

**DESIGN, FABRICATION, AND PERFORMANCE EVALUATION OF A TWO-STAGE GAS CLEANING SYSTEM FOR BIOGAS DIGESTER**

**RENDELL IAN A. SOLLANO**

An Undergraduate Thesis Submitted to the Faculty of the Department of Agricultural and Biosystems Engineering, College of Engineering, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines  
in Partial Fulfillment of the Requirements  
for the Degree of

**BACHELOR OF SCIENCE IN AGRICULTURAL AND BIOSYSTEMS ENGINEERING  
(AB Process Engineering)**

**JULY 2023**

## TABLE OF CONTENTS

	PAGE
LIST OF TABLES	ix
LIST OF FIGURES	x
LIST OF APPENDIX TABLES	xi
LIST OF APPENDIX FIGURES	xii
ABSTRACT	xiii
INTRODUCTION	1
Background of the Study	1
Statement of the Problem	3
Objectives of the Study	4
Significance of the Study	4
Scope and Limitation of the Study	5
Time and Place of the Study	6
REVIEW OF RELATED LITERATURE	7
Biogas Production	7
Impact of Methane on the Environment	9
Current Application of Biogas	10
The Need for Biogas Cleaning/Upgrading	12
Cleaning/Upgrading of Biogas	14
Removal of Carbon Dioxide	14
Water Vapor Removal	15
Removal of Hydrogen Sulfide	17
Removal of Oxygen & Nitrogen	19
Removal of Ammonia	20
Current Technology for Biogas Cleaning/Upgrading	20
Adsorption Method	21
Absorption Method	22
Separation by Membranes	23
Cryogenic Separation	25

Advantages and Disadvantages of Different Technique in Studies on Design and Fabrication of Biogas Digester	25 28
Performance Evaluation of Biogas Digester	34
Existing Small-Scale Biogas Cleaning/Upgrading	35
Metener OY	35
Biosling	36
Green Brick Eco Solutions	37
Chesterfield Biogas	37
METHODOLOGY	39
Conceptualization of the Study	39
Design Considerations	41
System Components	44
Collection of Substrates and Installation to Digester	45
Gas Cleaning/Upgrading Process	46
Testing and Evaluation of the Biogas Cleaning System for Biogas Digester	48
Preliminary Testing	48
Actual Testing	49
Data Collection and Evaluation	49
Removal Efficiency of CO <sub>2</sub> and H <sub>2</sub> S	51
Duration of Flaming	51
Cost Analysis	52
Statistical Analysis	52
RESULTS AND DISCUSSION	54
Fabrication and Installation of Gas Cleaning System	53
Biogas Yield Concentration	55
Removal Efficiency of CO <sub>2</sub> and H <sub>2</sub> S	59
Duration of Flaming	61
Flame Quality	62
Cost Analysis	63
SUMMARY, CONCLUSION AND RECOMMENDATION	67
Summary	67
Conclusions	69

## LIST OF TABLES

TABLE		PAGE
1	Different Upgrading/Cleaning Techniques	26
2	Biogas Analysis	32
3	Performance of Different Substrates	33
4	Gas Yield	51
5	Gas Yield Data Before and After Passing through the Two-stage Gas Cleaning	55
6	Gas Yield Data Before and After Passing through the Two-stage Gas Cleaning an AC	57
7	Removal Efficiency of CO <sub>2</sub>	59
8	Removal Efficiency of H <sub>2</sub> S	59
9	Duration of Continuous Gas Flow, min	61
10	Water Boiling Test	61
11	Bill of Materials	64
12	Water Consumption	65
13	Summary of Operational Cost	65

