

LIBRARY  
UNIVERSITY OF MORATUWA, SRI LANKA. LB/DON/62/2012  
MORATUWA

# DEVELOPMENT OF A PILOT-SCALE BIOGAS PLANT TO UTILIZE BIOMETHANE AS A TRANSPORT FUEL

M. A. D. I. C. Kularatna

08 / 8024

Thesis / Dissertation submitted in partial fulfilment of the requirements for the  
degree Master of Science



Department of Chemical and Process Engineering

66\*10  
66(043)

University of Moratuwa  
Sri Lanka

TH

December 2010

102861  
+  
CD-ROM

102861

## DECLARATION OF THE CANDIDATE AND SUPERVISOR

I declare that this is my own work and this thesis / dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any University or other institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

Signature: *L. Kularat*

Date: 2011-12-27

I hereby grant the University of Moratuwa the right to archive and to make available my thesis or dissertation in whole or part in the University Libraries in all forms of media, subject to the provisions of the current copyright act of Sri Lanka. I retain all proprietary rights, such as patent rights. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature: *L. Kularat*

Date: 2011-12-27

I have supervised and accepted this thesis / dissertation for the award of the degree.

*Opik de Alva*  
Signature of the Supervisor:

Date: 27/12/11

*Rathm*

27/12/2011

## ABSTRACT

This project was to develop a system to utilize Biomethane as a transport fuel. It was started at the Department of Chemical and Process Engineering, University of Moratuwa funded by the Ministry of Science and technology. In this project, initially a suitable process was developed to produce biogas utilizing food waste obtained from university canteens and upgraded as a vehicle fuel. Then the pilot-scale biogas plant was designed and construction of the building and fabrication of equipments were preceded.

Initially laboratory scale experiments were conducted to find out the design parameters such as analysis of food waste, composition for optimum gas production rate, etc. According to that, the total solid content (TS) is 37% and total volatile solid content (TVS) is 23%. The best composition for optimum gas production is 10% solid in the slurry.

The pilot-scale biogas plant was operated and produces biogas utilizing food waste and upgraded using a water scrubber to remove  $\text{CO}_2$  and  $\text{H}_2\text{S}$ . After that, the cleaned gas, which is having a composition of 85%  $\text{CH}_4$ , was used as a vehicle fuel. For the initial trials, biogas was replaced with LPG in a LPG three-wheeler without any modification to the three-wheeler system and it was successfully operated. According to the emission tests carried out for biogas vehicle fuel, it shows that it is operating environment friendly than gasoline.

Keywords: Biogas, Food Waste, Vehicle Fuel, Anaerobic Digestion

## DEDICATION

I dedicate this thesis to the two pillars in my life: my parents and my husband. I might not come into this plane without my parents who have dedicated their life for making me an educated and a successful person. In addition, I might not complete this without the love, understanding, support and company received from my husband. I would like to express my love and appreciation for the encouragement and the sacrifices made by both my parents and my husband.

## ACKNOWLEDGEMENT

I would like to express my appreciation to my main supervisor Prof. Ajith De Alwis for his precious guidance and encouragement to complete this project. I am deeply grateful to him for spending his valuable time in evaluating the progress of my research project. Without his valuable perception and guidance, this research would not have become a reality. Dear Sir, it has been an honour to work with you. In addition, my special thanks goes to my second supervisor, Dr. P.G. Rathnasiri, for being a guiding light right through the research. Also thanks for giving me the opportunity to be part of the research.

I would like to extend my sincere appreciation to the Ministry of Science and Technology for the project initiation and for making this study possible by providing its funding and especially to Mr. P.G. Joseph, Director, Alternative Energy Division, Ministry of Science and Technology, for his time, patience and the tremendous help throughout the research.

My special thanks to Mr. Nuditha Dilnayana, who is continuing the research after me and helped me to finalize many of the works remaining. Special thanks to Mr. Sugath Perera, the operator of the plant for helping me to run the plant and experiments, without which I could not carry my research successfully.

