UNIVERSITI PUTRA MALAYSIA

KINETIC STUDY OF AN AEROBIC DIGESTION WITH BIOMASS RETENTION B Y ULTRAFILTRATION MEMBRANES

KHOR OOI HONG

KINETIC STUDY OF ANAEROBIC DIGESTION WITH BIOMASS RETENTION BY ULTRAFILTRATION MEMBRANES

By

KHOR OOI HONG

Thesis Submitted in Partial Fulfilment of the Requirements
for the Degree of Master of Science
in the Faculty of Engineering,
Universiti Putra Malaysia

April 1997

TO ALL MY TEACHERS

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my chairman, Dr. Fakhru'l-Razi Ahmadun for constantly guiding and encouraging me during the many *crisis* in this study. Also, I wish to thank members of my supervisory committee, En. Ahmad Jusoh and En. Megat Johari Megat Mohd. Noor, for their time and energy spent in making this a better work.

My appreciations to En. Ismail Ghani of the Env. Eng. Lab for his assistance and technical support throughout this study. I am grateful to the staff of the Engineering Faculty,

way or another, and to the staff of GSO for their cheerfulness and professionalism in handling their work.

Special thanks to Boon Yan, Abdullah and Aloysius for their kind assistance. To my lab mates, I hope they don't break the last beaker.

Last but not least, I

their love, understanding and steadfast support. May all beings be well and happy. May they realise the wisdom and happiness that they seek.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

Figure		Page

LIST OF PLATES

LIST OF ABBREVIATIONS

BLR	Biological Loading Rate
COD	Chemical Oxygen Demand
CSTR	Completely Mixed, Stirred Tank Reactor
CUF	Crossflow Ultrafiltration Membrane
CUMAR	Crossflow Ultrafiltration Membrane Anaerobic Reactor
FFB	Fresh Fruit Bunch
HRT	Hydraulic Retention Time
MAS	Membrane Anaerobic System
MF	Microf
MWCO	Molecular Weight Cut-off
OLR	Organic Loading Rate
POME	Palm Oil Mill Effluent
PVC	Polyvynilchloride
RO	Reverse Osmosis
SEM	Scanning Electron Microscope
SRT	Solids Retention Time
SS	Steady State
SSUR	Specific Substrate Utilisation Rate
SUR	Substrate Utilisation Rate
TSS	Total Suspended Solids
UF	Ultrafiltration
VFA	Volatile Fatty Acid
VSS	Volatile Suspended Solids

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in partial fulfilment of the requirements for the degree of Master of Science.

KINETIC STUDY OF ANAEROBIC DIGESTION WITH BIOMASS RETENTION BY ULTRFILTRATION MEMBRANES

By

KHOR OOI HONG

MARCH 1997

Chairman : Dr. Fakhru'l-Razi Ahmadun

Faculty : Engineering

In this study, a 50 litre laboratory-scaled membrane anaerobic system (MAS) combining ultrafiltration (UF) membrane with anaerobic reactor was used to treat palm oil mill effluent (POME) at ambient temperature. Six steady states were attained as part of a kinetic study. The results of steady state 4 (SS4) was adversely affected by a long shutdown due to pump leakage. The results of the five remaining steady states were successfully fitted, above 96%, by Monod, Contois, and Chen and Hashimoto models. Contois Model appeared to be the best at 99.7%. The microbial kinetic constants are Y = 0.83 gVSS/gCOD and b = 0.15 day^{-1}. Minimum solids retention time, θ_c^{min} obtained from the three simulation models range from 6-14.3 days. Maximum total gas yield was measured at 0.621 litre/g COD at an organic loading rate (OLR) of 5.0 $kgCOD/m^3/d$. $\%CH_4$ composition decreases from 75.7% at OLR of 1.8

kgCOD/m^3/d, to 62.3% at OLR of 6.0 kgCOD/m^3/d. The percentages of COD removal were achieved between 99.0%-88.9% over a range of mixed liquor suspended solids of 10,033-22,175 mg/l. The final hydraulic and solids retention time, θ and θ_c have been reduced to 8.3 days and 12.5 days, respectively during SS6. Under scanning electron microscope (SEM), the effective pores of the membrane was found to be pores larger than 0.1 μm. Layers of fibrous growth on the membrane surface increase separation efficiency. More efficient and frequent cleaning is required to inhibit membrane fouling and increase permeate flux. Overall, this study indicated that MAS is capable of treating higher OLR when θ_c is maintained above 20 days.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi sebahagian daripada syarat untuk Ijazah Master Sains.

