed/VSS destroyed ratios over the %COD reduction/%VSS destruction ratios remained constant for each of the batch tests, i.e. the average percentage increase of the COD removed/VSS destroyed ratios over the %COD reduction/%VSS destruction ratios for a specific batch test was equal to each daily value of that batch test.
As shown in Figure 5.9, the decrease in the concentration of COD and the percent COD reduction for BT-7 and BT-8, with undiluted and diluted waste activated sludges respectively, were very close. Moreover, when the diluted WAS was ‘undiluted’ by multiplying it with the dilution factor, the pattern of the decrease in COD concentration was equivalent to that of the undiluted WAS.

5.2.5 Nitrogen

The fractions of nitrogen present in the WAS bulk liquid are the FSA and the unbiodegradable soluble organic nitrogen \( N_{\text{ousi}} = N_{\text{ouse}} \) (both very low < 3 mgN l\(^{-1}\)), and the organic nitrogen bound in the sludge mass. Of these fractions, the unbiodegradable soluble organic fraction remained unaffected by the digestion process. The organic nitrogen contained in the sludge mass was released by endogenous respiration as FSA by the OHOs and PAOs. The released FSA and the FSA that was originally present in the WAS are nitrified to nitrate by the autotrophic nitrifying organisms in the WAS. Nitrification was complete and no significant amount of ammonia and nitrite existed in the batch tests at any time of the digestion period (< 2 mg \( NH_4^+ - N \) l\(^{-1}\) and < 1 mg \( NO_2^- - N \) l\(^{-1}\)).
As shown in Figure 5.10, the nitrate concentration increased rapidly within 7 days of the commencement of aerobic digestion. At the end of the digestion period the increase in nitrate concentration was small, especially for the BT-3 where it showed a slight increase following a decrease during the 13th and 14th day of the digestion period.

Figure 5.10a and b. Concentration of nitrate and FSA, and TKN and percentage of TKN reduction during the aerobic digestion process

The appearance of nitrate on the second day of digestion indicated the immediate commencement of nitrification, which is expected from the nitrifiers from the parent system. Except for BT-6, where FSA concentrations of 3.50 mg l⁻¹ and 3.08 mg l⁻¹ were obtained on the fifth and sixth days, the concentrations of the FSA for the rest of the digestion period were below 2 mg l⁻¹. Moreover, during the second half of the batch tests the measured concentrations of the FSA were below detectable limits of the FSA procedure, i.e. 0.5 mg l⁻¹.

The decrease in TKN concentration and the percent reduction in TKN are given in Figure 5.11a and b. After the initial high decrease in TKN, the magnitude of the decrease became smaller as the test progresses and was low at the end of the test. This trend is similar to the changes in COD and VSS. The organic nitrogen bound within the sludge cell decreased uniformly during the digestion process. The TKN reductions obtained ranged between 31.7 and 66.4%. Because there was no build up of FSA and nitrite, the decrease in TKN should mirror the increase in nitrate. This is shown in Figure 5.11a. Moreover, as the increase in the soluble unbiodegradable organics in relation to the decrease of total COD was negligible,
similarly the increase in organic unbiodegradable soluble nitrogen was negligible compared to the total reduction in TKN.

Figure 5.11a and b. Ratios of TKN/VSS and percentage reduction of TKN/percentage TSS reduction and percentage reduction of TKN/ percentage the degradation of VSS during the aerobic digestion process

During the digestion process, the nitrogen content of the sludge (TKN/VSS ratio) slightly decreased while fluctuating between a minimum and maximum values of 0.071 (BT-5) and 0.113 mgN mgVSS\(^{-1}\) (BT-6) respectively. The average TKN/VSS ratio obtained for BT-3 to BT-6 was 0.09 mgN mgVSS\(^{-1}\) with a standard deviation of 0.009 (Figure 5.12). For the parent system for all the SBs from March 2005 to May 2006 and for SBs where the WAS was harvested for these six batch tests, the average TKN/VSS ratio in the aerobic reactor was 0.09 mgN mgVSS\(^{-1}\) with standard deviation of 0.01 (du Toit et al., 2006), which is identical to the average value for the batch tests. This value is very close to the conventionally accepted TKN/VSS ratio of 0.10 mgN mgVSS\(^{-1}\).
Figure 5.12. Statistical plot for average TKN/VSS ratios of BT-3 to BT-6

Moreover, the reduction of TKN with respect to VSS destruction ($\Delta$TKN/$\Delta$VSS) and TSS reduction ($\Delta$TKN/$\Delta$TSS) were similar (Figure 5.11b). This almost identical TKN reduction observed with respect to the VSS and TSS degradation renders the solubilization of the organic N in the sludge cell and subsequent conversion to FSA to be solely associated with the degradation of VSS.
Figure 5.13. Comparison of the concentration of TKN and percentage TKN reduction for BT-7 (undiluted WAS) and BT-8 (diluted WAS)

In comparing BT-7 and BT-8, the simultaneous tests carried out with undiluted and diluted WAS respectively, apart for some small deviations, comparable percent TKN reductions were observed. When the diluted WAS was 'undiluted' by multiplying it with the dilution factor, its pattern matched almost identically that of the undiluted WAS (Figure 5.13). This indicated that dilution or concentration did not influence the aerobic digestion process.
5.2.6 Phosphorus

Phosphorus contained in the WAS either as organically bound P or internally stored P is released into the bulk liquid by aerobic digestion as OP. During this study of aerobic digestion of WAS an approximately linear increase of OP in the bulk liquid was observed. It is only near the end of the digestion period that the increase became smaller with time.

The main objective of doing the diluted WAS batch test (BT-8) was to ensure that no mineral precipitation would take place with which to compare the undiluted test (BT-7) in which mineral precipitation possibly could take place, even though the ammonia concentration was generally less than 1 mgNH₄-N l⁻¹ due to complete nitrification during the batch tests. Because the measured ortho P concentration at the end of the undiluted BT-7 (208.5 mgP l⁻¹) was only about 65% of the diluted BT-8 times the dilution factor (5), it was possible that precipitation of P took place in the undiluted batch test.

In the comparison of the VSS, TKN and COD between the undiluted BT-7 and diluted BT-8, when the measured values for the diluted test were multiplied back by the dilution factor they were comparable to the corresponding values of the undiluted WAS of BT-7. This 1:1 relationship, however, was not obtained for the phosphorus concentrations (Figure 5.14).

![Graphs showing total P and ortho P concentrations for BT-5 to BT-8 and OP concentrations for undiluted BT-7, diluted BT-8 and diluted BT-8 multiplied by the dilution factor (5)]
As shown in Figure 5.14a and b, there was significant difference between the TP of BT-7 (with undiluted WAS) and BT-8 (with diluted WAS). Moreover, when the measured TP concentration of BT-8 was multiplied by the dilution factor (5) it was much higher than that of BT-7. Similarly, when comparing the OP concentrations of BT-7 and BT-8, the difference between the measured OP concentrations was high. When the OP concentration of BT-8 was ‘undiluted’ by multiplying back by the dilution factor (5) it was higher than that of the undiluted WAS of BT-7. This difference could be (1) a dilution effect in the OP or TP test method, (2) mineral precipitation, or (3) no P release by the PAO biomass. This last reason was considered highly unlikely because the biomass nitrogen was released (as FSA which was nitrified to nitrate) at the expected concentrations. The remaining two possible sources of the difference are discussed below.

5.2.6.1. Dilution effect

As explained in the previous section, the OP and the TP analyses were done using a vanadomolybdate colour development using a UNICAM 8625 UV/VIS spectrometer. The standards used in the test were within a concentration range of 0 to 25 mgP l⁻¹. The concentrations of the measured OP and TP were much higher than the range of standards used in the analysis. Because the samples tested for OP and TP were not diluted to fall below the 25 mgP l⁻¹, a comparison was made between undiluted samples of BT-5 and diluting these samples so that the OP concentration would be within the range of the standards (0 to 25 mgP l⁻¹). Comparison of these dilution effect tests produced no difference in the OP concentration of the analyzed diluted and undiluted samples (Figure 5.15a). Additionally, to check the effect of dilution, standard concentrations of di-potassium hydrogen orthophosphate (K₂HPO₄) ranging from 0 to 400 mgP l⁻¹ were prepared and analysed using the same procedure. As shown in Figure 5.15b, apart for small deviation at concentrations of >350 mgP l⁻¹, the analyzed results were equivalent to the prepared standard concentration of K₂HPO₄, showing that a linear relationship was still valid for concentrations out of the 0 – 25 mgP l⁻¹ range of the standards up to 400 mgP l⁻¹ (Figure 5.15b). This eliminated ‘out of range’ as possible cause for the deviation between the diluted and undiluted batch tests OP concentrations (Figure 5.14b). The difference could be due to mineral precipitation because it is the undiluted test that has lower P concentrations than the diluted test – if precipitation occurs it is more likely in the undiluted test. This is considered in detail below.
Figure 5.15a and b. Comparison of diluted and undiluted samples of BT-5, and prepared and analyzed concentrations of di-potassium hydrogen orthophosphate

5.2.6.2 Calcium, Magnesium and Mineral precipitation

In the endogenous respiration process when the micro-organisms die, they release the cations which were contained in the cells to stabilize the stored polyphosphate. The cations calcium and magnesium were measured in the batch tests. During the aerobic digestion of the WAS, the concentration of calcium remained almost constant while fluctuating between a minimum and maximum values of 19.4 and 41.0 mg l\(^{-1}\) while the magnesium concentration increased linearly with time from 0 to 77 mg l\(^{-1}\) (Figure 5.16a and b).
Figure 5.16a and b. Concentrations of calcium and magnesium during the digestion process.

With the occurrence of a conducive environment, the magnesium (Mg), ammonium (NH₄) and phosphate (PO₄³⁻) released into the bulk liquid may react to form magnesium ammonium phosphate (MgNH₄PO₄) precipitate, known as struvite, which forms a hard crystalline deposit blocking aerators, pipes and pumps of sludge treatment facilities.

Struvite precipitation is expected to occur if the molar concentration product of magnesium, orthophosphate and ammonium exceeds the solubility product, Kₛₚ, of struvite. The occurrence for this condition for the precipitation of struvite was examined by comparing of the product of the measured concentrations of magnesium, orthophosphate and ammonium with the solubility product of struvite as shown in Table 5.3.
Table 5.3. Comparison of the product of molar concentrations of magnesium, ammonium and phosphate with the solubility product of struvite ($\leq$ = less; $>$ = greater).

<table>
<thead>
<tr>
<th>Detention Time (d)</th>
<th>Molar Product (Mg$^{2+}$NH$_4$$^+$PO$_4$)</th>
<th>Molar Product Compared to $K_{sp}$ of Struvite (2.512E-13)</th>
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Though without uniform trend, in a number of cases the molar product of concentrations of Mg$^{2+}$, NH$_4$$^+$ and PO$_4^{3-}$ were observed to exceed (as indicated by $>$) the solubility product of struvite. Because the Mg and OP concentrations were generally increasing during the batch tests, the fluctuation in ionic product was mainly caused by the fluctuating ammonia concentration between 0.5 and 2 mgN l$^{-1}$. The fact that the ionic product fluctuated around the solubility product during the course of the batch tests, indicated that mineral precipitation probably did take place. This conclusion is supported by

1. the much lower OP concentration in the undiluted BT-7 compared with the diluted BT-8 "corrected" for dilution (Figure 5.14b)
2. the only batch test which the OP concentration could be correctly predicted was diluted BT-8 – all the other undiluted batch tests had predicted OP concentrations
2 to 3 times higher than the measured OP concentrations (see below – Figure 5.41). Such a big difference is unlikely for a calibrated simulation model for which the starting TP concentrations are the same as those measured, unless the P remains in the solid phase either through P precipitation or through non-release of the stored P of the PAOs. (3) the measured Mg concentration was only about 1/3\textsuperscript{rd} of that expected from the polyphosphate content and batch test simulation model predicted OP concentration. From Mg:K:Ca:P = 0.275:0.295:0.05:1 content of polyphosphate, the predicted bulk liquid cation concentrations from the predicted final OP concentration of around 700 mgPl\textsuperscript{-1} should be 192:206:35:700. The observed final concentrations were significantly below these predicted concentrations from the P content of the PAOs at around 60: 30:300 (Mebrahtu et al., 2007). In hindsight, K should have been measured also because it does not readily precipitate. High and increasing K concentrations with digestion time would have provided further evidence that P was being released by the PAOs but Mg and OP remained low in the bulk liquid due to struvite precipitation.

The initial liquid OP concentrations for BT-4, BT-5, BT-6 and BT-7 were 0.3, 6.2, 2.1 and 2.4 mgOP l\textsuperscript{-1} respectively. After aeration times of 21, 11, 15 and 9 days the liquid OP concentrations for BT-4, BT-5, BT-6 and BT-7 reached 218.7, 289.5, 378.1 and 208.5 mgOP l\textsuperscript{-1} respectively. The initial TP content of the VSS, (P/VSS), and TSS, (P/TSS), for BT-5, BT-6 and BT-7 were 7.3, 6.6 and 5.1% and 5.8, 5.1 and 4.0%, respectively. The initial and final aeration had the effect of transferring P from the particulate to the dissolved phase. This also indicated that P did not go missing in the batch tests – the question was in relation to the simulated model, what caused it to stay in the sludge – mineral precipitation or incomplete release of PAO P content.

The lowest (P/VSS) and (P/TSS), ratios (BT-7) resulted in the lowest OP release into the bulk liquid, while the highest (P/VSS), and (P/TSS), ratios (BT-6) resulted in the highest OP release into the bulk liquid. This shows that the release of OP into the bulk liquid was directly related to the initial concentration of the suspended solids. The higher the initial phosphorus content of the sludge, the higher the OP released in to the bulk liquid. This is in agreement with the findings of Ju et al. (2005), where they observed a clear dependency of
the liquid phosphorus concentration on the initial phosphorus content of the solids; the higher the initial phosphorus content in the solids, the higher the supernatant phosphorus concentration. If the released P was precipitating one would not expect a consistent relationship between the bulk liquid OP concentration and the initial P content of the VSS. In comparison with the calibrated simulation model (see below), which shows also a consistent relationship between P released and initial P/VSS ratio, but with a P release 2 to 3 times higher than measured, this observation seems to indicate that the complete P content of the PAOs is not being released to the bulk liquid as aerobic digestion progresses.

As shown in Figure 5.17a, during the aerobic digestion of the WAS the OP concentration increased almost linearly until the end of the digestion period. On the other hand, as explained earlier, the decrease of VSS concentration during the digestion process was almost linear. This implies that the observed P release can be attributed to the degradation of the VSS. Similar conclusion was drawn by Ju et al. (2005) when they asserted that P release is not independent of the VSS destruction. From this it can be inferred, with caution that, with regulated pH, P release due to inorganic P dissolution did not occur during the aerobic digestion process. On the contrary, it is more likely that precipitation would occur.

Besides, the unfiltered TP concentration showed a slight decrease from the initial values of 934.4, 905.3 and 794.3 mgP l⁻¹ to 873.9, 864.1 and 771.3 mgP l⁻¹ for BT-5, BT-6 and BT-7 respectively. While for BT-8, the TP concentration showed a slight increase from the initial value of 598.5 to final value of 619.2 mgP l⁻¹ (Figure 5.19b). This shows that P balances in the batch tests were reasonable (94 – 103 %).
Figure 5.17a and b. Orthophosphate concentrations as compared to the data of Ju et al. (2005) and the daily incremental P release with respect to the total P release (in percentage) during the aerobic digestion process.

The daily incremental P release with respect to the total P release fluctuated between initial and final values of 8.9, 2.2, 4.3, 1.7 and 11.1% and 2.2, 2.6, 9.4, 5.9 and 4.6% for BT-3, BT-4, BT-5, BT-6 and BT-8 respectively. For BT-3, BT-4, BT-5 and BT-6, the minimum and maximum daily incremental P release with respect to the total P release were 1.7, 2.2, 4.3 and 1.7% and 9.3, 7.6, 12.7 and 11.6% respectively (Figure 5.17b). Though the daily incremental P release with respect to the total P release for BT-3, BT-4, BT-5 and BT-6 follow no definite pattern, generally after an initial slight increase, a gradual decrease with digestion time was observed. Omitting the extreme values, the almost comparable daily incremental daily P release values seem to indicate the P release was due to the release of the organically bound P in the sludge mass of the OHOs and the PAOs as the endogenous process proceeded. The observed initial slight increase may be due to a delay of the onset of true ‘endogenous respiration’ behaviour of PAOs, and that of the gradual decrease with digestion time due to the high death rate of the OHOs and low death rate of the PAOs where the P release from the death of the OHOs diminishes faster leaving behind a gradual P release from the organically bound P of the sludge mass of the dying PAOs. Besides, the absence of a consistent high discrepancy between the percentage daily incremental P release values with respect to the total P release suggest that the poly phosphate (PP) content of the remaining live PAOs remains constant during the digestion process. An initial high release of P by all the live PAOs until their P content is the same low value as OHOs before the endogenous respiration
commences was not observed. It is, therefore, reasonable to accept that P is released by PAOs during aerobic digestion as they die at their endogenous rate, i.e. as their VSS mass decreases.

The liquid OP/ΔVSS and OP/ΔTSS ratios, in percentage, for BT-4, BT-5 and BT-6 increased from initial values of 1.9, 1.0 and 1.3 mgOP mgVSS⁻¹ and 1.1, 1.4 and 1.9 mgOP mgTSS⁻¹ to final values of 4.7, 5.0 and 2.8 mgOP mgVSS⁻¹ and 3.8, 4.2 and 2.2 mgOP mgTSS⁻¹ respectively. For BT-3 within 21 days of digestion, the OP/ΔVSS and OP/ΔTSS ratios (in percentage) increased from 2.6 mgOP mgVSS⁻¹ and 3.0 mgOP mgTSS⁻¹ to 4.1 mgOP mgVSS⁻¹ and 3.5 mgOP mgTSS⁻¹ respectively (Figure 5.18a). Generally, the OP/ΔVSS ratios were higher than the OP/ΔTSS ratios. The trends of the incremental P-release with respect to VSS degradation (ΔP/ΔVSS) and TSS reduction (ΔP/ΔTSS) were similar. Except for some initial values of BT-5 and BT-6 where ΔP/ΔTSS were higher than ΔP/ΔVSS, generally the incremental P release with respect to VSS destruction was higher that the corresponding TSS reduction (Figure 5.18b).

![Graphs showing OP/ΔVSS and OP/ΔTSS ratios](image)

Figure 5.18a and b. Ratios of liquid OP/ΔVSS and OP/ΔTSS in percentages, and ΔOP/ΔVSS and ΔOP/ΔTSS in percentages during the aerobic digestion process

The average OP/ΔVSS ratio (%) for the batch tests was 3.8 mgOP mgVSS⁻¹ with standard deviation of 0.83. The variation for the OP/ΔVSS ratios among the batch tests ranged from 3.1 mgOP mgVSS⁻¹ (BT-5), with a standard deviation of 1.68 and detention time of 11 days,
to 4.9 mgOP mgVSS\(^{-1}\) (BT-3) with standard deviation of 2.50 and detention time of 21 days (Figure 5.19). This high variation is also related to the variability of the initial P content of the solids before the aerobic digestion of the WAS.

For all the SBs of the parent system (from March 2005 to May 2006) the average P/VSS ratio was 8.3%. For the SBs where the WAS was harvested for batch tests, the average P/VSS ratio was 6.8%.

![Figure 5.19. Statistical plot of measured average OP/ΔVSS (%) ratio during the aerobic digestion process](image)

For comparison, the finding of Ju et al. (2005) on aerobic digestion of WAS, with regulated pH at 7.0, from a BNR WWTP is plotted in Figure 5.17a. Though the difference between the parent systems where the sludges were harvested and the acclimatization of the samples shipped from the WWTP to the laboratory where Ju et al. (2005) done the batch tests would create a hindrance for a comparative evaluation of the results of both studies, the data of Ju et al. (2005) when compared to the results of the undiluted WAS sludge of BT-3 to BT-6, for the first five days of digestion, the P release trends of both sludges coincided well. Thereafter, the rate of P release of Ju et al. (2005) flattened out till the end of the digestion period (Figure 5.17a). Moreover, when compared to the result of BT-8, with diluted WAS, the P release of
Ju et al. (2005) followed a similar trend, though at a slightly higher level. Though the sludge used in the study of Ju et al. (2005) had low TSS concentration (~1500 mg l\(^{-1}\)) as compared to the undiluted WAS of BT-7 (19660 mg l\(^{-1}\)) and diluted WAS of BT-8 (3770 mg l\(^{-1}\)), its initial (P/TSS) content (~7.0%) was higher than that of BT-7 (4.0%) and lower than that of BT-8 (15.9%). However, a slightly higher P release was observed with Ju et al. (2005) than obtained for BT-8 (diluted WAS) and lower than BT-7 (undiluted WAS) of this study.

Comparing the undiluted BT-7 and diluted BT-8, their initial P/VSS and P/TSS ratios were not the same which is contrary to what was expected. The initial TP concentration of the diluted BT-8 (598.5 mgP l\(^{-1}\)) was only 75% of that of the undiluted BT-7 (794.3 mgP l\(^{-1}\)). Considering that the dilution factor was 5:1, it was expected that the initial P for BT-8 be 20% (i.e. ~150 mgP l\(^{-1}\)) of that of BT-7. Moreover, in the diluted BT-8 the OP released was only 10% of the initial TP concentration, whereas for the undiluted BT-7 it was ~26% of its corresponding initial TP concentration, which seems to contradict the conclusion that mineral precipitation took place in BT-7 and not BT-8 – in the undiluted BT-7 the released OP concentration with respect to the initial TP concentration was higher than that of the diluted BT-8. This completely deepens when considering the simulation results (see below). The predicted P release matched that observed in BT-8 but was ~2 times higher for BT-7, speculated to be due to mineral precipitation in BT-7. No definite explanation can be given at this point.
5.28 Oxygen Utilization Rate and Specific Oxygen Utilization Rate

During the aerobic digestion process the sludge cells are oxidized to CO₂ and H₂O. The impracticality of measuring the by-product, i.e. the water, has urged the use of an indirect way of measuring it. The oxygen utilized represents the substrate (or cell material) oxidized to form the water. Hence, the OUR serves as an important indicator of biological activity in aerobic biological process, a reflection of the rate of mass reduction through endogenous respiration. The oxygen uptake rate of aerobically digesting sludge depends on the temperature, the type of sludge fed to the digester, the initial concentration of the sludge, and the sludge age of the digesting sludge. The oxygen uptake rate would normally decrease with increasing detention time and decreasing reactor temperature.

For BT-4 and BT-6 the OUR, as shown in Figure 5.20a, decreased from initial values of 43.8 and 34.0 mgO l⁻¹ h⁻¹ to final values of to 6.1 and 1.9 mgO l⁻¹ h⁻¹ respectively. For BT-5 the OUR decreased from an initial value of 31.8 to 7.4 mgO l⁻¹ h⁻¹ in 10 days of aerobic digestion. Except for BT-4 where the OUR dropped sharply from the beginning, the OUR for BT-3, BT-5 and BT-6 fluctuated unevenly for the first four days of the digestion period. For all the batch tests the sharp decline of the OUR occurred within 11 days of the digestion process. Thereafter, the decrease of OUR was much lower until the end of each digestion test. For BT-3 the 'initial' value of OUR considered is that of the 4th day, i.e. 31.6 mgO l⁻¹ h⁻¹. This value is an average of 89 readings taken for that day, as all the daily OUR values shown as one data point are the computed daily average values. Taking the decrease of OUR in the fourth day alone, there was a sharp decrease from the first value of 46.3 to the last, 29.2 mgO l⁻¹ h⁻¹ in an interval of 16 hours. However, considering the daily averages, after some fluctuations during the first 8 days, there was a steep decrease in OUR until the 14th day to an OUR value of 6.2 mgO l⁻¹ h⁻¹. Thereafter, the OUR decreased gradually to a final value of 3.7 mgO l⁻¹ h⁻¹.
The ratio of the consecutive OUR values remained almost constant with slight fluctuations between a minimum and maximum value of 0.8 and 1.6 respectively. The ratio of consecutive daily average OURs of 1.2, 1.1, 1.1, 1.3, 1.1 and 1.2 were obtained for BT-3, BT-4, BT-5, BT-6, BT-7 and BT-8 respectively.

The area under the OUR-time plot, computed using the method of Riemann sum (Swokowski, 1984), gives the total oxygen utilized (OU) for the respective batch tests. As shown from the plot of the total OU against the measured nitrate and OP concentrations (Figure 5.21a and b), an almost linear increase of OP with increase in the total oxygen utilized was observed. Similarly, apart for some deviation for BT-4, the increase of nitrate was almost linear with the corresponding increase of the total oxygen utilized. Hence, it can be said that the total oxygen utilized has a stoichiometric relation to the OP and nitrate concentrations in the bulk solution. This, therefore, signifies that the solubilization of organic nitrogen to ammonia and the subsequent conversion to nitrate, and the P release were as a result of VSS destruction via the endogenous process.
Figure 5.21a and b. Relationship of total oxygen utilized (OU) with the orthophosphate and nitrate concentration in the bulk solution during aerobic digestion

The rate of substrate removal and endogenous mass decrease are ultimately dependent on the active mass concentration of the mixed liquor. Therefore, when the OUR is expressed as specific values (i.e. per mass of VSS) it serves as an indicator of the specific activity of the mixed liquor only. The specific oxygen utilization rate (SOUR) changes with sludge age (Eikum et al., 1974; Huag and Cheng, 1984) and organic load (Edwards and Sherrard, 1982). Ahlberg and Boyko (1972) and Samson and Ekama (2000) stated that the specific uptake rate is a more reliable indication of digested sludge stability because it is a measure of biological activity. Because the purpose of the aerobic digestion process is to oxidize organic compounds to stable organic and inorganic end products biologically, and because the biological activity decreases as the unstable organic fraction of material in the sludge decreases, this measure of biological activity (specific uptake rate) is an absolute basis of sludge stability that is not peculiar to an individual plant. On the other hand, Mavinic and Koers (1979) contend that OUR is not a suitable parameter as an indicator of stability of low-temperature, digested, waste activated sludges.

The SOUR divided the digestion period into three regions (Figure 5.20b). In the first region, i.e., the first one third of the digestion period, the SOUR, with some fluctuations decreased very gradually. In the second region, i.e., the second one third period of digestion, a sharp decrease in SOUR is exhibited. The sharp decent of the SOUR, therefore, shows the period where much of the microbial activity with a fast decline in the microbial population takes
place. During the last one third period of the digestion the SOUR declines gradually to the end of the digestion process.

The SOUR decreased from initial values of 3.3 and 2.2 mgO gVSS⁻¹ h⁻¹ to final values of 0.7 and 0.8 mgO gVSS⁻¹ h⁻¹ for BT-4 and BT-5 respectively. For BT-3 and BT-6, the SOUR decreased from 2.5 mgO gVSS⁻¹ h⁻¹ to 0.5 mgO gVSS⁻¹ h⁻¹ within 19 and 13 days of digestion process respectively. The final values of the SOUR, even for BT-5 where test was stopped due to motor failure just before the degradation process was completed, were all well below the accepted SOUR value for a ‘stable’ sludge, i.e., less than 1 mgO gVSS⁻¹ h⁻¹. Therefore, according to this measure of biodegradability, the WAS aerobically digested in the batch tests was well stabilized to an acceptable degree. For their batch fed aerobic digestion of non-BEPR WAS, Benedek et al. (1972) obtained an average value of oxygen consumption per gram of organic matter decomposed of 1.7 mgO (gVSS)⁻¹ hr⁻¹.

For BT-3, BT-5 and BT-6, the fluctuation of the OUR and the corresponding increase of SOUR values for the first six days of the digestion period seem to indicate the occurrence of growth as opposed to endogenous respiration. It is paradoxical, though it may be possible, that growth, on a slowly degradable substrate, could occur on the aerobic digestion process of the waste activated sludge cultivated from a 20 days sludge age parent system. Though further verification may be needed, the apparent growth could also be associated with that of the PAOs using their stored PHA and growth of OHOs on biodegradable organics of dead PAOs.
Figure 5.22. Comparison of OUR and SOUR for BT-7 (undiluted WAS) and BT-8 (diluted WAS).

The OUR of BT-8, with diluted WAS, decreased uniformly from an initial value of 11.7 to a final value of 2.5 mgO l$^{-1}$ h$^{-1}$ (Figure 5.22). During the corresponding detention time of 8 days, the OUR for BT-7, with undiluted WAS, decreased from an initial value of 64.7 to 33.4 mgO l$^{-1}$ h$^{-1}$. The decrease of OUR for BT-7, like the other batch tests with undiluted WAS, was not on a uniform scale. The sharp decrease of OUR at the beginning of the digestion was followed by a plateau, thereafter the OUR decreased gradually.

The irregular decrease of OUR during the very few days of digestion may have two causes: (1) The high concentrations of the WAS studied. The high concentration of the suspended solids may affect the rate of oxygen transfer to the micro-organisms, though this conclusion merits further investigation. Besides, Upadhyaya & Eckenfelder (1975) remarked that a variation in floc sizes with different VSS concentrations could have an effect on the oxygen penetration through the floc. (2) Residual enmeshed slowly biodegradable particulate organics in the WAS from the parent system. Since DO penetration in the floc at high MLSS did not appear to affect the kinetic rates in the parent MBR system (Parco et al., 2006) as second cause is the most likely.
5.2.9 COD Balance of Batch Tests

A COD balance of the batch tests was done to check the equivalency of the change in total (unfiltered) COD to the cumulative carbonaceous OUR for a successive 1-day interval values and for the initial and values from measured COD, OUR and NO₃ concentrations. Since the measured OUR is the lumped total OUR, the carbonaceous OUR is obtained by deducting nitrification OUR from the measured total OUR for the respective batch test. The nitrification OUR was computed by multiplying the respective nitrate concentrations by the equivalency factor 4.57. The cumulative OUR was obtained from the OUR-digestion time plot using the best fit line. The values of the COD balance obtained for both the 1-day interval and initial and final values is given in Table 5.4.

Table 5.4. COD balance of the batch tests based on measured 1-day interval and initial and final values

<table>
<thead>
<tr>
<th>BT</th>
<th>COD Balance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-Day Interval Values</td>
</tr>
<tr>
<td>3</td>
<td>93.0</td>
</tr>
<tr>
<td>4</td>
<td>96.2</td>
</tr>
<tr>
<td>5</td>
<td>93.7</td>
</tr>
<tr>
<td>6</td>
<td>92.3</td>
</tr>
<tr>
<td>7</td>
<td>95.8</td>
</tr>
<tr>
<td>8</td>
<td>88.1</td>
</tr>
</tbody>
</table>

As shown in Table 5.4, the COD balance based on 1-day interval and initial and final values for BT-3 to BT-8 ranged from 88.1 to 96.2% and 88.1 to 105.0% respectively. Except for the diluted BT-8, where the COD balance based on 1-day interval and initial and final values was 88.1%, the rest of the COD balance values were within close proximity to 100%, that is 90 to 110%, showing that the experimental data was internally consistent. Hence the disappearance of COD was consistent with the consumption of oxygen in the experimental data.

5.2.10 Reaction Rate and Decay Constants

The rate constant, b is a net value of the OHO and PAO endogenous respiration rates. From the derived batch reactor models (Chapter 4, Section 4.1) it may be possible to determine the b rate of OHOs and PAOs from the batch digestion data. Hence, employing the Marais and
Ekama (1976) method and assuming a single lumped organism group the endogenous respiration (b) rates of OHOs and PAOs are determined from the measured OUR, VSS, OP, nitrate and COD concentrations. The summary of the rate constants computed with the different test parameters is given in Table 5.5.

Table 5.5. Net PAO and OHO endogenous respiration rate (b) determined using the VSS, OUR, OP, COD and nitrate analysis.

<table>
<thead>
<tr>
<th>Batch Test</th>
<th>Rate Constant, b (d⁻¹)</th>
<th>Average (std.dev.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VSS</td>
<td>R²</td>
</tr>
<tr>
<td>BT-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BT-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BT-3</td>
<td>0.05</td>
<td>0.92</td>
</tr>
<tr>
<td>BT-4</td>
<td>0.15</td>
<td>0.98</td>
</tr>
<tr>
<td>BT-5</td>
<td>0.20</td>
<td>0.95</td>
</tr>
<tr>
<td>BT-6</td>
<td>0.64</td>
<td>0.93</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>0.48</strong></td>
<td><strong>0.18</strong></td>
</tr>
<tr>
<td>BT-8</td>
<td>0.22</td>
<td>0.95</td>
</tr>
</tbody>
</table>

The endogenous respiration (b) rates obtained from the measured VSS concentrations showed the highest variation for the different batch tests, ranging from 0.05 d⁻¹ (BT-3) to 0.64 d⁻¹ (BT-6), with correlation coefficients of 0.92 and 0.93 respectively. The b rates with the least variation among the different batch tests were obtained with OUR, with the lowest of 0.12 d⁻¹ (BT-4) and highest of 0.25 d⁻¹ (BT-3) and correlation coefficients of 0.97 and 0.84 respectively.

When considering the average values of b rates computed from the different measured parameters for each batch test, the lowest value was 0.13 d⁻¹ (BT-3) and the highest 0.29 d⁻¹ (BT-6) with standard deviations of 0.07 and 0.19 respectively. Comparable values of b rates were obtained for the diluted BT-8, where a minimum b rate of 0.17 d⁻¹ was obtained from the OUR and the highest value of 0.26 d⁻¹ from the COD. As shown in Figure 5.23a and b, the average b rate for BT-1 to BT-6 obtained using the OUR and nitrate were 0.18 and 0.19 d⁻¹ with a standard deviation of 0.046 and 0.075 respectively. For BT-8, with diluted WAS,
the average b rate obtained from the different measured parameters was 0.26 d\(^{-1}\) with standard deviation of 0.073.

![Graph showing statistical analysis of b rate values determined using OUR and nitrate]  

Figure 5.23a and b. Statistical plot for average b\(\text{H}\) values determined using OUR and nitrate

As mentioned above, the b rate is a lumped value obtained as a result of endogenous mass loss of the OHOs, PAOs and ANOs. The ANOs are too few to make any significant difference, but the different b\(\text{H}\) and b\(\text{G}\) rates of the OHOs and PAOs should have a major impact on the net b rate. With b\(\text{H}\) = 0.24 day\(^{-1}\) and b\(\text{G}\) = 0.04 day\(^{-1}\) at 20°C in the steady BEPR model, a lumped net rate between these of ~0.17 day\(^{-1}\) is reasonable.

The simultaneous presence of the OHO and PAO in the aerobically digested sludge adds to the complexity and difficulty of determining the individual b rates of each group from the measured OUR and other parameters. The measured parameters are combined values for the OHOs and PAOs. That is,

\[
O_{\text{R}} = \frac{1}{24} \left\{ \left[ \frac{f_{\text{rH}} + 4.57f_{\text{s}}}{1 - f_{\text{rH}}} b_{\text{H}} X_{\text{H}} e^{-b_{\text{H}} t} \right] + \left[ \frac{f_{\text{rG}} + 4.57f_{\text{s}}}{1 - f_{\text{rG}}} b_{\text{G}} X_{\text{G}} e^{-b_{\text{G}} t} \right] \right\} 
\]  

(mgO l\(^{-1}\) h\(^{-1}\)) \hspace{1cm} (4.75)

Determination of the initial concentration of the active OHOs and PAOs from the measured OUR would require knowing the relative proportion of these groups of micro-organisms as well as their individual b rates and COD/VSS ratios. This also adds to the complexity of the problem. Even if the initial concentrations of the OHOs and PAOs could be taken from the simulated OHO and PAO concentrations in the aerobic reactor of the parent (MBR UCT) system and/or from the measured initial concentration of the batch aerobic digestion test,
determining the b rates of both of the OHOs and the PAOs from the semi-log plot of OUR versus time is not feasible as demonstrated below.

From the steady state models of the OHOs and PAOs (Marais and Ekama, 1976 and Wentzel et al., 1990), the b value of the OHOs and PAOs are very different viz. \( b_H = 0.24 \text{ day}^{-1} \) and \( b_G = 0.04 \text{ day}^{-1} \). With such a large difference the changes at the start of the batch test are dominated by the OHOs and those at the end of the batch test by the PAOs. So assuming the early stages of the digestion process the changes are dominated by the OHOs and the late stages of the digestion process by the PAOs, the decay rates of the OHOs and the PAOs were obtained from the head and tail ends of the ln(OUR) versus retention time plot respectively. The OUR for the ANOs does not change the slope of the ln (OUR) versus time plot, therefore, does not influence the determination of the b rates. The results are shown in Figure 5.24.

![Figure 5.24a and b. Plot of ln(OUR) versus retention time for computing b rates of the OHOs and PAOs from the measured OUR](image)

From the head end (where the OHO activity is expected to be the highest) of the plot of ln(OUR) versus retention time, the b rates of the OHOs for BT-3 to BT-6 and BT-8 ranged from 0.02 to 0.16 d\(^{-1}\) with correlation coefficients (\(R^2\)) of 0.15 and 0.95 respectively. For BT-6 and BT-4, the b rate of the OHOs obtained were 0.05 and 0.07 d\(^{-1}\) with correlation coefficients of 0.74 and 0.89 respectively. An OHOs b rate of 0.16 d\(^{-1}\) with correlation coefficient of 0.95 was obtained for BT-8, with diluted WAS (Figure 5.24a).
From the tail end of the OUR (where the OHO activity is expected to have ceased), the \( b \) rates of the PAOs obtained varied between 0.10 and 0.31 \( \text{d}^{-1} \) with correlation coefficients ranging from 0.68 to 0.92. For the diluted WAS of BT-8, a PAOs \( b \) rate of 0.15 \( \text{d}^{-1} \) with a correlation coefficient of 0.95 was obtained (Figure 5.24b).

Though the cause or nature of variation could not be explained, the obtained \( b \) rates of the OHOs and the PAOs are at variance with the accepted rates of 0.24 \( \text{d}^{-1} \) (Marais and Ekama, 1976) and 0.04 \( \text{d}^{-1} \) (Wentzel *et al.*, 1989) respectively. Besides, the correlation coefficients \( (R^2) \) for the obtained \( b \) rates of the OHOs and PAOs were mostly very low with only two greater than 0.90. This indicated that the individual \( b_H \) and \( b_G \) rates cannot be determined from batch test data. This conclusion was made also by Wentzel *et al.* (1988) when conducted the BEPR research to obtain the \( b_G \) and other kinetic constants of the PAOs from enhanced PAO cultures, in which the PAOs dominated the observed behaviour (OUR, VSS, etc) and negligible OHO contribution. The N and P release behaviour under aerobic digestion condition was, therefore, determined via modelling with ASM-2 as described in Chapter 3.

5.3 Simulation

5.3.1 Parent system

The simulation of the MBR UCT system was performed by adjusting the one of two kinetic constants (1) the maximum rate of fermentation of the OHOs \( (q_{F_e}) \) and (2) the rate constant for storage of PP \( (q_{pp}) \) and two wastewater characteristics (3) the fraction of unbiodegradable particulate \( (f_{s_{up}}) \) and (4) the influent ISS concentration into the biological reactor to match the measured and simulated OP, VSS and TSS concentrations in the aerobic reactor respectively. One of the two kinetic constants was adjusted to the match the predicted P removal to that measured, the first \( (q_{Fe}) \) by reducing the mass of PAOs in the system or the second \( (q_{pp}) \) by reducing the P content of the PAOs. The wastewater characteristics, \( f_{s_{up}} \) was adjusted to match the measured VSS and the influent ISS to match the measured TSS, which includes the OHO and PAO generated ISS. Details on how and why this was done are given in Section 3.3.3.
As shown in Figure 5.26b, in the two ways of simulation done, i.e., by adjusting the constants number (1), (3) and (4) or (2), (3) and (4) above the simulated OP concentrations closely matched the measured values for all the SB periods of the MBR UCT system where WAS was harvested for batch tests. The two ways of matching the measured and simulated effluent OP concentrations does alter the simulated VSS concentrations. In the two situations, the simulated VSS concentrations in the anaerobic, anoxic and aerobic reactors were almost equal (Figure 5.25). This is so because increasing \( q_{Fe} \) (1) increases the VSS values (more PAOs, fewer OHOs) and decreasing \( f_{S_{up}} \) increases the effluent OP concentrations. That is, when matching up the measured and simulated effluent OP concentrations, increasing the magnitude of \( q_{Fe} \) to increase the simulated concentration of the PAOs resulted in higher simulated VSS concentrations. To reduce the simulated VSS concentration until a close match up to the measured VSS values was obtained, the magnitude of the \( f_{S_{up}} \) was reduced. This means that higher \( q_{Fe} \) is accompanied by lower \( f_{S_{up}} \) and vice versa. The increase or decrease of the simulated PAO concentration was, therefore, compensated by the decrease or increase in the inert material. As a result, under both ways of simulation the simulated VSS concentration remained the same in the anaerobic, anoxic and aerobic reactors of the MBR UCT system (Figure 5.25). As shown in Figure 5.25, in the aerobic reactor the measured VSS concentration and those two-way simulated coincided in a single line on the graph. In the two-way simulation the VSS concentrations in the anoxic and anaerobic reactors were similar lying on the same line on the graph. However, the measured VSS concentrations in the anoxic and anaerobic reactors were higher than those simulated.
Figure 5.25. Comparison of measured and simulated VSS for SB-1 in the anaerobic, anoxic and aerobic reactors of the MBR UCT system.

The simulation results, along with the mass balances, of all the measured parameters of the parent system (MBR UCT system) are given in Appendix A. The summary of the comparison of the measured and simulated concentrations of VSS, TSS, FSA, nitrate and OP are given in Table 5.6. Also Tables 5.7 and 5.8 give the values of the influent wastewater characteristics and kinetic constants for these simulations.

### Table 5.6. Comparison of some of the measured parameters of the MBR UCT system with simulated results

<table>
<thead>
<tr>
<th>Batch No.</th>
<th>VSS (Aerobic)</th>
<th>TSS (Anoxic)</th>
<th>FSA (Effluent)</th>
<th>NO₃ (Effluent)</th>
<th>OP (Effluent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured (mg l⁻¹)</td>
<td>Simulated (mg l⁻¹)</td>
<td>Measured (mg l⁻¹)</td>
<td>Simulated (mg l⁻¹)</td>
<td>Measured (mg l⁻¹)</td>
</tr>
<tr>
<td>B-1</td>
<td>13006½</td>
<td>13034</td>
<td>13068</td>
<td>12170</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>13014</td>
<td>13014</td>
<td>12100</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>B-2</td>
<td>12726</td>
<td>12689</td>
<td>13060</td>
<td>12430</td>
<td>2.35</td>
</tr>
<tr>
<td></td>
<td>12682</td>
<td>12682</td>
<td>12480</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>B-5</td>
<td>13856</td>
<td>13831</td>
<td>13358</td>
<td>13460</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>13865</td>
<td>13865</td>
<td>13530</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>B-26</td>
<td>13520</td>
<td>13561</td>
<td>13292</td>
<td>13380</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>13561</td>
<td>13561</td>
<td>13460</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>B-28</td>
<td>14640</td>
<td>14615</td>
<td>13198</td>
<td>14720</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>14662</td>
<td>14662</td>
<td>14780</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>B-30</td>
<td>13661</td>
<td>13662</td>
<td>13170</td>
<td>13070</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>13682</td>
<td>13682</td>
<td>13100</td>
<td>0.48</td>
<td></td>
</tr>
</tbody>
</table>

The graphical comparison of the measured and simulated VSS and effluent OP concentrations is depicted in Figure 5.26a and b.

---

⁴ For one measured value of a parameter two simulated values are given. This is, as explained in the experimental procedure, due to the two ways of simulation employed, i.e., by adjusting the kinetic constants related to the population of the PAOs (qₚₑ) and the poly-P content of the PAOs (qₚₚ).
Figure 5.26a and b. Comparison of measured and simulated VSS and effluent OP for the MBR UCT system.

The measured and simulated values of effluent OP and aerobic reactor VSS concentrations MBR UCT system were almost the same (Figure 5.26a and b). In the aerobic reactor the simulated ISS concentration, and therefore, the simulated TSS were higher than the measured values, except for SB-1 where the simulated ISS and TSS were equivalent to those measured. This is despite the fact that the influent ISS concentration in ISS model of Ekama and Wentzel (2004) was adjusted to the minimum value near to zero. In the anoxic reactor, the simulated and measured ISS and TSS concentrations were equivalent while in the anaerobic reactor the simulated ISS and TSS were lower than those measured (Appendix A). The influent ISS concentration is very sensitive to the BEPR achieved due to the very large contribution to the reactor ISS by the P content of the PAOs. A small difference in PAO P content would significantly increase the influent ISS to realistic values of 10-20 mg ISS l⁻¹. The simulated effluent nitrate concentrations of SB-2, SB-5 and SB-28 were higher than the measured effluent nitrate concentrations. For SB-1, the simulated effluent nitrate concentration was lower than the measured effluent nitrate concentration, while comparable values of measured and simulated effluent nitrate concentrations were obtained for SB-26.
Table 5.7. Stoichiometric coefficients and kinetic constants, which are the same for all the SBs, used in simulating the MBR UCT system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta_{TF}$</td>
<td>Anaerobic hydrolysis reduction factor</td>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td>$\eta_{NO3}$</td>
<td>Anoxic hydrolysis reduction factor</td>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td>$f_c$</td>
<td>COD/VSS ratio</td>
<td>mgCOD mgVSS$^{-1}$</td>
<td>1.48</td>
</tr>
<tr>
<td>$f_{SI}$</td>
<td>Fraction of inert COD in particulate substrate</td>
<td>mgCOD mgCOD$^{-1}$</td>
<td>0.00</td>
</tr>
<tr>
<td>$i_{NBM}$</td>
<td>N content of the OHO, PAO and ANO biomass</td>
<td>mgN mgCOD$^{-1}$</td>
<td>0.07</td>
</tr>
<tr>
<td>$i_{NSI}$</td>
<td>N content of soluble substrate</td>
<td>mgN mgCOD$^{-1}$</td>
<td>0.03</td>
</tr>
<tr>
<td>$i_{NSI}$</td>
<td>N content of inert soluble COD</td>
<td>mgN mgCOD$^{-1}$</td>
<td>0.01</td>
</tr>
<tr>
<td>$i_{NX}$</td>
<td>N content of inert particulate COD</td>
<td>mgN mgCOD$^{-1}$</td>
<td>0.07</td>
</tr>
<tr>
<td>$i_{NX}$</td>
<td>N content of particulate substrate</td>
<td>mgN mgCOD$^{-1}$</td>
<td>0.04</td>
</tr>
<tr>
<td>$i_{PBM}$</td>
<td>P content of the OHO, PAO and ANO biomass</td>
<td>mgP mgCOD$^{-1}$</td>
<td>0.02</td>
</tr>
<tr>
<td>$i_{PSI}$</td>
<td>P content of soluble substrate</td>
<td>mgP mgCOD$^{-1}$</td>
<td>0.01</td>
</tr>
<tr>
<td>$i_{PSI}$</td>
<td>P content of inert soluble COD</td>
<td>mgP mgCOD$^{-1}$</td>
<td>0.00</td>
</tr>
<tr>
<td>$i_{PX}$</td>
<td>P content of inert particulate COD</td>
<td>mgP mgCOD$^{-1}$</td>
<td>0.01</td>
</tr>
<tr>
<td>$i_{PX}$</td>
<td>P content of particulate substrate</td>
<td>mgP mgCOD$^{-1}$</td>
<td>0.01</td>
</tr>
<tr>
<td>$K_h$</td>
<td>Hydrolysis rate constant</td>
<td>day$^{-1}$</td>
<td>2.00</td>
</tr>
<tr>
<td>$K_{LA}$</td>
<td>Oxygen mass transfer rate</td>
<td>day$^{-1}$</td>
<td>700.00</td>
</tr>
<tr>
<td>$K_{NO3}$</td>
<td>Saturation/inhibition coefficient/factor for nitrate</td>
<td>mgN l$^{-1}$</td>
<td>0.10</td>
</tr>
<tr>
<td>$K_{O2}$</td>
<td>Saturation/inhibition coefficient/factor for oxygen</td>
<td>mgO l$^{-1}$</td>
<td>0.20</td>
</tr>
<tr>
<td>$K_{X20}$</td>
<td>Saturation coefficient for particulate COD (@ 20°C)</td>
<td>mgCOD mgcellCOD$^{-1}$</td>
<td>0.03</td>
</tr>
<tr>
<td>$Q$</td>
<td>Influent flow rate</td>
<td>l day$^{-1}$</td>
<td>140.00</td>
</tr>
<tr>
<td>$R_a$</td>
<td>Hydraulic retention time</td>
<td>day</td>
<td>0.536</td>
</tr>
<tr>
<td>$R_s$</td>
<td>Sludge age</td>
<td>day</td>
<td>20.00</td>
</tr>
<tr>
<td><strong>OHOs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$b_{OH}$</td>
<td>OHOs decay rate</td>
<td>day$^{-1}$</td>
<td>0.62</td>
</tr>
<tr>
<td>$\eta_{NOM}$</td>
<td>Reduction factor for denitrification by the OHOs</td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>$f_{OH}$</td>
<td>ISS content of the OHOs</td>
<td>mgISS mgOHO$^{-1}$</td>
<td>0.15</td>
</tr>
<tr>
<td>$f_{OX}$</td>
<td>Fraction of inert COD in OHO biomass</td>
<td>mgCOD mgCOD$^{-1}$</td>
<td>0.08</td>
</tr>
<tr>
<td>$K_{AOH}$</td>
<td>Saturation coefficient for acetate</td>
<td>mgCOD l$^{-1}$</td>
<td>4.00</td>
</tr>
<tr>
<td>$K_f$</td>
<td>Saturation coefficient for growth on soluble substrate</td>
<td>mgCOD l$^{-1}$</td>
<td>4.00</td>
</tr>
<tr>
<td>$K_r$</td>
<td>Saturation coefficient for fermentation of soluble substrate</td>
<td>mgCOD l$^{-1}$</td>
<td>150.00</td>
</tr>
<tr>
<td>$K_{NH4OHO}$</td>
<td>Saturation coefficient for ammonium</td>
<td>mgN l$^{-1}$</td>
<td>0.01</td>
</tr>
<tr>
<td>$Y_{OH}$</td>
<td>Yield of OHOs</td>
<td>day$^{-1}$</td>
<td>0.67</td>
</tr>
<tr>
<td>$\mu_{OH20}$</td>
<td>Maximum specific growth rate (@ 20°C)</td>
<td>day$^{-1}$</td>
<td>6.00</td>
</tr>
<tr>
<td><strong>PAOs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$b_{PAO}$</td>
<td>PAOs decay rate</td>
<td>day$^{-1}$</td>
<td>0.04</td>
</tr>
<tr>
<td>$b_{PHA}$</td>
<td>Decay rate of PHA</td>
<td>day$^{-1}$</td>
<td>0.04</td>
</tr>
<tr>
<td>$b_{PP}$</td>
<td>Decay rate of PP</td>
<td>day$^{-1}$</td>
<td>0.04</td>
</tr>
<tr>
<td>$f_{PAOM}$</td>
<td>ISS content of the PAO cell mass</td>
<td>mgISS mgPAO$^{-1}$</td>
<td>0.15</td>
</tr>
<tr>
<td>$f_{PKAO}$</td>
<td>Fraction of inert COD in PAO biomass</td>
<td>mgCOD mgCOD$^{-1}$</td>
<td>0.25</td>
</tr>
<tr>
<td>$K_{PAO}$</td>
<td>Saturation coefficient for acetate</td>
<td>mgCOD l$^{-1}$</td>
<td>1.00</td>
</tr>
<tr>
<td>$K_{PP}$</td>
<td>Inhibition coefficient for PP storage</td>
<td>mgPP mgPAO$^{-1}$</td>
<td>0.02</td>
</tr>
<tr>
<td>$K_{MAX}$</td>
<td>Maximum ratio of PP/PAO</td>
<td>mgPP mgPAO$^{-1}$</td>
<td>1.00</td>
</tr>
<tr>
<td>$K_{NH2PAO}$</td>
<td>Saturation coefficient for ammonium</td>
<td>mgN l$^{-1}$</td>
<td>0.001</td>
</tr>
<tr>
<td>$K_p$</td>
<td>Saturation coefficient for P in PP</td>
<td>mgP l$^{-1}$</td>
<td>0.01</td>
</tr>
<tr>
<td>$K_{PHA}$</td>
<td>Saturation coefficient for PHA</td>
<td>mgPHA mgPAO$^{-1}$</td>
<td>0.18</td>
</tr>
<tr>
<td>$K_{PP}$</td>
<td>Saturation coefficient for PP</td>
<td>mgPP mgPAO$^{-1}$</td>
<td>0.001</td>
</tr>
<tr>
<td>Parameter</td>
<td>Description</td>
<td>Unit</td>
<td>Value</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------------------------------------</td>
<td>---------------</td>
<td>-------</td>
</tr>
<tr>
<td>$K_{PS}$</td>
<td>Saturation coefficient for P in PP storage</td>
<td>mgP l$^{-1}$</td>
<td>0.10</td>
</tr>
<tr>
<td>$q_{PHA20}$</td>
<td>Rate constant for storage of PHA</td>
<td>mgCOD mgPAO$^{-1}$ d$^{-1}$</td>
<td>6.00</td>
</tr>
<tr>
<td>$Y_{PAO}$</td>
<td>Yield of PAOs</td>
<td>day$^{-1}$</td>
<td>0.67</td>
</tr>
<tr>
<td>$Y_{PHA}$</td>
<td>PHA requirement for PP storage</td>
<td>day$^{-1}$</td>
<td>0.03</td>
</tr>
<tr>
<td>$Y_{P04}$</td>
<td>Yield of P release/PHA storage</td>
<td>day$^{-1}$</td>
<td>0.52</td>
</tr>
<tr>
<td>$\mu_{PAO20}$</td>
<td>Maximum specific growth rate (@ 20°C)</td>
<td>day$^{-1}$</td>
<td>1.20</td>
</tr>
</tbody>
</table>

**ANOs**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_{AUT}$</td>
<td>ANOs decay rate</td>
<td>day$^{-1}$</td>
<td>0.04</td>
</tr>
<tr>
<td>$f_{XIAUT}$</td>
<td>Fraction of inert COD in ANO biomass</td>
<td>mgCOD mgCOD$^{-1}$</td>
<td>0.08</td>
</tr>
<tr>
<td>$K_{NH4AUT}$</td>
<td>Saturation coefficient for ammonium</td>
<td>mgN l$^{-1}$</td>
<td>1.00</td>
</tr>
<tr>
<td>$Y_{AUT}$</td>
<td>Yield coefficient (biomass/nitrate)</td>
<td>mgCOD mgN$^{-1}$</td>
<td>0.15</td>
</tr>
<tr>
<td>$\mu_{AUT20}$</td>
<td>Maximum specific growth rate (@ 20°C)</td>
<td>day$^{-1}$</td>
<td>0.45</td>
</tr>
</tbody>
</table>

For all the SBs of the MBR UCT system the simulated FSA concentrations were lower than 1 mg l$^{-1}$. The measured effluent FSA concentration of the MBR UCT system were all close to or less than 1 mg l$^{-1}$ except for SB-2 where the measured effluent FSA concentration was 2.4 mg l$^{-1}$. Hence, while the simulated effluent FSA values were lower than the measured concentrations for SB-1, SB-2 and SB-5, for SB-26 and SB-28 the simulated and measured effluent FSA concentrations were comparable (Table 5.6). Moreover, the measured and simulated volumes of sludge wasted were equivalent. The mass balances for simulated COD, phosphorus nitrogen and of the MBR UCT system were checked and found to be in the range of 99.8 to 100.5, 99.8 to 100.0 and 99.9 to 100.2%, respectively (Appendix A1 to A6).
Table 5.8. Wastewater characteristics and kinetic constants used in simulating the MBR UCT system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Name</th>
<th>Unit</th>
<th>Sewage Batch Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>SB-1</td>
</tr>
<tr>
<td>$f_{sc}$</td>
<td>Fraction of acetate</td>
<td>mgCOD</td>
<td>0.301</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mgCOD$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$f_{bs}$</td>
<td>Fraction of biodegradable</td>
<td>mgCOD</td>
<td>0.441</td>
</tr>
<tr>
<td></td>
<td>soluble COD</td>
<td>mgCOD$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$f_{sb}^u$</td>
<td>Fraction of unbiodegradable</td>
<td>mgCOD</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td>soluble COD</td>
<td>mgCOD$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$f_{so}^{up}$</td>
<td>Fraction of unbiodegradable</td>
<td>mgCOD</td>
<td>0.205$^e$</td>
</tr>
<tr>
<td></td>
<td>particulate COD</td>
<td>mgCOD$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$q_{Fe}$</td>
<td>anaerobic fermentation rate</td>
<td>mgCOD</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mgCOD$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$q_{PP}$</td>
<td>rate constant for storage</td>
<td>mgPP</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>of PP</td>
<td>mgPAO$^{-1}$ d$^{-1}$</td>
<td></td>
</tr>
<tr>
<td>$X_{ion}$</td>
<td>Influent ISS</td>
<td>mgISS$^{-1}$</td>
<td>22.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20.1200</td>
</tr>
<tr>
<td>$S_{ti}$</td>
<td>Influent COD</td>
<td>mgCOD$^{-1}$</td>
<td>958.41$^g$</td>
</tr>
<tr>
<td>$N_{ti}$</td>
<td>Influent nitrogen</td>
<td>mgN$^{-1}$</td>
<td>101.42</td>
</tr>
<tr>
<td>$P_{i}$</td>
<td>Influent P</td>
<td>mgP$^{-1}$</td>
<td>18.25</td>
</tr>
<tr>
<td>$NH_{4i}^h$</td>
<td>Influent FSA</td>
<td>mgN$^{-1}$</td>
<td>64.23</td>
</tr>
</tbody>
</table>

5.3.2 Aerobic batch digestion

5.3.2.1 Comparison of observed data with ASM-2

The two way simulation$^h$ of the MBR UCT system for the adjustment of the simulated effluent OP to the measured concentrations for all the SBs where WAS was harvested for

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$^e$ Simulation with the adjustment of the anaerobic fermentation rate, $q_{Fe}$.

$^f$ Simulation with the adjustment of the PP content of the PAOs, $q_{PP}$.

$^g$ The influent COD ($S_{ti}$), TKN ($N_{ti}$) and OP ($P_{i}$) remain the same under both simulations, i.e. with the adjustment of $q_{Fe}$ and $q_{PP}$. These influent parameters are average values of the measured concentrations.