## LIST OF FIGURES

FIGURE		PAGE
1	Methane concentrations up to May 2018	10
2	Biogas application	11
3	Use of biogas in countries with most biogas production	12
4	Biogas purification conditions	16
5	Biogas purification conditions: (a) H <sub>2</sub> S concentration (b) Removal efficiency	18
6	Current technologies for biogas upgrading	20
7	Flow Diagram of PSA System	22
8	Scheme of membrane gas separation process	24
9	Digester Configuration	29
10	Digester Assemble	30
11	Biogas Digester	31
12	Conceptual Framework of the Study	40
13	Solubility data of CO <sub>2</sub> and CH <sub>4</sub> in water	42
14	Design of Two-Stage Gas Cleaning System for 200 L Drum Anaerobic Biogas Digester	44
15	Biogas Digestion and Cleaning System	45
16	IRCD4 Portable Biogas Analyzer	50
17	Fabrication of Gas Cleaning System	53
18	Anaerobic Digestion and Gas Cleaning System	54
19	Removal Efficiency of CO <sub>2</sub> and H <sub>2</sub> S	60
20	Biogas Flame on Single Burner Stove	62

## LIST OF APPENDIX TABLES

APPENDIX TABLE		PAGE
1	Paired Sample t-test for raw and upgraded biogas	79
2	Paired Sample t-test for raw and upgraded biogas (with AC)	79

## LIST OF APPENDIX FIGURES

APPENDIX FIGURE		PAGE
1	Fabrication of Water Column	79
2	Fabrication of Biogas Digester	79
3	Collection of Pig Manure Substrate	80
4	Weighing of Water & Pig Manure	81
5	Mixing of Water & Pig Manure (1:1), forming slurry	81
6	Substrate fed in the digester	82
7	Gas valve installed in the compressor	82
8	Tightening of fittings to avoid gas leak	83
9	Preparation of activated carbon filter	83
10	Gas valve installed in the cylinder tank	84
11	Biogas compression at 10 bars	84
12	Flame from a single-burner cooking stove	85
13	Boiling of 2L water	85
14	Biogas Yield Reading using IRCD4 Analyzer	86
15	Measuring biogas yield (kg) after upgrading	86
16	Field Visit	87
17	Aurelco Electrical Bill	88
18	System One Line Diagram	89
19	System Details	90
20	Layout Perspective	90

## ABSTRACT

**SOLLANO, RENDELL IAN A.**, Department of Agricultural and Biosystems Engineering, College of Engineering, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines, **July 2023, DESIGN, FABRICATION, AND PERFORMANCE EVALUATION OF A TWO-STAGE GAS CLEANING SYSTEM BIOGAS DIGESTER**

Adviser: MARLON T. DELOS SANTOS, M.Sc.

Biogas is a renewable energy source produced through Anaerobic Digestion (AD) and is considered as sustainable compared to traditional fossil fuels. However, impurities in biogas can reduce its energy content, which can be addressed by removing the impurities and incombustible gases. This has driven the study to design, fabricate, and evaluate a two-stage gas cleaning system for anaerobic biogas digester. The gas cleaning system for anaerobic biogas digestion was designed focusing on water scrubbing absorption technique and was fabricated using locally available materials. The experiment involved using pig manure as substrate for biogas production and conducting tests on the system's gas yield using IRCD4 biogas analyzer. Six sets of trials were carried out to determine CH<sub>4</sub> increase and removal efficiency of CO<sub>2</sub> and H<sub>2</sub>S after passing through the gas cleaning system. T-test for two dependent samples was done to analyze the gathered data.

Based on the analysis of the study, increase in methane concentrations after the biogas passed through the gas cleaning system were 9.30%, 4.76%, and 7.14%, 4.87%, 2.44%, and 4.87%, respectively. The average removal efficiency level of H<sub>2</sub>S and CO<sub>2</sub> across six (6) trials was 88.88% and 11.95%, respectively. T-test for two dependent samples revealed there is a significant difference ( $p < 0.05$ ) between the concentration of

CH<sub>4</sub> and H<sub>2</sub>S before and after the gas cleaning/upgrading process while there is no significant difference ( $p>0.05$ ) between the concentration of CO<sub>2</sub>.

