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Development of a Water Scrubber for Biogas Upgrading

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Abstract— *This study examined the effect of absorption-based upgrading on a farm-scale anaerobic digester. Biogas scrubbing removes impurities from biogas, such as carbon dioxide and hydrogen sulfide. An absorption process using water, steel wool, and silica gel was used. Biogas was produced from cow dung and water in a 3:1 mix ratio (water: dung). The raw biogas produced comprises the following composition: methane 65.48%, carbon dioxide 30.52%, hydrogen sulfide 0.4%, and others 3.6%. The gas was scrubbed using three flow rates: 0.013L/s, 0.108 L/s, and 0.129L/s, respectively, 1181.1 g of steel (packed bed) was placed inside the scrubbing chamber, and 500g of silica gel was added for moisture drying. The results obtained from the scrubbing using the flow rates are as follows: 0.013L/s methane 88.80%, carbon dioxide 11.14%, hydrogen sulfide 0.00062% and others 0.06%, 0.108 L/s, methane 88.92%, carbon dioxide11.05%, hydrogen sulfide 0.00058% and others 0.03%, and lastly methane 89.14%, carbon dioxide 10.83%, hydrogen sulfide 0.00058% others 0.03%. There was an increase in the composition of methane from 65.48% to 89.14% and a decrease in carbon dioxide, hydrogen sulfide, and others.*

Keywords—*Anaerobic digestion, Biogas, Biogas upgrading, Cow manure, Renewable gas, Water scrubbing.*

I. INTRODUCTION

Raw biogas compositions may vary depending on the biomass used. According to the result obtained from a methane gas analyzer, the components of biogas are combustible methane (57%), non-combustible carbon dioxide (CO_2) (36%), and the small traces of critical impurities such as the water vapor (H_2O) (5%), hydrogen sulfide (H_2S) (0.5%), nitrogen (N_2) (1%), oxygen (O_2) (0-2%) and ammonia (NH_3) (0-1%) (Liu et al., 2015). Biogas is a renewable fuel, meaning "fuel from biological matter." A more comprehensive definition by Olugasa et al. 2013, described biogas as a mixture of carbon dioxide and inflammable gas, Methane, produced by bacterial conversion of organic matter under anaerobic (oxygen-free) conditions.

However, biogas has some limitations, which, in a way, restrict its commercial use; these limitations have also reared their ugly heads in the awaiting success story of this impressive energy source. They include low energy content, difficulty compressing and storing biogas. Besides methane, other components in biogas are considered impurities; they hinder its compression ability and cause mechanical damage to the system. As a result, biogas must be cleaned, filtered, and improved using a variety of techniques to separate and remove these pollutants.

Biogas produced by anaerobic digestion is commonly used in gas turbines to generate electricity, among other applications. Upgrading biogas can enhance the value of the gas and enable its use in additional applications. This process involves removing carbon dioxide and various impurities to produce biomethane. Biomethane is similar to natural gas and can be used in similar applications, such as feeding into the natural gas pipeline, vehicle fuel, and compressed natural gas, but this application requires upgrading. Biogas must first be compressed to a pressure of 20 MPa in a three or four-stage compressor and stored in a high-pressure cylinder before it can be used as vehicle fuel. Prior to this, the methane concentration of the biogas must be increased.

Upgrading techniques have been developed to increase the energy content (Methane content) in biogas, including polyethylene glycol scrubbing, chemical absorption, pressure swing adsorption, bio trickling filter, cryogenic separation, iron absorptive media, biological scrubbing, and, most importantly, water scrubbing technology.

1.0 Aims and Objectives

The objective of this research is to design and develop a biogas digester and scrubber using materials readily available in the locality. This project would provide clean cooking and heating fuel, a clean energy source, significantly reduce carbon dioxide and hydrogen sulfide emissions, and offer a more affordable method for purifying biogas.

1.1 Research Justification

Embarking on this project and achieving success would provide a clean cooking and heating fuel, offer a clean energy source, significantly reduce carbon dioxide and hydrogen sulfide emissions, and implement a cheaper method of purifying biogas.

II. LITERATURE REVIEW

2.1 Impurities in Biogas

Elaborating more on the impurities introduced in the previous section, CO_2 in biogas lowers engine power output, occupies space when compressed and stored in cylinders, and can cause freezing problems of valves and metering points during gas expansion. Additionally, traces of H_2S produce H_2SO_4, which corrodes pipes and fittings, while moisture causes corrosion and reduces the fuel's heating value (Vijay et al., 2013). These impurities necessitate using a biogas scrubber, which removes impurities from biogas and converts them into biomethane.

