

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.



# **Volatile Fatty Acids Production from Fermentation of Secondary Sewage Sludge**

A thesis presented in partial fulfillment of the requirements for the  
degree of

**Master of Engineering**

in

**Environmental Engineering**

By

**Sumit Banker**

Institute of Technology and Engineering,  
College of Sciences,  
Massey University  
Palmerston North  
New Zealand

**2008**

**Abstract**

Sludge fermentation is used worldwide as an economical means to produce volatile fatty acids (VFA), which can be used as readily available carbon in biological nutrient removal (BNR) systems. In this research, secondary sludge was tested for its potential to generate VFA. Fermentation of secondary sludge was carried out in a lab-scale sequencing batch reactor (SBR). The SBR was fed with secondary sludge of 1% total solids and run with hydraulic retention time (HRT) of 48 hours and 28 hours in phase 1 (40 days) and phase 2 (12 days) respectively. The SBR produced net VFA (expressed as acetic acid) of  $365 \pm 62.5$  mg  $\text{VFA}_{\text{HAc}}/\text{l}$  which was equivalent to a VFA yield of  $0.28 \pm 0.05$  mg  $\text{VFA}_{\text{HAc}}/\text{mg VSS}_{\text{feed}}$  during phase 1. A change in operating HRT from 48 hours to 28 hours led to a reduction in solids retention time (SRT) from 2.65 days to 2 days in phase 2. The reduction in SRT during phase 2 led to poor hydrolysis and hence could not support the fermentation. Net VFA generation decreased during phase 2 and reached 0 mg/l. Acetic acid was the main acid produced comprising 45% of total VFA content during the run with 48 hours HRT.

The effect of total solids (TS) concentration on secondary sludge fermentation was tested using batch experiments. The batch with 2.8% TS secondary sludge showed a maximum net VFA production of 60 mg  $\text{VFA}_{\text{HAc}}/\text{l}$ , which appeared to be superior to the 1% TS secondary sludge batch fermentation where no net VFA production observed throughout the test period. Primary sludge (3% TS) exhibited 1200 mg  $\text{VFA}_{\text{HAc}}/\text{l}$  in a batch fermentation, which was superior to the net VFA produced during secondary sludge (2.8% TS) batch fermentation. The effects of sonication on fermentability of primary and secondary sludges were tested. A sonic power application of 0.0017 Watt/ml/min density increased soluble content of primary and secondary sludges. In batch fermentations, sonicated secondary sludge improved fermentation over unsonicated secondary sludge. A maximum net VFA production of 130 mg  $\text{VFA}_{\text{HAc}}/\text{l}$  was observed in the secondary sludge batch fermentation.

In this research work, an investigation into inhibiting VFA degradation in secondary sludge batch fermentations was also carried out. The effects of a methanogenic bacteria inhibitor (bromoethane sulfonic acid) and low pH (range of 4.02-6.07) were considered. The addition of 1 mM bromoethane sulfonic acid (BES) in secondary sludge (1% TS) batch fermentation successfully inhibited VFA degradation. pH values as low as 4.02 showed an inhibitory effect on secondary sludge (1% TS) batch fermentation which led to poor hydrolysis and hence no net VFA generated during the test period. However, low pH values reduced the VFA degradation rate in the batch fermentations.

Secondary sludge used in the present research showed the potential to generate VFA. The amount of VFA produced in the present work showed the potential to improve the performance of a BNR system. Moreover, in batch fermentations, VFA generation was improved using various pre-treatments like sonication and BES addition.

## **Acknowledgment**

First and foremost person I would like to thank is my supervisor Dr. Steven Pratt for giving me intellectual guidance, providing valuable suggestions and always being helpful throughout this research project.

I express deep sense of gratitude to Dr. Andy Shilton for continued encouragement, precious suggestions and healthy criticisms which enabled me to finish writing this thesis.

I convey my profound thanks to Dr Sean Barnes and Rotorua District Council for providing fund and support without which this project could not have originated.