$^h$ When characterizing the influent TKN to its various components a discrepancy was observed on the measured TKN and FSA concentrations. These discrepancies were reconciled by adjusting the measured FSA in which the sum of the various components of the TKN would equal to the measured TKN concentration. The variation of the fraction of the unbiodegradable particulate COD during the two-way simulation, therefore results in variation of the influent ammonia ($NH_{4i}$) concentration.
batch tests resulted in two sets of initial concentrations of the ANOs, OHOs, PAOs, PP, PHAs and inert material. Among the initial concentrations of these two sets of parameters the highest variation was observed for the PAOs, PP and the inert material. However, as explained earlier, the total VSS concentration of the MBR UCT system under both simulation conditions remained the same. As a result, though the simulation of the batch aerobic digestion was carried out with two sets of initial conditions, both sets of initial conditions rendered no variation in the aerobic batch test simulation results. The behaviour of a low PAO population with a high P content was the same as that of a higher PAO population with a low P content. Therefore, the results and discussion of the simulation of one set of initial conditions also equally apply to the other set of initial conditions. A comparison of the simulated and measured batch test results are given in Figures 5.27 to 5.44.

As shown in Figure 5.27 and 5.28, for BT-3 and BT-4, for the first one third of the digestion period the measured and simulated total COD concentrations were equivalent. Thereafter, the simulated total COD concentrations were observed to lie above those measured. For BT-1, BT-5 and BT-6, the simulated concentrations were higher than those measured. For BT-2, except for the initial COD concentrations, the measured COD concentrations were higher than those simulated. Generally, the measured total COD concentrations dropped faster than those simulated.

![Image](image_url)

Figure 5.27. Measured and simulated total COD for BT-1, BT-2 and BT-3
A close match of the simulated and measured VSS concentrations was obtained for BT-1 and BT-2. Apart for the end of the digestion period where the drop in the measured VSS concentration was higher than the simulated values, for BT-3 the simulated and measured VSS concentration coincided very well (Figure 5.29). Except for the early periods of digestion, the drop in the measured VSS was higher than that of the simulated values for BT-4, BT-5 and BT-6 (Figure 5.30).
Figure 5.30. Measured and simulated VSS for BT-4, BT-5 and BT-6

The lowest average measured COD/VSS ratio was 1.16 mgCOD mgVSS$^{-1}$ (BT-5) and the highest 1.50 mgCOD mgVSS$^{-1}$ (BT-4), the average value for the first six batch tests being 1.36 mgCOD mgVSS$^{-1}$ with standard deviation of 0.113. The simulated COD/VSS ratios for all the first six batch aerobic digestion tests remained constant at $\sim$1.48 mgCOD mgVSS$^{-1}$, which is equal to the accepted COD/VSS ratio (Figure 5.31). Hence, the simulated COD/VSS ratios were higher than the measured COD/VSS ratios, except for BT-4 where the mid values were slightly higher than 1.48 mgCOD mgVSS$^{-1}$. 
Figure 5.31. Measured and simulated COD/VSS ratios for BT-4, BT-5 and BT-6

For BT-6, except for the fluctuating measured concentrations at the beginning of the digestion period, the simulated ISS concentrations matched those measured. For BT-4, the simulated and measured ISS values were equivalent for the first quarter of the digestion period. Thereafter, the drop in simulated ISS concentrations was higher than that of the measured. For BT-5, the simulated ISS concentrations were equivalent to those measured, save for the undulations of measured ISS concentrations at the beginning of the digestion period and the higher drop of the measured ISS concentrations at the end of the digestion period (Figure 5.32).
The measured TSS concentrations were higher than those simulated for BT-1 and for BT-2, except at the beginning of the digestion period where the measured TSS concentration matched the simulated for BT-2. For BT-3, the measured and simulated TSS concentrations were comparable except at the end of the digestion period where the measured TSS concentration dropped more sharply than those simulated (Figure 5.33) due to sharp decrease in VSS (Figure 5.29). For BT-5, the simulated TSS concentrations were higher than those measured. For BT-4 and BT-6, during the first six days of digestion the simulated TSS concentrations coincided with those measured. Thereafter the drop in the measured TSS concentration was higher than that of the simulated values (Figure 5.34).
The measured VSS/TSS ratio for BT-1 to BT-6 remained almost constant, with an average value of 0.78 and a standard deviation of 0.016. The simulated VSS/TSS ratios for all the batch tests, however, were observed to slightly increase with retention time (Figure 5.35). For BT-2 and BT-3 the simulated VSS/TSS ratios linearly increased from an initial value of 0.76 mgVSS mgTSS$^{-1}$ to final values of 0.78 and 0.88 mgVSS mgTSS$^{-1}$ with retention times of 6 and 25 days respectively. For BT-4, BT-5 and BT-6, the simulated VSS/TSS ratios
linearly increased from initial values of 0.77, 0.75 and 0.73 mgVSS mgTSS\(^{-1}\) to final values of 0.87, 0.80 and 0.80 mgVSS mgTSS\(^{-1}\) with detention times of 21, 11 and 14 respectively.

![Graph showing VSS/TSS ratios](image)

**Figure 5.35.** Measured and simulated VSS/TSS ratios for BT-4, BT-5 and BT-6

Though during the second half period of the digestion process the FSA concentrations for the entire batch tests were lower than 1 mg l\(^{-1}\), during the beginning of the digestion FSA concentrations as high as 1.5 mg l\(^{-1}\) were obtained. On the other hand, the simulated FSA concentrations were lower than 0.5 mg l\(^{-1}\) (Figure 5.36). As a result the measured concentrations were higher than the simulated values, but the difference is of no concern.
Figure 5.36. Measured and simulated FSA for BT-1, BT-2 and BT-3

Except for the first half of the digestion period where the simulated nitrate concentrations were slightly higher than those measured, as shown in Figure 5.37, for BT-3 and BT-5 the measured nitrate concentrations closely matched those simulated. For BT-4, the simulated nitrate concentrations were higher for the first three quarters of the digestion period while for the last quarter of the digestion period the measured nitrate concentrations were slightly higher than those simulated. For BT-6, except for the first quarter of the digestion period, the measured nitrate concentrations were higher than those measured. The measured and simulated initial nitrate concentrations, however, were exactly the same for all the batch tests.
The simulated TKN concentrations were higher than those measured for BT-5. For BT-3, BT-4 and BT-6, except for the first few days of digestion period where the measured and simulated TKN concentrations matched up, for the rest of the digestion period the simulated concentrations were higher than those measured (Figure 5.38). Generally, the rate of TKN reduction was higher for the measured concentrations than those simulated.
As shown in Figure 5.39, for BT-1 the measured OP concentrations matched those simulated for the first half of the digestion period and thereafter the measured OP concentrations were much higher than those simulated. For BT-2, BT-3, BT-4, BT-5 and BT-6, the simulated OP concentrations were higher than those measured (Figure 5.40). For BT-8 (with diluted WAS) the simulated OP concentrations were comparable to those measured, while the simulated OP concentration for BT-7 (with undiluted WAS) was higher than those measured (Figure 5.41).

The above observation is probably the strongest evidence for mineral precipitation for the released P. The fact that in the diluted BT-8 the predicted and measured OP concentrations were closely the same, indicated that in this batch test, experimentally all the PAO P content was released to the bulk liquid. It would seem unlikely that concentration alone would change the PAO endogenous behaviour and cause them to release only one third to one half of their P content. In the batch tests the quantity of mineral precipitation is too small to detect a change in VSS/TSS ratio within the natural variation in the VSS and TSS data. In fact, as mentioned above, the ISS concentration decreases during digestion - but this is expected from the ISS model of Ekama and Wentzel (2004), the decrease being much larger than the increase due to precipitation.

As explained in section 5.3.2.1, the two different ways of calibrating the P removal made negligible difference to the predicted P concentrations in the batch tests. From these simulations, the P content of the PAOs was known because it accounted for the observed P removal in the parent UCT NDBEPR system. Also from Fukase et al. (1982), Arvin and Christensen (1985), Comeau et al. (1985) and Wentzel et al. (1989), the cation and P content of polyphosphate is Mg:K:Ca:P = 0.0275:0.295:0.05:1, which gives an ISS/P ratio of 31.9 mgISS mgP⁻¹, which closely matched the ISS/P ratio found by Ekama and Wentzel in the ISS model (2004). This indicated that the Mg, K and Ca concentrations expected in the bulk liquid can be calculated from the simulated P release. The measured Mg concentration was only about 1/3rd of that expected from the polyphosphate content and batch test simulation model predicted OP concentration. From Mg:K:Ca:P = 0.275:0.295:0.05:1 content of polyphosphate, the predicted bulk liquid cation concentrations from the predicted final OP concentration of around 700 mgP⁻¹ should be 192:206:35:700. The observed final concentrations were significantly below these predicted concentrations from the P content of the PAOs at around 60: - :30:300. In hindsight, K should have been measured also because it does not readily precipitate. High and increasing K concentrations with digestion time would
have provided further evidence that P was being released by the PAOs but Mg and OP remained low in the bulk liquid due to struvite precipitation.

Figure 5.39. Measured and simulated orthophosphate for BT-1, BT-2 and BT-3

Like that of nitrate, for all the batch tests the measured and simulated initial ortho P concentrations were exactly the same.

Figure 5.40. Measured and simulated orthophosphate for BT-4, BT-5 and BT-6
Figure 5.41. Measured and simulated orthophosphate for BT-7 (undiluted WAS) and BT-8 (diluted WAS)

Except for BT-2 (Figure 5.42) where the simulated OUR values coincided with the measured values, for the rest of the batch tests the simulated OUR values were lower than those measured (Figure 5.43). Besides, the fluctuation of the observed OUR during the beginning of the digestion process could not be reflected in the simulation even if a lag of up to four days was introduced in the simulation. With regard to the OUR, therefore, there is marked deviation of the predicted from the measured values. As has been mentioned earlier this could be due to the high concentration of the WAS under consideration influencing the oxygen mass transfer rate. Due to this or some unknown reason(s), however, the simulated OUR results could not match the measured values. For BT-8, except for the last measured value of OUR which coincided with that simulated, the measured OUR values were higher than those simulated (Figure 5.44).
Figure 5.42. Measured and simulated OUR for BT-1, BT-2 and BT-3

Figure 5.43. Measured and simulated OUR for BT-4, BT-5 and BT-6
Figure 5.44. Measured and simulated total OUR and OUR for OHOs, ANOs and PAOs for BT-8 (with diluted WAS)

Similar to the graphical comparison of the observed released OP and nitrate concentrations to the total oxygen utilized (OU) given in Section 5.2.8, graphs of simulated total OU against the simulated released OP and nitrate concentration is given in Figure 5.45a and b. The total OU was determined using the method of Riemann sum (Swokowski, 1984) from the OUR-time plot for the respective batch tests. For BT-4, BT-5 and BT-6, the increase in simulated total OU was accompanied by a corresponding linear increase of simulated released OP and nitrate concentrations. For BT-7 and BT-8, though the increase in simulated released OP and nitrate concentration was linear, it was at a scale lower than the increase in simulated total OU. In contrast to the almost linear increase in simulated OU, a subdued increase in simulated released OP and nitrate concentrations was observed for the diluted BT-8. Generally speaking, however, the observed and simulated patterns of increase of the released OP and nitrate concentrations with the corresponding increase of the total OU were similar.
Figure 5.45a and b. Relationship of total oxygen utilized (OU) with simulated OP and nitrate concentrations in the bulk solution.

In determining the specific b rates of the OHOs from the simulated OUR for OHOs, the average b rate of the OHOs was 0.13 d⁻¹ (Figure 5.46). As the simulated OUR for the PAOs was essentially a horizontal line just above the x-axis for all the batch tests (e.g. Figure 5.44), the death rate of the PAO could not be determined from the simulated OUR for the PAOs, i.e. the b rate of the PAOs as computed from the simulated OUR for PAOs was very close to zero.

Figure 5.46. Plot of ln(OUR) versus retention time for computing b rates of the OHOs from the simulated OUR for OHOs for BT-3 and BT-6.
As shown in Figure 5.47a and b, for BT-3 and BT-4 the b rates of the OHOs and the PAOs computed from the head and tail ends of the simulated total OUR were 0.18 and 0.04 d⁻¹ respectively. The average b rate of the OHOs computed from the simulated OUR for OHOs (0.13 d⁻¹) was lower than that computed from the head end of the simulated total OUR (0.18 d⁻¹). Similarly, the b rate of the PAOs computed from the simulated OUR for PAOs (0 d⁻¹) was lower than that computed from the tail end of the simulated total OUR (0.04 d⁻¹) (Table 5.8). Although computed from the head end of the simulated OUR, because the active fraction of PAOs is high (due to the acetate supplement to the parent system feed), the b value of the OHOs (b_H) is low due to significant effect of the PAOs with the lower b value (b_G = 0.04 day⁻¹).

![Plot of ln(OUR) versus retention time for computing b rates of the OHOs and PAOs from the head and tail ends of the simulated total OUR for BT-3 and BT-4](image)

Figure 5.47a and b. Plot of ln(OUR) versus retention time for computing b rates of the OHOs and PAOs from the head and tail ends of the simulated total OUR for BT-3 and BT-4

Moreover, the variation between the measured and simulated total OUR values resulted in the observed discrepancy between the b rates of OHOs and PAOs from the measured and simulated total OUR. The summary of the b rates of OHOs and PAOs computed from simulated OUR is given in Table 5.9.
Table 5.9. Summary of the b rates of OHOs and PAOs computed from simulated OUR using ASM-2

<table>
<thead>
<tr>
<th>b rate (d⁻¹)</th>
<th>Batch Test No.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BT-3</td>
<td>BT-4</td>
</tr>
<tr>
<td><strong>Computed from simulated OUR for OHOs and PAOs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OHO</td>
<td>0.13</td>
<td>0.12</td>
</tr>
<tr>
<td>PAO</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Computed from the head and tail ends of simulated total OUR</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OHO</td>
<td>0.19</td>
<td>0.18</td>
</tr>
<tr>
<td>PAO</td>
<td>0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>

5.3.2.2 COD Balance of simulation values

The values of the COD balance obtained for both the simulated 1-day interval and intial and final values is given in Table 5.10.

Table 5.10. COD balance of the batch tests based on simulated 1-day interval and initial and final values

<table>
<thead>
<tr>
<th>BT</th>
<th>COD Balance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-Day Interval Values</td>
</tr>
<tr>
<td>3</td>
<td>100.0</td>
</tr>
<tr>
<td>4</td>
<td>100.0</td>
</tr>
<tr>
<td>5</td>
<td>100.0</td>
</tr>
<tr>
<td>6</td>
<td>100.1</td>
</tr>
<tr>
<td>7</td>
<td>100.1</td>
</tr>
<tr>
<td>8</td>
<td>100.2</td>
</tr>
</tbody>
</table>

As expected, the COD balance for the simulated 1-day interval values was close to 100%. The COD balance for the simulated intial and final values, however, ranged from 100.2 to 101.1% (Table 5.10).
5.3.2.3 Comparison of batch reactor with simulation model

The comparison of the results simulated with ASM-2 and those computed with the batch reactor model (BRM) is done graphically\(^1\).

As shown in Figure 5.48 and 5.49, similar trends of decrease of VSS concentration with retention time was observed with ASM-2 and the BRM, though at a slightly higher level for ASM-2 simulation results than those computed with BRM.

![Graph showing comparison of VSS concentrations](image)

Figure 5.48. Comparison of VSS concentrations simulated with ASM-2 and computed with BRM for BT-1 and BT-2

\(^1\) For the comparison of ASM-2 and BRM, in order to get similar initial concentrations for both models a slight adjustment of the initial set of conditions was made.
Figure 5.49. Comparison of VSS concentrations simulated with ASM-2 and computed with BRM for BT-3 and BT-4

For BT-2, the VSS concentrations simulated with ASM-2 and computed with the BRM decreased from initial values of 12900 and 12600 mgVSS l⁻¹ to final values of 9430 and 8950 mgVSS l⁻¹ respectively (Figure 5.48). Similarly, for BT-4 and BT-5 the VSS concentrations decreased from initial values of 13350 and 14600, and 13080 and 14390 mgVSS l⁻¹ to final values of 10820 and 11490, and 10370 and 11010 mgVSS l⁻¹ when simulated with ASM-2 and computed with BRM respectively (Figure 5.49 and 4.50).
Like that of the VSS, a similar pattern of decrease of TSS concentrations was observed with ASM-2 and BRM. However, unlike that of VSS, the magnitude of the TSS concentrations computed with BRM was slightly higher than those simulated with ASM-2. For BT-2 the TSS concentrations decreased from initial values of 17570 and 16900 mgTSS l\(^{-1}\) to final values of 11160 and 10770 mgTSS l\(^{-1}\) when computed with BRM and simulated with ASM-2 respectively (Figure 5.51). As shown in Figure 5.52, for BT-4 the TSS concentration decreased from initial values of 18190 and 17380 mgTSS l\(^{-1}\) to final values of 12830 and 12240 mgTSS l\(^{-1}\) when computed with BRM and simulated with ASM-2 respectively.
Figure 5.51. Comparison of TSS concentrations simulated with ASM-2 and computed with BRM for BT-1 and BT-2

Likewise, for BT-5, when computed with BRM and simulated with ASM-2 the TSS concentration decreased from initial values of 20230 and 19320 mgTSS l\(^{-1}\) to final values of 13740 and 13130 mgTSS l\(^{-1}\) respectively (Figure 5.53).

Figure 5.52. Comparison of TSS concentrations simulated with ASM-2 and computed with BRM for BT-3 and BT-4
During the aerobic digestion process, the increase in nitrate concentrations as simulated with ASM-2 and computed with BRM was almost the same apart from a slightly higher magnitudes of nitrate computed with the BRM. For BT-3 the nitrate concentration computed with the BRM and simulated with ASM-2 increased from initial value of 0.5 and 5.7 mgN l\(^{-1}\) to final values of 403.1 and 380.8 mgN l\(^{-1}\) respectively (Figure 5.54). For BT-6 the nitrate concentration increased from initial values of 0.6 and 31.8 mgN l\(^{-1}\) to final values of 277.2 and 286.9 mgN l\(^{-1}\) when computed with the BRM and simulated with ASM-2 respectively (Figure 5.55).
The increase of liquid OP concentrations with aeration time as simulated with ASM-2 was slightly higher than that computed with BRM. For BT-2 the liquid OP concentration simulated with ASM-2 and computed with the BRM increased from an initial value of 0.4 mgOP l\(^{-1}\) to final values of 726.0 and 649.9 mgOP l\(^{-1}\) respectively (Figure 5.56).
Figure 5.56. Comparison of OP concentrations simulated with ASM-2 and computed with BRM for BT-1 and BT-2

For BT-3, when simulated with ASM-2 and computed with BRM, the liquid OP concentrations increased from an initial value of 3.1 mgOP l\(^{-1}\) to final values of 810.9 and 717.9 mgOP l\(^{-1}\) respectively (Figure 5.57).

Figure 5.57. Comparison of OP concentrations simulated with ASM-2 and computed with BRM for BT-3 and BT-4
Similarly, for BT-5 the liquid OP concentration increased from an initial value of 1.1 mgOP l$^{-1}$ to final values of 850.6 and 760.3 mgOP l$^{-1}$ when simulated with ASM-2 and computed with the BRM respectively (Figure 5.58).

![Graph showing comparison of OP concentrations simulated with ASM-2 and computed with BRM for BT-5 and BT-6](image)

**Figure 5.58. Comparison of OP concentrations simulated with ASM-2 and computed with BRM for BT-5 and BT-6**

As shown in Figures 5.59, 5.60 and 5.61, the OUR values computed with BRM were higher than those simulated with ASM-2, especially at the beginning of the aerobic digestion. At the end of the aeration time, however, the OUR values simulated with ASM-2 and computed with BRM reached similar final lowest levels.
Figure 5.59. Comparison of OUR values simulated with ASM-2 and computed with BRM for BT-1 and BT-2

Figure 5.60. Comparison of OUR values simulated with ASM-2 and computed with BRM for BT-3 and BT-4

For BT-2 the OUR values computed with the BRM and simulated with ASM-2 decreased from initial values of 75.5 and 53.7 mgO (l.h)\(^{-1}\) to final values of 3.0 and 2.6 mgO (l.h)\(^{-1}\) respectively (Figure 5.59). Likewise, for BT-5 the OUR values decreased from initial values
of 62.7 and 47.3 mgO (l.h)$^{-1}$ to final values of 3.7 and 3.0 mgO (l.h)$^{-1}$ when computed with the BRM and simulated with ASM-2 respectively (Figure 5.61).

![Graph showing comparison of OUR values simulated with ASM-2 and computed with BRM for BT-5 and BT-6.](image)

Figure 5.61. Comparison of OUR values simulated with ASM-2 and computed with BRM for BT-5 and BT-6

### 5.3.2.4 Comparison of observed data with the batch reactor model (BRM)

The variable inputs into the BRM are the initial concentrations of the OHOs and PAOs and the organic and inorganic inert materials (or equivalently the OHO and PAO active fractions). The occurrence of two sets of initial conditions as a result of the two way simulation of the MBR UCT system to match the simulated effluent OP concentration to the corresponding measured concentrations would, therefore, result in variation of the results computed with the BRM. However, as explained earlier, since the increase or decrease of the PAOs was accompanied by a corresponding decrease or increase of inert organic material and PAO P content, both sets of initial conditions resulted in no substantial changes in the results of the BRM except for small differences in the OP concentrations. Consideration of one set of initial conditions in the BRM would, therefore, represent the other set of initial conditions.

For BT-1, for the first half of the digestion period the measured VSS concentrations were higher than those computed with BRM and vice versa for the second half of the digestion
period. For BT-2, the measured VSS concentrations were higher than those computed with BRM. For BT-3, except for the end of the digestion periods where the measured VSS concentrations were lower than those computed with the BRM, the measured VSS concentrations were slightly higher than those computed with BRM (Figure 5.62).

![Graph showing measured and computed VSS concentrations for BT-1, BT-2 and BT-3](image)

Figure 5.62. Measured and computed (with BRM) VSS concentrations for BT-1, BT-2 and BT-3

For BT-4, BT-5 and BT-6, for the first one third of the digestion period the measured VSS concentrations were equivalent to those computed with BRM. For the last two third of the digestion period, however, the measured VSS concentrations decreased at higher rate than those computed with BRM (Figure 5.63).
Figure 5.63. Measured and computed (with BRM) VSS concentrations for BT-4, BT-5 and BT-6

Generally, the VSS concentrations computed with SSM were similar to those simulated with the ASM-2. During the early periods of the digestion process the measured VSS concentrations were almost equivalent to those computed, while during the end of the digestion period the measured VSS concentrations were lower than those computed with BRM.

For BT-1 and BT-3, for the first half of the digestion period the measured VSS reductions were lower than those calculated with BRM while during the second half of the digestion period the calculated VSS reductions were higher than those measured. For BT-2, the measured VSS reductions were lower than those simulated (Figure 5.64). For BT-4 and BT-6, except for the early periods of digestion, the measured VSS reductions were higher than those calculated while for BT-5 the measured VSS reductions were higher than those calculated with BRM (Figure 5.65). Generally, as shown in Figures 5.64 and 5.65, except for the first quarter of the digestion period where the measured and calculated VSS reductions were equivalent, for the entire batch tests the measured VSS reductions were higher than those computed with BRM.
For BT-1 and BT-2, the measured fractions of VSS removed, $f_{vr}$, were lower than those computed with BRM. For BT-3, the measured fractions of VSS removed were lower than those computed with BRM, except for the last quarter of the digestion period where the measured fraction of VSS removed were higher than those computed with BRM. Hence, for BT-3 the measured and computed fractions of VSS removed increased from initial values of 5.5 and 10.4% to final values of 50.1 and 36.1% respectively (Figure 5.66).
Figure 5.66. Measured and calculated fractions of VSS removed (percentage of VSS destruction) for BT-1, BT-2 and BT-3

For BT-5, like that of VSS reductions, the measured fractions of VSS removed were higher than those computed with BRM. For BT-4 and BT-6, except for the first quarter of the digestion period, the measured fractions of VSS removed were higher than those computed with BRM. Hence, for BT-4 and BT-6 the measured and computed fractions of VSS removed increased from initial values of 2.6 and 7.1%, and 1.1 and 6.5% to final values of 34.9 and 25.1%, and 26.4 and 22.5% respectively (Figure 5.67).
Figure 5.67. Measured and computed fractions of VSS removed (percentage of VSS destruction) for BT-4, BT-5 and BT-6

For BT-1, though the measured TSS concentrations were higher than those computed with BRM for the first half of the digestion period, for the second half of the digestion period the measured TSS concentrations were comparable to those computed with BRM. For BT-2 and BT-3, the measured TSS concentrations were equivalent to those computed with BRM, except at the end of the digestion period where the measured TSS concentrations of BT-3 decreased faster than those computed with BRM. Generally, as the comparable measured TSS concentrations for BT-1, BT-2 and BT-3 decreased in similar pattern, the TSS concentrations computed with BRM also decreased similarly except for BT-1 where the decrease in TSS concentration computed with BRM was gradual (Figure 5.68).
As shown in Figure 5.69, for BT-4, BT-5 and BT-6 the measured TSS concentrations were lower than those computed with BRM.

For BT-2, the measured TSS reductions were lower than those computed with BRM. For BT-1 and BT-3, the measured TSS reductions were lower than those computed with BRM for the first half and two third of the aerobic digestion period, respectively. However, for the second
half and last one third of the digestion period the measured TSS reductions were higher than those calculated with BRM (Figure 5.70).

![Graph showing TSS reductions vs. retention time for Sim-1, Sim-2, Sim-3, Meas-1, Meas-2, Meas-3](image)

Figure 5.70. Measured and calculated TSS reductions for BT-1, BT-2 and BT-3

For BT-4 and BT-6, close match of the measured and calculated TSS reductions were observed. For BT-5, for the first half of the aerobic digestion period measured TSS reductions were equivalent to those computed with BRM. For the second half of the digestion period, however, the measured TSS reductions were higher than those computed with BRM (Figure 5.71).
As shown in Figure 5.72, for BT-2 the measured fractions of TSS removed, fT, (%) were lower than those computed with BRM. For BT-1, the measured fT were lower than those computed with BRM for the first half of the digestion period; thereafter, the measured fT were higher than those computed with BRM. For BT-3, for the first two thirds of the aerobic digestion period the measured fT were lower than those computed with BRM and vice versa for the last one third period of the digestion period. The measured and computed fractions of TSS removed for BT-3 increased from initial values of 2.2 and 7.3\% to final values of 48.3 and 30.0\% respectively.
For BT-4 and BT-6, for the first quarter of the aerobic digestion period, the measured $f_r$ were comparable to those computed with BRM. For the last three quarters of the digestion period, however, the measured $f_r$ were higher than those computed with BRM. The measured and computed fractions of TSS removed, for BT-6, increased from initial values of 2.3 and 4.3% to final values of 29.3 and 17.7% respectively. For BT-5, the measured $f_r$ were higher than those calculated with BRM (Figure 5.73).
Figure 5.73. Measured and calculated fractions of TSS removed (percentage of TSS destruction) for BT-4, BT-5 and BT-6.

For BT-3, the measured nitrate concentrations were lower than those computed with BRM. For the first two third of the digestion period, for BT-4, the measured nitrate concentrations were lower than those computed with BRM, and vice versa for the last one third of the digestion period. For BT-5, the measured nitrate concentrations were almost equivalent to those computed with BRM. For BT-6, while the measured nitrate concentrations were close to those computed with BRM for the first one third of the digestion period, for the last two third of the digestion period the measured nitrate concentrations were higher than those computed with BRM. Generally, the trend of increase of the calculated and measured nitrate concentrations was the same for BT-3, BT-4, BT-5 and BT-6 (Figure 5.74).
Figure 5.74. Measured and calculated nitrate concentrations for BT-3, BT-4, BT-5 and BT-6

The two sets of initial conditions for the aerobic batch digestion as a result of the two way simulation of the parent (MBR UCT) system, i.e. with the adjustment of (1) the maximum rate of fermentation of the OHOs (q_{Fe}) and (2) the rate constant for storage of PP (q_{pp}), rendered the OP concentrations computed with BRM to be higher for the set of initial conditions related to q_{Fe} than that of q_{pp}. The comparison of the measured OP concentrations with those computed with BRM for the two sets of initial conditions is shown in Figures 5.75 and 5.76.
Figure 5.75. Measured and calculated orthophosphate concentrations (using the set of initial conditions with the adjustment of $q_{Fe}$) for BT-1, BT-2 and BT-3

Figure 5.76. Measured and calculated orthophosphate concentrations (using the set of initial conditions with the adjustment of $q_{PP}$) for BT-1, BT-2 and BT-3

As shown in Figures 5.75, 5.76 and 5.77, however, except for BT-1 where the measured OP concentrations were higher than those computed with BRM for the set of initial conditions with the adjustment of $q_{Fe}$, the measured OP concentrations were, generally, lower than those computed with BRM for both sets of initial conditions.
Figure 5.77. Measured and calculated orthophosphate concentrations for BT-4, BT-5 and BT-6

As shown in Figures 5.78 and 5.79, although the OUR values computed with the BRM were higher than those simulated with the ASM-2, they were still lower than the measured OUR values for BT-1 to BT-6. For BT-8, with diluted WAS, the measured and computed OUR values were almost equivalent with similar trends of decrease.

Figure 5.78. Measured and computed OUR values for BT-1, BT-2 and BT-3
Figure 5.79. Measured and computed OUR values for BT-4, BT-5, BT-6 and BT-8 (diluted WAS)

The endogenous respiration (b) rates of the OHOs and PAOs determined from the computed OUR using the BRM were 0.23 and 0.04 d\(^{-1}\) respectively. The summary of the b rates of OHOs and PAOs determined from OUR computed with BRM is given in Table 5.11.

Table 5.9. Summary of the endogenous respiration (b) rates of OHOs and PAOs determined from OUR computed with the BRM

<table>
<thead>
<tr>
<th>b rate (d(^{-1}))</th>
<th>Batch Test No.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BT-3</td>
<td>BT-4</td>
</tr>
<tr>
<td>Determined from computed OUR for OHOs and PAOs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OHO</td>
<td>0.23</td>
<td>0.24</td>
</tr>
<tr>
<td>PAO</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Determined from the head and tail ends of computed total OUR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OHO</td>
<td>0.20</td>
<td>0.18</td>
</tr>
<tr>
<td>PAO</td>
<td>0.07</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Besides, from the OUR values computed with BRM, the sensitivity of the endogenous respiration (b) rate of the OHOs to the change in b of the PAOs and vice versa were evaluated. By varying the b of the PAOs from 0.01 to 0.12 the b rate of the OHOs were computed from In(OUR) vs. retention time plot. The variation in the b rate of the PAOs did
not alter the slope of the \( \ln(OUR) \) vs. time plot, therefore did not affect the \( b \) of the OHOs which remained constant at 0.23 d\(^{-1}\) (Figure 5.80a and b).

![Graphs showing the relationship between ln(OUR) and retention time for BRM with different conditions.](image)

Figure 5.80a and b. Sensitivity of the endogenous respiration (b) rate of OHOs to the change of b rate of the PAOs

On the other hand, when the b rate of the OHOs was varied from 0.05 to 0.28 d\(^{-1}\), the corresponding b rate of the PAOs remained almost constant at 0.04 d\(^{-1}\) (Figure 5.81a and b). This confirms that the OHOs and the PAOs operated independently during the aerobic digestion process.
Figure 5.81a and b. Sensitivity of the endogenous respiration (b) rate of PAOs to the change of b rate of the OHOs

5.4 Closure

In this chapter the general experimental conditions of the parent system and the aerobic batch digestion of the WAS were described. The results of all the measured parameters of the aerobic batch tests were presented numerically and graphically. Explanation of the trends of variation with detention times as related to other relevant and interlinked parameters were given. The average measured values of parameters under aerobic digestion process were seen in comparison with the corresponding average values of the parent system. Comparative check up for the effect of dilution with diluted and undiluted tests and samples analysis were made. Moreover, a comparative evaluation of other researchers' published data in relation to results of this study was performed. Along with the procedural explanation, the two way simulation (with the adjustment of (1) the maximum rate of fermentation of the OHOs, \( q_{re} \) and (2) the rate constant for storage of PP, \( q_{pp} \)) of the parent system and comparison of the measured and simulated concentrations of parameters both for the parent system and aerobic batch digestion tests were presented. The conclusion drawn from this section will be presented in Chapter 6.
CHAPTER 6
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Aerobic batch digestion of waste activated sludge (WAS) from a laboratory scale nitrification denitrification biological excess P removal (NDBEPR) system was carried out with regulated pH (7.20) and in the temperature regulated (20°C) water research laboratory of the University of Cape Town. The parent NDBEPR system operated at 20 days sludge age and high mixed liquor suspended solids (MLSS) concentration in the aerobic reactor (16 to 20 g l⁻¹) because submerged panel membranes effected the solid-liquid separation step. The influent COD concentration was 1000 mgCOD l⁻¹, of which 200 mgCOD l⁻¹ was added acetate to increase the BEPR in the system. Eight batch aerobic digestion tests were conducted on aerobic reactor with sludge harvested from this system; seven at high MLSS concentration (~16 to 20 g l⁻¹) and one at low MLSS concentration (~4 g l⁻¹). Both the NDBEPR parent system and the eight batch digestion tests on sludge harvested from it were simulated with the Activated Sludge Model No. 2 (ASM-2) modified to include the ISS model of Ekama and Wentzel (2004). The model was calibrated against the parent NDBEPR system data as follows: From the measured influent COD characteristics, i.e. RBCOD and unbiodegradable soluble COD fraction (fS_us), the unbiodegradable particulate COD fraction (fS_up) was selected such that the predicted VSS concentrations in the system matched those measured – an average value of fS_up of 0.183 was obtained, which is in the range of values obtained in the past. Next the influent RBCOD split between the OHOs and POAs was determined to match the predicted P removal to that measured. This was done in two ways, by changing the (1) influent RBCOD anaerobic fermentation rate to VFA or (2) the PAO polyphosphate uptake rate. These have the effect of (1) changing PAO mass at a fixed PAO P content (~0.38 mgP mgPAOVSS⁻¹) or (2) changing the PAO content for a fixed PAO mass. Finally, the influent ISS concentration is selected such that the predicted ISS mass in the system matched that measured. This was an iterative process because of the interaction between the predicted variables such as the P removal and system ISS concentration. Once calibrated against the measured NDBEPR system performance, the predicted results were used as initial conditions for the simulation of the batch test data and the calibration
established for the parent system was used unchanged for the batch tests. The two different ways of calibrating the P removal made negligible difference to the predicted P concentrations in the batch tests:

1) A lag of two to four days was observed experimentally for the onset of a true endogenous behaviour during the aerobic digestion process. This possibly was caused by an apparent growth during the early period of the digestion, for the phosphorus accumulating organisms (PAOs), on the stored polyhydroxyalkanoates (PHA) and for the ordinary heterotrophic organisms (OHOs) on slowly biodegradable substrate enmeshed in the sludge harvested from the NDBEPR system. This behaviour was not observed theoretically – the concentration of stored PHA in the PAOs and enmeshed SBCOD were low.

2) Similar trends and rates of volatile suspended solids (VSS) destruction and total suspended solids (TSS) reduction were observed in the aerobic digestion tests and the VSS/TSS ratio remained almost constant with digestion time. The parallel reduction in VSS and TSS implies that there is also a reduction in inorganic suspended solids (ISS). This reduction is both qualitatively and quantitatively described by the ISS model of Ekama and Wentzel (2004). The calibrated ASM-2 model predicted closely the observed decrease in VSS and TSS with time in the batch digestion tests.

3) Although subject to some variation, the filtered COD was observed to increase, on average, about 30 mg l⁻¹ indicating a very low generation of residual filtered unbiodegradable COD during the aerobic digestion process. Considering the very high total COD concentration at which seven batch tests were done (17,000 to 20,000 mgCOD l⁻¹) this increase is negligible. The total COD reductions obtained were comparable to the VSS destructions. The COD/VSS ratio remained approximately constant during aerobic digestion. While no unbiodegradable soluble COD is generated in the model, the simulated COD and COD/VSS ratio for the batch test matched closely those observed.

4) The highest percentage of VSS destruction and total COD reduction were obtained with the longest batch detention times. However, experimentally there was some variation in that the percentage VSS reduction did not consistently follow the aerobic digestion time for all eight batch tests. For the percentage COD reduction consistency was observed. The removal efficiency of VSS was slightly higher than that of the COD, indicating a slight increase in COD/VSS ratio (0.03 mgCOD mgVSS⁻¹) of the
remaining solids. Because this increase was small, the correlation between the predicted and measured COD/VSS ratio was good.

5) With complete mixing and adequate aeration (2 – 5 mgO l⁻¹) complete nitrification was observed. The FSA concentrations in the bulk solution at the end of the digestion period were all well below 1 mgN l⁻¹. This was also predicted by the model.

6) Similar TKN reductions with respect to VSS destruction and TSS reduction were observed. The almost identical TKN reductions with respect to VSS destruction and TSS reduction and linear increase in nitrate concentration with cumulative total oxygen utilized during the digestion period indicates, as expected from the model, that the source of the released N was the solubilization of the organic N in the sludge mass. And this N release is solely associated with the degradation of OHO and PAO biodegradable organics. Moreover, the nitrogen content of the WAS was almost constant throughout the digestion period, i.e., at an average of 0.087 mgN mgVSS⁻¹ for the eight batch tests. The calibrated ASM-2 model predicted reasonably well the measured ammonia and nitrate concentrations with time, indicating that the observed OHO death and PAO endogenous respiration rates matched those of the ASM-2 model. The observed increase in soluble (unbiodegradable) organic N was extremely low in relation to the total TKN reduction in unfiltered TKN and validates the ASM-2 model (zero generation) in this respect.

7) A direct relationship was observed between the supernatant ortho phosphate (OP) concentration in the batch tests and the initial phosphorus content in the solids; the higher the initial P content, the higher the supernatant OP concentration with time. The P release was significantly more than from biomass P content only, indicating that PAO poly phosphate was released during aerobic digestion. The calibrated ASM-2 in which all the stored poly phosphate of the PAOs that have “died” in the endogenous respiration as well as the biomass P content of the PAOs and OHOs that have “died”, was used to assess the magnitude of the P release observed in the batch tests.

8) The absence of a consistent high discrepancy between the observed percentage daily incremental P release with respect to the total P release in the batch tests suggest that the poly phosphate (PP) content of the remaining live PAOs remains approximately constant during the digestion process. An initial very high release of P by all the live PAOs until their P content is the same low value as OHOs before the endogenous respiration commences was not observed. It seems, therefore, reasonable to accept, as
is the case in the ASM-2 model, that P is released by PAOs during aerobic digestion as they die at their endogenous rate, i.e. as their VSS mass decreases, though validation of this may entail further investigation due to the confounding issue of mineral precipitation in the batch tests.

9) Compared with the ASM-2 predicted OP concentration with time, the observed OP concentration was much lower, by 2 to 3 times, for the seven concentrated TSS batch tests (16 – 20 g l⁻¹). The only batch test for which the predicted OP concentration with time matched that observed was the diluted one (BT-8, 4 g l⁻¹). Although complete nitrification kept the FSA concentration low (< 1 mg l⁻¹), the ionic product of Mg, OP and FSA was close to the solubility product for struvite during digestion time indicating that, for the concentrated batch tests mineral precipitation was possible in these tests. Although the measured Mg and OP concentrations increased progressively with digestion time in the concentrated batch tests, it was concluded that struvite precipitation took place in these tests, which would account for the much lower observed OP release than predicted by the ASM-2 model. This was confirmed with the simulation model predicted OP concentration and known polyphosphate Mg, K, Ca and P composition - only about 1/3rd of the simulation model expected Mg and P concentrations were measured in the bulk liquid. For all other parameters, the correlation between predicted and observed results was reasonable considering the complexity of the system being modelled.

10) The predicted OUR declined much more rapidly over the first 2 to 3 days than observed. The theoretical (predicted) nitrate and OP concentrations versus cumulative oxygen utilized (OU) was linear. Due to the high initial observed OUR, the observed nitrate versus cumulative OU has an initial lag but thereafter becomes linear at the same slope as that predicted. This confirms that the nitrate generated is due to the OHO and PAO death/endogenous processes. There was also a lag for the observed OP concentration versus cumulative OU. However, the observed slope did not become linear but continued to increase with digestion time. This suggests that PAOs die/release P faster as digestion progresses but this observation cannot be validated due to the high likelihood of P precipitation in the concentrated batch tests.

11) Except for the initial OUR where a marked deviation of the predicted from the measured values was observed over the first 2 to 4 days of the batch test, the calibrated ASM-2 model acceptably predicted the COD, TKN, FSA, VSS and nitrate concentrations. With regard to the OP concentration, it would appear that ASM-2 can
predict the potential supernatant OP concentration correctly for low concentration (~4 gTSS l⁻¹) aerobic digestion, but whether the high predicted OP concentration will be actually observed in high concentration (16 – 20 gTSS l⁻¹) aerobic digestion seems unlikely due to struvite precipitation. Therefore, once calibrated the ASM-2 model can be used to simulate aerobic digestion systems to estimate the nitrate and maximum OP concentrations in digester liquor. From simulation runs with anoxic-aerobic digestion (50% aerobic time with 2 or 3 hour air on), near complete denitrification can be obtained (nitrate < 2) in the aerobic digester. This also helps keep digester alkalinity and pH up without chemical dosing.

12) A steady state aerobic digestion model for NDEPR WAS was developed based on the OHO and PAO active fractions of the VSS. With the widely accepted endogenous respiration rates of OHOs (0.24 d⁻¹) and PAOs (0.04 d⁻¹) this steady state model including nitrification and extended to include the ISS and TSS concentration, yielded closely similar VSS, TSS, ortho P and nitrate concentrations with time in batch aerobic digestion as ASM-2. The developed VSS-based and TSS (with the addition of ISS to the VSS-based model) aerobic batch reactor and steady state models, therefore, acceptably describes the aerobic digestion of WAS from BEPR AS systems.

13) The average values of the endogenous respiration (b) rate for OHOs obtained from the initial part (6 – 8 days) of the batch tests (where the OHO activity is expected to be the highest) with the different measured test parameters, such as COD, OUR, VSS and nitrate was very variable and differed widely from the commonly accepted values of b₁₂₀ = 0.24 d⁻¹ due to variability in measured data. The b rate of the OHOs determined from the ASM-2 batch test simulated OUR was 0.13 d⁻¹. This was between the commonly accepted b₁₂₀ (0.24 d⁻¹) and b₂₂₀ (0.04 d⁻¹) rates, which was reasonable considering that the PAO active fraction was higher due to the acetate dosing to the parent system resulting in a high PAO OUR also at the start of the batch test. The b rate obtained for the PAOs from the simulated results of the last part of the batch tests (where the OHO activity is expected to have ceased) was quite consistent and close to the commonly accepted value b₂₂₀ = 0.04 d⁻¹. It was concluded from this that the b₁ and b₂ rates cannot be determined experimentally from aerobic batch tests or sludge harvested from NDEPR systems. Besides, from the OUR values computed with batch reactor models (BRMs), the sensitivity of the endogenous respiration (b) rate of the OHOs to the variation of the b rate of the PAOs from 0.01 to 0.12 d⁻¹ did not affect the b of the OHOs but remained constant at 0.23 d⁻¹. Likewise, when the b
rate of the OHOs was varied from 0.05 to 0.28 d\(^{-1}\), the corresponding b rate of the PAOs remained almost constant at 0.04 d\(^{-1}\). This confirms that the OHOs and the PAOs operated independently during the aerobic digestion process.

14) Generally, VSS reduction is accepted as a measure of residual biodegradability in treated sludge in which sludges with > 38% reduction VSS and 20 – 30% TSS are considered stable. However, specific oxygen uptake rate (SOUR) of sludges has recently gained in popularity as a method of measuring aerobic digester effectiveness. For land disposal, the biosolids must achieve a SOUR criteria of less than 1.5 mgO gTSS\(^{-1}\) h\(^{-1}\) for biosolids treated by an aerobic process (Tonkovic, 1999) and generally, SOUR < 1 mgO (gVSS)\(^{-1}\) h\(^{-1}\) are considered well-stabilized sludges. The SOUR observed at the end of the batch tests were all below the SOUR < 1 mgO gVSS\(^{-1}\) h\(^{-1}\) threshold value signifying that the aerobically digested waste activated sludge was well stabilized.

15) Aerobic digestion, modified to include intermittent aeration to promote nitrate removal and lime addition to enhance mineral precipitation, is a simple stabilization system for NDBEPR WAS producing a low N and P dewatering liquor for recycle to the biological reactor.

6.2 Recommendation

In this research mineral precipitation in aerobic digestion of concentrated BDBEPR sludge was not expected and resulted in significantly (by 2 to 3 times) lower OP concentration in the bulk liquid. While this is a major advantage practically because it leads to much lower OP concentration in digester dewatering liquors it is an aspect that requires further investigation. Perhaps it is possible to integrate the biological processes of ASM-2 into a 3 phase mixed weak acid base chemistry model so that mineral precipitation can be modelled also. ASM-1 and Anaerobic Digestion Model No. 1 (ADM1) have been integrated into a two phase (aqueous gas) mixed weak acid base model (Sötemann et al., 2005a and b) but not into three phase weak acid base chemistry models yet.
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## APPENDIX

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<td>Mass Balance of the Simulated Values for the MBR UCT System with the Adjustment of the Anaerobic RBCOD Fermentation Rate ($q_{FE}$) and the Rate Constant for Storage of PP ($q_{pp}$)</td>
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<td>B</td>
<td>Raw Data of the Aerobic Digestion of WAS</td>
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<td>C</td>
<td>Matrix Representation of ASM-2 and Program Listing for the Simulation of the MBR UCT System and Batch Aerobic Digestion</td>
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APPENDIX A

Mass Balance of the Simulated Values for the MBR UCT System
with the Adjustment of the Anaerobic RBCOD Fermentation Rate \( (q_{Fe}) \) and the Rate Constant for Storage of PP \( (q_{pp}) \)

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#### Influent

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N Mass Balance | % | 99.89| 99.84| 99.95| 99.89| 99.95| 99.89 |
## APPENDIX A.2

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COMPUTATION OF N MASS BALANCE

Formula for computing the N mass balance

\[
\begin{align*}
MN_{te} &= (Q_w - Q_{w-}) \times (S_{NH_4(eff)} + S_{NO_3(eff)} + S_{N_2} + (i_{NSf} \times S_{F_{eff}}) + (i_{NSi} \times S_{I})) \\
MN_w &= Q_w \times (i_{NBM} \times (PAO_w + OHO_w + ANO_w) + (i_{NXs} \times X_{S_w}) + (i_{NXs} \times X_{I_w})) \\
MN_{w(s)} &= Q_w \times (S_{NH_4(eff)} + S_{NO_3(eff)} + S_{N_2} + (i_{NSf} \times S_{F_{eff}}) + (i_{NSi} \times S_{I})) \\
MN_{ii} &= Q_i \times N_{ii} \\
N-MB (%) &= 100 \times (MN_{te} + MN_w + MN_{w(s)}) / MN_{ii}
\end{align*}
\]

where

ANO_w = Concentration of autotrophic nitrifying organisms in the waste sludge

i_{NBM} = Nitrogen content of biomass

i_{NSf} = Nitrogen content of F-RBCOD

i_{NSi} = Nitrogen content of inert soluble COD

i_{NXs} = Nitrogen content of particulate COD

MN_{te} = Mass of effluent nitrogen in the effluent

MN_{ii} = Mass of influent nitrogen in the influent

MN_w = Mass of organic nitrogen in the waste sludge

MN_{w(s)} = Mass of soluble nitrogen in the waste sludge

N_{ii} = Influcent total nitrogen

OHO_w = Concentration of ordinary heterotrophic organisms in the waste sludge

PAO_w = Concentration of phosphorus accumulating organisms in the waste sludge

Q_i = Influent flow

Q_w = Waste flow

S_{F_{eff}} = Fermentable RBCOD

S_{I} = Unbiodegradable soluble COD

S_{N_2} = Denitrogen

S_{NH_4(eff)} = FSA concentration in the effluent

S_{NO_3(eff)} = Nitrate concentration in the effluent

X_{I_w} = Concentration of unbiodegradable particulate COD in the waste sludge

X_{S_w} = Concentration of slowly biodegradable particulate COD in the waste sludge

N-MB (%) = Nitrogen mass balance (in percentage)
### APPENDIX A.3

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<th>Parameter</th>
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**COD Mass Balance %**

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### COD Mass Balance

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COMPUTATION OF COD MASS BALANCE

Formula for computing the COD mass balance

\[
\begin{align*}
\text{MO}_c &= \text{OUR}_c \times \text{V}_{\text{aer}} \times 24 \\
\text{MO}_d &= 2.86 \times Q_i \times S_{\text{N}_2} \\
\text{MS}_{\text{tw}} &= Q_w (\text{PAO}_w + \text{OHO}_w + [\text{ANO}_w] + \text{PP}_w + \text{PHA}_w + X_{\text{I}_w} + X_{\text{S}_w}) \\
\text{MS}_{\text{tw}(t)} &= Q_w \times S_{\text{I}} \\
\text{MS}_{\text{te}} &= (Q_i - Q_w) \times S_{\text{I}} \\
\text{MS}_{\text{ii}} &= Q_i \times S_{\text{ii}} \\
\text{COD-MB (\%)} &= 100 \times (\text{MO}_c + \text{MO}_d + \text{MS}_{\text{tw}} + \text{MS}_{\text{tw}(t)} + \text{MS}_{\text{te}}) / \text{MS}_{\text{ii}}
\end{align*}
\]

where

- \text{ANO}_w = Concentration of autotrophic nitrifying organisms in the waste sludge
- \text{MO}_c = Mass of carbonaceous oxygen demand
- \text{MO}_d = Mass of denitrification oxygen demand
- \text{MS}_{\text{te}} = Mass of effluent COD
- \text{MS}_{\text{tw}} = Mass of particulate COD in the waste sludge
- \text{MS}_{\text{tw}(t)} = Mass of soluble COD in the waste sludge
- \text{MS}_{\text{ii}} = Mass of influent COD
- \text{OHO}_w = Concentration of ordinary heterotrophic organisms in the waste sludge
- \text{OUR}_c = Carbonaceous oxygen utilization rate
- \text{PAO}_w = Concentration of phosphorus accumulating organisms in the waste sludge
- \text{PHA}_w = Concentration of polyhydroxyalkanoates in the waste sludge
- \text{PP}_w = Concentration of popy phosphate in the waste sludge
- Q_i = Influent flow
- Q_w = Waste flow
- S_{\text{I}} = Concentration of unbiodegradable soluble COD
- S_{\text{N}_2} = Denitrogen
- S_{\text{ii}} = Influent COD
- V_{\text{aer}} = Volume of the aerobic reactor
- X_{\text{I}_w} = Concentration of unbiodegradable particulate COD in the waste sludge
- X_{\text{S}_w} = Concentration of slowly biodegradable particulate COD in the waste sludge
- \text{COD-MB (\%)} = COD mass balance (in percentage)
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COMPUTATION OF P MASS BALANCE

Formula for computing the P mass balance

\[
\begin{align*}
MP_{tw} &= Q_w \{ i_{PBM} \cdot (PAO_w + OHO_w + ANO_w) + (i_{PSf} \cdot X_Sw) + (i_{PSi} \cdot X_Iw) + PP_w \} \\
MP_{tw(s)} &= Q_w \cdot (S_{PO_{eff}} + (i_{PSf} \cdot S_{F_{eff}}) + (i_{PSi} \cdot S_I)) \\
MP_{te} &= (Q_e - Q_w) \cdot (S_{PO_{eff}} + (i_{PSf} \cdot S_{F_{eff}}) + (i_{PSi} \cdot S_I)) \\
MP_{ii} &= Q_e \cdot P_i \\
P-MB (%) &= 100 \cdot (MP_{tw} + MP_{tw(s)} + MP_{te}) / MP_{ii}
\end{align*}
\]

where

ANO_w = Concentration of autotrophic nitrifying organisms in the waste sludge
i_{PBM} = Phosphorus content of the biomass
i_{PSf} = Phosphorus content of F-RBCOD
i_{PSi} = Phosphorus content of inert soluble COD
i_{PXs} = Phosphorus content of particulate COD
MP_{te} = Mass of phosphorus in the effluent
MP_{ii} = Mass of phosphorus in the influent
MP_{tw} = Mass of organic phosphorus in the waste sludge
MP_{tw(s)} = Mass of ortho phosphate in the waste sludge
OHO_w = Concentration of ordinary heterotrophic organisms in the waste sludge
PAO_w = Concentration of phosphorus accumulating organisms in the waste sludge
PP_w = Concentration of popy phosphate in the waste sludge
P_{ii} = Influent phosphorus
Q_i = Influent flow
Q_w = Waste flow
S_{F_{eff}} = Effluent unbiodegradable soluble COD concentration
S_I = Unbiodegradable soluble COD concentration
S_{PO_{eff}} = Effluent orthophosphate concentration
X_Iw = Concentration of unbiodegradable particulate COD in the waste sludge
X_Sw = Concentration of slowly biodegradable particulate COD in the waste sludge
P-MB (%) = Phosphorus mass balance (in percentage)
## APPENDIX B

Raw Data of the Aerobic Digestion of WAS

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APPENDIX C

Matrix Representation of ASM-2 and Program Listing for the Simulation of the MBR UCT System and Batch Aerobic Digestion

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APPENDIX C1

Matrix representation of ASM-2
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APPENDIX C2

Program Listing of ASM-2 for the Simulation of the MBR UCT System
AQUASIM Version 2.0 (win/mfc) - Listing of System Definition

Date and time of listing: 02/12/2007 21:37:15

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<td>b_PAO20<em>exp(the_bPAO</em>(T-20))</td>
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<th>Description:</th>
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<td>b_PP</td>
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<td>Calculation number</td>
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<td>CODf</td>
<td>Filtered COD</td>
</tr>
<tr>
<td>CODf_m</td>
<td>Measured effluent filtered COD</td>
</tr>
<tr>
<td>CODf_m1</td>
<td>Measured effluent filtered COD</td>
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<tr>
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</table>
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (1 pairs):
  1 0

CODf_m2: Description: Measured effluent filtered COD B-2
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (1 pairs):
  1 0

CODf_m3: Description: Measured effluent filtered COD B-5
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (1 pairs):
  1 0

CODf_m4: Description: Measured effluent filtered COD B-26
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (1 pairs):
  1 80.7

CODf_m5: Description: Measured effluent filtered COD B-28
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
### CODf_m6
- **Description:** Measured effluent filtered COD B-30
- **Type:** Real List Variable
- **Unit:** mgCOD/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:**
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive

### CODt
- **Description:** Total COD
- **Type:** Formula Variable
- **Unit:** mgCOD/l
- **Expression:** S_A+S_F+S_I+X_I+X_S+X_H+X_PAO+X_PHA +X_AUT

### CODt_m
- **Description:** Measured effluent total COD
- **Type:** Variable List Variable
- **Unit:** mgCOD/l
- **Argument:** Calcnum
- **Interpolation Method:** linear interpolation

### Real-Variable Data Pairs (6 pairs):
- 1: CODt_m1
- 2: CODt_m2
- 3: CODt_m3
- 4: CODt_m4
- 5: CODt_m5
- 6: CODt_m6

### CODt_m1
- **Description:** Measured effluent total COD B-1
- **Type:** Real List Variable
- **Unit:** mgCOD/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:**
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive

### Real Data Pairs (1 pairs):
- 1: 95

### CODt_m2
- **Description:** Measured effluent total COD B-2
- **Type:** Real List Variable
- **Unit:** mgCOD/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:**
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive
Real Data Pairs (1 pairs):

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<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CODt_m3</td>
<td>Measured effluent total COD B-5</td>
<td>Real List Variable</td>
<td>mgCOD/l</td>
<td>t</td>
<td>global</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1e+009</td>
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<td>Measured effluent total COD B-26</td>
<td>Real List Variable</td>
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<td>t</td>
<td>global</td>
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<td>1 134.1</td>
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<tr>
<td>CODt_m5</td>
<td>Measured effluent total COD B-28</td>
<td>Real List Variable</td>
<td>mgCOD/l</td>
<td>t</td>
<td>global</td>
<td>0</td>
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<td>linear interpolation</td>
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<td>CODt_m6</td>
<td>Measured effluent total COD B-30</td>
<td>Real List Variable</td>
<td>mgCOD/l</td>
<td>t</td>
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<td>1e+009</td>
<td>linear interpolation</td>
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<tr>
<td>eta_fe</td>
<td>Anaerobic hydrolysis reduction fact or</td>
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<td></td>
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<td></td>
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</table>
Type: Constant Variable
Unit: 
Value: 0.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**eta_NO3:**
Description: Anoxic hydrolysis reduction factor
Type: Constant Variable
Unit: 
Value: 0.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**eta_NO3d:**
Description: Reduction factor for denitrification by heterotrophs
Type: Constant Variable
Unit: 
Value: 1
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**f_ac:**
Description: Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD
Type: Variable List Variable
Unit: gCOD/gCOD
Argument: Calcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1  f_ac1a
2  f_ac2a
3  f_ac3a
4  f_ac4a
5  f_ac5a
6  f_ac6a
11 f_ac1b
12 f_ac2b
13 f_ac3b
14 f_ac4b
15 f_ac5b
16 f_ac6b

**f_ac1a:**
Description: Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B1)
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.301
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
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<thead>
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<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
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<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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<td>f_ac1b</td>
<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B1)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.301</td>
<td>0.1</td>
<td>0</td>
<td>1</td>
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<td>inactive</td>
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<tr>
<td>f_ac2a</td>
<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B2)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.31</td>
<td>0.1</td>
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<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B2)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.31</td>
<td>0.1</td>
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<td>f_ac3a</td>
<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B5)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.48</td>
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<td>f_ac3b</td>
<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B5)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.48</td>
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<td>Parameter Estimation</td>
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<tr>
<td>f_ac4a</td>
<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B26)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.42</td>
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<td>f_ac4b</td>
<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B26)</td>
<td>Constant Variable</td>
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<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B28)</td>
<td>Constant Variable</td>
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<td>Fraction of short chain fatty acids (acetate) wrt biodegradable soluble COD (B30)</td>
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<td>gCOD/gCOD</td>
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**f_ac6b:**

