

LB/DON/71/02

**DEVELOPMENT OF A HIGH RATE  
BIOMETHANATION REACTOR SYSTEM:  
A PILOT STUDY OF AN INDUSTRIAL WASTE  
STREAM**

By

**PUSHPANJALI IRANGA JAYASURIYA**

B.Sc.Eng. (Hons.) THE UNIVERSITY OF MORATUWA, SRI LANKA, 1998

A thesis submitted in fulfillment  
of the requirement for the degree  
of Master of Engineering  
in  
**Energy Technology**

621 "02"

628.5

පුස්තකාලය  
මොරටුව විශ්ව විද්‍යාලය, ශ්‍රී ලංකාව  
මොරටුව

**DEPARTMENT OF MECHANICAL ENGINEERING**

**FACULTY OF ENGINEERING**

**UNIVERSITY OF MORATUWA**

**SRI LANKA**

March, 2002

074681



University of Moratuwa

74681

TH

74681



## DECLARATION

“ I certify that this thesis does not incorporate without acknowledge any material previously submitted for a degree or diploma in any university or higher educational institution in Sri Lanka or abroad and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text”.



University of Moratuwa, Sri Lanka  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

***UOM Verified Signature***

P.I.Jayasuriya


## Abstract

A pilot scale two-phase anaerobic reactor system was constructed and the feasibility of Biomethanation using two-phase systems was evaluated. As the raw materials, a batter mixture washing effluent from a wafer biscuit manufacturing plant was used. This effluent has a high COD due to vegetable fats and oils. Acetogenic reaction was allowed to take place in the first reactor and when the VFA level came to around 12000 mg/l it was fed to the methanogenic reactor. Without an initial seeding of microbial population and a growing media the trial was not successful. So a filter bed was introduced to the second reactor with a 20 liters of methanogenic bacterial sludge from a running reactor. Research trials indicate that the two-phase system works successfully with proper controlling. It also gave out biogas with 84% methane, which is very rich in methane. From these pilot trials, it was able to find out design process parameters for a suitable large-scale two-phase system where the biogas can be generated in large scale with the same waste effluent. These findings help industries to generate energy from their organic waste, hence reducing the dependency on fossil fuels as well as reducing waste disposal problem.

## TABLE OF CONTENT

	<b>Page no.</b>
<b>Abstract</b>	<b>iii</b>
<b>Table of contents</b>	<b>iv</b>
<b>List of figures</b>	<b>ix</b>
<b>List of Tables</b>	<b>xiv</b>
<b>Acknowledgement</b>	<b>xvi</b>
<b>Chapter</b>	
<b>1.0 Introduction</b>	<b>1</b>
1.1 Problem Statement	3
1.2 Objectives	4
1.3 Scope	4
<b>2.0 Industrial waste management in Sri Lanka</b>	<b>6</b>
2.1 Nature of waste	9
2.2 Current methods of Industrial waste disposal	23
2.3 Waste to energy option	29
2.3.1 Incineration	30
2.3.2 Land fill	31
2.3.3 Biomethanation	33

	<b>Page no.</b>
2.4 Process of Biomethanation	34
2.4.1 Low rate Biomethanation systems	36
2.4.2 High rate Biomethanation systems	38
<b>3.0 High rate Biomethanation</b>	<b>48</b>
3.1 Evolution of High rate Biomethanation technology – a brief history	49
3.2 Process fundamentals	51
3.2.1 Microbiology of Biomethanation digester system	53
3.2.2 Why high rate Biomethanation is efficient	58
3.3 Technological aspects	60
3.3.1 Energy and the Biomethanation	64
3.4 Characteristic of Feedstock	66
3.4.1 Total Solids (TS)	69
3.4.2 Volatile solids (VS)	70
3.4.3 Chemical oxygen demand (COD)	71
3.4.4 Carbon to Nitrogen ratio	71
3.4.5 Toxic effect	72
3.4.6 Sulfides	75
3.4.7 Heavy Metals	76