2.2 Biogas Upgrading

Different methods exist to remove the impurities contained in biogas: adsorption, absorption, gas permeation, and cryogenic distillation. In adsorption, the selective affinity of

CO_2 onto a media surface (adsorption) at different pressures is used to control the separation. The technology is thus also called pressure swing adsorption (PSA). Absorption uses the difference in selective affinity of dissolving gas into liquid media. The temperatures and pressures utilized for controlling the absorption and desorption (stripping) process are subject to the media used. Examples of media are water, amines, and organic solvents; thus, the main biogas upgrading techniques using the absorption process are water scrubbing, amine scrubbing, and organic physical scrubbing. Gas permeation uses the process by which CO_2 and CH_4 gas molecules travel with different ease (permeates) through membranes. The permeability is higher for CO_2 than CH_4, and membranes can thus separate this mixture. Cryogenic distillation uses the process that CO_2 and CH_4 have different boiling points (-164˚C for CH_4 and -78 ˚C for CO_2 at 1 ATM) (Bauer F. et al., 2013).

2.3 Types of Upgrading Technologies

2.3.1 Pressure Swing Adsorption (PSA)

PSA is a dry method to separate gases via their physical properties (Svensson & Hulteberg, 2013). The basic principle is that raw biogas is compressed to an elevated pressure and then fed into an adsorption column, which retains the carbon dioxide but not the methane. When the column material is saturated with carbon dioxide, the pressure is released, and the carbon dioxide can be desorbed and led into an off-gas stream. Continuous manufacturing requires multiple columns since they will be opened and closed in sequence (Svensson & Hulteberg, 2013). The typical setup contains four adsorption columns operated in parallel in 4 step cycles (the Skarstrom cycle), allowing for continuous operation. Adding more columns and optimizing advanced flow between the columns is a way to increase separation efficiency and, potentially, energy efficiency. However, it must be balanced against acceptable complexity and investment costs. (Bauer, F., et al, 2013).

2.3.2 Amine Scrubbing

Amine scrubbing uses a reagent that chemically binds to the CO_2 molecule, removing it from the biogas. It is commonly performed using a water solution of amines (molecules with carbon and nitrogen), with the reaction product either in the molecular or ion form. The most common amines used historically are methyl diethanolamine (MDEA), diethanolamine (DEA), monoethanolamine (MEA) (Kohl, A.L. and R.B. Nielsen,1997), and primarily activated MDEA (DEA), which is a mixture of MDEA and piperazine.

2.3.3 Organic Physical Scrubbing

Genosorb is the most used solvent for biogas upgrading processes among organic physical scrubbers. The solvent consists of dimethyl ethers and polyethylene glycol (Bauer et al., 2013.; Ernst et al., 1990). Henry's law explains the absorption occurring in these organic physical scrubbers, like that in water scrubbers. This results in the recirculating volume of the solvent being much lower when using the organic solvent, and thus, the required column diameter is much smaller. The biogas is compressed to a pressure of 7-8 bar(a), cooled, and then fed to the bottom of an absorption column. Here, CO_2 is absorbed into the liquid phase.

2.3.4 Membrane Separation

Biogas upgrading using membrane technology uses the fact that gases have different permeability through a membrane (Vrbová & Ciahotný, 2017). During the separation of carbon dioxide and methane in biogas upgrading, some membrane types include polyimides, liquid membranes, and facilitated transport (Kárászová et al., 2015). pressure in a membrane separation is classified as high and low, with the high ranging from 8-20 bar (Gomes et al., 2019). The membrane fibers available in the market are constantly being improved to have greater selectivity and permeability to achieve better separation and less methane slippage.

2.3.5 Cryogenic Upgrading

In this upgrading method, the biogas is transformed into a liquid after cooling to a temperature of about -162°C; it produces CO_2 and methane as byproducts in their purist form (Ahmad et al., 2018).

2.3.6 Water Scrubbing

Water scrubbing uses the higher solubility of CO_2 and H_2S in water (Biogas: Cleaning and Uses, 2008; Islamiyah et al., 2015). The CO_2 in raw biogas reacts with water, forming carbonic acid Equation 1 (Islamiyah et al., 2015).

$$CO_2 + H_2O \longrightarrow H_2CO_3 \quad (1)$$

It is the cheapest and easiest method of biogas upgrading in which pressurized water is used as an absorbent. The raw biogas can be introduced into the scrubber column directly at storage pressure, or it can be compressed and introduced into the column from the bottom at the same time, while pressurized water is sprayed from the top of the column via nozzles; the absorption process is thus made counter current one, which dissolves CO_2 as well as H_2S in water (Islamiyah et al., 2015). The H_2S and CO_2 can be selectively removed through physical absorption because they are more soluble than methane in water. Water scrubbing can also be used to selectively remove H_2S by raising the biogas pressure even more.

