Investigation of Potato Starch and Sonicated Return Activated Sludge as Alternative Carbon Sources for Biological Nitrogen Removal

by

Gideon Bani Kuncoro

School of Chemical Engineering
The University of Adelaide

A thesis submitted for the degree of
Masters of Engineering Science

June 2008

Declaration

This work contains no material which has been accepted for the award of any other degrees or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Mr. Gideon Bani Kuncoro: …………………..

Date……………………………………………

Abstract

High nitrogen discharge from the municipal wastewater is a major concern for the South Australian Government, primarily due to negative impacts on the marine environment. Therefore, under the South Australian Environmental Improvement Program, (SA EIP), all metropolitan wastewater treatment plants have been reconfigured to achieve enhanced nitrogen removal. Secondary treatment (denitrification process) at the metropolitan wastewater treatment plants must be optimised to meet the discharge guideline of 10 mg/L total nitrogen. However, secondary treatment at some plants is carbon limited (low C/N ratio), and external carbon supplementation is required to meet this discharge guideline.

Molasses provides the current external carbon source at two plants. It is relatively inexpensive, but other carbon sources, particularly industrial waste streams, may be more attractive, due to the potentially lower material cost, as it is practically free, and environmentally friendly. Potato starch and sonicated return activated sludge (RAS) were considered.

In this study, the bioavailability of the soluble carbon in potato starch and ultrasound treated RAS were assessed. The associated objective was to investigate the potential of both carbon sources as an external carbon donor for the denitrification zone of wastewater treatment plants to economically improve biological nitrogen removal. The economic analysis was performed using mainly United States dollars and the fixed capital investments and total capital costs were converted to Australian dollars. This was due to the United States dollars currency quotes obtained for the materials and unit operations required.

SCOD from the three sources was quantified and preliminary results were presented. Molasses provided the highest SCOD release of 1.1285×10^6 mg-SCOD/L, sonicated RAS produced 5.6 to 68.4 times the SCOD release of the untreated RAS (35.6 mg-SCOD/L) depending on the ultrasound intensity and treatment time, while the highest soluble carbon release obtained using potato starch was 809 mg-SCOD/L (using 20.9 g/100 mL potato starch concentration).

Based on the experimental SCOD results, batch denitrification tests using the proposed carbon sources were carried out. The nitrogen removal efficiency at low dose (12.48 mg-SCOD/L) using molasses, potato starch and sonicated RAS were 77.54%, 57.24%, and 72.76% respectively, whilst at high dose (124.80 mg-SCOD/L) were 94.04%, 66.32%, and 92.10% correspondingly. In similar order of the proposed carbon sources, the nitrate removal rates for the first phase denitrification with low dose were 1.44, 1.16, and 1.18 mg-NO_3^-/h respectively, whilst the nitrate removal rate of the first phase denitrification with high dose improved to 2.01, 1.26, and 1.96 mg-NO_3^-/h correspondingly.

From the denitrification test results, molasses proved to be the optimal carbon source in terms of nitrate removal. However sonicated RAS possesses similar denitrification performance and may be a suitable alternative.

An economic analysis for sonicated RAS Option 2 confirmed it as the most viable substitute. The time to recover the initial investment (payback period) is approximately 6.5 years and the breakeven point is approximately 8 years.

Both denitrification tests and economic analyses demonstrate that sonicated RAS may be a viable and attractive substitute for the molasses.

Acknowledgment

I would like to express my appreciation to numerous people and their organisations who have greatly contributed and assisted me to complete this research study. In particular I would like to acknowledge:

- Dr Yung Ngothai, School of Chemical Engineering, The University of Adelaide, my principal supervisor, for supervisions, encouragement, discussions, ideas and the opportunity to carry out research in this field.
- A/Prof. Brian O'Neill, School of Chemical Engineering, The University of Adelaide, my co-supervisor, for support, guidance, ideas and assistance in power output calculations.
- Mr. Uwe Kaeding, United Water International, my external supervisor, for support, materials and data, and the ideas, for the completion of this thesis.
- Dr. David Sweeney, United Water International, my external supervisor, for support, materials and data, and the ideas, for the completion of this thesis.
- United Water International, for the financial support and the opportunity to participate in CHEMECA Conference 2006, which led to the paper publication in The International Journal of Environment and Waste Management (IJEWM).
- Mr Ian Mackenzie, United Water International, Glenelg Wastewater Treatment Plant supervisors, for data and assistance in wastewater sampling.
- Dr. Chris Colby, School of Chemical Engineering, The University of Adelaide, for permission to use the Microbiology Laboratory, provided initial laboratory equipments, guidance in insulation design for power output determination, advice and encouragement
- A/Prof. Dzuy Nguyen, School of Chemical Engineering, The University of Adelaide, for permission to use the Rheology Laboratory and ultrasound device.
- Smiths Snackfoods, and Ms. Yvette Lee, for assistance and providing potato starch; Andrew Wright, Peter Kay, Jason Peak and the workshop for assistance in laboratory, construction and modification of apparatus; Aning Ayucitra, M. Eng. Sc, for the assistance in overnight experiments, support and encouragements; Daniel Ford, United Water International, (responsible