	<b>Page no.</b>
3.5 Industrial Potential for high rate Biomethanation	77
3.5.1 Yield Estimation	79
3.5.2 Industrial Potential	79
<b>4.0 Process Control of high rate systems</b>	<b>86</b>
4.1 Physical parameters	86
4.1.1 Temperature	86
4.1.2 Mixing effects	89
4.1.3 Start-up	92
	
4.2 Chemical parameters	92
4.2.1 Redox potential	92
4.2.2 pH	94
4.2.3 Nutrient balance	95
4.2.4 Alkalinity	96
4.3 Other Factors	98
4.3.1 Toxicity	98
4.3.2 Sulfides	98
4.3.3 Heavy Metals	99
4.3.4 Loading	100
4.3.5 Biological Parameters	101

	<b>Page no.</b>
<b>5.0 Development of high rate biogas technology</b>	<b>105</b>
5.1 Introduction	105
5.2 High rate digestion studies – Pilot scale digester	106
5.3.1 Overview	106
5.3 Design of appropriate reactor configuration	107
5.4 Material of Construction	110
<b>6.0 Industrial Effluent for high rate biometanation</b>	<b>114</b>
6.1 Biscuits Industry in Sri Lanka	114
6.2 Wafer biscuit manufacturing process	116
6.2.1 Formulation of wafer batter	116
6.2.2 Mixing of wafer batter	118
6.2.3 Process description	119
6.3 Analysis of Chocolate waste effluent for feed preparation	120
6.3.1 Nitrogen supplement requirement	120
6.3.2 Phosphorous supplement requirement	122
6.4 Feed preparation	123
6.5 Theoretical calculation of energy production from wafer biscuit effluent	124

	<b>Page no.</b>
<b>7.0 Experimental studies using wafer biscuit waste effluent</b>	<b>126</b>
7.1 Process kinetics	139
7.1.1 Models	139
7.1.2 Process Monitoring Parameters	141
7.1.3 Process Control systems	149
7.2 Fundamental design consideration	157
7.2.1 Digester volume and retention time	159
7.2.2 COD loading on reactor	160
7.2.3 Biogas production	161
7.2.4 Sludge production	162
<b>8.0 Conclusions &amp; Recommendations</b>	<b>164</b>
8.1 Conclusions	164
8.2 Recommendations	166
References	169
Appendix I	173



## List of figures

Figure	Page no.
2.1a Solid waste from industries flashy untreated into the urban environment	8
2.1b Liquid waste from industries flashy untreated into the urban environment	8
2.2 Solid Waste Generation	10
2.3 Solid Waste Disposal	10
2.4 Solid Waste Disposal Details	11
2.5 Wastewater generating industries	14
2.6 Hazardous waste generation	20
2.7 Industrial areas and proposed future areas for industrialization	25
2.8 Wastewater treatment availability – sector wise	27
2.9 Wastewater treatment non-availability- sector wise	28
2.10 Projection of extractable landfill gas quantities.	32
2.11 Biogas collecting network of a landfill –CETEM, Belgium.	33
2.12 Process of Biomethanation	34
2.13 Various types of methanogenic bacteria.	35
2.14 The gas production rate in low rate Biomethanation	37
2.15 Diagrammatic representation of a high rate digester	39
2.16 A schematic diagram of an anaerobic contact digestion	40



<b>Figure</b>	<b>Page no.</b>
2.17 Anaerobic filter	41
2.18 Upflow Anaerobic Sludge Bed Reactor	42
2.19. Granules developed in a UASB reactor.	42
2.20 Anaerobic fluidized or expanded bed	43
2.21 Down flow stationery fixed film reactor	44
2.22 Packing of an anerobic contact process	45
2.23 Schematic diagram of two-stage digestion consisting of high rate digestion in the first stage and conventional unmixed digestion in the second stage.	46
2.24 A schematic diagram of two-phase digestion involving two high rate digesters in series.	47
3.1 The three stage anaerobic fermentation of biomass	52
3.2. Mainly Methanosarcina sp. from the stationary bed reactor described in “Ney, U.,A.J.L.Macario,Aaivasidis, S.M.Schoberth, and H.Sahm. 1990. Appl. Environ. Microbiol. 56:2389-2398”	57
3.3 Methanogenic Communities	57
3.4 Engine running on biogas, Denmark	60
3.5 Typical systems for the anaerobic digestion	61
3.6 An overview of the anaerobic digestion process	64
3.7 Biogas requirement for various purposes.	67