I special thank to John Sykes and Mike Sahayam for providing valuable assistance throughout this project.

I am extremely thankful to my parents, my brother, sister-in-law and niece and my family for their support, love, encouragement and patience without which I could not have finish this project.

I extend my thanks to my colleagues Nichola Powel, Selina Zhang, Dave Miller and Mike Tan for being helpful during this project.

Finally I would like to thank my friends Sachi, Rajish, Karan, Vijyant, Himanshu, Jaimin, and Nigam for providing encouragement and assistance during this project.

## **Table of contents**

1	Introduction .....	1
1.1	General: .....	1
1.2	Prior research: .....	2
1.3	Thesis aims and objectives:.....	2
2	Literature review .....	4
2.1	Importance of readily available carbon in BNR: .....	4
2.2	Carbon source for biological nutrient removal: .....	5
2.3	Sewage sludge:.....	6
2.3.1	Primary sludge: .....	6
2.3.2	Secondary sludge: .....	6
2.4	Sludge as a carbon source: .....	7
2.5	Fermentation process bio-chemistry: .....	8
2.5.1	Hydrolysis: .....	8
2.5.2	Acidogenesis: .....	10
2.5.3	Acetogenesis: .....	10
2.5.4	Methanogenesis:.....	11
2.6	Characteristics of VFA produced during fermentation:.....	12
2.7	Suitability of VFA in BNR: .....	13
2.8	VFA production: .....	14
2.8.1	Net VFA production: .....	14
2.8.2	VFA production yield: .....	14
2.8.3	Specific VFA production: .....	15
2.8.4	Gross VFA yield: .....	15
2.9	Types of pre-fermenters (fermenters): .....	15
2.10	Factors governing volatile fatty acid generation:.....	16
2.10.1	Solids retention time: .....	17
2.10.2	Hydraulic retention time: .....	18
2.10.3	Solids concentration:.....	19
2.10.3.1	Effect of low solids on sludge fermentation: .....	19
2.10.3.2	Effect of high solids on sludge fermentation: .....	20
2.11	pH In the fermentation process: .....	21
2.12	Pre-treatment of sludge to enhance fermentation: .....	23
2.12.1	Sludge pre-treatment by sonication:.....	23
2.13	Inhibition of methanogens to prevail acidogenic condition:.....	25
2.14	Summary: .....	26
2.15	Opportunity of research: .....	28
2.15.1	Based on different characteristics, does secondary sludge have potential to support fermentation?.....	28
2.15.2	Does secondary sludge have the ability to support fermentation in a reactor study? .....	28
2.15.3	Do secondary sludge characteristics have the effect on fermentation?.....	29
2.15.3.1	Effects of solids concentration on secondary sludge fermentation:..	29
2.15.3.2	Comparison between primary and secondary sludges fermentation:	29