III. Materials And Methods

3.1 Material for Construction of Anaerobic Digester

To select the most suitable material for the construction of the anaerobic digester, some important factors were considered, such as geological, hydrological, local conditions, and local availability of materials (Shian,1979). With technological advances, materials with improved properties and economic advantages have been introduced to the market. Underground biogas digesters are very popular and mainly used in India. The construction materials used for this type of digester include stone or bricks (Anand,1993); investment costs are very high, which is a significant constraint. Advances have been made to develop digesters from cheaper, locally available materials such as PVC and polyethylene, which are relatively cheap (An, 1997). Different construction materials with their advantages and disadvantages are summarized in Table 1.

TABLE I. Different materials used to construct digesters, their advantages and disadvantages (Karthik et. al., 2012).

MATERIAL	MODIFICATION	ADVANTAGES	DISADVANTAGES
Polyvinyl chloride (PVC) Polyethylene (PE)	Red mud PVC (mixed with aluminum) PE with UV filter	Less weight Easily portable PE is much cheaper than PVC.	Short life span
Neoprene and Rubber	Reinforced with nylon	Weather resistance elastic	Expensive Low pressure Less life span
Bricks and concrete	Pre-fired earthen rings, lime concrete, slag concrete, fired clay, bricks, reinforced concrete, Ferro cement (crack proof)	Long life span, less maintenance cost	Gas could escape through concrete pores when pressure increases. Built underground. Difficult to clean. Occupies more space.
Bamboo and wood support	Usually a support material, Reinforced with flax	Locally available material	Can break easily
Steel drum		Produce gas at constant flow. Leakproof	Corrosion The heavy weight of the gas holder

Polyvinyl chloride (PVC) was selected as the construction material for an anaerobic digester, considering its advantages and disadvantages.

3.2 Biogas Production Methodology

Biomass (cow dung) was obtained at the College of Veterinary Medicine, FUNAAB cattle unit, which consisted mainly of about 12kg of fresh cattle dung. An 80-liter slurry was loaded into the anaerobic digester in a mix ratio of 3:1 (water to waste): 12kg of cow dung and 60 liters of water. The slurry had a retention period of 30 days, after which the digester was reloaded with the same quantity of slurry. Figure 1 below shows the schematic layout of the project.

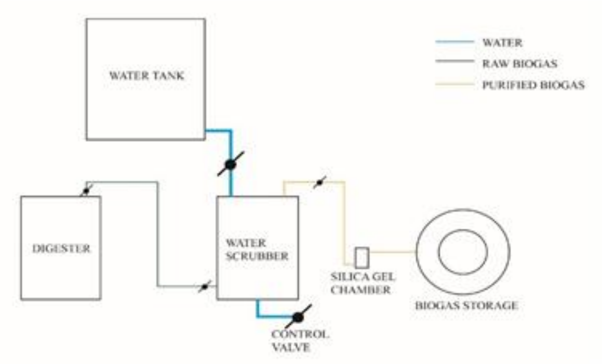

Fig. 1. Schematic layout of the project.

The digester, a sizable tank, is the focal point of a biogas system. Organic materials are transformed into methane gas by bacteria within this tank via anaerobic digestion. The stages of biogas production are hydrolysis, acidogenesis, acetogenesis, and methanogenesis. A plastic drum of 120 liters capacity was obtained from the local market to construct the anaerobic digester. The plastic drum has a plastic cover that can be opened and closed. It is also equipped with a metallic sealing clip to make it air-tight. The biogas outlet was created at the top. The gas outlet was connected to a rubber tube, where gas was temporarily stored using a flexible hose. The outlet for sludge was created at the bottom using a water tank outlet; Figure 2 shows the locally-made anaerobic digester.

Fig. 2. An anaerobic digester made from PVC.