I take this opportunity to thank the academic staff of the Department who provided valuable support throughout my research project and who gave me valuable advice whenever required. At the same time, I should not forget the technical and office staff at the Department, for offering me their honest help without any hesitation whenever required. Special thanks to Dr. Victor Mendis, Senior Lecturer, Mechanical Engineering Department, for the guidance and support provided for us regarding vehicle trials.

I would like to thank the Vice Chancellor and the Dean, Faculty of Engineering and the Registrar for spending their valuable time for considering requests made throughout the research period providing directions. Also thanks to the staff at Vice Chancellor Office, Dean Office and Registrar Office for supporting the administrative works. My special thanks to the Postgraduate Studies Division, University of Moratuwa for approving my research project.

In addition, I would like to express my gratitude for Dr. Bandara Dissanayake, Mr. Deshai Botheju, Mr. Suranga Chaminda, Mr. D.G. Dhanushka, Mr. Dilan Piyarathna, and Mr. Deshaka Kottage for their personal involvement in designing process and machinery. This project will not become a success without their valuable insights and direction.

My special thanks go to Mr. Ariyasheela Wickramanayake, Master Divers for having time to help us always no matter how busy he is and for donating the compressor for our experiments and providing biogas from the Pelawatte Sugar Industries. In addition, Mr. Dananjaya Munasinghe, Mr. Ranjith Fernando and other staff members from Master Divers who were involved with us for continuing vehicle trials.

I would fall short in my duty, if I fail to thank the people whose support is a part of the success.

- Maintenance Division for supporting throughout the research project at building construction, repairs, etc. and especially former Maintenance Engineer Mr. Leelarathna for the excellent support given during plant building construction
- Mr. Kumar, Electrical Superintendent and his staff for the outstanding support given for electrical maintenance and other technical matters
- Mr. Ravindra Irugalbandara, civil engineer, for preparing plant drawings and estimates
- Mr. Heshan De Silva, Deputy General Manager, Laugfs, Kelaniya for providing guidance in technical matters

- Ms. Sanjeevi Jayathilake at Ceylon Oxygen for the support given for the testing gas cylinders
- Mr. Dananjaya P. Kuruppu, Enviromec International (Pvt) Ltd., for providing guidance in technical matters
- Mr. Janaka B Doloswala, Assistant Sales Manager, Solex Engineering (Pvt) Ltd., for repairing pumps at free of charge
- Mr. Amila Chandra for preparing 3D drawing of the pilot-scale plant
- Mr. Janaka at Abans for helping us to dispose the slurry when it needs to refill
- Vidatha Centre, Bokundara for providing Gliricedia leaves as a feed material for the plant
- Mr. Prasad Niroschan, Sales Officer and Mr. Mahesh Dharmajith, Mechanical Engineer, David Peris Motor Company Limited, for providing additional technical details required for vehicle trials.
- Mr. Namiz Musofer, Country Manager, Practical Action, for providing required technical support and Mr. Pushpakumara, Practical Action, for the technical support and also for the personal involvement by spending his time at the university during construction of the dry batch plant.
- Sesatha Enterprises, Katubedda, for fabricating the biogas reactor vessel and the scrubber
- Mr. Jayasiri, Odiris Engineering Company for fabricating the food waste crusher and providing valuable suggestions for improvements
- Mr. Sarathchandra and Mr. Charitha Jayanath, Trittech Engineers Private Limited, for plumbing in the plant
- Ruwan Trade Centre, Siddhamulla for constructing the plant building
- Mr. Arjuna, Sampath Iron Works, Moratuwa for doing modifications in the roof of the plant building
- Mr. Asanka Sanjeewa, Bandaragama for making and fixing Bamboo Tats in windows of the plant building
- Mr. Saranelis, Thisara Cleaning Service for supporting with workforce

- Workshop Engineer, Department of Mechanical Engineering, Mr.Somasiri, Mr. Amal Shantha for the support provided at time to time in mechanical related works
- Finance division of the University for handling project funds and supporting with financial matters
- General Administration Division for the administrative works related to the three wheeler possess by the project
- Security Division of the University for providing adequate security facilities for the plant building and machinery
- Supply Division of the University for administrative works done in purchasing capital equipments
- Capital Works and Services Division of the University for administrative works done in construction of the plant building
- University canteens 1 and2 for providing food waste to feed the plant

I sincerely thank my beloved husband for providing continued support and encouragement during my research work who was always there to support me whenever I needed support on my research work in whatsoever.