Keywords: biogas; gas cleaning; water scrubbing; methane

## LITERATURE CITED

- Allegue, L. B., & Hinge, J. (2012). Biogas and bio-syngas upgrading. *Danish Technological Institute*, December, 1–97. [http://www.teknologisk.dk/\\_root/media/52679\\_Report-Biogas and syngas upgrading.pdf](http://www.teknologisk.dk/_root/media/52679_Report-Biogas_and_syngas_upgrading.pdf)
- Andriani, D., Wresta, A., Atmaja, T. D., & Saepudin, A. (2014). A review on optimization production and upgrading biogas through CO<sub>2</sub> removal using various techniques. *Applied Biochemistry and Biotechnology*, 172(4), 1909–1928. <https://doi.org/10.1007/s12010-013-0652-x>
- Aroon, M. A., Ismail, A. F., Matsuura, T., & Montazer-Rahmati, M. M. (2010). Performance studies of mixed matrix membranes for gas separation: A review. *Separation and Purification Technology*, 75(3), 229–242. <https://doi.org/10.1016/j.seppur.2010.08.023>
- Asghar, Z. (2008). Applied Econometrics and International Development. *Econpapers.Repec.Org*, 8, 44. <http://econpapers.repec.org/article/eaaaeinde/default7.htm>
- Awe, O. W., Zhao, Y., Nzihou, A., Minh, D. P., & Lyczko, N. (2017). A Review of Biogas Utilisation, Purification and Upgrading Technologies. *Waste and Biomass Valorization*, 8(2), 267–283. <https://doi.org/10.1007/s12649-016-9826-4>
- Bade Shrestha, S. O., & Narayanan, G. (2008). Landfill gas with hydrogen addition - A fuel for SI engines. *Fuel*, 87(17–18), 3616–3626. <https://doi.org/10.1016/j.fuel.2008.06.019>
- Bauer, F., Hulteberg, C., Persson, T., & Tamm, D. (2013). *Biogas upgrading – Review of commercial technologies. Swedish Gas Center Report SGC 2013:270 Available at http://vav.griffel.net/filer/C\_SGC2013-270.pdf Last access August 2017.* [http://vav.griffel.net/filer/C\\_SGC2013-270.pdf](http://vav.griffel.net/filer/C_SGC2013-270.pdf)
- Bishir, M., & Atta, H. (2016). *Quantitative and Qualitative Analysis of Biogas Produces From Three Organic Wastes.* January. [https://www.researchgate.net/publication/301634350\\_Quantitative\\_and\\_qualitative\\_analysis\\_of\\_biogas\\_produces\\_from\\_three\\_organic\\_wastes](https://www.researchgate.net/publication/301634350_Quantitative_and_qualitative_analysis_of_biogas_produces_from_three_organic_wastes)
- Cengel, Y. & A. Boles (2008). *Thermodynamics. An Engineering Approach* (6th Ed.), McGraw- Hill, New York, New York, USA
- C. S. Agu and J.E. Igwe. (2016). *Open Access Design and Construction of an Indigenous Biogas Plant American Journal Of Engineering Research (AJER)*. 8, 88–97. [https://www.ajer.org/papers/v5\(08\)/N05080888097.pdf](https://www.ajer.org/papers/v5(08)/N05080888097.pdf)

