TREATMENT OF MEAT PROCESSING WASTEWATER FOR CARBON, NITROGEN AND PHOSPHORUS REMOVAL IN A SEQUENCING BATCH REACTOR

A thesis presented in partial fulfilment of the requirements
for the degree of
Doctor of Philosophy
in Process & Environmental Technology

at Massey University

Nagalingam Thayalakumaran

2002

ABSTRACT

The typical New Zealand meat processing industry wastewater was treated by a laboratory scale Sequencing Batch Reactor (SBR) to determine an effective operating cycle for biological carbon, nitrogen and phosphorus removal. The Activated Sludge Model No. 1 and Model No. 2 with modifications were used to simulate the treatment of meat processing wastewater using the SBR.

The average values of main pollution parameters of the wastewater were characterised as 1390 mg total COD L^{-1}, 755 mg soluble COD L^{-1}, 75 mg L^{-1} NH_3 – N, 145 mg L^{-1} TKN and 34 mg L^{-1} TP. The readily biodegradable COD (RBCOD) accounts for 15 – 18 % of the total COD, while the inert soluble and particulate portion were 4 % each.

In order to establish an effective operating cycle for the simultaneous removal of nutrients and organic carbon, different dissolved oxygen (DO) concentrations in the mixed liquor, duration of operating phases and hydraulic retention time (HRT) of a 6 h cycle were tested. The most effective cycle consisted of seven phases. The first two hours of the anaerobic period was followed by the aerobic and anoxic periods. The first aerobic period was maintained at a DO concentration of 0.5 ± 0.25 mg L^{-1} for 1 h, the second aerobic period for 1 h at a DO concentration of 3.75 ± 0.25 mg L^{-1} and the third aerobic period for half an hour at 0.5 ± 0.25 mg L^{-1} DO concentration. A half an hour anoxic period followed the first aerobic period. A settling period of 0.75 h followed the third aerobic period. The last quarter of an hour was for decanting and idling. The solids retention time (SRT) was 15 d, while the HRT was 2.5 d. Greater than 99 % removal of biodegradable soluble COD, NH_3 – N and PO_4 – P was achieved in the effective operating cycle where the TN and TP in the wastewater were reduced to 10 mg L^{-1} and 1.0 mg L^{-1}, respectively. In addition the soluble COD was reduced to 98 mg L^{-1}.

The key kinetic and stoichiometric parameters for ASM 1 and ASM 2 models were determined using batch tests. The heterotrophic maximum specific growth rate, yield coefficient and the half saturation constant were 2.0 d^{-1}, 0.63 mg cell COD (mg COD)$^{-1}$ and 8 mg L^{-1} respectively. The maximum specific growth rate of autotrophs was 0.65 – 0.80 d^{-1}. The anaerobic phosphorus removal stoichiometric coefficients were also

determined in batch tests. During the anaerobic period, when 1 g of acetate COD was initially present, 1.48 g of PHA COD was stored while 0.48 g of P was released. The batch trials conducted using acetate to assess the influence of Mg^{2+} in P uptake showed that the Mg^{2+} could limit the P uptake and the uptake rate could be represented by Monod type kinetics. In the Monod kinetic expression the Mg^{2+} half saturation constant was found to be 4.7 mg L^{-1}. The molar ratio of Mg^{2+} with P was 0.21 during the anaerobic period, and 0.33 during the aerobic period.

The SBR performance was modelled using ASM 1 and ASM 2 models after the addition of more processes in these models. Ammonification of the soluble organic N process rate was modified in the ASM 1 model. Similarly it was necessary to add anoxic P uptake and anoxic growth processes involving PHA of Bio-P bacteria in the ASM 2 model. Glycogen storage and glycogen lysis processes of Bio-P bacteria were added in the ASM 2 model to understand the involvement of glycogen in P removal. Also a modification was performed to the storage process of poly-P in the ASM 2 model to account for potential Mg^{2+} limitation in meat processing wastewater treatment for P removal. During the settling period anoxic hydrolysis was assumed to be negligible. The calibrated ASM 1 and ASM 2 models in general well simulated the effluent NH_3 – N, NO_3 – N and PO_4 – P of SBR cycles carried out in distinctly different periods of time and in different batch tests.