**Description:** Fraction of short chain fatty acids (acetate) wrt biodegradable solubl e COD (B30)

**Type:** Constant Variable

**Unit:** gCOD/gCOD

**Value:** 0.43

**Standard Deviation:** 0.1

**Minimum:** 0

**Maximum:** 1

**Sensitivity Analysis:** inactive

**Parameter Estimation:** inactive

**f_avOH0:**

**Description:** Fraction of the VSS concentration which is OHO

**Type:** Formula Variable

**Unit:** mgVSS/mgVSS

**Expression:** $X_{OH0}/mVSS$

**f_avPA0:**

**Description:** Fraction of the VSS concentration which is PAO

**Type:** Formula Variable

**Unit:** mgVSS/mgVSS

**Expression:** $X_{PA0}/mVSS$

**f bs:**

**Description:** Fraction of biodegradable soluble wrt biodegradable COD

**Type:** Variable List Variable

**Unit:** gCOD/gCOD

**Argument:** Calcium

**Interpolation Method:** linear interpolation

**Real-Variable Data Pairs (12 pairs):**

1. f_bs1a
2. f_bs2a
3. f_bs3a
4. f_bs4a
5. f_bs5a
6. f_bs6a
7. f_bs1b
8. f_bs2b
9. f_bs3b
10. f_bs4b
11. f_bs5b
12. f_bs6b

**f bs1a:**

**Description:** Fraction of biodegradable soluble wrt biodegradable COD (B1)

**Type:** Constant Variable

**Unit:** gCOD/gCOD

**Value:** 0.441

**Standard Deviation:** 0.1

**Minimum:** 0

**Maximum:** 1

**Sensitivity Analysis:** inactive

**Parameter Estimation:** inactive

**f bs1b:**

**Description:** Fraction of biodegradable soluble wrt biodegradable COD (B1)

**Type:** Constant Variable

**Unit:** gCOD/gCOD

**Value:** 0.441

**Standard Deviation:** 0.1
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<th>Parameter</th>
<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
</tr>
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<tbody>
<tr>
<td>f_bs2a</td>
<td>Fraction of biodegradable soluble w r t biodegradable COD (B2)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.431</td>
<td>0.1</td>
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<tr>
<td>f_bs2b</td>
<td>Fraction of biodegradable soluble w r t biodegradable COD (B2)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.431</td>
<td>0.1</td>
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<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>f_bs3a</td>
<td>Fraction of biodegradable soluble w r t biodegradable COD (B5)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.459</td>
<td>0.1</td>
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<tr>
<td>f_bs3b</td>
<td>Fraction of biodegradable soluble w r t biodegradable COD (B5)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.459</td>
<td>0.1</td>
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<td>1</td>
<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>f_bs4a</td>
<td>Fraction of biodegradable soluble w r t biodegradable COD (B26)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
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<td>0.1</td>
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<td>inactive</td>
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<tr>
<td>f_bs4b</td>
<td>Fraction of biodegradable soluble w r t biodegradable COD (B26)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.45</td>
<td>0.1</td>
<td>0</td>
<td>1</td>
<td>inactive</td>
<td>inactive</td>
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</table>
rt biodegradable COD (B26)
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.45
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

\[ f_{bs5a}: \]
Description: Fraction of biodegradable soluble with rt biodegradable COD (B28)
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.499
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

\[ f_{bs5b}: \]
Description: Fraction of biodegradable soluble with rt biodegradable COD (B28)
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.499
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

\[ f_{bs6a}: \]
Description: Fraction of biodegradable soluble with rt biodegradable COD (B30)
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.457
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

\[ f_{bs6b}: \]
Description: Fraction of biodegradable soluble with rt biodegradable COD (B30)
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.457
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

\[ f_{cv}: \]
Description: COD/VSS ratio
Type: Formula Variable
Unit: mgCOD/mgVSS
Expression: 1.48

\[ f_{na}: \]
Description: Measured NH4/TKN ratio
Type: Formula Variable
Unit: \( \text{mgNH}_4\text{-N/mgN} \)
Expression: \( S_{\text{NH}_4\text{in/N}_{-\text{ti}}} \)

<table>
<thead>
<tr>
<th>Description: Fraction of inert COD in particulate substrate</th>
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<tbody>
<tr>
<td>Type: Constant Variable</td>
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<tr>
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<td>Sensitivity Analysis: inactive</td>
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<tr>
<td>Parameter Estimation: inactive</td>
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<table>
<thead>
<tr>
<th>Description: Fraction of unbiodegradable particulate wrt influent COD</th>
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<tbody>
<tr>
<td>Type: Variable List Variable</td>
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<tr>
<td>Unit: gCOD/gCOD</td>
</tr>
<tr>
<td>Argument: Calcium</td>
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<tr>
<td>Interpolation Method: linear interpolation</td>
</tr>
<tr>
<td>Real-Variable Data Pairs (12 pairs):</td>
</tr>
<tr>
<td>1          f_up1a</td>
</tr>
<tr>
<td>2          f_up2a</td>
</tr>
<tr>
<td>3          f_up3a</td>
</tr>
<tr>
<td>4          f_up4a</td>
</tr>
<tr>
<td>5          f_up5a</td>
</tr>
<tr>
<td>6          f_up6a</td>
</tr>
<tr>
<td>11         f_up1b</td>
</tr>
<tr>
<td>12         f_up2b</td>
</tr>
<tr>
<td>13         f_up3b</td>
</tr>
<tr>
<td>14         f_up4b</td>
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<tr>
<td>15         f_up5b</td>
</tr>
<tr>
<td>16         f_up6b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description: Fraction of unbiodegradable particulate wrt influent COD B-1</th>
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</thead>
<tbody>
<tr>
<td>Type: Constant Variable</td>
</tr>
<tr>
<td>Unit: gCOD/gCOD</td>
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<tr>
<td>Value: 0.205</td>
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<tr>
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<tr>
<td>Sensitivity Analysis: inactive</td>
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<tr>
<td>Parameter Estimation: inactive</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Description: Fraction of unbiodegradable particulate wrt influent COD B-1</th>
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</thead>
<tbody>
<tr>
<td>Type: Constant Variable</td>
</tr>
<tr>
<td>Unit: gCOD/gCOD</td>
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<tr>
<td>Value: 0.142</td>
</tr>
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<td>Standard Deviation: 0.1</td>
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<td>Minimum: 0</td>
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<td>Maximum: 1</td>
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<td>Sensitivity Analysis: inactive</td>
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<td>Parameter Estimation: inactive</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description: Fraction of unbiodegradable particulate wrt influent COD B-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type: Constant Variable</td>
</tr>
<tr>
<td>Unit: gCOD/gCOD</td>
</tr>
<tr>
<td>Value: 0.092</td>
</tr>
</tbody>
</table>
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

f_up2b:
Description: Fraction of unbiodegradable particu late wrt influent COD B-2
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.052
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

f_up3a:
Description: Fraction of unbiodegradable particu late wrt influent COD B-5
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.215
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

f_up3b:
Description: Fraction of unbiodegradable particu late wrt influent COD B-5
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.239
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

f_up4a:
Description: Fraction of unbiodegradable particu late wrt influent COD B-26
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.168
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

f_up4b:
Description: Fraction of unbiodegradable particu late wrt influent COD B-26
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.145
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive
f_up5a: Description: Fraction of unbiodegradable particulate \[ \text{wrt influent COD B-28} \]
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.211
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_up5b: Description: Fraction of unbiodegradable particulate \[ \text{wrt influent COD B-28} \]
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.206
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_up6a: Description: Fraction of unbiodegradable particulate \[ \text{wrt influent COD B-30} \]
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.206
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_up6b: Description: Fraction of unbiodegradable particulate \[ \text{wrt influent COD B-30} \]
Type: Constant Variable
Unit: gCOD/gCOD
Value: 0.195
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_us: Description: Fraction of unbiodegradable soluble
wrt influent COD
Type: Variable List Variable
Unit: gCOD/gCOD
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1 f_us1a
2 f_us2a
3 f_us3a
4 f_us4a
5 f_us5a
6 f_us6a
11 f_us1b
12 f_us2b
13 f_us3b
14 f_us4b
| f_us1a: | Description: | Fraction of unbiodegradable soluble wrt influent COD (B1) |
|        | Type:        | Constant Variable                                      |
|        | Unit:        | gCOD/gCOD                                              |
|        | Value:       | 0.031                                                   |
|        | Standard Deviation: | 0.1                                                       |
|        | Minimum:     | 0                                                        |
|        | Maximum:     | 1                                                        |
|        | Sensitivity Analysis: | inactive                                                  |
|        | Parameter Estimation: | inactive                                                  |

| f_us1b: | Description: | Fraction of unbiodegradable soluble wrt influent COD (B1) |
|        | Type:        | Constant Variable                                      |
|        | Unit:        | gCOD/gCOD                                              |
|        | Value:       | 0.031                                                   |
|        | Standard Deviation: | 0.1                                                       |
|        | Minimum:     | 0                                                        |
|        | Maximum:     | 1                                                        |
|        | Sensitivity Analysis: | inactive                                                  |
|        | Parameter Estimation: | inactive                                                  |

| f_us2a: | Description: | Fraction of unbiodegradable soluble wrt influent COD (B2) |
|        | Type:        | Constant Variable                                      |
|        | Unit:        | gCOD/gCOD                                              |
|        | Value:       | 0.037                                                   |
|        | Standard Deviation: | 0.1                                                       |
|        | Minimum:     | 0                                                        |
|        | Maximum:     | 1                                                        |
|        | Sensitivity Analysis: | inactive                                                  |
|        | Parameter Estimation: | inactive                                                  |

| f_us2b: | Description: | Fraction of unbiodegradable soluble wrt influent COD (B2) |
|        | Type:        | Constant Variable                                      |
|        | Unit:        | gCOD/gCOD                                              |
|        | Value:       | 0.037                                                   |
|        | Standard Deviation: | 0.1                                                       |
|        | Minimum:     | 0                                                        |
|        | Maximum:     | 1                                                        |
|        | Sensitivity Analysis: | inactive                                                  |
|        | Parameter Estimation: | inactive                                                  |

| f_us3a: | Description: | Fraction of unbiodegradable soluble wrt influent COD (B5) |
|        | Type:        | Constant Variable                                      |
|        | Unit:        | gCOD/gCOD                                              |
|        | Value:       | 0.036                                                   |
|        | Standard Deviation: | 0.1                                                       |
|        | Minimum:     | 0                                                        |
|        | Maximum:     | 1                                                        |
|        | Sensitivity Analysis: | inactive                                                  |
|        | Parameter Estimation: | inactive                                                  |

<p>| f_us3b: | Description: | Fraction of unbiodegradable soluble wrt influent COD (B5) |
|        | Type:        | Constant Variable                                      |</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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</thead>
<tbody>
<tr>
<td>f_us4a</td>
<td>Fraction of unbiodegradable soluble wrt influent COD (B26)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.043</td>
<td>0.1</td>
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<td>inactive</td>
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<tr>
<td>f_us4b</td>
<td>Fraction of unbiodegradable soluble wrt influent COD (B26)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.043</td>
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<td>0</td>
<td>1</td>
<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>f_us5a</td>
<td>Fraction of unbiodegradable soluble wrt influent COD (B28)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.041</td>
<td>0.1</td>
<td>0</td>
<td>1</td>
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<tr>
<td>f_us5b</td>
<td>Fraction of unbiodegradable soluble wrt influent COD (B28)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
<td>0.041</td>
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<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>f_us6a</td>
<td>Fraction of unbiodegradable soluble wrt influent COD (B30)</td>
<td>Constant Variable</td>
<td>gCOD/gCOD</td>
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<td>inactive</td>
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</table>
Parameter Estimation: inactive

\textbf{f\_us6b:}
\begin{itemize}
  \item \textbf{Description:} Fraction of unbiodegradable soluble wrt influent COD (B30)
  \item \textbf{Type:} Constant Variable
  \item \textbf{Unit:} gCOD/gCOD
  \item \textbf{Value:} 0.043
  \item \textbf{Standard Deviation:} 0.1
  \item \textbf{Minimum:} 0
  \item \textbf{Maximum:} 1
  \item \textbf{Sensitivity Analysis:} inactive
  \item \textbf{Parameter Estimation:} inactive
\end{itemize}

\textbf{f\_VTG:}
\begin{itemize}
  \item \textbf{Description:} VSS/TSS for PAOs
  \item \textbf{Type:} Formula Variable
  \item \textbf{Unit:} mgCOD/mgTSS
  \item \textbf{Expression:} 0.46
\end{itemize}

\textbf{f\_VTH:}
\begin{itemize}
  \item \textbf{Description:} VSS/TSS for OHOs
  \item \textbf{Type:} Formula Variable
  \item \textbf{Unit:} mgCOD/mgTSS
  \item \textbf{Expression:} 0.75
\end{itemize}

\textbf{f\_XiAUT:}
\begin{itemize}
  \item \textbf{Description:} Fraction of inert COD in biomass (f or AUT)
  \item \textbf{Type:} Constant Variable
  \item \textbf{Unit:} gCOD(gCOD)-1
  \item \textbf{Value:} 0.08
  \item \textbf{Standard Deviation:} 0.1
  \item \textbf{Minimum:} 0
  \item \textbf{Maximum:} 1
  \item \textbf{Sensitivity Analysis:} inactive
  \item \textbf{Parameter Estimation:} inactive
\end{itemize}

\textbf{f\_XiOHO:}
\begin{itemize}
  \item \textbf{Description:} Fraction of inert COD in biomass (f or OHO)
  \item \textbf{Type:} Constant Variable
  \item \textbf{Unit:} gCOD(gCOD)-1
  \item \textbf{Value:} 0.08
  \item \textbf{Standard Deviation:} 0.1
  \item \textbf{Minimum:} 0
  \item \textbf{Maximum:} 1
  \item \textbf{Sensitivity Analysis:} inactive
  \item \textbf{Parameter Estimation:} inactive
\end{itemize}

\textbf{f\_XiPAO:}
\begin{itemize}
  \item \textbf{Description:} Fraction of inert COD in biomass (f or PAO)
  \item \textbf{Type:} Constant Variable
  \item \textbf{Unit:} gCOD(gCOD)-1
  \item \textbf{Value:} 0.25
  \item \textbf{Standard Deviation:} 0.1
  \item \textbf{Minimum:} 0
  \item \textbf{Maximum:} 1
  \item \textbf{Sensitivity Analysis:} inactive
  \item \textbf{Parameter Estimation:} inactive
\end{itemize}

\textbf{ISS\_AeroM:}
\begin{itemize}
  \item \textbf{Description:} Measured ISS in the reactor
  \item \textbf{Type:} Variable List Variable
  \item \textbf{Unit:} mgISS/l
  \item \textbf{Argument:} Calcnum
  \item \textbf{Interpolation Method:} linear interpolation
Real-Variable Data Pairs (6 pairs):
1. ISS_AeroM1
2. ISS_AeroM2
3. ISS_AeroM3
4. ISS_AeroM4
5. ISS_AeroM5
6. ISS_AeroM6

<table>
<thead>
<tr>
<th>Description</th>
<th>Measured ISS (Inorganic Suspended Solids) in the reactor (B-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
</tr>
<tr>
<td>Unit:</td>
<td>mgISS/1</td>
</tr>
<tr>
<td>Value:</td>
<td>3769</td>
</tr>
<tr>
<td>Standard Deviation:</td>
<td>0.1</td>
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<td>Minimum:</td>
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<tr>
<td>Maximum:</td>
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</tr>
<tr>
<td>Sensitivity Analysis:</td>
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</tr>
<tr>
<td>Parameter Estimation:</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Measured ISS (Inorganic Suspended Solids) in the reactor (B-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
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<tr>
<td>Unit:</td>
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<tr>
<td>Value:</td>
<td>2812</td>
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<td>Standard Deviation:</td>
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<td>Minimum:</td>
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<td>Sensitivity Analysis:</td>
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<tr>
<td>Parameter Estimation:</td>
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</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Measured ISS (Inorganic Suspended Solids) in the reactor (B-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
</tr>
<tr>
<td>Unit:</td>
<td>mgISS/1</td>
</tr>
<tr>
<td>Value:</td>
<td>3345</td>
</tr>
<tr>
<td>Standard Deviation:</td>
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<tr>
<td>Minimum:</td>
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<td>Maximum:</td>
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<td>Sensitivity Analysis:</td>
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<tr>
<td>Parameter Estimation:</td>
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</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Measured ISS (Inorganic Suspended Solids) in the reactor (B-26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
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<td>Unit:</td>
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<td>Value:</td>
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<td>Sensitivity Analysis:</td>
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</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Measured ISS (Inorganic Suspended Solids) in the reactor (B-28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
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<tr>
<td>Unit:</td>
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<td>Value:</td>
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<tr>
<td>Sensitivity Analysis:</td>
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</tr>
<tr>
<td>Parameter Estimation:</td>
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</tr>
</tbody>
</table>
ISS_AeroM6: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-30)
Type: Constant Variable
Unit: mgISS/l
Value: 3284
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_AnaerM: Description: Measured ISS in the reactor
Type: Variable List Variable
Unit: mgISS/l
Argument: Calcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (6 pairs):
1 ISS_AnaerM1
2 ISS_AnaerM2
3 ISS_AnaerM3
4 ISS_AnaerM4
5 ISS_AnaerM5
6 ISS_AnaerM6

ISS_AnaerM1: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-1)
Type: Constant Variable
Unit: mgISS/l
Value: 1643.4
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_AnaerM2: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-2)
Type: Constant Variable
Unit: mgISS/l
Value: 1238.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_AnaerM3: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-5)
Type: Constant Variable
Unit: mgISS/l
Value: 1348.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_AnaerM4: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-26)
**ISS_AnaerM5:**
- **Description:** Measured ISS (Inorganic Suspended Solids) in the reactor (B-28)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 1431
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_AnaerM6:**
- **Description:** Measured ISS (Inorganic Suspended Solids) in the reactor (B-30)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 1126
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_AnoxM:**
- **Description:** Measured ISS in the reactor
- **Type:** Variable List Variable
- **Unit:** mgISS/l
- **Argument:** Calcium
- **Interpolation Method:** linear interpolation
- **Real-Variable Data Pairs (6 pairs):**
  1. ISS_AnoxM1
  2. ISS_AnoxM2
  3. ISS_AnoxM3
  4. ISS_AnoxM4
  5. ISS_AnoxM5
  6. ISS_AnoxM6

**ISS_AnoxM1:**
- **Description:** Measured ISS (Inorganic Suspended Solids) in the reactor (B-1)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 2945.3
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_AnoxM2:**
- **Description:** Measured ISS (Inorganic Suspended Solids) in the reactor (B-2)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 2389.6
- **Standard Deviation:** 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

ISS_AnoxM3: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-5)
Type: Constant Variable
Unit: mgISS/l
Value: 2622.3
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

ISS_AnoxM4: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-26)
Type: Constant Variable
Unit: mgISS/l
Value: 2848.9
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

ISS_AnoxM5: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-28)
Type: Constant Variable
Unit: mgISS/l
Value: 2309.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

ISS_AnoxM6: Description: Measured ISS (Inorganic Suspended Solids) in the reactor (B-30)
Type: Constant Variable
Unit: mgISS/l
Value: 2524.2
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

ISS_fioH0: Description: Inorganic content of the OHO cell mass
Type: Formula Variable
Unit: mgISS/mgOHOVSS
Expression: 0.15

---

ISS_fiPAO: Description: Total inorganic solids content of the PAOs
Type: Formula Variable
Unit: mgISS/mgPAOVSS
Expression: 3.286*(X_P/(X_PA0/f_cv))+ISS_fiPAO
### ISS_flPAOBM

**Description:** Inorganic material content of the P AO active biomass

**Type:** Formula Variable

**Unit:** mgISS/mgPAO VSS

**Expression:** 0.15

### ISS_Xioi

**Description:** Reactor ISS from influent ISS (inorganic suspended solids)

**Type:** Dyn. Volume State Var.

**Unit:** mgISS/l

**Relative Accuracy:** 1e-006

**Absolute Accuracy:** 1e-006

### ISS_Xioin

**Description:** Inorganic Suspended Solids in the influent

**Type:** Variable List Variable

**Unit:** mgISS/l

**Argument:** Calcium

**Interpolation Method:** linear interpolation

**Real-Variable Data Pairs (12 pairs):**

1. ISS_Xioin1a
2. ISS_Xioin2a
3. ISS_Xioin3a
4. ISS_Xioin4a
5. ISS_Xioin5a
6. ISS_Xioin6a
11. ISS_Xioin1b
12. ISS_Xioin2b
13. ISS_Xioin3b
14. ISS_Xioin4b
15. ISS_Xioin5b
16. ISS_Xioin6b

### ISS_Xioin1a

**Description:** Inorganic Suspended Solids in the influent (B-1)

**Type:** Constant Variable

**Unit:** mgISS/l

**Value:** 22

**Standard Deviation:** 0.1

**Minimum:** 0

**Maximum:** 30000

**Sensitivity Analysis:** inactive

**Parameter Estimation:** inactive

### ISS_Xioin1b

**Description:** Inorganic Suspended Solids in the influent (B-1)

**Type:** Constant Variable

**Unit:** mgISS/l

**Value:** 20.12

**Standard Deviation:** 0.1

**Minimum:** 0

**Maximum:** 30000

**Sensitivity Analysis:** inactive

**Parameter Estimation:** inactive

### ISS_Xioin2a

**Description:** Inorganic Suspended Solids in the influent (B-2)

**Type:** Constant Variable

**Unit:** mgISS/l

**Value:** 0.001
<table>
<thead>
<tr>
<th>Description</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
</tr>
</thead>
<tbody>
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<tr>
<td>Inorganic Suspended</td>
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<td>30000</td>
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<tr>
<td>Solids in the influent (B-2)</td>
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<tr>
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<td>30000</td>
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<tr>
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<tr>
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<tr>
<td>Solids in the influent (B-5)</td>
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<td>Solids in the influent (B-26)</td>
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ISS_Xioin5a: Description: Inorganic Suspended Solids in the influent (B-28)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0001
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xioin5b: Description: Inorganic Suspended Solids in the influent (B-28)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0001
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xioin6a: Description: Inorganic Suspended Solids in the influent (B-30)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0001
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xioin6b: Description: Inorganic Suspended Solids in the influent (B-30)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0001
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xioini: Description: Initial concentration of Inorganic Suspended Solids in the influent
Type: Variable List Variable
Unit: mgISS/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1  ISS_Xioini1a
2  ISS_Xioini2a
3  ISS_Xioini3a
4  ISS_Xioini4a
5  ISS_Xioini5a
6  ISS_Xioini6a
11  ISS_Xioini1b
12  ISS_Xioini2b
13  ISS_Xioini3b
14  ISS_Xioini4b
ISS_Xioinila: Description: Initial concentration of Inorganic Suspended Solids in the influent (B-1)
Type: Constant Variable
Unit: mgISS/l
Value: 805
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xioinilb: Description: Initial concentration of Inorganic Suspended Solids in the influent (B-1)
Type: Constant Variable
Unit: mgISS/l
Value: 656
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xioini2a: Description: Initial concentration of Inorganic Suspended Solids in the influent (B-2)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0375
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xioini2b: Description: Initial concentration of Inorganic Suspended Solids in the influent (B-2)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0377
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xioini3a: Description: Initial concentration of Inorganic Suspended Solids in the influent (B-5)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0372
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**ISS_Xioini3b:** Description: Initial concentration of Inorganic Suspended Solids in the influent (B-5)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0375
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**ISS_Xioini4a:** Description: Initial concentration of Inorganic Suspended Solids in the influent (B-26)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0373
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**ISS_Xioini4b:** Description: Initial concentration of Inorganic Suspended Solids in the influent (B-26)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0173
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**ISS_Xioini5a:** Description: Initial concentration of Inorganic Suspended Solids in the influent (B-28)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0173
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**ISS_Xioini5b:** Description: Initial concentration of Inorganic Suspended Solids in the influent (B-28)
Type: Constant Variable
Unit: mgISS/l
Value: 0.0173
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive
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<th>Parameter Estimation</th>
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<td>Initial concentration of Inorganic Suspended Solids in the influent (B-30)</td>
<td>Constant Variable</td>
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<td>ISS_Xoi</td>
<td>Total ISS (Inorganic Suspended Solids) in the reactor</td>
<td>Formula Variable</td>
<td>mgISS/l</td>
<td>ISS_Xioi+(ISS_fiOHO*(X_H/f_cv))+(ISS_S_fiPAO*(X_PAO/f_cv))</td>
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<tr>
<td>i_NBM</td>
<td>Nitrogen content of biomass, X_H, X_PAO, X_AUT</td>
<td>Constant Variable</td>
<td>gN(gCOD)-1</td>
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<td>i_NSf</td>
<td>Nitrogen content of soluble substrate, S_F</td>
<td>Constant Variable</td>
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<td>i_NSi</td>
<td>Nitrogen content of inert soluble COD, S_I</td>
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<td>gN/gCOD</td>
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### Parameter Estimation: inactive

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<td>Nitrogen content of inert particulate COD, (X_I)</td>
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<td>Constant Variable</td>
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Value: 0.01
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

i_FXs: Description: P content of particulate substrate, \( X_S \)
Type: Constant Variable
Unit: gP(gCOD)^{-1}
Value: 0.01
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

i_TSSBM: Description: TSS to biomass ratio for \( X_H, X_PA \)
Type: Constant Variable
Unit: gTSS(gCOD)^{-1}
Value: 0.9
Standard Deviation: 1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

i_TSSXi: Description: TSS to \( X_I \) ratio
Type: Constant Variable
Unit: gTSS(gCOD)^{-1}
Value: 0.75
Standard Deviation: 1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

i_TSSXs: Description: TSS to \( X_S \) ratio
Type: Constant Variable
Unit: gTSS(gCOD)^{-1}
Value: 0.75
Standard Deviation: 1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_ALK: Description: Saturation coefficient for alkalinity
Type: Constant Variable
Unit: mole HCO3 (m)^{-3}
Value: 0.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_ALKAUT: Description: Saturation coefficient for alkalinity
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<td>Saturation coefficient for alkalinity (precipitation)</td>
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A.60
Parameter Estimation: inactive

\textbf{mue}_AUT:  
\textbf{Description:} Maximum growth rate of autotrophs  
\textbf{Type:} Formula Variable  
\textbf{Unit:} per day  
\textbf{Expression:} \( \text{mue}_{AUT20} \cdot \exp(\text{the}_{mueAUT} \cdot (T-20)) \)

\textbf{mue}_AUT20:  
\textbf{Description:} Maximum specific growth rate of ANO  
\textbf{Type:} Constant Variable  
\textbf{Unit:} per day  
\textbf{Value:} 0.45  
\textbf{Standard Deviation:} 0.1  
\textbf{Minimum:} 0  
\textbf{Maximum:} 1  
\textbf{Sensitivity Analysis:} inactive  
\textbf{Parameter Estimation:} inactive

\textbf{mue}_H:  
\textbf{Description:} Maximum growth rate of heterotrophs  
\textbf{Type:} Formula Variable  
\textbf{Unit:} per day  
\textbf{Expression:} \( \text{mue}_{H20} \cdot \exp(\text{the}_{mueH} \cdot (T-20)) \)

\textbf{mue}_H20:  
\textbf{Description:} Maximum growth rate on substrate (OHO)  
\textbf{Type:} Constant Variable  
\textbf{Unit:} per day  
\textbf{Value:} 6  
\textbf{Standard Deviation:} 0.1  
\textbf{Minimum:} 0  
\textbf{Maximum:} 10  
\textbf{Sensitivity Analysis:} inactive  
\textbf{Parameter Estimation:} inactive

\textbf{mue}_PAO:  
\textbf{Description:} Maximum growth rate  
\textbf{Type:} Formula Variable  
\textbf{Unit:} per day  
\textbf{Expression:} \( \text{mue}_{PAO20} \cdot \exp(\text{the}_{muePAO} \cdot (T-20)) \)

\textbf{mue}_PAO20:  
\textbf{Description:} Maximum growth rate (PAO)  
\textbf{Type:} Constant Variable  
\textbf{Unit:} per day  
\textbf{Value:} 1.2  
\textbf{Standard Deviation:} 0.1  
\textbf{Minimum:} 0  
\textbf{Maximum:} 10  
\textbf{Sensitivity Analysis:} inactive  
\textbf{Parameter Estimation:} inactive

\textbf{mVSS:}  
\textbf{Description:} Model VSS in COD units  
\textbf{Type:} Formula Variable  
\textbf{Unit:} mgCOD/l  
\textbf{Expression:} \( X_{AUT} + X_{H} + X_{PAO} + X_{PHA} + X_{I} \)

\textbf{N}_{ti}:  
\textbf{Description:} Influent TKN  
\textbf{Type:} Variable List Variable  
\textbf{Unit:} mgN/l  
\textbf{Argument:} Calcium  
\textbf{Interpolation Method:} linear interpolation  
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| OUR_AUT | Description | OUR for autotrophic growth (Nitri
| Formula Variable | mg/l/h | \((-1/24)*(-(4.57-Y_AUT)/Y_AUT)*mue_A UT*(S_O2/(K_O2+S_O2))*(S_NH4/(K_NH4 AUT+S_NH4))*(S_P04/(K_P+S_P04))^{2}X_AUT\) |
| OUR_c | Description | Total OUR (B-I) |
| Formula Variable | mg/l/h | \(OUR_{HSF}+OUR_{HSA}+OUR_{PAO}+OUR_{PP}\) |
| OUR_HSA | Description | OUR for heterotrophic growth on \(S_A\) |
| Formula Variable | mg/l/h | \((-1/24)*(-(1-Y_H)/Y_H)*mue_H*(S_A/(S_F+S_A))*(S_O2/(K_O2+S_O2))*(S_A/(K_AOHO+S_A))*(S_NH4/(K_NH4OHO+S_NH4 ))*(S_P04/(K_P+S_P04))^{2*(X_H)}\) |
| OUR_HSF | Description | OUR for heterotrophic growth on \(S_F\) |
| Formula Variable | mg/l/h | \((-1/24)*(-(1-Y_H)/Y_H)*mue_H*(S_F/(S_F+S_A))*(S_O2/(K_O2+S_O2))*(S_F/(K_F+S_F))*(S_NH4/(K_NH4OHO+S_NH4 ))*(S_P04/(K_P+S_P04))^{2*(X_H)}\) |
| OUR_PAO | Description | OUR for PAO growth |
| Formula Variable | mg/l/h | \((-1/24)*(-(1-Y_PAO)/Y_PAO)*mue_PAO*S_O2/(K_O2+S_O2))*(S_NH4/(K_NH4PAO +S_NH4))*(S_P04/(K_P+S_P04))^{2*(X_PHA/X_PAO)}/(K_PHA+(X_PHA/X_PAO))*X_PAO\) |
| OUR_PP | Description | OUR for \(X_PP\) storage |
| Formula Variable | mg/l/h | \((-1/24)*(-Y_PH{A}*q_PP*S_O2/(K_O2+S _O2))*(S_P04/(K_PS+S_P04))^{2*(X_PH{A}/X_PAO)}/(K_PHA+(X_PH{A}/X_PAO))^{2*(K_M ax-(X_PP/X_PAO)/(K_{IPP}+X_{Max}-(X_PP /X_PAO)))}X_PAO\) |
| OUR_t | Description | Total OUR |
| Formula Variable | mg/l/h | \(OUR_{HSF}+OUR_{HSA}+OUR_{AUT}+OUR_{PAO}+OUR\) |
PP

OUR_t_meas: Description: Measured OUR (B-1)
Type: Variable List Variable
Unit: mg/l/h
Argument: Calcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (6 pairs):
1 OUR_t_meas1
2 OUR_t_meas2
3 OUR_t_meas3
4 OUR_t_meas4
5 OUR_t_meas5
6 OUR_t_meas6

OUR_t_meas1: Description: Measured OUR (B-2)
Type: Constant Variable
Unit: mg/l/h
Value: 129
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

OUR_t_meas2: Description: Measured OUR (B-5)
Type: Constant Variable
Unit: mg/l/h
Value: 129
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

OUR_t_meas4: Description: Measured OUR (B-26)
Type: Constant Variable
Unit: mg/l/h
Value: 81
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

OUR_t_meas5: Description: Measured OUR (B-28)
Type: Constant Variable
Unit: mg/l/h
Value: 140
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

OUR_t_meas6:
Description: Measured OUR (B-30)
Type: Constant Variable
Unit: mg/l/h
Value: 129
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

P_1:
Description: Influent P
Type: Variable List Variable
Unit: mgP/l
Argument: Calcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1  P_1la
2  P_12a
3  P_13a
4  P_14a
5  P_15a
6  P_16a
11 P_1lb
12 P_12b
13 P_13b
14 P_14b
15 P_15b
16 P_16b

P_1la:
Description: Influent P B-1
Type: Constant Variable
Unit: mgP/l
Value: 18.25
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

P_1lb:
Description: Influent P B-1
Type: Constant Variable
Unit: mgP/l
Value: 18.25
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

P_12a:
Description: Influent P B-2
Type: Constant Variable
Unit: mgP/l
Value: 30.94
Standard Deviation: 0.1
Minimum: 0
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Sensitivity Analysis: inactive
### Parameter Estimation: inactive

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Sensitivity Analysis: inactive
Parameter Estimation: inactive

\(Q_i\):
Description: Influent flow
Type: Formula Variable
Unit: 1/d
Expression: 140

\(q_{\text{PHA}}\):
Description: Rate constant for storage of PHA (base: \(X_{\text{PP}}\))
Type: Formula Variable
Unit: gCOD\(\text{gPAO}^{-1}\) d-1
Expression: \(q_{\text{PHA20}}\cdot\exp(\text{the}_{\text{PHA}}\cdot(T-20))\)

\(q_{\text{PHA20}}\):
Description: Rate constant for storage of PHA (base: \(X_{\text{PP}}\))
Type: Constant Variable
Unit: gCOD\(\text{gPAO}^{-1}\) d-1
Value: 6
Standard Deviation: 0.1
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Sensitivity Analysis: inactive
Parameter Estimation: inactive

\(q_{\text{PP}}\):
Description: Rate constant for storage of PP
Type: Formula Variable
Unit: gPP\(\text{gPAO}^{-1}\) d-1
Expression: \(q_{\text{PP20}}\cdot\exp(\text{the}_{\text{PP}}\cdot(T-20))\)

\(q_{\text{PP20}}\):
Description: Rate constant for storage of PP
Type: Variable List Variable
Unit: gPP\(\text{gPAO}^{-1}\) d-1
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):

\begin{align*}
1 & \quad q_{\text{PP20}_1} \\
2 & \quad q_{\text{PP20}_2} \\
3 & \quad q_{\text{PP20}_3} \\
4 & \quad q_{\text{PP20}_4} \\
5 & \quad q_{\text{PP20}_5} \\
6 & \quad q_{\text{PP20}_6} \\
11 & \quad q_{\text{PP20}_1b} \\
12 & \quad q_{\text{PP20}_2b} \\
13 & \quad q_{\text{PP20}_3b} \\
14 & \quad q_{\text{PP20}_4b} \\
15 & \quad q_{\text{PP20}_5b} \\
16 & \quad q_{\text{PP20}_6b}
\end{align*}

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Unit: gPP\(\text{gPAO}^{-1}\) d-1
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| Q_r       | Description | r_recycle flow from anoxic to anaerobic |
Q_rec: Description: "Underflow recycle"
Type: Formula Variable
Unit: 1/d
Expression: 1*Q_i

Q_w: Description: Waste flow
Type: Formula Variable
Unit: 1/d
Expression: ((V_anox*X_tanaer)+(V_anox*X_tanox) + (V_aero*X_taero))/([R_s*X_taero])

Q_wm: Description: Measured waste flow
Type: Variable List Variable
Unit: 1/d
Argument: Calcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (6 pairs):
1 Q_wm1
2 Q_wm2
3 Q_wm3
4 Q_wm4
5 Q_wm5
6 Q_wm6

Q_wm1: Description: Measured waste flow for B-1
Type: Constant Variable
Unit: 1/d
Value: 2.9
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

Q_wm2: Description: Measured waste flow for B-2
Type: Constant Variable
Unit: 1/d
Value: 2.46
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

Q_wm3: Description: Measured waste flow for B-5
Type: Constant Variable
Unit: 1/d
Value: 3
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

Q_wm4: Description: Measured waste flow for B-26
Type: Constant Variable
Unit: 1/d

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<th>Unit</th>
<th>Value</th>
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<th>Minimum</th>
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<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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<td>Sludge age</td>
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<td>Dyn. Volume State Var.</td>
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<td>S_Ain</td>
<td>Influent concentration of fermentable products (acetate)</td>
<td>Formula Variable</td>
<td>mg/l</td>
<td>(f_ac*f_bs)<em>S_ti</em>(1-f_us-f_up)</td>
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<td>Initial concentration of fermentable products (acetate)</td>
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<td>Fermentable, readily biodegradable organic substrate</td>
<td>Dyn. Volume State Var.</td>
<td>mg/l</td>
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<td>Influent concentration of fermentable, readily biodegradable organic substrate</td>
<td>Formula Variable</td>
<td>mg/l</td>
<td>((1-f_{ac})*f_{bs}<em>S_{ti}</em>(1-f_{us-f_{up}}))</td>
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<td>S_{Fin}i</td>
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<td>Formula Variable</td>
<td>mg/l</td>
<td>((1-f_{ac})*f_{bs}<em>S_{ti}</em>(1-f_{us-f_{up}}))</td>
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<td>S_I</td>
<td>Inert soluble organic material</td>
<td>Dyn. Volume State Var.</td>
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<td>(f_{us}*S_{ti})</td>
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<td>Formula Variable</td>
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<td>Influent concentration of ammonium plus ammonia nitrogen B-1</td>
<td>mg/l</td>
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<td>Influent concentration of ammonium plus ammonia nitrogen B-2</td>
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<td>mg/l</td>
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Real-Variable Data Pairs (12 pairs):

1. S_NH4in1a
2. S_NH4in2a
3. S_NH4in3a
4. S_NH4in4a
5. S_NH4in5a
6. S_NH4in6a
7. S_NH4in1b
8. S_NH4in2b
9. S_NH4in3b
10. S_NH4in4b
11. S_NH4in5b
12. S_NH4in6b
Value: 94.43
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4in2b: Description: Influent concentration of ammonium plus ammonia nitrogen B-2
Type: Constant Variable
Unit: mg/l
Value: 95.87
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4in3a: Description: Influent concentration of ammonium plus ammonia nitrogen B-5
Type: Constant Variable
Unit: mg/l
Value: 96.32
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4in3b: Description: Influent concentration of ammonium plus ammonia nitrogen B-5
Type: Constant Variable
Unit: mg/l
Value: 94.94
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4in4a: Description: Influent concentration of ammonium plus ammonia nitrogen B-26
Type: Constant Variable
Unit: mg/l
Value: 62.61
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4in4b: Description: Influent concentration of ammonium plus ammonia nitrogen B-26
Type: Constant Variable
Unit: mg/l
Value: 63.17
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive
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<td>Constant Variable</td>
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Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1  S_NH4in1a
2  S_NH4in2a
3  S_NH4in3a
4  S_NH4in4a
5  S_NH4in5a
6  S_NH4in6a
11 S_NH4in11b
12 S_NH4in12b
13 S_NH4in13b
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<td>Initial concentration of ammonium plus ammonia nitrogen B-26</td>
<td>Constant Variable</td>
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<td>Initial concentration of ammonium plus ammonia nitrogen B-26</td>
<td>Constant Variable</td>
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<td>S_NH4ini5a</td>
<td>Initial concentration of ammonium plus ammonia nitrogen B-28</td>
<td>Constant Variable</td>
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<td>S_NH4ini5b</td>
<td>Initial concentration of ammonium plus ammonia nitrogen B-28</td>
<td>Constant Variable</td>
<td>mg/l</td>
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<tr>
<td>S_NH4ini6a</td>
<td>Initial concentration of ammonium plus ammonia nitrogen B-30</td>
<td>Constant Variable</td>
<td>mg/l</td>
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<td>Measured soluble ammonia in the effluent (B-1)</td>
<td>Constant Variable</td>
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<td>Measured soluble ammonia in the effluent (B-2)</td>
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<td>Measured soluble ammonia in the effluent (B-30)</td>
<td>Constant Variable</td>
<td>mg/l</td>
</tr>
<tr>
<td>S_NO3</td>
<td>Nitrate plus nitrite nitrogen</td>
<td>Dyn. Volume State Var.</td>
<td>mg/l</td>
</tr>
<tr>
<td>S_NO3in</td>
<td>Influent concentration of nitrate plus nitrite nitrogen</td>
<td>Constant Variable</td>
<td>mg/l</td>
</tr>
<tr>
<td>S_NO3ini</td>
<td>Initial concentration of nitrate plus nitrite nitrogen</td>
<td>Constant Variable</td>
<td>mg/l</td>
</tr>
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### S_NO3meas:
**Description:** Measured nitrate in the effluent
**Type:** Variable List Variable
**Unit:** mg/l
**Argument:** Calculated
**Interpolation Method:** linear interpolation
**Real-Variable Data Pairs (6 pairs):**
1. S_NO3meas1
2. S_NO3meas2
3. S_NO3meas3
4. S_NO3meas4
5. S_NO3meas5
6. S_NO3meas6

#### S_NO3meas1
**Description:** Measured nitrate in the effluent (B-1)
**Type:** Constant Variable
**Unit:** mg/l
**Value:** 24.85
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 100
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

#### S_NO3meas2
**Description:** Measured nitrate in the effluent (B-2)
**Type:** Constant Variable
**Unit:** mg/l
**Value:** 23.81
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 100
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

#### S_NO3meas3
**Description:** Measured nitrate in the effluent (B-5)
**Type:** Constant Variable
**Unit:** mg/l
**Value:** 18.7
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 100
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

#### S_NO3meas4
**Description:** Measured nitrate in the effluent (B-26)
**Type:** Constant Variable
**Unit:** mg/l
**Value:** 19.2
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 100
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

#### S_NO3meas5
**Description:** Measured nitrate in the effluent (B-28)
**Type:** Constant Variable
**Unit:** mg/l
Value: 12.4
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**S_NO3meas6:**
Description: Measured nitrate in the effluent (B-30)
Type: Constant Variable
Unit: mg/l
Value: 19.774
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**S_O2:**
Description: Dissolved oxygen
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

**S_O2sat:**
Description: Saturation dissolved oxygen concentration
Type: Constant Variable
Unit: mg/l
Value: 8.5
Standard Deviation: 0.1
Minimum: 2
Maximum: 9
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**S_PO4:**
Description: Phosphate
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

**S_PO4in:**
Description: Influent concentration of PO4-P
Type: Variable List Variable
Unit: mg/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1  S_PO4in1a
2  S_PO4in2a
3  S_PO4in3a
4  S_PO4in4a
5  S_PO4in5a
6  S_PO4in6a
11 S_PO4in1b
12 S_PO4in2b
13 S_PO4in3b
14 S_PO4in4b
15 S_PO4in5b
16 S_PO4in6b

**S_PO4in1a:**
Description: Influent concentration of PO4-P (B-
1) Type: Constant Variable
Unit: mg/l
Value: 18.25
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4in1b: Description: Influent concentration of PO4-P (B-1)
Type: Constant Variable
Unit: mg/l
Value: 18.25
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4in2a: Description: Influent concentration of PO4-P (B-2)
Type: Constant Variable
Unit: mg/l
Value: 30.94
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4in2b: Description: Influent concentration of PO4-P (B-2)
Type: Constant Variable
Unit: mg/l
Value: 30.94
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4in3a: Description: Influent concentration of PO4-P (B-5)
Type: Constant Variable
Unit: mg/l
Value: 25.19
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4in3b: Description: Influent concentration of PO4-P (B-5)
Type: Constant Variable
Unit: mg/l
Value: 25.19
Standard Deviation: 0.1
Minimum: 0
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<th>Description</th>
<th>Unit</th>
<th>Value</th>
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<th>Maximum</th>
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<td>S_PO4in4a</td>
<td>Influent concentration of PO4-P (B-26)</td>
<td>mg/l</td>
<td>29.3</td>
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<td>S_PO4in4b</td>
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<td>mg/l</td>
<td>29.3</td>
<td>0</td>
<td>100</td>
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<td>S_PO4in5a</td>
<td>Influent concentration of PO4-P (B-28)</td>
<td>mg/l</td>
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<td>S_PO4in5b</td>
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<td>S_PO4in6a</td>
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<td>mg/l</td>
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Type: Constant Variable
Unit: mg/1
Value: 26.099
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4in1a: Description: Initial concentration
Type: Variable List Variable
Unit: mg/1
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1 S_PO4in1a
2 S_PO4in1a
3 S_PO4in1a
4 S_PO4in1a
5 S_PO4in1a
6 S_PO4in1a
7 S_PO4in1a
8 S_PO4in1a
9 S_PO4in1a
10 S_PO4in1a
11 S_PO4in1a
12 S_PO4in1a

S_PO4in1a: Description: Initial concentration of orthophosphate (B-1)
Type: Constant Variable
Unit: mg/1
Value: 18.25
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4in1b: Description: Initial concentration of orthophosphate (B-1)
Type: Constant Variable
Unit: mg/1
Value: 18.25
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4in2a: Description: Initial concentration of orthophosphate (B-2)
Type: Constant Variable
Unit: mg/1
Value: 30.94
Standard Deviation: 0.1
Minimum: 0
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Sensitivity Analysis: inactive
Parameter Estimation: inactive
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<td>Constant Variable</td>
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**S_PO4ini5b:**
- **Description:** Initial concentration of orthophosphate (B-28)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 31
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 100
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**S_PO4ini6a:**
- **Description:** Initial concentration of orthophosphate (B-30)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 26.099
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 100
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**S_PO4ini6b:**
- **Description:** Initial concentration of orthophosphate (B-30)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 26.099
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 100
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**S_PO4meas:**
- **Description:** Measured soluble phosphorus in the effluent
- **Type:** Variable List Variable
- **Unit:** mg/l
- **Argument:** Calcium
- **Interpolation Method:** linear interpolation
- **Real-Variable Data Pairs (6 pairs):**
  1. S_PO4meas1
  2. S_PO4meas2
  3. S_PO4meas3
  4. S_PO4meas4
  5. S_PO4meas5
  6. S_PO4meas6

**S_PO4meas1:**
- **Description:** Measured soluble phosphorus in the effluent (B-1)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 11.6
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 100
- **Sensitivity Analysis:** inactive
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<table>
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Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
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2    S_tila
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4    S_tila
5    S_tila
6    S_tila
11   S_tilb
12   S_tilb
13   S_tilb
14   S_tilb
15   S_tilb
16   S_tilb

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<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Maximum</td>
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</tr>
<tr>
<td>Sensitivity Analysis</td>
<td>inactive</td>
</tr>
<tr>
<td>Parameter Estimation</td>
<td>inactive</td>
</tr>
</tbody>
</table>

**S_ti3b:**
- **Description:** Influent COD (B-5)
- **Type:** Constant Variable
- **Unit:** mgCOD/l
- **Value:** 912.44
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**S_ti4a:**
- **Description:** Influent COD (B-26)
- **Type:** Constant Variable
- **Unit:** mgCOD/l
- **Value:** 993.5
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**S_ti4b:**
- **Description:** Influent COD (B-26)
- **Type:** Constant Variable
- **Unit:** mgCOD/l
- **Value:** 993.5
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**S_ti5a:**
- **Description:** Influent COD (B-28)
- **Type:** Constant Variable
- **Unit:** mgCOD/l
- **Value:** 956.3
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**S_ti5b:**
- **Description:** Influent COD (B-28)
- **Type:** Constant Variable
- **Unit:** mgCOD/l
- **Value:** 956.3
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**S_ti6a:**
- **Description:** Influent COD (B-30)
- **Type:** Constant Variable
- **Unit:** mgCOD/l
- **Value:** 943.983
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

**S_ti6b:**
- **Description:** Influent COD (B-30)
- **Type:** Constant Variable
- **Unit:** mgCOD/l
- **Value:** 943.983
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

---

**T:**
- **Description:** Temperature
- **Type:** Formula Variable
- **Unit:** degC
- **Expression:** 20

---

**t:**
- **Description:** Time
- **Type:** Program Variable
- **Unit:** d
- **Reference to:** Time

---

**the_bAUT:**
- **Description:** Arrhenius constant for the decay rate of autotrophs
- **Type:** Constant Variable
- **Unit:**
- **Value:** 1.029
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

---

**the_bH:**
- **Description:** Arrhenius constant for the rate constant for lysis of heterotrophs
- **Type:** Constant Variable
- **Unit:**
- **Value:** 1.029
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

---

**the_bPAO:**
- **Description:** Arrhenius constant for the rate constant for lysis of X_PAO
- **Type:** Constant Variable
- **Unit:**
- **Value:** 1.029
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

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**the_bPHA:**
- **Description:** Arrhenius constant for the rate constant for lysis of X_PHA
- **Type:** Constant Variable
- **Unit:**
- **Value:** 1.029
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>the_bPP</strong></td>
<td>Arrhenius constant for the rate constant for lysis of X_PP</td>
<td>1.029</td>
<td>0.1</td>
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<td>inactive</td>
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<tr>
<td><strong>the_Kh</strong></td>
<td>Arrhenius constant</td>
<td>1.08</td>
<td>0.1</td>
<td>10</td>
<td>inactive</td>
<td>inactive</td>
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<tr>
<td><strong>the_KX</strong></td>
<td>Arrhenius constant for saturation coefficient for particulate COD</td>
<td>0.91</td>
<td>0.1</td>
<td>10</td>
<td>inactive</td>
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<tr>
<td><strong>the_mueAUT</strong></td>
<td>Arrhenius constant for maximum growth rate of autotrophs</td>
<td>1.123</td>
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<td><strong>the_mueH</strong></td>
<td>Arrhenius constant for maximum growth rate of heterotrophs</td>
<td>1.2</td>
<td>0.1</td>
<td>10</td>
<td>inactive</td>
<td>inactive</td>
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<tr>
<td><strong>the_muePAO</strong></td>
<td>Arrhenius constant for maximum growth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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The document contains information about parameters, their descriptions, types, units, values, and other relevant details. Each parameter is listed with its associated characteristics.
### the_qfe:
**Description:** Arrhenius constant for maximum rate of fermentation
**Type:** Constant Variable
**Unit:** /d
**Value:** 1.016
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 10
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

### the_qPHA:
**Description:** Arrhenius constant for rate constant for storage of PHA (base: Xpp)
**Type:** Constant Variable
**Unit:** /d
**Value:** 1
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 10
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

### the_qPP:
**Description:** Arrhenius constant for rate constant for storage of PP
**Type:** Constant Variable
**Unit:** /d
**Value:** 1
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 10
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

### TKN:
**Description:** Total Kjeldahl Nitrogen
**Type:** Formula Variable
**Unit:** mgN/l
**Expression:** \( S_{\text{NH4}} + (S_{\text{I}*i_{\text{NSi}}}) + (S_{\text{F}*i_{\text{NSf}}}) + (X_{\text{I}*i_{\text{NXi}}}) + (X_{\text{S}*i_{\text{NXs}}}) + (X_{H+X_{PAO}+X_{AU}*i_{i_{\text{NBM}}}}) \)

### TKN_meas:
**Description:** Measured TKN
**Type:** Variable List Variable
**Unit:** mg/l
**Argument:** Calcium
**Interpolation Method:** linear interpolation
**Real-Variable Data Pairs (6 pairs):**
1. TKN_meas1
2. TKN_meas2
3. TKN_meas3
4. TKN_meas4
5. TKN_meas5
<table>
<thead>
<tr>
<th>TKN_meas1:</th>
<th>Description: Measured TKN (B-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
</tr>
<tr>
<td>Unit:</td>
<td>mg/l</td>
</tr>
<tr>
<td>Value:</td>
<td>3.11</td>
</tr>
<tr>
<td>Standard Deviation:</td>
<td>0.1</td>
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<tr>
<td>Minimum:</td>
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<td>Maximum:</td>
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<td>Sensitivity Analysis:</td>
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<td>Parameter Estimation:</td>
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<thead>
<tr>
<th>TKN_meas2:</th>
<th>Description: Measured TKN (B-2)</th>
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<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
</tr>
<tr>
<td>Unit:</td>
<td>mg/l</td>
</tr>
<tr>
<td>Value:</td>
<td>3.92</td>
</tr>
<tr>
<td>Standard Deviation:</td>
<td>0.1</td>
</tr>
<tr>
<td>Minimum:</td>
<td>0</td>
</tr>
<tr>
<td>Maximum:</td>
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<td>Sensitivity Analysis:</td>
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<tr>
<td>Parameter Estimation:</td>
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<tr>
<th>TKN_meas3:</th>
<th>Description: Measured TKN (B-5)</th>
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<tr>
<td>Type:</td>
<td>Constant Variable</td>
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<tr>
<td>Unit:</td>
<td>mg/l</td>
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<tr>
<td>Value:</td>
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<tr>
<td>Standard Deviation:</td>
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<td>Minimum:</td>
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<tr>
<td>Maximum:</td>
<td>100</td>
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<td>Sensitivity Analysis:</td>
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<td>Parameter Estimation:</td>
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<thead>
<tr>
<th>TKN_meas4:</th>
<th>Description: Measured TKN (B-26)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
</tr>
<tr>
<td>Unit:</td>
<td>mg/l</td>
</tr>
<tr>
<td>Value:</td>
<td>1.3</td>
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<td>Standard Deviation:</td>
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<td>Sensitivity Analysis:</td>
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<tr>
<td>Parameter Estimation:</td>
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<table>
<thead>
<tr>
<th>TKN_meas5:</th>
<th>Description: Measured TKN (B-28)</th>
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</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
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<td>Unit:</td>
<td>mg/l</td>
</tr>
<tr>
<td>Value:</td>
<td>1.3</td>
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<thead>
<tr>
<th>TKN_meas6:</th>
<th>Description: Measured TKN (B-30)</th>
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<tr>
<td>Type:</td>
<td>Constant Variable</td>
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<td>Unit:</td>
<td>mg/l</td>
</tr>
<tr>
<td>Value:</td>
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</tr>
<tr>
<td>Standard Deviation:</td>
<td>0.1</td>
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<td>Sensitivity Analysis:</td>
<td>inactive</td>
</tr>
<tr>
<td>Parameter Estimation:</td>
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</tr>
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</table>
TSS: Description: TSS
   Type: Formula Variable
   Unit: mgTSS/l
   Expression: VSS+ISS_Xoi

TSS_measAero: Description: Measured TSS (aerobic)
   Type: Variable List Variable
   Unit: mgTSS/l
   Argument: Cahnnum
   Interpolation Method: linear interpolation
   Real-Variable Data Pairs (6 pairs):
   1  TSS_measAero1
   2  TSS_measAero2
   3  TSS_measAero3
   4  TSS_measAero4
   5  TSS_measAero5
   6  TSS_measAero6

TSS_measAero1: Description: Measured TSS (B-1) (aerobic)
   Type: Constant Variable
   Unit: mgTSS/l
   Value: 16774.8
   Standard Deviation: 0.1
   Minimum: 0
   Maximum: 20000
   Sensitivity Analysis: inactive
   Parameter Estimation: inactive

TSS_measAero2: Description: Measured TSS (B-2) (aerobic)
   Type: Constant Variable
   Unit: mgTSS/l
   Value: 15538.44
   Standard Deviation: 0.1
   Minimum: 0
   Maximum: 20000
   Sensitivity Analysis: inactive
   Parameter Estimation: inactive

TSS_measAero3: Description: Measured TSS (B-5) (aerobic)
   Type: Constant Variable
   Unit: mgTSS/l
   Value: 17201
   Standard Deviation: 0.1
   Minimum: 0
   Maximum: 20000
   Sensitivity Analysis: inactive
   Parameter Estimation: inactive

TSS_measAero4: Description: Measured TSS (B-26) (aerobic)
   Type: Constant Variable
   Unit: mgTSS/l
   Value: 17316
   Standard Deviation: 0.1
   Minimum: 0
   Maximum: 20000
   Sensitivity Analysis: inactive
   Parameter Estimation: inactive

TSS_measAero5: Description: Measured TSS (B-28) (aerobic)
   Type: Constant Variable
Unit: mgTSS/l
Value: 17819.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

TSS_measAero6: Description: Measured TSS (B-30) (aerobic)
Type: Constant Variable
Unit: mgTSS/l
Value: 16945.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

TSS_measAnaer: Description: Measured TSS (anaerobic)
Type: Variable List Variable
Unit: mgTSS/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (6 pairs):
1: TSS_measAnaer1
2: TSS_measAnaer2
3: TSS_measAnaer3
4: TSS_measAnaer4
5: TSS_measAnaer5
6: TSS_measAnaer6

TSS_measAnaer1: Description: Measured TSS (B-1) (anaerobic)
Type: Constant Variable
Unit: mgTSS/l
Value: 7953.2
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

TSS_measAnaer2: Description: Measured TSS (B-2) (anaerobic)
Type: Constant Variable
Unit: mgTSS/l
Value: 8251.11
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

TSS_measAnaer3: Description: Measured TSS (B-5) (anaerobic)
Type: Constant Variable
Unit: mgTSS/l
Value: 7523.09
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive
TSS_measAnaer4: Description: Measured TSS (B-26) (anaerobic)
Type: Constant Variable
Unit: mgTSS/l
Value: 7494.2
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

TSS_measAnaer5: Description: Measured TSS (B-28) (anaerobic)
Type: Constant Variable
Unit: mgTSS/l
Value: 7195.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

TSS_measAnaer6: Description: Measured TSS (B-30) (anaerobic)
Type: Constant Variable
Unit: mgTSS/l
Value: 7648.56
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

TSS_measAnox1: Description: Measured TSS (B-1) (anoxic)
Type: Constant Variable
Unit: mgTSS/l
Value: 13068.4
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