3.2.1 Components of the Biogas Digester

1. Plastic drum (air-tight)
2. Gas outlet
3. Effluent outlet

3.3 Material Selection for the Water Scrubber

The major components of the scrubbing system include:

- The scrubbing chambers
- Packed bed (steel wool)

3.3.1 Components of the Water Scrubber

Water: This is used to absorb carbon dioxide from the biogas and a small amount of hydrogen sulfide. It is done by an absorption process whereby the water comes from the top and the biogas from the bottle, hereby having a countercurrent direction. Upon contact with the water, the carbon dioxide is absorbed.

Steel wool: This is used to remove hydrogen sulfide by reacting with it.

Blue silica gel: It is used to reduce the percentage of water in the biogas after scrubbing.

Separator: It is used to separate the steel wool from the bottom of the container; it serves as a support for the packing bed (i.e., steel wool).

Iron drum: The scrubbing vessel where the gas is purified inside, and water flows through it. It houses the separator and the steel bed.

Vacuum pump: This is a device that extracts gas molecules from a closed chamber, resulting in a partial vacuum (Tariq

Mobin, 2015). It was used to draw out the scrubbed gas from the scrubbing unit.

3.3.2 Water Scrubber Design Criteria and Estimation

A metal plate was placed at the bottom of the drum with a three-legged stand each of 10cm to support the packed bed (steel wool). Water was supplied to the scrubbing chamber using a connected overhead 1000-liter tank, and the water was distributed utilizing a water sprayer connected to the cover of the scrubber.

3.4 Water Scrubbing System

The scrubbing chamber has a height of 87cm and a radius of 28cm; the water for scrubbing the biogas was passed through the overhead tank into the shower head located inside the chamber, and the raw biogas was also passed from the bottom simultaneously, thus allowing a countercurrent reaction. The steel wool (packed bed) was placed on the separator 10cm above the bottom of the drum and perforated 9mm round to allow the gas to pass through. The height of the packed bed was 40cm, and it weighed 1181.8 grams. Three different flow rates were used to scrub the gas (the water control valve was calibrated to indicate a specific flow rate level). The gas outlet was connected to a bottle filled with silica gel (500g) and was connected to a vacuum pump, which helped in sucking out the purified biogas. The scrubbing setup consists of the water scrubber with steel wool packed bed connected to a one-thousand-liter tank consisting of pure water with the help of reducers (1 inch to ½ inch), Teflon tapes, and target gum, which was used to tighten the internal and external threading and pipe fitting. The scrubber was connected to raw biogas at the lower bottle of the system. In contrast, water was connected from the top, and the gas outlet was connected to a bottle filled with blue silica gel (Marozava et al., 2014) and then to the vacuum pump connected to the rubber tube for the purified biogas. Figure 3 shows the water scrubbing setup.

Fig. 3. Water scrubbing system.

3.4 Determination of Flow Rates

The flow rate was determined by marking three points using a protractor: 30^0, 60^0, and $90^{0,}$ respectively, on the control valve. The control valve was opened to each point and used to fill a four (4) liter bucket each. The following result was obtained as shown in table 2 below.

TABLE III. Calibration of water flow rate valve

Flowrate and Position	Time allowed for 4 liters to flow (min)	Calculated flow rate (L/s)
1(30°)	5.19	0.013
2(60°)	0.62	0.108
3(90°)	0.52	0.129

IV. Results and Discussion

4.1 Biogas Production and Scrubbing

Biogas was produced using an anaerobic digester utilizing cow manure as feedstock. The raw biogas and scrubbed gas at the three flow rates were analyzed in a laboratory, and the following result was obtained, as shown in Table 3.

TABLE IIIII. Comparison of the composition of produced Raw and Purified Gas

Parameters	Raw	Flow Rate 1	Flow Rate 2	Flow Rate 3
CH_4 (%)	65.48	88.80	88.92	89.14
CO_2 (%)	30.52	11.14	11.05	10.83
H_2S (%)	0.04	0.00062	0.00058	0.00058
Others (%)	3.96	0.06	0.03	0.03

4.2 Discussion

The biogas scrubber increased the methane content in the biogas from 65.48% to 89.14% at the third flow rate, indicating that the higher the flow rate, the higher the purity percentage. Although a significant difference between the flow rates is not necessary, there is still an impact Figure 4 and 5 shows the percentage of methane and carbon dioxide in raw biogas and the three different flow rates.

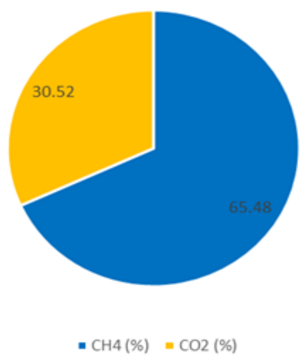

Fig. 4a. Biogas composition before scrubbing.

