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BIOLOGICAL NUTRIENTS REMOVAL APPLICATION OF SOFTWARE PACKAGES FOR PLANT DESIGN

BY

Bushra Waheed, John P. Barford

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Bushra Waheed[1], John P. Barford[2]

ABSTRACT

Biological processes are the cheapest and most successful technique for achieving a defined effluent standard for large volumes of effluent. The advent of mathematical modeling has advanced the tertiary wastewater treatment. Superpro-2 (using Monod's kinetic model) and SASSPRO (based on the UCT model) are two window-based software packages which make it easier to apply these models. Superpro-2 is a powerful package very useful for designing purposes, while SASSPRO is more suitable for process evaluation, monitoring and updating due to the availability of multiple design features. Even though based on different models, they produce compatible outputs when simulation was performed for a Sewage treatment plant using a Conventional and the Bardenpho configuration for biological nutrient removal. Thorough understanding of the biological processes and availability of accurate kinetic data is essential for effective utilization of these packages.

INTRODUCTION

Removal of nitrogen and phosphorous from wastewater by biological means has gained much recognition especially after IAWPRC (International association of Water Pollution Control Research and Control Model) assembled a task group on mathematical Modeling for the design and operation of Biological wastewater treatment. The model developed is capable of carbonaceous oxidation, nitrification, denitrification and also excess phosphorous removal. These models in matrix format describing complex systems are difficult to follow the author's ideas and the interaction between various components. The use of these models is difficult unless converted to computer packages.

SASSPRO(Steady State Activated Sludge Simulator, Program) , a computerized version of the University of Cape Town (UCT) model is good step in making the application of models easier. SASSPRO (Steady-state Activated Sludge Simulator Program) is a modeling program for wastewater research based on University of Cape Town (UCT) mathematical modeling algorithms. It provides evaluation for activated sludge processes ranging from conventional fully aerobic system to the complex activated sludge processes for biological nitrogen and phosphorus removal. To evaluate the performance of this package another software package Superpro-2 was also used . This was done by considering two design cases. The design is carried out for Conventional Activated Sludge Process for carbon removal only by manual calculations and the two software for Design Case-I. The Design

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case -II is carried out for the following plant configurations: Bardenpho four stage nitrogen removal process carried out on both Superpro-2 and SASSPRO, and modified Bardenpho for both nitrogen and phosphorous removal using SASSPRO only.

SALIENT FEATURES OF THE SASSPRO

SASSPRO (steady state Activated Sludge simulation program) is a window based computer program which allows rapid access to simulation by performing dynamic calculations and graphing of the parameters involved in the activated sludge process. It operates under the constant conditions of flow and load and variants are modeled in the steady state mode. SASSPRO provides output data in numeric and graphic formats.

These two formats can be compared for summer and winter conditions.
Influent parameters are plotted against Sludge age or Recycle rate (a). Graphs can be plotted in auto, normalized and manual modes. Variety of scales are available for y-axis scales. Effects of changing a parameter can be seen by using the overlaying mode. The program has 8 plant configurations for fully aerobic process, nitrification, denitrification and phosphorus removal activated sludge process defined by up to 14 separate process parameters, 10 influent parameters, 11 biomass parameters and 8 temperature sensitive kinetic parameters. All these parameters and features are defined at the bottom of the screen each time the cursor passes over the symbol. SASSPRO is capable of providing about 60 outputs.

Model Inputs

1. Process Choice

Plant configuration can be chosen from the 8 processes available and biomass temperature T, sludge age Rs(days), Plant inflow(Q) and recycle ratio(a) can be specified for each graph and system of units and graph can be obtained for mass/ concentration and volume systems. After specification of Q and reactor sizes, Vp is calculated automatically.

2. Influent Characteristics

The wastewater characteristics required are Sti, Nti, Pti, fup, fus fbs fna fnu and Oi where,

S_{ti} (influent COD) mg/l
N_{ti} (total influent Kjeldahl Nitrogen) mg/l
P_{ti} (total influent phosphorous) mg/l
Alkalinity as CaCO3
f_{up} Influent unbiodegradable particulate fraction
f_{us} Influent unbiodegardable soluble fraction
f_{bs} Influent biodegradable soluble fraction
f_{na} Ammonia Fraction of the influent TKN
f_{nu} Soluble unbiodegradable organic nitrogen fraction of the influent TKN
O_i Dissolve oxygen concentration in the influent

3. Biomass Characteristics:

These comprise fcv, Yn, Yh, f, fi, fn, fp, , Csp, K and a' where

f_{cv} COD to VSS ratio of the volatile sludge mass
Y_n specific yield coefficient of nitrifier organisms
Y_h specific yield coefficient of heterotrophic organisms
f Unbiodegradable fraction of the active mass
f_i Ratio of MLVSS to MLSS in the mixed liquor
f_n Nitrogen fraction of the MLVSS
f_p Phosphorous fraction of the inert MLVSS and endogenous residue MLVSS
Coefficient of excess phosphorous removal
C_{sp} Stoichiometric ratio of phosphorous release to COD converted
K Rate constant for RBCOD conversion to Short chain fatty acids(SCFA)
a' Phosphorous uptake/release ratio

4. Kinetic Contants/Temperature constants

These comprise of site as well as of temperature dependent constants which are b_{nT}, b_{hT}, $_{nmT}$, k_{1T}, k_{2T}, k_{3T}, K_{nT} and K_{rT} where

b_{nT} Endogenous decay rate for nitrifiers
b_{hT} Endogenous decay rate for heterotrophic organisms
$_{nmT}$ Maximum specific growth rate of nitrifiers
k_{1T} First Denitrification rate in the primary anoxic basin
k_{2T} Second denitrification rate in the primary anoxic basin
k_{3T} Endogenous denitrification rate in the secondary anoxic zone/basin
K_{nT} Half saturation coefficient in the Monod equation for nitrification
K_{rT} Conversion rate of the biodegradable organic nitrogen to free saline ammonia by active mass

Model Outputs

SASSPRO model outputs from the calculations options can be obtained as:

1. Biomass parameters

These include MLSS and MLVSS components Xa(active), Xe(endogenous), Xi(inert), Xv(volatile), Xt(total) and Xn (Nitrifiers), fractions of active sludge wrt volatile solids (fav) and total solids (fat), nitrogen and phosphorous content of biomass Ns) and (Ps) respectively.

2. Oxygen parameters

Oxygen requirements parameters include Oc (carbonaceous oxygen demand), On (nitrification oxygen demand), Od (oxygen recovered by denitrification), O(t) (total oxygen demand) and fxt (total aerobic fraction).

3. Nitrification parameters

These include the Ns (nitrogen required for biomass production), Nc (nitrification capacity (Nti) nitrogen available for nitrification, Nae (effluent ammonia concentration), Nne (effluent nitrate concentration) and Nte(Effluent TKN). Also includes On (oxygen demand for nitrification), Xn (nitrifiers organic sludge mass).

4. Denitrification parameters

These consist of Effluent and recycle nitrogen levels, denitrification potentials Dp1, Dp3, Dpp, Dpt), anoxic and anaerobic mass fractions and Od (oxygen recovered by denitrification. For each graph the optimum recycle rate is calculated is calculated and displayed.

