Fundamentals of Renewable Energy and Applications

Olugasa and Oyesile, J Fundam Renewable Energy Appl 2015, 5:5
http://dx.doi.org/10.4172/2090-4541.1000190

Research Article

Open Access

Design and Construction of a Water Scrubber for the Upgrading of Biogas

Temilola T Olugasa* and Oluwafemi A Oyesile

Department of Mechanical Engineering, University of Ibadan, Ibadan, Nigeria

Abstract

This paper discusses the results of studies conducted on raw biogas produced from a prototypic biogas production plant located at the Teaching and Research Farm, University of Ibadan, Ibadan. This setup consists of a mixing chamber, a biogas digester and a stabilizing unit, locally designed and fabricated. It further discusses preliminary and detailed design coupled with the construction of an effective and efficient technology used in purifying raw biogas generated from the prototypic biogas production plant; this technology is otherwise known as the Water Scrubbing technology. The Scrubbing system consists of the Water scrubber with iron wool packed bed connected to a 500 litre water tank, and two tyre tubes which were used in storing the pre scrubbed (raw) biogas and the scrubbed (purified) biogas. The water scrubber has an inlet for the entry of the raw biogas and a discharge for the exit of the scrubbed biogas. Raw biogas from the plant was stored in a tyre tube and directly fed into the Water scrubber housing the iron wool packed bed, the purified biogas from the exit was also collected into another tyre tube. The samples of the gas mixture were taken before and after scrubbing and analyzed with Pascal Manometric Glass Tube technique. Results indicated that methane content of the scrubbed/ purified biogas was raised from 58% to 82% due to the reduction of Carbon dioxide and Hydrogen Sulphide. CO_2 was reduced from 31% to 14% while H_2S was reduced from 1% to 0.4%.

The corresponding Energy content of the purified biogas was evaluated to be 41MJ/kg which is higher than that of the raw biogas which was evaluated to be 29MJ/kg.

Keywords: Biogas; Water scrubber; Packed bed; Methane; Purify; Upgrade

Introduction

In Nigeria, we are posed with the problem of generating electricity, producing adequate electricity for the entire population of the country has been observed as a bone of contention. There is also a problem of finding and using alternative energy sources. The major source of electricity generation in Nigeria is fossil fuels; these fuels have an adverse effect on the biological system because they facilitate global warming. As a result of this development, researches have shown that renewable fuels are genuinely important in solving these problems. An example of a renewable fuel is biogas which simply means "fuel from biological matter". A more comprehensive definition was given by Olugasa et al. [1] and described biogas as a of the mixture of carbon dioxide, CO_2 and inflammable gas Methane, CH_4 which is produced by bacterial conversion of organic matter under anaerobic (oxygen-free) conditions.

However, biogas has some limitations; these limitations have in one way or the other restricted the commercial use of biogas. The limitations have also reared its ugly head in the awaiting success story of this impressive source of energy. These limitations include low energy content and a challenging difficulty in compressing and storing biogas. Another notable limitation of biogas is the fact that there have been little technological advancements in the production of biogas. The low energy content is majorly caused by unwanted constituents or impurities in the biogas like Carbon dioxide (CO_2), hydrogen sulphide (H_2S), siloxanes, halogens etc. There is therefore an urgent and essential need to purify biogas before it can be used to generate adequate electricity and be used as a vehicle fuel; hence, the need for this study. A lot of processes have been developed in increasing the energy content (Methane content) in biogas. Some of these processes are Polyethylene Glycol scrubbing, chemical absorption, pressure swing adsorption, Bio trickling filter, Cryogenic separation, Iron absorptive media, biological scrubbing and most importantly the Water Scrubbing technology. According to Vijay [2] the water scrubber's advantage over other purification techniques is its simplicity, availability of water; it's suitability for biogas enrichment in rural areas, and characteristic as a universal solvent. In addition to these, the packing material in the scrubbing setup increases the contact time between the biogas and water. This work is therefore aimed at providing an effective and efficient scrubbing technique that would be capable of removing significant amounts of Carbon dioxide and Hydrogen sulphide, resulting to an increase in the energy content of biogas and the recommendation of the commercial use of purified biogas in Nigeria [3-10].