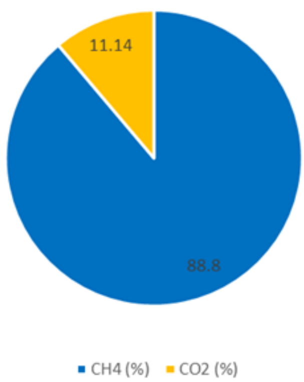

Fig. 4b. Biogas composition (Flowrate 1).

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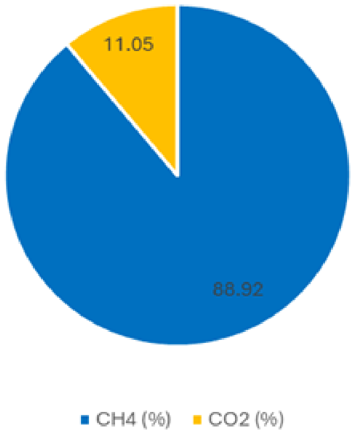

Fig. 5a. Biogas composition (Flowrate 2).

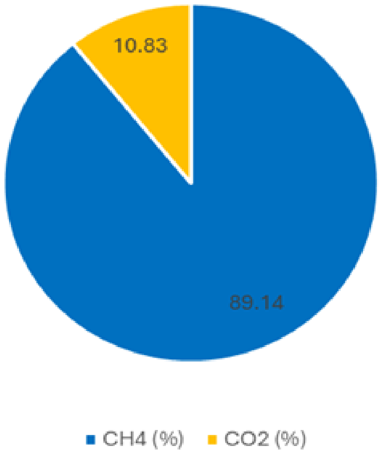

Fig. 5b. Biogas composition (Flowrate 3).

V. Conclusion

Biogas was successfully produced in the digester, with an initial composition of approximately 65.48% methane, 30.52% carbon dioxide, 0.4% hydrogen sulfide, and 3.6% other gases. A water scrubber system was designed, fabricated, and implemented to purify the biogas. After scrubbing, the biogas quality improved significantly, with the methane content increasing from 65.48% to 89.14%, accompanied by a reduction in hydrogen sulfide, carbon dioxide, and other impurities.