5. Phosphorus parameters

Psm(metabolic phosphorous), Pse (excess phosphorous fractions, Pte(total effluent phosphorous, Prem(phosphorous removal) and %Prem (percentage phosphorous removal parameters are included.

6. Effluent Parameters

These include Ste(total effluent COD), Nte (TKN), Nae(effluent ammonia), (Nne) nitrate and Pte (total phosphorus content of the effluent).

7. Sludge handling

This provides with the Sludge volumes, tonnage and sludge disposal costs for wasting from mixed liquor or RAS with or without mechanical dewatering. WsRet(Waste return sludge volume required to be wasted from the RAS line), Ws (waste Mixed liqour volume) and Wprod (sludge production daily if sludge is dewatered mechanically and depends on the percentage of the solids in the sludge mass).

8. Aeration Parameters

Aeration required by the system can be entered kWh , oxygen transfer capacity and the number of units required. Aeration cost can also be computed for the system.

SALIENT FEATURES OF SUPERPRO-2

Superpro-2 is a powerful program using the windows format provides simulation for a broad range of wastewater and air pollution control plants. It's salient features are:

- ☐ The user has to define and draw the plant configuration required to be simulated.
- ☐ It operates for organic flow rate in components by either using the mass percentages of the flow components and total organic flow rate, or by keying in the component flow rates.
- ☐ Density of the flow is calculated by the program. Option is available for the user to set the density as well.
- ☐ Temperature and pressure can be adjusted for the flow.
- ☐ Component kinetics and environmental properties along with basic properties are adjustable.
- ☐ The program can be run for batch mode as well as for the continuous mode of operation.
- ☐ Program has about 18 unit operations which are used in drawing the flow diagram.
- ☐ Reactions taking place in the reactor need to be specified along with the residence time and aeration mode.
- ☐ Program is run for the solution of mass balance and energy equations from the tasks menu.
- ☐ Results are saved in form of stream reports and input data report and environment report.
- ☐ Reactor and other unit sizes are calculated by the program.

DESIGN CASE 1

Design a sewage treatment Plant at Lucas Heights for a small community of 70 people where after treatment, the liquid effluent is not discharged to sewer but rather applied (irrigated) on the land area.

Peak daily flow = 15,000 l/d
Average weekly flow = 25,594 l/w
Average daily flow = 3,656 l/d

The characteristics of the waste are:

Organic load	:	70 g BOD per equivalent person per day
Waste Strength	:	300 mg BOD / l (raw)
	:	250 mg BOD / l (settled)
Nutrient Composition	:	30 mg / l Nitrogen (Ammonia)
	:	2 mg / l Nitrate
	:	3.6 mg / l Phosphate Phosphorous

Effluent Standards:

BOD	:	20 mg / l
Phosphate Phosphorous	:	1 mg / l
Nitrogen (Ammonia)	:	5 mg / l

Steady State Activated Sludge Simulator and Superpro-2 Analysis

For the two software analysis, primary sedimentation tank design is not considered and its assumed that primary sedimentation reduces the organic concentration by 20% which is 240 mg/l and no change in the inorganic loading. Appendix 1 and Appendix 2 give complete inputs and outputs while table 1 and table 2 present comparisons.

Table 1: Comparison of outputs for SASSPRO and Superpro-2 simulation for Conventional process: Plant Parameters Output Comparison

Method	Aeration Basin Volume m^3	HRT days	SRT days	Clarifier volume
Manual	9	0.6	10	8.84
SASSPRO	9(derived from manual calculations)	0.6	5	Not considered
SUPERPRO-2	9.55	0.5	4.14	2.39

Table 2: Comparison of Effluent Streams for SASSPRO and Superpro-2 at 20 °C

Method	Effluent COD mg/l	Effluent Ammonia mg/l	Effluent Nitrate mg/l
Manual	20	-------	-------
SASSPRO	19.2	0.4867	23.025
Superpro-2	2	19.8	31.2

Comments:

- The effluent output from both the packages provide results required by the standards.
- The size of the clarifier from the Superpro-2 deviates from that calculated manually. This is due to the difference in design approaches employed for manual and Superpro-2 calculations. Superpro-2 is using modified Stoke's Law while manual calculations apply Solids flux theory taking into account the thickening effect resulting in more volume requirements.
- The difference in effluent COD values for the two packages differ can be attributed to the use of different Kinetics and also SASSPRO considers a variety of COD fractions like soluble degradable and non-degradable fractions while Superpro-2 does not distinguish between degradable and non-degradable percentage of the COD.

DESIGN CASE 2:

Design a sewage treatment plant for a small country town of 100,000 people capable of discharging the treated effluent to the local river meeting the discharge effluent standards. The characteristics of the sewage are as follows:

Organic load	:	70 g BOD per equivalent person per day
Waste Strength	:	300 mg BOD / l (raw)
	:	250 mg BOD / l (settled)
Nutrient Composition	:	30 mg / l Nitrogen (Ammonia)
	:	2 mg / l Nitrate
	:	3.6 mg / l Phosphate Phosphorous

Effluent Standards

BOD	:	20 mg / l
Phosphate Phosphorous	:	1 mg / l
Nitrogen (Ammonia)	:	5 mg / l

Assumptions:

1. It is assumed that primary sedimentation is not provided.
2. Assuming BOD_5 Degradation takes place at the rate of 1.5 kg BOD/m^3biomass.d

SASSPRO and Superpro-2 Analysis:

Analysis on SASSPRO is carried for two plant configurations, Bardenpho for BNR(Biological Nitrogen Removal) and Modified Bardenpho for NDBEPR(Nitrification Denitrification Biological Excess Phosphorous Removal). SASSPRO analysis for BNR is referred to as Design 2A and NDBEPR as Design case 2B.

Superpro-2-2 analysis is performed for BNR i.e. Design case 2A for which components of denitification and separate inlet stream for Methanol is provided. For complete inputs and outputs refer to Appendices 3, 4, 5, 6 and 7 while table 3, 4, 5 and 6 present the comparison of plant parameters and outputs for BNR and NDBEPR processes for the SASSPRO and SUPERPRO-2-2.

Table 3: Comparison of plant parameters at 20 °C for SASSPRO and Superpro-2 for BNR process

Plant parameters	SASSPRO	Superpro-2
Aeration basin Vol., m^3	14,000	14907.0
Aeration HRT,d	0.5	0.5
Aeration SRT,d	6	2
Primary Anoxic reactor Vol., m^3	1000	3500
P. Anoxic HRT, d	0.083	0.125
P. anoxic SRT, d	6	----
Secondary Anoxic Reactor Vol., m^3	1000	2000
S. Anoxic HRT, d	0.043	0.125
S. Anoxic SRT, d	6	---
Reaeration basin volume, m^3	1000	7084
Reaeration HRT,d	0.043	0.25
Reaeration SRT,d	6	0
Clarifier Volume, m^3	------	3000

Table 4: Comparison of effluents from the two packages at 20 °C

Method	Effluent COD, mg/l	Effluent Ammonia, mg/l	Effluent Nitrate, mg/l
SASSPRO	18	0.523	2.06
Superpro-2	0	27.6	1.26

Comments on the result :

- The effluent concentration of ammonia and nitrate for Superpro-2 models is much higher due to some technical fault in the package.