As the calibrated modified ASM 2 model was able to predict the performance of an SBR cycle conducted over a time period of three months, it was used to identify the most promising treatment strategies of the SBR performance. Variation in duration of feed cycle during the first non-aerated mixed period did not affect the effluent NO_3 – N, NH_3 – N and PO_4 – P concentrations significantly. DO concentration of 3.75 mg L^{-1} during the third aerobic period instead of 0.5 mg L^{-1} increased the effluent NO_3 – N and PO_4 – P concentrations. The simulations confirmed that the operating conditions identified in a 6-h cycle period for the simultaneous organic carbon and nutrient removal are effective.

Acknowledgements

I wish to thank Professor Rao Bhamidimarri for his guidance and supervision over the past three years. I also thank Mr. Paul Bickers for his helpful discussions and suggestions.

Many thanks to Professor Bob Chong, Dr. Magnus Christensson and Mr. Ken Butler for their valuable suggestions.

Thanks to Dr. Manderson and Dr. John Brounland who gave me the fundamentals of microorganisms and MATLAB programming.

I am very grateful to Mr. Bruce, Mr. John Syke, and Mr. Andrew for their help in the reactor set up. Thanks to my fellow postgraduates in the lab. for their friendship.

Thanks to the Massey University for providing me with financial assistance for presenting papers at the IWA conference held in Melbourne and the Biotechnology conference held in Palmerston North.

Thanks to the Environmental Management Team of Manawatu Beef Packers in Fielding for allowing me to collect their wastewater.

I also wish to thank Dr. David Scotter and Dr. Tessa Mills for their help in proof-reading and editing my thesis.

Thanks to my wife, Thabo, and daughter, Varshi, for their patience and encouragement throughout the study.

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Abbreviations

3H2MB	3-hydroxy-2-methylbutyrate
3H2MV	3-hydroxy-2-methylvalerate
3HB	3-hydroxybutyrate
3HV	3-hydroxyvalerate
AA	Anoxic-anoxic
AO	Anaerobic-aerobic
AS	Activated Sludge
ASM 1	Activated Sludge Model No. 1
ASM 2	Activated Sludge Model No. 2
Bio-P	Biological phosphorus removing bacteria
BNR	Biological nutrient removal
BOD	Biochemical Oxygen Demand (mg L^{-1})
BOD_5	5 d biochemical oxygen demand (mg L^{-1})
BPR	Biological phosphorus Removal
b_A	Autotrophic decay coefficient (d^{-1})
b_H	Heterotrophic Task Group model decay coefficient (d^{-1})
b'_H	Heterotrophic biomass endogenous decay rate (d^{-1})
C	Carbon
Ca^{2+}	Calcium
COD	Chemical Oxygen Demand (mg L^{-1})
C_{T1}	Initial total COD in the reactor 1 (mg COD L^{-1})
$(C_T)_1$, $(C_T)_2$	Final total COD in the reactors 1 and 2 (mg COD L^{-1})
DAF	Dissolved air floatation
DO	Dissolved Oxygen (mg L^{-1})
EBPR	Enhanced Biological Phosphate Removal
f_{ES}, f_{EX}	Fraction of soluble and particulate inert COD generated in biomass decay
f_P	Fraction of biomass yielding to particulate products
F/M ratio	Food (substrate) to Mass (Biomass) ratio
H_2	Hydrogen
HAc	Acetic acid
HRT	Hydraulic Retention Time (d)
HMP	Hexametaphosphate
IAWPRC	International Association on Water Pollution Research and Control
IAWQ	International Association on Water Quality
IWA	International Water Association
i_{XB}	Mass of nitrogen per mass of COD in biomass
i_{XP}	Mass of nitrogen per mass of COD in products from biomass
K^+	Potassium
K_{Mg}	Magnesium half saturation constant (mg L^{-1})
K_{NH}	Ammonia half saturation coefficient for autotrophic biomass (mg L^{-1})
$K_{N,O}$	Nitrate half saturation coefficient for denitrifying heterotrophic biomass (mg L^{-1})
$K_{O,A}$	Oxygen half saturation constant for autotrophs (mg L^{-1})
$K_{O,H}$	Oxygen half saturation constant for heterotrophs (mg L^{-1})
K_S	Substrate half saturation coefficient (mg L^{-1})
K_X	Half saturation coefficient for hydrolysis of slowly biodegradable substrate (g slowly biodegradable COD (g cell COD)$^{-1}$)
k_a	Ammonification rate (m^3 (g COD d)$^{-1}$)
Mg^{2+}	Magnesium
MLVSS	Mixed liquor volatile suspended solid
N	Nitrogen
N_2	Nitrogen gas
$NH_3 - N$	Ammonia nitrogen + Ammonium nitrogen
$NO_2 - N$	Nitrite nitrogen
$NO_3 - N$	Nitrate nitrogen, 0.6 Nitrite nitrogen plus nitrate nitrogen