Materials and Methods

Assessment and selection of a biogas plant

The biogas plant at the Teaching and Research Farm, University of Ibadan was selected as the case study. This biogas plant has a bio-digester of 2 m^3 capacities, a mixing chamber and a stabilizing unit. 8 kg of Cow dung was transported from the dairy farm, University of Ibadan to the location of the biogas plant at the Teaching and Research Farm. The system was charged with cow dung at the ratio of 1:1 (water to cow dung) and left in an open area with ambient daily average temperature of 31.5°C and monitored for a period of 14 days. After proper mixing in the mixing chamber, the system was left air-tight to ensure an anaerobic environment inside the digester and manually stirred occasionally every day.

A biogas collection setup made up of a ½ inch hose, 50 cm long was

***Corresponding author:** Olugasa TT, Bsc, Department of Mechanical Engineering University of Ibadan, Oyo State Nigeria, Tel: 234-803-577-5040; E-mail: temilola18@yahoo.co.uk

Received May 06, 2015; **Accepted** October 14, 2015; **Published** October 20, 2015

Citation: Olugasa TT, Oyesile OA (2015) Design and Construction of a Water Scrubber for the Upgrading of Biogas. J Fundam Renewable Energy Appl 5: 190. doi:10.4172/20904541.1000190

designed and connected to the biogas plant for the collection of raw biogas to be tested and analyzed, and for the subsequent use of the raw biogas to be scrubbed.

Design of the biogas scrubber

The design of a packed bed water scrubber involves the following steps:

i. Assumptions of basic data.
ii. Solubility data generation.
iii. Material balance and determination of water flow rate.
iv. Selection of packing material.
v. Determination of column diameter.
vi. Determination of the height of the packed bed column.
vii. Selection of packing support and water distributor.

Assumptions of basic data

The basic data assumed during the design of the scrubber were:

Inlet pressure of the biogas = 100 kPa

Inlet temperature of biogas = 25 °C

Volume of Biogas to be Scrubbed= 0.050 m^3

Percentage of carbon dioxide in biogas = 35%

Partial pressure of CO_2= 0.35 kPa

Solubility data generation: Henry's Law was used to determine the solubility of CO_2 in water. Solubility of CO_2 in water at 1 bar and 298K is given as 2857 $Pa.m^3/mol$

Henry's Law:

$$P_t = K_H C_{max} \quad (1)$$

C_{max} = Saturation concentration of CO_2 in mol/m^3

K_H = Henry's coefficient [$Pa.m^3/mol$] = 2857 $Pa.m^3/mol$

P_i = Partial pressure of CO_2 component in biogas (P_a)

This equation was used in determining the Henry's law constant of Methane; it gives us a guideline as to the solubility of methane in water. It further introduces us to the relationship between the Henry's law constant and the concentration of methane in water, an inverse relationship. The Henry's law constant of methane is very high due to the insolubility of methane, compared to that of Carbon dioxide and Hydrogen sulphide which are both soluble in water.

Material balance and determination of water flow rate

Material/mass balance equation: Rate of Accumulation of species I in the volume element = (Rate of inward flow of species I in the volume element) – (Rate of outward flow of species I from the volume element) + (Rate of species I generation in the element)

$$P_{A1} - P_{A2} = \left(\frac{F_l \pi}{F_g C_T}\right)(C_{A1} - C_{A2}) \quad (2)$$

$$F_l / F_g = 10 \quad (3)$$

Equations 2 and 3 were used in calculating the pressure drop in the scrubber with known parameters like the ratio of molar flow rate of water to biogas, molar density of water, total pressure and difference in concentration of biogas at inlet and outlet.

Ergun Equation:

$$\Delta P = \frac{150\mu(1-\varepsilon)2V_s L}{\varepsilon^3 D_P^2} + \frac{1.75(1-\varepsilon)\rho V_s^2 L}{\varepsilon^3 D_p} \quad (4)$$

Equation 4 was used in determining the superficial velocity of carbon dioxide using parameters such as gas density, void fraction, equivalent spherical diameter of packing, dynamic viscosity of the gas, length of the packed bed and pressure drop.