- Deublin, Dieter and Steinhauser, A. (2011). *Biogas from Waste and Renewable Resources*. [https://chemistry.pixel-online.org/files/ed\\_pack/04/further03/DeubleinD.Steinhauser A.-Biogas from Waste and Renewable Resources.pdf](https://chemistry.pixel-online.org/files/ed_pack/04/further03/DeubleinD.Steinhauser A.-Biogas from Waste and Renewable Resources.pdf)
- Divyabharathi, R., Randjawali, E., Waris, A., Soliu, G. A., & Onunka, C. (2018). *The flame characteristics of the biogas has produced through the digester method with various starters*. <https://doi.org/10.1088/1757-899X/299/1/012091>
- Donkin, S. S., Doane, P. H., & Cecava, M. J. (2013). Expanding the role of crop residues and biofuel co-products as ruminant feedstuffs. *Animal Frontiers*, 3(2), 54–60. <https://doi.org/10.2527/af.2013-0015>
- Evergreen Gas (2012) *Small-Scale Biogas Upgrade For Vehicle Fuel PDF | PDF | Biogas | Anaerobic Digestion*
- Frazier, R. S. and N. P. (2019). *Biogas Utilization and Cleanup – Livestock and Poultry Environmental Learning Community*. <https://lpelc.org/biogas-utilization-and-cleanup/>
- Gantina, T. M., Iriani, P., Maridjo, & Wachjoe, C. K. (2020). Biogas purification using water scrubber with variations of water flow rate and biogas pressure. *Journal of Physics: Conference Series*, 1450(1). <https://doi.org/10.1088/1742-6596/1450/1/012011>
- Hoornweg, D., & Bhada-Tata, P. (2012). *What a Waste : A Global Review of Solid Waste Management*. [https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/E-Learning/Moocs/Solid\\_Waste/W1/What\\_Waste\\_Global\\_Review\\_2012.pdf](https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/E-Learning/Moocs/Solid_Waste/W1/What_Waste_Global_Review_2012.pdf)
- Horikawa, M. S., Rossi, F., Gimenes, M. L., Costa, C. M. M., & Da Silva, M. G. C. (2004). Chemical absorption of H<sub>2</sub>S for biogas purification. *Brazilian Journal of Chemical Engineering*, 21(3), 415–422. <https://doi.org/10.1590/S0104-66322004000300006>
- Horváth, I. S., Tabatabaei, M., Karimi, K., & Kumar, R. (2016). Recent updates on biogas production - A review Recent updates on biogas production - a review. *Biofuel Research Journal*, June. <https://doi.org/10.18331/BRJ2016.3.2.4>
- Howarth, J. (2019, December 2). *When will fossil fuels run out? Octopus Energy*. When Will Fuels Run Out? <https://octopus.energy/blog/when-will-fossil-fuels-run-out/>
- International Energy Agency. (2020). *Key World Energy Statistics 2020. International Energy Agency, August*. [https://iea.blob.core.windows.net/assets/1b7781df-5c93-492a-acd6-01fc90388b0f/Key\\_World\\_Energy\\_Statistics\\_2020.pdf](https://iea.blob.core.windows.net/assets/1b7781df-5c93-492a-acd6-01fc90388b0f/Key_World_Energy_Statistics_2020.pdf)

- IRENA. (2018). *Technology Brief: Biogas for Road Vehicles* (Issue March).
- Jørgensen, P. J. (2009). Biogas - Green Energy. *Environmental Energy*, 2, 27. <https://www.lemvigbiogas.com/BiogasPJJuk.pdf>
- J.A. Dean (1999). *Lange's Handbook of Chemistry*. 15<sup>th</sup> Edition., McGraw Hill Inc.
- López-Rendón, R., & Alejandre, J. (2008). Molecular Dynamics Simulations of the Solubility of H<sub>2</sub>S and CO<sub>2</sub> in Water. *Journal of the Mexican Chemical Society*, 52(1), 88–92. [https://www.researchgate.net/publication/239280849\\_Molecular\\_Dynamics\\_Simulations\\_of\\_the\\_Solubility\\_of\\_H\\_2\\_S\\_and\\_CO\\_2\\_in\\_Water](https://www.researchgate.net/publication/239280849_Molecular_Dynamics_Simulations_of_the_Solubility_of_H_2_S_and_CO_2_in_Water)
- Magomnang, A., & Villanueva, E. (2015). *Removal of Hydrogen Sulfide from Biogas Using a Fixed Bed of Regenerated Steel Wool*. <https://doi.org/10.17758/IAAST.A1214001>
- Mamone, R. M. (2014). *Small-Scale Biogas Upgrading with Membranes : A Farm Based Techno-Economic and Social Assessment for Sustainable Development*. Master thesis in Sustainable Development Small-Scale Biogas Upgrading with Membranes : A Farm Based Techno-Economic and Social Ass. <https://uu.diva-portal.org/smash/get/diva2:745594/FULLTEXT01.pdf>
- Mandal, T., Kiran, B. A., & Mandal, N. K. (1999). *Determination of the quality of biogas by flame temperature measurement*. 40, 1225–1228.
- Mitchell, M. J., Jensen, O. E., Cliffe, K. A., & Maroto-Valer, M. M. (2010). A model of carbon dioxide dissolution and mineral carbonation kinetics. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 466(2117), 1265–1290. <https://doi.org/10.1098/rspa.2009.0349>
- Møller, H. B., Sommer, S. G., & Ahring, B. K. (2004). Methane productivity of manure, straw and solid fractions of manure. *Biomass and Bioenergy*, 26(5), 485–495. <https://doi.org/10.1016/j.biombioe.2003.08.0>
- Nallamothu, Ramesh Babu ,Abyot Teferra, & Prof B.V. Appa Rao. (2013). Biogas Purification, Compression and Bottling. *Global Journal of Engineering, Design & Technology (G.J. E.D.T)*, 2(6), 34–38.
- Noorain, R., Kindaichi, T., Ozaki, N., Aoi, Y., & Ohashi, A. (2019). Biogas purification performance of new water scrubber packed with sponge carriers. *Journal of Cleaner Production*, 214, 103–111. <https://doi.org/10.1016/j.jclepro.2018.12.209>