KAJIAN KINETIK KE ATAS PENCERNAAN ANAEROBIK DENGAN PENAHANAN BIOMAS OLEH MEMBRAN ULTRATURASAN

Oleh

KHOR OOI HONG

MAC 1997

Pengerusi : Dr. Fakhru'l-Razi Ahmadun

Fakulti : Kejuruteraan

Dalam kajian ini, suatu sistem anaerobik membran (MAS) berskala-makmal saiz 50 liter, yang menggabungkan membran ultraturasan (UF) dengan reaktor anaerobik, telah digunakan untuk merawat efluen kilang kelapa sawit (POME) pada suhu persekitaran. Enam tahap tetap (steady state) telah dicapai sebagai sebahagian daripada kajian kinetik. Keputusan tahap tetap 4 (SS4) telah mengalami gangguan, kesan daripada pemberhentian lama setelah pam mengalami kebocoran. Keputusan tahap tetap yang selebihnya berjaya digunakan untuk mendapat *fit* pada 96% ke atas, bagi model-model Monod, Contois, serta Chen dan Hashimoto. Model Contois didapati paling baik dengan 99.7%. Koefisien kinetik mikrobial yang didapati adalah Y = 0.83 gVSS/gCOD dan b = 0.15 hari^{-1}. Masa tahanan pepejal minimum, θ_c^{min} yang didapati daripada simulasi ketiga-tiga model mempunyai julat antara

6-14.3 hari. Jumlah biogas maksimum ialah 0.621 liter/hari bagi kadar beban organik (OLR) 5.0 kgCOD/m^3/hari. %CH_4 berkurang daripada 75.7% pada OLR 1.8 kgCOD/m^3/hari, kepada 62.3% pada OLR 6.0 kgCOD/m^3/hari. Peratusan penyingkiran COD telah dicapai di antara 99.0%-88.9% untuk pepejal terampai larutan campuran (MLSS) antara 10,033-22,175 mg/l. Masa tahanan hidraulik dan pepejal, θ and θ_c telah dikurangkan kepada 8.3 hari dan 12.5 hari, masing-masing pada SS6. Di bawah mikroskop elektron *scanning* (SEM), liang membran yang berkesan adalah liang besar berukuran lebih daripada 0.1 μm. Lapisan tumbesaran berfiber di atas permukaan membran meningkatkan kecekapan pemisahan. Pembersihan membran yang lebih cekap and kerap diperlukan untuk menghalang membran daripada tersumbat (*fouling*) serta meningkatkan kadar alir *permeate*. Secara keseluruhan, kajian ini menunjukkan bahawa MAS mampu untuk merawat OLR yang lebih tinggi dengan pengekalan θ_c lebih daripada 20 hari.

CHAPTER I

INTRODUCTION

Anaerobic digestion is a naturally occurring microbiological process in the environment; best observed in swamps, and deep reaches of sediments in water and soil. The confinement and optimisation of the naturally occurring anaerobic digestion process leads to the pioneering use of anaerobic digestion in treating human excreta in septic tanks. Since then, anaerobic digestion has moved into other areas of waste reduction, such as agriculture, farming and industry.

The 1970s energy crisis revealed another role of anaerobic digestion - that of providing methane gas as an alternative fuel. The crisis stimulated world-wide research and development in anaerobic digestion. In highly industrialised and populated countries in Europe, considerable research efforts were spent in this field. The European Commission, for example, predicted that 10% of Europe's energy needs could be met by renewable energy and thus, invested £100M in research and development at one time (Hobson, 1993). However, with the drop in oil price, there remained no immediate economic reason for alternative energies. Furthermore, the energy contribution from digesters were below expectation. The total value of the fraction of biogas that was effective as an energy source was much less than the amount spent on research and development programmes (Coombs, 1990).

From then on, the continuing research on anaerobic digestion was fuelled by growing awareness of pollution control. An early 1980s survey of biogas plants in Europe (Table 1) found that most of the plants were used to treat agricultural waste. Apart from that, over 80% of the plants were in fact full-scale operating plants. The widespread attraction of anaerobic digestion technology may be attributed to its ability to treat concentrated waste with lower energy requirement.

In Malaysia, the heightened consciousness that waste treatment is necessary to avoid environmental pollution, was reinforced in the recent 7th Malaysia Plan (RM7). Anaerobic digestion will have a bigger role to play in treating large volumes of high to medium-range concentrated wastes. This is especially so if the agricultural development, which focuses on large-scale production of food and high-value produce, goes according to the RM7.

Table 1

Geographical Distribution of Full- and Pilot-Scale Biogas Plants in the European Community and in Switzerland According to the Type of Waste Treated.

Country	Type of Waste				
	Agricultural	Energy Crops	Domestic residues (landfills)	Industrial	Total
	Full- + pilot-scale	Pilot-scale	Full- + pilot-scale	Full- + pilot-scale	Full- + pilot-scale
Belgium	21 + 4			6 + 4	27 + 8
Denmark	22 + 1			3 + 3	25 + 4
FRG	75		10	12	97
France	62 +12		2+ 3	10 + 5	74 +20
Greece	3 + 1			1	4 + 1
Ireland	2 + 3			1 + 3	3 + 6
Italy	58 + 5	1	1	11 + 2	70 + 8
Netherlands	21 + 1		3 + 8	22 + 1	46 +10
UK	12 + 9		7 + 2	3 + 2	22 +13
Switzerland	102 + 6				102 + 6
Total	378 +42	1	23 + 13	69 + 20	470 +76

(Ferranti, 1987)

Likewise, there is continuous expansion in other sectors such as the local manufacturing and industrial sectors, and solid and hazardous waste disposal. At the same time, the industrial sector will find more stringent standards and imposition of fees for treated waste discharges with the implementation of the RM7. This will in turn create the demand for more efficient and better waste treatment systems.