Flow Rate Equation: $Q = V_s A$ (5)

Equation 5 was used in verifying the Area of the reacting column using the calculated superficial velocity and the molar flow rate of the gas.

Determination of volume of reactor, packed bed height and diameter:

Volume of a cylinder: V=AH (6)

$$V_\gamma = hA_{cs} \frac{F_g}{\pi K_G \alpha}(P_{A2} - P_{A1}) \quad (7)$$

With a specified volume and a known area, the height of the packed bed was also established using equation 7

Selection of packing material: A packing material used in enhancing the contact time (interfacial area) between the gas and water. The packing material selected for the scrubber was iron wool with the following specifications:

Equivalent spherical diameter of packing=5×10^{-3}m

Void fraction=0.5

Iron wool was selected because it removes hydrogen sulphide from biogas

Selection of packing support and water distributor: Metal sieves were placed at the top and bottom of the middle section of the scrubber to act as support for the iron wool packing.

Water was supplied to the scrubbing tower by means of a connected overhead 500 litre tank and the water was distributed by means of a water sprayer connected to the top section of the scrubber.

Basic Parameters

P_A Partial pressure

C_A Concentration

P_{A1} Partial Pressure at inlet

P_{A2} Partial Pressure at outlet

F_l Molar flow rate of liquid

Fg Molar flow rate of gas

π = Total Pressure

C_T Molar density of water

C_{A1} Concentration of CO_2 in water at inlet

C_{A2} Concentration of CO_2 in water at outlet

ΔP Pressure drop

μ Dynamic viscosity of gas

ε Void fraction

V_s Superficial Velocity

L Length of bed

ρ Density of gas

D_p Equivalent spherical diameter of packing

Equivalent spherical diameter of packing=5×10^{-3} m

Void fraction=0.5

Gas (methane) density = 0.72 kg/m^3

Gas (Carbon dioxide) density = 1.98 kg/m^3

Gas (methane) viscosity = 7.39×10^{-6} m^2/s at 25^{0}C

Viscosity of carbon dioxide = 0.0855×10^{-6} m^2/s at 25 ^{0}C [3,4]

CAD Models

Detailed designs of a Water Scrubber with iron wool packed bed were produced using CATIA software. These are shown in Figures 1, 2 and 3. Figure 2 shows the 3-dimensional view of the scrubber, while Figure 3 shows the details of the scrubbing process as being counter current with the biogas coming in from the side of the tank and going out from the top of the tower while the water is introduced from the top of the scrubber and the flows out from the bottom of the tower.

The scrubbing setup consists of the water scrubber with an iron wool packed bed connected to a five hundred litre tank containing pure water with the aid of a piping network that consists of a one inch pipe, reducers (2 inches to 1 inch), 2 inches and 1 inch nipples and a 1 inch elbow, Teflon tapes were used to tighten the internal and external threading in the pipe and pipe fittings. The scrubber was also connected to two tyre tubes for collection of raw and purified biogas respectively at the inlet and the discharge of the water scrubber. The tyre tubes were connected to the water scrubber with the aid of ½ inch hoses, ½ ball valves, ½ inch reducers, ½ inch nipples, top gut gum, and araldite glue. Raw biogas was stored in one of the tyre tubes and pressurized before it was sent into the bottom section of the water scrubber. The iron wool packed bed was used to enhance the contact time (interfacial area) between the biogas and water, and also to react with the hydrogen sulphide in the biogas. Pressurized water was also sprayed from top with the aid of a shower sprayer to absorb the CO_2 and H_2S from pressurized biogas. The movement of the biogas was achieved by means of upward displacement, downward delivery elemental technique. Purified biogas

Figure 1: Isometric view of the Water scrubber with an iron wool packed bed.