---

2.15.3.3	Effects of pre-treatments like sonication and bromoethane sulfonic acid (BES) addition on secondary sludge fermentation: .....	29
2.15.3.4	Effects of pH on secondary sludge fermentation: .....	30
3	Materials and methods .....	31
3.1	Sludge sources: .....	31
3.1.1	Primary sludge: .....	31
3.1.2	Secondary sludge: .....	31
3.2	Reactor study:.....	32
3.2.1	Sequencing batch reactor: .....	32
3.2.2	Feed: .....	33
3.2.3	Reactor operation: .....	33
3.3	Sonication of sludge:.....	34
3.4	Batch study 1:.....	35
3.5	Batch study 2:.....	36
3.6	Characteristics of sludges: .....	37
3.6.1	Solids:.....	37
3.6.2	Chemical oxygen demand:.....	38
3.6.3	pH:.....	38
3.6.4	Biochemical oxygen demand: .....	38
3.6.5	Ammonia:.....	39
3.6.6	Total Kjeldahl nitrogen: .....	39
3.6.7	Volatile fatty acids (VFA):.....	39
3.6.8	Alkalinity: .....	40
3.6.9	Carbohydrates: .....	40
4	Sludge characteristics.....	41
4.1	Solids:.....	41
4.2	Carbonaceous content: .....	42
4.3	pH:.....	42
4.4	Nitrogen content:.....	43
4.5	Summary: .....	43
5	VFA production in a laboratory scale SBR .....	44
5.1.1	Solids:.....	44
5.1.2	VFA Production: .....	46
5.1.3	Solubilization: .....	49
5.1.4	Specific VFA production rate and VFA yield: .....	50
5.1.5	VFA speciation: .....	52
5.1.6	pH:.....	54
5.2	Implications for nutrient removal: .....	55
5.3	Brief summary of the SBR:.....	55
6	Effects of feed sludge characteristics on VFA production.....	57
6.1	Solids concentration: .....	57
6.2	Primary v secondary sludges fermentation: .....	59
6.3	Preconditioning of sludge by sonication:.....	60
6.3.1	Characteristics of sonicated sludge: .....	61
6.3.1.1	Soluble chemical oxygen demand (SCOD): .....	61
6.3.1.2	Soluble carbohydrates: .....	62

---

6.3.1.3	Biochemical oxygen demand (BOD):.....	64
6.4	Effect of pretreatments to improve fermentation: .....	65
6.4.1	Effect of sonication on secondary sludges fermentation: .....	65
6.4.2	Effect of methanogenic inhibitor on fermentation: .....	66
6.5	Effect of pH:.....	68
6.6	Effect of low pHs: .....	70
6.6.1	pH profile for low set pH study: .....	74
6.7	Summary of the batch fermentations: .....	74
7	Conclusions and recommendations.....	76
8	References .....	79



## **List of figures**

Figure 2-1 Anaerobic digestion process .....	9
Figure 3-1 Unit operations of Palmerston North wastewater treatment plant.....	31
Figure 3-2 Unit operations of Fielding sewage treatment plant .....	32
Figure 3-3 Sequencing batch reactor.....	32
Figure 3-4 Sonication set-up .....	34
Figure 5-1 TSS and VSS profiles of the SBR .....	44
Figure 5-2 TSS and VSS profile of feed .....	46
Figure 5-3 VFA profile of the SBR .....	47
Figure 5-4 Profile of Soluble COD accumulation of the SBR.....	49
Figure 5-5 Specific VFA production rate of the SBR .....	51
Figure 5-6 Fractions of VFA produced during fermentation .....	53
Figure 5-7 pH profile of the SBR set-up.....	54
Figure 6-1 Net VFA production profile for secondary sludges batch fermentation .....	58
Figure 6-2 Net VFA production profile for primary and secondary sludges .....	59
Figure 6-3 Net VFA yield for primary and secondary sludges batch fermentation .....	60
Figure 6-4 SCOD release over sonication.....	61
Figure 6-5 Soluble carbohydrates release over sonication .....	63
Figure 6-6 BOD profile of sonicated and unsonicated primary sludges .....	64
Figure 6-7 BOD profile of sonicated and unsonicated secondary sludges .....	64
Figure 6-8 Net total VFA profile for sonicated and unsonicated sludges .....	65
Figure 6-9 Net VFA production for with and without BES added sludge fermentation .....	66
Figure 6-10 Individual VFA profile for BES added sludge fermentation .....	67
Figure 6-11 (A) and (B) pH profile (C) and (D) VFA profile .....	69
Figure 6-12 VFA profile for low pH batch fermentations .....	71
Figure 6-13 VFA profile of batch with glucose as substrate.....	72
Figure 6-14 SCOD profile for low pH batch fermentations .....	73
Figure 6-15 pH profile for low pH batch fermentations.....	74