TSS_measAnox2: Description: Measured TSS (B-2) (anoxic)
Type: Constant Variable
Unit: mgTSS/l
Value: 13059.78
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
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<thead>
<tr>
<th>Parameter Estimation: inactive</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS_measAnox3: Description: Measured TSS (B-5) (anoxic)</td>
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<tr>
<td>Type: Constant Variable</td>
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<tr>
<td>Unit: mgTSS/l</td>
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<tr>
<td>Value: 13357.45</td>
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<tr>
<td>Standard Deviation: 0.1</td>
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<tr>
<td>Minimum: 0</td>
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<tr>
<td>Maximum: 20000</td>
</tr>
<tr>
<td>Sensitivity Analysis: inactive</td>
</tr>
<tr>
<td>Parameter Estimation: inactive</td>
</tr>
</tbody>
</table>

| TSS_measAnox4: Description: Measured TSS (B-26) (anoxic) |
| Type: Constant Variable |
| Unit: mgTSS/l |
| Value: 13292.2 |
| Standard Deviation: 0.1 |
| Minimum: 0 |
| Maximum: 20000 |
| Sensitivity Analysis: inactive |
| Parameter Estimation: inactive |

| TSS_measAnox5: Description: Measured TSS (B-28) (anoxic) |
| Type: Constant Variable |
| Unit: mgTSS/l |
| Value: 13197.6 |
| Standard Deviation: 0.1 |
| Minimum: 0 |
| Maximum: 20000 |
| Sensitivity Analysis: inactive |
| Parameter Estimation: inactive |

| TSS_measAnox6: Description: Measured TSS (B-30) (anoxic) |
| Type: Constant Variable |
| Unit: mgTSS/l |
| Value: 13170.28 |
| Standard Deviation: 0.1 |
| Minimum: 0 |
| Maximum: 20000 |
| Sensitivity Analysis: inactive |
| Parameter Estimation: inactive |

| t_mode: Description: |
| Type: Formula Variable |
| Unit: |
| Expression: t mod 10 |

| Volume: Description: Volume |
| Type: Program Variable |
| Unit: 1 |
| Reference to: Reactor Volume |

| VSS: Description: Actual VSS |
| Type: Formula Variable |
| Unit: mgVSS/l |
| Expression: mVSS/f_cv |

| VSS_measAero: Description: Measured VSS (aerobic) |
| Type: Variable List Variable |
| Unit: mgCOD/l |
| Argument: Calcium |
Interpolation Method: linear interpolation
Real-Variable Data Pairs (6 pairs):

<table>
<thead>
<tr>
<th>VSS_measAero1</th>
<th>Description: Measured VSS (B-1) (aerobic)</th>
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</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
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<tr>
<td>Unit:</td>
<td>mgCOD/l</td>
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<tr>
<td>Value:</td>
<td>19248.88</td>
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<tr>
<td>Standard Deviation:</td>
<td>0.1</td>
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<td>Minimum:</td>
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<td>Maximum:</td>
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<td>Sensitivity Analysis:</td>
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<tr>
<td>Parameter Estimation:</td>
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<table>
<thead>
<tr>
<th>VSS_measAero2</th>
<th>Description: Measured VSS (B-2) (aerobic)</th>
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</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Constant Variable</td>
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<tr>
<td>Unit:</td>
<td>mgCOD/l</td>
</tr>
<tr>
<td>Value:</td>
<td>18835.138</td>
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<td>Standard Deviation:</td>
<td>0.1</td>
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<table>
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<tr>
<th>VSS_measAero3</th>
<th>Description: Measured VSS (B-5) (aerobic)</th>
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<tbody>
<tr>
<td>Type:</td>
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<tr>
<td>Unit:</td>
<td>mgCOD/l</td>
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<tr>
<td>Value:</td>
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<td>Minimum:</td>
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<td>Sensitivity Analysis:</td>
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<td>Parameter Estimation:</td>
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<table>
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<th>Description: Measured VSS (B-26) (aerobic)</th>
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<tr>
<td>Unit:</td>
<td>mgCOD/l</td>
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<tr>
<td>Value:</td>
<td>20008.94</td>
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<td>Sensitivity Analysis:</td>
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<td>Parameter Estimation:</td>
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<table>
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<th>VSS_measAero5</th>
<th>Description: Measured VSS (B-29) (aerobic)</th>
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<tbody>
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<td>Type:</td>
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<tr>
<td>Unit:</td>
<td>mgCOD/l</td>
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<tr>
<td>Value:</td>
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<td>Parameter Estimation:</td>
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<th>Description: Measured VSS (B-30) (aerobic)</th>
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Unit: \( \text{mgCOD/l} \)  
Value: 20218.92  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 25000  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

### VSS measAnaer

**Description:** Measured VSS (anaerobic)  
**Type:** Variable List Variable  
**Unit:** \( \text{mgCOD/l} \)  
**Argument:** Calcium  
**Interpolation Method:** linear interpolation  
**Real-Variable Data Pairs (6 pairs):**

1. VSS_measAnaer1  
2. VSS_measAnaer2  
3. VSS_measAnaer3  
4. VSS_measAnaer4  
5. VSS_measAnaer5  
6. VSS_measAnaer6

### VSS_measAnaer1

**Description:** Measured VSS (B-1) (anaerobic)  
**Type:** Constant Variable  
**Unit:** \( \text{mgCOD/l} \)  
**Value:** 9338.4711  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 20000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

### VSS_measAnaer2

**Description:** Measured VSS (B-2) (anaerobic)  
**Type:** Constant Variable  
**Unit:** \( \text{mgCOD/l} \)  
**Value:** 10378.5  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 20000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

### VSS_measAnaer3

**Description:** Measured VSS (B-5) (anaerobic)  
**Type:** Constant Variable  
**Unit:** \( \text{mgCOD/l} \)  
**Value:** 9138.26  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 20000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

### VSS_measAnaer4

**Description:** Measured VSS (B-26) (anaerobic)  
**Type:** Constant Variable  
**Unit:** \( \text{mgCOD/l} \)  
**Value:** 8973.61  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 20000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive
VSS_measAnaer5: Description: Measured VSS (B-28) (anaerobic)
Type: Constant Variable
Unit: mgCOD/l
Value: 8982.268
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

VSS_measAnaer6: Description: Measured VSS (B-30) (anaerobic)
Type: Constant Variable
Unit: mgCOD/l
Value: 9318.084
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

VSS_measAnox: Description: Measured VSS (anoxic)
Type: Variable List Variable
Unit: mgCOD/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (6 pairs):
1 VSS_measAnox1
2 VSS_measAnox2
3 VSS_measAnox3
4 VSS_measAnox4
5 VSS_measAnox5
6 VSS_measAnox6

VSS_measAnox1: Description: Measured VSS (B-1) (anoxic)
Type: Constant Variable
Unit: mgCOD/l
Value: 14982.204
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

VSS_measAnox2: Description: Measured VSS (B-2) (anoxic)
Type: Constant Variable
Unit: mgCOD/l
Value: 15791.929
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

VSS_measAnox3: Description: Measured VSS (B-5) (anoxic)
Type: Constant Variable
Unit: mgCOD/l
Value: 15888.047
Standard Deviation: 0.1
Minimum: 0
Maximum: 20000
Sensitivity Analysis: inactive
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| VSS measAnox4: Description: | Measured VSS (B-26) (anoxic) |
| Type: | Constant Variable |
| Unit: | mgCOD/l |
| Value: | 15456.13 |
| Standard Deviation: | 0.1 |
| Minimum: | 0 |
| Maximum: | 20000 |

| Sensitivity Analysis: inactive |
| Parameter Estimation: inactive |

| VSS measAnox5: Description: | Measured VSS (B-28) (anoxic) |
| Type: | Constant Variable |
| Unit: | mgCOD/l |
| Value: | 16114.24 |
| Standard Deviation: | 0.1 |
| Minimum: | 0 |
| Maximum: | 20000 |

| Sensitivity Analysis: inactive |
| Parameter Estimation: inactive |

| VSS measAnox6: Description: | Measured VSS (B-30) (anoxic) |
| Type: | Constant Variable |
| Unit: | mgCOD/l |
| Value: | 15756.19 |
| Standard Deviation: | 0.1 |
| Minimum: | 0 |
| Maximum: | 20000 |

| Sensitivity Analysis: inactive |
| Parameter Estimation: inactive |

| V_aero: Description: | Volume of aerobic reactor |
| Type: | Formula Variable |
| Unit: | 1 |
| Expression: | 35 |

| V_anaer: Description: | Volume of anaerobic reactor |
| Type: | Formula Variable |
| Unit: | 1 |
| Expression: | 19 |

| V_anox: Description: | Volume of anoxic reactor |
| Type: | Formula Variable |
| Unit: | 1 |
| Expression: | 21 |

| X_AUT: Description: | Nitrifying organisms |
| Type: | Dyn. Volume State Var. |
| Unit: | mg/l |
| Relative Accuracy: | 1e-006 |
| Absolute Accuracy: | 1e-006 |

| X_AUTin: Description: | Influent concentration of nitrifying organisms |
| Type: | Constant Variable |
| Unit: | mg/l |
| Value: | 0 |
| Standard Deviation: | 0.1 |
| Minimum: | 0 |
| Maximum: | 10 |
Sensitivity Analysis: inactive
Parameter Estimation: inactive

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X_AUTini1a: Description: Initial concentration of nitrifying organisms (B-1)
Type: Constant Variable
Unit: mg/l
Value: 221
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_AUTini1b: Description: Initial concentration of nitrifying organisms (B-1)
Type: Constant Variable
Unit: mg/l
Value: 221
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_AUTini2a: Description: Initial concentration of nitrifying organisms (B-2)
Type: Constant Variable
Unit: mg/l
Value: 327
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_AUTini2b: Description: Initial concentration of nitrifying organisms (B-2)
Type: Constant Variable
Unit: mg/l
Value: 328
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**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

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X_AUTini3a:  
**Description:** Initial concentration of nitrifying organisms (B-5)  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 313  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 1000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

---

X_AUTini3b:  
**Description:** Initial concentration of nitrifying organisms (B-5)  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 314  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 1000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

---

X_AUTini4a:  
**Description:** Initial concentration of nitrifying organisms (B-26)  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 217  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 1000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

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X_AUTini4b:  
**Description:** Initial concentration of nitrifying organisms (B-26)  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 218  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 1000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

---

X_AUTini5a:  
**Description:** Initial concentration of nitrifying organisms (B-28)  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 192  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 1000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive
X_AUTini5b: Description: Initial concentration of nitrifying organisms (B-28)
Type: Constant Variable
Unit: mg/l
Value: 191
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_AUTini6a: Description: Initial concentration of nitrifying organisms (B-30)
Type: Constant Variable
Unit: mg/l
Value: 249
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_AUTini6b: Description: Initial concentration of nitrifying organisms (B-30)
Type: Constant Variable
Unit: mg/l
Value: 249
Standard Deviation: 0.1
Minimum: 0
Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_H: Description: Heterotrophic organisms
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

X_Hin: Description: Influent concentration of heterotrophic organisms
Type: Constant Variable
Unit: mg/l
Value: 0
Standard Deviation: 1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_Hini: Description: Initial concentration of heterotrophic organisms
Type: Variable List Variable
Unit: mg/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1 X_Hini1a
2 X_Hini2a
3 X_Hini3a
4 X_Hini4a
5  X_Hini5a
6  X_Hini6a
11 X_Hini1b
12 X_Hini2b
13 X_Hini3b
14 X_Hini4b
15 X_Hini5b
16 X_Hini6b

---

**X_Hini5a:**

*Description:* Initial concentration of heterotrophic organisms (B-1)

*Type:* Constant Variable

*Unit:* mg/l

*Value:* 2567

*Standard Deviation:* 0.1

*Minimum:* 0

*Maximum:* 10000

*Sensitivity Analysis:* inactive

*Parameter Estimation:* inactive

---

**X_Hini1b:**

*Description:* Initial concentration of heterotrophic organisms (B-1)

*Type:* Constant Variable

*Unit:* mg/l

*Value:* 2261

*Standard Deviation:* 0.1

*Minimum:* 0

*Maximum:* 10000

*Sensitivity Analysis:* inactive

*Parameter Estimation:* inactive

---

**X_Hini2a:**

*Description:* Initial concentration of heterotrophic organisms (B-2)

*Type:* Constant Variable

*Unit:* mg/l

*Value:* 3195

*Standard Deviation:* 0.1

*Minimum:* 0

*Maximum:* 10000

*Sensitivity Analysis:* inactive

*Parameter Estimation:* inactive

---

**X_Hini2b:**

*Description:* Initial concentration of heterotrophic organisms (B-2)

*Type:* Constant Variable

*Unit:* mg/l

*Value:* 3018

*Standard Deviation:* 0.1

*Minimum:* 0

*Maximum:* 10000

*Sensitivity Analysis:* inactive

*Parameter Estimation:* inactive

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**X_Hini3a:**

*Description:* Initial concentration of heterotrophic organisms (B-5)

*Type:* Constant Variable

*Unit:* mg/l

*Value:* 2020

*Standard Deviation:* 0.1

*Minimum:* 0

*Maximum:* 10000
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<td>Constant Variable</td>
</tr>
<tr>
<td>X_Ini6a</td>
<td>Initial particulate inert organic matter (B-30)</td>
<td>Constant Variable</td>
</tr>
<tr>
<td>X_Ini6b</td>
<td>Initial particulate inert organic matter (B-30)</td>
<td>Constant Variable</td>
</tr>
</tbody>
</table>
X_PAO: Description: Phosphate accumulating organisms
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

X_PAOin: Description: Influent concentration of PAO
Type: Constant Variable
Unit: mg/l
Value: 0
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PAOini: Description: Initial concentration of PAO
Type: Variable List Variable
Unit: mg/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1  X_PAOini1a
2  X_PAOini2a
3  X_PAOini3a
4  X_PAOini4a
5  X_PAOini5a
6  X_PAOini6a
11  X_PAOini11b
12  X_PAOini12b
13  X_PAOini13b
14  X_PAOini14b
15  X_PAOini15b
16  X_PAOini16b

X_PAOini1a: Description: Initial concentration of PAO (B-1)
Type: Constant Variable
Unit: mg/l
Value: 1253
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PAOini1b: Description: Initial concentration of PAO (B-1)
Type: Constant Variable
Unit: mg/l
Value: 3540
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PAOini2a: Description: Initial concentration of PAO (B-2)
Type: Constant Variable
Unit: mg/l
Value: 2507
Standard Deviation: 0.1
Minimum: 0
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<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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<td>Constant Variable</td>
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<td>X_PAOn13a</td>
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<td>Constant Variable</td>
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<td>2890</td>
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<td>X_PAOn13b</td>
<td>Initial concentration of PAO (B-5)</td>
<td>Constant Variable</td>
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<tr>
<td>X_PAOn14a</td>
<td>Initial concentration of PAO (B-26)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>2953</td>
<td>0.1</td>
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<td>X_PAOn14b</td>
<td>Initial concentration of PAO (B-26)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>3854</td>
<td>0.1</td>
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<tr>
<td>X_PAOn15a</td>
<td>Initial concentration of PAO (B-28)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>3640</td>
<td>0.1</td>
<td>0</td>
<td>10000</td>
<td>inactive</td>
<td>inactive</td>
</tr>
</tbody>
</table>
### X_PAOnini5b:
- **Description:** Initial concentration of PAO (B-28)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:**
- **Standard Deviation:**
- **Minimum:**
- **Maximum:**
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_PAOnini6a:
- **Description:** Initial concentration of PAO (B-30)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:**
- **Standard Deviation:**
- **Minimum:**
- **Maximum:**
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_PAOnini6b:
- **Description:** Initial concentration of PAO (B-30)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:**
- **Standard Deviation:**
- **Minimum:**
- **Maximum:**
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_PHA:
- **Description:** A cell internal storage product of phosphate accumulating organisms
- **Type:** Dyn. Volume State Var.
- **Unit:** mg/l
- **Relative Accuracy:**
- **Absolute Accuracy:**

### X_PHAin:
- **Description:** Influent concentration of PHA
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:**
- **Standard Deviation:**
- **Minimum:**
- **Maximum:**
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_PHAini:
- **Description:** Initial concentration of PHA
- **Type:** Variable List Variable
- **Unit:** mg/l
- **Argument:** Calcium
- **Interpolation Method:** linear interpolation
- **Real-Variable Data Pairs (12 pairs):**
  1. X_PHAini1a
  2. X_PHAini2a
  3. X_PHAini3a
  4. X_PHAini4a
  5. X_PHAini5a
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<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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<tr>
<td>X_PHAini1a</td>
<td>Initial concentration of PHA (B-1)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>59</td>
<td>0.1</td>
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<td>inactive</td>
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<td>X_PHAini1b</td>
<td>Initial concentration of PHA (B-1)</td>
<td>Constant Variable</td>
<td>mg/l</td>
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<td>0.1</td>
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<td>X_PHAini2a</td>
<td>Initial concentration of PHA (B-2)</td>
<td>Constant Variable</td>
<td>mg/l</td>
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<td>X_PHAini2b</td>
<td>Initial concentration of PHA (B-2)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>60</td>
<td>0.1</td>
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<td>inactive</td>
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<tr>
<td>X_PHAini3a</td>
<td>Initial concentration of PHA (B-5)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>34</td>
<td>0.1</td>
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<td>X_PHAini3b</td>
<td>Initial concentration of PHA (B-5)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td></td>
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X_PHAini14a: Description: Initial concentration of PHA (B-26)
Type: Constant Variable
Unit: mg/l
Value: 59
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PHAini14b: Description: Initial concentration of PHA (B-26)
Type: Constant Variable
Unit: mg/l
Value: 59
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PHAini5a: Description: Initial concentration of PHA (B-26)
Type: Constant Variable
Unit: mg/l
Value: 58
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PHAini5b: Description: Initial concentration of PHA (B-26)
Type: Constant Variable
Unit: mg/l
Value: 58
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PHAini6a: Description: Initial concentration of PHA (B-26)
Type: Constant Variable
Unit: mg/l
Value: 62
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PHAini6b: Description: Initial concentration of PHA (B-26)
Type: Constant Variable
Unit: mg/l
Value: 60
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 100  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

X_PP:  
Description: Poly-phosphate  
Type: Dyn. Volume State Var.  
Unit: mg/l  
Relative Accuracy: 1e-006  
Absolute Accuracy: 1e-006

X_PPin:  
Description: Influent concentration of PP  
Type: Constant Variable  
Unit: mg/l  
Value: 0  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 10  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

X_PPin1:  
Description: Initial concentration of PP  
Type: Variable List Variable  
Unit: mg/l  
Argument: Calcnum  
Interpolation Method: linear interpolation  
Real-Variable Data Pairs (12 pairs):  
1  X_PPin1a  
2  X_PPin2a  
3  X_PPin3a  
4  X_PPin4a  
5  X_PPin5a  
6  X_PPin6a  
11  X_PPin11b  
12  X_PPin12b  
13  X_PPin13b  
14  X_PPin14b  
15  X_PPin15b  
16  X_PPin16b

X_PPin1a:  
Description: Initial concentration of PP (B-1)  
Type: Constant Variable  
Unit: mg/l  
Value: 352  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 1000  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

X_PPin1b:  
Description: Initial concentration of PP (B-1)  
Type: Constant Variable  
Unit: mg/l  
Value: 357  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 1000  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive
X_PPini2a:  Description: Initial concentration of PP (B-2)
  Type: Constant Variable
  Unit: mg/l
  Value: 722
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 1000
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

X_PPini2b:  Description: Initial concentration of PP (B-2)
  Type: Constant Variable
  Unit: mg/l
  Value: 737
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 1000
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

X_PPini3a:  Description: Initial concentration of PP (B-5)
  Type: Constant Variable
  Unit: mg/l
  Value: 834
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 1000
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

X_PPini3b:  Description: Initial concentration of PP (B-5)
  Type: Constant Variable
  Unit: mg/l
  Value: 848
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 1000
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

X_PPini4a:  Description: Initial concentration of PP (B-26)
  Type: Constant Variable
  Unit: mg/l
  Value: 839
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 1000
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

X_PPini4b:  Description: Initial concentration of PP (B-26)
  Type: Constant Variable
  Unit: mg/l
  Value: 860
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 1000
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

X_PPini5a:  Description: Initial concentration of PP (B-28)
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<tr>
<th>Parameter</th>
<th>Description</th>
<th>Type:</th>
<th>Unit:</th>
<th>Value:</th>
<th>Standard Deviation:</th>
<th>Minimum:</th>
<th>Maximum:</th>
<th>Sensitivity Analysis:</th>
<th>Parameter Estimation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>X_PPini5b</td>
<td>Initial concentration of PP (B-28)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>1018</td>
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<td>X_PPini6a</td>
<td>Initial concentration of PP (B-30)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>733</td>
<td>0.1</td>
<td>0</td>
<td>1000</td>
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<td>inactive</td>
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<tr>
<td>X_PPini6b</td>
<td>Initial concentration of PP (B-30)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>734</td>
<td>0.1</td>
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<td>X_S</td>
<td>Slowly biodegradable substrate</td>
<td>Dyn. Volume State Var.</td>
<td>mg/l</td>
<td></td>
<td>1e-006</td>
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<td>1e-006</td>
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<td>X_Sin</td>
<td>Influent concentration of slowly biodegradable substrate</td>
<td>Formula Variable</td>
<td>mg/l</td>
<td></td>
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<td></td>
<td>(1-f_bs)<em>S_ti</em>(1-f_us-f_up)</td>
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<td>X_Sini1</td>
<td>Initial concentration of slowly biodegradable substrate</td>
<td>Formula Variable</td>
<td>mg/l</td>
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<td>(1-f_bs)<em>S_ti</em>(1-f_us-f_up)</td>
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<tr>
<td>X_taero</td>
<td>TSS concentration in aerobic reactor</td>
<td>Variable List Variable</td>
<td>mgTSS/l</td>
<td></td>
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</table>
Argument: Calculcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1  X_taerola
2  X_taero2a
3  X_taero3a
4  X_taero4a
5  X_taero5a
6  X_taero6a
11 X_taerolb
12 X_taero2b
13 X_taero3b
14 X_taero4b
15 X_taero5b
16 X_taero6b

X_taerola: Description: TSS concentration in aerobic reactor (B-1)
Type: Constant Variable
Unit: mgTSS/l
Value: 16210
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_taerolb: Description: TSS concentration in aerobic reactor (B-1)
Type: Constant Variable
Unit: mgTSS/l
Value: 16200
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_taero2a: Description: TSS concentration in aerobic reactor (B-2)
Type: Constant Variable
Unit: mgTSS/l
Value: 16610
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_taero2b: Description: TSS concentration in aerobic reactor (B-2)
Type: Constant Variable
Unit: mgTSS/l
Value: 16760
Standard Deviation: 0.1
Minimum: 0
Maximum: 30000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_taero3a: Description: TSS concentration in aerobic reactor
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<td>Constant Variable</td>
<td>mgTSS/l</td>
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<td>Constant Variable</td>
<td>mgTSS/l</td>
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<td>Constant Variable</td>
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<td>TSS concentration in aerobic reactor (B-28)</td>
<td>Constant Variable</td>
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<td>Constant Variable</td>
<td>mgTSS/l</td>
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<th>Value</th>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>6482</td>
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<td>X_tanaer6b</td>
<td>TSS concentration in anaerobic reactor (B-30)</td>
<td>Constant Variable</td>
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<td>Variable List Variable</td>
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Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (12 pairs):
1   X_tanox1a
2   X_tanox2a
3   X_tanox3a
4   X_tanox4a
5   X_tanox5a
6   X_tanox6a
11  X_tanox1b
12  X_tanox2b
13  X_tanox3b
14  X_tanox4b
15  X_tanox5b
16  X_tanox6b

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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<tbody>
<tr>
<td>X_tanox1a</td>
<td>TSS concentration in anoxic reactor (B-1)</td>
<td>Constant Variable</td>
<td>mgTSS/1</td>
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<td>Parameter</td>
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<td>Minimum</td>
<td>Maximum</td>
<td>Sensitivity Analysis</td>
<td>Parameter Estimation</td>
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<td>Constant Variable</td>
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<td>Yield coefficient (biomass/nitrate) of ANO</td>
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<td>gCOD(gN)-1</td>
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<td>Y_PAO</td>
<td>Yield coefficient (biomass/PHA) of PAO</td>
<td>Constant Variable</td>
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Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

Y_P04:
Description: Yield of P release/PFA storage (PP requirement (S_PO4 release) for PFA storage)
Type: Constant Variable
Unit: per day
Value: 0.52
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

Processes
Aeration:
Description: Dynamic Process
Rate: K_La*(S_O2sat-S_O2)
Stoichiometry:
Variable: Stoichiometric Coefficient
S_O2 = 1

AerobicHydrolysis:
Description: Aerobic hydrolysis
Type: Dynamic Process
Rate: K_h*(S_O2/(K_O2+S_O2))*((X_S/X_H)/(K_X+(X_S/X_H)))*X_H
Stoichiometry:
Variable: Stoichiometric Coefficient
S_F = 1-f_SI
S_I = f_SI
X_S = -I
S_PO4 = i_PXs-((1-f_SI)*i_PSf)-(f_SI*i_PSi)
S_NH4 = i_NXs-((1-f_SI)*i_NSf)-(f_SI*i_NSi)

AeroGrowthS_A:
Description: Aerobic growth on fermentable products, S_A
Type: Dynamic Process
Rate: mu_e_H*(S_O2/(K_O2+S_O2))*(S_A/(K_AO+K_AOH+S_A))*(S_A/(S_F+S_A))*(S_NH4/(K_NH4+K_NH4OH+S_NH4))*(S_PO4/(K_P+S_PO4))*X_H
Stoichiometry:
Variable: Stoichiometric Coefficient
S_O2 = -(1-Y_H)/Y_H
S_A = -1/Y_H
X_H = 1
S_NH4 = -i_NBM
S_PO4 = -i_PBM

AeroGrowthS_F: Description: Aerobic growth on fermentable subst...
A.131

Type: Dynamic Process
Rate: 
\[ \text{mue}_H \left( \frac{S_{O2}}{(K_{O2}+S_{O2})} \right) \times \left( \frac{S_F}{(K_F+S_F)} \right) \times \left( \frac{S_{NH4}}{(K_{NH4}+S_{NH4})} \right) \times \left( \frac{S_{PO4}}{(K_P+S_{PO4})} \right) \times (X_H) \]

Stoichiometry:
Variable: Stoichiometric Coefficient
\[ S_{O2} : \frac{-1}{Y_H} \]
\[ S_F : -1/Y_H \]
\[ X_H : 1 \]
\[ S_{NH4} : \left( \left( \frac{1}{Y_H} \right) \times i_{NSf} \right) - i_{NBM} \]
\[ S_{PO4} : \left( \left( \frac{1}{Y_H} \right) \times i_{PSf} \right) - i_{PBM} \]

AeroGrowthX_PAo:
Description: Aerobic growth of X_PAo on X_PHa
Type: Dynamic Process
Rate: 
\[ \text{mue}_PAO \left( \frac{S_{O2}}{(K_{O2}+S_{O2})} \right) \times \left( \frac{S_{NH4}}{(K_{NH4}+S_{NH4})} \right) \times \left( \frac{S_{PO4}}{(K_P+S_{PO4})} \right) \times (X_{PHa}/X_{PAO}) \times (X_{PHa}+X_{PAO}) \times X_{PAO} \]

Stoichiometry:
Variable: Stoichiometric Coefficient
\[ S_{O2} : \frac{-1}{Y_{PAO}} \]
\[ S_{PO4} : -i_{PBM} \]
\[ X_{PAO} : 1 \]
\[ X_{PHa} : -1/Y_{PAO} \]
\[ S_{NH4} : -i_{NBM} \]

AnaerobicHydrolysis:
Description: Anaerobic hydrolysis
Type: Dynamic Process
Rate: 
\[ K_h \times \text{eta_fe} \times \left( \frac{K_{O2}}{(K_{O2}+S_{O2})} \right) \times \left( \frac{K_{NO3}}{(K_{NO3}+S_{NO3})} \right) \times \left( \frac{X_S/X_H}{K_X+(X_S/X_H)} \right) \times X_H \]

Stoichiometry:
Variable: Stoichiometric Coefficient
\[ S_F : 1-f_{SI} \]
\[ S_{NH4} : i_{NXs} - (1-f_{SI}) \times i_{NSf} - (f_{SI} \times i_{NSi}) \]
\[ S_I : f_{SI} \]
\[ X_S : -1 \]
\[ S_{PO4} : i_{PXs} - (1-f_{SI}) \times i_{PSf} - (f_{SI} \times i_{PSi}) \]

AnoxicGrowthS_A:
Description: Aerobic growth on fermentable products, S_A (Denitrification)
Type: Dynamic Process
Rate: 
\[ \text{mue}_H \times \text{eta_NO3d} \times \left( \frac{K_{O2}}{(K_{O2}+S_{O2})} \right) \times \left( \frac{S_A}{(K_{AO}+S_A)} \right) \times \left( \frac{S_A}{(S_F+S_A)} \right) \times \left( \frac{S_{NH4}}{(K_{NH4}+S_{NH4})} \right) \times \left( \frac{S_{NO3}}{(K_N + O3+S_{NO3})} \right) \times \left( \frac{S_{PO4}}{(K_P+S_{PO4})} \right) \times (X_H) \]

Stoichiometry:
Variable: Stoichiometric Coefficient
\[ S_A : -1/Y_H \]
\[ X_H : 1 \]
\[ S_{NH4} : -i_{NBM} \]
\[ S_{PO4} : -i_{PBM} \]
\[ S_{NO3} : \left( \frac{-1}{Y_H} \right) / (2.86 \times Y_H) \]
\[ S_{N2} : \left( \frac{1}{Y_H} \right) / (2.86 \times Y_H) \]
AnoxicGrowthS_F:  
Description: Anoxic growth on fermentable substrates, S_F Denitrification  
Type: Dynamic Process  
Rate: $\mu_e H^*eta_N03d^*(K_02/(K_02+S_02))^* (S_F/(K_F+S_F))^* (S_F/(S_F+S_A))^* (S_NH4/(K_NH4+S_NH4))^* (S_NO3/(K_NO3+S_NO3))^* (S_PO4/(K_PO4+S_PO4))^* (X_H)$  
Stoichiometry:  
Variable : Stoichiometric Coefficient  
$S_F : -1/Y_H$  
$X_H : 1$  
$S_NH4 : ((1/Y_H)*i_NSf)-i_NBM$  
$S_PO4 : ((1/Y_H)*i_Psf)-i_PBM$  
$S_NO3 : -(1-Y_H)/(2.86*Y_H)$  
$S_N2 : (1-Y_H)/(2.86*Y_H)$  

Anoxichydrolysis:  
Description: Anoxic hydrolysis  
Type: Dynamic Process  
Rate: $K_h^*eta_N03^*(K_02/(K_02+S_02))^* (S_NO3/(K_NO3+S_NO3))^* (X_S/X_H)/(K_X+(X_S/X_H))^* X_H$  
Stoichiometry:  
Variable : Stoichiometric Coefficient  
$S_F : 1-f_SI$  
$S_NH4 : i_NXs-((1-f_SI)*i_NSf)-(f_SI*i_NSI)$  
$X_S : -1$  
$S_PO4 : i_PXs-((1-f_SI)*i_Psf)-(f_SI*i_PSI)$  
$S_I : f_SI$  

Fermentation:  
Description: Fermentation  
Type: Dynamic Process  
Rate: $q_fe^*(K_02/(K_02+S_02))^* (K_NO3/(K_NO3+S_NO3))^* (S_F/(K_fe+S_F))^* X_H$  
Stoichiometry:  
Variable : Stoichiometric Coefficient  
$S_F : -1$  
$S_A : 1$  
$S_NH4 : i_NSf$  
$S_PO4 : i_Psf$  

GrowthX_AUT:  
Description: Growth of nitrifying organisms (autotrophic organisms)  
Type: Dynamic Process  
Rate: $\mu_e AUT^*(S_O2/(K_O2+S_O2))^* (S_NH4/(K_NH4AUT+S_NH4))^* (S_PO4/(K_P+S_PO4))^* X_AUT$  
Stoichiometry:  
Variable : Stoichiometric Coefficient  
$S_O2 : -(4.57-Y_AUT)/Y_AUT$  
$S_NH4 : -(1/Y_AUT)-i_NBM$  
$S_NO3 : 1/Y_AUT$  
$S_PO4 : -i_PBM$  
$X_AUT : 1$  

LysisX_AUT:  
Description: Lysis/death of autotrophic (nitrifying) organisms  
Type: Dynamic Process  
Rate: $b_AUT^*X_AUT$  
Stoichiometry:
Variable: Stoichiometric Coefficient
S_NH4: i_NBM-(f_XIAUT*i_NXi)-((1-f_XIAUT)*i_NXs)
S_PO4: i_PBM-(f_XIAUT*i_PXi)-((1-f_XIAUT)*i_PXs)
X_I: f_XIAUT
X_S: 1-f_XIAUT
X_AUT: -1

LysisX_H:
Description: Lysis/death of heterotrophic organims
Type: Dynamic Process
Rate: b_H*X_H
Stoichiometry:
Variable: Stoichiometric Coefficient
X_I: f_XIOHO
X_S: 1-f_XIOHO
X_H: -1
S_NH4: i_NBM-(f_XIOHO*i_NXi)-((1-f_XIOHO)*i_NXs)
S_PO4: i_PBM-(f_XIOHO*i_PXi)-((1-f_XIOHO)*i_PXs)

LysisX_PAO:
Description: Lysis/death of X_PAO
Type: Dynamic Process
Rate: b_PAO*X_PAO
Stoichiometry:
Variable: Stoichiometric Coefficient
S_PO4: i_PBM-(f_XI_PAO*i_PXi)-((1-f_XI_PAO)*i_PXs)
X_I: f_XI_PAO
X_S: 1-f_XI_PAO
X_PAO: -1
S_NH4: i_NBM-(f_XI_PAO*i_NXi)-((1-f_XI_PAO)*i_NXs)

LysisX_PHA:
Description: Lysis of X_PHA
Type: Dynamic Process
Rate: b_PHA*X_PHA
Stoichiometry:
Variable: Stoichiometric Coefficient
S_A: 1
X_PHA: -1

LysisX_PP:
Description: Lysis of X_PP
Type: Dynamic Process
Rate: b_PP*X_PP
Stoichiometry:
Variable: Stoichiometric Coefficient
S_PO4: 1
X_PP: -1

StorageX_PHA:
Description: Sequestration of S_A / Storage of X_PHA
Type: Dynamic Process
Rate: q_PHA*(S_A/(K_PAO+S_A))*(X_PP/X_PAO)/(K_PP+(X_PP/X_PAO))*X_PAO
Stoichiometry:
Variable: Stoichiometric Coefficient
S_A: -1
S_PO4: Y_PO4
X_PP: -Y_PO4
X_PHA: 1

StorageX_PP:
Description: Storage of X_PP
Type: Dynamic Process
Rate: q_PP*(S_O2/(K_O2+S_O2))*(S_PO4/(K_P...
Stoichiometry:
Variable: Stoichiometric Coefficient
S_O2: -Y_PHA
S.PO4: -1
X_PP: 1
X_PHA: -Y_PHA

****************************************************

Compartment:

AerobicR:
Description: Mixed Reactor Compartment
Type: 0
Compartment Index: 0
Active Variables:

b_AUT, b_AUT20, b_H, b_H20, b_PAO,
b_PAO20, b_PHA, b_PHA20, b_PP, b_PP
20, Calcium, CODf, CODf_m, CODf_m1,
CODf_m2, CODf_m3, CODf_m4, CODf_m5,
CODf_m6, CODT, CODT_m, CODT_m1, CODT_m2,
CODT_m3, CODT_m4, CODT_m5,
CODT_m6, eta_fe, eta_NO3, eta_NO3d,
f_ac, f_ac1a, f_ac1b, f_ac2a, f_ac2b,
f_ac3a, f_ac3b, f_ac4a, f_ac4b,
f_ac5a, f_ac5b, f_ac6a, f_ac6b, f_avoH2O,
f_avPAO, f bs, f bs1a, f bs1b,
 f bs2a, f bs2b, f bs3a, f bs3b,
 f bs4a, f bs4b, f bs5a, f bs5b, f_b
s6a, f bs6b, f cv, f na, f SI, f_up,
 f_upa1, f_up1b, f_up2a, f_up2b, f
_up3a, f_up3b, f_up4a, f_up4b, f_up
5a, f_up5b, f_up6a, f_up6b, f_us,
 f_us1a, f_us1b, f_us2a, f_us2b, f_us
3a, f_us3b, f_us4a, f_us4b, f_us5a,
 f_us5b, f_us6a, f_us6b, f_vTG, f_v
TH, f_xiaUT, f_xioH2O, f_xioPAO, I S
AeroM, I S_AeroM1, I S_AeroM2, I S
AeroM3, IS_AeroM4, I S_AeroM5, I S
_AeroM6, IS_AanaerM, I S_AanaerM1, I
S_AanaerM2, I S_AanaerM3, I S_AanaerM
4, I S_AanaerM5, I S_AanaerM6, I S_A
oxM, I S_AnoxM1, I S_AnoxM2, I S_A
oxM3, I S_AnoxM4, I S_AnoxM5, I S_A
noxM6, I S_fiH2O, I S_fiPAO, I S_fi
PAOdB, I S_xioi, I S_xioi1, I S_xioi
1a, I S_xioi1b, I S_xioi2a, I S_xioi
2b, I S_xioi3a, I S_xioi3b, I S_xioi4a,
 I S_xioi4b, I S_xioi5a, I S_xioi5b,
 I S_xioi6a, I S_xioi6b, I S_xoi, i_NBM, i_NSf
Active Processes:
Aeration, AerobicHydrolysis, Aerogr
growthA, AerogrowthF, AerogrowthX
_PAQ, AnaerobicHydrolysis, AnoxicGr
rowthA, AnoxicGrowthF, AnoxicHydro
lysis, Fermentation, GrowthX_AUT,
LysisX_AUT, LysisX_H, LysisX_PAQ,
LysisX_PHA, LysisX_PP, StorageX_PHA,
StorageX_PP

Initial Conditions:
Variable(Zone) : Initial Condition
S_I(Bulk Volume) : \( S_{Iini} \)
S_NH4(Bulk Volume) : \( S_{NH4ini} \)
X_AUT(Bulk Volume) : \( X_{AUTini} \)
X_H(Bulk Volume) : \( X_{Hini} \)
X_I(Bulk Volume) : \( X_{Iini} \)
X_PAQ(Bulk Volume) : \( X_{PAQini} \)
X_S(Bulk Volume) : \( X_{Sini} \)
S_A(Bulk Volume) : \( S_{Aini} \)
S_NO3(Bulk Volume) : \( S_{NO3ini} \)
S_PO4(Bulk Volume) : \( S_{PO4ini} \)
X_PHA(Bulk Volume) : \( X_{PHAini} \)
X_PP(Bulk Volume) : \( X_{PPini} \)
S_F(Bulk Volume) : \( S_{Fini} \)
S_N2(Bulk Volume) : \( S_{N2ini} \)
ISS_Xi(10i(Bulk Volume) : \( ISS_{Xi(10ini} \)

Inflow: 0
Loadings:
Volume: 35

Accuracies:
Rel. Acc. Q: 0.001
Abs. Acc. Q: 0.001
Rel. Acc. V: 0.001
Abs. Acc. V: 0.001

AnoxicR:

Description: Mixed Reactor Compartment
Type: 0
Compartment Index:
Active Variables:
\( b_{AUT}, b_{AUT20}, b_{H2O}, b_{PAO}, b_{PAO20}, b_{PHA}, b_{PHA20}, b_{PP}, b_{PP}
20, Calcnm, CODf, CODf_m, CODf_m1,
CODf_m2, CODf_m3, CODf_m4, CODf_m5
, CODf_m6, CODf, CODf_m, CODf_m1, C
ODf_m2, CODf_m3, CODf_m4, CODf_m5,
CODf_m6, \( eta_fe, eta_NO3, eta_NO3d,
\), f_ac, f_ac1a, f_ac1b, f_ac2a, f_ac
2b, f_ac3a, f_ac3b, f_ac4a, f_ac4b,
f_ac5a, f_ac5b, f_ac6a, f_ac6b, f_avOHO,
f_avPAO, f_bs, f_bsa1, f_bsa2, f_bsa3,
b, f_bs4a, f_bs4b, f_bs5a, f_bs5b, f_bs
6a, f_bs6b, f_cv, f_na, f_S1, f_up,
, f_up1a, f_up1b, f_up2a, f_up2b, f_up
3a, f_up3b, f_up4a, f_up4b, f_up5a,
f_up5b, f_up6a, f_up6b, f_us, f_us
1a, f_us1b, f_us2a, f_us2b, f_us
Active Processes:

Initial Conditions:
Variable (Zone) : Initial Condition
S_I(Bulk Volume) : S Ini
S_NH4(Bulk Volume) : S NH4 ini
X_AUT(Bulk Volume) : X AUT ini
X_H(Bulk Volume) : X H ini
X_I(Bulk Volume) : X Ini
X_PAO(Bulk Volume) : X PAO ini
X_S(Bulk Volume) : X S ini
S_A(Bulk Volume) : S A ini
S_NO3(Bulk Volume) : S NO3 ini
S_PO4(Bulk Volume) : S PO4 ini
X_PH(A(Bulk Volume) : X PHA ini
X_PP(Bulk Volume) : X PP ini
S_F(Bulk Volume) : S Fin
S_N2(Bulk Volume) : S N2 ini
ISS_Xiol(Bulk Volume) : ISS_Xio ini

Inflow: Q_i

Loadings:
Variable : Loading
S_A : Q_i*S_A ini
S_F : Q_i*S_F ini
S_I : Q_i*S_Ini
S_N2 : Q_i*S_N2 ini
S_NH4 : Q_i*S_NH4 ini
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Active Processes:


Initial Conditions:

Variable(Zone): Initial Condition

S_I(Bulk Volume): S_Iini
S_NH4(Bulk Volume): S_NH4ini
X_AUT(Bulk Volume): X_AUTini
X_H(Bulk Volume): X_Hini
X_I(Bulk Volume): X_Iini
X_PA0(Bulk Volume): X_PA0ini
X_S(Bulk Volume): X_Sini
S_A(Bulk Volume): S_Aini
S_NO3(Bulk Volume): S_NO3ini
S_PO4(Bulk Volume): S_PO4ini
X_PHA(Bulk Volume): X_PHAini
X_PP(Bulk Volume): X_PPini
S_F(Bulk Volume): S_Fini
S_N2(Bulk Volume): S_N2ini
ISS_Xioi(Bulk Volume): ISS_Xioini

Inflow: 0
Loadings: Volume: 21
Accuracies:

Rel. Acc. Q: 0.001
Abs. Acc. Q: 0.001
Rel. Acc. V: 0.001
Abs. Acc. V: 0.001

Effluent Description:

Type: Mixed Reactor Compartment
Compart Index: 0
Active Variables:

b_AUT, b_AUT20, b_H, b_H20, b_PA0, b_PA20, b_PHA, b_PA20, b_PP, b_PP20, Calcium, CODf, CODf_m, CODf_m1, CODf_m2, CODf_m3, CODf_m4, CODf_m5, CODf_m6, CODt, CODt_m, CODt_m1, CODt_m2, CODt_m3, CODt_m4, CODt_m5, CODt_m6, eta_fe, eta_NO3, eta_NO3d, f_ac, f_ac1a, f_ac1b, f_ac2a, f_ac2b, f_ac3a, f_ac3b, f_ac4a, f_ac4b, f_ac5a, f_ac5b, f_ac6a, f_ac6b, f_avOH0, f_avPAO, f_bs, f_bsl, f_bsl1, f_bsl2, f_bsl2b, f_bsl3a, f_bsl3b, f_bsl4a, f_bsl4b, f_bsl5a, f_bsl5b, f_bsl6a, f_bsl6b, f_cv, f_na, f_SI, f_up1a, f_up1b, f_up2a, f_up2b, f_up3a, f_up3b, f_up4a, f_up4b, f_up5a, f_up5b, f_up6a, f_up6b, f_us, f_us1a, f_us1b, f_us2a, f_us2b, f_us3a, f_us3b, f_us4a, f_us4b, f_us5a,
Active Processes:
Initial Conditions:
Inflow: 0
Loadings: 0.001
Accuracies:
Rel. Acc. Q: 0.001
Abs. Acc. Q: 0.001
Rel. Acc. V: 0.001
Abs. Acc. V: 0.001

Separator1:
Description: Mixed Reactor Compartment
Type: 0
Compartment Index:
Active Variables:

<table>
<thead>
<tr>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>b_AUT, b_AUT20, b_H, b_H20, b_PAQ, b_PAQ20, b_PHA, b_PHA20, b_PP, b_PP20, Calcurn, CODF, CODF_m, CODF_m1, CODF_m2, CODF_m3, CODF_m4, CODF_m5, CODF_m6, CODT, CODT_m, CODT_m1, CODT_m2, CODT_m3, CODT_m4, CODT_m5, CODT_m6, eta_fe, eta_NO3, eta_NO3d, f_ac, f_ac1a, f_ac1b, f_ac2a, f_ac2b, f_ac3a, f_ac3b, f_ac4a, f_ac4b, f_ac5a, f_ac5b, f_ac6a, f_ac6b, f_avOH0, f_avPAQ, f_bs, f_bsl, f_bsl1, b_b, b_bs2a, b_bs2b, b_bs3a, f_bsb3b, f_bsb4a, f_bsb5a, f_bsb5b, f_bsb6a, f_bsb6b, f_cv, f_na, f_S1, f_up2, f_up2b, f_up2a, f_up3a, f_up3b, f_up4a, f_up4b, f_up5a, f_up5b, f_us1a, f_us2b, f_us2a, f_us3a, f_us3b, f_us4a, f_us4b, f_us5a, f_us5b, f_us6a, f_us6b, f_vTG, f_v</td>
</tr>
</tbody>
</table>
Active Processes:
Initial Conditions:
Variable (Zone): Initial Condition
S_I (Bulk Volume): S_Init
S_NH4 (Bulk Volume): S_NH4Init
X_AUT (Bulk Volume): X_AUTinit
X_H (Bulk Volume): X_HInit
X_I (Bulk Volume): X_Init
X_PAO (Bulk Volume): X_PAOinit
X_S (Bulk Volume): X_SInit
S_A (Bulk Volume): S_AInit
S_NO3 (Bulk Volume): S_NO3init
S_PO4 (Bulk Volume): S_PO4init
X_PHA (Bulk Volume): X_PHAinit
X_PP (Bulk Volume): X_PPinit
S_F (Bulk Volume): S_Finit
S_N2 (Bulk Volume): S_N2init

Inflow:
Loadings:
Volume: 0.0001
Accuracies:
Rel. Acc. Q: 0.001
Abs. Acc. Q: 0.001
Rel. Acc. V: 0.001
Abs. Acc. V: 0.001

Separator2:
Description: Mixed Reactor Compartment
Type: b_AUT, b_AUT20, b_H, b_H2O, b_PAO, b_PAO20, b_PHA, b_PHA20, b_PP, b_PP20, Calcium, CODf, CODf_m, CODf_m1, CODf_m2, CODf_m3, CODf_m4, CODf_m5, CODf_m6, CODt, CODt_m, CODt_m1, CODt_m2, CODt_m3, CODt_m4, CODt_m5,
nila, X_AUTini1b, X_AUTini2a, X_AUTini2b, X_AUTini3a, X_AUTini3b, X_AUTini4a, X_AUTini4b, X_AUTini5a, X_AUTini5b, X_AUTini6a, X_AUTini6b, X_H, X_Hini, X_Hini1, X_Hini1a, X_Hini1b, X_Hini12a, X_Hini12b, X_Hini13a, X_Hini13b, X_Hini14a, X_Hini14b, X_Hini15a, X_Hini15b, X_Hini16a, X_Hini16b, X_I, X_Ini, X_Ini1, X_Ini1a, X_Ini1b, X_Ini12a, X_Ini12b, X_Ini13a, X_Ini13b, X_Ini14a, X_Ini14b, X_Ini15a, X_Ini15b, X_Ini16a, X_Ini16b, X_PAO, X_PAOni, X_PAOnila, X_PAOni1b, X_PAOni12a, X_PAOni12b, X_PAOni3a, X_PAOni3b, X_PAOni4a, X_PAOni4b, X_PAOni5a, X_PAOni5b, X_PAOni6a, X_PAOni6b, X_PHA, X_PHAini, X_PHAIni1, X_PHAIni1a, X_PHAIni1b, X_PHAIni12a, X_PHAIni12b, X_PHAIni13a, X_PHAIni13b, X_PHAIni14a, X_PHAIni14b, X_PHAIni15a, X_PHAIni15b, X_PHAIni16a, X_PHAIni16b, X_PP, X_PPin, X_PPini, X_PPini1, X_PPini1a, X_PPini1b, X_PPini2a, X_PPini2b, X_PPini3a, X_PPini3b, X_PPini4a, X_PPini4b, X_PPini5a, X_PPini5b, X_PPini6a, X_PPini6b, X_S, X_Sini, X_Sini, X_taero, X_taero1a, X_taero1b, X_taero2a, X_taero2b, X_taero3a, X_taero3b, X_taero4a, X_taero4b, X_taero5a, X_taero5b, X_taero6a, X_taero6b, X_tanaer, X_tanaer1a, X_tanaer1b, X_tanaer2a, X_tanaer2b, X_tanaer3a, X_tanaer3b, X_tanaer4a, X_tanaer4b, X_tanaer5a, X_tanaer5b, X_tanaer6a, X_tanaer6b, X_tanox, X_tanox1a, X_tanox1b, X_tanox2a, X_tanox2b, X_tanox3a, X_tanox3b, X_tanox4a, X_tanox4b, X_tanox5a, X_tanox5b, X_tanox6a, X_tanox6b, Y_AUT, Y_H, Y_PAO, Y_PHA, Y_PO

Active Processes:
Initial Conditions:
Variable(Zone) : Initial Condition
S_I (Bulk Volume) : S_Ini
S_NH4 (Bulk Volume) : S_NH4ini1a
X_AUT (Bulk Volume) : X_AUTini1a
X_H (Bulk Volume) : X_Hini1a
X_I (Bulk Volume) : X_Ini1a
X_PAO (Bulk Volume) : X_PAOnila
X_S (Bulk Volume) : X_Sini
S_A (Bulk Volume) : S_Aini
S_NO3 (Bulk Volume) : S_NO3ini
S_PO4 (Bulk Volume) : S_PO4ini1a
X_PHA (Bulk Volume) : X_PHAini1a
X_PP (Bulk Volume) : X_PPinila
S_F (Bulk Volume) : S_Fini
S_N2 (Bulk Volume) : S_N2ini

Inflow: 0
Loadings: 0.0001
Volume: 0.0001
Accuracies:
Waste: Mixed Reactor Compartment
Type: 0
Compartment Index:
Active Variables:
  b_AUT, b_AUT20, b_H, b_H2O, b_PA0,
b_PA020, b_PHA, b_PH2A0, b_PP, b_PP
  O2, Calcnum, CODf, CODf_m, CODf_m1,
CODf_m2, CODf_m3, CODf_m4, CODf_m5,
CODf_m6, CODf_e, CODf_m, CODf_m1, C
ODT_m2, CODT_m3, CODT_m4, CODT_m5,
CODT_m6, eta_fe, eta_NO3, eta_NO3d,
  f_ac, f_ac1a, f_ac1b, f_ac2a, f_ac
  2b, f_ac3a, f_ac3b, f_ac4a, f_ac4b,
  f_ac5a, f_ac5b, f_ac6a, f_ac6b, f
  avOHO, f_avPAO, f_bs, f_bs1a, f_bs1
  b, f_bs2a, f_bs2b, f_bs3a, f_bs3b,
  f_bs4a, f_bs4b, f_bs5a, f_bs5b, f_b
  s6a, f_bs6b, f_cv, f_na, f_SI, f_up
, f_up1a, f_up1b, f_up2a, f_up2b, f
  _up3a, f_up3b, f_up4a, f_up4b, f_up
5a, f_up5b, f_up6a, f_up6b, f_us, f
  _us1a, f_us1b, f_us2a, f_us2b, f_us
3a, f_us3b, f_us4a, f_us4b, f_us5a,
  f_us5b, f_us6a, f_us6b, f_vTG, f_v
TH, f_XiAUT, f_XiOHO, f_XiPAO, ISS
_AeroM, ISS_AeroM1, ISS_AeroM2, ISS
_AeroM3, ISS_AeroM4, ISS_AeroM5, ISS
_AeroM6, ISS_AnaerM, ISS_AnaerM1, I
SS_AnaerM2, ISS_AnaerM3, ISS_AnaerM
4, ISS_AnaerM5, ISS_AnaerM6, ISS_An
oxM, ISS_AnoxM1, ISS_AnoxM2, ISS_An
oxM3, ISS_AnoxM4, ISS_AnoxM5, ISS_A
noxM6, ISS_fiOHO, ISS_fiPAO, ISS_fi
PAOBM, ISS_Xi1, ISS_Xi0in, ISS_Xio
in1a, ISS_Xi0in1b, ISS_Xi0in2a, ISS
_Xi0in2b, ISS_Xi0in3a, ISS_Xi0in3b,
ISS_Xi0in4a, ISS_Xi0in4b, ISS_Xio
in5a, ISS_Xi0in5b, ISS_Xi0in6a, ISS
_Xi0in6b, ISS_Xi0ini, ISS_Xi0in1a,
ISS_Xi0inib, ISS_Xi0ini2a, ISS_Xio
ini2b, ISS_Xi0ini3a, ISS_Xi0ini3b,
ISS_Xi0ini4a, ISS_Xi0ini4b, ISS_Xio
ini5a, ISS_Xi0ini5b, ISS_Xi0ini6a,
ISS_Xi0ini6b, ISS_Xoi, i_NBM, i_NSf
, i_NSI, i_NX1, i_NXs, i_PBM, i_PSf
, i_PSi, i_IX1, i_IXs, i_TSSBM, i_T
SSX1, i_TSSXs, K_ALK, K_ALKAUT, K_A
LKPRE, K_AOH0, K_APA0, K_F, K_fe, K
_h, K_h2O, K_IPP, K_La, K_Max, K_NH
4AUT, K_NH4OHO, K_NH4PA0, K_NO3, K
O2, K_P, K_PHA, K_PP, k_PRE, k_PS,
k_RED, K_X, K_X20, mue_AUT, mue_AUT
20, mue_H, mue_H2O, mue_PA0, mue_PA
O20, mVSS, N_t1, N_t1a, N_t1b, N_t1
2a, N_t12b, N_t13a, N_t13b, N_t14
a, N_t14b, N_t15a, N_t15b, N_t16a,
N_t16b, OUR_AUT, OUR_c, OUR_HSA, OU
Active Processes:
Initial Conditions:
Inflow: 0
Loadings:
Volume: 0.001
Accuracies:
Rel. Acc. Q: 0.001
Abs. Acc. Q: 0.001
Rel. Acc. V: 0.001
Abs. Acc. V: 0.001

Links

linkR1R2: Type: Advective Link
Link Index: 0
Compartment In: AnoxicR
Connection In: Outflow
Compartment Out: AnoxicR
Connection Out: Inflow
Bifurcations:

linkR2R3: Description: r-recycle flow to anaerobic
Type: Advective Link
Link Index: 0
Compartment In: AnoxicR
Connection In: Outflow
Compartment Out: AerobicR
Connection Out: Inflow
Bifurcations:
  Q_r:
    Description: AnoxicR
    Compartment Out: Inflow
    Water Flow: Q_r

linkR3S1: Type: Advective Link
Link Index: 0
Compartment In: AerobicR
Connection In: Outflow
Compartment Out: Separator1
Connection Out: Inflow
Bifurcations:
  Q_w:
    Description: Waste flow
    Compartment Out: Waste
    Connection Out: Inflow
    Water Flow: Q_w

linkS1S2: Type: Advective Link
Link Index: 0
Compartment In: Separator1
Connection In: Outflow
Compartment Out: Separator2
Connection Out: Inflow
Bifurcations:
  Q_as:
    Description: AnoxicR
    Compartment Out: Inflow
    Water Flow: Q_as

linkS2E: Type: Advective Link
Link Index: 0
Compartment In: Separator2
Connection In: Outflow
Compartment Out: Effluent
Connection Out: Inflow
Bifurcations:
  Q_rec:
    Description:
    Compartment Out: AerobicR
    Connection Out: Inflow
    Water Flow: Q_rec
    Mass Loadings:
    Variable : Loading
    S_A : Q_rec*S_A
    S_F : Q_rec*S_F
    S_I : Q_rec*S_I
    S_N2 : Q_rec*S_N2
    S_NH4 : Q_rec*S_NH4
    S_NO3 : Q_rec*S_NO3
    S_O2 : Q_rec*S_O2
    S_PO4 : Q_rec*S_PO4
    X_AUT : Q*X_AUT
    X_H : Q*X_H
    X_I : Q*X_I
    X_PA0 : Q*X_PA0
    X_THA : Q*X_THA
    X_PP : Q*X_PP
    X_S : Q*X_S
    ISS_Xioi : Q*ISS_Xioi

*******************************************************************************************************

Definitions of Calculations
*******************************************************************************************************
calc01:
  Description:
  Calculation Number: 1
  Initial Time: 0
  Initial State: given, made consistent
  Step Size: 0.001
  Num. Steps: 20000
  Status: active for simulation
  inactive for sensitivity analysis

calc02:
  Description:
  Calculation Number: 2
  Initial Time: 0
  Initial State: given, made consistent
  Step Size: 0.001
  Num. Steps: 20000
  Status: active for simulation
  inactive for sensitivity analysis

calc03:
  Description:
  Calculation Number: 3
  Initial Time: 0
  Initial State: given, made consistent
  Step Size: 0.001
<table>
<thead>
<tr>
<th>Calculation</th>
<th>Description</th>
<th>Calculation Number</th>
<th>Initial Time</th>
<th>Initial State</th>
<th>Step Size</th>
<th>Num. Steps</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>calc04</td>
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<td>4</td>
<td>0</td>
<td>given, made consistent</td>
<td>0.001</td>
<td>20000</td>
<td>active for simulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>inactive for sensitivity analysis</td>
</tr>
<tr>
<td>calc05</td>
<td></td>
<td>5</td>
<td>0</td>
<td>given, made consistent</td>
<td>0.001</td>
<td>20000</td>
<td>active for simulation</td>
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<td></td>
<td></td>
<td></td>
<td>inactive for sensitivity analysis</td>
</tr>
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<td>calc06</td>
<td></td>
<td>6</td>
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<td>given, made consistent</td>
<td>0.001</td>
<td>20000</td>
<td>active for simulation</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>inactive for sensitivity analysis</td>
</tr>
<tr>
<td>calc11</td>
<td></td>
<td>11</td>
<td>0</td>
<td>given, made consistent</td>
<td>0.001</td>
<td>20000</td>
<td>active for simulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>inactive for sensitivity analysis</td>
</tr>
<tr>
<td>calc12</td>
<td></td>
<td>12</td>
<td>0</td>
<td>given, made consistent</td>
<td>0.001</td>
<td>20000</td>
<td>active for simulation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>inactive for sensitivity analysis</td>
</tr>
<tr>
<td>calc13</td>
<td></td>
<td>13</td>
<td>0</td>
<td>given, made consistent</td>
<td>0.001</td>
<td>20000</td>
<td>active for simulation</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>inactive for sensitivity analysis</td>
</tr>
<tr>
<td>calc14</td>
<td></td>
<td>14</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 20000
Status: active for simulation
in active for sensitivity analysis