Table 5: Comparison of Plant Parameters for BNR and NDBEPR outputs for SASSPRO Design case 2A and Design case 2B

Plant parameters	SASSPRO BNR	SASSPRO NDBEPR
Aeration basin Vol., m^3	14,000	12,000
Aeration HRT,d	0.6	
Aeration SRT,d	6	
Primary Anoxic reactor Vol., m^3	1000	2000
P. Anoxic HRT, d	0.083	
P. anoxic SRT, d	6	
Secondary Anoxic Reactor Vol., m^3	1000	1000
S. Anoxic HRT, d	0.043	
S. Anoxic SRT, d	6	
Reaeration basin volume, m^3	1000	1000
Reaeration HRT,d	0.043	0.043
Reaeration SRT,d	6	6
Anaerobic Reactor Volume,m^3	------	2000
Anaerobic HRT, d	------	0.083
Anaerobic SRT, d		6

Table 6: Comparison of effluents for BNR and NDBEPR at 20 °C at SRT of 6 days

Method	Effluent Phosphorous mg/l	Effluent COD, mg/l	Effluent Ammonia, mg/l	Effluent Nitrate, mg/l
SASSPRO, BNR	1.8	18	0.523	2.06
SASSPRO, NDBEPR	0.00	18	0.3751	1.12

Comments :

- The lower concentration of phosphorous in BNR process is due to minimum limits of the temperature and biomass coefficients resulting in calculation for phosphorous removal also.

- The program was run for two different temperatures 20 and 15 °C which showed on effect on carbonaceous removal. At higher temperature nitrification and denitrification increase giving lower concentration of ammonia and nitrate in the effluent. Temperature variation however has no effect on Phosphorous concentration.

COMPARISON OF THE TWO PACKAGES

- Superpro-2 is more broad and can be used for a vast range of plant layouts while SASSPRO is small scale version for assessing the model plants of eight different configurations and aimed mainly at biological nutrient removal from the wastewater.
- Superpro-2 requires the components of the streams, flow rates of the components and their properties and kinetics and reactor stoichiometry while SASSPRO considers the characteristics of the total flow of the waste stream.
- SASSPRO requires the reactor sizes and sludge ages before simulation, Superpro-2 on the other hand calculates the sludge age and the reactor size required.
- The kinetics involved in SASSPRO are based on UCT model including the fractions of the substrate while Superpro-2 simulate by solving the mass balance equations around each reactor. Kinetics of both the packages are fixed.
- Unlike SASSPRO, Superpro-2-2 has no provision for Phosphorous removal.
- To design a case for simulation purposes accurate provision of the kinetics data is very critical for getting the required outputs for both the programs.
- SASSPRO is very handy for monitoring the existing plants and for extensions while Superpro-2 can be used for designing a new wastewater treatment plant.

CONCLUSIONS

A variety of biological processes are available for the removal of nitrogen and phosphorous from wastewaters. Some of the recent ones involve a number of recycle streams making it difficult to control the process. Bardenpho and its modified version are so far the better options. Selection of the process configuration depends on the type of wastewater and the level of treatment required. Use of computer packages based on mathematical models like SASSPRO can be very useful for better control of the recent process configurations like the UCT and its modified version. Removal of phosphorous by biological means is a developing technique as more research is being done about the species responsible for the removal.

The use of these packages can play a significant role in advancing the understanding of biological treatment processes, conceptual and mathematical models of these processes and the use of computer modeling serves as an operational tool as the trend for use of complex biological treatment processes increases. It assists in exploration of the impact of a wide range of system variables, thereby operating the experiential space regarding a proposed process.

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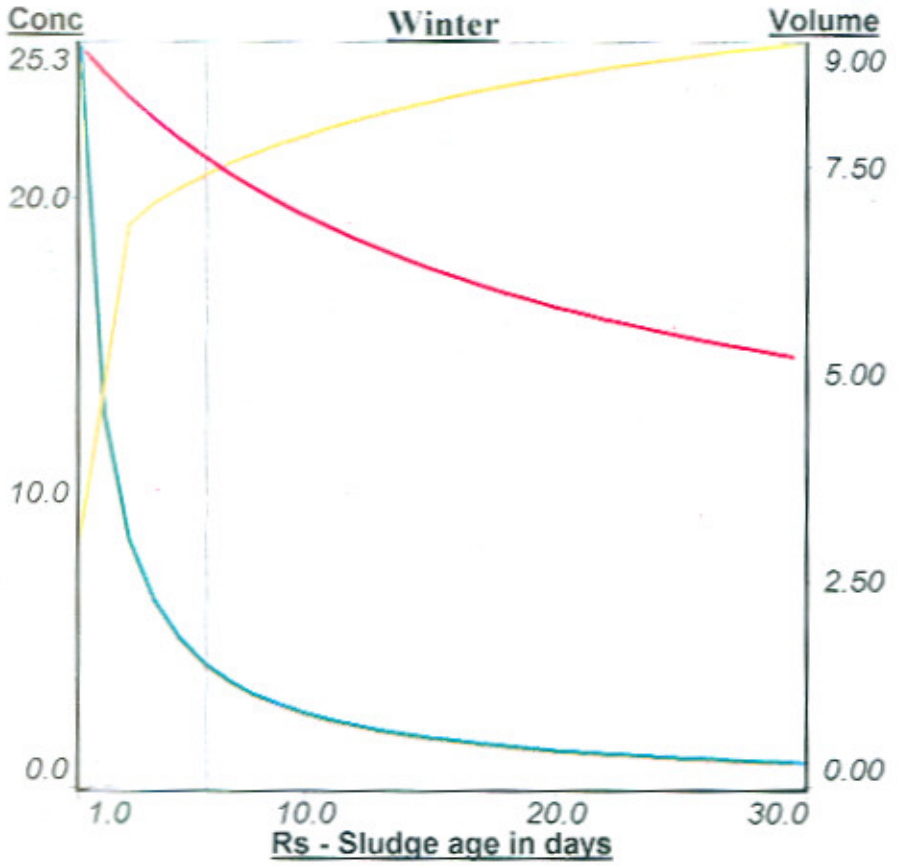
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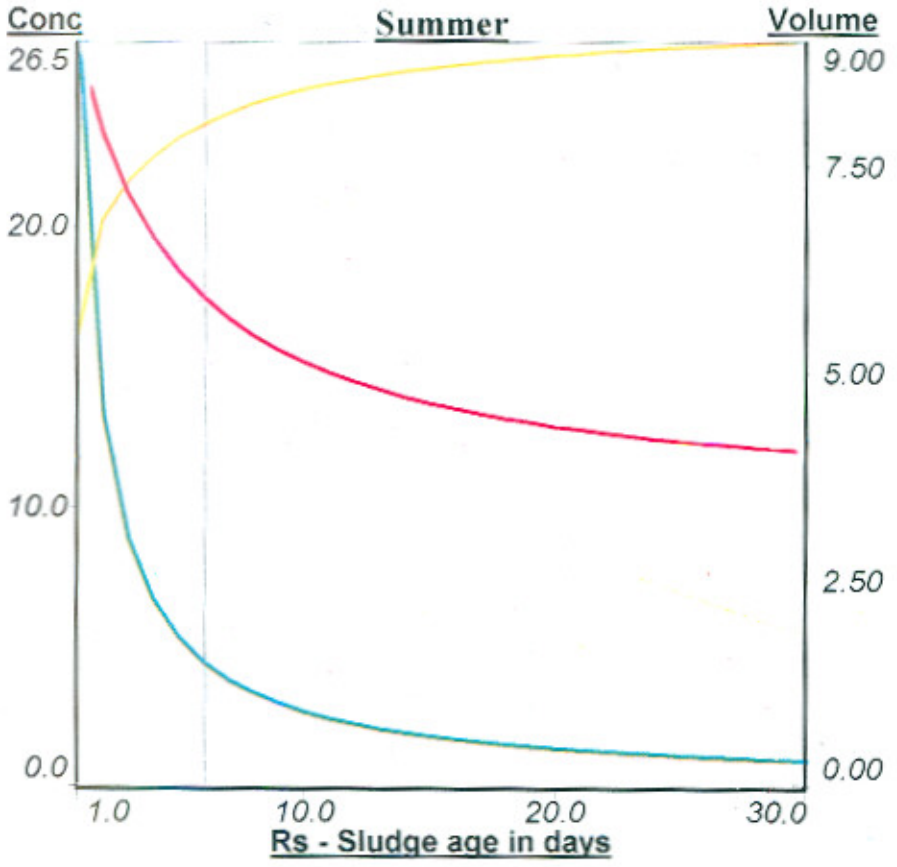
APPENDIX 1

