UNIVERSITI PUTRA MALAYSIA

KINETICS STUDY OF SEWAGE SLUDGE TREATMENT BY ANAEROBIC DIGESTION

ABDURAHMAN HAMID NOUR

KINETICS STUDY OF SEWAGE SLUDGE TREATMENT BY ANAEROBIC DIGESTION

By

ABDURAHMAN HAMID NOUR

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

April 2000

Dedicated
To
My

Parents, Brothers, and Sisters.

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

KINETICS STUDY OF SEWAGE SLUDGE TREATMENT BY ANAEROBIC DIGESTION

By

ABDURAHMAN HAMID NOUR

April 2000

Chairman : Dr. Fakhru'l – Razi Ahmadun

Faculty : Engineering

This study was carried out to evaluate the applicability of three known kinetics models (Monod, Contois and Chen and Hashimoto), overall microbial kinetics, as well as to experimentally assess the influence of the organic loading rates and retention times on kinetic models.

To accomplish the objectives of this study, a 50 litre laboratory scaled membrane anaerobic system (MAS) combining ultrafiltration (UF) membrane with anaerobic reactor was used to treat raw sewage sludge, which collected from Taman Tun Dr. Ismail, sewage treatment plant (T.T.Dr.Ismail). Six steady states were attained as a part of a kinetic study.

The results of all six steady states were successfully fitted, above 98 %, by Monod, Contois, and Chen and Hashimoto models. Contois model appeared to be the best at 99.7 % .The microbial kinetic constants were Y = 0.74 gVSS/gCOD

and b = 0.20 day^{-1}. The minimum solids retention time, θ_c^{min} obtained from the three kinetic models ranged from 5 – 16.9 days. The total gas yield obtained ranged from 0.28 l/gCOD/d to 0.81 l/gCOD/d at organic loading rate (OLR) of between 0.1 $kgCOD/m^3.d$ to 10 $kgCOD/m^3d$. The solids retention time (SRT) decreased from 1250 days to 16.1 days, (from SS_1 to SS_6).

The composition of methane gas, CH_4 varied from 66.3 % to76.3 %. At CH_4, 66.3 % , the solids retention time and hydraulic retention time were found to be 16.1 day and 7.8 days, with the COD removal efficiency range of between 96.5 – 99 % as well as high solids retention time θ_c .

The range of mixed liquor suspended solids was from 12760 mg/l to 21800 mg/l. The two methods of membrane cleaning (Mild brushing , flush with water and soak membrane in 0.1 M NaOH for day), were very important in order to increase the permeate flux and flowrate. The flux recovery time was 15 to 18 days. The maximum and minimum level of the flux were found to be 62.1 $l/m^2/hr$ and 6.9 $l/m^2/hr$ respectively.

Abstrak tesis yang dikemukakan Kepada Senat Universiti Putra Malaysia
sebagai memenuhi Keperluan untuk ijazah Master Sains.

KAJIAN KINETIK TERHADAP ENAPCEMAR KUMBAHAN DENGAN MENGGUNAKAN RAWATAN PENCERNAAN ANAROBIK

Oleh

ABDURAHMAN HAMID NOUR

April 2000

Pengerusi : Dr. Fakhru'l – Razi Ahmadun

Fakulti : Kejuruteraan

Bagi mencapai objektif kajian ini, satu pencerna skala makmal berisipada 50 liter yang dikenali sebagai sistem anaerobik membran (MAS) yang mengabungkan membran ultra penurasan telah digunakan bagi merawat enapcemar kumbahan mentah. Enam keadaan mantap telah dicapai bagi sebahagian dari pada kajian kinetic.

Keputusan bagi keenam – enam keadaan mantap tersebut berjaya memenuhi lebih daripada 98 % , model oleh Monod, Contois, Chen and Hashimoto. Model Contois merupakan yang terbaik dengan 99.7 %. Pemalar kinetik mikrob adalah Y = 0.74 gVSS/gCOD dan b = 0.20 day^{-1}.