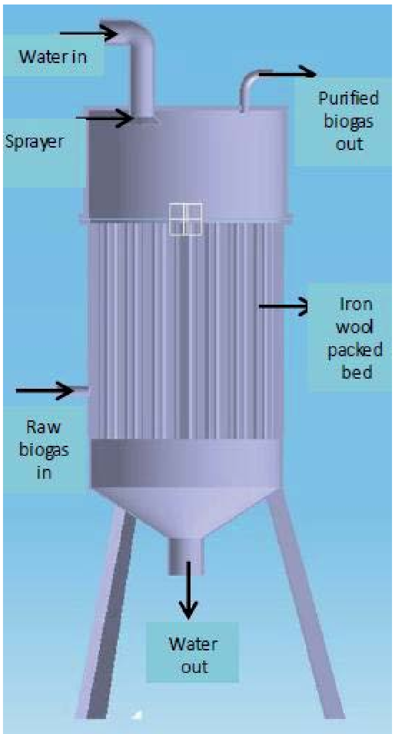


Figure 2: Testing of the Scrubbing System.

Figure 3: Pascal Manometric Glass tube.

Citation: Olugasa TT, Oyesile OA (2015) Design and Construction of a Water Scrubber for the Upgrading of Biogas. J Fundam Renewable Energy Appl 5: 190. doi:10.4172/20904541.1000190

was then collected into another tyre tube where it was stored for further analysis [11-14].

Chemical analysis of raw and purified biogas

The chemical analysis used in determining the composition of biogas was done using Pascal Manometric glass tube. 30cm^3 of the gas was trapped into the Pascal Manometric glass tube via the gas regulator. The Pascal Manometric glass was filled with known volume of fractionating reagents mixture which consists of 1M magnesium perchlorate, 1M Sodium hydroxide, 1M Barium sulphate and 1M Nitric acid. The fractionation uses the redox principle in which the reduction oxidation process will precipitate the fractions of the gases. The percentage of the gas fractions was got

Percentage of CH4 in biogas = $\frac{a \times 16.04}{\text{Volume of biogas used}}$

Percentage of CO_2 in biogas= $\frac{b \times 44.01}{\text{Volume of biogas used}}$

Percentage of H_2S in biogas= $\frac{c \times 34.06}{\text{Volume of Biogas used}}$

Where a, b and c are the volume of CH_4, CO_2 and H_2S gases trapped respectively [5].

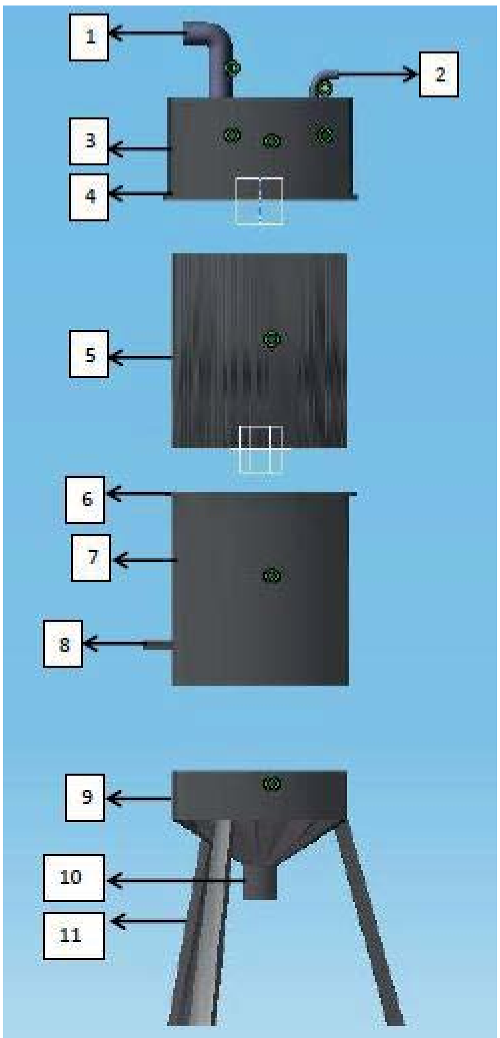
Results and Discussion

Design Specifications

Using the Material/ mass balance equation, the Ergun equation, the flow rate equation, the relationship between volume, area and height of a packed bed; the following design specifications of a water scrubber with iron wool packed bed were obtained:

A superficial velocity of 2.4×10^{-3} m/s was obtained; the packed bed area of 0.1158 m$^{2;}$ a diameter of 38.4 cm and a packed bed height of 60.5cm.