SASSPro Report - CONVEN3



Winter

Rs	=	6.0	days
Rsm	=	1.9	days
Temp	=	20.0	°C
Oc	=	1.594	kg/day
On	=	1.595	kg/day
Ot	=	3.189	kg/day
Ws	=	1.500	kL/day
O%Cap	=	0.015	%
WProd	=	2685	kg/day



Summer

Rs	=	6.0	days
Rsm	=	0.7	days
Temp	=	28.0	°C
Oc	=	2.145	kg/day
On	=	1.716	kg/day
Ot	=	3.861	kg/day
Ws	=	1.500	kL/day
O%Cap	=	0.018	%
WProd	=	1824	kg/day

APPENDIX 2

STREAM REPORT

STREAM NAME		S-101	S-102	S-103	S-104	S-105
SOURCE		INPUT	M-101	AEB-101	CL-101	FS-101
DESTINATION		M-101	AEB-101	CL-101	FS-101	M-101
STREAM PROPERTIES						
ACTIVITY	U/ml	0.0	0.0	0.0	0.0	0.0
TEMP	°C	20.0	20.0	20.0	25.0	25.0
PRES	bar	1.0	1.0	1.0	1.0	1.0
DENSITY	g/l	998.2	951.1	39.9	48.7	48.7
COMPONENT FLOWRATES (kg/h averaged)						
Ammonia		0.0187	0.0187	0.0187	0.0000	0.0000
Auto Biomass		0.0000	0.0000	0.0000	0.0000	0.0000
Carb. Dioxide		0.0000	0.0000	0.0039	0.0000	0.0000
Dead Biomass		0.0000	0.0070	0.0089	0.0087	0.0070
Glucose		0.0750	0.0750	0.0675	0.0000	0.0000
Het Biomass		0.0000	0.0055	0.0070	0.0069	0.0055
Nitrate		0.0000	0.0000	0.0004	0.0000	0.0000
Nitrogen		0.0000	0.0011	14.7740	0.0014	0.0011
Oxygen		0.0000	0.0003	3.6901	0.0004	0.0003
Phosphoric Acid		0.0187	0.0187	0.0187	0.0000	0.0000
Urea		0.1123	0.1123	0.1117	0.0000	0.0000
Water		623.8330	623.8810	623.8848	0.0599	0.0480
TOTAL (kg/h)		624.0577	624.1196	642.5857	0.0774	0.0619
TOTAL (m3/h)		0.6252	0.6562	16.1176	0.0016	0.0013

STREAM NAME		S-106	S-107	S-110
SOURCE		CL-101	FS-101	INPUT
DESTINATION		OUTPUT	OUTPUT	AEB-101
STREAM PROPERTIES				
ACTIVITY	U/ml	0.0	0.0	0.0
TEMP	°C	20.0	25.0	20.0
PRES	bar	1.0	1.0	1.0
DENSITY	g/l	39.9	48.7	1.2
COMPONENT FLOWRATES (kg/h averaged)				
Ammonia		0.0187	0.0000	0.0000
Auto Biomass		0.0000	0.0000	0.0000
Carb. Dioxide		0.0039	0.0000	0.0000
Dead Biomass		0.0002	0.0017	0.0000
Glucose		0.0675	0.0000	0.0000
Het Biomass		0.0001	0.0014	0.0000
Nitrate		0.0004	0.0000	0.0000
Nitrogen		14.7726	0.0003	14.7729
Oxygen		3.6897	0.0001	3.6932
Phosphoric Acid		0.0187	0.0000	0.0000

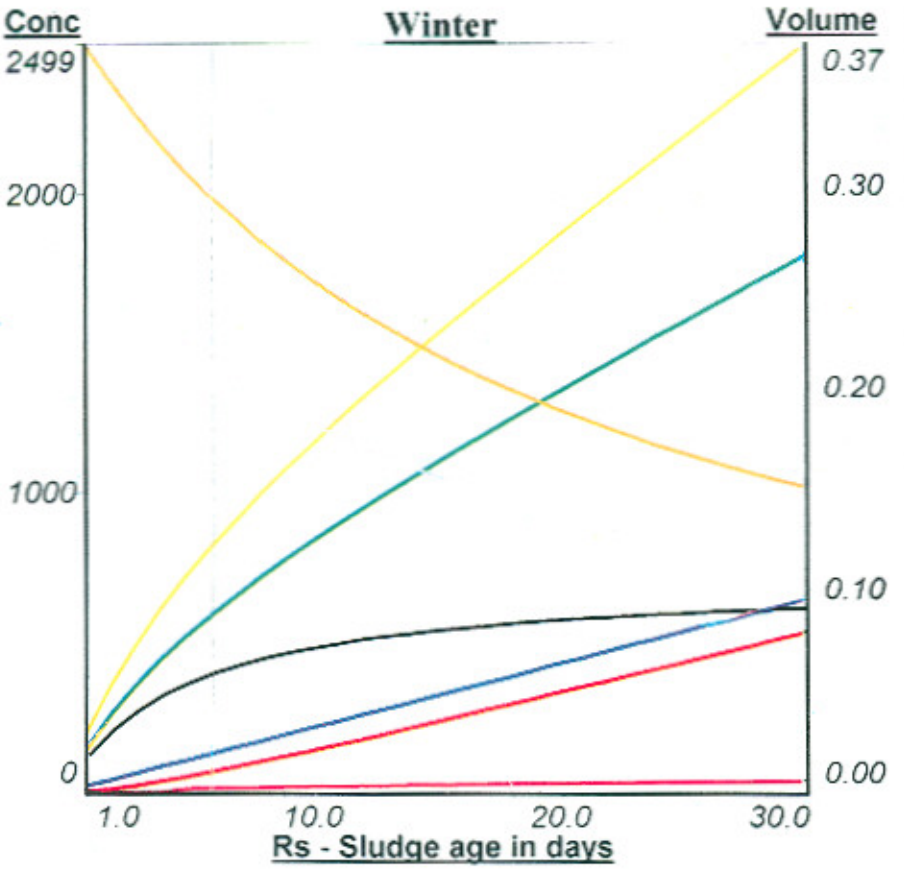
Urea	0.1117	0.0000	0.0000
Water	623.8249	0.0120	0.0000
TOTAL (kg/h)	642.5084	0.0155	18.4661
TOTAL (m3/h)	16.1160	0.0003	15.4618