Masa tahanan minimum θ_c^{min} yang diperolehi dari 3 model adalah dalam lingkungan 5 hingga 16.9 hari. Jumlah penghasilan gas yang didapati adalah dalam lingkungan 0.28 l/g COD.d hingga 0.81 l/g COD.d pada kadar muatan organik berada di antara 0.1 kg COD/m^3/d hingga 10 kg COD/m^3/d

Apabila masa tahanan dikurangkan dari 1250 hari kepada 16.1 hari maka ianya berubah dari SS_1 ke SS_6. Komposisi gas metana (CH_4 %) berada dalam lingkungan 76.3 % ke 66.3 %. Pada komposisi CH_4 66.3 % , masa tahanan pepejal dan masa tahanan hidrolik didapati menjadi 16.1 hari dan 7.8 manakala kecekapan penyingkiran COD adalah dalam lingkungan 96.5 % hingga 99 % dengan masa tahanan pepejal (θ_c) yang tinggi dari SS_1 ke SS_6. Pepejal ampaian campuran liquor (MLSS) berada di dalam lingkungan 12760 – 21800 mg/l. Dua kaedah pembersihan selaput membran (pengosokkan lembut, disembur dengan air dan direndam selaput membran dalam 0.1 M NaOH untuk satu hari) adalah penting bagi memastikan penambahan dalam kadar alir dan hasil telapan fluks. Fluks mengambil masa 15 hingga 18 hari untuk kembali kepada fluks sebelumnya. Tahap maksimum dan minimum fluks adalah 62.1 l/m^2/hr dan 6.9 l/m^2/hr.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my chairman, Dr. Fakhru'l – Razi Ahmadun for constantly guiding and encouraging me throughout this study.

Also, I wish to thank members of my supervisory committee, Assoc. Prof. Badlishah Sham Baharin and Pn. Faridah Emby, for their time and energy spent in making this a better work.

My appreciation to En. Haridan Mohd Rodzi of the Chemical and Environmental Computer Laboratory for his assistance and support throughout this study. I am grateful to the staff of the Engineering Faculty, and also to staff of GSO for their cheerfulness and professionalism in handling their work.

My special thanks to En. Abakar H. Nour and Adam A. Baggal for their patience and kind assistance. To my Lab mates, I hope they don't break the last breaker.

TABLE OF CONTENTS

LIST OF TABLES

Table		Page

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

COD	Chemical Oxygen Demand
OLR	Organic Loading Rate
CUF	Crossflow Ultrafiltration Membrane
MF	Microfiltration
RO	Reverse Osmosis
AD	Anaerobic Digestion
T.T.Dr.Ismail	Taman Tun Dr Ismail, Sewage Treatment Plant
PVC	Polyvinylchloride
SS	Steady State
SUR	Substrate Utilization Rate
UF	Ultrafiltration
TSS	Total Suspended Solids
VSS	Volatile Suspended Solids
VFA	Volatile Fatty Acids
SRT	Solids Retention Time
HRT	Hydraulic Retention Time
SSUR	Specific Substrate Utilization Rate
MAS	Membrane Anaerobic System
CSTR	Completed Mixed, Stirred Tank Reactor

BLR	Biological Loading Rate
MWCO	Molecular Weight Cut – off
CUMAR	Crossflow Ultrafiltration Membrane Anaerobic Reactor

CHAPTER 1

INTRODUCTION

Anaerobic digestion is a naturally occuring microbiological process in the environment; best observed in swamps, and deep reaches of sediments in water and soil. The confinement and optimization of the naturally occuring anaerobic digestion process leads to the pioneering use of anaerobic digestion in treating human excreta in septic tanks. Since then, the anaerobic process 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. An early 1980s survey of biogas plants in Europe (Table 1) found that most of the plants were used in fact ful – scale operating plants. The wide spread attraction of anaerobic digestion technology may be attributed to its ability to treat concentrated waste with lower energy requirement. There fore, 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. In today's urbanized industrial society, it is becoming increasingly important to prevent the pollution of vital and limited water resources by providing adequate treatment of liquid wastes emanating from domestic and industrial sources. The major pollutional constituents of these liquid wastes are dissolved and suspended organic materials. Because of the organic nature of the pollutants, biological processes which depend on the controlled metabolic activity of microorgamisms have long been employed for waste treatment. Biological processes can be employed in removing soluble organic material from the waste stream before discharge into a water course and in stabilizing particulate organic matter previously removed from the waste stream by physical-chemical means.