$NO_X - N$	Nitrite nitrogen plus nitrate nitrogen
NUR	Nitrate Utilisation Rate (g $NO_3 - N\ m^{-3}\ h^{-1}$)
OUR	Oxygen Uptake Rate (mg $O_2\ L^{-1}\ h^{-1}$)
PAO	Phosphorus Accumulating Organisms
P	Phosphorus
PHA	Poly-β-hydroxyalkanoate
PHB	Poly-β-hydroxybutyrate
PHV	Poly-β-hydroxyvalerate
poly-P	Polyphosphate
$PO_4 - P$	Soluble phosphate phosphorus
ppm	Particles per million
Q	Influent flow rate ($m^3\ s^{-1}$)
q	Phosphorus uptake rate (mg P (g VSS d)$^{-1}$)
q_{max}	Maximum phosphorus uptake rate (mg P (g VSS d)$^{-1}$)
RBCOD	Readily biodegradable COD
R_{EQ}	Oxygen reduction equivalent
rpm	revolution per minute
r_X	Specific substrate removal rate (d^{-1})
r's	Substrate utilisation rate, g $(m^3 s)^{-1}$
r'X	Rate of biomass growth, g $(m^3 s)^{-1}$
S	Substrate concentration in the reactor (mg L^{-1})
SBCOD	Slowly Biodegradable COD
SBR	Sequencing Batch Reactor
SCFA	Short Chain Fatty Acids
SCOD	Soluble COD (mg L^{-1}), defined as GFC filterable COD for this study
S_{G1}	Initial soluble COD in the glucose reactor (mg COD L^{-1})
S_H	Rapidly hydrolysable substrate (mg L^{-1})
S_I	Soluble inert substrate concentration (mg L^{-1})
SMP	Soluble Microbial Products
S_{Mg}	Soluble magnesium concentration (mg L^{-1})
SND	Simultaneous Nitrification and Denitrification
S_{ND}	Soluble biodegradable organic nitrogen (mg N L^{-1})
S_{NH}	Ammonia nitrogen + Ammonium nitrogen (g N m^{-3})
S_{NO}	Concentration of oxidised nitrogen (mg L^{-1})
S_O	Substrate concentration of the influent/ initial (mg L^{-1})
SOUR	Specific Oxygen Uptake Rate (mg O_2 (g VSS h)$^{-1}$)
SRT	Solids Retention Time (d)
S_S	Readily biodegradable substrate concentration (mg COD L^{-1})
S_{T1}	Initial soluble COD in the reactors 1 and 2 (mg COD L^{-1})
$(S_T)_1$, $(S_T)_2$	Final soluble COD in the reactors 1 and 2 (mg COD L^{-1})
SVI	Sludge Volume Index (ml g^{-1})
TCA	Tricarboxylic acid
TCOD	Total COD
TKN	Total Kjeldahl Nitrogen (mg N L^{-1})
TN	Total Nitrogen (mg N L^{-1})
TP	Total Phosphorus (mg L^{-1})
TS	Total Solids (mg L^{-1})
TSS	Total Suspended Solids (mg L^{-1})
V_{ml}	Volume of mixed liquor
V_O	Initial reactor volume before feeding, m^3
VSS	Volatile Suspended Solids (mg L^{-1})
V_{WW}	Volume of wastewater
X	Biomass concentration in the reactor (mg L^{-1})
$X_{B,A}$	Active autotrophic biomass (mg COD L^{-1})
$X_{B,H}$	Active heterotrophic biomass (mg COD L^{-1})
X_I	Particulate inert substrate concentration (mg COD L^{-1})
X_{ND}	Particulate biodegradable organic nitrogen (mg N L^{-1})
X_O	Biomass concentration of the influent/initial (mg L^{-1})

X_S	Slowly biodegradable substrate (mg COD L^{-1})
$(X_T)_1$	Final particulate COD of raw wastewater reactor (mg COD L^{-1})
Y_A	Autotrophic yield coefficient (g Cell COD g N $oxidised^{-1}$)
Y_H	Heterotrophic yield coefficient (g Cell COD g substrate COD^{-1})
Y_{obs}	Coefficient of observed biomass yield (g Cell COD g substrate COD^{-1})
Y_{SP}	Fraction of biodegradable COD converted into soluble inert microbial products
Y_{XP}	Fraction of biodegradable COD converted into particulate inert microbial products
$\hat{\mu}_H$, μ_{max}	Maximum specific growth rate of heterotrophs (d^{-1})
$\hat{\mu}_A$, $\mu_{max,A}$	Maximum specific growth rate of autotrophs (d^{-1})
η_g	Correction factor for anoxic growth of heterotrophs
η_h	Correction factor for anoxic hydrolysis