OVERALL MATERIAL BALANCE (kg/h averaged)

COMPONENT	IN	OUT	(OUT-IN)
Ammonia	0.018700	0.018700	-0.000000
Auto Biomass	0.000000	0.000000	0.000000
Carb. Dioxide	0.000000	0.003907	0.003907
Dead Biomass	0.000000	0.001925	0.001925
Glucose	0.075000	0.067457	-0.007543
Het Biomass	0.000000	0.001522	0.001522
Nitrate	0.000000	0.000369	0.000369
Nitrogen	14.772910	14.772910	0.000000
Oxygen	3.693228	3.689780	-0.003447
Phosphoric Acid	0.018700	0.018700	0.000000
Urea	0.112300	0.111686	-0.000614
Water	623.833000	623.836883	0.003883
TOTAL	642.523838	642.523838	0.000000

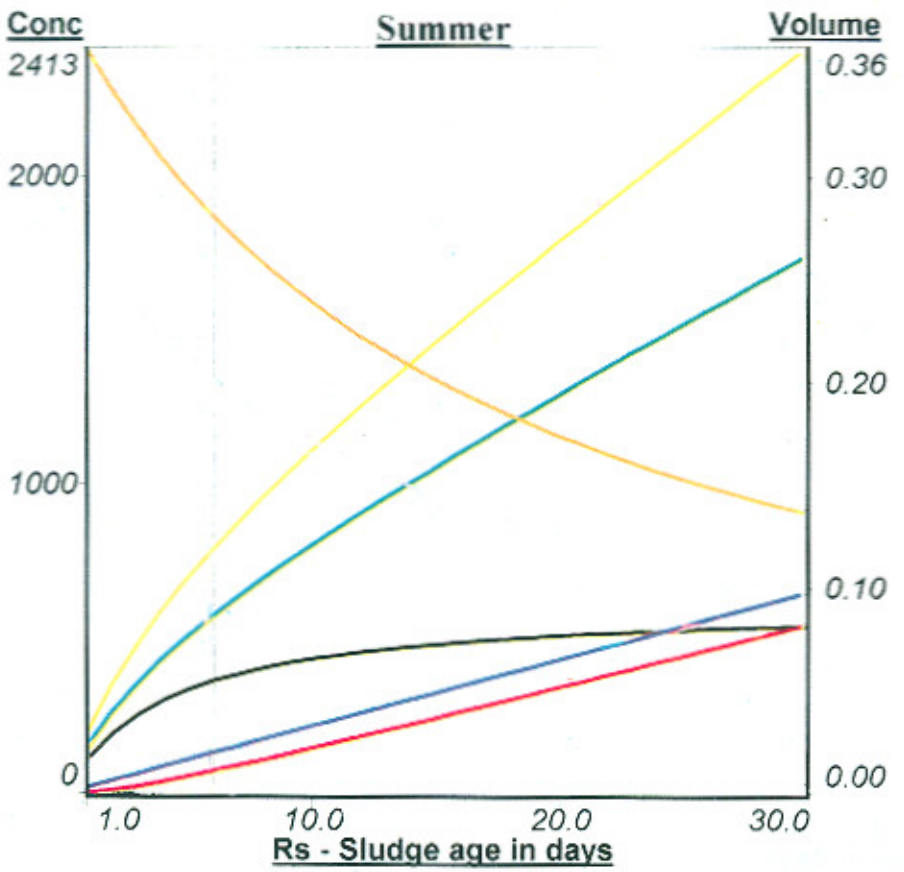
APPENDIX 3

SASSPro Report - BNR2



Winter

Rs	=	6.0	days
Rsm	=	3.9	days
a	=	115.0	ML/day
ao	=	5.4	ML/day
Temp	=	15.0	°C
Xa	=	395.9	mg/L
Xe	=	69.19	mg/L
Xi	=	129.6	mg/L
Xv	=	594.7	mg/L
Xt	=	825.9	mg/L
Xn	=	14.06	mg/L
fav	=	0.666	
fat	=	0.479	

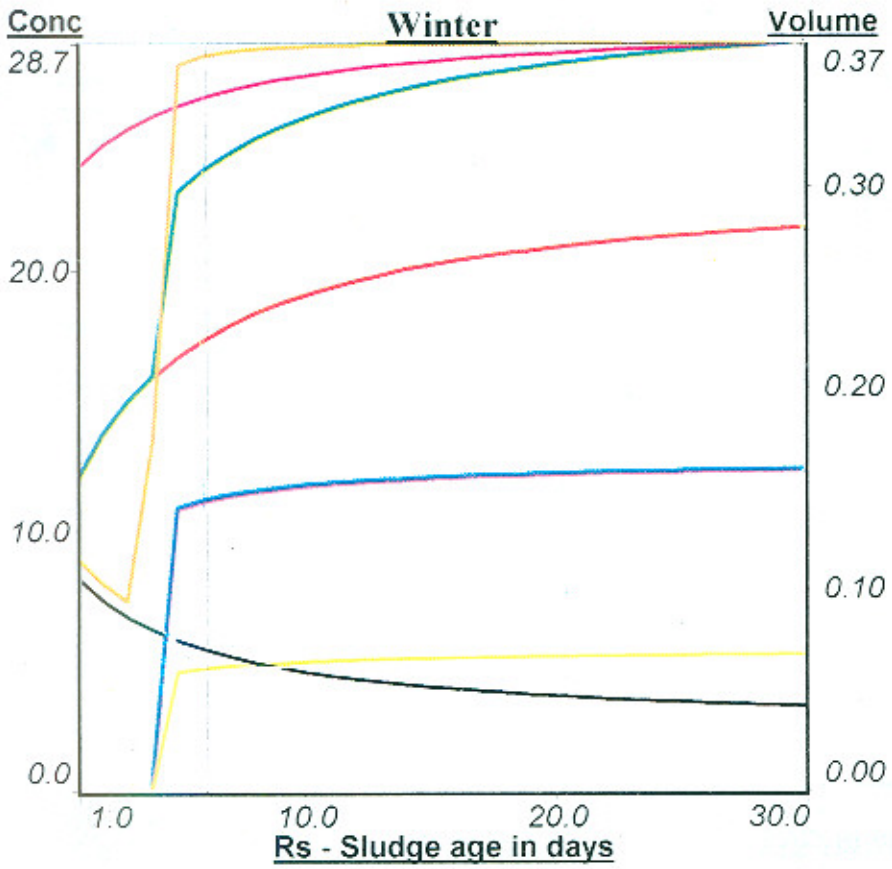


Summer

Rs	=	6.0	days
Rsm	=	2.0	days
a	=	115.0	ML/day
ao	=	146.7	ML/day
Temp	=	20.0	°C
Xa	=	364.8	mg/L
Xe	=	73.54	mg/L
Xi	=	129.6	mg/L
Xv	=	567.9	mg/L
Xt	=	788.8	mg/L
Xn	=	13.86	mg/L
fav	=	0.642	
fat	=	0.462	