Anaerobic waste treatment is one of the major biological waste treatment processes in use today. This process has been employed for many years in stabilizing municipal sewage sludges. In such applications the process is usually called sludge digestion because of the resulting liquefaction of the organic particulate matter in the sludge. More recently there has been considerable interest in applying this process to the treatment of strong and medium strength industrial wastes. Initial efforts in treating meat-packing wastes have yielded promising results.

Despite widespread application in the past, the fundamental microbiology and biochemistry of the anaerobic process were poorly understood. With out such knowledge, empiricism governed process design and control, and optimum operation of the process was not achieved. Recent studies dealing with nutrient requirements, ionic environment, and biochemistry of anaerobic waste treatment process have provided much of this needed information. Evaluation of the kinetics of anaerobic waste treatment depends on an understanding of the complex nature of the process. Anaerobic treatment may be considered to be a three-step process. In the first step, complex organics are converted to less complex soluble organic compounds by enzymatic hydrolysis. In the second step, these hydrolysis products are fermented by a group of facultative and anaerobic bacteria collectively called "acid formers". The end products of this fermentation are simple organic compounds with the short chain fatty acids predominating. In the third step, the simple organic compounds are fermented to methane and carbon dioxide by a group of substrate specific, strictly anaerobic bacteria called the "methane formers". Thus anaerobic treatment effectively converts organic waste materials to bacterial protoplasm and the gaseous end products, methane and carbon dioxide. In such a multi step complex process, the overall kinetics of waste utilization will be governed by the kinetics of slowest step. Therefore the overall process kinetics can be determined if this slowest or rate limiting step can be identified and its kinetics evaluated.

Anaerobic digesters produce conditions that encourage the natural breakdown of organic matter by bacteria in the absence of air. Anaerobic digestion (AD) provides an effective method for turning residues from livestock farming and food processing industries into:

- **Biogas** (rich in methane) which can be used to generate heat and/ or electricity.
- **Fiber** which can be used as a nutrient – rich soil conditioner, and
- **Liquor** which can be used as liquid fertilizer.

It has been used in the agricultural sector in the form of small on - farm digesters producing biogas to heat farmhouses, dairies and other farm buildings. Experience has shown that anaerobic digestion project is most likely to be financially viable if it is treated as part of an integrated farm waste management system in which the food stocks and the products from anaerobic digestion all play apart.

Table1 : Geographical Distribution of Full – and Pilot - Scale Biogas Plants in the European community and in Switzerland According to Type of Waste Treated.

Country	Type of waste				
	Agricultural	Energy Crops	Domestic Residues (landfills)	Industrial	Total
	Full - + Pilot - +	Pilot- scale	Full - + Pilot- scale	Full - + Pilot - +	Full - + Pilot - scale
Belgium	21 + 1			6 + 4	27 + 8
Denmark	22 + 1			3 + 3	25 + 4
FRG	75		10	12	79
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
Total	378 + 42	1	23 + 13	69 + 20	470 + 76

(Ferranti, 1987)

Objectives

The objectives of kinetics study of sewage sludge treatment by anaerobic digestion was:

(i) To evaluate the overall microbial kinetics.

(ii) To evaluate the application of three known kinetic models, (Monod, Contois, and Chen and Hashimoto).

(iii) To experimentally assess the influence of, organic loading rates, and retention times on the kinetic models.

Scope of the study

To accomplish these objectives, a laboratory digester was scaled membrane anaerobic system (MAS) with an effective 50 - litre volume used to treat raw sewage sludge. Enrichment cultures of methanogenic bacteria was developed in digester. The laboratory digester is completely mixed - semi continuously followed steady state operation, so that the experimental results could be used to evaluate the developed steady state kinetic models.