By means of an indispensable design process, coupled with the right design specifications, as well as accurate construction and fabrication, along with precise and proper assembling; Figure 4 shows an enhanced purification technique which is the water scrubber with iron wool



Part Nos.	Description	Specification	Material used
1	Water inlet	1 inch diameter pipe	Polyvinyl chloride pipe
2	Gas discharge	½ inch diameter pipe.	Polyvinyl chloride pipe
3	Head	10 inches diameter, 8 inches long.	Mild steel pipe
4	Flange	10 ¾ inches internal diameter, 13$\frac{1}{4}$ inches external diameter, 1$\frac{1}{2}$ inches height.	Mild steel circular bar
5	Packed bed	9inches diameter,20inche s long	Steel wool
6	Sieve	10 inches diameter	Mild steel circular bar
7	Body	10 inches diameter, 20 inches long	Mild steel pipe
8	Gas inlet	½ inch diameter pipe	Polyvinyl chloride pipe
9	Base	10 inches diameter, 8 inches long.	Mild steel pipe
10	Water discharge	2 inches diameter valve	Stainless steel valve
11	Stand	24 inches long.	Iron angle bar

Figure 4: Exploded view of the Water Scrubber with an iron wool packed bed and the Bill of Materials.

packed bed which has been proffered to improve the qualities and increase the energy content in biogas.

Most scrubbers use raschig rings/ balls as the contactors for the packed bed. This study has however, explored the use of a packed bed in order to investigate if there will be increased absorption of hydrogen sulphide, which is only absorbed in water scrubbing in small

The scrubbing setup shown below in Figure 5 comprises of the water scrubber with iron wool packed bed connected to a five hundred litre tank which contains pure water with the aid of a pipe network. The water scrubber is connected to two tyre tubes for collection and storage of raw and purified biogas respectively at its inlet and discharge.

Chemical Analysis

Figures 6 and 7 show diagrams (pie charts) which represent the composition of raw biogas (pre scrubbed) and composition of purified biogas (scrubbed). The figures show that there is an increase in methane content from 58% to 82%, due to removal of Carbon dioxide and Hydrogen Sulphide. Carbon dioxide was reduced from 31% to 14% while Hydrogen Sulphide was reduced from 1% to 0.4%. This implies that CO2 was reduced by 55% and H2S was reduced by 60%, while CH_4 increased by 41%. The mass of raw biogas was measured to be 1.26 kg while that of purified biogas was measured to be 1.18 kg.

The corresponding Energy content of the purified biogas is evaluated to be 16.4 MJ/kg or 27.675 MJ/m^3 which is more than that of the raw biogas, 11.6 MJ/kg or 19.575 MJ/m^3. [15-17].

Figure 5: Biogas scrubbing set up.

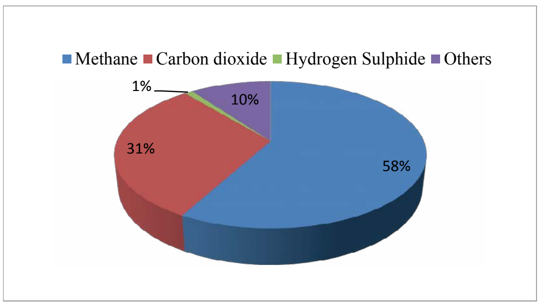


Figure 6: Composition of raw biogas.

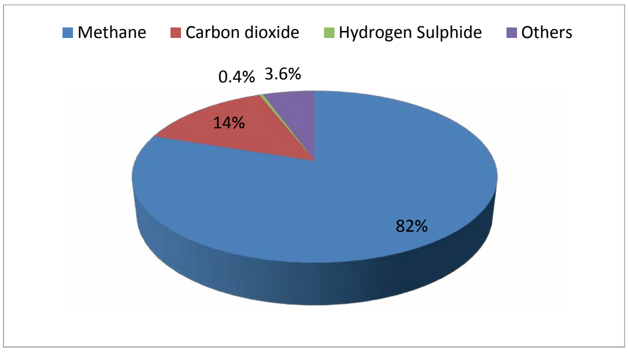


Figure 7: Composition of purified gas.