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References

[1] Ahmad, N. E., Mel, M., & Sinaga, N. (2018). Design of Liquefaction Process of Biogas using Aspen HYSYS Simulation. In *Journal of Advanced Research in Biofuel and Bioenergy* (Vol. 2). www.akademiabaru.com/arbb.html
[2] A.M. I. Yousef, Y. A. Eldrainy, W. M. El-Maghlany and A. Attia,,Alexandria. 2016. *Engineering Journal 55, 1143-1150*
[3] Bajracharya TR, Dhungana A, Thapaliya N, Hamal G (2009) Purification and Compression of Biogas: A research experience. *J Instit Engg 7: 1-9.*
[4] Bauer, F., Hulteberg, C., Persson, T., & Tamm, D. (n.d.). Biogas upgrading-Review of commercial technologies (Biogasuppgradering-Granskning av kommersiella tekniker) SGC Rapport 2013:270 "Catalyzing energygas development for sustainable solutions." www.sgc.se.
[5] *Biogas: Cleaning and Uses.* (2008). http://www1.agric.gov.ab.ca/general/progserv.nsf/all/
[6] Borjesson P, Mattiasson B (2007) Biogas as a resource-efficient vehicle fuel. Trends in Biotechnology. 2nd Nordic Biogas Conference, Malmo
[7] Borilek JK, Winner K (1998) Pascal modified method for biogas fractionation. Chem Engg Technol Series no 15: 345
[8] C. Mao, Y. Feng, X. Wang and G. Ren. 2015. Renewable and Sustainable Energy Reviews 45, 540-555
[9] Divyang R. Shah 1, Prof. (Dr.) Hemant J. Nagarsheth. 2015. Biogas Up-Gradation Using Water Scrubbing For Its Use In Vehicular Application
[10] D. Shah and H. J. Nagarseth. 2015. International Journal of Innovative Science, Engineering and Technology 2, 308-312
[11] Edison E. Mojica, Ar-Ar S.Ardaniel, Jeancou G. Leguil and Andrea T. Loyola. 2018. AIP conference proceeding
[12] E. Mojica and A. Paglinawan,. 2016. "Electrical performance analysis of biogas fuelled generator with purifier," in IEEE International SoC Design Conference, (Institute of Electrical and Electronics Engineers, Piscataway, NJ), pp. 3-4.
[13] Energiforsk AB. 2016. Biogas upgrading- Technique review
[14] Ernst, W. R., Chen, M. S. K., & Mitchell, D. L. (1990). Hydrolysis of carbonyl sulfide: Comparison to reactions of isocyanates. *The Canadian Journal of Chemical Engineering*, *68*(2), 319–323. https://doi.org/10.1002/cjce.5450680218
[15] Eze JI (2010) Preliminary Studies on Biogas Scrubbing system for Family sized Biogas Digester. Global J Sci Frontier Res 10: 13-17.
[16] Gomes, M. G., De Morais, L. C., & Pasquini, D. (2019). Use of membranas for biogas purification: review. *Holos Environment*, *19*(3), 466. https://doi.org/10.14295/holos.v19i3.12339
[17] Islamiyah, M., Soehartanto, T., Hantoro, R., & Abdurrahman, A. (2015). Water Scrubbing for Removal of CO2 (Carbon Dioxide) and H2S (Hydrogen Sulfide) in Biogas from Manure. *KnE Energy*, *2*(2), 126. https://doi.org/10.18502/ken.v2i2.367
[18] Jones J, Partington B (2008) Biogas cleaning and Uses, Agriculture and Rural Development, Alberta. AGRI-FACTS, Practical Information For Alberta's Agriculture Industry. Agdex 768-775.
[19] Kapdi SS, Vijay VK, Rajesh SK, Guar RR (2003) Feasibility study on purification and compression of biogas for rural areas. International Conference in Energy and Rural Development MNT, Jaipur, India
[20] Kárászová, M., Sedláková, Z., & Izák, P. (2015). Review: Gas permeation processes in biogas upgrading: A short review. In *Chemical Papers* (Vol. 69, Issue 10, pp. 1277–1283). De Gruyter Open Ltd. https://doi.org/10.1515/chempap-2015-0141
[21] Kohl, A.L. and R.B. Nielsen. 1997. Gas Purification Gulf Pub
[22] Levenspiel O 1999 Chemical Reaction Engineering. (3rd edn.) John Wiley and Sons Inc, New York: 685.
[23] L. Liu, T. Zhang, H. Wan, Y. Chen, X. Wang and G. Yang. 2015. Energy Conversion and Management 97, 132-139
[24] Marozava, S., Röling, W. F. M., Seifert, J., Küffner, R., von Bergen, M., & Meckenstock, R. U. (2014). Physiology of Geobacter metallireducens under excess and limitation of electron donors. Part II. Mimicking environmental conditions during cultivation in retentostats. *Systematic and Applied Microbiology*, *37*(4), 287–295. https://doi.org/10.1016/j.syapm.2014.02.005
[25] Olugasa TT, Odesola IF, Oyewola MO (2013) Energy production from biogas: A conceptual review for use in Nigeria. J Renew Sustain Energy Rev 32: 770– 776
[26] Olugasa TT, Oyesile OA. 2015.Design and Construction of a Water Scrubber for the Upgrading of Biogas. J Fundamental Renewable Energy Appl

[27] Olukayode AI. 2015. Effects of Some Physical and Chemical Scrubbers on the Purification of Biogas Produced with Anaerobic Digester
[28] Peters MS, Klaus D. Timmerhaus (2004) Plant Design and Economics for Chemical Engineers. (5th edn.) Mc Graw-Hill Companies Inc: 88.
[29] R. M. Kapoor. 2017. "Development of methane loss minimisation and carbon dioxide recovery systems in a water scrubbing based biogas upgradation," Ph.D. thesis, Indian Institute of Technology Delhi, February
[30] Svensson, H., & Hulteberg, C. (n.d.). Carbon dioxide removal in indirect gasification (Koldioxidavskiljning vid indirekt förgasning) "Catalyzing energygas development for sustainable solutions." www.sgc.se
[31] Tariq Mobin, S. (n.d.). Design And Development Of Solar Panel Cleaning System Mechanical Engineering Mechatronics and Automation Under the Supervision of Prof Subrata Kumar Panda Department Of Mechanical Engineering National Institute Of Technology Rourkela-769008, ODISHA (INDIA).
[32] Vrbová, V., & Ciahotný, K. (2017). Upgrading Biogas to Biomethane Using Membrane Separation. *Energy and Fuels*, *31*(9), 9393–9401. https://doi.org/10.1021/acs.energyfuels.7b00120