---
calc15: Description:
Calculation Number: 15
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 20000
Status: active for simulation
inactive for sensitivity analysis

---
calc16: Description:
Calculation Number: 16
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 20000
Status: active for simulation
inactive for sensitivity analysis

---
Plot Definitions

ANO_01: Description: Autotrophic nitrifying organisms
Abscissa: Time
Title: Autotrophic nitrifying organisms
Abscissa Label: Operation time (d)
Ordinate Label: ANO (mgCOD/1)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: X_AUT [1, Anoxic, Bulk Volume, 0]
Value: X_AUT [1, Anoxic, Bulk Volume, 0]
Value: X_AUT [1, Aerobic, Bulk Volume, 0]
Value: X_AUT [1, Aerobic, Bulk Volume, 0]
Value: X_AUT [1, Aerobic, Bulk Volume, 0]
Value: X_AUT [1, Aerobic, Bulk Volume, 0]

CODf_01: Description: Filtered COD
Abscissa: Time
Title: Filtered COD
Abscissa Label: Operation time (d)
Ordinate Label: Filtered COD (mgCOD/1)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_I [1, Aerobic, Bulk Volume, 0]
Value: S_I [1, Aerobic, Bulk Volume, 0]
Value: S_I [1, Aerobic, Bulk Volume, 0]
Value: S_I [1, Aerobic, Bulk Volume, 0]
Value: CODf_m [1, Aerobic, Bulk Volume, 0]

CODt_01: Description: Total COD
Abscissa: Time
Title: Total COD
Abscissa Label: Operation time (d)
Ordinate Label: Total COD (mgCOD/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: CO2t [1, AnaerobicR, Bulk Volume, 0]
Value: CO2t [1, AerobicR, Bulk Volume, 0]
Value: CO2t [11, AnaerobicR, Bulk Volume, 0]
Value: CO2t [11, AerobicR, Bulk Volume, 0]
Value: CO2t_m [1, AerobicR, Bulk Volume, 0]

DO:
Description: Dissolved oxygen concentration
Abscissa: Time
Title: Dissolved oxygen concentration
Abscissa Label: Operation time (d)
Ordinate Label: DO (mgO/1)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_O2 [1, AerobicR, Bulk Volume, 0]
Value: S_O2 [2, AerobicR, Bulk Volume, 0]
Value: S_O2 [3, AerobicR, Bulk Volume, 0]
Value: S_O2 [4, AerobicR, Bulk Volume, 0]

ISS_Xoi01:
Description: Total ISS in the reactor
Abscissa: Time
Title: Total ISS in the reactor
Abscissa Label: Operation time (d)
Ordinate Label: ISS (mgISS/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: ISS_Xoi [1, AnaerobicR, Bulk Volume, 0]
Value: ISS_Xoi [1, AnoxicR, Bulk Volume, 0]
Value: ISS_Xoi [1, AerobicR, Bulk Volume, 0]
Value: ISS_Xoi [11, AnaerobicR, Bulk Volume, 0]
Value: ISS_Xoi [11, AnoxicR, Bulk Volume, 0]
Value: ISS_Xoi [11, AerobicR, Bulk Volume, 0]

mVSS_01:
Description: Model VSS (in COD/l)
Abscissa: Time
Title: Model VSS (in COD/l)
Abscissa Label: Operation time (d)
Ordinate Label: VSS (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: mVSS [1, AnaerobicR, Bulk Volume, 0]
Value: mVSS [1, AnoxicR, Bulk Volume, 0]
Value: mVSS [1, AerobicR, Bulk Volume, 0]
Value: mVSS [11, AnaerobicR, Bulk Volume, 0]
Value: mVSS [11, AnoxicR, Bulk Volume, 0]
Value: mVSS [11, AerobicR, Bulk Volume, 0]
Value: VSS_measAnaer1 [1, AnaerobicR, Bulk Volume, 0]
Value: VSS_measAnox1 [1, AnoxicR, Bulk Volume, 0]
Value: VSS_measAero1 [1, AerobicR, Bulk Volume, 0]

mVSS_02:
Description: Model VSS (in COD/l)
Abscissa: Time
Title: Model VSS (in COD/l)
Abscissa Label: Operation time (d)
Ordinate Label: VSS (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value : mVSS [2, AnaerobicR, Bulk Volume, 0]
Value : mVSS [2, AnoxicR, Bulk Volume, 0]
Value : mVSS [2, AerobicR, Bulk Volume, 0]
Value : mVSS [12, AnaerobicR, Bulk Volume, 0]
Value : mVSS [12, AnoxicR, Bulk Volume, 0]
Value : mVSS [12, AerobicR, Bulk Volume, 0]
Value : VSS_measAnaer2 [2, AnaerobicR, Bulk Volume, 0]
Value : VSS_measAnaer2 [2, AnoxicR, Bulk Volume, 0]
Value : VSS_measAnaer2 [2, AerobicR, Bulk Volume, 0]

----------

mVSS_03:
Description: Model VSS (in COD/l)
Abscissa: Time
Title: Model VSS (in COD/l)
Abscissa Label: Operation time (d)
Ordinate Label: VSS (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value : mVSS [3, AnaerobicR, Bulk Volume, 0]
Value : mVSS [3, AnoxicR, Bulk Volume, 0]
Value : mVSS [3, AerobicR, Bulk Volume, 0]
Value : mVSS [13, AnaerobicR, Bulk Volume, 0]
Value : mVSS [13, AnoxicR, Bulk Volume, 0]
Value : mVSS [13, AerobicR, Bulk Volume, 0]
Value : VSS_measAnaer3 [3, AnaerobicR, Bulk Volume, 0]
Value : VSS_measAnaer3 [3, AnoxicR, Bulk Volume, 0]
Value : VSS_measAnaer3 [3, AerobicR, Bulk Volume, 0]

----------

mVSS_04:
Description: Model VSS (in COD/l)
Abscissa: Time
Title: Model VSS (in COD/l)
Abscissa Label: Operation time (d)
Ordinate Label: VSS (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value : mVSS [4, AnaerobicR, Bulk Volume, 0]
Value : mVSS [4, AnoxicR, Bulk Volume, 0]
Value : mVSS [4, AerobicR, Bulk Volume, 0]
Value : mVSS [14, AnaerobicR, Bulk Volume, 0]
Value : mVSS [14, AnoxicR, Bulk Volume, 0]
Value : mVSS [14, AerobicR, Bulk Volume, 0]
Value : VSS_measAnaer4 [4, AnaerobicR, Bulk Volume, 0]
Value : VSS_measAnaer4 [4, AnoxicR, Bulk Volume, 0]
Value : VSS_measAnaer4 [4, AerobicR, Bulk Volume, 0]

----------

mVSS_05:
Description: Model VSS (in COD/l)
Abscissa: Time
Title: Model VSS (in COD/l)
Abscissa Label: Operation time (d)
Ordinate Label: VSS (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value : mVSS [5, AnaerobicR, Bulk Volume, 0]
Value : mVSS [5, AnoxicR, Bulk Volume, 0]
Value : mVSS [5, AerobicR, Bulk Volume, 0]
Value : mVSS [15, AnaerobicR, Bulk Volume, 0]
Value : mVSS [15, AnoxicR, Bulk Volume, 0]
Value : mVSS [15, AerobicR, Bulk Volume, 0]
Value : VSS_measAnaer5 [5, AnaerobicR, Bulk Volume, 0]
Value : VSS_measAnaer5 [5, AnoxicR, Bulk Volume, 0]
Value : VSS_measAnaer5 [5, AerobicR, Bulk Volume, 0]
mVSS_06:
Description: Model VSS (in COD/l)
Abscissa: Time
Title: Model VSS (in COD/l)
Abscissa Label: Operation time (d)
Ordinate Label: VSS (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: mVSS [6, AnaerobicR, Bulk Volume, 0]
Value: mVSS [6, AnoxicR, Bulk Volume, 0]
Value: mVSS [6, AerobicR, Bulk Volume, 0]
Value: mVSS [16, AnaerobicR, Bulk Volume, 0]
Value: mVSS [16, AnoxicR, Bulk Volume, 0]
Value: mVSS [16, AerobicR, Bulk Volume, 0]
Value: VSS_measAneaR6 [6, AnaerobicR, Bulk Volume, 0]
Value: VSS_measAnoxR6 [6, AnoxicR, Bulk Volume, 0]
Value: VSS_measAeroR6 [6, AerobicR, Bulk Volume, 0]

OHO_01:
Description: Ordinary heterotrophic organisms
Abscissa: Time
Title: Ordinary heterotrophic organisms
Abscissa Label: Operation time (d)
Ordinate Label: OHO (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: X_H [1, AnaerobicR, Bulk Volume, 0]
Value: X_H [1, AnoxicR, Bulk Volume, 0]
Value: X_H [1, AerobicR, Bulk Volume, 0]
Value: X_H [11, AnaerobicR, Bulk Volume, 0]
Value: X_H [11, AnoxicR, Bulk Volume, 0]
Value: X_H [11, AerobicR, Bulk Volume, 0]

OUR_01:
Description: OUR
Abscissa: Time
Title: OUR
Abscissa Label: Operation time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_t [1, AerobicR, Bulk Volume, 0]
Value: OUR_c [1, AerobicR, Bulk Volume, 0]
Value: OUR_t [11, AerobicR, Bulk Volume, 0]
Value: OUR_c [11, AerobicR, Bulk Volume, 0]
Value: OUR_t_meas [1, AerobicR, Bulk Volume, 0]

PAO_01:
Description: Phosphorus accumulating organisms
Abscissa: Time
Title: Phosphorus accumulating organisms
Abscissa Label: Operation time (d)
Ordinate Label: PAO (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: X_PAO [1, AnaerobicR, Bulk Volume, 0]
Value: X_PAO [1, AnoxicR, Bulk Volume, 0]
Value: X_PAO [1, AerobicR, Bulk Volume, 0]
Value: X_PAO [11, AnaerobicR, Bulk Volume, 0]
Value: X_PAO [11, AnoxicR, Bulk Volume, 0]
Value: X_PAO [11, AerobicR, Bulk Volume, 0]

PHA_01:
Description: PHA storage
Abscissa: Time
Title: PHA storage
Abscissa Label: Operation time (d)
Ordinate Label: PHA (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: X_PHA [1,AneerobicR, Bulk Volume, 0]
Value: X_PHA [1, AnoxicR, Bulk Volume, 0]
Value: X_PHA [1, AerobicR, Bulk Volume, 0]
Value: X_PHA [11, AneerobicR, Bulk Volume, 0]
Value: X_PHA [11, AnoxicR, Bulk Volume, 0]
Value: X_PHA [11, AerobicR, Bulk Volume, 0]

PP_01:
Description: Polyphosphate
Abscissa: Time
Title: Polyphosphate
Abscissa Label: Operation time (d)
Ordinate Label: PP (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: X_PP [1, AneerobicR, Bulk Volume, 0]
Value: X_PP [1, AnoxicR, Bulk Volume, 0]
Value: X_PP [1, AerobicR, Bulk Volume, 0]
Value: X_PP [11, AneerobicR, Bulk Volume, 0]
Value: X_PP [11, AnoxicR, Bulk Volume, 0]
Value: X_PP [11, AerobicR, Bulk Volume, 0]

Q_w:
Description: Waste sludge
Abscissa: Time
Title: Waste sludge
Abscissa Label: Operation time (d)
Ordinate Label: Qw (1/d)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: Q_w [1, AerobicR, Bulk Volume, 0]
Value: Q_w [11, AerobicR, Bulk Volume, 0]
Value: Q_w [11, AerobicR, Bulk Volume, 0]

S_A_01:
Description: Acetate
Abscissa: Time
Title: Acetate
Abscissa Label: Operation time (d)
Ordinate Label: Acetate (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_A [1, AneerobicR, Bulk Volume, 0]
Value: S_A [1, AnoxicR, Bulk Volume, 0]
Value: S_A [1, AerobicR, Bulk Volume, 0]
Value: S_A [11, AneerobicR, Bulk Volume, 0]
Value: S_A [11, AnoxicR, Bulk Volume, 0]
Value: S_A [11, AerobicR, Bulk Volume, 0]

S_F_01:
Description: Fermentable, readily biodegradable organic substrate
Abscissa: Time
Title: Fermentable, readily biodegradable organic substrate
Abscissa Label: Operation time (d)
Ordinate Label: RBCOD (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_F [1, AneerobicR, Bulk Volume, 0]
Value: S_F [1, AnoxicR, Bulk Volume, 0]
<table>
<thead>
<tr>
<th>Description</th>
<th>Abscissa Label</th>
<th>Operation time (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_N2_Anaer</td>
<td>Time</td>
<td>S_N2 (mgN/L)</td>
</tr>
<tr>
<td>S_N2_Annox</td>
<td>Time</td>
<td>S_N2 (mgN/L)</td>
</tr>
<tr>
<td>S_NH4_01</td>
<td>S_NH4 meas</td>
<td>FSA (mgN/L)</td>
</tr>
<tr>
<td>S_NO3_01</td>
<td>Time</td>
<td>Nitraten (mgN/L)</td>
</tr>
<tr>
<td>S_PO4_01</td>
<td>Time</td>
<td>Orthophosphate</td>
</tr>
</tbody>
</table>

Value : S_F [1,AerobicR,Bulk Volume,0]
Value : S_F [11,AneorobicR,Bulk Volume,0]
Value : S_F [11,AnoxicR,Bulk Volume,0]
Value : S_F [11,AerobicR,Bulk Volume,0]
Title: Orthophosphate
Abscissa Label: Operation time (d)
Ordinate Label: PO4-P (mgP/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [1, AnearobicR, Bulk Volume, 0]
Value: S_PO4 [1, AnoxicR, Bulk Volume, 0]
Value: S_PO4 [1, Effluent, Bulk Volume, 0]
Value: S_PO4 [11, AnearobicR, Bulk Volume, 0]
Value: S_PO4 [11, AnoxicR, Bulk Volume, 0]
Value: S_PO4 [11, Effluent, Bulk Volume, 0]
Value: S_PO4meas [1, AerobicR, Bulk Volume, 0]

S_PO4_02: Description: Orthophosphate
Abscissa: Time
Title: Orthophosphate
Abscissa Label: Operation time (d)
Ordinate Label: PO4-P (mgP/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [2, AnearobicR, Bulk Volume, 0]
Value: S_PO4 [2, AnoxicR, Bulk Volume, 0]
Value: S_PO4 [2, Effluent, Bulk Volume, 0]
Value: S_PO4 [12, AnearobicR, Bulk Volume, 0]
Value: S_PO4 [12, AnoxicR, Bulk Volume, 0]
Value: S_PO4 [12, Effluent, Bulk Volume, 0]
Value: S_PO4meas [2, AerobicR, Bulk Volume, 0]

S_PO4_03: Description: Orthophosphate
Abscissa: Time
Title: Orthophosphate
Abscissa Label: Operation time (d)
Ordinate Label: PO4-P (mgP/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [3, AnearobicR, Bulk Volume, 0]
Value: S_PO4 [3, AnoxicR, Bulk Volume, 0]
Value: S_PO4 [3, Effluent, Bulk Volume, 0]
Value: S_PO4 [13, AnearobicR, Bulk Volume, 0]
Value: S_PO4 [13, AnoxicR, Bulk Volume, 0]
Value: S_PO4 [13, Effluent, Bulk Volume, 0]
Value: S_PO4meas [3, AerobicR, Bulk Volume, 0]

S_PO4_04: Description: Orthophosphate
Abscissa: Time
Title: Orthophosphate
Abscissa Label: Operation time (d)
Ordinate Label: PO4-P (mgP/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [4, AnearobicR, Bulk Volume, 0]
Value: S_PO4 [4, AnoxicR, Bulk Volume, 0]
Value: S_PO4 [4, Effluent, Bulk Volume, 0]
Value: S_PO4 [14, AnearobicR, Bulk Volume, 0]
Value: S_PO4 [14, AnoxicR, Bulk Volume, 0]
Value: S_PO4 [14, Effluent, Bulk Volume, 0]
Value: S_PO4meas [4, AerobicR, Bulk Volume, 0]

S_PO4_05: Description: Orthophosphate
Abscissa: Time
Title: Orthophosphate
Abscissa Label: Operation time (d)
Ordinate Label: F04-P (mgP/1)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_P04 [5, AnoxicR, Bulk Volume, 0]
Value: S_P04 [5, AnoxicR, Bulk Volume, 0]
Value: S_P04 [5, Effluent, Bulk Volume, 0]
Value: S_P04 [15, AnoxicR, Bulk Volume, 0]
Value: S_P04 [15, AnoxicR, Bulk Volume, 0]
Value: S_P04 [15, Effluent, Bulk Volume, 0]
Value: S_P04meas [5, AerobicR, Bulk Volume, 0]

S_P04_06:
Description: Orthophosphate
Abscissa: Time
Title: Orthophosphate
Abscissa Label: Operation time (d)
Ordinate Label: F04-P (mgP/1)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_P04 [6, AnoxicR, Bulk Volume, 0]
Value: S_P04 [6, AnoxicR, Bulk Volume, 0]
Value: S_P04 [6, Effluent, Bulk Volume, 0]
Value: S_P04 [16, AnoxicR, Bulk Volume, 0]
Value: S_P04 [16, AnoxicR, Bulk Volume, 0]
Value: S_P04 [16, Effluent, Bulk Volume, 0]
Value: S_P04meas [6, AerobicR, Bulk Volume, 0]

TKN_01:
Description: TKN
Abscissa: Time
Title: TKN
Abscissa Label: Operation time (d)
Ordinate Label: TKN (mgN/1)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: TKN [1, AnoxicR, Bulk Volume, 0]
Value: TKN [1, AnoxicR, Bulk Volume, 0]
Value: TKN [1, Effluent, Bulk Volume, 0]
Value: TKN [11, AnoxicR, Bulk Volume, 0]
Value: TKN [11, AnoxicR, Bulk Volume, 0]
Value: TKN [11, Effluent, Bulk Volume, 0]
Value: TKNmeas [1, AerobicR, Bulk Volume, 0]

TSS_01:
Description: TSS
Abscissa: Time
Title: TSS
Abscissa Label: Operation time (d)
Ordinate Label: TSS (mgTSS/1)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: TSS [1, AnoxicR, Bulk Volume, 0]
Value: TSS [1, AnoxicR, Bulk Volume, 0]
Value: TSS [1, AerobicR, Bulk Volume, 0]
Value: TSS [11, AnoxicR, Bulk Volume, 0]
Value: TSS [11, AnoxicR, Bulk Volume, 0]
Value: TSS [11, AerobicR, Bulk Volume, 0]
Value: TSSmeasAn aer [1, AerobicR, Bulk Volume, 0]
Value: TSSmeasAn ox [1, AnoxicR, Bulk Volume, 0]
Value: TSSmeasAero [1, AerobicR, Bulk Volume, 0]

X_I_01:
Description: Inert material
Abscissa: Time
Title: Inert material
Abscissa Label: Operation time (d)
Ordinate Label: Inert (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: X_I [1, AnaerobicR, Bulk Volume, 0]
Value: X_I [1, AnoxicR, Bulk Volume, 0]
Value: X_I [1, AerobicR, Bulk Volume, 0]
Value: X_I [11, AnaerobicR, Bulk Volume, 0]
Value: X_I [11, AnoxicR, Bulk Volume, 0]
Value: X_I [11, AerobicR, Bulk Volume, 0]

X_S_01:
Description: Slowly biodegradable substrate
Abscissa:
Title: Slowly biodegradable substrate
Abscissa Label: Operation time (d)
Ordinate Label: SBCOD (mgCOD/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: X_S [1, AnaerobicR, Bulk Volume, 0]
Value: X_S [1, AnoxicR, Bulk Volume, 0]
Value: X_S [1, AerobicR, Bulk Volume, 0]
Value: X_S [11, AnaerobicR, Bulk Volume, 0]
Value: X_S [11, AnoxicR, Bulk Volume, 0]
Value: X_S [11, AerobicR, Bulk Volume, 0]

******************************************************************************
Calculation Parameters
******************************************************************************
Numerical Parameters: Maximum Int. Step Size: 1
Maximum Integrat. Order: 5
Number of Codiagonals: 1000
Maximum Number of Steps: 1000

Fit Method: secant
Max. Number of Iterat.: 100
******************************************************************************
APPENDIX C3

Program Listing of ASM-2 and SSM for the Simulation of the Aerobic Batch Digestion
### Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>b_AUT</td>
<td>Maximum growth rate of autotrophs</td>
<td>Formula Variable</td>
<td>per day</td>
<td>$b_{AUT} \cdot \exp\left(\text{the}_{{AUT}} \cdot (T-20)\right)$</td>
</tr>
<tr>
<td>b_AUT20</td>
<td>Decay coefficient for autotrophic biomass</td>
<td>Constant Variable</td>
<td>per day</td>
<td>0.04</td>
</tr>
<tr>
<td>b_AUT20_SS</td>
<td>Decay coefficient for autotrophic biomass (SSM)</td>
<td>Constant Variable</td>
<td>per day</td>
<td>0.04</td>
</tr>
<tr>
<td>b_H</td>
<td>Rate constant for lysis of heterotrophs</td>
<td>Formula Variable</td>
<td>per day</td>
<td>$b_{H} \cdot \exp\left(\text{the}_{{H}} \cdot (T-20)\right)$</td>
</tr>
<tr>
<td>b_H20</td>
<td>Rate constant for lysis of heterotrophs</td>
<td>Constant Variable</td>
<td>per day</td>
<td>0.62</td>
</tr>
<tr>
<td>b_H20_SS</td>
<td>Rate constant for lysis of heterotrophs (SSM)</td>
<td>Constant Variable</td>
<td>per day</td>
<td>0.62</td>
</tr>
</tbody>
</table>

**Date and time of listing:** 02/13/2007 00:14:39
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>b_PA0:</td>
<td>Rate constant for lysis of X_PA0</td>
<td>Formula Variable</td>
<td>per day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b_PA20:</td>
<td>Rate constant for lysis of X_PA0</td>
<td>Constant Variable</td>
<td>per day</td>
<td>0.04</td>
<td>0.1</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b_PA020_SS:</td>
<td>Rate constant for lysis of X_PA0 (S SM)</td>
<td>Constant Variable</td>
<td>per day</td>
<td>0.04</td>
<td>0.1</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b_PHA:</td>
<td>Rate constant for lysis of X_PHA</td>
<td>Formula Variable</td>
<td>per day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b_PHA20:</td>
<td>Rate constant for lysis of X_PHA</td>
<td>Constant Variable</td>
<td>per day</td>
<td>0.04</td>
<td>0.1</td>
<td>0</td>
<td>10</td>
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<td></td>
</tr>
<tr>
<td>b_PP:</td>
<td>Rate constant for lysis of X_PP</td>
<td>Formula Variable</td>
<td>per day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b_PP20:</td>
<td>Rate constant for lysis of X_PP</td>
<td>Constant Variable</td>
<td>per day</td>
<td>0.04</td>
<td>0.1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Maximum: 10  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

b_PP20_SS:  
Description: Rate constant for lysis of X_PP (SS M)  
Type: Constant Variable  
Unit: per day  
Value: 0.04  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 10  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

Calcnum:  
Description: Calculation number  
Type: Program Variable  
Unit:  
Reference to: Calculation Number

CODf:  
Description: Filtered COD  
Type: Formula Variable  
Unit: mg/l  
Expression: S_I

CODf_m:  
Description: Measured filtered COD  
Type: Variable List Variable  
Unit: mg/l  
Argument: Calcnum  
Interpolation Method: linear interpolation  
Real-Variable Data Pairs (6 pairs):  
1 CODf_m1  
2 CODf_m2  
3 CODf_m3  
4 CODf_m4  
5 CODf_m5  
6 CODf_m6

CODf_m1:  
Description: Measured CODf (BT-1)  
Type: Real List Variable  
Unit: mg/l  
Argument: t  
Standard Deviations: global  
Rel. Stand. Deviat.: 0  
Abs. Stand. Deviat.: 1  
Minimum: 0  
Maximum: 1e+009  
Interpolation Method: linear interpolation  
Sensitivity Analysis: inactive  
Real Data Pairs (11 pairs):  
1 103.8  
2 203.4  
3 66.4  
4 76.8  
6 272  
7 118.3  
8 85.1  
9 97.6  
10 120.4  
11 124.6  
12 141.2
CODf_m2:  Description: Measured CODf (BT-2)  
Type:    Real List Variable  
Unit:    mg/l  
Argument:  t  
Standard Deviations:  global  
Rel. Stand. Deviat.:  0  
Abs. Stand. Deviat.:  1  
Minimum:  0  
Maximum:  1e+009  
Interpolation Method:  linear interpolation  
Sensitivity Analysis:  inactive  
Real Data Pairs (6 pairs):  
  1  78.89  
  2  62.28  
  3  70.58  
  4  64.36  
  5  80.96  
  6  89.27  

CODf_m3:  Description: Measured CODf (BT-3)  
Type:    Real List Variable  
Unit:    mg/l  
Argument:  t  
Standard Deviations:  global  
Rel. Stand. Deviat.:  0  
Abs. Stand. Deviat.:  1  
Minimum:  0  
Maximum:  1e+009  
Interpolation Method:  linear interpolation  
Sensitivity Analysis:  inactive  
Real Data Pairs (24 pairs):  
  2  76.81  
  3  97.57  
  4  72.66  
  5  78.89  
  6  83.04  
  .  .   
  21  79.93  
  22  92.38  
  23 108.99  
  24  96.534  
  25  84.078  

CODf_m4:  Description: Measured CODf (BT-4)  
Type:    Real List Variable  
Unit:    mg/l  
Argument:  t  
Standard Deviations:  global  
Rel. Stand. Deviat.:  0  
Abs. Stand. Deviat.:  1  
Minimum:  0  
Maximum:  1e+009  
Interpolation Method:  linear interpolation  
Sensitivity Analysis:  inactive  
Real Data Pairs (21 pairs):  
  1  51.9  
  2  56.05  
  3  60.2  
  4  60.2
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<td>Unit:</td>
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Expression: \[ S_A + S_F + S_I + X_I + X_S + X_H + X_PAO + X_PHA + X_{AUT} \]

---

**CODt_m:**
Description: Measured total COD
Type: Variable List Variable
Unit: mg/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (8 pairs):
1. CODt_m1
2. CODt_m2
3. CODt_m3
4. CODt_m4
5. CODt_m5
6. CODt_m6
7. CODt_m7
8. CODt_m8

---

**CODt_m1:**
Description: Measured CODt (BT-1)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (4 pairs):
5. 15746.46
7. 15405.996
8. 13192.98
9. 14725.068

---

**CODt_m2:**
Description: Measured CODt (BT-2)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (5 pairs):
1. 17874.36
2. 18044.592
4. 17789.244
5. 18810.636
6. 17448.78

---

**CODt_m3:**
Description: Measured CODt (BT-3)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum:      -1e+009  
Interpolation Method:  linear interpolation  
Sensitivity Analysis:  inactive  
Real Data Pairs (17 pairs):
  1   19832.028  
  2   18980.868  
  4   18129.708  
  5   17533.896  
  6   17363.664  
  9   17010.331  
  10   14384.604  
  20   13831.35  
  21   11448.102  
  22   10596.942  
  24   10086.246  

CODt_m4: Description:  Measured CODt (BT-4)  
Type:  Real List Variable  
Unit:  mg/l  
Argument:  t  
Standard Deviations:  global  
Rel. Stand. Deviat.:  0  
Abs. Stand. Deviat.:  1  
Minimum:  0  
Maximum:  1e+009  
Interpolation Method:  linear interpolation  
Sensitivity Analysis:  inactive  
Real Data Pairs (19 pairs):
  1   19661.796  
  2   19151.1  
  3   18640.404  
  4   18470.172  
  5   18299.94  
  6   15932.725  
  16   13278.096  
  17   12937.632  
  18   12597.168  
  20   12256.704  
  21   12171.588  

CODt_m5: Description:  Measured CODt (BT-5)  
Type:  Real List Variable  
Unit:  mg/l  
Argument:  t  
Standard Deviations:  global  
Rel. Stand. Deviat.:  0  
Abs. Stand. Deviat.:  1  
Minimum:  0  
Maximum:  1e+009  
Interpolation Method:  linear interpolation  
Sensitivity Analysis:  inactive  
Real Data Pairs (18 pairs):
  1   16682.736  
  3   14469.72  
  4   14129.256  
  6   12937.632  
  7   12086.472  
  8   11575.776  
  9   11065.08
### CODt_m6:
- **Description:** Measured CODt (BT-6)
- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive

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<td>15</td>
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### CODt_m7:
- **Description:** Measured CODt (BT-7) - Undiluted WAS
- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive

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### CODt_m8:
- **Description:** Measured CODt (BT-8) - Diluted WAS
- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive

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</table>

**CODt_m8x5:**
- **Description:** Measured CODt (BT-8) - (Diluted batch h)³
- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive
- **Real Data Pairs (9 pairs):**
  - 1: 20095.68
  - 2: 19068.06
  - 3: 16898.64
  - 4: 16670.28
  - 5: 16213.56
  - 6: 15414.3
  - 7: 14386.68
  - 8: 13929.96
  - 9: 13929.96

**deltaTSSs_s8:**
- **Description:** Reduction of TSS at time t (SSM)
- **Type:** Formula Variable
- **Unit:** mgTSS/l
- **Expression:**

\[
(X_{\text{Hini}}/f_{\text{cv}_{\text{SS}}})*(1-f_{\text{H}_{\text{SS}}}+\text{ISS}_{\text{FiO}})*(1-\exp(-b_{\text{H}_{\text{SS}})*t})) + ((X_{\text{PAOini}}/f_{\text{cv}_{\text{SS}}})*(1-f_{\text{G}_{\text{SS}}}+\text{ISS}_{\text{FiPAO}})*(1-\exp(-b_{\text{PAO}_{\text{SS}})*t}))
\]

**deltaVSSs_s8:**
- **Description:** Reduction of VSS at time t (SSM)
- **Type:** Formula Variable
- **Unit:** mgVSS/l
- **Expression:**

\[
(X_{\text{Hini}})*(1-f_{\text{H}_{\text{SS}}})*(1-\exp(-b_{\text{H}_{\text{SS}})*t})) + ((X_{\text{PAOini}})*(1-f_{\text{G}_{\text{SS}}})*(1-\exp(-b_{\text{PAO}_{\text{SS}})*t}))
\]

**eta_fe:**
- **Description:** Anaerobic hydrolysis reduction factor
- **Type:** Constant Variable
- **Unit:**
- **Value:** 0.1
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**eta_NO3:**
- **Description:** Anoxic hydrolysis reduction factor
- **Type:** Constant Variable
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<td>Initial active fraction of the PAOs (with respect to TSS)</td>
<td>Formula Variable</td>
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<td>Formula Variable</td>
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<td>X_PA0ini/X_Vi_SS</td>
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<td>Initial active fraction of the OHOs (with respect to TSS)</td>
<td>Formula Variable</td>
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**f_cvM:**

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Unit: gCOD/gVSS
Argument: Calcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (8 pairs):
1  f_cvM1
2  f_cvM2
3  f_cvM3
4  f_cvM4
5  f_cvM5
6  f_cvM6
7  f_cvM7
8  f_cvM8

f_cvM1:
Description: Measured average COD/VSS ratio for BT-1
Type: Constant Variable
Unit: gCOD/gVSS
Value: 1.4
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_cvM2:
Description: Measured COD/VSS ratio for BT-1
Type: Real List Variable
Unit: gCOD/gVSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (1 pairs):
7  1.52

f_cvM2:
Description: Measured average COD/VSS ratio for BT-2
Type: Constant Variable
Unit: gCOD/gVSS
Value: 1.44
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_cvM2:
Description: Measured COD/VSS ratio for BT-2
Type: Real List Variable
Unit: gCOD/gVSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (2 pairs):
f_cvM3:
Description: Measured average COD/VSS ratio for BT-3
Type: Constant Variable
Unit: gCOD/gVSS
Value: 1.39
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_cvM3:
Description: Measured COD/VSS ratio for BT-3
Type: Real List Variable
Unit: gCOD/gVSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (13 pairs):
1 1.39
2 1.41
4 1.41
5 1.36
8 1.47
13 1.3301891
15 1.377924
16 1.3764089
18 1.3862452
20 1.429991
21 1.3853259
22 1.365644
24 1.3925188

f_cvM4:
Description: Measured average COD/VSS ratio for BT-4
Type: Constant Variable
Unit: gCOD/gVSS
Value: 1.5
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_cvM4:
Description: Measured COD/VSS ratio for BT-4
Type: Real List Variable
Unit: gCOD/gVSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (17 pairs):
1  1.47
2  1.46
3  1.46
4  1.48
5  1.53
...
16  1.46
17  1.45
18  1.44
20  1.42
21  1.39

f_cvm5:
Description: Measured average COD/VSS ratio for BT-5
Type: Constant Variable
Unit: gCOD/gVSS
Value: 1.16
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_cvm5:
Description: Measured COD/VSS ratio for BT-5
Type: Real List Variable
Unit: gCOD/gVSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (7 pairs):
1  1.14
3  1.15
4  1.15
6  1.23
7  1.16
9  1.09
11  1.23

f_cvm6:
Description: Measured average COD/VSS ratio for BT-6
Type: Constant Variable
Unit: gCOD/gVSS
Value: 1.26
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_cvm6:
Description: Measured COD/VSS ratio for BT-6
Type: Real List Variable
Unit: gCOD/gVSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
3
5
6
7
11
12
13
14
1.25
1.36
1.39
1.3
1.18
1.23
1.24
1.15

f_cvM7:
Description: Measured average COD/VSS ratio for BT-7 (Undiluted)
Type: Constant Variable
Unit: gCOD/gVSS
Value: 1.2
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_cvM7:
Description: Measured COD/VSS ratio for BT-7 (Undiluted)
Type: Real List Variable
Unit: gCOD/gVSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1
2
3
5
6
7
8
9
1.26
1.33
1.24
1.2
1.16
1.15
1.14
1.13

f_cvM8:
Description: Measured average COD/VSS ratio for BT-8 (Diluted)
Type: Constant Variable
Unit: gCOD/gVSS
Value: 1.27
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive
f_cvm8: Description: Measured COD/VSS ratio for BT-8 (Diluted)
Type: Real List Variable
Unit: gCOD/gVSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1  1.35
2  1.37
3  1.22
5  1.24
6  1.28
7  1.21
8  1.22
9  1.22

f_cv_SS: Description: COD/VSS ratio (SSM)
Type: Constant Variable
Unit: gCOD/gCOD
Value: 1.48
Standard Deviation: 1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_GTrt_SS: Description: Fraction of PAOs (with respect to TSS) removed at time t
Type: Formula Variable
Unit: %
Expression: 100*(f_aGTi_SS*(1-f_G_SS+ISS_fPAO) *(1-(exp(-b_PA020_SS*t))))

f_GVrt_SS: Description: Fraction of PAOVSS removed at time t
Type: Formula Variable
Unit: %
Expression: 100*(f_aGVi_SS*(1-(exp(-b_PA020_SS* t))))

f_G_SS: Description: Constant Variable
Type: Value: 0.25
Unit: Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_HTrt_SS: Description: Fraction of OHOS (with respect to TSS) removed at time t
Type: Formula Variable
Unit: %
Expression: 100*(f_aHTi_SS*(1-f_H_SS+ISS_fIOHO)
\((1-(\exp(-b_{\text{H}_2\text{O}_{\text{SS}}^*t})))\)

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<td>(100\times(f_{\text{aHV1 SS}}*(1-(\exp(-b_{\text{H}<em>2\text{O}</em>{\text{SS}}^*t})))))</td>
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<th>f_i6b:</th>
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<tbody>
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<tr>
<td>Unit:</td>
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<td>Expression:</td>
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<tr>
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<td>Expression:</td>
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</table>
Type: Formula Variable
Unit: gVSS/gTSS
Expression: VSS/TSS_ISS

---

**f_iM:**

Description: Average measured VSS/TSS ratio
Type: Variable List Variable
Unit: gVSS/gTSS
Argument: Canvas
Interpolation Method: linear interpolation
Real-Variable Data Pairs (8 pairs):

1. $f_{iM1}$
2. $f_{iM2}$
3. $f_{iM3}$
4. $f_{iM4}$
5. $f_{iM5}$
6. $f_{iM6}$
7. $f_{iM7}$
8. $f_{iM8}$

---

**f_iM1:**

Description: Average measured VSS/TSS ratio for BT-1
Type: Constant Variable
Unit: gCOD/gTSS
Value: 0.78
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

**f_iM2:**

Description: Average measured VSS/TSS ratio for BT-2
Type: Constant Variable
Unit: gVSS/gTSS
Value: 0.8
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

**f_iM3:**

Description: Average measured VSS/TSS ratio for BT-3
Type: Constant Variable
Unit: gVSS/gTSS
Value: 0.79
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

**f_iM4:**

Description: Average measured VSS/TSS ratio for BT-4
Type: Constant Variable
Unit: gVSS/gTSS
Value: 0.78
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
### Parameter Estimation: inactive

#### f_im5:
- **Description:** Average measured VSS/TSS ratio for BT-5
- **Type:** Constant Variable
- **Unit:** gVSS/gTSS
- **Value:** 0.76
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

#### f_im6:
- **Description:** Average measured VSS/TSS ratio for BT-6
- **Type:** Constant Variable
- **Unit:** gVSS/gTSS
- **Value:** 0.75
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

#### f_im7:
- **Description:** Average measured VSS/TSS ratio for BT-7 (Undiluted)
- **Type:** Constant Variable
- **Unit:** gVSS/gTSS
- **Value:** 0.79
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

#### f_im8:
- **Description:** Average measured VSS/TSS ratio for BT-8 (Diluted)
- **Type:** Constant Variable
- **Unit:** gVSS/gTSS
- **Value:** 0.81
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

#### f imeas:
- **Description:** Daily values of measured VSS/TSS ratio
- **Type:** Variable List Variable
- **Unit:** gVSS/gTSS
- **Argument:** Calcnum
- **Interpolation Method:** linear interpolation
- **Real-Variable Data Pairs (8 pairs):**
  1. f_imeasl
  2. f_imeas2
  3. f_imeas3
  4. f_imeas4
  5. f_imeas5
  6. f_imeas6
  7. f_imeas7
  8. f_imeas8
### f imeas1:

**Description:** Daily values of measured VSS/TSS ratio for BT-1

<table>
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<th>Type:</th>
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<tr>
<td>Unit:</td>
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<tr>
<td>Argument:</td>
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</tr>
<tr>
<td>Standard Deviations:</td>
<td>global</td>
</tr>
<tr>
<td>Rel. Stand. Deviat.:</td>
<td>0</td>
</tr>
<tr>
<td>Abs. Stand. Deviat.:</td>
<td>1</td>
</tr>
<tr>
<td>Minimum:</td>
<td>0</td>
</tr>
<tr>
<td>Maximum:</td>
<td>1e+009</td>
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<tr>
<td>Interpolation Method:</td>
<td>linear interpolation</td>
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<tr>
<td>Sensitivity Analysis:</td>
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Real Data Pairs (6 pairs):

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<tr>
<td>1</td>
<td>0.75</td>
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<tr>
<td>2</td>
<td>0.78</td>
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<tr>
<td>3</td>
<td>0.79</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
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<tr>
<td>6</td>
<td>0.79</td>
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<tr>
<td>7</td>
<td>0.78</td>
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### f imeas2:

**Description:** Daily values of measured VSS/TSS ratio for BT-2

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<th>Type:</th>
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<tbody>
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<td>Unit:</td>
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<tr>
<td>Argument:</td>
<td>t</td>
</tr>
<tr>
<td>Standard Deviations:</td>
<td>global</td>
</tr>
<tr>
<td>Rel. Stand. Deviat.:</td>
<td>0</td>
</tr>
<tr>
<td>Abs. Stand. Deviat.:</td>
<td>1</td>
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<tr>
<td>Minimum:</td>
<td>0</td>
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<tr>
<td>Maximum:</td>
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<tr>
<td>Interpolation Method:</td>
<td>linear interpolation</td>
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<tr>
<td>Sensitivity Analysis:</td>
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Real Data Pairs (4 pairs):

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<tbody>
<tr>
<td>2</td>
<td>0.8</td>
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<tr>
<td>3</td>
<td>0.79</td>
</tr>
<tr>
<td>4</td>
<td>0.79</td>
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<tr>
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### f imeas3:

**Description:** Daily values of measured VSS/TSS ratio for BT-3

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</tr>
<tr>
<td>Argument:</td>
<td>t</td>
</tr>
<tr>
<td>Standard Deviations:</td>
<td>global</td>
</tr>
<tr>
<td>Rel. Stand. Deviat.:</td>
<td>0</td>
</tr>
<tr>
<td>Abs. Stand. Deviat.:</td>
<td>1</td>
</tr>
<tr>
<td>Minimum:</td>
<td>0</td>
</tr>
<tr>
<td>Maximum:</td>
<td>1e+009</td>
</tr>
<tr>
<td>Interpolation Method:</td>
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<tr>
<td>Sensitivity Analysis:</td>
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Real Data Pairs (20 pairs):

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<td>1</td>
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</tr>
<tr>
<td>2</td>
<td>0.79</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
</tr>
<tr>
<td>7</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>0.79</td>
</tr>
<tr>
<td>22</td>
<td>0.79</td>
</tr>
</tbody>
</table>
23  0.79
24  0.79
25  0.79

---

**f imeas4:**  
**Description:** Daily values of measured VSS/TSS ratio for BT-4  
**Type:** Real List Variable  
**Unit:** gVSS/gTSS  
**Argument:** t  
**Standard Deviations:** global  
**Rel. Stand. Deviat.:** 0  
**Abs. Stand. Deviat.:** 1  
**Minimum:** 0  
**Maximum:** 1e+009  
**Interpolation Method:** linear interpolation  
**Sensitivity Analysis:** inactive  
**Real Data Pairs (16 pairs):**  
2  0.79  
3  0.79  
4  0.78  
5  0.79  
6  0.78  
   .  
17  0.77  
18  0.77  
19  0.77  
20  0.77  
21  0.78

---

**f imeas5:**  
**Description:** Daily values of measured VSS/TSS ratio for BT-5  
**Type:** Real List Variable  
**Unit:** gVSS/gTSS  
**Argument:** t  
**Standard Deviations:** global  
**Rel. Stand. Deviat.:** 0  
**Abs. Stand. Deviat.:** 1  
**Minimum:** 0  
**Maximum:** 1e+009  
**Interpolation Method:** linear interpolation  
**Sensitivity Analysis:** inactive  
**Real Data Pairs (10 pairs):**  
1  0.8  
2  0.75  
3  0.74  
4  0.75  
5  0.76  
6  0.75  
7  0.75  
8  0  
10  0.77  
11  0.77

---

**f imeas6:**  
**Description:** Daily values of measured VSS/TSS ratio for BT-6  
**Type:** Real List Variable  
**Unit:** gVSS/gTSS  
**Argument:** t  
**Standard Deviations:** global  
**Rel. Stand. Deviat.:** 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):

2 0.76
3 0.76
4 0.71
5 0.72
6 0.73
7 0.76
13 0.78
14 0.78

f_imeas7: Description: Daily values of measured VSS/TSS ratio for BT-7 (Undiluted)
Type: Real List Variable
Unit: gVSS/gTSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (7 pairs):

1 0.79
2 0.77
5 0.78
6 0.78
7 0.79
8 0.8
9 0.8

f_imeas8: Description: Daily values of measured VSS/TSS ratio for BT-8 (Diluted)
Type: Real List Variable
Unit: gVSS/gTSS
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):

1 0.79
2 0.79
3 0.81
5 0.81
6 0.81
7 0.82
8 0.81
9 0.83

f_n_SS: Description: N content of the VSS
Type: Constant Variable
Unit: gN/gVSS
Value: 0.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 2
Sensitivity Analysis: inactive
Parameter Estimation: inactive

f_pg_SS: Description: P content of the PROs
  Type: Constant Variable
  Unit: gP/gPROVSS
  Value: 0.38
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 2
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

f_ph_SS: Description: P content of the OHOs
  Type: Constant Variable
  Unit: gP/gOHOVSS
  Value: 0.03
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 2
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

f_SI: Description: Fraction of inert COD in particulate substrate
  Type: Constant Variable
  Unit: gCOD/gCOD
  Value: 0
  Standard Deviation: 0.1
  Minimum: 0
  Maximum: 1
  Sensitivity Analysis: inactive
  Parameter Estimation: inactive

f_TrtMeas: Description: Measured fractions of TSS removed
  Type: Variable List Variable
  Unit: %
  Argument: Calcium Interpolation Method: linear interpolation
  Real-Variable Data Pairs (6 pairs):
  1 f_TrtMeas1
  2 f_TrtMeas2
  3 f_TrtMeas3
  4 f_TrtMeas4
  5 f_TrtMeas5
  6 f_TrtMeas6

f_TrtMeas1: Description: Measured fraction of TSS removed for BT-1
  Type: Real List Variable
  Unit: %
  Argument: t
  Standard Deviations: global
  Rel. Stand. Deviat.: 0
  Abs. Stand. Deviat.: 1
  Minimum: 0
  Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (6 pairs):
2 1.19
3 1.93
4 5.08
5 19.07
7 20.42
8 22.83
f_TrtMeas2: Description: Measured fraction of TSS removed for BT-2
Type: Real List Variable
Unit: %
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (3 pairs):
4 0.06
5 0.06
7 6.55
f_TrtMeas3: Description: Measured fraction of TSS removed for BT-3
Type: Real List Variable
Unit: %
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (19 pairs):
2 2.4
4 6.96
5 6.83
7 16.3
8 15.36
21 39.753942
22 43.799747
23 44.865491
24 47.283025
25 48.516187
f_TrtMeas4: Description: Measured fraction of TSS removed for BT-4
Type: Real List Variable
Unit: %
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (18 pairs):
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\[f_{\text{TrtMeas5}}: \]
- **Description:** Measured fraction of TSS removed for BT-5
- **Type:** Real List Variable
- **Unit:** %
- **Argument:** \( t \)
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive

Real Data Pairs (9 pairs):
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\[f_{\text{TrtMeas6}}: \]
- **Description:** Measured fraction of TSS removed for BT-6
- **Type:** Real List Variable
- **Unit:** %
- **Argument:** \( t \)
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive

Real Data Pairs (11 pairs):
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<td>Description:</td>
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<td>--------------</td>
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</tr>
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<td>Unit:</td>
<td>%</td>
</tr>
<tr>
<td>Expression:</td>
<td>$100\times ((f_{aH2O_SS}(1-f_{H_SS+SS_fiOHO})'(1-(\exp(-b_{H2O_SS}*t})) + (f_{aGTS_SS}(1-f_{G_SS+SS_fiPAO})'(1-(\exp(-b_{P AO20_SS}*t))))))$</td>
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**Interpolation Method:** linear interpolation

**Sensitivity Analysis:** inactive

**Real Data Pairs (19 pairs):**

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**Interpolation Method:** linear interpolation

**Sensitivity Analysis:** inactive

**Real Data Pairs (18 pairs):**

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**Description:** Measured fraction of VSS removed for BT-5

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Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
2 12.24
3 14.24
4 16.22
5 18.93
6 28.13
7 29.11
9 30.5
10 33.57
11 39.31

---
f_VrtMeas6:
Description: Measured fraction of VSS removed for BT-6
Type: Real List Variable
Unit: %
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (10 pairs):
2 1.58
3 4.77
4 17.96
5 18.53
6 22.08
7 20.51
11 23.05
12 25.11
13 26.463174
14 26.642612

---
f_Vrt_SS:
Description: Fraction of VSS removed at time t
Type: Formula Variable
Unit: %
Expression: f_GVrt_SS+f_HVrt_SS

---
f_XIAUT:
Description: Fraction of inert COD in biomass for AUT
Type: Constant Variable
Unit: gCOD(gCOD)-1
Value: 0.08
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

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Description: Fraction of inert COD in biomass for OHO
Type: Constant Variable
Unit: gCOD(gCOD)-1
Value: 0.08
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<td>Formula Variable</td>
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<td>Maximum:</td>
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<tr>
<td>Interpolation Method:</td>
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<td></td>
</tr>
<tr>
<td>Sensitivity Analysis:</td>
<td>inactive</td>
<td></td>
</tr>
<tr>
<td>Real Data Pairs (16 pairs):</td>
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</table>
2 3499
3 3471.5
4 3462.33
5 3217.83
6 3219.83
    ...
17 2625.17
18 2599.5
19 2576.67
20 2563.83
21 2508.5

ISS_meas5: Description: Measured ISS (BT-5)
Type: Real List Variable
Unit: mgISS/1
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
1 3733.83
2 4192.67
3 4349.33
4 4103.17
5 3677.67
6 3502.5
7 3519.5
10 2939.83
11 2629.83

ISS_meas6: Description: Measured ISS (BT-6)
Type: Real List Variable
Unit: mgISS/1
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
2 4087.5
3 3893.67
4 4512
5 4237.83
6 3833.17
7 3319.5
13 2774.5
14 2678.5

ISS_meas7: Description: Measured ISS (BT-7) Undiluted WAS
Type: Real List Variable
Unit: mgISS/1
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (7 pairs):
1 4098.75
2 4342.5
5 3786
6 3549
7 3314
8 2800
9 2846

ISS_meas8: Description: Measured ISS (BT-8) Diluted WAS
Type: Real List Variable
Unit: mgISS/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 785.25
2 761.75
3 653.5
5 595.5
6 580.25
7 517
8 546.25
9 474.75

ISS_meas8x5: Description: Measured ISS (BT-8) Diluted batch*5
Type: Real List Variable
Unit: mgISS/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 3926.25
2 3808.75
3 3267.5
5 2977.5
6 2901.25
7 2585
8 2731.25
9 2373.75

ISS_Xioi: Description: Inorganic suspended solids
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
### ISS_Xio1n:

**Description:** Influent inorganic suspended solids concentration entering the reactor

- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 0
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### ISS_Xio1ni:

**Description:** Initial concentration of the Inorganic suspended solids

- **Type:** Variable List Variable
- **Unit:** mg/l
- **Argument:** Calcium
- **Interpolation Method:** linear interpolation
- **Real-Variable Data Pairs (16 pairs):**

1. ISS_Xio1ni1a
2. ISS_Xio1ni2a
3. ISS_Xio1ni3a
4. ISS_Xio1ni4a
5. ISS_Xio1ni5a
6. ISS_Xio1ni6a
7. ISS_Xio1ni7a
8. ISS_Xio1ni8a
9. ISS_Xio1ni9a
10. ISS_Xio1ni10b
11. ISS_Xio1ni11b
12. ISS_Xio1ni12b
13. ISS_Xio1ni13b
14. ISS_Xio1ni14b
15. ISS_Xio1ni15b
16. ISS_Xio1ni16b
17. ISS_Xio1ni17b
18. ISS_Xio1ni18b

#### ISS_Xio1ni1a:

**Description:** Initial concentration of Inorganic suspended solids (B-1)

- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 6521.1
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

#### ISS_Xio1ni1b:

**Description:** Initial concentration of Inorganic suspended solids (B-1)

- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 6521.1
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

#### ISS_Xio1ni2a:

**Description:** Initial concentration of Inorganic suspended solids (B-2)
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<tr>
<th>Parameter</th>
<th>Description</th>
<th>Type: Constant Variable</th>
<th>Unit: mgISS/l</th>
<th>Value:</th>
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<tbody>
<tr>
<td>ISS_Xioini2b</td>
<td>Initial concentration of Inorganic suspended solids (B-2)</td>
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<td>10000</td>
</tr>
<tr>
<td>ISS_Xioini3a</td>
<td>Initial concentration of Inorganic suspended solids (B-3)</td>
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<td>5306.8</td>
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<td>6104.5</td>
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<td>ISS_Xioini4b</td>
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<tr>
<td>ISS_Xioini5a</td>
<td>Initial concentration of Inorganic suspended solids (B-5)</td>
<td>Constant Variable</td>
<td>mgISS/l</td>
<td>6347.5</td>
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<tr>
<td>ISS_Xioini5b</td>
<td>Initial concentration of Inorganic suspended solids (B-5)</td>
<td>Constant Variable</td>
<td>mgISS/l</td>
<td>6347.5</td>
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<td>ISS_Xioini6a</td>
<td>Initial concentration of Inorganic suspended solids (B-6)</td>
<td>Constant Variable</td>
<td>mgISS/l</td>
<td>7402.7</td>
</tr>
<tr>
<td>ISS_Xioini6b</td>
<td>Initial concentration of Inorganic suspended solids (B-6)</td>
<td>Constant Variable</td>
<td>mgISS/l</td>
<td>7402.7</td>
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<tr>
<td>ISS_Xioini7a</td>
<td>Initial concentration of Inorganic suspended solids, BT-7 (Undiluted)</td>
<td>Constant Variable</td>
<td>mgISS/l</td>
<td>6968</td>
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<td>ISS_Xioini7b</td>
<td>Initial concentration of Inorganic suspended solids, BT-7 (Undiluted)</td>
<td>Constant Variable</td>
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<tr>
<td>ISS_Xioini8a: Description</td>
<td>Initial concentration of Inorganic suspended solids, BT-8 (Diluted)</td>
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<tr>
<td>Unit: mgISS/l</td>
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<tr>
<th>ISS_Xioini8b: Description</th>
<th>Initial concentration of Inorganic suspended solids, BT-8 (Diluted)</th>
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<tbody>
<tr>
<td>Type: Constant Variable</td>
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<tr>
<td>Unit: mgISS/l</td>
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<th>ISS_Xioini_SS: Description</th>
<th>Initial concentration of the Inorganic suspended solids (for SSM)</th>
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<td>Unit: mg/l</td>
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<td>Argument: Calcium</td>
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<td>Interpolation Method: linear interpolation</td>
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<td>Real-Variable Data Pairs (16 pairs):</td>
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<tr>
<td>1  ISS_Xioini_SS1a</td>
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<tr>
<td>2  ISS_Xioini_SS2a</td>
<td></td>
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<tr>
<td>3  ISS_Xioini_SS3a</td>
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<tr>
<td>4  ISS_Xioini_SS4a</td>
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<tr>
<td>5  ISS_Xioini_SS5a</td>
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<tr>
<td>6  ISS_Xioini_SS6a</td>
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<td>7  ISS_Xioini_SS7a</td>
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<td>11 ISS_Xioini_SS1b</td>
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<th>ISS_Xioini_SS1a: Description</th>
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<tr>
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<tr>
<td>Unit: mgISS/l</td>
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<tr>
<td>Value: 1150.8</td>
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<td>Parameter</td>
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<td>Minimum</td>
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<td>Maximum</td>
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<td>Parameter Estimation</td>
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**ISS_Xioini_SS1b:**
- **Description:** Initial concentration of Inorganic suspended solids (B-1)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 1150.8
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_Xioini_SS2a:**
- **Description:** Initial concentration of Inorganic suspended solids (B-2)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 902.9
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_Xioini_SS2b:**
- **Description:** Initial concentration of Inorganic suspended solids (B-2)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 902.9
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_Xioini_SS3a:**
- **Description:** Initial concentration of Inorganic suspended solids (B-3)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 936.5
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_Xioini_SS3b:**
- **Description:** Initial concentration of Inorganic suspended solids (B-3)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 936.5
- **Standard Deviation:** 0.1
- **Minimum:** 0
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<tr>
<td>Parameter Estimation</td>
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**ISS_Xicini_SS4a:**
- **Description:** Initial concentration of Inorganic suspended solids (B-4)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 1077.3
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_Xicini_SS4b:**
- **Description:** Initial concentration of Inorganic suspended solids (B-5)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 1077.3
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_Xicini_SS5a:**
- **Description:** Initial concentration of Inorganic suspended solids (B-5)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 1120.1
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_Xicini_SS5b:**
- **Description:** Initial concentration of Inorganic suspended solids (B-5)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 1120.1
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**ISS_Xicini_SS6a:**
- **Description:** Initial concentration of Inorganic suspended solids (B-6)
- **Type:** Constant Variable
- **Unit:** mgISS/l
- **Value:** 1306.4
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xiomi_SS6b:
Description: Initial concentration of Inorganic suspended solids (B-6)
Type: Constant Variable
Unit: mgISS/l
Value: 1306.4
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xiomi_SS7a:
Description: Initial concentration of Inorganic suspended solids (B-7)
Type: Constant Variable
Unit: mgISS/l
Value: 1229.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xiomi_SS7b:
Description: Initial concentration of Inorganic suspended solids (B-7)
Type: Constant Variable
Unit: mgISS/l
Value: 1229.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xiomi_SS8a:
Description: Initial concentration of Inorganic suspended solids (B-8, diluted)
Type: Constant Variable
Unit: mgISS/l
Value: 696.8
Standard Deviation: 0.1
Minimum: 0
Maximum: 10000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

ISS_Xiomi_SS8b:
Description: Initial concentration of Inorganic suspended solids (B-8, diluted)
Type: Constant Variable
Unit: mgISS/l
Value: 696.8
Standard Deviation: 0.1
Minimum: 0
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Sensitivity Analysis: inactive
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<table>
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<th>Description: Inorganic suspended solids in the reactor</th>
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<tbody>
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<tr>
<td>Unit:</td>
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</tr>
<tr>
<td>Expression:</td>
<td>(ISS_Xioin)+(ISS_fiOHO*(X_H/f_cv))+ (ISS_fiPAO*(X_PA0/f_cv))</td>
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<th>i_NBM:</th>
<th>Description: Nitrogen content of biomass, X_h, X_PA0, X_AUT</th>
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<tr>
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<tr>
<td>Unit:</td>
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<td>Value:</td>
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<td>Minimum:</td>
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<th>i_NSf:</th>
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<th>i_NSi:</th>
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<tr>
<th>i_NXs:</th>
<th>Description: Nitrogen content of particulate substrate, X_s</th>
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<tr>
<td>Type:</td>
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<tr>
<td>Unit:</td>
<td>gN(gCOD)-1</td>
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<td>Value:</td>
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Parameter Estimation: inactive