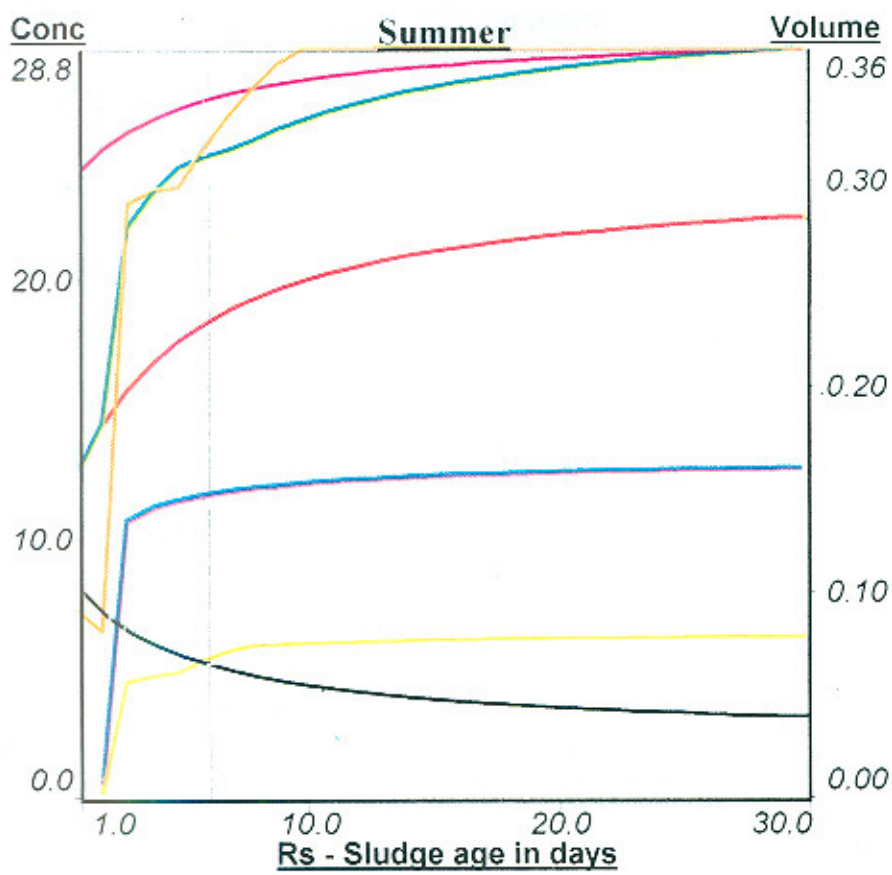
APPENDIX 3

SASSPro Report - BNR3



Winter

Rs	=	6.0	days
Rsm	=	3.9	days
a	=	115.0	ML/day
ao	=	5.4	ML/day
Temp	=	15.0	°C
Ns	=	5.430	mg/L
Oc	=	3.953	Tonne/day
On	=	2.529	Tonne/day
Ot	=	5.429	Tonne/day
Od	=	1.053	Tonne/day
N'ti	=	26.57	mg/L
N%rem	=	80.90	%

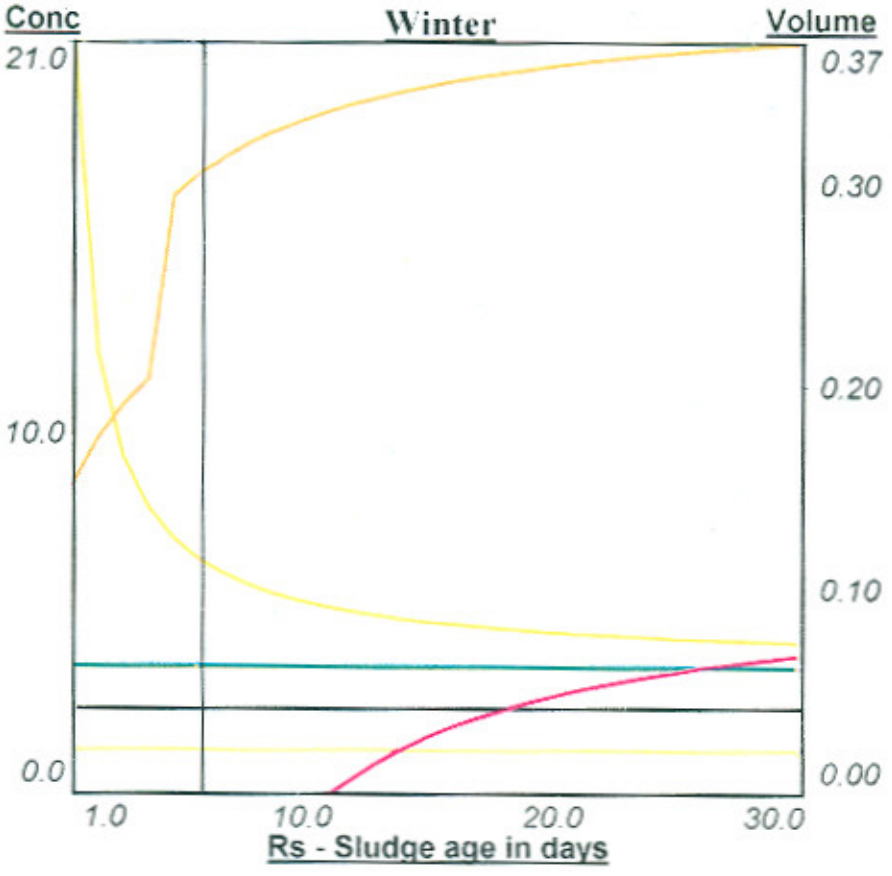


Summer

Rs	=	6.0	days
Rsm	=	2.0	days
a	=	115.0	ML/day
ao	=	146.7	ML/day
Temp	=	20.0	°C
Ns	=	5.185	mg/L
Oc	=	4.067	Tonne/day
On	=	2.584	Tonne/day
Ot	=	5.491	Tonne/day
Od	=	1.159	Tonne/day
N'ti	=	26.81	mg/L
N%rem	=	86.58	%