Finally, I would like to express my thankfulness for many individuals and friends who have not been mentioned here personally and helped me by thought, word or deeds in making this research a success.



# TABLE OF CONTENT

	Page
Declaration of the Candidate and Supervisor .....	i
Abstract .....	ii
Dedication .....	iii
Acknowledgement .....	iv
Table of content .....	viii
List of figures .....	xii
List of tables .....	xiv
List of abbreviations .....	xvi
List of APPENDICES .....	xvii
CHAPTER 1 – INTRODUCTION .....	1
1.1 Background .....	2
1.2 Introduction to the Project .....	2
1.3 Objectives of the Project .....	2
1.4 Thesis Structure .....	3
CHAPTER 2 — LITERATURE SURVEY .....	4
2.1 Biogas and Its Properties .....	4
2.2 Biogas Production Processes .....	7
2.3 Operational Conditions in the Biogas Production Processes .....	10
2.3.1 Temperature .....	10
2.3.2 pH and Alkalinity .....	12

2.3.3	Total Solid (TS).....	13
2.3.4	Total Volatile Solids (TVS).....	14
2.3.5	Chemical Oxygen Demand (COD) .....	14
2.3.6	Volatile Fatty Acid Content (VFA).....	15
2.3.7	Carbon – Nitrogen Ratio (C: N).....	15
2.3.8	Retention Times .....	15
2.3.9	Toxicity.....	17
2.4	Anaerobic Digestion.....	18
2.4.1	Hydrolysis .....	22
2.4.2	Acedogenesis.....	23
2.4.3	Acetogenesis .....	23
2.4.4	Methanogenesis .....	23
2.5	Feed stocks.....	26
2.6	Characteristics/properties .....	31
2.7	Advantages / Disadvantages .....	32
2.8	Uses / Applications.....	33
2.9	As a vehicle fuel.....	33
2.10	Upgrading Biogas.....	37
2.10.1	Water scrubbing.....	39
2.10.2	Pressure Swing Adsorption (PSA) .....	40
2.10.3	Membrane separation.....	41
2.10.4	Cryogenic separation .....	41
2.10.5	Biological desulphurization.....	41
2.10.6	Ferrous chloride dosing to digester slurry.....	42
2.10.7	Impregnated activated carbon .....	42
2.10.8	Chemical conversion method .....	42
2.10.9	Dry oxidation process .....	42
2.10.10	Liquid phase oxidation process .....	43
CHAPTER 3 - BIOMETHANATION STUDIES: LAB SCALE .....		44

3.1 Objectives .....	44
3.2 Materials and Methods .....	44
3.3 Feed Characterization.....	45
3.3.1 Analysis of feed types.....	45
3.4 Lab Scale Reactor System .....	48
3.4.1 Feed preparation .....	48
3.4.2 Results of Lab Scale Reactors.....	49
3.5 Testing equipment specifications.....	49
3.6 Process Trouble Shooting.....	51
 Chapter 4 – Process Design and Construction of the Pilot-scale Biogas Plant.....	 54
4.1 Process Design .....	54
4.1.1 Plant Building.....	56
4.1.2 Feed Preparation System.....	57
4.1.3 Feed Transfer System .....	58
4.1.4 High Rate Biogas Reactor.....	59
4.1.5 Carbon Dioxide Scrubber .....	62
4.1.6 H <sub>2</sub> S Scrubber .....	64
4.1.7 Moisture Removal .....	64
4.1.8 Piping and Instrumentation .....	65
4.1.9 Sedimentation.....	66
4.1.10 Intermediate Storage and Compression .....	67
4.2 Dry Batch Biogas Pits .....	68
4.3 Software used for designing .....	69
4.4 Trouble Shooting – Plant Machinery .....	70
4.5 Modifications in Future Use .....	72
 Chapter 5 – Pilot Plant Operation.....	 73
5.1 Plant Safety .....	73