Conclusion

Many new and stimulating developments have been discovered in recent years through the study of biogas and its vast technology, though they are of worthy note, there are still more benefits that have not been optimally utilized.

This research paper has made a huge effort in offering a very important solution to the problems affecting the optimal and commercial use of Biogas. The water scrubbing technology which involves the use of a water scrubber with an additional modification which is the iron wool packed bed has been proven to achieve eighty two percent (82%) purified biogas by reducing Carbon dioxide and Hydrogen Sulphide to a large extent, which in turn enhances adequate compression and storage; and makes it suitable for the utmost use of generating adequate electricity, faster cooking and fuel for automobiles, power generators and boilers. The by-product of the water scrubbing process is fairly easy to dispose unlike the products of chemical scrubbing process because it contains very weak carbonic acid. This shows that water scrubbing with the use of an iron wool-packed bed is quite effective in the removal of CO_2 and H_2S from biogas.

Acknowledgement

The Author's wish to acknowledge the grant provided by the Department of Mechanical Engineering, University of Ibadan, Nigeria for this study.

References

1. 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.
2. Vijay VK (2011) Biogas purification using water scrubbing systems.
3. Peters MS, Klaus D. Timmerhaus (2004) Plant Design and Economics for Chemical Engineers. (5th edn.) Mc Graw-Hill Companies Inc: 88.
4. Levenspiel O (1999) Chemical Reaction Engineering. (3rd edn.) John Wiley and Sons Inc, New York: 685.
5. Borilek JK, Winner K (1998) Pascal modified method for biogas fractionation. Chem Engg Technol Series no 15: 345.
6. Borjesson P, Mattiasson B (2007) Biogas as a resource-efficient vehicle fuel. Trends in Biotechnol. 2nd Nordic Biogas Conference, Malmo.
7. Bajracharya TR, Dhungana A, Thapaliya N, Hamal G (2009) Purification and Compression of Biogas: A research experience. J Instit Engg 7: 1-9.
8. Eze JI (2010) Preliminary Studies on Biogas Scrubbing system for Family sized Biogas Digester. Global J Sci Frontier Res 10: 13-17.

9. 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.

10. 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.

11. Karki AB, Shrestha JN, Bajgain S (2005) Biogas: as renewable source of energy in Nepal. SNV Publisher, Nepal.

12. Kossmann W, Pönitz U, Habermehl S, Hoerz T, Krämer P, et al. (2011) Biogas Digest. Biogas Basics, Information and Advisory Service on Appropriate Technology (ISAT) 1.

13. Prasertsan S, Sajjakulnukit B (2006) Biomass and biogas energy in Thailand: potential, opportunity and barriers in Renewable Energy. Renew Energy 31: 599-610.

14. Zhao Q, Leonhardt E, MacConnell C, Frear C, Chen S (2010) Purification Technologies for Biogas Generated by Anaerobic Digestion. CSANR Research Report: 001.

15. Ilyas SZ (2006) A Case Study to Bottle the Biogas in Cylinders as Source of Power for Rural Industries Development in Pakistan. World Appl Sci J 1: 27-130.

16. Tippayawong N, Promwungkwa A, Rerkkriangkrai P (2007) Long-term operation of a small biogas/diesel dual-fuel engine for on-farm electricity generation. Iranian J Sci Technol Transact B: Engg 34: 167-177.

17. Wise DL, Rato B (1981) Analysis of systems for purification of fuel gas. Fuel gas production from biomass. CRC Press 2.

Citation: Olugasa TT, Oyesile OA (2015) Design and Construction of a Water Scrubber for the Upgrading of Biogas. J Fundam Renewable Energy Appl 5: 190. doi:10.4172/20904541.1000190