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<th>Minimum</th>
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<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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<tr>
<td>i_PEM</td>
<td>P content of biomass, X_H, X_PAO, X_AUT</td>
<td>Constant Variable</td>
<td>gP(gCOD)-1</td>
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<td>i_PSf</td>
<td>P content of soluble substrate S_F</td>
<td>Constant Variable</td>
<td>gP(gCOD)-1</td>
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<td>0.1</td>
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<td>i_PSl</td>
<td>P content of inert soluble COD S_I</td>
<td>Constant Variable</td>
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<td>P content of inert particulate COD, X_I</td>
<td>Constant Variable</td>
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<td>i_PXs</td>
<td>P content of particulate substrate, X_S</td>
<td>Constant Variable</td>
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<td>i_TSSBM</td>
<td>TSS to biomass ratio for X_H, X_PA</td>
<td>Constant Variable</td>
<td>gTSS(gCOD)-1</td>
<td>0.9</td>
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Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

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i_TSSXi:
Description: TSS to X_I ratio
Type: Constant Variable
Unit: gTSS(gCOD)-1
Value: 0.75
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

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i_TSSXs:
Description: TSS to X_S ratio
Type: Constant Variable
Unit: gTSS(gCOD)-1
Value: 0.75
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

K_ALK:
Description: Saturation coefficient for alkalinity
Type: Constant Variable
Unit: mole HCO3 (m)-3
Value: 0.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

K_ALKAUT:
Description: Saturation coefficient for alkalinity (Autotrophs)
Type: Constant Variable
Unit: mole HCO3 (m)-3
Value: 0.5
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

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K_ALKPRE:
Description: Saturation coefficient for alkalinity (precipitation)
Type: Constant Variable
Unit: mole HCO3 (m)-3
Value: 0.5
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

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K_AOHO:
Description: Saturation coefficient for S_A (acetate) (heterotrophs)
Type: Constant Variable
Unit: gCOD(m)-3
Value: 4
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_APAO: Description: Saturation coefficient for S_A (acetate) (PAO)
Type: Constant Variable
Unit: gCOD(m)-3
Value: 1
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_F: Description: Saturation coefficient for growth of heterotrophs on S_F
Type: Constant Variable
Unit: gCOD(m)-3
Value: 4
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_fe: Description: Saturation coefficient for fermentation of S_F (heterotrophs)
Type: Constant Variable
Unit: gCOD(m)-3
Value: 150
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_h: Description: Hydrolysis rate constant
Type: Formula Variable
Unit: per day
Expression: \( K_{h20} \times \exp(\text{the}_K \times (T-20)) \)

K_h20: Description: Hydrolysis rate constant
Type: Constant Variable
Unit: per day
Value: 2
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_IPP: Description: Inhibition coefficient for X_PP storage
Type: Constant Variable
Unit: gPP(gPAO)-1
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<th>Type</th>
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<th>Value</th>
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<th>Sensitivity Analysis</th>
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<td>Oxygen mass transfer coefficient</td>
<td>Constant Variable</td>
<td>per day</td>
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<td>K_{Max}</td>
<td>Maximum ratio of X_PP/X_PAO</td>
<td>Constant Variable</td>
<td>gFP(gPAO)-1</td>
<td>1</td>
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<tr>
<td>K_{NH4AUT}</td>
<td>Saturation coefficient for ammonium (nutrient) (ANO)</td>
<td>Constant Variable</td>
<td>gN(m)^-3</td>
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<td>K_{NH4OHO}</td>
<td>Saturation coefficient for ammonium (nutrient) (OHO)</td>
<td>Constant Variable</td>
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<td>K_{NH4PAO}</td>
<td>Saturation coefficient for ammonium (nutrient) (PAO)</td>
<td>Constant Variable</td>
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<td>K_{NO3}</td>
<td>Saturation/inhibition coefficient</td>
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actor for nitrate
Type: Constant Variable
Unit: gN(m)^-3
Value: 0.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_O2:
Description: Saturation/inhibition coefficient/f actor for oxygen
Type: Constant Variable
Unit: gO2(m)^-3
Value: 0.02
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_P:
Description: Saturation coefficient for phosphorus (nutrient) in X_PP
Type: Constant Variable
Unit: gP(m)^-3
Value: 0.01
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_PHA:
Description: Saturation coefficient for PHA
Type: Constant Variable
Unit: gPHA(gPAO)^-1
Value: 0.18
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_PP:
Description: Saturation coefficient for poly-phosphate
Type: Constant Variable
Unit: gPP(gPAO)^-1
Value: 0.001
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

k_PRE:
Description: Rate constant for P precipitation
Type: Constant Variable
Unit: m3/(gFe(OH)3)/d
Value: 1
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_PS:
Description: Saturation coefficient for phosphorus in PP storage
Type: Constant Variable
Unit: gP(m)^-3
Value: 0.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

k_RED:
Description: Rate constant for redissolution
Type: Constant Variable
Unit: per day
Value: 0.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

K_X:
Description: Saturation coefficient for particulate COD
Type: Formula Variable
Unit: gCOD(gcellCOD)^-1
Expression: K_X20*exp(the_kX*(T-20))

K_X20:
Description: Saturation coefficient for particulate COD
Type: Constant Variable
Unit: gCOD(gcellCOD)^-1
Value: 0.03
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

mue_AUT:
Description: Maximum growth rate of autotrophs
Type: Formula Variable
Unit: per day
Expression: mue_AUT20*exp(the_mueAUT*(T-20))

mue_AUT20:
Description: Maximum specific growth rate of ANO
Type: Constant Variable
Unit: per day
Value: 0.45
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

mue_H:
Description: Maximum growth rate of heterotrophs
Type: Formula Variable
Unit: per day
Expression: mue_H20*exp(the_mueH*(T-20))

mue_H20:
Description: Maximum growth rate on substrate
Type: Constant Variable
Unit: per day
Value: 6
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

mue_PA0: Description: Maximum growth rate
Type: Formula Variable
Unit: per day
Expression: mue_PRO20*exp(the_muePA0*(T-20))

mue_PA020: Description: Maximum growth rate
Type: Constant Variable
Unit: per day
Value: 1.2
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

mVSS: Description: Model VSS
Type: Formula Variable
Unit: mgCOD/l
Expression: X_AUT+X_H+X_PA0+X_I

Nnt_SS: Description: Nitrate at time t (SSM)
Type: Formula Variable
Unit: mg/l
Expression: f_n_SS*(((X_Hini/f_cv_SS)*(1-f_H_SS)*(1-(exp(-b_H20_SS*t))))+((X_PA0in
1/f_cv_SS)*(1-f_G_SS)*(1-(exp(-b_PA
O20_SS*t)))))

OUR_AUT: Description: OUR for autotrophic growth (Nitrification OUR)
Type: Formula Variable
Unit: mg/l/h
Expression: (-1/24)*(-((4.57-Y_AUT)/Y_AUT)*mue_A
UT*(S_O2/(K_O2+S_O2))*(S_NH4/(K_NH4
AUT+S_NH4))*(S_P04/(K_P+S_P04))*X_A
UT

OUR_c: Description: Carbonaceous OUR
Type: Variable List Variable
Unit: mg/l/h
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1 OUR_c1a
2 OUR_c2a
3 OUR_c3a
4 OUR_c4a
5 OUR_c5a
6 OUR_c6a
7 OUR_c7a
8 OUR_c8a
9 OUR_c9a
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<tr>
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<td>Type:</td>
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<tr>
<td>Unit:</td>
<td>mg/l/h</td>
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<tr>
<td>Expression:</td>
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<tr>
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<td>Expression:</td>
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<tr>
<td>Expression:</td>
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<th>OUR_c6a:</th>
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<td><strong>OUR_c7a:</strong></td>
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<td><strong>Description:</strong></td>
<td>Carbonaceous OUR for BT-7 (Undiluted)</td>
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<td><strong>Unit:</strong></td>
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<td><strong>Expression:</strong></td>
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<td><strong>Description:</strong></td>
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<td><strong>Description:</strong></td>
<td>Carbonaceous OUR for BT-8 (Diluted)</td>
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<tr>
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<tr>
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<td>Real Data Pairs (7 pairs):</td>
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**OUR_meas1:**

| Description: | Measured instantaneous OUR (BT-1) |
| Type: | Real List Variable |
| Unit: | mg/l/h |
| Argument: | t |
| Standard Deviations: | global |
| Rel. Stand. Deviat.: | 0 |
| Abs. Stand. Deviat.: | 1 |
| Minimum: | 0 |
| Maximum: | 1e+009 |
| Interpolation Method: | linear interpolation |
| Sensitivity Analysis: | inactive |
| Real Data Pairs (981 pairs): |
| 0.001194444 | 30.64 |
| 1.0116776 | 30.64 |
| 1.8508385 | 30.58 |
| 2 | 33.98 |
| 2.5609027 | 27.97 |
| . | . |
| 24.833087 | 4.03 |
| 24.877922 | 3.67 |
| 24.918418 | 4.54 |
| 24.9564 | 4.59 |
| 25 | 3.5 |

---

**OUR Meas2:**

| Description: | Daily average measured OUR (BT-2) |
| Type: | Real List Variable |
| Unit: | mg/l/h |
| Argument: | t |
| Standard Deviations: | global |
| Rel. Stand. Deviat.: | 0 |
| Abs. Stand. Deviat.: | 1 |
| Minimum: | 0 |
| Maximum: | 1e+009 |
| Interpolation Method: | linear interpolation |
| Sensitivity Analysis: | inactive |
| Real Data Pairs (3 pairs): |
| 2 | 33.9 |
| 3 | 26.44 |
| 5 | 19.44 |

---

**OUR_meas2:**

| Description: | Measured instantaneous OUR (BT-2) |
| Type: | Real List Variable |
| Unit: | mg/l/h |
Argument: \( t \)
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: \( 1e+009 \)
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (70 pairs):
\[
\begin{array}{cc}
0.176 & 48.93 \\
0.315 & 37.99 \\
0.325 & 34.46 \\
0.334 & 34.36 \\
0.345 & 32.28 \\
\vdots & \vdots \\
1.119 & 22.12 \\
1.128 & 29.59 \\
1.135 & 26.26 \\
1.144 & 30.65 \\
2.173 & 19.44 \\
\end{array}
\]

---

**OUR_Meas3:**
Description: Daily average measured OUR (BT-3)
Type: Real List Variable
Unit: mg/1/h
Argument: \( t \)
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: \( 1e+009 \)
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (19 pairs):
\[
\begin{array}{cc}
4 & 31.55 \\
5 & 31.87 \\
6 & 38.93 \\
7 & 32.76 \\
8 & 32.76 \\
\vdots & \vdots \\
19 & 6.13 \\
20 & 7.59 \\
21 & 6.94 \\
22 & 9.55 \\
23 & 3.66 \\
\end{array}
\]

---

**OUR_meas3:**
Description: Measured instantaneous OUR (BT-3)
Type: Real List Variable
Unit: mg/1/h
Argument: \( t \)
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: \( 1e+009 \)
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (1115 pairs):
\[
\begin{array}{cc}
3.0387 & 46.3 \\
3.0485 & 43.65 \\
\end{array}
\]
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<tr>
<td>20</td>
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**OUR_Meas4**: Description: Daily average measured OUR (BT-4)
Type: Real List Variable
Unit: mg/l/h
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (16 pairs):

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<td>4</td>
<td>34.96</td>
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<tr>
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<td>16</td>
<td>7.58</td>
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**OUR_meas4**: Description: Measured instantaneous OUR (BT-4)
Type: Real List Variable
Unit: mg/l/h
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (1151 pairs):

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<td>46.07</td>
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<tr>
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<td>6.11</td>
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<tr>
<td>14.602</td>
<td>6.37</td>
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<td>6.61</td>
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<tr>
<td>14.679</td>
<td>6.7</td>
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<tr>
<td>14.71</td>
<td>6.72</td>
</tr>
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</table>
A.226

OUR_Meas5: Description: Daily average measured OUR (BT-5)
Type: Real List Variable
Unit: mg/l/h
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (10 pairs):
  1     31.83
  2     35.83
  3     33.57
  4     35.06
  5     32.5
  6     27.49
  7     22.21
  8     18.51
  9     14.36
 10     7.44

OUR_meas5: Description: Measured instantaneous OUR (BT-5)
Type: Real List Variable
Unit: mg/l/h
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (1151 pairs):
  0.002  45.07
  0.008  46.51
  0.014  44.49
  0.027  46.44
  0.033  46.07
 .    .
  14.569  6.11
  14.602  6.37
  14.646  6.61
  14.679  6.7
  14.71   6.72

OUR_Meas6: Description: Daily average measured OUR (BT-6)
Type: Real List Variable
Unit: mg/l/h
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (15 pairs):
  1     34
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<td>Interpolation Method: linear interpolation</td>
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<td>Real Data Pairs (1151 pairs):</td>
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<td>0.008 46.51</td>
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<td>0.014 44.49</td>
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<td>0.027 46.44</td>
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<td>14.679 6.7</td>
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<td>14.71 6.72</td>
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<tr>
<td>Argument: t</td>
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<td>Standard Deviations: global</td>
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<tr>
<td>Interpolation Method: linear interpolation</td>
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<tr>
<td>Real Data Pairs (8 pairs):</td>
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<tr>
<td>2 50.59</td>
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<td>3 50.53</td>
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<tr>
<td>4 43.6</td>
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<td>5 39.98</td>
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<td>6 39.26</td>
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<td>7 36.7</td>
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<td>8 33.41</td>
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Type: Real List Variable
Unit: mg/l/h
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 11.7
2 9.39
3 8.54
4 6.57
5 5.98
6 5.27
7 4.15
8 2.15

----------------------------------------
OUR_Mea8x5: Description: Daily average measured OUR (BT-8 -D iluted*5)
Type: Real List Variable
Unit: mg/l/h
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 58.49
2 46.97
3 42.68
4 32.85
5 29.9
6 26.35
7 20.76
8 10.75

----------------------------------------
OUR_P: Description: PolyPhosphate OUR
Type: Variable List Variable
Unit: mg/l/h
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1 OUR_P1a
2 OUR_P2a
3 OUR_P3a
4 OUR_P4a
5 OUR_P5a
6 OUR_P6a
7 OUR_P7a
8 OUR_P8a
11 OUR_P1b
12 OUR_P2b
13 OUR_P3b
14 OUR_P4b
15 OUR_P5b
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<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
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<tr>
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<td>OUR_P2a:</td>
<td>Description: PolyPhosphate OUR for BT-2</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P2b:</td>
<td>Description: PolyPhosphate OUR for BT-2</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P3a:</td>
<td>Description: PolyPhosphate OUR for BT-3</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P3b:</td>
<td>Description: PolyPhosphate OUR for BT-3</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P4a:</td>
<td>Description: PolyPhosphate OUR for BT-4</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P4b:</td>
<td>Description: PolyPhosphate OUR for BT-4</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P5a:</td>
<td>Description: PolyPhosphate OUR for BT-5</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P5b:</td>
<td>Description: PolyPhosphate OUR for BT-5</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P6a:</td>
<td>Description: PolyPhosphate OUR for BT-6</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td></td>
<td>OUR_P6b:</td>
<td>Description: PolyPhosphate OUR for BT-6</td>
<td>Type: Formula Variable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Unit: mg/l/h
Expression: OUR_PP

OUR_P7a: Description: PolyPhosphate OUR for BT-7 (Undiluted)
Type: Formula Variable
Unit: mg/l/h
Expression: OUR_PP

OUR_P7b: Description: PolyPhosphate OUR for BT-7 (Undiluted)
Type: Formula Variable
Unit: mg/l/h
Expression: OUR_PP

OUR_P8a: Description: PolyPhosphate OUR for BT-8 (Diluted)
Type: Formula Variable
Unit: mg/l/h
Expression: OUR_PP

OUR_P8b: Description: PolyPhosphate OUR for BT-8 (Diluted)
Type: Formula Variable
Unit: mg/l/h
Expression: OUR_PP

OUR_PAo: Description: OUR for PAO growth
Type: Formula Variable
Unit: mg/l/h
Expression: \((-1/24)*[-(1-Y_PAo)/Y_PAo]*mue_PAo*(S_O2/(K_O2+S_O2))*(S_NH4/(K_NH4PAO+S_NH4))*(S_PO4/(K_P+S_PO4))\)

OUR_PP: Description: OUR for X_PP storage
Type: Formula Variable
Unit: mg/l/h
Expression: \((-1/24)*[-Y_PHA]*q_PP*(S_O2/(K_O2+S _O2))*(S_PO4/(K_PS+S_PO4))*(X_PHA/ X_PAo)/(K_PHA+(X_PHA/X_PAo))*((K_M ax-(X_PP/X_PAo))/(KIPP+K_Max-(X_PP /X_PAo)))*X_PAo

OUR_t: Description: Total OUR
Type: Variable List Variable
Unit: mg/l/h
Argument: Calcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1  OUR_t1a
2  OUR_t2a
3  OUR_t3a
4  OUR_t4a
5  OUR_t5a
6  OUR_t6a
7  OUR_t7a
8  OUR_t8a
11  OUR_t1b
12  OUR_t2b
<table>
<thead>
<tr>
<th>OUR_t1a:</th>
<th>Description: Total OUR for BT-1</th>
<th>Type: Formula Variable</th>
<th>Unit: mg/l/h</th>
<th>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUR_t1b:</td>
<td>Description: Total OUR for BT-1</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td>OUR_t2a:</td>
<td>Description: Total OUR for BT-2</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td>OUR_t2b:</td>
<td>Description: Total OUR for BT-2</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td>OUR_t3a:</td>
<td>Description: Total OUR for BT-3</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td>OUR_t3b:</td>
<td>Description: Total OUR for BT-3</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td>OUR_t4a:</td>
<td>Description: Total OUR for BT-4</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td>OUR_t4b:</td>
<td>Description: Total OUR for BT-4</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td>OUR_t5a:</td>
<td>Description: Total OUR for BT-5</td>
<td>Type: Formula Variable</td>
<td>Unit: mg/l/h</td>
<td>Expression: OUR_HSF+OUR_HSA+OUR_AUT+OUR_PA0+OUR_PP</td>
</tr>
<tr>
<td>Variable</td>
<td>Description</td>
<td>Type</td>
<td>Unit</td>
<td>Expression</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------------</td>
<td>--------------------</td>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>OUR_t5b</td>
<td>Total OUR for BT-5</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>OUR_HSF+OUR_HSA+OUR_AUT+OUR_PAO+OUR_PP</td>
</tr>
<tr>
<td>OUR_t6a</td>
<td>Total OUR for BT-6</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>OUR_HSF+OUR_HSA+OUR_AUT+OUR_PAO+OUR_PP</td>
</tr>
<tr>
<td>OUR_t6b</td>
<td>Total OUR for BT-6</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>OUR_HSF+OUR_HSA+OUR_AUT+OUR_PAO+OUR_PP</td>
</tr>
<tr>
<td>OUR_t7a</td>
<td>Total OUR for BT-7 (Undiluted)</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>OUR_HSF+OUR_HSA+OUR_AUT+OUR_PAO+OUR_PP</td>
</tr>
<tr>
<td>OUR_t7b</td>
<td>Total OUR for BT-7 (Undiluted)</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>OUR_HSF+OUR_HSA+OUR_AUT+OUR_PAO+OUR_PP</td>
</tr>
<tr>
<td>OUR_t8a</td>
<td>Total OUR for BT-8 (Diluted)</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>OUR_HSF+OUR_HSA+OUR_AUT+OUR_PAO+OUR_PP</td>
</tr>
<tr>
<td>OUR_t8b</td>
<td>Total OUR for BT-8 (Diluted)</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>OUR_HSF+OUR_HSA+OUR_AUT+OUR_PAO+OUR_PP</td>
</tr>
<tr>
<td>O_c_SS</td>
<td>Carbonaceous OUR (SSM)</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>O_G_SS+O_H_SS</td>
</tr>
<tr>
<td>O_G_SS</td>
<td>Carbonaceous OUR (PAO) - SSM</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>(1/24)<em>(1-f_G_SS)<em>f_cv_SS</em>b_PAO20_S</em>S<em>X_PA0ini</em>exp(-b_PAO20_SS*t)</td>
</tr>
<tr>
<td>O_H_SS</td>
<td>Carbonaceous OUR (OHO) - SSM</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td>(1/24)<em>(1-f_H_SS)<em>f_cv_SS</em>b_H2O_SS</em>X_Hini<em>exp(-b_H2O_SS</em>t)</td>
</tr>
<tr>
<td>O_n_SS</td>
<td>Nitrification OUR (SSM)</td>
<td>Formula Variable</td>
<td>mg/l/h</td>
<td></td>
</tr>
</tbody>
</table>
Unit: mg/l/h
Expression: \(((4.57/24)\times f_{n\_SS})\times((1-f_{H\_SS})\times(b_{H2O\_SS}\times(X_{Hini}/f_{cv\_SS})\times(\exp(-b_{H2O\_SS}\times t)))+(1-f_{G\_SS})\times(b_{PAO20\_SS}\times(X_{PAOini}/f_{cv\_SS})\times(\exp(-b_{PAO20\_SS}\times t))))\)

O_T_SS: Description: Total OUR (SSM)
Type: Formula Variable
Unit: mg/l/h
Expression: O_c_SS+O_n_SS

Pst_G_SS: Description: Orthophosphate concentration at time t (due to PAOs)
Type: Formula Variable
Unit: mgP/l
Expression: \((f_{pG\_SS}\times f_{aGVi\_SS}\times(X_{V_i\_SS}/f_{cv\_SS})\times(1-\exp(-b_{PAO20\_SS}\times t)))\)

Pst_H_SS: Description: Orthophosphate concentration at time t (due to PAOs)
Type: Formula Variable
Unit: mgP/l
Expression: \((f_{pH\_SS}\times f_{aHVi\_SS}\times(X_{V_i\_SS}/f_{cv\_SS})\times(1-\exp(-b_{H2O\_SS}\times t)))\)

Pst_T_SS: Description: Total OP at time t
Type: Formula Variable
Unit: mgP/l
Expression: Pst_G_SS+Pst_H_SS

q_fe: Description: Maximum rate of fermentation for heterotrophs
Type: Formula Variable
Unit: gCOD(g.COD)-1
Expression: q_fe20a*exp(the_qfe*(T-20))

q_fe20: Description: Maximum rate of fermentation
Type: Variable List Variable
Unit: gCOD(g.COD)-1
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1  q_fe20a
2  q_fe20a
3  q_fe20a
4  q_fe20a
5  q_fe20a
6  q_fe20a
7  q_fe20a
8  q_fe20a
9  q_fe20a
10 q_fe20b
11 q_fe20b
12 q_fe20b
13 q_fe20b
14 q_fe20b
15 q_fe20b
16 q_fe20b
17 q_fe20b
18 q_fe20b

q_fe20a: Description: Maximum rate of fermentation
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>q_fe20b</td>
<td>Maximum rate of fermentation</td>
<td>Constant Variable</td>
<td>gCOD (g.COD) - 1</td>
<td>5</td>
<td>0.1</td>
<td>0</td>
<td>20</td>
<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>q_PHA</td>
<td>Rate constant for storage of PHA (base: X_PP)</td>
<td>Formula Variable</td>
<td>gCOD (gPAO) - 1 d - 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q_PHA20</td>
<td>Rate constant for storage of PHA (base: X_PP)</td>
<td>Constant Variable</td>
<td>gCOD (gPAO) - 1 d - 1</td>
<td>6</td>
<td>0.1</td>
<td>0</td>
<td>10</td>
<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>q_PP</td>
<td>Rate constant for storage of PP</td>
<td>Formula Variable</td>
<td>gPP (gPAO) - 1 d - 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q_PP20</td>
<td>Rate constant for storage of PP</td>
<td>Variable List Variable</td>
<td>gPP (gPAO) - 1 d - 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Interpolation Method: linear interpolation

Real-Variable Data Pairs (16 pairs):

1. q_PP20a
2. q_PP20a
3. q_PP20a
4. q_PP20a
5. q_PP20a
6. q_PP20a
7. q_PP20a
8. q_PP20a
9. q_PP20a
10. q_PP20a
11. q_PP20a
12. q_PP20a
13. q_PP20a
14. q_PP20a
### q_PP20a:
- **Description:** Rate constant for storage of PP
- **Type:** Constant Variable
- **Unit:** gPP (gPAO)-1 d-1
- **Value:** 1.35
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### q_PP20b:
- **Description:** Rate constant for storage of PP
- **Type:** Constant Variable
- **Unit:** gPP (gPAO)-1 d-1
- **Value:** 1.35
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 10
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### R_hn:
- **Description:** Nominal hydraulic retention time
- **Type:** Variable List Variable
- **Unit:** d
- **Argument:** Calcium
- **Interpolation Method:** linear interpolation
- **Real-Variable Data Pairs (16 pairs):**
  |   | R_hn1a | R_hn2a | R_hn3a | R_hn4a | R_hn5a | R_hn6a | R_hn7a | R_hn8a | R_hn9b | R_hn10b | R_hn11a | R_hn12a | R_hn13a | R_hn14a | R_hn15a | R_hn16a | R_hn17a | R_hn18a |
  |---|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|
  1  | R_hn1a|
  2  | R_hn2a|
  3  | R_hn3a|
  4  | R_hn4a|
  5  | R_hn5a|
  6  | R_hn6a|
  7  | R_hn7a|
  8  | R_hn8a|
  9  | R_hn9b|
 10  | R_hn10b|
 11  | R_hn11a|
 12  | R_hn12a|
 13  | R_hn13a|
 14  | R_hn14a|
 15  | R_hn15a|
 16  | R_hn16a|
 17  | R_hn17a|
 18  | R_hn18a|

### R_hn1a:
- **Description:** Hydraulic retention time (Retention time) for BT-1
- **Type:** Formula Variable
- **Unit:** d
- **Expression:** 12

### R_hn1b:
- **Description:** Hydraulic retention time (Retention time) for BT-1
- **Type:** Formula Variable
- **Unit:** d
- **Expression:** 12

### R_hn2a:
- **Description:** Hydraulic retention time (Retention time) for BT-2
- **Type:** Formula Variable
Unit: d
Expression: 6

---

R_hn2b: Description: Hydraulic retention time (Retention time) for BT-2
Type: Formula Variable
Unit: d
Expression: 6

---

R_hn3a: Description: Hydraulic retention time (Retention time) for BT-3
Type: Formula Variable
Unit: d
Expression: 25

---

R_hn3b: Description: Hydraulic retention time (Retention time) for BT-3
Type: Formula Variable
Unit: d
Expression: 25

---

R_hn4a: Description: Hydraulic retention time (Retention time) for BT-4
Type: Formula Variable
Unit: d
Expression: 21

---

R_hn4b: Description: Hydraulic retention time (Retention time) for BT-4
Type: Formula Variable
Unit: d
Expression: 21

---

R_hn5a: Description: Hydraulic retention time (Retention time) for BT-5
Type: Formula Variable
Unit: d
Expression: 11

---

R_hn5b: Description: Hydraulic retention time (Retention time) for BT-5
Type: Formula Variable
Unit: d
Expression: 11

---

R_hn6a: Description: Hydraulic retention time (Retention time) for BT-6
Type: Formula Variable
Unit: d
Expression: 15

---

R_hn6b: Description: Hydraulic retention time (Retention time) for BT-6
Type: Formula Variable
Unit: d
Expression: 15

---

R_hn7a: Description: Hydraulic retention time (Retention time) for BT-7 (Undiluted)
Type: Formula Variable
Unit: d
<table>
<thead>
<tr>
<th>Expression:</th>
<th>9</th>
</tr>
</thead>
</table>
| **R_{hn7b}:**
  Description: | Hydraulic retention time (Retention time) for BT-7 (Undiluted) |
  Type: | Formula Variable |
  Unit: | d |
  Expression: | 9 |
| **R_{hn8a}:**
  Description: | Hydraulic retention time (Retention time) for BT-8 (Diluted) |
  Type: | Formula Variable |
  Unit: | d |
  Expression: | 9 |
| **R_{hn8b}:**
  Description: | Hydraulic retention time (Retention time) for BT-8 (Diluted) |
  Type: | Formula Variable |
  Unit: | d |
  Expression: | 9 |
| **R_s:**
  Description: | Sludge age |
  Type: | Variable List Variable |
  Unit: | d |
  Argument: | Calcium |
  Interpolation Method: | linear interpolation |
  Real-Variable Data Pairs (16 pairs):
  1 R_{s1a}
  2 R_{s2a}
  3 R_{s3a}
  4 R_{s4a}
  5 R_{s5a}
  6 R_{s6a}
  7 R_{s7a}
  8 R_{s0a}
  11 R_{s1b}
  12 R_{s2b}
  13 R_{s3b}
  14 R_{s4b}
  15 R_{s5b}
  16 R_{s6b}
  17 R_{s7b}
  18 R_{s8b} |
| **R_{s1a}:**
  Description: | Sludge age (Retention time) for BT-1 |
  Type: | Formula Variable |
  Unit: | d |
  Expression: | 12 |
| **R_{s1b}:**
  Description: | Sludge age (Retention time) for BT-1 |
  Type: | Formula Variable |
  Unit: | d |
  Expression: | 12 |
| **R_{s2a}:**
  Description: | Sludge age (Retention time) for BT-2 |
  Type: | Formula Variable |
  Unit: | d |
  Expression: | 6 |
<table>
<thead>
<tr>
<th>R_s2b:</th>
<th>Description:</th>
<th>Sludge age (Retention time) for BT-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Formula Variable</td>
<td></td>
</tr>
<tr>
<td>Unit:</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>Expression:</td>
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</tr>
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<table>
<thead>
<tr>
<th>R_s3a:</th>
<th>Description:</th>
<th>Sludge age (Retention time) for BT-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Formula Variable</td>
<td></td>
</tr>
<tr>
<td>Unit:</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>Expression:</td>
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<table>
<thead>
<tr>
<th>R_s3b:</th>
<th>Description:</th>
<th>Sludge age (Retention time) for BT-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Formula Variable</td>
<td></td>
</tr>
<tr>
<td>Unit:</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>Expression:</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R_s4a:</th>
<th>Description:</th>
<th>Sludge age (Retention time) for BT-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Formula Variable</td>
<td></td>
</tr>
<tr>
<td>Unit:</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>Expression:</td>
<td>21</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>R_s4b:</th>
<th>Description:</th>
<th>Sludge age (Retention time) for BT-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Formula Variable</td>
<td></td>
</tr>
<tr>
<td>Unit:</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>Expression:</td>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R_s5a:</th>
<th>Description:</th>
<th>Sludge age (Retention time) for BT-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Formula Variable</td>
<td></td>
</tr>
<tr>
<td>Unit:</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>Expression:</td>
<td>11</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>R_s5b:</th>
<th>Description:</th>
<th>Sludge age (Retention time) for BT-5</th>
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<th>R_s7a:</th>
<th>Description:</th>
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<td>R_s8a</td>
<td>Sludge age (Retention time) for BT-8 (Diluted)</td>
<td>Formula Variable</td>
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<td>R_s8b</td>
<td>Sludge age (Retention time) for BT-8 (Diluted)</td>
<td>Formula Variable</td>
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<td>S_A</td>
<td>Fermentable products (acetate)</td>
<td>Dyn. Volume State Var.</td>
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<td>S_Aini</td>
<td>Initial concentration of fermentable products (acetate)</td>
<td>Variable List Variable</td>
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Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):

1. S_Aini1a
2. S_Aini2a
3. S_Aini3a
4. S_Aini4a
5. S_Aini5a
6. S_Aini6a
7. S_Aini7a
8. S_Aini8a
11. S_Aini11b
12. S_Aini12b
13. S_Aini13b
14. S_Aini14b
15. S_Aini15b
16. S_Aini16b
17. S_Aini17b
18. S_Aini18b

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<td>Parameter Estimation: inactive</td>
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<td>Constant Variable</td>
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<td>Parameter</td>
<td>Description</td>
<td>Type</td>
<td>Unit</td>
<td>Value</td>
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<tr>
<td>S_Aini2a</td>
<td>Initial concentration of fermentable products (acetate) for BT-2</td>
<td>Constant Variable</td>
<td>mg/l</td>
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<tr>
<td>S_Aini2b</td>
<td>Initial concentration of fermentable products (acetate) for BT-2</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>0.0001716</td>
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<tr>
<td>S_Aini3a</td>
<td>Initial concentration of fermentable products (acetate) for BT-3</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>0.0001716</td>
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<tr>
<td>S_Aini3b</td>
<td>Initial concentration of fermentable products (acetate) for BT-3</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>0.0001716</td>
</tr>
<tr>
<td>S_Aini4a</td>
<td>Initial concentration of fermentable products (acetate) for BT-4</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>0.0001716</td>
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Parameter Estimation: inactive

**S_Aini4b:** Description: Initial concentration of fermentable products (acetate) for BT-4
Type: Constant Variable
Unit: mg/l
Value: 0.0001716
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**S_Aini5a:** Description: Initial concentration of fermentable products (acetate) for BT-5
Type: Constant Variable
Unit: mg/l
Value: 0.0001716
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**S_Aini5b:** Description: Initial concentration of fermentable products (acetate) for BT-5
Type: Constant Variable
Unit: mg/l
Value: 0.0001716
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**S_Aini6a:** Description: Initial concentration of fermentable products (acetate) for BT-6
Type: Constant Variable
Unit: mg/l
Value: 0.0001716
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**S_Aini6b:** Description: Initial concentration of fermentable products (acetate) for BT-6
Type: Constant Variable
Unit: mg/l
Value: 0.0001716
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**S_Aini7a:** Description: Initial concentration of fermentable products (acetate) for BT-7 (Undiluted)
Type: Constant Variable
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<thead>
<tr>
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<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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</thead>
<tbody>
<tr>
<td>S_Aini7b:</td>
<td>Initial concentration of fermentable products (acetate) for BT-7 (Undiluted)</td>
<td>Constant Variable</td>
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<td>S_Aini8a:</td>
<td>Initial concentration of fermentable products (acetate) for BT-8 (Diluted)</td>
<td>Constant Variable</td>
<td>mg/l</td>
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<td>Initial concentration of fermentable products (acetate) for BT-8 (Diluted)</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>0.0001716</td>
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<td>S_Fini:</td>
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<td>Variable List Variable</td>
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Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1. S_Fini1a
2. S_Fini2a
S_Fini3a: Description: Initial concentration of fermentable, readily biodegradable organic substrate for BT-1
Type: Constant Variable
Unit: mg/l
Value: 0.5855
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_Fini4a: Description: Initial concentration of fermentable, readily biodegradable organic substrate for BT-1
Type: Constant Variable
Unit: mg/l
Value: 0.5821
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_Fini5a: Description: Initial concentration of fermentable, readily biodegradable organic substrate for BT-2
Type: Constant Variable
Unit: mg/l
Value: 0.5467
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_Fini6a: Description: Initial concentration of fermentable, readily biodegradable organic substrate for BT-2
Type: Constant Variable
Unit: mg/l
Value: 0.5748
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive
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<th>Minimum</th>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>S_Fini7a</td>
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<td>Constant Variable</td>
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S_Fini8a: Description: Initial concentration of fermentable, readily biodegradable organic substrate for BT-8 (Diluted)
Type: Constant Variable
Unit: mg/l
Value: 0.1109
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_Fini8b: Description: Initial concentration of fermentable, readily biodegradable organic substrate for BT-8 (Diluted)
Type: Constant Variable
Unit: mg/l
Value: 0.1109
Standard Deviation: 0.1
Minimum: 0
Maximum: 1
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_I: Description: Inert soluble organic material
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

S_Ini1: Description: Initial concentration of inert soluble organic material
Type: Variable List Variable
Unit: mg/l
Argument: Calculated
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1  S_Ini1a
2  S_Ini2a
3  S_Ini3a
4  S_Ini4a
5  S_Ini5a
6  S_Ini6a
7  S_Ini7a
8  S_Ini8a
11 S_Ini11b
12 S_Ini12b
13 S_Ini13b
14 S_Ini14b
15 S_Ini15b
16 S_Ini16b
17 S_Ini17b
18 S_Ini18b

S_Ini1a: Description: Initial concentration of inert soluble organic material for BT-1
Type: Constant Variable
Unit: mg/l
Value: 29.7
Standard Deviation: 0.1
Minimum: 0
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<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
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<td>Constant Variable</td>
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<td>S_Ini2a</td>
<td>Initial concentration of inert soluble organic material for BT-2</td>
<td>Constant Variable</td>
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<td>S_Ini2b</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>Constant Variable</td>
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<td>S_Ini4a</td>
<td>Initial concentration of inert soluble organic material for BT-4</td>
<td>Constant Variable</td>
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<td>Minimum</td>
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<td>Sensitivity Analysis</td>
<td>Parameter Estimation</td>
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<td>S Ini4b</td>
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<td>Constant Variable</td>
<td>mg/l</td>
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<td>S Ini5a</td>
<td>Initial concentration of inert soluble organic material for BT-5</td>
<td>Constant Variable</td>
<td>mg/l</td>
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<td>Constant Variable</td>
<td>mg/l</td>
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<tr>
<td>S Ini6a</td>
<td>Initial concentration of inert soluble organic material for BT-6</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>39.2</td>
<td>0.1</td>
<td>0</td>
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<td>Constant Variable</td>
<td>mg/l</td>
<td>39.2</td>
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Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_Ini7a: Description: Initial concentration of inert soluble organic material for BT-7 (Undiluted)
Type: Constant Variable
Unit: mg/l
Value: 40.59
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_Ini7b: Description: Initial concentration of inert soluble organic material for BT-7 (Undiluted)
Type: Constant Variable
Unit: mg/l
Value: 40.59
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_Ini8a: Description: Initial concentration of inert soluble organic material for BT-8 (Diluted)
Type: Constant Variable
Unit: mg/l
Value: 8.118
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_Ini8b: Description: Initial concentration of inert soluble organic material for BT-8 (Diluted)
Type: Constant Variable
Unit: mg/l
Value: 8.118
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_N2: Description: Denitrogen gas
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

S_N2ini: Description: Initial concentration of denitrogen
Type: Variable List Variable
Unit: mg/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1 S_N2ini1a
2 S_N2ini2a
3 S_N2ini3a
4 S_N2ini4a
5 S_N2ini5a
6 S_N2ini6a
7 S_N2ini7a
8 S_N2ini8a
11 S_N2ini11b
12 S_N2ini12b
13 S_N2ini13b
14 S_N2ini14b
15 S_N2ini15b
16 S_N2ini16b
17 S_N2ini17b
18 S_N2ini18b

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**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 0  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 10  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

S_NH4:  
**Description:** Ammonium plus ammonia nitrogen  
**Type:** Dyn. Volume State Var.  
**Unit:** mg/l  
**Relative Accuracy:** 1e-006  
**Absolute Accuracy:** 1e-006

S_NH4ini:  
**Description:** Initial concentration of ammonium plus ammonia nitrogen  
**Type:** Variable List Variable  
**Unit:** mg/l  
**Argument:** Calcium  
**Interpolation Method:** linear interpolation  
**Real-Variable Data Pairs (16 pairs):**
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2. S_NH4ini2a  
3. S_NH4ini3a  
4. S_NH4ini4a  
5. S_NH4ini5a  
6. S_NH4ini6a  
7. S_NH4ini7a  
8. S_NH4ini8a  
9. S_NH4ini9a  
10. S_NH4ini10a  
11. S_NH4ini11a  
12. S_NH4ini12a  
13. S_NH4ini13a  
14. S_NH4ini14a  
15. S_NH4ini15a  
16. S_NH4ini16a  
17. S_NH4ini17a  
18. S_NH4ini18a

S_NH4ini1a:  
**Description:** Initial concentration of ammonium plus ammonia nitrogen for BT-1  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 1.54  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 10  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

S_NH4ini1b:  
**Description:** Initial concentration of ammonium plus ammonia nitrogen for BT-1  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 1.54  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 10
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Value: 1.12
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

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S_NH4ini5a:
Description: Initial concentration of ammonium plus ammonia nitrogen for BT-5
Type: Constant Variable
Unit: mg/l
Value: 0.4765
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

S_NH4ini5b:
Description: Initial concentration of ammonium plus ammonia nitrogen for BT-5
Type: Constant Variable
Unit: mg/l
Value: 0.4758
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

S_NH4ini6a:
Description: Initial concentration of ammonium plus ammonia nitrogen for BT-6
Type: Constant Variable
Unit: mg/l
Value: 0.4713
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

S_NH4ini6b:
Description: Initial concentration of ammonium plus ammonia nitrogen for BT-6
Type: Constant Variable
Unit: mg/l
Value: 0.4722
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

---

S_NH4ini7a:
Description: Initial concentration of ammonium plus ammonia nitrogen for BT-7 (Undiluted)
Type: Constant Variable
Unit: mg/l
Value: 0.478
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4ini7b: Description: Initial concentration of ammonium plus ammonia nitrogen for BT-7 (Undiluted)
Type: Constant Variable
Unit: mg/l
Value: 0.4778
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4ini8a: Description: Initial concentration of ammonium plus ammonia nitrogen for BT-8 (Diluted)
Type: Constant Variable
Unit: mg/l
Value: 0.0956
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4ini8b: Description: Initial concentration of ammonium plus ammonia nitrogen for BT-8 (Diluted)
Type: Constant Variable
Unit: mg/l
Value: 0.0956
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_NH4meas: Description: Measured soluble ammonia
Type: Variable List Variable
Unit: mg/l
Argument: Calculation
Interpolation Method: linear interpolation
Real-Variable Data Pairs (8 pairs):
1  S_NH4meas1
2  S_NH4meas2
3  S_NH4meas3
4  S_NH4meas4
5  S_NH4meas5
6  S_NH4meas6
7  S_NH4meas7
8  S_NH4meas8

S_NH4meas1: Description: Measured soluble ammonia (BT-1)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (6 pairs):
1  1.54
6  1.4
7  1.4
8  0.84
9  0.28
10 0.21

S_NH4meas2: Description: Measured soluble ammonia (BT-2)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (5 pairs):
1  1.54
2  0.42
3  0.14
5  0.42
6  0.42

S_NH4meas3: Description: Measured soluble ammonia (BT-3)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (20 pairs):
2  0.14
4  0.42
5  0.56
7  0.56
8  0.42
...
19 0.28
21 0.28
22 0.56
23 0.7
25 0.28

S_NH4meas4: Description: Measured soluble ammonia (BT-4)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1  
Minimum: 0  
Maximum: 1e+009  
Interpolation Method: linear interpolation  
Sensitivity Analysis: inactive  
Real Data Pairs (18 pairs):  
1  1.12  
2  1.68  
3  1.26  
5  1.82  
6  1.12  
.  .  
17  0.14  
18  0.14  
19  0.14  
20  0.14  
21  0.14

S_NH4meas5:  
Description: Measured soluble ammonia (BT-5)  
Type: Real List Variable  
Unit: mg/l  
Argument: t  
Standard Deviations: global  
Rel. Stand. Deviat.: 0  
Abs. Stand. Deviat.: 1  
Minimum: 0  
Maximum: 1e+009  
Interpolation Method: linear interpolation  
Sensitivity Analysis: inactive  
Real Data Pairs (2 pairs):  
5  1.12  
11  0.14

S_NH4meas6:  
Description: Measured soluble ammonia (BT-6)  
Type: Real List Variable  
Unit: mg/l  
Argument: t  
Standard Deviations: global  
Rel. Stand. Deviat.: 0  
Abs. Stand. Deviat.: 1  
Minimum: 0  
Maximum: 1e+009  
Interpolation Method: linear interpolation  
Sensitivity Analysis: inactive  
Real Data Pairs (5 pairs):  
5  3.5  
6  3.08  
8  1.4  
11  1.68  
14  1.4

S_NH4meas7:  
Description: Measured soluble ammonia (BT-7) Undiluted  
Type: Real List Variable  
Unit: mg/l  
Argument: t  
Standard Deviations: global  
Rel. Stand. Deviat.: 0  
Abs. Stand. Deviat.: 1  
Minimum: 0
### S_NH4meas8:

**Description:** Measured soluble ammonia (BT-8) Diluted

- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009

**Real Data Pairs (4 pairs):**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.52</td>
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<td>5</td>
<td>4.76</td>
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<td>8</td>
<td>3.78</td>
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<tr>
<td>9</td>
<td>2.8</td>
</tr>
</tbody>
</table>

### S_NO3:

**Description:** Nitrate plus nitrite nitrogen

- **Type:** Dyn. Volume State Var.
- **Unit:** mg/l
- **Relative Accuracy:** 1e-006
- **Absolute Accuracy:** 1e-006

### S_NO3ini:

**Description:** Initial concentration of nitrate plus nitrite nitrogen

- **Type:** Variable List Variable
- **Unit:** mg/l
- **Argument:** Calcium

**Interpolation Method:** linear interpolation

**Real-Variable Data Pairs (16 pairs):**

<p>| | |</p>
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<tr>
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<tbody>
<tr>
<td>1</td>
<td>S_NO3ini1a</td>
</tr>
<tr>
<td>2</td>
<td>S_NO3ini2a</td>
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<td>S_NO3ini6a</td>
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<td>S_NO3ini7a</td>
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<td>S_NO3ini8a</td>
</tr>
<tr>
<td>11</td>
<td>S_NO3ini1b</td>
</tr>
<tr>
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<td>S_NO3ini2b</td>
</tr>
<tr>
<td>13</td>
<td>S_NO3ini3b</td>
</tr>
<tr>
<td>14</td>
<td>S_NO3ini4b</td>
</tr>
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<td>15</td>
<td>S_NO3ini5b</td>
</tr>
<tr>
<td>16</td>
<td>S_NO3ini6b</td>
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<td>17</td>
<td>S_NO3ini7b</td>
</tr>
<tr>
<td>18</td>
<td>S_NO3ini8b</td>
</tr>
</tbody>
</table>

### S_NO3inila:

**Description:** Initial concentration of nitrate plus nitrite nitrogen for BT-1
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Sensitivity Analysis</th>
<th>Parameter Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>S_NO3ini1b</td>
<td>Initial concentration of nitrate plus nitrite nitrogen for BT-1</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>17.72</td>
<td>0.1</td>
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<tr>
<td>S_NO3ini2a</td>
<td>Initial concentration of nitrate plus nitrite nitrogen for BT-2</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>22.54</td>
<td>0.1</td>
<td>0</td>
<td>100</td>
<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>S_NO3ini2b</td>
<td>Initial concentration of nitrate plus nitrite nitrogen for BT-2</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>27.45</td>
<td>0.1</td>
<td>0</td>
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<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>S_NO3ini3a</td>
<td>Initial concentration of nitrate plus nitrite nitrogen for BT-3</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>38.31</td>
<td>0.1</td>
<td>0</td>
<td>50</td>
<td>inactive</td>
<td>inactive</td>
</tr>
<tr>
<td>S_NO3ini3b</td>
<td>Initial concentration of nitrate plus nitrite nitrogen for BT-3</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>13.56</td>
<td>0.1</td>
<td>0</td>
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<td>inactive</td>
<td>inactive</td>
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Real-Variable Data Pairs (8 pairs):
1  S_NO3meas1
2  S_NO3meas2
3  S_NO3meas3
4  S_NO3meas4
5  S_NO3meas5
6  S_NO3meas6
7  S_NO3meas7
8  S_NO3meas8

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<tr>
<td><strong>S_NO3meas1</strong></td>
<td><strong>Description:</strong> Measured nitrate (BT-1)</td>
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<td><strong>Type:</strong></td>
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<td><strong>Unit:</strong></td>
<td>mg/l</td>
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<tr>
<td><strong>Argument:</strong></td>
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<tr>
<td><strong>Standard Deviations:</strong></td>
<td>global</td>
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<td><strong>Rel. Stand. Deviat.:</strong></td>
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<tr>
<td><strong>Abs. Stand. Deviat.:</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Minimum:</strong></td>
<td>0</td>
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<tr>
<td><strong>Maximum:</strong></td>
<td>1e+009</td>
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<tr>
<td><strong>Interpolation Method:</strong></td>
<td>linear interpolation</td>
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<tr>
<td><strong>Sensitivity Analysis:</strong></td>
<td>inactive</td>
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Real Data Pairs (1 pairs):
1  0

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<tr>
<td><strong>S_NO3meas2</strong></td>
<td><strong>Description:</strong> Measured nitrate (BT-2)</td>
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<td><strong>Type:</strong></td>
<td>Real List Variable</td>
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<tr>
<td><strong>Unit:</strong></td>
<td>mg/l</td>
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<tr>
<td><strong>Argument:</strong></td>
<td>t</td>
</tr>
<tr>
<td><strong>Standard Deviations:</strong></td>
<td>global</td>
</tr>
<tr>
<td><strong>Rel. Stand. Deviat.:</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Abs. Stand. Deviat.:</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Minimum:</strong></td>
<td>0</td>
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<tr>
<td><strong>Maximum:</strong></td>
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<tr>
<td><strong>Interpolation Method:</strong></td>
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<td><strong>Sensitivity Analysis:</strong></td>
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Real Data Pairs (1 pairs):
2  0

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<tr>
<td><strong>S_NO3meas3</strong></td>
<td><strong>Description:</strong> Measured nitrate (BT-3)</td>
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<tr>
<td><strong>Type:</strong></td>
<td>Real List Variable</td>
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<tr>
<td><strong>Unit:</strong></td>
<td>mg/l</td>
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<tr>
<td><strong>Argument:</strong></td>
<td>t</td>
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<tr>
<td><strong>Standard Deviations:</strong></td>
<td>global</td>
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<tr>
<td><strong>Rel. Stand. Deviat.:</strong></td>
<td>0</td>
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<tr>
<td><strong>Abs. Stand. Deviat.:</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Minimum:</strong></td>
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<tr>
<td><strong>Maximum:</strong></td>
<td>1e+009</td>
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<tr>
<td><strong>Interpolation Method:</strong></td>
<td>linear interpolation</td>
</tr>
<tr>
<td><strong>Sensitivity Analysis:</strong></td>
<td>inactive</td>
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</table>

Real Data Pairs (19 pairs):
1  13.564199
2  49.870416
3  48.141548
4  77.532295
5  138.04266
.
.
15  316.11601
16  329.94695
17  359.33769
18  361.06656
S_NO3meas4:  Description:  Measured nitrate (BT-4)
Type:  Real List Variable
Unit:  mg/l
Argument:  t
Standard Deviations:  global
Rel. Stand. Deviat.:  0
Abs. Stand. Deviat.:  1
Minimum:  0
Maximum:  1e+009
Interpolation Method:  linear interpolation
Sensitivity Analysis:  inactive
Real Data Pairs (15 pairs):
  1  20.851983
  3  56.804381
  5  64.183258
  8  67.6372
  9  99.978659
   .
  16  262.48645
  17  261.63349
  18  272.72198
  20  277.83975
  21  286.88113

S_NO3meas5:  Description:  Measured nitrate (BT-5)
Type:  Real List Variable
Unit:  mg/l
Argument:  t
Standard Deviations:  global
Rel. Stand. Deviat.:  0
Abs. Stand. Deviat.:  1
Minimum:  0
Maximum:  1e+009
Interpolation Method:  linear interpolation
Sensitivity Analysis:  inactive
Real Data Pairs (11 pairs):
  1  39.846786
  2  41.668895
  3  65.356313
  4  87.768254
  5  129.13013
  6  167.39442
  7  212.94715
  8  227.52402
  9  244.10521
 10  253.58018
 11  262.14409

S_NO3meas6:  Description:  Measured nitrate (BT-6)
Type:  Real List Variable
Unit:  mg/l
Argument:  t
Standard Deviations:  global
Rel. Stand. Deviat.:  0
Abs. Stand. Deviat.:  1
Minimum:  0
Maximum:  1e+009
Interpolation Method:  linear interpolation
### Sensitivity Analysis: inactive

**Real Data Pairs (15 pairs):**

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<td>3</td>
<td>53.714122</td>
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<td>4</td>
<td>114.26167</td>
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<td>5</td>
<td>156.32847</td>
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<td>8</td>
<td>281.13095</td>
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<td>9</td>
<td>285.62759</td>
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<td>10</td>
<td>288.23854</td>
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<td>11</td>
<td>293.02528</td>
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<td>299.40761</td>
</tr>
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</table>

**S_NO3meas7:**

- **Description:** Measured nitrate (BT-7) (Undiluted)
- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation

**Real Data Pairs (9 pairs):**

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<tbody>
<tr>
<td>1</td>
<td>13.934025</td>
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<tr>
<td>2</td>
<td>57.487339</td>
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<td>3</td>
<td>97.611250</td>
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<td>4</td>
<td>139.8962</td>
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<td>5</td>
<td>175.98381</td>
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<td>6</td>
<td>218.14568</td>
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<td>7</td>
<td>236.99451</td>
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<td>8</td>
<td>256.58738</td>
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<td>9</td>
<td>263.90371</td>
</tr>
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</table>

**S_NO3meas8:**

- **Description:** Measured nitrate (BT-8) (Diluted)
- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation

**Real Data Pairs (9 pairs):**

<table>
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<tr>
<th>Pair</th>
<th>Value</th>
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<tbody>
<tr>
<td>1</td>
<td>4.3518924</td>
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<td>2</td>
<td>12.683305</td>
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<td>3</td>
<td>22.1444</td>
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<tr>
<td>9</td>
<td>80.796692</td>
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</tbody>
</table>

**S_NO3meas8x5:**

- **Description:** Measured nitrate (BT-8) (Diluted*5)
- **Type:** Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
1   21.759462
2   63.416523
3   110.722
4   174.1804
5   233.97929
6   303.79684
7   343.24532
8   381.75456
9   403.98346

S_O2: Description: Dissolved oxygen
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

S_O2aer: Description: Aeration dissolved oxygen concentration
Type: Constant Variable
Unit: mg/l
Value: 3
Standard Deviation: 0.1
Minimum: 1
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_O2sat: Description: Saturation dissolved oxygen concentration
Type: Constant Variable
Unit: mg/l
Value: 6
Standard Deviation: 0.1
Minimum: 1
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_PO4: Description: Orthophosphate
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

S_PO4ini: Description: Initial concentration of orthophosphate
Type: Variable List Variable
Unit: mg/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
S_P04ini1a: Description: Initial concentration of orthophosphate for BT-1
Type: Constant Variable
Unit: mg/l
Value: 39.38
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_P04ini1b: Description: Initial concentration of orthophosphate for BT-1
Type: Constant Variable
Unit: mg/l
Value: 39.38
Standard Deviation: 0.1
Minimum: 0
Maximum: 100
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_P04ini2a: Description: Initial concentration of orthophosphate for BT-2
Type: Constant Variable
Unit: mg/l
Value: 1.25
Standard Deviation: 0.1
Minimum: 0
Maximum: 50
Sensitivity Analysis: inactive
Parameter Estimation: inactive

S_P04ini2b: Description: Initial concentration of orthophosphate for BT-2
Type: Constant Variable
Unit: mg/l
Value: 1.25
Standard Deviation: 0.1
Minimum: 0
Maximum: 50
Sensitivity Analysis: inactive
Parameter Estimation: inactive
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<tr>
<th>Parameter</th>
<th>Description</th>
<th>Type</th>
<th>Unit</th>
<th>Value</th>
<th>Standard Deviation</th>
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<th>Parameter Estimation</th>
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</thead>
<tbody>
<tr>
<td>S_PO4ini3a</td>
<td>Initial concentration of orthophosphate for BT-3</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>15.21</td>
<td>0.1</td>
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<td>inactive</td>
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<tr>
<td>S_PO4ini3b</td>
<td>Initial concentration of orthophosphate for BT-3</td>
<td>Constant Variable</td>
<td>mg/l</td>
<td>15.21</td>
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<td>Constant Variable</td>
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<td>Initial concentration of orthophosphate for BT-4</td>
<td>Constant Variable</td>
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<td>Parameter</td>
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<td>Unit</td>
<td>Value</td>
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<td>Minimum</td>
<td>Maximum</td>
<td>Sensitivity Analysis</td>
<td>Parameter Estimation</td>
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<td>Constant Variable</td>
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<td>2.36</td>
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<td>Constant Variable</td>
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### S_PO4meas:

**Description:** Measured orthophosphate concentration

- **Type:** Variable List Variable
- **Unit:** mg/l
- **Argument:** Calcium
- **Interpolation Method:** linear interpolation
- **Real-Variable Data Pairs (8 pairs):**

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<th>S_PO4meas2</th>
<th>S_PO4meas3</th>
<th>S_PO4meas4</th>
<th>S_PO4meas5</th>
<th>S_PO4meas6</th>
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### S_PO4meas1:

**Description:** Measured soluble phosphorus (BT-1)

- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive
- **Real Data Pairs (9 pairs):**

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### S_PO4meas2:

**Description:** Measured soluble phosphorus (BT-2)

- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive
- **Real Data Pairs (6 pairs):**

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S_P04meas3: Description: Measured soluble phosphorus (BT-3)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (22 pairs):
  4   36.94
  5   63.17
  6   88.1
  7  115.64
  8  134.34
  21  288.71
  22  272.24
  23  278.71
  24  289.59
  25  296.06

S_P04meas4: Description: Measured soluble phosphorus (BT-4)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (21 pairs):
  1   0.31
  2   5.03
  3  12.81
  4  29.19
  5  42.25
  17 176.33
  18 198.37
  19 207.1
  20 213.01
  21 218.65

S_P04meas5: Description: Measured soluble phosphorus (BT-5)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (11 pairs):
1
2
3
4
5
6
7
8
9
10
11

S_PO4meas6: Description: Measured soluble phosphorus (BT-6)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (15 pairs):
1
2
3
4
5
11
12
13
14
15

S_PO4meas7: Description: Measured soluble phosphorus (BT-7)
Undiluted
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
1
2
3
4
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<td>Real Data Pairs (9 pairs):</td>
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Real Data Pairs (11 pairs):

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Real Data Pairs (15 pairs):

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<tr>
<td>Minimum:</td>
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Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
1  794.3
2  769.82
3  745.34
4  848.19
5  809.75
6  796.94
7  822.56
8  784.13
9  771.31

S_Ptmess8: Description: Measured total phosphorus (BT-8) Diluted
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
1  590.48
2  574
3  561.76
4  668.81
5  604.75
6  617.56
7  617.56
8  617.56
9  656