5.2 Plant Operation .....	73
5.3 Plant Monitoring and Discussion .....	75
<b>Chapter 6 – Biogas in Vehicles .....</b>	<b>76</b>
6.1 Introduction.....	76
6.2 Application and Results.....	76
6.3 Discussion.....	79
<b>Chapter 7 – Conclusions and Future Work.....</b>	<b>80</b>
7.1 Conclusion .....	80
7.2 Future Work: Recommendations .....	81
References .....	82
Appendices .....	87

# LIST OF FIGURES

	Page
Figure 1: Role of Biogas .....	7
Figure 2: Sri Lankan Batch Type Digester.....	9
Figure 3: Variation of digestion time with temperature.....	11
Figure 4: Energy comparison of waste treatment in OFMSW.....	20
Figure 5: Theory of Anaerobic Digestion .....	21
Figure 6: Standard digester .....	25
Figure 7: Anaerobic contact process.....	25
Figure 8: Anaerobic filter.....	25
Figure 9: Up flow anaerobic sludge blanket .....	26
Figure 10: Composition of Municipal Solid Wastes in Sri Lanka .....	27
Figure 11: Greenhouse gas emissions for different fuels.....	32
Figure 12: Bi-fuel System (CNG and Biogas) .....	36
Figure 13: Water scrubbing system .....	39
Figure 14: PSA Technology for Scrubbing.....	40
Figure 15: Composition of the Lab Scale reactor.....	48
Figure 16: Lab Scale Reactor System (1) .....	49
Figure 17: Lab Scale Reactor System (2) .....	52
Figure 18: Gas production in lab scale .....	52
Figure 19: Process Flow of the Pilot Plant.....	54
Figure 20: Waste segregating system in the university .....	55
Figure 21: Pilot-scale Biogas Plant Building .....	56
Figure 22: Initial Design of the Food Waste Crusher .....	57
Figure 24: Final view of the Crusher .....	58
Figure 23: (a) Internal blades (b) Water inlet system in the Crusher .....	58
Figure 25: Submersible Slurry Pump.....	59
Figure 26: Initial Design of the Reactor.....	60
Figure 27: (a) Biogas Reactor Vessel (b) Motor for Inside Impellers (c) Drain out System .....	61

Figure 28: Vegetable plantation using the drain out slurry as the fertilizer.....	61
Figure 29: Initial Design of the Scrubber.....	62
Figure 30: Top of the Water Scrubber .....	63
Figure 31: Bottom of the water Scrubber.....	64
Figure 33: Moisture Removing Setup (Metal) .....	65
Figure 32: Moisture Removing Setup (Glass).....	65
Figure 34: (a) Inline pressure gauge (b) Electricity panel board in the pilot plant.....	66
Figure 35: Sedimentation Tank .....	66
Figure 36: Compressor.....	67
Figure 37: Intermediate Storage Tanks.....	68
Figure 38: Operation of Dry Batch Biogas Pits in the University (a) Collecting straw (b) Submerge straw in a mixture of urea and cow dung (c) During feeding to the pit (d) After feeding and fixing the lid .....	68
Figure 40: Software - Packed Bed Calculator.....	69
Figure 39: Gas Collection System - Dry Batch Biogas Pits.....	69
Figure 41: Selection of packing materials in the software.....	70
Figure 42: Preparing and Fixing of Mesh Guard (a) Mesh guard (b) Finalize making the mesh guard (c) Fix to the pump (d) Fixing pipe lines .....	71
Figure 43: Gas Leak Detection - Reactor Vessel (a) Checking the top of the vessel (b) Apply soap solution (c) Air leaks as bubbles.....	72
Figure 44: LPG - Biogas three-wheeler .....	77
Figure 45: Biogas Test Bench .....	81