Components in the ASM 2 model

S_A	Fermentation products (mg COD L^{-1})
S_{ALK}	Alkalinity of the wastewater (mol HCO_3 L^{-1})
S_F	Fermentable, readily biodegradable organic substrates (mg COD L^{-1})
S_I	Inert soluble organic material (mg COD L^{-1})
S_{N2}	Dinitrogen (mg N L^{-1})
S_{NH4}	Ammonium plus ammonia nitrogen (mg N L^{-1})
S_{NO3}	Nitrate + 0.6times the Nitrite nitrogen (mg N L^{-1})
S_{O2}	Dissolved oxygen (mg O_2 L^{-1})
S_{PO4}	Inorganic soluble phosphorus (mg P L^{-1})
X_{AUT}	Nitrifying organisms (mg COD L^{-1})
X_H	Heterotrophic organisms (mg COD L^{-1})
X_I	Inert particulate organic material (mg COD L^{-1})
X_{PAO}	Phosphate accumulating organisms (mg COD L^{-1})
X_{PHA}	A cell internal storage product of Bio-P (mg COD L^{-1})
X_{PP}	Polyphosphate (mg P L^{-1})
X_S	Slowly biodegradable substrates (mg COD L^{-1})
X_{TSS}	Total suspended solids (mg TSS L^{-1})

Conversion factors in the ASM 2 model:

i_{NSF}	N content of fermentable substrate S_F, g N(g COD)$^{-1}$
i_{NSI}	N content of inert soluble COD S_I, g N(g COD)$^{-1}$
i_{NXI}	N content of inert particulate COD X_I, g N(g COD)$^{-1}$
i_{NXS}	N content of slowly biodegradable substrate X_S, g N(g COD)$^{-1}$
i_{NBM}	N content of biomass X_H, X_{PAO}, X_{AUT}, g N(g COD)$^{-1}$
i_{PSF}	P content of fermentable substrate S_F, g P(g COD)$^{-1}$
i_{PSI}	P content of inert soluble COD S_I, g P(g COD)$^{-1}$
i_{PXI}	P content of inert particulate COD X_I, g P(g COD)$^{-1}$
i_{PXS}	P content of slowly biodegradable substrate X_S, g P(g COD)$^{-1}$
i_{PBM}	P content of biomass X_H, X_{PAO}, X_{AUT}, g P(g COD)$^{-1}$
i_{TSSXI}	TSS to X_I ratio, g TSS(g COD)$^{-1}$
i_{TSSXS}	TSS to X_S ratio, g TSS(g COD)$^{-1}$
i_{TSSBM}	TSS to biomass ratio for X_H, X_{PAO}, X_{AUT}, g TSS(g COD)$^{-1}$
f_{SI}	Fraction of inert COD in particulate substrate, g COD(g COD)$^{-1}$
f_{XI}	Fraction of inert COD generated in biomass lysis, g COD(g COD)$^{-1}$

Stoichiometric parameters in the ASM 2 model:

Hydrolysis

f_{SI}	Production of S_I in hydrolysis

Heterotrophic biomass: X_H

Y_H	Yield coefficient, g COD (g COD)$^{-1}$
f_{XI}	Fraction of inert COD generated in biomass lysis

Phosphorus accumulating organisms: X_{PAO}

Y_{PAO}	Yield coefficient (biomass/PHA), g COD (g COD)$^{-1}$
Y_{PO4}	PO_4 release per X_{PHA} stored, g P (g COD)$^{-1}$
Y_{PHA}	X_{PHA} requirement for X_{PP} storage, g COD (g P)$^{-1}$
f_{XI}	Fraction of inert COD generated in biomass lysis
Y_{SA}	S_A requirement for X_{PHA} storage, g COD (g COD)$^{-1}$
Y_{MgPHA}	Yield of magnesium during X_{PHA} storage g Mg (g COD)$^{-1}$
Y_{MgXPP}	Yield of magnesium during X_{PP} storage g Mg (g P)$^{-1}$

Nitrifying organisms: X_{AUT}

Y_A	Yield of autotrophic biomass per $NO_3 - N$, g COD (g N)$^{-1}$
f_{XI}	Fraction of inert COD generated in biomass lysis