<b>Figure</b>	<b>Page no.</b>
3.8 Waste types used for Biomethanation	68
3.9 Industrial wastewater (chemical) treatment plant, Tuntex, Taiwan-UASB digester	77
3.10 Dairy factory in France. Fixed film stationery bed digester developed by Proserpol SA, France.	78
3.11 Sewage sludge treatment plant, Bottrop, Germany. The largest in the world Egg shaped digesters – volume 4* 15000 m <sup>3</sup> – capacity 3000 m <sup>3</sup> sludge/day	78
4.1. (a) Internal heating, (b) External heating	87
4.2 Performance of the process according to temperature	88
4.3. Advantages of mixing	89
4.4 (a) Hydraulic mixing	90
4.4 (b) Submerged motor with rotor stirring	90
4.4. ©Mechanical paddle rotor	91
4.4 (d) Shaft-driven rotor	91
4.4 (e) Mixing through injection of biogas	91
4.5 Variation of redox potential with time	93
4.6 Methane formation at different pH in an anaerobic filter (Methane generation from wastes)	95
4.7 MCRT vs. Methane production	97

<b>Figure</b>	<b>Page no.</b>
4.8 The estimated relation between the imposed sludge loading rate, the sludge retention time, the total granule yield and the composition	101
5.1 Arrangement of four tanks; holding tank, acedogenic tank, buffer tank and methanogenic tank	108
5.2 Two-phase digester system –pilot scale	109
5.3 Gas valves, developed by Organics Ltd, United Kingdom	113
6.1 Waste water treatment plant at wafer manufacturing plant	115
6.2 Basic flow diagram of the process and the wastewater treatment plant.	121
7.1 Variation of pH with residence time for sucrose solution	128
7.2. COD variation with Residence time for the Sucrose solution	128
7.3 COD reduction with retention time	129
7.4 Variation of pH with residence Time for the wafer waste effluent in acedogenic reactor	130
7.5 Variation of COD with residence Time for the wafer waste effluent in acedogenic reactor	130
7.6 Variation of VFA with time for the acedogenic reactor.	133
7.7 Change in COD, VFA and Methane production with time.	135
7.8 Biogas combustion in a modified gas cooker	138



<b>Figure</b>	<b>Page no.</b>
7.9 Variation of COD, VFA, and Methane produced with retention time for wafer biscuit effluent of methanogenic Reactor	138
7.9 Combustion of biogas	139
7.10 Variation of methane production rate with temperature	143
7.11 Effect of pH, on rates of methane and total gas production from formic acid.	147
7.12 Methane Production at 55°C as a function of wastewater from distillery at RT=18.2 days.	149
7.13 An improved digester control system	151
7.14 High rate systems incorporate detailed process control system ensuring process stability (Chemical Engineer, 1975).	154
7.15 Rotameter	156
7.16 S0/S vs retention time	158
7.17 Plot of R vs $\frac{VS_0}{g}$	162
10.1 Modified two-phase Biomethanation system	170