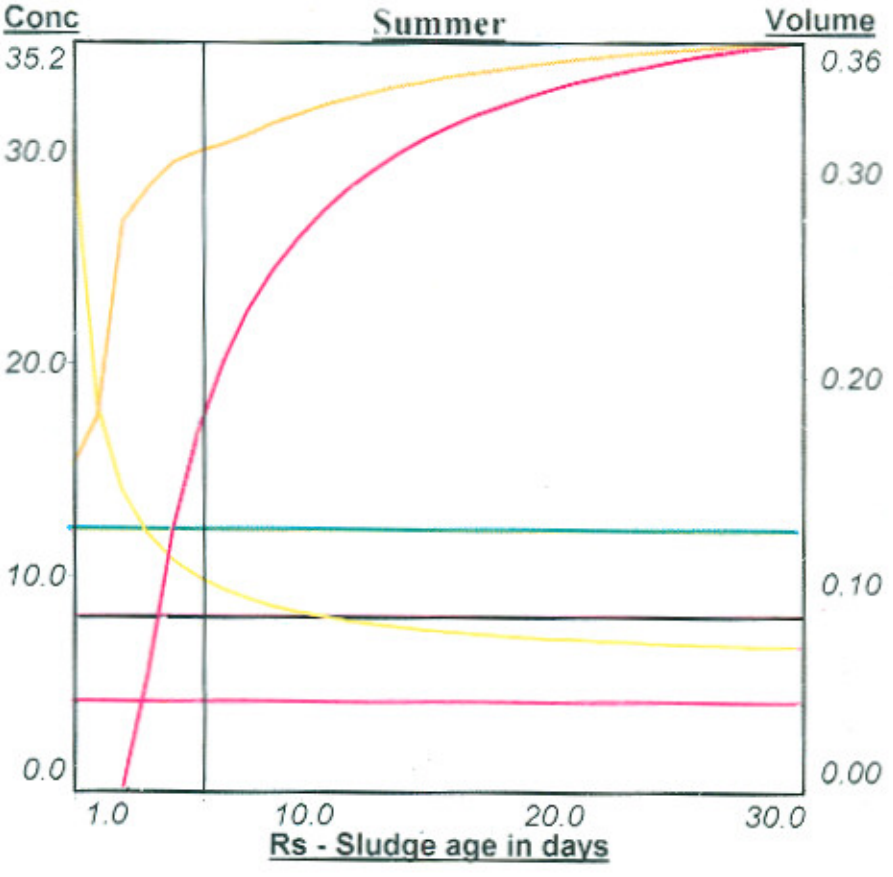
APPENDIX 3

SASSPro Report - BNR5



Winter

Rs	=	6.0	days
Rsm	=	3.9	days
a	=	115.0	ML/day
ao	=	5.4	ML/day
Temp	=	15.0	°C
fx1	=	0.111	
fx3	=	0.056	
fxdm	=	-0.27	
fxdt	=	0.167	
fx1min	=	0.312	
fxm	=	-0.27	
O%Cap	=	35.71	%



Summer

Rs	=	6.0	days
Rsm	=	2.0	days
a	=	115.0	ML/day
ao	=	146.7	ML/day
Temp	=	20.0	°C
fx1	=	0.111	
fx3	=	0.056	
fxdm	=	0.230	
fxdt	=	0.167	
fx1min	=	0.136	
fxm	=	0.230	
O%Cap	=	36.13	%

STREAM REPORT

STREAM NAME		S-102 Metha	S-103	S-101 Infl	S-104	S-105
SOURCE		INPUT	M-101	INPUT	AXR-101	AXR-101
DESTINATION		M-101	AXR-101	M-101	OUTPUT	AEB-101
STREAM PROPERTIES						
ACTIVITY	U/ml	0.0	0.0	0.0	0.0	0.0
TEMP	°C	20.0	20.3	20.0	30.0	30.0
PRES	bar	1.0	1.0	1.0	1.0	1.0
DENSITY	g/l	791.3	959.5	959.5	1.1	958.1
COMPONENT FLOWRATES (kg/h averaged)						
Ammonia		0.0000	31.6065	29.1234	0.0000	31.6065
Auto Biomass		0.0000	0.8729	0.0000	0.0000	0.8729
Carb. Dioxide		0.0000	0.0000	0.0000	0.0000	0.0969
Dead biomass		0.0000	69.0804	0.0000	0.0000	69.0804
Glucose		0.0000	291.3816	291.2338	0.0000	291.3816
Heter biomass		0.0000	287.0516	0.0000	0.0000	287.0728
Methanol		52.0000	56.4099	0.0000	0.0000	56.2307
Nitrate		0.0000	0.1026	0.0000	0.0000	0.0014
Nitrogen		0.0000	0.0000	0.0000	0.0382	0.0000
Oxygen		0.0000	0.0000	0.0000	0.0000	0.0000
Water		0.00001054879.4149		970458.8299	0.00001054879.5392	
TOTAL (kg/h)		52.00001055615.9205		970779.1870	0.03821055615.8824	
TOTAL (m3/h)		0.0657	1100.1989	1011.7903	0.0339	1101.7238

STREAM NAME		S-106	S-107	S-108	S-109	S-110
SOURCE		INPUT	AEB-101	AEB-101	FS-101	FS-101
DESTINATION		AEB-101	OUTPUT	FS-101	M-101	AXR-102
STREAM PROPERTIES						

APPENDIX 4

Process flow diagram for BNR process

(the Bardenpho Plant)

Oxygen	415771.7529	415655.1850	0.0000	0.0000	0.0000
Water	0.0000	0.00001055024.0647		52760.73731002454.0081	
TOTAL (kg/h)	1792119.62451792147.37661055588.1303			52789.04451002991.8454	
TOTAL (m3/h)	1494422.56471519902.7126		1100.2688	55.0148	1045.2805

STREAM NAME		S-111	S-112	S-113	S-118	S-119
SOURCE		AXR-102	AXR-102	AEB-102	INPUT	FS-102
DESTINATION		OUTPUT	AEB-102	OUTPUT	AEB-102	M-101
STREAM PROPERTIES						
ACTIVITY	U/ml	0.0	0.0	0.0	0.0	0.0
TEMP	°C	30.0	30.0	25.0	20.0	25.0
PRES	bar	1.0	1.0	1.0	1.0	1.0
DENSITY	g/l	1.1	958.0	1.2	1.2	960.1
COMPONENT FLOWRATES (kg/h averaged)						
Ammonia		0.0000	29.5710	0.0000	0.0000	0.9268
Auto Biomass		0.0000	1.0973	0.0000	0.0000	0.8151
Carb. Dioxide		0.0000	1.4114	1.4114	0.0000	0.0000
Dead biomass		0.0000	80.2952	0.0000	0.0000	64.8543
Glucose		0.0000	2.7868	0.0000	0.0000	0.0012
Heter biomass		0.0000	369.5593	0.0000	0.0000	267.6173
Methanol		0.0000	50.7335	0.0000	0.0000	1.6023
Nitrate		0.0000	0.0151	0.0000	0.0000	0.0242
Nitrogen		0.5561	0.0000	653930.3376	653930.3376	0.0000
Oxygen		0.0000	0.0000	197539.6171	197541.4561	0.0000
Water		0.00001002455.8198		0.0000	0.0000	31659.8478
TOTAL (kg/h)		0.55611002991.2893		851471.3662	851471.7937	31995.6890
TOTAL (m3/h)		0.4938	1046.9717	722139.7116	710029.9804	33.3269

STREAM NAME		S-120	S-114	S-116 Efflu	S-117
SOURCE		FS-102	AEB-102	CL-101	CL-101
DESTINATION		OUTPUT	CL-101	OUTPUT	FS-102
STREAM PROPERTIES					
ACTIVITY	U/ml	0.0	0.0	0.0	0.0
TEMP	°C	25.0	25.4	25.4	25.0
PRES	bar	1.0	1.0	1.0	1.0
DENSITY	g/l	960.1	959.6	959.6	960.1
COMPONENT FLOWRATES (kg/h averaged)					
Ammonia		0.3089	29.3454	28.1097	1.2357
Auto Biomass		0.2717	1.1090	0.0222	1.0868