T: Description: Temperature
Type: Formula Variable
Unit: degC
Expression: 20

t: Description: Time
Type: Program Variable
Unit: d
Reference to: Time

the_bAUT: Description: Arrhenius constant for the decay rate of autotrophs
Type: Constant Variable
Unit:
Value: 1.029
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

the_bH: Description: Arrhenius constant for the rate constant for lysis of heterotrophs
Type: Constant Variable
the_bPAO: Description: Arrhenius constant for the rate constant for lysis of X_PAO
Type: Constant Variable
Unit: Value: 1.029
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

the_bPHA: Description: Arrhenius constant for the rate constant for lysis of X_PHA
Type: Constant Variable
Unit: Value: 1.029
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

the_bPP: Description: Arrhenius constant for the rate constant for lysis of X_PP
Type: Constant Variable
Unit: Value: 1.029
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

the_Kh: Description: Arrhenius constant
Type: Constant Variable
Unit: Value: 1.08
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
Sensitivity Analysis: inactive
Parameter Estimation: inactive

the_KX: Description: Arrhenius constant for saturation coefficient for particulate COD
Type: Constant Variable
Unit: Value: 0.91
Standard Deviation: 0.1
Minimum: 0
Maximum: 10
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Parameter Estimation: inactive
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<td>S_NH4+(S_I<em>i_NS1)+(S_F</em>i_NSf)+(X_I<em>i_NXl)+(X_S</em>i_NXs)+((X_H+X_PA0+X_AU*T)*i_NBM)</td>
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Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (19 pairs):
1   1450.8
2   1400.98
3   1370.62
4   1228.36
5   1125.04
   ...
17  809.34
18  826.56
21  688.8
22  551.04
25  487.9

TKN_meas4: Description: Measured TKN (BT-4)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (15 pairs):
1   1308.72
3   1234.1
4   1027.46
5   1193.92
9   958.58
   ...
15  849.52
16  740.46
17  769.16
20  677.32
21  596.96

TKN_meas5: Description: Measured TKN (BT-5)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
1   1033.2
2   1038.94
3   1038.94
5   906.92
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<th>Measured TKN (BT-7) Undiluted</th>
<th>Measured TKN (BT-8) Diluted</th>
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<tr>
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<td>3 1274.28</td>
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<td>4 1222.62</td>
<td>4 1357.6</td>
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<td>7 1090.6</td>
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<td>11 1015.98</td>
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<td>15 901.18</td>
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Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
1 291.06
2 283.36
3 274.12
4 264.88
5 263.34
6 258.72
7 242.56
8 232.37
9 220

TKN_meas8x5:
Description: Measured TKN (BT-8) (Diluted*5)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 1262.8
2 1455.3
3 1201.2
4 1370.6
5 1416.8
6 1293.6
7 1316.7
9 1324.4

TSS_fi:
Description: TSS computed by dividing VSS by VSS/TSS ratio
Type: Formula Variable
Unit: mg/l
Expression: VSS/f_i

TSS_ISS:
Description: TSS computed by adding ISS to VSS
Type: Formula Variable
Unit: mg/l
Expression: VSS+ISS_Xoi

TSS_meas:
Description: Measured TSS
Type: Variable List Variable
Unit: mg/l
Argument: Calcmum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (8 pairs):
1 TSS_meas1
2 TSS_meas2
3 TSS_meas3
4 TSS_meas4
5 TSS_meas5
6 TSS_meas6
7 TSS_meas7
8 TSS_meas8

TSS_meas1:
Description: Measured TSS (BT-1)
### TSS_meas2:
- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive
- **Real Data Pairs (5 pairs):**
  1. 1 15956.67
  2. 2 15990
  3. 3 15947.67
  4. 4 15946.33
  5. 6 14910.83

### TSS_meas3:
- **Description:** Measured TSS (BT-2)
- **Type:** Real List Variable
- **Unit:** mg/l
- **Argument:** t
- **Standard Deviations:** global
- **Rel. Stand. Deviat.:** 0
- **Abs. Stand. Deviat.:** 1
- **Minimum:** 0
- **Maximum:** 1e+009
- **Interpolation Method:** linear interpolation
- **Sensitivity Analysis:** inactive
- **Real Data Pairs (20 pairs):**
  1. 1 17421.33
  2. 2 17003.17
  4. 4 16208.33
  5. 5 16230.67
  7. 7 14582.33
  21. 10495.67
  22. 22 9790.83
  23. 23 9605.17
  24. 24 9184
  25. 25 8969.17
TSS_meas4: Description: Measured TSS (BT-4)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (19 pairs):
1 16992.08
2 16630.833
3 16211
4 15928.833
5 15157.833
   .
17 11570.167
18 11374.833
19 11166
20 11204.333
21 11280.5

TSS_meas5: Description: Measured TSS (BT-5)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (10 pairs):
1 18380.67
2 17046.67
3 16910.5
4 16374.67
5 15551.67
6 14029.83
7 13902
8 12747.5
10 12669.83
11 11519.17

TSS_meas6: Description: Measured TSS (BT-6)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (12 pairs):
1 17543.83
TSS_meas7: Description: Measured TSS (BT-7) Undiluted
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+09
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 19656.5
2 18814.25
4 17142.5
5 17147.75
6 15879
7 15609.5
8 14307.5
9 14270

TSS_meas8: Description: Measured TSS (BT-8) Diluted
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+09
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 3770
2 3544.25
3 3431.75
5 3215.75
6 2981.25
7 2889.75
8 2833.5
9 2766.75

TSS_meas8x5: Description: Measured TSS (BT-8) (Diluted*5)
Type: Real List Variable
Unit: mg/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1  18850
2  17721.25
3  17158.75
5  16078.75
6  14906.25
7  14448.75
8  14167.5
9  13833.75

TSS_RedMeas:  Description: Measured TSS reduction (delta TSS)
              Type: Variable List Variable
              Unit: mgTSS/1
              Argument: Calcnun
              Interpolation Method: linear interpolation
Real-Variable Data Pairs (6 pairs):
1  TSS_RedMeas1
2  TSS_RedMeas2
3  TSS_RedMeas3
4  TSS_RedMeas4
5  TSS_RedMeas5
6  TSS_RedMeas6

TSS_RedMeas1:  Description: Measured TSS reduction (delta TSS) for BT-1
               Type: Real List Variable
               Unit: mgTSS/1
               Argument: t
               Standard Deviations: global
               Rel. Stand. Deviat.: 0
               Abs. Stand. Deviat.: 1
               Minimum: 0
               Maximum: 1e+009
               Interpolation Method: linear interpolation
               Sensitivity Analysis: inactive
Real Data Pairs (6 pairs):
2  200.04
3  325.04
4  853.71
5  3207.04
7  3433.71
8  3839.71

TSS_RedMeas2:  Description: Measured TSS reduction (delta TSS) for BT-2
               Type: Real List Variable
               Unit: mgTSS/1
               Argument: t
               Standard Deviations: global
               Rel. Stand. Deviat.: 0
               Abs. Stand. Deviat.: 1
               Minimum: 0
               Maximum: 1e+009
               Interpolation Method: linear interpolation
               Sensitivity Analysis: inactive
Real Data Pairs (3 pairs):
3  9
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<th>Description: Measured TSS reduction (delta TSS) for BT-3</th>
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Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
2
  1334
3
  1470.17
4
  2006
5
  2829
6
  4350.83
7
  4478.67
8
  5633.17
10
  5710.83
11
  6861.5

TSS_RedMeas6: Description: Measured TSS reduction (delta TSS)
for BT-6
Type: Real List Variable
Unit: mgTSS/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (11 pairs):
2
  475.67
3
  1089.83
4
  2211.33
5
  2561.17
6
  3434
7
  3739.67
8
  4729
9
  4734.17
10
  4901.67
13
  5070.333
14
  5190

VSS: Description: Actual VSS (mgVSS/l)
Type: Formula Variable
Unit: mgVSS/l
Expression: mVSS/f_cvK

VSS_meas: Description: Measured VSS
Type: Variable List Variable
Unit: mg/l
Argument: Calcnum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (8 pairs):
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  VSS_meas1
2
  VSS_meas2
3
  VSS_meas3
4
  VSS_meas4
5
  VSS_meas5
6
  VSS_meas6
7
  VSS_meas7
8
  VSS_meas8
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| 17 | 13238.6 |
| 18 | 12987.493 |
| 19 | 12712.213 |
| 20 | 12787.94 |
| 21 | 12982.56 |

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VSS_meas7:
Description: Measured VSS (BT-7) (Undiluted)
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 23025.47
2 21418.19
3 21051.15
5 19775.39
6 18248.4
7 18197.34
8 17031.1
9 16907.52

VSS_meas8:
Description: Measured VSS (BT-8) (Diluted)
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1 4417.43
2 4118.1
3 4111.81
4 3988.35
5 3877.97
6 3553.48
7 3511.67
8 3385.13

VSS_meas8x5:
Description: Measured VSS (BT-8) (Diluted*5)
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (8 pairs):
1   22087.15
2   20590.5
3   20559.05
5   19389.85
6   17767.4
7   17558.35
8   16925.65
9   16960.8

VSS_RedMeas: Description: Measured VSS reduction (delta VSS)
Type: Variable List Variable
Unit: mgCOD/l
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (6 pairs):
1   VSS_RedMeas1
2   VSS_RedMeas2
3   VSS_RedMeas3
4   VSS_RedMeas4
5   VSS_RedMeas5
6   VSS_RedMeas6

VSS_RedMeas1: Description: Measured VSS reduction (delta VSS) for BT-1
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (6 pairs):
2   734.26
3   76.64
4   565.04
5   3188.59
7   3472.75
8   4248.27

VSS_RedMeas2: Description: Measured VSS reduction (delta VSS) for BT-2
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (4 pairs):
2   188.51
3  491.17
4  465.77
6  1581.69

VSS_RedMeas3: Description: Measured VSS reduction (delta VSS)
for BT-3
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (19 pairs):
  2  1183.51
  4  2086.8
  5  2058.43
  7  4355.64
  8  4031.77
  ...
  21  8933.0333
  22  9679.2
  23  9995.6733
  24  10443.62
  25  10619.247

VSS_RedMeas4: Description: Measured VSS reduction (delta VSS)
for BT-4
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (18 pairs):
  2  398.61
  3  979.27
  4  1383.31
  5  2162.53
  6  2889.95
  ...
  17  6595.1267
  18  6846.2333
  19  7121.5133
  20  7045.7867
  21  6851.1667

VSS_RedMeas5: Description: Measured VSS reduction (delta VSS)
for BT-5
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (9 pairs):
2  2652.39
3  3086.79
4  3515.49
5  4103.79
6  6096.86
7  6311.21
9  6611.65
10 7276.91
11 8521.1

VSS_RedMeas6: Description: Measured VSS reduction (delta VSS) for BT-6
Type: Real List Variable
Unit: mgCOD/l
Argument: t
Standard Deviations: global
Rel. Stand. Deviat.: 0
Abs. Stand. Deviat.: 1
Minimum: 0
Maximum: 1e+009
Interpolation Method: linear interpolation
Sensitivity Analysis: inactive
Real Data Pairs (10 pairs):
2  308.79
3  930.89
4  3505.84
5  3617.83
6  4310.71
7  4002.87
11 4499.91
12 4901.48
13 5165.6588
14 5200.6855

X_AUT: Description: Nitrifying organisms
Type: Dyn. Volume State Var.
Unit: mg/l
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

X_AUTini: Description: Initial concentration of nitrifying organisms
Type: Variable List Variable
Unit: mg/l
Argument: CalcuNum
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1   X_AUTini1a
2   X_AUTini2a
3   X_AUTini3a
4   X_AUTini4a
5   X_AUTini5a
6   X_AUTini6a
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Value: 488.8
Standard Deviation: 0.1
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Maximum: 1000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_AUTini4a:**
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Value: 403.9
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Parameter Estimation: inactive

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Type: Constant Variable
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Sensitivity Analysis: inactive
Parameter Estimation: inactive

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Type: Constant Variable
Unit: mg/l
Value: 311.4
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Parameter Estimation: inactive

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Unit: mg/l
Value: 312
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Parameter Estimation: inactive  

\[ X_{eGt\_SS} : \text{Description: Concentration of endogenous residue (PAO) at time } t \]  
\[ \text{Type: Formula Variable} \]  
\[ \text{Unit: mgCOD/l} \]  
\[ \text{Expression: } f_{G\_SS}\times X\_PAOini\times(1-(\exp(-b\_PAO20\_SS\times t))) \]  

\[ X_{eHt\_SS} : \text{Description: Concentration of endogenous residue (PAO) at time } t \]  
\[ \text{Type: Formula Variable} \]  
\[ \text{Unit: mgCOD/l} \]  
\[ \text{Expression: } f_{H\_SS}\times X\_Hini\times(1-(\exp(-b\_H20\_SS\times t))) \]  

\[ X_{et\_SS} : \text{Description: Total concentration of endogenous residue at time } t \]  
\[ \text{Type: Formula Variable} \]  
\[ \text{Unit: mgCOD/l} \]  
\[ \text{Expression: } X_{eGt\_SS}+X_{eHt\_SS} \]  

\[ X_{Gt\_SS} : \text{Description: Concentration of PAOs at time } t \]  
\[ \text{Type: Formula Variable} \]  
\[ \text{Unit: mgCOD/l} \]  
\[ \text{Expression: } X\_PAOini\times(\exp(-b\_PAO20\_SS\times t)) \]  

\[ X_H : \text{Description: Heterotrophic organisms} \]  
\[ \text{Type: Dyn. Volume State Var.} \]  
\[ \text{Unit: mg/l} \]  
\[ \text{Relative Accuracy: } 1e-006 \]  
\[ \text{Absolute Accuracy: } 1e-006 \]  

\[ X_{Hini} : \text{Description: Initial concentration of heterotrophic organisms} \]  
\[ \text{Type: Variable List Variable} \]  
\[ \text{Unit: mg/l} \]  
\[ \text{Argument: Calcium} \]  
\[ \text{Interpolation Method: linear interpolation} \]  
\[ \text{Real-Variable Data Pairs (16 pairs):} \]  
1. X_Hini1a  
2. X_Hini12a  
3. X_Hini3a  
4. X_Hini4a  
5. X_Hini5a  
6. X_Hini6a  
7. X_Hini7a  
8. X_Hini8a  
9. X_Hini11b  
10. X_Hini12b  
11. X_Hini13b  
12. X_Hini14b  
13. X_Hini15b  
14. X_Hini16b  
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16. X_Hini18b  

\[ X_{Hini1a} : \text{Description: Initial concentration of heterotrophic organisms for BT-1} \]
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<td></td>
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Real-Variable Data Pairs (16 pairs):
1. X Ini1a
2. X Ini2a
3. X Ini3a
4. X Ini4a
5. X Ini5a
6. X Ini6a
7. X Ini7a
8. X Ini8a
9. X Ini11b
10. X Ini12b
11. X Ini13b
12. X Ini14b
13. X Ini15b
14. X Ini16b
15. X Ini17b
16. X Ini18b

---

X Ini1a:  
**Description:** Initial particulate inert organic matter for BT-1  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 13487.4  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 25000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

---

X Ini11b:  
**Description:** Initial particulate inert organic matter for BT-1  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 10834.6  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 25000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

---

X Ini2a:  
**Description:** Initial particulate inert organic matter for BT-2  
**Type:** Constant Variable  
**Unit:** mg/l  
**Value:** 10478.7  
**Standard Deviation:** 0.1  
**Minimum:** 0  
**Maximum:** 25000  
**Sensitivity Analysis:** inactive  
**Parameter Estimation:** inactive

---

X Ini2b:  
**Description:** Initial particulate inert organic matter for BT-2
### A.302

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</tr>
<tr>
<td><strong>Value</strong></td>
<td>8454.8</td>
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<td><strong>Minimum</strong></td>
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<tr>
<td><strong>Maximum</strong></td>
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**X_Ini3a:**

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<td><strong>Maximum</strong></td>
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**X_Ini3b:**

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<td><strong>Value</strong></td>
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<td><strong>Maximum</strong></td>
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**X_Ini4a:**

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<td><strong>Maximum</strong></td>
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**X_Ini4b:**

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<td><strong>Maximum</strong></td>
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**X_Ini5a:**

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<td><strong>Value</strong></td>
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<td><strong>Minimum</strong></td>
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</tr>
<tr>
<td><strong>Maximum</strong></td>
<td>15000</td>
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### X_Ini5b:
- **Description:** Initial particulate inert organic matter for BT-5
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 12183.4
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 15000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_Ini6a:
- **Description:** Initial particulate inert organic matter for BT-6
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 12273.4
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 15000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_Ini6b:
- **Description:** Initial particulate inert organic matter for BT-6
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 12026.9
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 15000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_Ini7a:
- **Description:** Initial particulate inert organic matter for BT-7 (Undiluted)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 15077
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 30000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_Ini7b:
- **Description:** Initial particulate inert organic matter for BT-7 (Undiluted)
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 14531.6
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 30000
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

### X_Ini8a:
- **Description:** Initial particulate inert organic matter for BT-8 (Diluted)
- **Type:** Constant Variable
Unit: \( \text{mg/l} \)
Value: 3015.4
Standard Deviation: 0.1
Minimum: 0
Maximum: 15000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_ini8b:**
Description: Initial particulate inert organic matter for BT-8 (Diluted)
Type: Constant Variable
Unit: \( \text{mg/l} \)
Value: 2906.3
Standard Deviation: 0.1
Minimum: 0
Maximum: 15000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_PAO:**
Description: Phosphate accumulating organisms
Type: Dyn. Volume State Var.
Unit: \( \text{mg/l} \)
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

**X_PAOini:**
Description: Initial concentration of PAO
Type: Variable List Variable
Unit: \( \text{mg/l} \)
Argument: Calcium
Interpolation Method: cubic spline interpolation
Real-Variable Data Pairs (16 pairs):
1  X_PAOini1a
2  X_PAOini2a
3  X_PAOini3a
4  X_PAOini4a
5  X_PAOini5a
6  X_PAOini6a
7  X_PAOini7a
8  X_PAOini8a
9  X_PAOini1b
10 X_PAOini2b
11 X_PAOini3b
12 X_PAOini4b
13 X_PAOini5b
14 X_PAOini6b
15 X_PAOini7b
16 X_PAOini8b

**X_PAOini1a:**
Description: Initial concentration of PAO for BT-1
Type: Constant Variable
Unit: \( \text{mg/l} \)
Value: 1693.4
Standard Deviation: 0.1
Minimum: 0
Maximum: 5000
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_PAOini1b:**
Description: Initial concentration of PAO for BT-1
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<tr>
<th>Description</th>
<th>Initial concentration of PAO for BT</th>
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<tr>
<td>X_PAOni2b</td>
<td>-3</td>
</tr>
<tr>
<td>X_PAOni3a</td>
<td>-3</td>
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<tr>
<td>X_PAOni3b</td>
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<tr>
<td>X_PAOni4a</td>
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**Type:** Constant Variable

**Unit:** mg/l

**Value:**

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<tr>
<td>X_PAOni2b</td>
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<td>X_PAOni3a</td>
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<td>X_PAOni3b</td>
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**Standard Deviation:**

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**Maximum:**

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<td>X_PAOni2b</td>
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**Sensitivity Analysis:** inactive

**Parameter Estimation:** inactive
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<th>Parameter Estimation</th>
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**Description:** Initial concentration of PAO for BT -7 (Undiluted)
**Type:** Constant Variable
**Unit:** mg/l
**Value:** 4500.5
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 7000
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

### X_PAOni8a:
**Description:** Initial concentration of PAO for BT -8 (Diluted)
**Type:** Constant Variable
**Unit:** mg/l
**Value:** 776.9
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 7000
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

### X_PAOni8b:
**Description:** Initial concentration of PAO for BT -8 (Diluted)
**Type:** Constant Variable
**Unit:** mg/l
**Value:** 900.1
**Standard Deviation:** 0.1
**Minimum:** 0
**Maximum:** 7000
**Sensitivity Analysis:** inactive
**Parameter Estimation:** inactive

### X_PHA:
**Description:** A cell internal storage product of phosphate accumulating organisms
**Type:** Dyn. Volume State Var.
**Unit:** mg/l
**Relative Accuracy:** 1e-006
**Absolute Accuracy:** 1e-006

### X_PHAini:
**Description:** Initial concentration of PHA
**Type:** Variable List Variable
**Unit:** mg/l
**Argument:** Calcnum
**Interpolation Method:** linear interpolation
**Real-Variable Data Pairs (16 pairs):**
1. X_PHA ini1a
2. X_PHA ini2a
3. X_PHA ini3a
4. X_PHA ini4a
5. X_PHA ini5a
6. X_PHA ini6a
7. X_PHA ini7a
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<td>Constant Variable</td>
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Value: 109
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_PHAini6b:**
Description: Initial concentration of PHA for BT -6
Type: Constant Variable
Unit: mg/l
Value: 117.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_PHAini7a:**
Description: Initial concentration of PHA for BT -7 (Undiluted)
Type: Constant Variable
Unit: mg/l
Value: 98.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_PHAini7b:**
Description: Initial concentration of PHA for BT -7 (Undiluted)
Type: Constant Variable
Unit: mg/l
Value: 113.5
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_PHAini8a:**
Description: Initial concentration of PHA for BT -8 (Diluted)
Type: Constant Variable
Unit: mg/l
Value: 20.946
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_PHAini8b:**
Description: Initial concentration of PHA for BT -8 (Diluted)
Type: Constant Variable
Unit: mg/l
Value: 20.946
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive  
Parameter Estimation: inactive  

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**X_PPini2b:**
- **Description:** Initial concentration of PP for BT-2
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 953.6
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1500
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**X_PPini3a:**
- **Description:** Initial concentration of PP for BT-3
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 1069
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1500
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**X_PPini3b:**
- **Description:** Initial concentration of PP for BT-3
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 1053
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1500
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**X_PPini4a:**
- **Description:** Initial concentration of PP for BT-4
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 1021.2
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1500
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**X_PPini4b:**
- **Description:** Initial concentration of PP for BT-4
- **Type:** Constant Variable
- **Unit:** mg/l
- **Value:** 1056.4
- **Standard Deviation:** 0.1
- **Minimum:** 0
- **Maximum:** 1500
- **Sensitivity Analysis:** inactive
- **Parameter Estimation:** inactive

**X_PPini5a:**
- **Description:** Initial concentration of PP for BT-5
Type: Constant Variable
Unit: mg/l
Value: 1179.5
Standard Deviation: 0.1
Minimum: 0
Maximum: 1500
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PPini5b: Description: Initial concentration of PP for BT-5
Type: Constant Variable
Unit: mg/l
Value: 1190.3
Standard Deviation: 0.1
Minimum: 0
Maximum: 1500
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PPini6a: Description: Initial concentration of PP for BT-6
Type: Constant Variable
Unit: mg/l
Value: 1180.4
Standard Deviation: 0.1
Minimum: 0
Maximum: 1500
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PPini6b: Description: Initial concentration of PP for BT-6
Type: Constant Variable
Unit: mg/l
Value: 1179.3
Standard Deviation: 0.1
Minimum: 0
Maximum: 1500
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PPini7a: Description: Initial concentration of PP for BT-7 (Undiluted)
Type: Constant Variable
Unit: mg/l
Value: 1085.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 1500
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PPini7b: Description: Initial concentration of PP for BT-7 (Undiluted)
Type: Constant Variable
Unit: mg/l
Value: 1077.6
Standard Deviation: 0.1
Minimum: 0
Maximum: 1500
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PPini8a: Description: Initial concentration of PP for BT-8 (Diluted)
Type: Constant Variable
Unit: mg/L
Value: 215.5
Standard Deviation: 0.1
Minimum: 0
Maximum: 1500
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_PPini8b: Description: Initial concentration of PP for BT-8 (Diluted)
Type: Constant Variable
Unit: mg/L
Value: 215.5
Standard Deviation: 0.1
Minimum: 0
Maximum: 1500
Sensitivity Analysis: inactive
Parameter Estimation: inactive

X_S: Description: Slowly biodegradable substrate
Type: Dyn. Volume State Var.
Unit: mg/L
Relative Accuracy: 1e-006
Absolute Accuracy: 1e-006

X_Sini: Description: Initial concentration of slowly biodegradable substrate
Type: Variable List Variable
Unit: mg/L
Argument: Calcium
Interpolation Method: linear interpolation
Real-Variable Data Pairs (16 pairs):
1  X_Sini1a
2  X_Sini2a
3  X_Sini3a
4  X_Sini4a
5  X_Sini5a
6  X_Sini6a
7  X_Sini7a
8  X_Sini8a
11 X_Sini1b
12 X_Sini2b
13 X_Sini3b
14 X_Sini4b
15 X_Sini5b
16 X_Sini6b
17 X_Sini7b
18 X_Sini8b

X_Sinila: Description: Initial concentration of slowly biodegradable substrate for BT-1a
Type: Constant Variable
Unit: mg/L
Value: 140.9
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_Sini1b:**
Description: Initial concentration of slowly bio degradable substrate for BT-1
Type: Constant Variable
Unit: mg/l
Value: 125.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_Sini2a:**
Description: Initial concentration of slowly bio degradable substrate for BT-2a
Type: Constant Variable
Unit: mg/l
Value: 159.3
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_Sini2b:**
Description: Initial concentration of slowly bio degradable substrate for BT-2
Type: Constant Variable
Unit: mg/l
Value: 164
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_Sini3a:**
Description: Initial concentration of slowly bio degradable substrate for BT-3a
Type: Constant Variable
Unit: mg/l
Value: 175.9
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_Sini3b:**
Description: Initial concentration of slowly bio degradable substrate for BT-3
Type: Constant Variable
Unit: mg/l
Value: 181.1
Standard Deviation: 0.1
Minimum: 0
Maximum: 200
Sensitivity Analysis: inactive
Parameter Estimation: inactive

**X_Sini4a:**
Description: Initial concentration of slowly bio
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Unit: mgTSS/l
Expression: 

\[
(X_{\text{Hi}n_i}/f_{\text{cv SS}})*(f_{\text{H SS}}+((1-f_{\text{H SS}})S+ISS_{\text{fOHO}})*(exp(-b_{\text{H2O SS}}^t))))+((X_{\text{PAOini}}/f_{\text{cv SS}})*(f_{\text{G SS}}+((1-f_{\text{G SS}})S+ISS_{\text{fPAO}})*(exp(-b_{\text{PAO20 SS}}^t))))+(X_{\text{Iini}}/f_{\text{cv SS}})+ISS_{\text{Xioini SS}}
\]

---

**X_{Vi SS}**: Description: Initial VSS concentration  
Type: Formula Variable  
Unit: mgCOD/l  
Expression: \(X_{\text{AUTini}}+X_{\text{Hini}}+X_{\text{PAOini}}+X_{\text{Iini}}\)

---

**X_{Vt SS}**: Description: VSS concentration at time t  
Type: Formula Variable  
Unit: mgCOD/l  
Expression: \(((X_{\text{Hini}})*((1-f_{\text{H SS}})*(exp(-b_{\text{H2O SS}}^t)))+f_{\text{H SS}}))+(X_{\text{PAOini}})*((1-f_{\text{G SS}})*(exp(-b_{\text{PAO20 SS}}^t)))+f_{\text{G SS}})+(X_{\text{Iini}})\)

---

**Y_{AUT}**: Description: Yield coefficient (biomass/nitrate) of ANO  
Type: Constant Variable  
Unit: gCOD(gN)-1  
Value: 0.15  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 1  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

---

**Y_{H}**: Description: Yield of OHO  
Type: Constant Variable  
Unit: per day  
Value: 0.67  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 1  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

---

**Y_{H SS}**: Description: Yield of OHO (SSM)  
Type: Constant Variable  
Unit: per day  
Value: 0.45  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 1  
Sensitivity Analysis: inactive  
Parameter Estimation: inactive

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**Y_{PAO}**: Description: Yield coefficient (biomass/PHA)  
Type: Constant Variable  
Unit: per day  
Value: 0.67  
Standard Deviation: 0.1  
Minimum: 0  
Maximum: 1  
Sensitivity Analysis: inactive  
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******************************************************************************

Processes
******************************************************************************

**Aeration:**
Description: Dynamic Process
Rate: \( K_{La} \cdot (S_{O2sat}-S_{O2}) \)
Stoichiometry:
Variable: Stoichiometric Coefficient
\( S_{O2} : 1 \)

**AerobicHydrolysis:**
Description: Aerobic hydrolysis
Type: Dynamic Process
Rate: \( K_h \cdot \left( \frac{S_{O2}}{(K_{O2+S_{O2}})} \right) \cdot \left( \frac{(X_S/X_H)}{(K_X+(X_S/X_H))} \right) \cdot X_H \)
Stoichiometry:
Variable: Stoichiometric Coefficient
\( S_F : 1-f_{SI} \)
\( S_I : f_{SI} \)
\( X_S : -1 \)
\( S_{PO4} : i_{PXs}-((1-f_{SI})i_{PSf})-(f_{SI}i_{PSi}) \)
\( S_{NH4} : i_{NXs}-((1-f_{SI})i_{NSf})-(f_{SI}i_{NSi}) \)
Aerobic Growth S_A: Description: Aerobic growth on fermentable products, S_A
Type: Dynamic Process
Rate: $\mu_e H S_A^\ast (S_{O2}/(K_{O2}+S_{O2}))^\ast (S_A/\left(K_A^\theta H^\theta S_A^\ast \right))^\ast (S_{NH4}/(K_{NH4}^\theta OH^\theta S_{NH4}^\ast ))^\ast (S_{PO4}/(K_F+S_{PO4}))^\ast (X_H/(S_F+S_A^\ast ))$

Stoichiometry:
Variable : Stoichiometric Coefficient
$S_{O2}$ : $-(1-Y_H)/Y_H$
$S_A$ : $-1/Y_H$
$X_H$ : 1
$S_{NH4}$ : $-i_{NBM}$
$S_{PO4}$ : $-i_{PBM}$

Aerobic Growth S_F: Description: Aerobic growth on fermentable substrate, S_F
Type: Dynamic Process
Rate: $\mu_e H S_F^\ast (S_{O2}/(K_{O2}+S_{O2}))^\ast (S_F/\left(K_F^\theta F^\theta S_{F}^\ast \right))^\ast (S_{NH4}/(K_{NH4}^\theta OH^\theta S_{NH4}^\ast ))^\ast (S_{PO4}/(K_F+S_{PO4}))^\ast (X_H/(S_F+S_A^\ast ))$

Stoichiometry:
Variable : Stoichiometric Coefficient
$S_{O2}$ : $-(1-Y_H)/Y_H$
$S_F$ : $-1/Y_H$
$X_H$ : 1
$S_{NH4}$ : $(1/Y_H)^\ast i_{NSf} - i_{NBM}$
$S_{PO4}$ : $(1/Y_H)^\ast (i_{Psf} - i_{PBM})$

Aerobic Growth X_PAO:
Description: Aerobic growth of X_PAO on X_PHA
Type: Dynamic Process
Rate: $\mu_e PAO^\ast (S_{O2}/(K_{O2}+S_{O2}))^\ast (S_{NH4}/(K_{NH4}^\theta PAO^\theta S_{NH4}^\ast ))^\ast (S_{PO4}/(K_F+S_{PO4}))^\ast ((X_{PHA}/X_{PAO})/(K_{PHA}+(X_{PHA}/X_{PAO}))^\ast X_{PAO}$

Stoichiometry:
Variable : Stoichiometric Coefficient
$S_{O2}$ : $-(1-Y_{PAO})/Y_{PAO}$
$S_{PO4}$ : $-i_{PBM}$
$X_{PAO}$ : 1
$X_{PHA}$ : $-1/Y_{PAO}$
$S_{NH4}$ : $-i_{NBM}$

Anaerobic hydrolysis:
Description: Anaerobic hydrolysis
Type: Dynamic Process
Rate: $K_h^\ast \eta_t^\ast (K_{O2}/(K_{O2}+S_{O2}))^\ast (K_NO_3/((NO_3+S_{NO3}))^\ast (X_S/X_H)/(K_X+(X_S/X_H)))^\ast X_H$

Stoichiometry:
Variable : Stoichiometric Coefficient
$S_F$ : $1-f_{SI}$
$S_{NH4}$ : $i_{NS}-((1-f_{SI})\ast i_{NSf}) - (f_{SI}\ast i_{NSi})$
$S_I$ : $f_{SI}$
$X_S$ : $-1$
$S_{PO4}$ : $i_{PXS}-((1-f_{SI})\ast i_{Psf}) - (f_{SI}\ast i_{PSi})$

Anoxic Growth S_A:
Description: Aerobic growth on fermentable products, S_A (Denitrification)
Type: Dynamic Process
Rate: $\text{mue}_H \times \eta_{NO3} \times S_A \times \left( \frac{K_{O2}}{(K_{O2} + S_{O2})} \right) \times \left( \frac{S_A}{(K_{AOH} + S_A)} \right) \times \left( \frac{S_{NH4}}{(K_{NH4} + S_{NH4})} \right) \times \left( \frac{S_NO3}{(K_NO3 + S_NO3)} \right) \times \left( \frac{S_PO4}{(K_P + S_PO4)} \right) \times \left( \frac{X_H}{(S_F + S_A)} \right)$

Stoichiometry:
Variable: Stoichiometric Coefficient
$S_A: -1/Y_H$
$X_H: 1$
$S_{NH4}: -i_{NBM}$
$S_{PO4}: -i_{PBM}$
$S_NO3: -(1-Y_H)/(2.86*Y_H)$
$S_N2: (1-Y_H)/(2.86*Y_H)$

AnoxicGrowthS_F:
Description: Anoxic growth on fermentable substrates, $S_F$ Denitrification
Type: Dynamic Process
Rate: $\text{mue}_H \times \eta_{NO3} \times S_F \times \left( \frac{K_{O2}}{(K_{O2} + S_{O2})} \right) \times \left( \frac{S_F}{(K_F + S_F)} \right) \times \left( \frac{S_{NH4}}{(K_{NH4} + S_{NH4})} \right) \times \left( \frac{S_NO3}{(K_NO3 + S_NO3)} \right) \times \left( \frac{S_PO4}{(K_P + S_PO4)} \right) \times \left( \frac{X_H}{(S_F + S_A)} \right)$

Stoichiometry:
Variable: Stoichiometric Coefficient
$S_F: -1/Y_H$
$X_H: 1$
$S_{NH4}: \left((1/Y_H) \times i_{NSf}\right) - i_{NBM}$
$S_{PO4}: \left((1/Y_H) \times i_{PSf}\right) - i_{PBM}$
$S_NO3: -(1-Y_H)/(2.86*Y_H)$
$S_N2: (1-Y_H)/(2.86*Y_H)$

Anoxichydrolysis:
Description: Anoxic hydrolysis
Type: Dynamic Process
Rate: $K_h \times \eta_{NO3} \times \left( \frac{K_{O2}}{(K_{O2} + S_{O2})} \right) \times \left( \frac{S_N03}{(K_NO3 + S_NO3)} \right) \times \left( \frac{X_S}{X_H} \right) \times \left( \frac{X_S}{X_H} \right)$

Stoichiometry:
Variable: Stoichiometric Coefficient
$S_F: 1-f_SI$
$S_{NH4}: i_{NSf} - ((1-f_SI) \times i_{NSf}) - (f_SI \times i_{NSI})$
$X_S: -1$
$S_{PO4}: i_{PSf} - ((1-f_SI) \times i_{PSf}) - (f_SI \times i_{PSI})$
$S_I: f_SI$

Fermentation:
Description: Fermentation
Type: Dynamic Process
Rate: $\text{q_fe} \times \left( \frac{K_{O2}}{(K_{O2} + S_{O2})} \right) \times \left( \frac{K_NO3}{(K_NO3 + S_NO3)} \right) \times \left( \frac{S_F}{(K_F + S_F)} \right)$

Stoichiometry:
Variable: Stoichiometric Coefficient
$S_F: -1$
$S_A: 1$
$S_{NH4}: i_{NSf}$
$S_{PO4}: i_{PSf}$

GrowthX_AUT:
Description: Growth of nitrifying organisms (autotrophic organisms)
Type: Dynamic Process
Rate: $\text{mue_AUT} \times \left( \frac{S_{O2}}{(K_{O2} + S_{O2})} \right) \times \left( \frac{S_{NH4}}{(K_{NH4} + S_{NH4})} \right) \times \left( \frac{S_PO4}{(K_P + S_PO4)} \right)$
Stoichiometry:
Variable: Stoichiometric Coefficient
S_O2 : -(4.57-Y_AUT)/Y_AUT
S_NH4 : -(1/Y_AUT)-i_NBM
S_NO3 : 1/Y_AUT
S_PO4 : -i_PBM
X_AUT : 1

LysisX_AUT: Description: Lysis/death of autotrophic (nitrifying) organisms
Type: Dynamic Process
Rate: b_AUT*X_AUT
Stoichiometry:
Variable: Stoichiometric Coefficient
S_NH4 : i_NBM-(f_XiAUT*i_NXi)-((1-f_XiAUT)*i_NXs)
S_PO4 : i_PBM-(f_XiAUT*i_PXi)-((1-f_XiAUT)*i_PXs)
X_I : f_XiAUT
X_S : 1-f_XiAUT
X_AUT : -1

LysisX_H: Description: Lysis/death of heterotrophic organisms
Type: Dynamic Process
Rate: b_H*X_H
Stoichiometry:
Variable: Stoichiometric Coefficient
X_I : f_XiOH0
X_S : 1-f_XiOH0
X_H : -1
S_NH4 : i_NBM-(f_XiOH0*i_NXi)-((1-f_XiOH0)*i_NXs)
S_PO4 : i_PBM-(f_XiOH0*i_PXi)-((1-f_XiOH0)*i_PXs)

LysisX_PAO: Description: Lysis/death of X_PAO
Type: Dynamic Process
Rate: b_PAO*X_PAO
Stoichiometry:
Variable: Stoichiometric Coefficient
S_PO4 : i_PBM-(f_XiPAO*i_PXi)-((1-f_XiPAO)*i_PXs)
X_I : f_XiPAO
X_S : 1-f_XiPAO
X_PAO : -1
S_NH4 : i_NBM-(f_XiPAO*i_NXi)-((1-f_XiPAO)*i_NXs)

LysisX_PHA: Description: Lysis of X_PHA
Type: Dynamic Process
Rate: b_PHA*X_PHA
Stoichiometry:
Variable: Stoichiometric Coefficient
S_A : 1
X_PHA : -1

LysisX_PP: Description: Lysis of X_PP
Type: Dynamic Process
Rate: b_PP*X_PP
Stoichiometry:
Variable: Stoichiometric Coefficient
S_PO4 : 1
X_PP : -1

StorageX_PHA: Description: Sequestration of S_A / Storage of X_PHA
Type: Dynamic Process
Rate: \( q_{PHA} \frac{(S_A / (K APAO+S_A)) * ((X_PP/X_P AO) / (K_PP + (X_PP/X_P AO))) * X_PA O}{X_PA O} \)

Stoichiometry:
Variable: Stoichiometric Coefficient
- \( S_A : -1 \)
- \( S_PO4 : Y_PO4 \)
- \( X_PP : -Y_PO4 \)
- \( X_PHA : 1 \)

---

Storage \( X_PP \):
Description: Storage of \( X_PP \)
Type: Dynamic Process
Rate: \( q_{PP} \frac{(S_O2 / (K_O2+S_O2)) * ((S_PO4 / (K_P S+S_PO4)) * ((X_PHA/X_PA O) / (K_P PAB+X_PHA/X_P AO))) * ((X_P_MAX- (X_PP/X_PA O)) / (K_PP+X_P_MAX- (X_PP/X_PA O))) * X_PA O}{X_PA O} \)

Stoichiometry:
Variable: Stoichiometric Coefficient
- \( S_O2 : -Y_PHA \)
- \( S_PO4 : -1 \)
- \( X_PP : 1 \)
- \( X_PHA : -Y_PHA \)

---

Compartments

Reactor:
Description: Mixed Reactor Compartment
Type: 
Compartment Index: 0
Active Variables: \( b_AUT, b_AUT20, b_AUT20_SS, b_H, b_H20, b_H20_SS, b_PA0, b_PA020, b_PA020_SS, b_PHA, b_PHA20, b_PP, b_PP2 0, b_PP20_SS, Calcdum, CODf, CODf_m , CODf_m1, CODf_m2, CODf_m3, CODf_m4, CODf_m5, CODf_m6, CODt, CODt_m, CODt_m1, CODt_m2, CODt_m3, CODt_m4, CODt_m5, CODt_m6, CODt_m7, CODt_m8 , CODT_m8x5, deltaTSSst_SS, deltaVSS t_SS, eta_fe, eta_NO3, eta_NO3d, f_aGTi_SS, f_aGVi_SS, f_aHTi_SS, f_aH Vi_SS, f_avOHO, f_avPAO, f_cv, f_cv 1a, f_cv1b, f_cv2a, f_cv2b, f_cv3a, f_cv3b, f_cv4a, f_cv4b, f_cv5a, f_cv5b, f_cv6a, f_cv6b, f_cv7a, f_cv 7b, f_cv8a, f_cv8b, f_cvK, f_cvm, f _cvm, f_cvm1, f_cvm1, f_cvm2, f_cvm2 , , f_cvm3, f_cvm3, f_cvm4, f_cvm4, f _cvm5, f_cvm5, f_cvm6, f_cvm6, f_cvm M7, f_cvm7, f_cvm8, f_cvm8, f_csv SS , f_GTTrt_SS, f_GVrt_SS, f_G_SS, f_H Trt_SS, f_HVrt_SS, f_H_SS, f_i, f_i 1a, f_i1b, f_i2a, f_i2b, f_i3a, f_i 3b, f_i4a, f_i4b, f_i5a, f_i5b, f_i 6a, f_i6b, f_i7a, f_i7b, f_i8a, f_i 8b, f_iM, f_im, f_im1, f_im2, f_im3, f_im

Initial Conditions:
Variable(Zone) : Initial Condition
S_I(Bulk Volume) : S_Ini
S_NH4(Bulk Volume) : S_NH4ini
X_AUT(Bulk Volume) : X_AUTini
X_H(Bulk Volume) : X_Hini
X_I(Bulk Volume) : X_Ini
X_PAO(Bulk Volume) : X_PAOini
X_S(Bulk Volume) : X_Sini
S_A(Bulk Volume) : S_Aini
S_NO3(Bulk Volume) : S_NO3ini
S_PO4(Bulk Volume) : S_PO4ini
X_PHA(Bulk Volume) : X_PHAini
X_PP(Bulk Volume) : X_PPini
S_F(Bulk Volume) : S_Fini
S_N2(Bulk Volume) : S_N2ini
ISS_Xioi(Bulk Volume) : ISS_Xioini

Inflow: 0
Loadings:
Volume: 5
Accuracies:
Rel. Acc. Q: 0.001
Abs. Acc. Q: 0.001
Rel. Acc. V: 0.001
Abs. Acc. V: 0.001

***********************************************************************************************

Definitions of Calculations
***********************************************************************************************
calc01: Description:
Calculation Number: 1
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation
inactive for sensitivity analysis

calc02: Description:
Calculation Number: 2
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
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A.328
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation

inactive for sensitivity analysis

calc12: Description:
Calculation Number: 12
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation
inactive for sensitivity analysis

calc13: Description:
Calculation Number: 13
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation
inactive for sensitivity analysis

calc14: Description:
Calculation Number: 14
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation
inactive for sensitivity analysis

calc15: Description:
Calculation Number: 15
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation
inactive for sensitivity analysis

calc16: Description:
Calculation Number: 16
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation
inactive for sensitivity analysis

calc17: Description:
Calculation Number: 17
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation
inactive for sensitivity analysis

calc18: Description:
Calculation Number: 18
Initial Time: 0
Initial State: given, made consistent
Step Size: 0.001
Num. Steps: 25000
Status: active for simulation
inactive for sensitivity analysis

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Plot Definitions

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<th>COD_fla:</th>
<th>Description:</th>
<th>Filtered COD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abscissa:</td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>Title:</td>
<td>(a) Measured and simulated filtered COD for BT-1, BT-2 and BT-3</td>
<td></td>
</tr>
<tr>
<td>Abscissa Label:</td>
<td>Retention time (d)</td>
<td></td>
</tr>
<tr>
<td>Ordinate Label:</td>
<td>Filtered COD (mg/l)</td>
<td></td>
</tr>
<tr>
<td>Curves:</td>
<td>Type: Variable [CalcNum, Comp., Zone, Time/Space]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value: CODf [1, Reactor, Bulk Volume, 0]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value: CODf [2, Reactor, Bulk Volume, 0]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value: CODf [3, Reactor, Bulk Volume, 0]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value: CODf_m1 [1, Reactor, Bulk Volume, 0]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value: CODf_m2 [2, Reactor, Bulk Volume, 0]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value: CODf_m3 [3, Reactor, Bulk Volume, 0]</td>
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</table>
COD_f1b:
Description: Filtered COD
Abscissa: Time
Title: Measured and simulated filtered-COD for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: Filtered COD (mg/l)
Curves:
  Type: Variable [CalcNum,Comp.,Zone,Time/Space]
  Value: CODf [11, Reactor, Bulk Volume, 0]
  Value: CODf [12, Reactor, Bulk Volume, 0]
  Value: CODf [13, Reactor, Bulk Volume, 0]
  Value: CODf_m1 [1, Reactor, Bulk Volume, 0]
  Value: CODf_m2 [2, Reactor, Bulk Volume, 0]
  Value: CODf_m3 [3, Reactor, Bulk Volume, 0]

COD_f2a:
Description: Filtered COD
Abscissa: Time
Title: (a) Measured and simulated filtered-COD for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Filtered COD (mg/l)
Curves:
  Type: Variable [CalcNum,Comp.,Zone,Time/Space]
  Value: CODf [4, Reactor, Bulk Volume, 0]
  Value: CODf [5, Reactor, Bulk Volume, 0]
  Value: CODf [6, Reactor, Bulk Volume, 0]
  Value: CODf_m4 [4, Reactor, Bulk Volume, 0]
  Value: CODf_m5 [5, Reactor, Bulk Volume, 0]
  Value: CODf_m6 [6, Reactor, Bulk Volume, 0]

COD_f2b:
Description: Filtered COD
Abscissa: Time
Title: Measured and simulated filtered-COD for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Filtered COD (mg/l)
Curves:
  Type: Variable [CalcNum,Comp.,Zone,Time/Space]
  Value: CODf [14, Reactor, Bulk Volume, 0]
  Value: CODf [15, Reactor, Bulk Volume, 0]
  Value: CODf [16, Reactor, Bulk Volume, 0]
  Value: CODf_m4 [4, Reactor, Bulk Volume, 0]
  Value: CODf_m5 [5, Reactor, Bulk Volume, 0]
  Value: CODf_m6 [6, Reactor, Bulk Volume, 0]

COD_tla:
Description: Total COD
Abscissa: Time
Title: (a) Measured and simulated total-COD for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: Total COD (mg/l)
Curves:
  Type: Variable [CalcNum,Comp.,Zone,Time/Space]
  Value: CODt [1, Reactor, Bulk Volume, 0]
  Value: CODt [2, Reactor, Bulk Volume, 0]
  Value: CODt [3, Reactor, Bulk Volume, 0]
  Value: CODt_m1 [1, Reactor, Bulk Volume, 0]
  Value: CODt_m2 [2, Reactor, Bulk Volume, 0]
  Value: CODt_m3 [3, Reactor, Bulk Volume, 0]

COD_tib:
Description: Total COD
Abscissa: Time
Title: (b) Measured and simulated total-COD D for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: Total COD (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: CODt [11, Reactor, Bulk Volume, 0]
Value: CODt [12, Reactor, Bulk Volume, 0]
Value: CODt [13, Reactor, Bulk Volume, 0]
Value: CODt_m1 [1, Reactor, Bulk Volume, 0]
Value: CODt_m2 [2, Reactor, Bulk Volume, 0]
Value: CODt_m3 [3, Reactor, Bulk Volume, 0]

COD_t2a:
Description: Total COD
Abscissa: Time
Title: (a) Measured and simulated total-COD D for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Total COD (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: CODt [4, Reactor, Bulk Volume, 0]
Value: CODt [5, Reactor, Bulk Volume, 0]
Value: CODt [6, Reactor, Bulk Volume, 0]
Value: CODt_m4 [4, Reactor, Bulk Volume, 0]
Value: CODt_m5 [5, Reactor, Bulk Volume, 0]
Value: CODt_m6 [6, Reactor, Bulk Volume, 0]

COD_t2b:
Description: Total COD
Abscissa: Time
Title: (b) Measured and simulated total-COD D for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Total COD (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: CODt [14, Reactor, Bulk Volume, 0]
Value: CODt [15, Reactor, Bulk Volume, 0]
Value: CODt [16, Reactor, Bulk Volume, 0]
Value: CODt_m4 [4, Reactor, Bulk Volume, 0]
Value: CODt_m5 [5, Reactor, Bulk Volume, 0]
Value: CODt_m6 [6, Reactor, Bulk Volume, 0]

COD_tDa:
Description: Total COD (Dilution check)
Abscissa: Time
Title: Measured and simulated total-COD for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: Total COD (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: CODt [7, Reactor, Bulk Volume, 0]
Value: CODt [8, Reactor, Bulk Volume, 0]
Value: CODt_m7 [8, Reactor, Bulk Volume, 0]
Value: CODt_m8 [8, Reactor, Bulk Volume, 0]

COD_tDb:
Description: Total COD (Dilution check)
Abscissa: Time
Title: Measured and simulated total-COD for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: Total COD (mg/l)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: CODt [17, Reactor, Bulk Volume, 0]
  Value: CODt [18, Reactor, Bulk Volume, 0]
  Value: CODt_m7 [8, Reactor, Bulk Volume, 0]
  Value: CODt_m8 [8, Reactor, Bulk Volume, 0]

deltaTSS1a:
  Description: TSS reduction (change of TSS)
  Abscissa: Time
  Title: (a) Measured and simulated TSS reduction (change of TSS) for BT-1, BT-2 and BT-3
  Abscissa Label: Retention time (d)
  Ordinate Label: TSS Reduction (mgTSS/l)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: deltaTSSt_SS [1, Reactor, Bulk Volume, 0]
  Value: deltaTSSt_SS [2, Reactor, Bulk Volume, 0]
  Value: deltaTSSt_SS [3, Reactor, Bulk Volume, 0]
  Value: TSS_RedMeas1 [1, Reactor, Bulk Volume, 0]
  Value: TSS_RedMeas2 [2, Reactor, Bulk Volume, 0]
  Value: TSS_RedMeas3 [3, Reactor, Bulk Volume, 0]

deltaTSS2a:
  Description: TSS Reduction (delta TSS)
  Abscissa: Time
  Title: (a) Measured and simulated TSS Reduction (delta TSS) for BT-4, BT-5 and BT-6
  Abscissa Label: Retention time (d)
  Ordinate Label: TSS Reduction (mgTSS/l)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: deltaTSSt_SS [4, Reactor, Bulk Volume, 0]
  Value: deltaTSSt_SS [5, Reactor, Bulk Volume, 0]
  Value: deltaTSSt_SS [6, Reactor, Bulk Volume, 0]
  Value: TSS_RedMeas4 [4, Reactor, Bulk Volume, 0]
  Value: TSS_RedMeas5 [5, Reactor, Bulk Volume, 0]
  Value: TSS_RedMeas6 [6, Reactor, Bulk Volume, 0]

deltaVSS1a:
  Description: VSS reduction (change of VSS)
  Abscissa: Time
  Title: (a) Measured and simulated VSS reduction (change of VSS) for BT-1, BT-2 and BT-3
  Abscissa Label: Retention time (d)
  Ordinate Label: VSS Reduction (mgCOD/l)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: deltaVSSSt_SS [1, Reactor, Bulk Volume, 0]
  Value: deltaVSSSt_SS [2, Reactor, Bulk Volume, 0]
  Value: deltaVSSSt_SS [3, Reactor, Bulk Volume, 0]
  Value: VSS_RedMeas1 [1, Reactor, Bulk Volume, 0]
  Value: VSS_RedMeas2 [2, Reactor, Bulk Volume, 0]
  Value: VSS_RedMeas3 [3, Reactor, Bulk Volume, 0]

deltaVSS2a:
  Description: VSS Reduction (delta VSS)
  Abscissa: Time
  Title: (a) Measured and simulated VSS Reduction (delta VSS) for BT-4, BT-5 an
A.334

Abscissa Label:Retention time (d)
Ordinate Label:VSS Reduction (mgCOD/l)

Curves:
Type:Variable [CalcNum,Comp.,Zone,Time/Space]
Value:deltaVSS_{SS} [4,Reactor,Bulk Volume,0]
Value:deltaVSS_{SS} [5,Reactor,Bulk Volume,0]
Value:deltaVSS_{SS} [6,Reactor,Bulk Volume,0]
Value:VSS_{RedMeas4} [4,Reactor,Bulk Volume,0]
Value:VSS_{RedMeas5} [5,Reactor,Bulk Volume,0]
Value:VSS_{RedMeas6} [6,Reactor,Bulk Volume,0]

DOa:
Description:Dissolved oxygen concentration (mg/1)
Abscissa:Time
Title:(a) Simulated DO concentration for BT-1 to BT-6
Abscissa Label:Retention time (d)
Ordinate Label:DO (mgO/l)
Curves:
Type:Variable [CalcNum,Comp.,Zone,Time/Space]
Value:S_{O2} [1,Reactor,Bulk Volume,0]
Value:S_{O2} [2,Reactor,Bulk Volume,0]
Value:S_{O2} [3,Reactor,Bulk Volume,0]
Value:S_{O2} [4,Reactor,Bulk Volume,0]
Value:S_{O2} [5,Reactor,Bulk Volume,0]
Value:S_{O2} [6,Reactor,Bulk Volume,0]

DOb:
Description:Dissolved oxygen concentration (mg/1)
Abscissa:Time
Title:(b) Simulated DO concentration for BT-1 to BT-6
Abscissa Label:Retention time (d)
Ordinate Label:DO (mgO/l)
Curves:
Type:Variable [CalcNum,Comp.,Zone,Time/Space]
Value:S_{O2} [11,Reactor,Bulk Volume,0]
Value:S_{O2} [12,Reactor,Bulk Volume,0]
Value:S_{O2} [13,Reactor,Bulk Volume,0]
Value:S_{O2} [14,Reactor,Bulk Volume,0]
Value:S_{O2} [15,Reactor,Bulk Volume,0]
Value:S_{O2} [16,Reactor,Bulk Volume,0]

fcv1a:
Description:COD/VSS ratio
Abscissa:Time
Title:Measured and simulated COD/VSS ratio for BT-1, BT-2 and BT-3
Abscissa Label:Retention time (d)
Ordinate Label:COD/VSS ratio (mgCOD/mgVSS)
Curves:
Type:Variable [CalcNum,Comp.,Zone,Time/Space]
Value:f_{cv} [1,Reactor,Bulk Volume,0]
Value:f_{cv} [2,Reactor,Bulk Volume,0]
Value:f_{cv} [3,Reactor,Bulk Volume,0]
Value:f_{cvml} [1,Reactor,Bulk Volume,0]
Value:f_{cvml} [2,Reactor,Bulk Volume,0]
Value:f_{cvml} [3,Reactor,Bulk Volume,0]

fcv1b:
Description:COD/VSS ratio
Abscissa:Time
Title: Measured and simulated COD/VSS ratio for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: COD/VSS ratio (mgCOD/mgVSS)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: f_cva [11, Reactor, Bulk Volume, 0]
Value: f_cva [12, Reactor, Bulk Volume, 0]
Value: f_cva [13, Reactor, Bulk Volume, 0]
Value: f_cva1 [1, Reactor, Bulk Volume, 0]
Value: f_cva2 [2, Reactor, Bulk Volume, 0]
Value: f_cva3 [3, Reactor, Bulk Volume, 0]

fcv2a:
Description: COD/VSS ratio
Abscissa: Time
Title: Measured and simulated COD/VSS ratio for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: COD/VSS ratio (mgCOD/mgVSS)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: f_cva [4, Reactor, Bulk Volume, 0]
Value: f_cva [5, Reactor, Bulk Volume, 0]
Value: f_cva [6, Reactor, Bulk Volume, 0]
Value: f_cva4 [4, Reactor, Bulk Volume, 0]
Value: f_cva5 [5, Reactor, Bulk Volume, 0]
Value: f_cva6 [6, Reactor, Bulk Volume, 0]

fcv2b:
Description: COD/VSS ratio
Abscissa: Time
Title: Measured and simulated COD/VSS ratio for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: COD/VSS ratio (mgCOD/mgVSS)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: f_cva [14, Reactor, Bulk Volume, 0]
Value: f_cva [15, Reactor, Bulk Volume, 0]
Value: f_cva [16, Reactor, Bulk Volume, 0]
Value: f_cva4 [4, Reactor, Bulk Volume, 0]
Value: f_cva5 [5, Reactor, Bulk Volume, 0]
Value: f_cva6 [6, Reactor, Bulk Volume, 0]

fcv_Da:
Description: COD/VSS ratio (Dilution check)
Abscissa: Time
Title: Measured and simulated COD/VSS ratio for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: COD/VSS ratio (mgCOD/mgVSS)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: f_cva [7, Reactor, Bulk Volume, 0]
Value: f_cva [8, Reactor, Bulk Volume, 0]
Value: f_cva7 [7, Reactor, Bulk Volume, 0]
Value: f_cva8 [8, Reactor, Bulk Volume, 0]

fcv_Db:
Description: COD/VSS ratio (Dilution check)
Abscissa: Time
Title: Measured and simulated COD/VSS ratio for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: COD/VSS ratio (mgCOD/mgVSS)

Curves:
- **Type**: Variable [CalcNum, Comp., Zone, Time/Space]
- **Value**:
  - f_cv [17, Reactor, Bulk Volume, 0]
  - f_cv [18, Reactor, Bulk Volume, 0]
  - f_cv [7, Reactor, Bulk Volume, 0]
  - f_cv [8, Reactor, Bulk Volume, 0]

---

fila:
- **Description**: VSS/TSS ratio
- **Abscissa**: Time
- **Title**: Measured and simulated VSS/TSS ratio for BT-1, BT-2 and BT-3
- **Abscissa Label**: Retention time (d)
- **Ordinate Label**: VSS/TSS ratio (mgVSS/mgTSS)

Curves:
- **Type**: Variable [CalcNum, Comp., Zone, Time/Space]
- **Value**:
  - f_i [1, Reactor, Bulk Volume, 0]
  - f_i [2, Reactor, Bulk Volume, 0]
  - f_i [3, Reactor, Bulk Volume, 0]
  - f_i [1, Reactor, Bulk Volume, 0]
  - f_i [2, Reactor, Bulk Volume, 0]
  - f_i [3, Reactor, Bulk Volume, 0]

---

filb:
- **Description**: VSS/TSS ratio
- **Abscissa**: Time
- **Title**: Measured and simulated VSS/TSS ratio for BT-1, BT-2 and BT-3
- **Abscissa Label**: Retention time (d)
- **Ordinate Label**: VSS/TSS ratio (mgVSS/mgTSS)