Therefore, there are plenty of reasons for coming up with more innovative and improved waste treatment facilities. In the design of anaerobic digestion alone, there are many such variations. Among them, there is a Membrane Anaerobic System (MAS) that combines membrane technology with anaerobic digestion (Tan, 1995; Fakhru'l-Razi, 1994). The membrane serves to retain the slow-growing active biomass in the digester while allowing the production of high quality effluent.

Objectives

Therefore, it is the purpose of this study on the treatment of palm oil mill effluent (POME) using Membrane Anaerobic System (MAS) to :-

(i) evaluate the overall microbial kinetics, and

(ii) evaluate the applicability of three known kinetic models.

CHAPTER II

LITERATURE REVIEW

Detailed knowledge of microbiology is not necessary in order to run an anaerobic digester. However, general knowledge of the microbiology of digestion is important. It is necessary to find out which part of the interdependent complex processes are limiting and therefore require control, and improvement in operation or digester design. Therefore, the following sections hope to bring forth that useful and vital background knowledge needed in this study.

Microbiology of Anaerobic Digestion

The microbial ecology of a digester consists of anaerobic bacteria that stabilise organic matter in the absence of free oxygen. Although there is a gradation in oxygen tolerance, most of the digester's bacteria are among the least tolerant of oxygen. Therefore, any exposure to air or oxygen will kill or inhibit these obligate anaerobes.

Classifying by their functions, anaerobic digestion of organic matter to methane involves the interaction of several groups of bacteria.

Hydrolysis

The hydrolytic bacteria excrete extracellular enzymes to convert complex particulate matter into soluble compounds. In the digestion of particulate or polymeric waste, hydrolysis is often found to be the rate-limiting process (Archer and Kirsop, 1990; Sleat and Mah, 1987).

Acidogenesis

Archer and Kirsop (1990) chose to classify the acidogens under the same group as hydrolytic bacteria. However, the acidogenic group was separately mentioned in another study by Haandel and Lettinga (1994). In Boone and Mah (1987), acidogens were also known as fermentative bacteria, and were classified together with acetogens as transitional bacteria.

The manner of classification by different researchers only seek to emphasise the complex interspecies activities among the digester's anaerobes. However, they all agreed that the hydrolytic products were taken up in the cells of these fermentative bacteria and further converted to simpler organic compounds, such as volatile fatty acids, and gaseous compounds, such as CO_2 , and H_2.

Acetogenesis

Based on the classification by Archer and Kirsop (1990), the acetogenic bacteria were divided into obligate proton-reducing (hydrogen producing) species and non-obligate proton-reducing species. Both the obligate and non-obligate proton-reducing acetogens produce the methanogenic substrates, acetate, H_2 and CO_2, from the intermediate compounds. The important distinction between these two types of bacteria is the ability of the non-obligate proton-reducing bacteria to grow unhampered in an environment of high H_2 concentration.

In an environment with high H_2 concentration, non-obligate proton-reducing bacteria produce 2 main reduced fermentative products, i.e butyrate and propionate. When the H_2 level is low enough, the main product is acetate. This is accompanied by the release of H_2 (which acts as proton-reducer). Under this non-obligate proton-reducing group, homoacetogens were identified to be capable of producing acetate from H_2 and CO_2 under certain conditions (Archer and Kirshop, 1990).

On the contrary, the obligate proton-reducing acetogens oxidise reduced fermentative products, such as butyrate and propionate, to form acetate and grow only by producing H_2. Therefore, they can only survive in an environment where the H_2-utilising bacteria co-exist (interspecies H_2 transfer), to keep the H_2 concentration at a low level.

According to Boone and Mah (1987), obligate proton-reducing acetogens were only one of the three groups of bacteria classified under transitional bacteria. The other two were fermentative bacteria (acidogens) and homoacetogens.

The obligate proton-reducing acetogen-mediated oxidising reactions of propionate and butyrate, to acetate and H_2 or CO_2 as proposed in literatures are presented below. According to Haandel and Lettinga (1994), most of the reactions in sewage treatment follow the general equation 2. If we consider butyric acid or propionic acid as substrates, where the H:O ratio is larger than 2 ($y > 2z$), this would hold true. Similarly, Boone and Mah (1987) proposed the oxidation of propionate (Eq. 3) and butyrate (Eq. 4) release H_2 in the production of acetate.