Table 21: Physical properties of various materials.....	31
Table 22: Specifications of Biogas 3-wheeler Pump and Service .....	34
Table 23: Physical properties of Swager.....	35
Table 24: Economic calculation of biogas vehicles.....	37
Table 25: Comparison of Properties of Biogas and LPG.....	38
Table 26: Components to be removed for different applications.....	38
Table 27: Fuel Method.....	39
Table 28: Analysis of Fuel Type.....	75
Table 29: Fuel measurement by TS.....	75

## LIST OF TABLES

	Page
Table 1: Composition of Biogas.....	4
Table 2: Calorific Value of Biogas.....	5
Table 3: Ultimate biogas production potential.....	5
Table 4: Properties of biogas.....	6
Table 5: Biogas production variation with mixing.....	10
Table 6: Temperature ranges of methane production.....	11
Table 7: Comparison of Mesophilic and Thermophilic Digesters.....	11
Table 8: Optimum pH Level.....	12
Table 9: Chemicals used for pH adjustment.....	13
Table 10: TS Values for SC-OFMSW.....	14
Table 11: TVS for SC-OFMSW.....	14
Table 12: Generating Times for different microbial.....	16
Table 13: Toxic levels on waste.....	17
Table 14: Parameters of Anaerobic Digestion.....	19
Table 15: Comparison of Single Stage and Two Stage Processes.....	20
Table 16: Biogas production capacities.....	28
Table 17: Biogas yields from various feedstock.....	29
Table 18: Analysis of market garbage collected from Matara Sunday fair.....	29
Table 19: Properties of bio-solids, rice and a mixed sample.....	30
Table 20: Estimation of methane yield.....	30
Table 21: Operational conditions for methane production.....	31
Table 22: Specifications of Biogas as a Fuel in France and Sweden.....	34
Table 23: Vehicle Emissions in Sweden.....	35
Table 24: Emission reduction of biogas vehicles.....	37
Table 25: Comparison of Properties of Biogas and Natural Gas.....	38
Table 26: Components to be removed for different applications.....	38
Table 27: Test Methods.....	44
Table 28: Analysis of Feed Types.....	45
Table 29: Initial measurements for TS.....	46





## LIST OF ABBREVIATIONS

Abbreviation	Description
AD	Anaerobic Digestion
ANC	Acid Neutralizing Capacity
CHP	Combine Heat and Power
CNG	Compressed Natural Gas
COD	Chemical Oxygen Demand
HRT	Hydraulic Retention Time
IANGV	International Association of Natural Gas Vehicles
LPG	Liquefied Natural gas
MS – FMSW	Mechanically Sorted Organic Fraction of Municipal Solid Wastes
MOST	Ministry of Science and Technology
MSW	Municipal Solid Waste
PSA	Pressure Swing Absorption
RPM	Revolutions Per Minute
SC – OFMSW	Separately collected Organic Fraction of Municipal Solid Wastes
SLR	Sri Lankan Rupees
SRT	Solids Retention Time
SS – OFMSW	Source Separated Organic Fraction of Municipal Solid Wastes
TS	Total Solids
TVS	Total Volatile Acid
UASB	Up flow Anaerobic Sludge Blanket
VFA	Volatile Fatty Acid

# LIST OF APPENDICES

## CHAPTER 1 - INTRODUCTION

Appendices	Description	Page
Appendices A	Initial Process Design of the Pilot Plant	86
Appendices B	Final Process Design of the Pilot Plant	87
Appendices C	Final Constructed Pilot-scale Biogas Plant	88
Appendices D	Final Constructed Pilot-scale Biogas Plant	89
Appendices E	Operating vehicles with biogas fuel	94