Curves:
- **Type**: Variable [CalcNum, Comp., Zone, Time/Space]
- **Value**:
  - f_i [11, Reactor, Bulk Volume, 0]
  - f_i [12, Reactor, Bulk Volume, 0]
  - f_i [13, Reactor, Bulk Volume, 0]
  - f_i [1, Reactor, Bulk Volume, 0]
  - f_i [2, Reactor, Bulk Volume, 0]
  - f_i [3, Reactor, Bulk Volume, 0]

---

fi2a:
- **Description**: VSS/TSS ratio
- **Abscissa**: Time
- **Title**: Measured and simulated VSS/TSS ratio for BT-4, BT-5 and BT-6
- **Abscissa Label**: Retention time (d)
- **Ordinate Label**: VSS/TSS ratio (mgVSS/mgTSS)

Curves:
- **Type**: Variable [CalcNum, Comp., Zone, Time/Space]
- **Value**:
  - f_i [4, Reactor, Bulk Volume, 0]
  - f_i [5, Reactor, Bulk Volume, 0]
  - f_i [6, Reactor, Bulk Volume, 0]
  - f_i [4, Reactor, Bulk Volume, 0]
  - f_i [5, Reactor, Bulk Volume, 0]
  - f_i [6, Reactor, Bulk Volume, 0]

---

fi2b:
- **Description**: VSS/TSS ratio
- **Abscissa**: Time
- **Title**: Measured and simulated VSS/TSS ratio for BT-4, BT-5 and BT-6
- **Abscissa Label**: Retention time (d)
- **Ordinate Label**: VSS/TSS ratio (mgVSS/mgTSS)

Curves:
- **Type**: Variable [CalcNum, Comp., Zone, Time/Space]
Value : f_i [14, Reactor, Bulk Volume, 0]
Value : f_i [15, Reactor, Bulk Volume, 0]
Value : f_i [16, Reactor, Bulk Volume, 0]
Value : f_meas4 [4, Reactor, Bulk Volume, 0]
Value : f_meas5 [5, Reactor, Bulk Volume, 0]
Value : f_meas6 [6, Reactor, Bulk Volume, 0]

---

fi_Da:  Description:  VSS/TSS ratio (Dilution check)
Abscissa:  Time
Title:  Measured and simulated VSS/TSS ratio for BT-7 and BT-8
Abscissa Label:  Retention time (d)
Ordinate Label:  VSS/TSS ratio (mgVSS/mgTSS)
Curves:
   Type:  Variable [CalcNum, Comp., Zone, Time/Space]
   Value:  f_i [7, Reactor, Bulk Volume, 0]
   Value:  f_i [8, Reactor, Bulk Volume, 0]
   Value:  f_meas7 [7, Reactor, Bulk Volume, 0]
   Value:  f_meas8 [8, Reactor, Bulk Volume, 0]

---

fi_Db:  Description:  VSS/TSS ratio (Dilution check)
Abscissa:  Time
Title:  Measured and simulated VSS/TSS ratio for BT-7 and BT-8
Abscissa Label:  Retention time (d)
Ordinate Label:  VSS/TSS ratio (mgVSS/mgTSS)
Curves:
   Type:  Variable [CalcNum, Comp., Zone, Time/Space]
   Value:  f_i [17, Reactor, Bulk Volume, 0]
   Value:  f_i [18, Reactor, Bulk Volume, 0]
   Value:  f_meas7 [7, Reactor, Bulk Volume, 0]
   Value:  f_meas8 [8, Reactor, Bulk Volume, 0]

---

f_Trl1a:  Description:  Fraction of TSS removed (%)
Abscissa:  Time
Title:  Measured and simulated fractions of TSS removed for BT-1, BT-2 and BT-3
Abscissa Label:  Retention time (d)
Ordinate Label:  Fraction of TSS removed (%)
Curves:
   Type:  Variable [CalcNum, Comp., Zone, Time/Space]
   Value:  f_Trl_SS [1, Reactor, Bulk Volume, 0]
   Value:  f_Trl_SS [2, Reactor, Bulk Volume, 0]
   Value:  f_Trl_SS [3, Reactor, Bulk Volume, 0]
   Value:  f_TrlMeas1 [1, Reactor, Bulk Volume, 0]
   Value:  f_TrlMeas2 [2, Reactor, Bulk Volume, 0]
   Value:  f_TrlMeas3 [3, Reactor, Bulk Volume, 0]

---

f_Trl2a:  Description:  Fraction of TSS removed (%)
Abscissa:  Time
Title:  Measured and simulated fraction of TSS removed (%) for BT-4, BT-5 and BT-6
Abscissa Label:  Retention time (d)
Ordinate Label:  Fraction of TSS removed (%)
Curves:
   Type:  Variable [CalcNum, Comp., Zone, Time/Space]
   Value:  f_Trl_SS [4, Reactor, Bulk Volume, 0]
   Value:  f_Trl_SS [5, Reactor, Bulk Volume, 0]
   Value:  f_Trl_SS [6, Reactor, Bulk Volume, 0]
Value : f_TrtMeas4 [4, Reactor, Bulk Volume, 0]
Value : f_TrtMeas5 [5, Reactor, Bulk Volume, 0]
Value : f_TrtMeas6 [6, Reactor, Bulk Volume, 0]

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<th>Title</th>
<th>Ordinate Label</th>
<th>Curves</th>
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<td>VSS removed for BT-1, BT-2 and BT-3</td>
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<td>Ordinate Label</td>
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<td></td>
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<td>f_VRTMeas3 [3, Reactor, Bulk Volume, 0]</td>
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<td>Time</td>
<td>Measured and simulated fraction of VSS removed (%) for BT-4, BT-5 and BT-6</td>
<td>Retention time (d)</td>
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<td>Abscissa Label</td>
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<td>Type</td>
<td>Variable</td>
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<tr>
<td></td>
<td>Value</td>
<td>f_VRT_SS [4, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>f_VRT_SS [5, Reactor, Bulk Volume, 0]</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>f_VRT_SS [6, Reactor, Bulk Volume, 0]</td>
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<tr>
<td></td>
<td></td>
<td>f_VRTMeas4 [4, Reactor, Bulk Volume, 0]</td>
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<tr>
<td></td>
<td></td>
<td>f_VRTMeas5 [5, Reactor, Bulk Volume, 0]</td>
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<tr>
<td></td>
<td></td>
<td>f_VRTMeas6 [6, Reactor, Bulk Volume, 0]</td>
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<tr>
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<th>Description</th>
<th>Abscissa</th>
<th>Title</th>
<th>Ordinate Label</th>
<th>Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS1a</td>
<td>ISS</td>
<td>Time</td>
<td>(a) Measured and simulated ISS for BT-1, BT-2 and BT-3</td>
<td>Retention time (d)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ISS (mgISS/l)</td>
<td></td>
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<tr>
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<td>Type</td>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>ISS_X01 [2, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>ISS_X01 [3, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISS_meas2 [2, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISS_meas3 [3, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
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</tbody>
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<table>
<thead>
<tr>
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<th>Title</th>
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<th>Curves</th>
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<tbody>
<tr>
<td>ISS1b</td>
<td>ISS</td>
<td>Time</td>
<td>Measured and simulated ISS for BT-1, BT-2 and BT-3</td>
<td>Retention time (d)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ISS (mgISS/l)</td>
<td></td>
</tr>
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<tr>
<td></td>
<td>Type</td>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value</td>
<td>ISS_X01 [12, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISS_X01 [13, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISS_meas2 [2, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISS_meas3 [3, Reactor, Bulk Volume, 0]</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
ISS2a: Description: ISS  
Abscissa: Time  
Title:  (a) Measured and simulated ISS for BT-4, BT-5 and BT-6  
Abscissa Label: Retention time (d)  
Ordinate Label: ISS (mgISS/l)  
Curves:  
Type: Variable [CalcNum, Comp., Zone, Time/Space]  
Value: ISS_Xoi [4, Reactor, Bulk Volume, 0]  
Value: ISS_Xoi [5, Reactor, Bulk Volume, 0]  
Value: ISS_Xoi [6, Reactor, Bulk Volume, 0]  
Value: ISS_meas4 [4, Reactor, Bulk Volume, 0]  
Value: ISS_meas5 [5, Reactor, Bulk Volume, 0]  
Value: ISS_meas6 [6, Reactor, Bulk Volume, 0]  

ISS2b: Description: ISS  
Abscissa: Time  
Title:  (b) Measured and simulated ISS for BT-4, BT-5 and BT-6  
Abscissa Label: Retention time (d)  
Ordinate Label: ISS (mgISS/l)  
Curves:  
Type: Variable [CalcNum, Comp., Zone, Time/Space]  
Value: ISS_Xoi [14, Reactor, Bulk Volume, 0]  
Value: ISS_Xoi [15, Reactor, Bulk Volume, 0]  
Value: ISS_Xoi [16, Reactor, Bulk Volume, 0]  
Value: ISS_meas4 [4, Reactor, Bulk Volume, 0]  
Value: ISS_meas5 [5, Reactor, Bulk Volume, 0]  
Value: ISS_meas6 [6, Reactor, Bulk Volume, 0]  

ISS_Da: Description: ISS  
Abscissa: Time  
Title: Measured and simulated ISS for BT-7 and BT-8  
Abscissa Label: Retention time (d)  
Ordinate Label: ISS (mgISS/l)  
Curves:  
Type: Variable [CalcNum, Comp., Zone, Time/Space]  
Value: ISS_Xoi [7, Reactor, Bulk Volume, 0]  
Value: ISS_Xoi [8, Reactor, Bulk Volume, 0]  
Value: ISS_meas7 [7, Reactor, Bulk Volume, 0]  
Value: ISS_meas8 [8, Reactor, Bulk Volume, 0]  

ISS_Db: Description: ISS  
Abscissa: Time  
Title: Measured and simulated ISS for BT-7 and BT-8  
Abscissa Label: Retention time (d)  
Ordinate Label: ISS (mgISS/l)  
Curves:  
Type: Variable [CalcNum, Comp., Zone, Time/Space]  
Value: ISS_Xoi [17, Reactor, Bulk Volume, 0]  
Value: ISS_Xoi [18, Reactor, Bulk Volume, 0]  
Value: ISS_meas7 [7, Reactor, Bulk Volume, 0]  
Value: ISS_meas8 [8, Reactor, Bulk Volume, 0]  

Nmt_SSa: Description: Nitrate (SSM)  
Abscissa: Time  
Title: (a) Nitrate computed with SSM and measured for BT-3, BT-4, BT-5 and BT
Abscissa Label: Retention time (d)
Ordinate Label: Nitrates (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: Nnt_SS [3, Reactor, Bulk Volume, 0]
Value: Nnt_SS [4, Reactor, Bulk Volume, 0]
Value: Nnt_SS [5, Reactor, Bulk Volume, 0]
Value: Nnt_SS [6, Reactor, Bulk Volume, 0]
Value: S_NO3meas3 [3, Reactor, Bulk Volume, 0]
Value: S_NO3meas4 [4, Reactor, Bulk Volume, 0]
Value: S_NO3meas5 [5, Reactor, Bulk Volume, 0]
Value: S_NO3meas6 [6, Reactor, Bulk Volume, 0]

Nnt_SSb:
Description: Nitrates (SSM)
Abscissa: Time
Title: (b) Nitrates computed with SSM and measured for BT-3, BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Nitrates (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: Nnt_SS [13, Reactor, Bulk Volume, 0]
Value: Nnt_SS [14, Reactor, Bulk Volume, 0]
Value: Nnt_SS [15, Reactor, Bulk Volume, 0]
Value: Nnt_SS [16, Reactor, Bulk Volume, 0]
Value: S_NO3meas3 [3, Reactor, Bulk Volume, 0]
Value: S_NO3meas4 [4, Reactor, Bulk Volume, 0]
Value: S_NO3meas5 [5, Reactor, Bulk Volume, 0]
Value: S_NO3meas6 [6, Reactor, Bulk Volume, 0]

OURa:
Description: OUR
Abscissa: Time
Title: Measured and simulated OUR for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_t [1, Reactor, Bulk Volume, 0]
Value: OUR_t [2, Reactor, Bulk Volume, 0]
Value: OUR_t [3, Reactor, Bulk Volume, 0]
Value: OUR_Meas1 [1, Reactor, Bulk Volume, 0]
Value: OUR_Meas2 [2, Reactor, Bulk Volume, 0]
Value: OUR_Meas3 [3, Reactor, Bulk Volume, 0]

OURb:
Description: OUR
Abscissa: Time
Title: Measured and simulated OUR for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_t [11, Reactor, Bulk Volume, 0]
Value: OUR_t [12, Reactor, Bulk Volume, 0]
Value: OUR_t [13, Reactor, Bulk Volume, 0]
Value: OUR_Meas1 [1, Reactor, Bulk Volume, 0]
Value: OUR_Meas2 [2, Reactor, Bulk Volume, 0]
Value: OUR_Meas3 [3, Reactor, Bulk Volume, 0]
OUR2a:
Description: OUR
Abscissa: Time
Title: (a) Measured and simulated OUR for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_t [4, Reactor, Bulk Volume, 0]
Value: OUR_t [5, Reactor, Bulk Volume, 0]
Value: OUR_t [6, Reactor, Bulk Volume, 0]
Value: OUR_Meas4 [4, Reactor, Bulk Volume, 0]
Value: OUR_Meas5 [5, Reactor, Bulk Volume, 0]
Value: OUR_Meas6 [6, Reactor, Bulk Volume, 0]

OUR2b:
Description: OUR
Abscissa: Time
Title: (b) Measured and simulated OUR for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_t [14, Reactor, Bulk Volume, 0]
Value: OUR_t [15, Reactor, Bulk Volume, 0]
Value: OUR_t [16, Reactor, Bulk Volume, 0]
Value: OUR_Meas4 [4, Reactor, Bulk Volume, 0]
Value: OUR_Meas5 [5, Reactor, Bulk Volume, 0]
Value: OUR_Meas6 [6, Reactor, Bulk Volume, 0]

OUR_1a:
Description: OUR for BT-1
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-1
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas1 [1, Reactor, Bulk Volume, 0]
Value: OUR_t [1, Reactor, Bulk Volume, 0]
Value: OUR_H [1, Reactor, Bulk Volume, 0]
Value: OUR_AUT [1, Reactor, Bulk Volume, 0]
Value: OUR_P [1, Reactor, Bulk Volume, 0]

OUR_1b:
Description: OUR for BT-1
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-1
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas1 [1, Reactor, Bulk Volume, 0]
Value: OUR_t [11, Reactor, Bulk Volume, 0]
Value: OUR_H [11, Reactor, Bulk Volume, 0]
Value: OUR_AUT [11, Reactor, Bulk Volume, 0]
Value: OUR_P [11, Reactor, Bulk Volume, 0]

OUR_2a:
Description: OUR for BT-2
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-2
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_Meas2 [2, Reactor, Bulk Volume, 0]
  Value: OUR_t [2, Reactor, Bulk Volume, 0]
  Value: OUR_H [2, Reactor, Bulk Volume, 0]
  Value: OUR_AUT [2, Reactor, Bulk Volume, 0]
  Value: OUR_P [2, Reactor, Bulk Volume, 0]

OUR_2b:
Description: OUR for BT-2
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-2
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_Meas2 [2, Reactor, Bulk Volume, 0]
  Value: OUR_t [12, Reactor, Bulk Volume, 0]
  Value: OUR_H [12, Reactor, Bulk Volume, 0]
  Value: OUR_AUT [12, Reactor, Bulk Volume, 0]
  Value: OUR_P [12, Reactor, Bulk Volume, 0]

OUR_3a:
Description: OUR for BT-3
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-3
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_Meas3 [3, Reactor, Bulk Volume, 0]
  Value: OUR_t [3, Reactor, Bulk Volume, 0]
  Value: OUR_H [3, Reactor, Bulk Volume, 0]
  Value: OUR_AUT [3, Reactor, Bulk Volume, 0]
  Value: OUR_P [3, Reactor, Bulk Volume, 0]

OUR_3b:
Description: OUR for BT-3
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-3
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_Meas3 [3, Reactor, Bulk Volume, 0]
  Value: OUR_t [13, Reactor, Bulk Volume, 0]
  Value: OUR_H [13, Reactor, Bulk Volume, 0]
  Value: OUR_AUT [13, Reactor, Bulk Volume, 0]
  Value: OUR_P [13, Reactor, Bulk Volume, 0]

OUR_4a:
Description: OUR for BT-4
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-4
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas4 [4, Reactor, Bulk Volume, 0]
Value: OUR_t [4, Reactor, Bulk Volume, 0]
Value: OUR_H [4, Reactor, Bulk Volume, 0]
Value: OUR_AUT [4, Reactor, Bulk Volume, 0]
Value: OUR_P [4, Reactor, Bulk Volume, 0]

OUR_4b:
Description: OUR for BT-4
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-4
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas4 [4, Reactor, Bulk Volume, 0]
Value: OUR_t [14, Reactor, Bulk Volume, 0]
Value: OUR_H [14, Reactor, Bulk Volume, 0]
Value: OUR_AUT [14, Reactor, Bulk Volume, 0]
Value: OUR_P [14, Reactor, Bulk Volume, 0]

OUR_5a:
Description: OUR for BT-5
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-5
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas5 [5, Reactor, Bulk Volume, 0]
Value: OUR_t [5, Reactor, Bulk Volume, 0]
Value: OUR_H [5, Reactor, Bulk Volume, 0]
Value: OUR_AUT [5, Reactor, Bulk Volume, 0]
Value: OUR_P [5, Reactor, Bulk Volume, 0]

OUR_5b:
Description: OUR for BT-5
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-5
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas5 [5, Reactor, Bulk Volume, 0]
Value: OUR_t [15, Reactor, Bulk Volume, 0]
Value: OUR_H [15, Reactor, Bulk Volume, 0]
Value: OUR_AUT [15, Reactor, Bulk Volume, 0]
Value: OUR_P [15, Reactor, Bulk Volume, 0]

OUR_6a:
Description: OUR for BT-6
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-6
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas6 [6, Reactor, Bulk Volume, 0]
Value: OUR_t [6, Reactor, Bulk Volume, 0]
Value: OUR_H [6, Reactor, Bulk Volume, 0]
Value: OUR_AUT [6, Reactor, Bulk Volume, 0]
Value : OUR_P [6, Reactor, Bulk Volume, 0]

OUR_6b:
Description: OUR for BT-6
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-6
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/1/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas6 [6, Reactor, Bulk Volume, 0]
Value: OUR_t [16, Reactor, Bulk Volume, 0]
Value: OUR_H [16, Reactor, Bulk Volume, 0]
Value: OUR_AUT [16, Reactor, Bulk Volume, 0]
Value: OUR_P [16, Reactor, Bulk Volume, 0]

OUR_7a:
Description: OUR for BT-7
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-7
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/1/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas7 [7, Reactor, Bulk Volume, 0]
Value: OUR_t [7, Reactor, Bulk Volume, 0]
Value: OUR_H [7, Reactor, Bulk Volume, 0]
Value: OUR_AUT [7, Reactor, Bulk Volume, 0]
Value: OUR_P [7, Reactor, Bulk Volume, 0]

OUR_7b:
Description: OUR for BT-7
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-7
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/1/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas7 [7, Reactor, Bulk Volume, 0]
Value: OUR_t [17, Reactor, Bulk Volume, 0]
Value: OUR_H [17, Reactor, Bulk Volume, 0]
Value: OUR_AUT [17, Reactor, Bulk Volume, 0]
Value: OUR_P [17, Reactor, Bulk Volume, 0]

OUR_8a:
Description: OUR for BT-8
Abscissa: Time
Title: Measured total-OUR and simulated components of OUR for BT-8
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/1/h)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: OUR_Meas8 [8, Reactor, Bulk Volume, 0]
Value: OUR_t [8, Reactor, Bulk Volume, 0]
Value: OUR_H [8, Reactor, Bulk Volume, 0]
Value: OUR_AUT [8, Reactor, Bulk Volume, 0]
Value: OUR_P [8, Reactor, Bulk Volume, 0]

OUR_8b:
Description: OUR for BT-8
Abscissa: Time
Title: Measured total-OUR and simulated co
Abscissa Label: Components of OUR for BT-8
Ordinate Label: Retention time (d)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_Meas8 [8, Reactor, Bulk Volume, 0]
  Value: OUR_t [18, Reactor, Bulk Volume, 0]
  Value: OUR_H [18, Reactor, Bulk Volume, 0]
  Value: OUR_AUT [18, Reactor, Bulk Volume, 0]
  Value: OUR_P [18, Reactor, Bulk Volume, 0]

OUR_ASM_SSMi: Description: OUR
Abscissa: Time
Title: Comparison of simulated OURs with AS M-2 and SSM (for BT-1 and BT-2)
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_t [1, Reactor, Bulk Volume, 0]
  Value: OUR_t [2, Reactor, Bulk Volume, 0]
  Value: O_T_SS [1, Reactor, Bulk Volume, 0]
  Value: O_T_SS [2, Reactor, Bulk Volume, 0]

OUR_ASM_SSMii: Description: OUR
Abscissa: Time
Title: Comparison of simulated OURs with AS M-2 and SSM (for BT-3 and BT-4)
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_t [3, Reactor, Bulk Volume, 0]
  Value: OUR_t [4, Reactor, Bulk Volume, 0]
  Value: O_T_SS [3, Reactor, Bulk Volume, 0]
  Value: O_T_SS [4, Reactor, Bulk Volume, 0]

OUR_ASM_SSMiii: Description: OUR
Abscissa: Time
Title: Comparison of simulated OURs with AS M-2 and SSM (for BT-5 and BT-6)
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_t [5, Reactor, Bulk Volume, 0]
  Value: OUR_t [6, Reactor, Bulk Volume, 0]
  Value: O_T_SS [5, Reactor, Bulk Volume, 0]
  Value: O_T_SS [6, Reactor, Bulk Volume, 0]

OUR_Da: Description: OUR (Dilution check)
Abscissa: Time
Title: (a) Measured and simulated OUR for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
  Type: Variable [CalcNum, Comp., Zone, Time/Space]
  Value: OUR_t [7, Reactor, Bulk Volume, 0]
  Value: OUR_t [8, Reactor, Bulk Volume, 0]
  Value: OUR_Meas7 [7, Reactor, Bulk Volume, 0]
Value : OUR_Meas8 [8, Reactor, Bulk Volume, 0]

**OUR_Db:**
**Description:** OUR (Dilution check)
**Abscissa:** Time
**Title:** (b) Measured and simulated OUR for BT-7 and BT-8
**Abscissa Label:** Retention time (d)
**Ordinate Label:** OUR (mg/l/h)
**Curves:**
- Type: Variable [CalcNum, Comp., Zone, Time/Space]
- Value: OUR_t [17, Reactor, Bulk Volume, 0]
- Value: OUR_t [18, Reactor, Bulk Volume, 0]
- Value: OUR_Meas7 [7, Reactor, Bulk Volume, 0]
- Value: OUR_Meas8 [8, Reactor, Bulk Volume, 0]

---

**O_Tla:**
**Description:** OUR (SSM)
**Abscissa:** Time
**Title:** (a) OUR computed with SSM and measured for BT-1, BT-2 and BT-3
**Abscissa Label:** Retention time (d)
**Ordinate Label:** OUR (mg/l/h)
**Curves:**
- Type: Variable [CalcNum, Comp., Zone, Time/Space]
- Value: O_T_SS [1, Reactor, Bulk Volume, 0]
- Value: O_T_SS [2, Reactor, Bulk Volume, 0]
- Value: O_T_SS [3, Reactor, Bulk Volume, 0]
- Value: OUR_Meas1 [1, Reactor, Bulk Volume, 0]
- Value: OUR_Meas2 [2, Reactor, Bulk Volume, 0]
- Value: OUR_Meas3 [3, Reactor, Bulk Volume, 0]

---

**O_Tlb:**
**Description:** OUR (SSM)
**Abscissa:** Time
**Title:** (b) OUR computed with SSM and measured for BT-1, BT-2 and BT-3
**Abscissa Label:** Retention time (d)
**Ordinate Label:** OUR (mg/l/h)
**Curves:**
- Type: Variable [CalcNum, Comp., Zone, Time/Space]
- Value: O_T_SS [11, Reactor, Bulk Volume, 0]
- Value: O_T_SS [12, Reactor, Bulk Volume, 0]
- Value: O_T_SS [13, Reactor, Bulk Volume, 0]
- Value: OUR_Meas1 [1, Reactor, Bulk Volume, 0]
- Value: OUR_Meas2 [2, Reactor, Bulk Volume, 0]
- Value: OUR_Meas3 [3, Reactor, Bulk Volume, 0]

---

**O_T2a:**
**Description:** OUR (SSM)
**Abscissa:** Time
**Title:** (a) OUR computed with SSM and measured for BT-4, BT-5 and BT-6
**Abscissa Label:** Retention time (d)
**Ordinate Label:** OUR (mg/l/h)
**Curves:**
- Type: Variable [CalcNum, Comp., Zone, Time/Space]
- Value: O_T_SS [4, Reactor, Bulk Volume, 0]
- Value: O_T_SS [5, Reactor, Bulk Volume, 0]
- Value: O_T_SS [6, Reactor, Bulk Volume, 0]
- Value: O_T_SS [8, Reactor, Bulk Volume, 0]
- Value: OUR_Meas4 [4, Reactor, Bulk Volume, 0]
- Value: OUR_Meas5 [5, Reactor, Bulk Volume, 0]
- Value: OUR_Meas6 [6, Reactor, Bulk Volume, 0]
- Value: OUR_Meas8 [8, Reactor, Bulk Volume, 0]
O_T2b:
Description: OUR (SSM)
Abscissa: Time
Title: (b) OUR computed with SSM and measured for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: OUR (mg/l/h)
Curves:
Type: Variable [CalcNum,Comp.,Zone,Time/Space]
Value: O_T_SS [14,Reactor,Bulk Volume,0]
Value: O_T_SS [15,Reactor,Bulk Volume,0]
Value: O_T_SS [16,Reactor,Bulk Volume,0]
Value: OUR_Meas4 [4,Reactor,Bulk Volume,0]
Value: OUR_Meas5 [5,Reactor,Bulk Volume,0]
Value: OUR_Meas6 [6,Reactor,Bulk Volume,0]

PsT_SSla:
Description: Orthophosphate concentration (SSM)
Abscissa: Time
Title: (a) Orthophosphate computed with SSM and measured for BT-1, BT-2 and B T-3
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)
Curves:
Type: Variable [CalcNum,Comp.,Zone,Time/Space]
Value: PsT_SS [1,Reactor,Bulk Volume,0]
Value: PsT_SS [2,Reactor,Bulk Volume,0]
Value: PsT_SS [3,Reactor,Bulk Volume,0]
Value: S_PO4meas1 [1,Reactor,Bulk Volume,0]
Value: S_PO4meas2 [2,Reactor,Bulk Volume,0]
Value: S_PO4meas3 [3,Reactor,Bulk Volume,0]

PsT_SSlb:
Description: Orthophosphate concentration (SSM)
Abscissa: Time
Title: (b) Orthophosphate computed with SSM and measured for BT-1, BT-2 and B T-3
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)
Curves:
Type: Variable [CalcNum,Comp.,Zone,Time/Space]
Value: PsT_SS [11,Reactor,Bulk Volume,0]
Value: PsT_SS [12,Reactor,Bulk Volume,0]
Value: PsT_SS [13,Reactor,Bulk Volume,0]
Value: S_PO4meas1 [1,Reactor,Bulk Volume,0]
Value: S_PO4meas2 [2,Reactor,Bulk Volume,0]
Value: S_PO4meas3 [3,Reactor,Bulk Volume,0]

PsT_SS2a:
Description: Phosphate (SSM)
Abscissa: Time
Title: (a) Orthophosphate computed with SSM and measured for BT-4, BT-5 and B T-6
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)
Curves:
Type: Variable [CalcNum,Comp.,Zone,Time/Space]
Value: PsT_SS [4,Reactor,Bulk Volume,0]
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Value: S_PO4meas4 [4,Reactor,Bulk Volume,0]
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<td>Abscissa:</td>
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<tr>
<td>Title:</td>
<td>(a) Measured and simulated FSA for BT-4, BT-5 and BT-6</td>
</tr>
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<td>Abscissa Label:</td>
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<tr>
<td>Value:</td>
<td>S_NH4 [5, Reactor, Bulk Volume, 0]</td>
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<td>Value:</td>
<td>S_NH4 [6, Reactor, Bulk Volume, 0]</td>
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<td>Value:</td>
<td>S_NH4meas4 [4, Reactor, Bulk Volume, 0]</td>
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Value : S\_NH4 meas5 [5, Reactor, Bulk Volume, 0]
Value : S\_NH4 meas6 [6, Reactor, Bulk Volume, 0]

---

S\_NH4\_2b: Description: FSA
Abscissa: Time
Title: (b) Measured and simulated FSA for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: FSA (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value : S\_NH4 [4, Reactor, Bulk Volume, 0]
Value : S\_NH4 [5, Reactor, Bulk Volume, 0]
Value : S\_NH4 [6, Reactor, Bulk Volume, 0]
Value : S\_NH4 meas4 [4, Reactor, Bulk Volume, 0]
Value : S\_NH4 meas5 [5, Reactor, Bulk Volume, 0]
Value : S\_NH4 meas6 [6, Reactor, Bulk Volume, 0]

---

S\_NO3a: Description: Nitrates
Abscissa: Time
Title: (a) Measured and simulated Nitrates for BT-3, BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Nitrates (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value : S\_NO3 [3, Reactor, Bulk Volume, 0]
Value : S\_NO3 [4, Reactor, Bulk Volume, 0]
Value : S\_NO3 [5, Reactor, Bulk Volume, 0]
Value : S\_NO3 [6, Reactor, Bulk Volume, 0]
Value : S\_NO3 meas3 [3, Reactor, Bulk Volume, 0]
Value : S\_NO3 meas4 [4, Reactor, Bulk Volume, 0]
Value : S\_NO3 meas5 [5, Reactor, Bulk Volume, 0]
Value : S\_NO3 meas6 [6, Reactor, Bulk Volume, 0]

---

S\_NO3b: Description: Nitrates
Abscissa: Time
Title: (b) Measured and simulated Nitrates for BT-3, BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Nitrates (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value : S\_NO3 [13, Reactor, Bulk Volume, 0]
Value : S\_NO3 [14, Reactor, Bulk Volume, 0]
Value : S\_NO3 [15, Reactor, Bulk Volume, 0]
Value : S\_NO3 [16, Reactor, Bulk Volume, 0]
Value : S\_NO3 meas3 [3, Reactor, Bulk Volume, 0]
Value : S\_NO3 meas4 [4, Reactor, Bulk Volume, 0]
Value : S\_NO3 meas5 [5, Reactor, Bulk Volume, 0]
Value : S\_NO3 meas6 [6, Reactor, Bulk Volume, 0]

---

S\_NO3 \_ASM\_SSM1: Description: Nitrates
Abscissa: Time
Title: Comparison of simulated nitrate with ASM2 and SSM (for BT-3 and BT-4)
Abscissa Label: Retention time (d)
Ordinate Label: Nitrates (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value : S\_NO3 [3, Reactor, Bulk Volume, 0]
Value : S_NO3 [4, Reactor, Bulk Volume, 0]
Value : Nnt_SS [3, Reactor, Bulk Volume, 0]
Value : Nnt_SS [4, Reactor, Bulk Volume, 0]

S_NO3_ASM_SSM2:
Description: Nitrate
Abscissa: Time
Title: Comparison of simulated nitrate with ASM2 and SSM (for BT-5 and BT-6)
Abscissa Label: Retention time (d)
Ordinate Label: Nitrate (mg/l)
Curves:
Type : Variable [CalcNum, Comp., Zone, Time/Space]
Value : S_NO3 [5, Reactor, Bulk Volume, 0]
Value : S_NO3 [6, Reactor, Bulk Volume, 0]
Value : Nnt_SS [5, Reactor, Bulk Volume, 0]
Value : Nnt_SS [6, Reactor, Bulk Volume, 0]

S_NO3_Da:
Description: Nitrate (Dilution check)
Abscissa: Time
Title: (a) Measured and simulated Nitrate for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: Nitrate (mg/l)
Curves:
Type : Variable [CalcNum, Comp., Zone, Time/Space]
Value : S_NO3 [7, Reactor, Bulk Volume, 0]
Value : S_NO3 [8, Reactor, Bulk Volume, 0]
Value : S_NO3meas7 [7, Reactor, Bulk Volume, 0]
Value : S_NO3meas8 [8, Reactor, Bulk Volume, 0]

S_NO3_Db:
Description: Nitrate (Dilution check)
Abscissa: Time
Title: (b) Measured and simulated Nitrate for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: Nitrate (mg/l)
Curves:
Type : Variable [CalcNum, Comp., Zone, Time/Space]
Value : S_NO3 [17, Reactor, Bulk Volume, 0]
Value : S_NO3 [18, Reactor, Bulk Volume, 0]
Value : S_NO3meas7 [7, Reactor, Bulk Volume, 0]
Value : S_NO3meas8 [8, Reactor, Bulk Volume, 0]

S_PO4_1a:
Description: Orthophosphate concentration
Abscissa: Time
Title: (a) Measured and simulated orthophosphate for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)
Curves:
Type : Variable [CalcNum, Comp., Zone, Time/Space]
Value : S_PO4 [1, Reactor, Bulk Volume, 0]
Value : S_PO4 [2, Reactor, Bulk Volume, 0]
Value : S_PO4 [3, Reactor, Bulk Volume, 0]
Value : S_PO4meas1 [1, Reactor, Bulk Volume, 0]
Value : S_PO4meas2 [2, Reactor, Bulk Volume, 0]
Value : S_PO4meas3 [3, Reactor, Bulk Volume, 0]

S_PO4_1b:
Description: Orthophosphate concentration
Abscissa: Time
Title: (b) Measured and simulated orthophosphate for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [11, Reactor, Bulk Volume, 0]
Value: S_PO4 [12, Reactor, Bulk Volume, 0]
Value: S_PO4 [13, Reactor, Bulk Volume, 0]
Value: S_PO4meas1 [1, Reactor, Bulk Volume, 0]
Value: S_PO4meas2 [2, Reactor, Bulk Volume, 0]
Value: S_PO4meas3 [3, Reactor, Bulk Volume, 0]

S_PO4_2a:
Description: Phosphate
Abscissa: Time
Title: (a) Measured and simulated orthophosphate for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [4, Reactor, Bulk Volume, 0]
Value: S_PO4 [5, Reactor, Bulk Volume, 0]
Value: S_PO4 [6, Reactor, Bulk Volume, 0]
Value: S_PO4meas4 [4, Reactor, Bulk Volume, 0]
Value: S_PO4meas5 [5, Reactor, Bulk Volume, 0]
Value: S_PO4meas6 [6, Reactor, Bulk Volume, 0]

S_PO4_2b:
Description: Phosphate
Abscissa: Time
Title: (b) Measured and simulated orthophosphate for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [14, Reactor, Bulk Volume, 0]
Value: S_PO4 [15, Reactor, Bulk Volume, 0]
Value: S_PO4 [16, Reactor, Bulk Volume, 0]
Value: S_PO4meas4 [4, Reactor, Bulk Volume, 0]
Value: S_PO4meas5 [5, Reactor, Bulk Volume, 0]
Value: S_PO4meas6 [6, Reactor, Bulk Volume, 0]

S_PO4_ASM_SSMi: Description: Orthophosphate concentration
Abscissa: Time
Title: Comparisons of simulated OP with AS M2 and SSM for BT-1 and BT-2
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [1, Reactor, Bulk Volume, 0]
Value: S_PO4 [2, Reactor, Bulk Volume, 0]
Value: PsT_SS [1, Reactor, Bulk Volume, 0]
Value: PsT_SS [2, Reactor, Bulk Volume, 0]

S_PO4_ASM_SSMii: Description: Phosphate
Abscissa: Time
Title: Comparisons of simulated OP with AS M2 and SSM for BT-3 and BT-4
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [3, Reactor, Bulk Volume, 0]
Value: S_PO4 [4, Reactor, Bulk Volume, 0]
Value: Pst_ST [3, Reactor, Bulk Volume, 0]
Value: Pst_ST [4, Reactor, Bulk Volume, 0]

S_PO4_ASM_SSMiii:
Description: Phosphate
Abscissa: Time
Title: Comparisons of simulated OP with AS M2 and SSM for BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [5, Reactor, Bulk Volume, 0]
Value: S_PO4 [6, Reactor, Bulk Volume, 0]
Value: Pst_ST [5, Reactor, Bulk Volume, 0]
Value: Pst_ST [6, Reactor, Bulk Volume, 0]

S_PO4_Da:
Description: Phosphate (Dilution check)
Abscissa: Time
Title: (a) Measured and simulated orthophosphate for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [7, Reactor, Bulk Volume, 0]
Value: S_PO4 [8, Reactor, Bulk Volume, 0]
Value: S_PO4meas7 [7, Reactor, Bulk Volume, 0]
Value: S_PO4meas8 [8, Reactor, Bulk Volume, 0]

S_PO4_Db:
Description: Phosphate (Dilution check)
Abscissa: Time
Title: (b) Measured and simulated orthophosphate for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: Orthophosphate (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: S_PO4 [17, Reactor, Bulk Volume, 0]
Value: S_PO4 [18, Reactor, Bulk Volume, 0]
Value: S_PO4meas7 [7, Reactor, Bulk Volume, 0]
Value: S_PO4meas8 [8, Reactor, Bulk Volume, 0]

TKNa:
Description: TKN
Abscissa: Time
Title: (a) Measured and simulated TKN for BT-3, BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: TKN (mg/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: TKN [3, Reactor, Bulk Volume, 0]
Value: TKN [4, Reactor, Bulk Volume, 0]
Value: TKN [5, Reactor, Bulk Volume, 0]
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<td>Retention time (d)</td>
<td>TKN (mg/l)</td>
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<td>TKN (mg/l)</td>
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<td>Time</td>
<td>TSS (mgTSS/l)</td>
<td>Type: Variable [CalcNum, Comp., Zone, Time/Space]</td>
</tr>
<tr>
<td></td>
<td>(a) Comparison of simulated TSS with ASM2 and SSM (BT-1 and BT-2)</td>
<td>Retention time (d)</td>
<td>TSS (mgTSS/l)</td>
<td>Value: TSS_ISS [1, Reactor, Bulk Volume, 0]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Value: TSS_ISS [2, Reactor, Bulk Volume, 0]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Value: X_Tt_SS [1, Reactor, Bulk Volume, 0]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Value: X_Tt_SS [2, Reactor, Bulk Volume, 0]</td>
</tr>
</tbody>
</table>
TSS_ASM_SSMii: Description: TSS
Abscissa: Time
Title: Comparison of simulated TSS with AS M2 and SSM (for BT-3 and BT-4)
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
  Type: Variable [CalNum, Comp., Zone, Time/Space]
  Value: TSS_ISS [3, Reactor, Bulk Volume, 0]
  Value: TSS_ISS [4, Reactor, Bulk Volume, 0]
  Value: X_TE_SS [3, Reactor, Bulk Volume, 0]
  Value: X_Tt_SS [4, Reactor, Bulk Volume, 0]

TSS_ASM_SSMii: Description: TSS
Abscissa: Time
Title: Comparison of simulated TSS with AS M2 and SSM (for BT-5 and BT-6)
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
  Type: Variable [CalNum, Comp., Zone, Time/Space]
  Value: TSS_ISS [5, Reactor, Bulk Volume, 0]
  Value: TSS_ISS [6, Reactor, Bulk Volume, 0]
  Value: X_TE_SS [5, Reactor, Bulk Volume, 0]
  Value: X_Tt_SS [6, Reactor, Bulk Volume, 0]

TSS_filb: Description: TSS calculated using fi
Abscissa: Time
Title: (b) Measured and simulated TSS (computed with VSS/TSS ratio from VSS) for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
  Type: Variable [CalNum, Comp., Zone, Time/Space]
  Value: TSS_fi [1, Reactor, Bulk Volume, 0]
  Value: TSS_fi [2, Reactor, Bulk Volume, 0]
  Value: TSS_fi [3, Reactor, Bulk Volume, 0]
  Value: TSS_meas1 [1, Reactor, Bulk Volume, 0]
  Value: TSS_meas2 [2, Reactor, Bulk Volume, 0]
  Value: TSS_meas3 [3, Reactor, Bulk Volume, 0]

TSS_filb: Description: TSS calculated using fi
Abscissa: Time
Title: (b) Measured and simulated TSS (computed with VSS/TSS ratio from VSS) for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
  Type: Variable [CalNum, Comp., Zone, Time/Space]
  Value: TSS_fi [11, Reactor, Bulk Volume, 0]
  Value: TSS_fi [12, Reactor, Bulk Volume, 0]
  Value: TSS_fi [13, Reactor, Bulk Volume, 0]
  Value: TSS_meas1 [1, Reactor, Bulk Volume, 0]
  Value: TSS_meas2 [2, Reactor, Bulk Volume, 0]
  Value: TSS_meas3 [3, Reactor, Bulk Volume, 0]

TSS_fi2a: Description: TSS calculated using fi
Abscissa: Time
Title: (a) Measured and simulated TSS (computed with VSS/TSS ratio from VSS) for BT-1, BT-2 and BT-3
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
  Type: Variable [CalNum, Comp., Zone, Time/Space]
  Value: TSS_fi [21, Reactor, Bulk Volume, 0]
  Value: TSS_fi [22, Reactor, Bulk Volume, 0]
  Value: TSS_fi [23, Reactor, Bulk Volume, 0]
  Value: TSS_meas1 [1, Reactor, Bulk Volume, 0]
  Value: TSS_meas2 [2, Reactor, Bulk Volume, 0]
  Value: TSS_meas3 [3, Reactor, Bulk Volume, 0]
Abcissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)

Curves:
   Type: Variable [CalcNum, Comp., Zone, Time/Space]
   Value: TSS_fi [4, Reactor, Bulk Volume, 0]
   Value: TSS_fi [5, Reactor, Bulk Volume, 0]
   Value: TSS_fi [6, Reactor, Bulk Volume, 0]
   Value: TSS_meas4 [4, Reactor, Bulk Volume, 0]
   Value: TSS_meas5 [5, Reactor, Bulk Volume, 0]
   Value: TSS_meas6 [6, Reactor, Bulk Volume, 0]

TSS_fi2b: Description: TSS calculated using fi
   Abcissa: Time
   Title: (b) Measured and simulated TSS (computed with VSS/TSS ratio from VSS) for BT-4, BT-5 and BT-6
   Abcissa Label: Retention time (d)
   Ordinate Label: TSS (mgTSS/l)

Curves:
   Type: Variable [CalcNum, Comp., Zone, Time/Space]
   Value: TSS_fi [14, Reactor, Bulk Volume, 0]
   Value: TSS_fi [15, Reactor, Bulk Volume, 0]
   Value: TSS_fi [16, Reactor, Bulk Volume, 0]
   Value: TSS_meas4 [4, Reactor, Bulk Volume, 0]
   Value: TSS_meas5 [5, Reactor, Bulk Volume, 0]
   Value: TSS_meas6 [6, Reactor, Bulk Volume, 0]

TSS_ISS1a: Description: TSS calculated using ISS
   Abcissa: Time
   Title: (a) Measured and simulated TSS (computed with ISS approach) for BT-1, BT-2 and BT-3
   Abcissa Label: Retention time (d)
   Ordinate Label: TSS (mgTSS/l)

Curves:
   Type: Variable [CalcNum, Comp., Zone, Time/Space]
   Value: TSS_ISS [1, Reactor, Bulk Volume, 0]
   Value: TSS_ISS [2, Reactor, Bulk Volume, 0]
   Value: TSS_ISS [3, Reactor, Bulk Volume, 0]
   Value: TSS_meas1 [1, Reactor, Bulk Volume, 0]
   Value: TSS_meas2 [2, Reactor, Bulk Volume, 0]
   Value: TSS_meas3 [3, Reactor, Bulk Volume, 0]

TSS_ISS1b: Description: TSS calculated using ISS
   Abcissa: Time
   Title: (b) Measured and simulated TSS (computed with ISS approach) for BT-1, BT-2 and BT-3
   Abcissa Label: Retention time (d)
   Ordinate Label: TSS (mgTSS/l)

Curves:
   Type: Variable [CalcNum, Comp., Zone, Time/Space]
   Value: TSS_ISS [11, Reactor, Bulk Volume, 0]
   Value: TSS_ISS [12, Reactor, Bulk Volume, 0]
   Value: TSS_ISS [13, Reactor, Bulk Volume, 0]
   Value: TSS_meas1 [1, Reactor, Bulk Volume, 0]
   Value: TSS_meas2 [2, Reactor, Bulk Volume, 0]
   Value: TSS_meas3 [3, Reactor, Bulk Volume, 0]
TSS_ISSa:
Description: TSS calculated using ISS
Abscissa: Time
Title: (a) Measured and simulated TSS (computed with ISS approach) for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: TSS_ISS [4, Reactor, Bulk Volume, 0]
Value: TSS_ISS [5, Reactor, Bulk Volume, 0]
Value: TSS_ISS [6, Reactor, Bulk Volume, 0]
Value: TSS_meas4 [4, Reactor, Bulk Volume, 0]
Value: TSS_meas5 [5, Reactor, Bulk Volume, 0]
Value: TSS_meas6 [6, Reactor, Bulk Volume, 0]

TSS_ISSb:
Description: TSS calculated using ISS
Abscissa: Time
Title: (b) Measured and simulated TSS (computed with ISS approach) for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: TSS_ISS [14, Reactor, Bulk Volume, 0]
Value: TSS_ISS [15, Reactor, Bulk Volume, 0]
Value: TSS_ISS [16, Reactor, Bulk Volume, 0]
Value: TSS_meas4 [4, Reactor, Bulk Volume, 0]
Value: TSS_meas5 [5, Reactor, Bulk Volume, 0]
Value: TSS_meas6 [6, Reactor, Bulk Volume, 0]

TSS_ISS_Da:
Description: TSS calculated using ISS (Dilution check)
Abscissa: Time
Title: (a) Measured and simulated TSS (computed with ISS approach) for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: TSS_ISS [7, Reactor, Bulk Volume, 0]
Value: TSS_ISS [8, Reactor, Bulk Volume, 0]
Value: TSS_meas7 [7, Reactor, Bulk Volume, 0]
Value: TSS_meas8 [8, Reactor, Bulk Volume, 0]

TSS_ISS_Db:
Description: TSS calculated using ISS (Dilution check)
Abscissa: Time
Title: (b) Measured and simulated TSS (computed with ISS approach) for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: TSS (mgTSS/l)
Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: TSS_ISS [17, Reactor, Bulk Volume, 0]
Value: TSS_ISS [18, Reactor, Bulk Volume, 0]
Value: TSS_meas7 [7, Reactor, Bulk Volume, 0]
Value: TSS_meas8 [8, Reactor, Bulk Volume, 0]
### T_P:
- **Description:** Total Phosphorus
- **Abscissa:** Time
- **Title:** Measured total phosphate for BT-5, BT-6, BT-7 and BT-8
- **Abscissa Label:** Retention time (d)
- **Ordinate Label:** Total-P (mg/l)

#### Curves:
- **Type:** Variable [CalcNum, Comp., Zone, Time/Space]
- **Value:** S_Ptmeas5 [5, Reactor, Bulk Volume, 0]
- **Value:** S_Ptmeas6 [6, Reactor, Bulk Volume, 0]
- **Value:** S_Ptmeas7 [7, Reactor, Bulk Volume, 0]
- **Value:** S_Ptmeas8 [8, Reactor, Bulk Volume, 0]

### VSS1a:
- **Description:** VSS
- **Abscissa:** Time
- **Title:** (a) Measured and simulated VSS for BT-1, BT-2 and BT-3
- **Abscissa Label:** Retention time (d)
- **Ordinate Label:** VSS (mgCOD/l)

#### Curves:
- **Type:** Variable [CalcNum, Comp., Zone, Time/Space]
- **Value:** mVSS [1, Reactor, Bulk Volume, 0]
- **Value:** mVSS [2, Reactor, Bulk Volume, 0]
- **Value:** mVSS [3, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas1 [1, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas2 [2, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas3 [3, Reactor, Bulk Volume, 0]

### VSS1b:
- **Description:** VSS
- **Abscissa:** Time
- **Title:** (b) Measured and simulated VSS for BT-1, BT-2 and BT-3
- **Abscissa Label:** Retention time (d)
- **Ordinate Label:** VSS (mgCOD/l)

#### Curves:
- **Type:** Variable [CalcNum, Comp., Zone, Time/Space]
- **Value:** mVSS [11, Reactor, Bulk Volume, 0]
- **Value:** mVSS [12, Reactor, Bulk Volume, 0]
- **Value:** mVSS [13, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas1 [1, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas2 [2, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas3 [3, Reactor, Bulk Volume, 0]

### VSS2a:
- **Description:** VSS
- **Abscissa:** Time
- **Title:** (a) Measured and simulated VSS for BT-4, BT-5 and BT-6
- **Abscissa Label:** Retention time (d)
- **Ordinate Label:** VSS (mgCOD/l)

#### Curves:
- **Type:** Variable [CalcNum, Comp., Zone, Time/Space]
- **Value:** mVSS [4, Reactor, Bulk Volume, 0]
- **Value:** mVSS [5, Reactor, Bulk Volume, 0]
- **Value:** mVSS [6, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas4 [4, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas5 [5, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas6 [6, Reactor, Bulk Volume, 0]

### VSS2b:
- **Description:** VSS
- **Abscissa:** Time
A.358

Title: (b) Measured and simulated VSS for BT-4, BT-5 and BT-6
Abscissa Label: Retention time (d)
Ordinate Label: VSS (mgCOD/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: mVSS [14, Reactor, Bulk Volume, 0]
Value: mVSS [15, Reactor, Bulk Volume, 0]
Value: mVSS [16, Reactor, Bulk Volume, 0]
Value: VSS_meas4 [4, Reactor, Bulk Volume, 0]
Value: VSS_meas5 [5, Reactor, Bulk Volume, 0]
Value: VSS_meas6 [6, Reactor, Bulk Volume, 0]

VSS_ASM_SSMi: Description: VSS
Abscissa: Time
Title: Comparison of simulated VSS with AS M2 and SSM (for BT-1 and BT-2)
Abscissa Label: Retention time (d)
Ordinate Label: VSS (mgCOD/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: mVSS [1, Reactor, Bulk Volume, 0]
Value: mVSS [2, Reactor, Bulk Volume, 0]
Value: X_Vt_SS [1, Reactor, Bulk Volume, 0]
Value: X_Vt_SS [2, Reactor, Bulk Volume, 0]

VSS_ASM_SSMii: Description: VSS
Abscissa: Time
Title: Comparison of simulated VSS with AS M2 and SSM (for BT-3 and BT-4)
Abscissa Label: Retention time (d)
Ordinate Label: VSS (mgCOD/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: mVSS [3, Reactor, Bulk Volume, 0]
Value: mVSS [4, Reactor, Bulk Volume, 0]
Value: X_Vt_SS [3, Reactor, Bulk Volume, 0]
Value: X_Vt_SS [4, Reactor, Bulk Volume, 0]

VSS_ASM_SSMiii: Description: VSS
Abscissa: Time
Title: Comparison of simulated VSS with AS M2 and SSM (for BT-5 and BT-6)
Abscissa Label: Retention time (d)
Ordinate Label: VSS (mgCOD/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: mVSS [5, Reactor, Bulk Volume, 0]
Value: mVSS [6, Reactor, Bulk Volume, 0]
Value: X_Vt_SS [5, Reactor, Bulk Volume, 0]
Value: X_Vt_SS [6, Reactor, Bulk Volume, 0]

VSS_Da: Description: VSS (Dilution check)
Abscissa: Time
Title: (a) Measured and simulated VSS for BT-7 and BT-8
Abscissa Label: Retention time (d)
Ordinate Label: VSS (mgCOD/l)

Curves:
Type: Variable [CalcNum, Comp., Zone, Time/Space]
Value: mVSS [7, Reactor, Bulk Volume, 0]
Value: mVSS [0, Reactor, Bulk Volume, 0]
Value: VSS_meas7 [7, Reactor, Bulk Volume, 0]
Value: VSS_meas8 [8, Reactor, Bulk Volume, 0]

---

**VSS_Db:**
**Description:** VSS (Dilution check)
**Abscissa:** Time
**Title:** (a) Measured and simulated VSS for BT-7 and BT-8
**Abscissa Label:** Retention time (d)
**Ordinate Label:** VSS (mgCOD/l)
**Curves:**
- **Type:** Variable [CalcNum, Comp., Zone, Time/Space]
- **Value:** mVSS [17, Reactor, Bulk Volume, 0]
- **Value:** mVSS [18, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas7 [7, Reactor, Bulk Volume, 0]
- **Value:** VSS_meas8 [8, Reactor, Bulk Volume, 0]

---

**XTtla:**
**Description:** TSS (SSM)
**Abscissa:** Time
**Title:** (a) TSS computed with SSM and measured for BT-1, BT-2 and BT-3
**Abscissa Label:** Retention time (d)
**Ordinate Label:** TSS (mgTSS/l)
**Curves:**
- **Type:** Variable [CalcNum, Comp., Zone, Time/Space]
- **Value:** X_Tt_SS [1, Reactor, Bulk Volume, 0]
- **Value:** X_Tt_SS [2, Reactor, Bulk Volume, 0]
- **Value:** X_Tt_SS [3, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas1 [1, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas2 [2, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas3 [3, Reactor, Bulk Volume, 0]

---

**XTt1b:**
**Description:** TSS (SSM)
**Abscissa:** Time
**Title:** (b) TSS computed with SSM and measured for BT-4, BT-5 and BT-6
**Abscissa Label:** Retention time (d)
**Ordinate Label:** TSS (mgTSS/l)
**Curves:**
- **Type:** Variable [CalcNum, Comp., Zone, Time/Space]
- **Value:** X_Tt_SS [11, Reactor, Bulk Volume, 0]
- **Value:** X_Tt_SS [12, Reactor, Bulk Volume, 0]
- **Value:** X_Tt_SS [13, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas1 [1, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas2 [2, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas3 [3, Reactor, Bulk Volume, 0]

---

**XTt2a:**
**Description:** TSS (SSM)
**Abscissa:** Time
**Title:** (a) TSS computed with SSM and measured for BT-4, BT-5 and BT-6
**Abscissa Label:** Retention time (d)
**Ordinate Label:** TSS (mgTSS/l)
**Curves:**
- **Type:** Variable [CalcNum, Comp., Zone, Time/Space]
- **Value:** X_Tt_SS [4, Reactor, Bulk Volume, 0]
- **Value:** X_Tt_SS [5, Reactor, Bulk Volume, 0]
- **Value:** X_Tt_SS [6, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas4 [4, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas5 [5, Reactor, Bulk Volume, 0]
- **Value:** TSS_meas6 [6, Reactor, Bulk Volume, 0]
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<thead>
<tr>
<th>Description</th>
<th>Abscissa:</th>
<th>Curves:</th>
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<tr>
<td><strong>XTt2b</strong></td>
<td>TSS (SSM)</td>
<td>Type: Variable [CalcNum, Comp., Zone, Time/Space]</td>
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<td></td>
<td>Time</td>
<td>Value: X_Tt_SS [14, Reactor, Bulk Volume, 0]</td>
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<tr>
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<td>Value: X_Tt_SS [15, Reactor, Bulk Volume, 0]</td>
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<td>Value: X_Tt_SS [16, Reactor, Bulk Volume, 0]</td>
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<td>Value: TSS_meas5 [5, Reactor, Bulk Volume, 0]</td>
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<tr>
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<td></td>
<td>Value: TSS_meas6 [6, Reactor, Bulk Volume, 0]</td>
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<tr>
<td><strong>Xvt1a</strong></td>
<td>VSS (SSM)</td>
<td>Type: Variable [CalcNum, Comp., Zone, Time/Space]</td>
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<td>Time</td>
<td>Value: X_Vt_SS [1, Reactor, Bulk Volume, 0]</td>
</tr>
<tr>
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<td></td>
<td>Value: X_Vt_SS [2, Reactor, Bulk Volume, 0]</td>
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<td></td>
<td>Value: X_Vt_SS [3, Reactor, Bulk Volume, 0]</td>
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<td>Value: VSS_meas2 [2, Reactor, Bulk Volume, 0]</td>
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<tr>
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<td></td>
<td>Value: VSS_meas3 [3, Reactor, Bulk Volume, 0]</td>
</tr>
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<td><strong>Xvt1b</strong></td>
<td>VSS (SS)</td>
<td>Type: Variable [CalcNum, Comp., Zone, Time/Space]</td>
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<td>Time</td>
<td>Value: X_Vt_SS [11, Reactor, Bulk Volume, 0]</td>
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<td></td>
<td>Value: X_Vt_SS [12, Reactor, Bulk Volume, 0]</td>
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<tr>
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<td>Value: X_Vt_SS [13, Reactor, Bulk Volume, 0]</td>
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<td>Value: VSS_meas1 [1, Reactor, Bulk Volume, 0]</td>
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<td>Value: VSS_meas2 [2, Reactor, Bulk Volume, 0]</td>
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<td>Type: Variable [CalcNum, Comp., Zone, Time/Space]</td>
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<td>Value: X_Vt_SS [4, Reactor, Bulk Volume, 0]</td>
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<td>Value: X_Vt_SS [5, Reactor, Bulk Volume, 0]</td>
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<td>Value: VSS_meas6 [6, Reactor, Bulk Volume, 0]</td>
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</table>
Xvt2b: Description: VSS (SSM)
Abcisssa: Time
Title: (b) VSS computed with SSM and measured for BT-4, BT-5 and BT-6
Abcisssa Label: Retention time (d)
Ordinate Label: VSS (mgCOD/1)
Curves:
  Type: Variable [CalcNum,Comp.,Zone,Time/Space]
  Value: X_Vt_SS [14, Reactor, Bulk Volume, 0]
  Value: X_Vt_SS [15, Reactor, Bulk Volume, 0]
  Value: X_Vt_SS [16, Reactor, Bulk Volume, 0]
  Value: VSS_meas4 [4, Reactor, Bulk Volume, 0]
  Value: VSS_meas5 [5, Reactor, Bulk Volume, 0]
  Value: VSS_meas6 [6, Reactor, Bulk Volume, 0]

Calculation Parameters

Numerical Parameters:  
  Maximum Int. Step Size: 1  
  Maximum Integrat. Order: 5  
  Number of Codionalgs: 1000  
  Maximum Number of Steps: 1000  

  Fit Method: secant  
  Max. Number of Iterat.: 100