for initial studies on the problem) for guidance and preliminary data; Manfred Glombowski, National Product Specialist - Laboratory Applications Environmental and Process Technologies, Biolab, for his help in selecting the suitable test kits and quote for the experiments involved; Fergus Rooksby, Enpure Limited, for providing V5 Sonix specification data and quote which has supported the economic analyses; Andrew Garland and Mellisa Murphy, Metaval/Eaton, for providing AFR Filters specification data and quote that has supported the economic analyses.

I would like to dedicate this thesis to my parents, Dr. Tjahjono Koentjoro, MPH, PhD and Dr. Lina Koerniawati, MPH.

I hope that the results of my thesis would satisfy the expectations of the people associated and provide a significant contribution to the society.

Table of Contents

List of Figures

List of Tables

Refereed Publications from this Thesis

Refereed International Journals

G. Kuncoro, Y. Ngothai, D. Sweeney, B. O'Neill, U. Kaeding, Investigation of potato starch and sonicated RAS as alternative carbon sources for biological nitrogen removal, International Journal of Environment and Waste Management (IJEWM), accepted for publication in Volume xxx, 2009.

Refereed Australasian Conference

G. Kuncoro, Y. Ngothai, D. Sweeney, B. O'Neill, U. Kaeding, Investigation of potato starch and sonicated RAS as alternative carbon sources for biological nitrogen removal, Proceedings: Chemeca 2006 34th Australasian Chemical Engineering Conference, D. Patterson & B. Young, Eds., The Institution of Engineers, Auckland, New Zealand, 17 – 20 September 2006, Environmental: Biological Treatment Processes II, Paper 248. (ISBN: 0-86869-110-0).

Nomenclature

A	area (m^2)
Alm	log mean area (m^2)
A_{st}	Area of steel (cu.in)
b	width of member in tank (in)
d	wall thickness (in)
cp	specific heat capacity (J/g.K)
d	tank diameter (m)
D	tank diameter (in, ft; see referred equation information)
E	Denitrification Efficiency
f_r	ring tension (lb/in^3)
G	gravitational acceleration (m/s^2)
h	tank depth (ft)
H	head of pump (m)
I	current (A)
I_E	actual vessel volume (m^3)
K	thermal conductivity (W/m.K)
L	length of conveyor (m)
m	mass flow rate (kg/s)
m	modular ratio
$[NO_x^- - N]$	nitrate concentration
p_{st}	tension of steel in the wall of the tank (lb/in^2)
P	power requirement (kW)
P	maximum pressure at bottom wall (kg/m^2)
pH	acidity of medium
q	heat; heat loss (W)
r_i	radius (m)
R^2	Correlation coefficient
R_1	resistance (K/W)
t	time (minutes; for carbon dosing test and denitrification analysis)
t	time (seconds; for power output and insulator thickness)

t	mixing time (h, for jet mixers)
t	wall thickness (in)
T_i, maximum assumed	inside temperature (°C)
T_0	ambient temperature (°C)
T	temperature (°C)
T	tension (kg)
V	voltage (V)
V	volume (m^3)
W	Branson Sonicator power output (W/ml)
W_s	mechanical energy (J/kg)
X	retention time (s)
X	*V5* Sonix power output (W/ml)
Y	concentration of SCOD released (mg-SCOD/L)

Subscripts

f	final
i	initial, inside
1	propylene layer
2	polystyrene layer

Greek

ΔQ	energy (J)
ΔT	temperature difference (°C or K)
$\sum V$	total delivered flow to jet mixers (m^3/h)
η	fractional efficiency
η_e	motor efficiency
ρ	density (kg/m^3)

Abbreviations

AU$	Australian dollars
C/N	carbon to nitrate ratio
COD	chemical oxygen demand
GBP	Great Britain Pounds

GF/C	glass fibre filter
HDPE	high density polyethylene
kWh	kilowatt hour
MLR	mix liquor return
PE	primary effluent
RAS	return activated sludge
SCOD	soluble chemical oxygen demand
SG	Specific Gravity
TEFC	totally enclosed fan cooled
US$	United States dollars
WWTP	Wastewater Treatment Plant