## List of Tables

Table	Page No.
2.1 Number of Industries Registered with the Ministry of Industrial Development	7
2.2 Waste collection in Colombo and surrounding urban areas.	12
2.3 General quality standard for the discharge of effluent	14
2.4 Industrial wastewater characteristics	15
2.5 Profile of Industrial sector (ERM report, February 1994)	23
2.6 Central Wastewater Treatment Plant in Industrial Estates	28
3.1 Substrates converted to CH <sub>4</sub> by various methanogenes	56
3.2 Characteristics of methanogenic bacteria	56
3.3 Possible conversion of manure to biogas	63
3.4 Industrial Feedstock	70
3.5 Carbon and Nitrogen content of feedstock	72
3.6 Stimulatory and Inhibitory Concentration of Light Metal cations	75
3.7 Concentration of Soluble Heavy Metals Exhibiting 50% Inhibition of Anaerobic Digesters (Biological waste treatment, Vol.12)	76
3.8 Waste effluent characteristics of various Industries	80
3.9 Biogas production from various industries	81
3.10 Characteristics of industrial wastes in Sri Lanka (CEA reports)	81
3.11 Summary of Table 3.10	84
4.1 Stimulatory and Inhibitory Concentration of Light Metal cations	100



<b>Table</b>	<b>Page no.</b>
4.2 Concentration of Soluble Heavy Metals Exhibiting 50% Inhibition of Anaerobic Digesters	102
6.1 Basic recipe of wafer.	117
6.2 Wafer batter composition	119
6.3 Feed characteristics	123
7.1 Parameters that were monitored	127
7.2 Feed characteristic of the effluent	131
7.3 pH and COD variation	132
7.4 Change in volatile fatty acid	133
7.5 Monitored Results observed	134
7.6 pH, COD and methane generated with time	135
7.7 pH, COD ,VFA and methane generated with time	136
7.8 pH, COD and methane generated in volume % with time	137
7.9 Several kinetic models have been developed	139
7.10 Concentration of VFA, which correspond to the 50% inhibition of methanogenic activity	146
7.11 Variation of COD and Fraction of COD with time	158
7.12 Calculated k values for various other products	159
7.13 Summary of process design parameters for the anaerobic digestion of wafer batter washing effluent.	165

## Acknowledgements

I wish to express my sincere gratitude to Dr Ajith De Alwis for supervising my research project and the invaluable assistance, guidance, advice and encouragement, given to me during the course of this research study.

Further more, let me sincerely thank Dr Rohan Thittagala, the Head of the Mechanical Engineering department of the University of Moratuwa and the staff, Dr Rahula Attalage, Dr Thusitha Sugathapala and Dr Kapila Perera for their valuable assistance in numerous ways in completing the research. I am also grateful to Eng. S.A.S Perera, Head of the Chemical & Process Engineering department and his staff for the never-ending support.

I would like to thank Mr. Sarath De Silva, Factory Manager, Mr. Rohan and Mr. Indika Abeyrathna all at Ceylon Biscuits (Pvt.) Ltd. Homagama for making arrangements to get down waste water samples throughout this research work providing process data.

Financial assistance from the University Research Fund for the research and the funds from Intermediate Technology Development Group (ITDG) for the purchase of the Methane Analyzer is gratefully acknowledged.





I also like to thank Mr. Upul, Mr. Sanadanayaka, Mr. Somasiri and Miss Kumari staff of the Department of Mechanical Engineering for giving their support in various ways. Another valuable thank should go to Mr. Somarathna & Mr. Jayanthlal for fixing the necessary pipe fittings. I should also appreciate the help given to me by Mr. Somasiri, (Technical officer), Mr. Dharsana (System Analysis) of Mechanical Engineering Department of university of Moratuwa when using workshop facilities and computers respectively.

Mr. D.C.A. Neville, the owner of the Nawajeewana Industries at Katubedda, Moratuwa gave his fullest support when fabricating the pilot plant unit. So I like to thank him too.



University of Moratuwa, Sri Lanka  
Electronic Theses & Dissertations  
[www.lib.mrt.ac.lk](http://www.lib.mrt.ac.lk)

I would like to include the following personnel in my word of appreciation, Mrs. Dineshi Martino, Mr. P.A.S Peris, Mr. U.G.Athula Fernando, Mr. Saraneris, Mr. N.L.Chandrasiri, Mr. W.L.Dayasiri Fernando, Mr. T.Masekorala, and Mr. Jayaweera of the Technical staff of Chemical Engineering Department of university of Moratuwa. Finally I like to thank Mr. Buddhika De Silva (Research Assistant) for his fullest support during the research.