APPENDIX 4

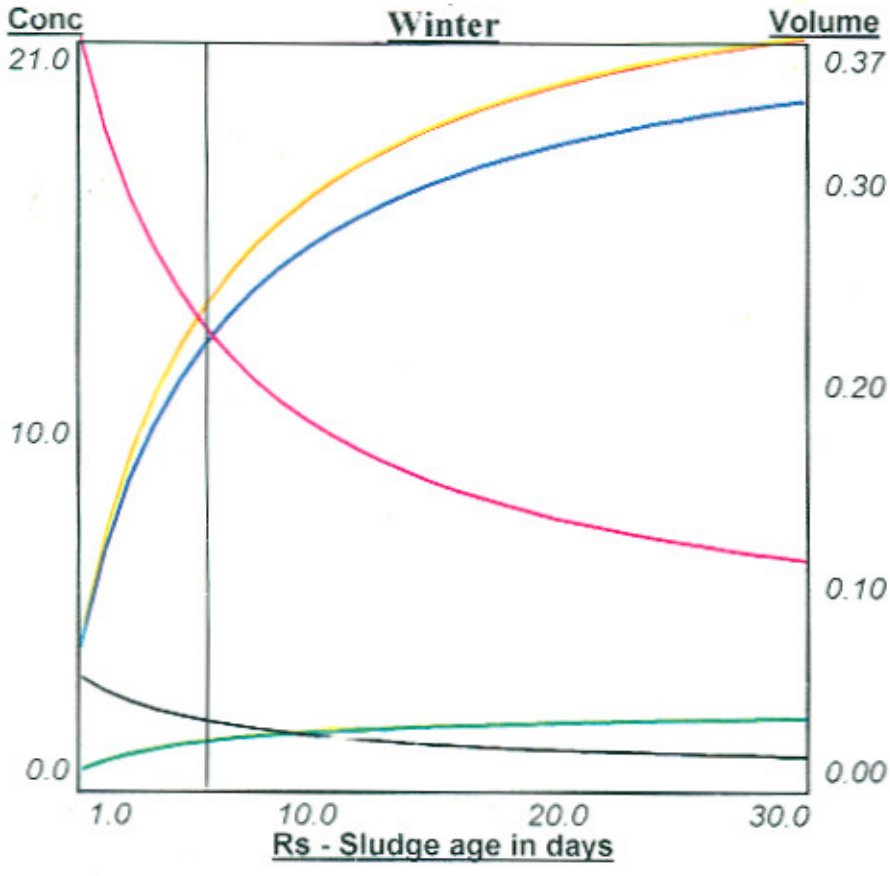
Carb. Dioxide	0.0000	0.0000	0.0000	0.0000
Dead biomass	21.6181	88.2371	1.7647	86.4724
Glucose	0.0004	0.0372	0.0357	0.0016
Heter biomass	89.2058	364.1052	7.2821	356.8231
Methanol	0.5341	50.7335	48.5971	2.1364
Nitrate	0.0081	0.7668	0.7345	0.0323
Nitrogen	0.0000	0.0000	0.0000	0.0000
Oxygen	0.0000	0.0000	0.0000	0.0000
Water	10553.2826	1002457.3825	960244.2522	42213.1304
TOTAL (kg/h)	10665.2297	1002991.7169	960330.7982	42660.9187
TOTAL (m3/h)	11.1090	1045.1987	1000.7604	44.4358

OVERALL MATERIAL BALANCE (kg/h averaged)

COMPONENT	IN	OUT	(OUT-IN)
Ammonia	29.123376	28.418651	-0.704725
Auto Biomass	0.000000	0.293892	0.293892
Carb. Dioxide	0.000000	145.731389	145.731389
Dead biomass	0.000000	23.382844	23.382844
Glucose	291.233756	0.036059	-291.197697
Heter biomass	0.000000	96.487887	96.487887
Methanol	52.000000	49.131204	-2.868796
Nitrate	0.000000	0.742587	0.742587
Nitrogen	2030278.209219	2030278.803535	0.594316
Oxygen	613313.209035	613194.802139	-118.406896
Water	970458.829868	970797.534777	338.704909
TOTAL	3614422.605254	3614615.364965	192.759711

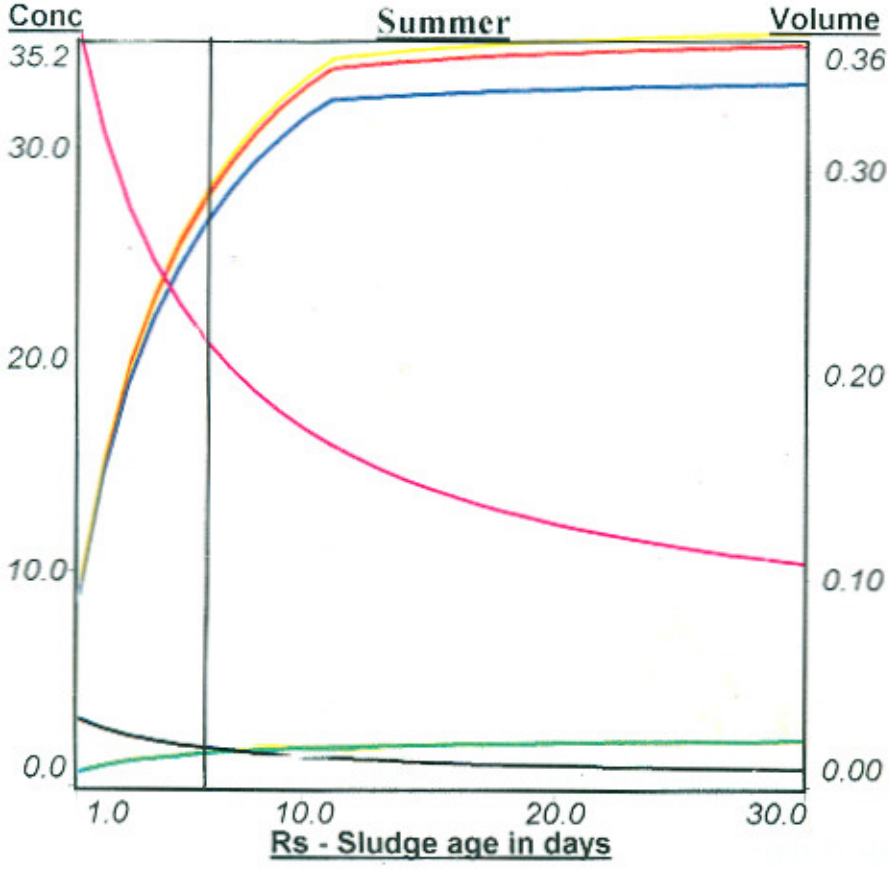
APPENDIX 4

SASSPro Report - BNR4



Winter

Rs	=	6.0	days
Rsm	=	3.9	days
a	=	115.0	ML/day
ao	=	5.4	ML/day
Temp	=	15.0	°C
Psm	=	1.938	mg/L
Dpt	=	13.48	mg/L
Dp1	=	12.33	mg/L
Dp3	=	1.149	mg/L
Dpp	=	13.51	mg/L
P%rem	=	53.84	%



Summer

Rs	=	6.0	days
Rsm	=	2.0	days
a	=	115.0	ML/day
ao	=	146.7	ML/day
Temp	=	20.0	°C
Psm	=	1.825	mg/L
Dpt	=	27.26	mg/L
Dp1	=	26.04	mg/L
Dp3	=	1.221	mg/L
Dpp	=	27.65	mg/L
P%rem	=	50.69	%