**List of tables**

Table 2-1 Standard free energy and equation of VFA degradation .....	11
Table 2-2 Volatile fatty acids characterisation .....	12
Table 2-3 Composition of VFA distributions in various lab and full scale studies	12
Table 2-4 VFA Production outcome of various research works.....	15
Table 2-5 Optimum SRT values for various studies .....	17
Table 2-6 Optimum HRT values for various studies .....	18
Table 2-7 Optimum solids concentration for various studies .....	21
Table 3-1 Duration of different phases of the SBR .....	34
Table 3-2 Initial conditions for batch fermentations 1 .....	36
Table 3-3 Initial conditions for batch fermentations 2 .....	36
Table 4-1 Characteristics of primary and secondary sludge .....	41
Table 5-1 Net VFA production of the SBR .....	47
Table 5-2 Optimum VFA production for various studies .....	48
Table 5-3 VFA yield and specific production rate for the SBR.....	51

# **1 Introduction**

## ***1.1 General:***

Growing urbanization and limited water resources demand advances in technology to preserve water quality. Over the last few decades, the influx of excess nutrients into water bodies has brought water quality into question. Excess quantities of nitrogen and phosphorus can result in eutrophication (enrichment of nutrients like nitrogen and phosphorus) of receiving water bodies, mainly lakes and slow moving rivers (Sundblad et al., 1994). Nutrients can be treated by various chemical treatments. However, biological treatments are preferred over chemical treatments for economical and environmental reasons. Therefore, biological nutrient removal (BNR) systems are increasingly being incorporated in wastewater treatment plants.

In BNR systems, micro-organisms require readily available carbon as an energy source to remove nitrogen and phosphorus. Therefore, external carbon sources are supplemented to facilitate nutrients removal in BNR processes. However, external carbon sources incur high costs and increase organic load. McDonald (1990) reported that methanol costs were 70% of the total operating and maintenance expenditure of a municipal wastewater treatment facility. An internal carbon source (wastewater or sludge or a mixture of both) can be employed as an economical alternative to external carbon supplementation. However, quite often internal carbon sources are not inherently rich enough in readily available carbon to support BNR systems. As a result, fermentation of sludge or wastewater is carried out to produce volatile fatty acids (VFA) which can be used as a readily consumable substrate for bacteria in BNR systems.

## **1.2 Prior research:**

Over the past few years, a lot of research has been conducted to optimise sludge-fermentation processes. The effects of various operational and sludge parameters like pH, hydraulic retention time (HRT), solids retention time (SRT), solids concentration and temperature on fermentation have been studied significantly. Also, a few studies have demonstrated the effect of different reactor configurations on VFA production. Furthermore, a myriad number of studies have dealt with various sludge pre-treatments to enhance solubility in order to boost fermentation.

Most of the previous studies of sludge fermentation were carried out on primary sludge. Secondary sludge fermentation has been given very little attention. It was believed that secondary sludge is hard to digest due to its characteristics, and hence its suitability to generate VFA via fermentation is lesser than primary sludge. Secondary sludge is reported as troublesome to stabilise because of difficulty in dewatering and digestion (Hogan et al., 2004; Mao et al., 2004). However, secondary sludge may contain high levels of organic matter and could be used to produce VFA, by which reduction and stabilization of organic wastes can also be achieved. Few full scale reactor and batch studies were attempted which focused on secondary sludge fermentation (Min et al., 2002; Yuan et al., 2006a, b; Chen et al., 2006). The findings of these studies are discussed later in the thesis.

## **1.3 Thesis aims and objectives:**

The main objective of this research was to assess the potential of secondary sludge fermentation to facilitate VFA production.

Specifically, the objectives of this research were:

1. To quantify VFA production resulting from fermentation of secondary sludge.

2. To assess the effect of pH and solids concentration on secondary sludge fermentation.
3. To examine the effect of sonic power application on secondary sludge in terms of enhancement of solubility, and to compare VFA production resulting from the fermentation of sonicated and unsonicated secondary sludges.

Throughout the study, results will be put into context through comparisons with data pertaining to primary sludge fermentation.