- Nwankwo, C. S., Eze, J. I., & Okoyeuzu, C. (2017). Design and fabrication of 3.60 m<sup>3</sup> household plastic bio digester loaded with kitchen waste and cow dung for biogas generation. *Scientific Research and Essays*, 12(14), 130–141. <https://doi.org/10.5897/sre2017.6516>
- Obileke, K., Makaka, G., Nwokolo, N., & Meyer, E. L. (2022). *Economic Analysis of Biogas Production via Biogas Digester Made from Composite Material*. 1–12. <https://www.mdpi.com/2305-7084/6/5/67/pdf>
- Ofori-Boateng, C., & Kwofie, E. M. (2009). Water Scrubbing: A Better Option for Biogas Purification for Effective Storage. *World Applied Sciences Journal Environmental Management and Technologies Towards Sustainable Development*, 5(August), 122–125.
- Oliveira, N. S., Sousa, I. D. P., & Borges, A. C. (2021). *CAN PORTABLE ANALYZERS BE RELIABLE FOR BIOGAS CHARACTERIZATION?* *April*. <https://doi.org/10.13083/reveng.v29i1.11575>
- Peter, M. K., Aluwong, M. I. A. G. D. K. C., & Hadi, M. I. (2017). *Design , Development and Performance Evaluation of an Anaerobic Plant American Journal of Engineering Research ( AJER ) Open Access Design , Development and Performance Evaluation of an Anaerobic Plant. August*. [https://www.researchgate.net/publication/319041190\\_Design\\_Development\\_and\\_Performance\\_Evaluation\\_of\\_an\\_Anaerobic\\_Plant](https://www.researchgate.net/publication/319041190_Design_Development_and_Performance_Evaluation_of_an_Anaerobic_Plant)
- Petersson, A., & Wellinger, A. (2009). Biogas upgrading technologies—developments and innovations. *IEA Bioenergy*, 20. <http://typo3.dena.de/fileadmin/biogas/Downloads/Studien/IEA-BiogasUpgradingTechnologies2009.pdf>
- Rashed, M., Mamun, A., & Torii, S. (2015). Removal of H<sub>2</sub>S and H<sub>2</sub>O by Chemical Treatment to Upgrade Methane of Biogas Generated from Anaerobic Co-digestion of Organic Biomass Waste. *IPASJ International Journal of Mechanical Engineering*, 3(12), 42–52.
- Renewable Energy Sources: LESSON 13. Microbiology of biogas production.* (n.d.) <http://ecoursesonline.iasri.res.in/mod/page/view.php?id=128410>
- Rasimphi, T. E., Tinarwo, D., Sambo, C., Mutheiwana, M. A., & Mhlanga, P. (2022). Decentralized biogas plants: status, prospects, and challenges. *Handbook of Biofuels*, 473–484. <https://doi.org/10.1016/B978-0-12-822810-4.00024-5>
- Ray, N. H. S., Mohanty, M. K., & Mohanty, R. C. (2015). Water Scrubbing of Biogas Produced from Kitchen Wastes for Enrichment and Bottling in LPG Cylinder for