Kinetic model parameters in the ASM 2 model

Hydrolysis of particulate substrate: X_S

K_h	Hydrolysis rate constant, d^{-1}
η_{NO3}	Anoxic hydrolysis reduction factor
η_{fe}	Anaerobic hydrolysis reduction factor
K_{O2}	Saturation/inhibition coefficient for oxygen, g O_2 m^{-3}
K_{NO3}	Saturation/ inhibition coefficient for nitrate, g N m^{-3}
K_X	Saturation coefficient for particulate COD, g X_S (g X_H)$^{-1}$

Heterotrophic organisms: X_H

μ_H	Maximum growth rate on substrate, g X_S(g X_H d)$^{-1}$
q_{fe}	Maximum rate for fermentation, g S_F (g X_H d)$^{-1}$
η_{NO3}	Reduction factor for denitrification
b_H	Rate constant for lysis and decay, d^{-1}
K_{O2}	Saturation/inhibition coefficient for oxygen, g O_2 m^{-3}
K_F	Saturation coefficient for growth on S_F , g COD m^{-3}
K_{fe}	Saturation coefficient for fermentation, g COD m^{-3}
K_A	Saturation coefficient for growth on acetate, S_A, g COD m^{-3}
K_{NO3}	Saturation/ inhibition coefficient for nitrate, g N m^{-3}
K_{NH4}	Saturation coefficient for ammonium, g N m^{-3}
K_P	Saturation coefficient for phosphate (nutrient), g P m^{-3}
K_{ALK}	Saturation coefficient for alkalinity (HCO_3), mol HCO_3 m^{-3}

Phosphorus accumulating organisms: X_{PAO}

q_{PHA}	Rate constant for storage of X_{PHA} (base X_{PP}), g X_{PHA} (g X_{PAO} d)$^{-1}$
q_{PP}	Rate constant for storage of X_{PP}, g X_{PP} (g X_{PAO} d)$^{-1}$
μ_{PAO}	Maximum growth rate of X_{PAO}, d^{-1}
η_{NO3}	Reduction factor for anoxic activity
b_{PAO}	Rate for lysis of X_{PAO}, d^{-1}
b_{PP}	Rate for lysis of X_{PP}, d^{-1}
b_{PHA}	Rate for lysis of X_{PHA}, d^{-1}
K_{O2}	Saturation/inhibition coefficient for oxygen, g O_2 m^{-3}
K_{NO3}	Saturation/inhibition coefficient for nitrate, g N m^{-3}

K_A	Saturation coefficient for acetate, S_A, g COD m^{-3}
K_{NH4}	Saturation coefficient for ammonium, g N m^{-3}
K_{PS}	Saturation coefficient for phosphorus in storage of X_{PP}, g P m^{-3}
K_P	Saturation coefficient for phosphate, g P m^{-3}
K_{ALK}	Saturation coefficient for alkalinity (HCO_3), mol HCO_3 m^{-3}
K_{PP}	Saturation coefficient for polyphosphate, g X_{PP} (g X_{PAO})$^{-1}$
K_{MAX}	Maximum ratio of X_{PP}/X_{PAO}, g X_{PP} (g X_{PAO})$^{-1}$
K_{IPP}	Inhibition coefficient for polyphosphate storage, g X_{PP} (g X_{PAO})$^{-1}$
K_{PHA}	Saturation coefficient for PHA, g X_{PHA} (g X_{PAO})$^{-1}$
q_{Gly}	Rate constant for glycogen storage, g X_{GLY} COD (g X_{PAO} COD d)$^{-1}$
K_{GLY}	Saturation coefficient for X_{GLY} , g X_{GLY} COD (g X_{PAO} COD)$^{-1}$
K_{PHAGLY}	Saturation coefficient for X_{PHA} for X_{GLY} storage, g COD (g X_{PAO} COD)$^{-1}$
b_{GLY}	Rate of lysis of X_{GLY} , d^{-1}
K_{Mg}	Mg^{2+} saturation constant, g Mg m^{-3}

Nitrifying organisms : X_{AUT}

μ_{AUT}	Maximum growth rate of X_{AUT}, d^{-1}
b_{AUT}	Decay rate of X_{AUT}, d^{-1}
K_{O2}	Saturation coefficient for oxygen, g O_2 m^{-3}
K_{NH4}	Saturation coefficient for ammonium (substrate), g N m^{-3}
K_{ALK}	Saturation coefficient for alkalinity (HCO_3), mol HCO_3 m^{-3}
K_P	Saturation coefficient for phosphorus, g P m^{-3}