- Cooking Applications. *IJSET - International Journal of Innovative Science, Engineering & Technology*, Vol. 2 Issue 5, May 2015. *Www.Ijiset.Com*, 2(5), 45–53.
- Ryckebosch, E., Drouillon, M., & Vervaeren, H. (2011). Techniques for transformation of biogas to biomethane. *Biomass and Bioenergy*, 35(5), 1633–1645. <https://doi.org/10.1016/j.biombioe.2011.02.033>
- Schweigkofler, M., & Niessner, R. (2001). Removal of siloxanes in biogases. *Journal of Hazardous Materials*, 83(3), 183–196. [https://doi.org/10.1016/S0304-3894\(00\)00318-6](https://doi.org/10.1016/S0304-3894(00)00318-6)
- Shzad, U. (2017). The Need For Renewable Energy Sources. *International Journal of Information Technology and Electrical Engineering*, May. [https://www.researchgate.net/publication/316691176\\_The\\_Need\\_For\\_Renewable\\_Energy\\_Sources](https://www.researchgate.net/publication/316691176_The_Need_For_Renewable_Energy_Sources)
- Silberberg, Martin S. (2009). *Chemistry: the molecular nature of matter and change* (5th ed.). Boston: McGraw-Hill. p. 206. ISBN 9780073048598.
- Tondeur, D. & F. Teng, (2008). Carbon capture and storage for greenhouse effect mitigation. In *Future Energy: Improved, sustainable and clean options for our planet*, T. M. Letcher (Ed.)
- Tran, L. T., Le, T. M., Nguyen, T. M., Tran, Q. T., Le, X. D., Pham, M. Q., Lam, V. T., & Do, M. Van. (2021). *Simultaneous removal efficiency of H<sub>2</sub>S and CO<sub>2</sub> by high-gravity rotating packed bed: Experiments and simulation*. 288–298.
- Ullah Khan, I., Hafiz Dzarfan Othman, M., Hashim, H., Matsuura, T., Ismail, A. F., Rezaei-DashtArzhandi, M., & Wan Azelee, I. (2017). Biogas as a renewable energy fuel – A review of biogas upgrading, utilisation and storage. *Energy Conversion and Management*, 150(July), 277–294. <https://doi.org/10.1016/j.enconman.2017.08.035>
- Vidania, G. (2017). *Comparative Hog Biogas Production from Plastic Drum Biogas Digester During Night and Daytime Collection*. Central Luzon State University, Science City of Munoz, Nueva, Ecija
- Vries, J. W. De, Vinken, T. M. W. J., Hamelin, L., & Boer, I. J. M. De. (2012). *Bioresource Technology Comparing environmental consequences of anaerobic mono- and co-digestion of pig manure to produce bio-energy – A life cycle perspective*. 125, 2011–2013.
- Warren, W. K. E. H. (2012). A techno-economic comparison of biogas upgrading technologies in Europe. *MSc Thesis*, 44. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.456.1353&rep=rep1&type=pdf>

- Wellington, A., Baraza, D. L., Mageto, M., & Kengara, F. O. (2018). *Energy Evaluation and Qualitative Analysis of Biogas Produced from Co-Digesting Kitchen Waste and Cow Dung*. *Energy Evaluation and Qualitative Analysis of Biogas Produced from Co-Digesting Kitchen Waste and Cow Dung*, January. <https://doi.org/10.9734/PSIJ/2017/38559>
- Werkneh, A. A. (2022). Biogas impurities: environmental and health implications, removal technologies and future perspectives. *Heliyon*, 8(10), e10929. <https://doi.org/10.1016/j.heliyon.2022.e10929>
- Zalameda, E., & Herrera, D. (2014). Department of Science and Technology Industrial Technology Development Institute. [https://itdi.dost.gov.ph/images/LivelihoodTechnologyBrochures/32-Portable\\_Biogas\\_Digester.pdf](https://itdi.dost.gov.ph/images/LivelihoodTechnologyBrochures/32-Portable_Biogas_Digester.pdf)
- Zulkefli, N. N., Noor Azam, A. M. I., Masdar, M. S., & Isahak, W. N. R. W. (2023). Adsorption–Desorption Behavior of Hydrogen Sulfide Capture on a Modified Activated Carbon Surface. *Materials*, 16(1). <https://doi.org/10.3390/ma16010462>