DEVELOPMENT OF BIOGAS SCRUBBER USING WATER PURIFICATION SYSTEM

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Abstract: Biogas can be used in the production of electricity, for heating and cooking. In compressed form, it can be used to replace compressed natural gas used in vehicles, such that it can fuel an internal combustion engine or fuel cells. Cleaning of gas is necessary to meet the pipeline quality requirement. The composition of the gas must be correct to be accepted by the local distribution network. Carbon dioxide (CO_2), moisture, hydrogen sulfide (H_2S), and particulate matter must be removed if present. This study aimed to develop a biogas scrubber using water purification system. Specifically, the objective was to evaluate the composition of biogas before and after scrubbing in terms of percentage methane (CH_4), CO_2, Nitrogen (N_2), and H_2S. The development of the biogas scrubbing machine considered system components and material specifications. After fabrication, preliminary testing was done to establish different parameters such as working pressure and scrubbing time and amount of water needed. The study also evaluated the performance of the biogas scrubber in terms of percentage increase in CH_4 and scrubber efficiency. An operation and maintenance manual for the utilization of the biogas scrubber was also prepared. After several trials and testing, the system inlet pressure operated at 4.6 psi. The system could increase CH_4 in biogas by approximately 21.67 %. The scrubber efficiency was 68.67 %. It was recommended that further study should be conducted and consultation with experts should be done to improve the design and automate the operation of the system.

Keywords: *biogas, scrubber, water purification system, scrubber efficiency*

1. INTRODUCTION

With the fast-paced technology ventures in the world nowadays, energy production is enhanced and developed to meet the growing needs of humanity. Because energy plays a vital role in the economic success of many countries, certain government and non-government organizations continue to seek alternative energy resources. These include hydropower energy, solar energy, geothermal energy, ocean-thermal energy and the like which are used as fuel. One of these is biogas that is used as raw material to produce fuel known as biomethane.

Biomethane can be obtained from upgraded biogas produced from anaerobic digestion. It can also be from cleaned syngas which is 100% renewable. Biogas is produced from organic matter digested anaerobically. The organic matter such as dead animal and plant material, animal manure, sewage, organic waste, etc. is converted into biogas which is combustible because of methane (CH_4) content and a liquid effluent. Generally, biogas composition includes 55% to 65% CH_4 and 30% to 45% carbon dioxide (CO_2). Small amounts of other gases such as ammonia (NH_3), hydrogen sulfide (H_2S), and water vapor (H_2O) may be present. This depends on the source of the organic matter and the way the anaerobic digestion process is managed (Deublein & Steinhauser, 2008).

Biogas can be used for electricity production on sewage works, in a combined heat and power (CHP) gas engine, in which the digester is heated by the waste heat from the gas engine, and for cooking, space heating, water heating, and process heating. In its compressed form, it can be used to fuel an internal combustion engine or fuel cells. It is also a much more effective displacer of CO_2 compared to normal CHP plants.

Biogas upgrading or "sweetening" consists of removing CO_2, H_2S, N_2 and other possible pollutants from biogas. This increases the concentration of CH_4 which gives the biogas a higher calorific value allowing for injection in the gas grid or use as a fuel. H_2S has to be removed because of its corrosiveness (Mclnnes *et al.*,1990). The three steps in upgrading biogas are removal of H_2S, removal of water and removal of CO_2. Moisture can be removed by refrigeration. H_2S can be removed by air injection, addition of iron chloride to influent, iron sponge, use of activated carbon, water scrubbing, lime or sodium hydroxide scrubbing, or biological removal of filter bed. CO_2 can be removed by water scrubbing, pressure swing absorption, chemical absorption, membrane separation, and cryogenic separation (Krich *et al*., 2005).

Water scrubbing is the method used in upgrading biogas in this study. This method is used to remove CO_2, N_2, and H_2S from biogas. The process works since CO_2, N_2 and H_2S are more soluble in water than CH_4. In this physical process, the raw biogas is compressed and then injected into the bottom of the scrubber. Along with this, water is fed in from the top and exits the column with absorbed H_2S, N_2 and CO_2. The fluid is regenerated by stripping or de-pressurizing with air. The gas leaving at the top of the scrubber needs to be dried. After this drying step, the obtained CH_4 purity is approximately 98% (McCabe & Harriott, 2001). This method has the following advantages over the other methods: environment-friendly techniques, economically feasible, removes gases and particulate matter, limitation of H_2S absorption due to changing pH, high purity, good yield, and simple technique which does not require special chemicals or equipment. However, this method requires a lot of water, even with the regenerative process (Mclnnes *et al.*, 1990).

BA Gonzales Integrated Farm Builder in Batangas, a province in the Southern Tagalog region of the Philippines, is one of the experts on biogas technology that utilizes biogas for electricity supply. Its biogas supply is produced from pig manure and is used to fuel the farm's generator. About 400 m^3/day of electricity is generated from biogas and is used to power the farm and feed mill, home utilization, and the streetlights in some parts of their community. It also serves as the source of income of the family as they fabricate generators powered by biogas.

Based on the experience of the owner of the farm, many components of the generator such as spark plugs, head and engine block, valve guttering, pistons, liners, and waste gate valves are affected by other contaminants of biogas such as traces of hydrogen (H_2), N_2, carbon monoxide (CO), sulphur gases, and siloxanes which cause them not to function properly due to heavy deposits of carbon.

In view of this, the researchers came up with the study introducing the biogas scrubber using water purification system to treat biogas and remove corrosive or dangerous contaminants. It is hoped that the system would reduce, if not totally eliminate, the contaminants, and produce nearly pure CH_4 for energy utilization.

The main purpose of the study was to fabricate a biogas scrubber using water purification system. Specifically, this study aimed to evaluate the composition of raw biogas in terms of % CH_4, % CO_2, % N_2 and % H_2S, develop a biogas scrubbing machine taking into account system components and material specifications, conduct preliminary testing in order to establish the operating parameters such as working pressure, scrubbing time, and amount of water needed for the process. It also aimed to evaluate the composition of cleaned biogas in terms of % CH_4, % CO_2, % N_2 and % H_2S, evaluate the performance of the biogas scrubber using water purification system in terms of scrubber efficiency and percent increase of CH_4 and to provide an operation and maintenance manual for the utilization of the developed biogas scrubber.

2. METHODOLOGY

This developmental study employed engineering design and analysis to achieve the objectives. There are three stages involved: design and development stage, preliminary testing stage, and the final gathering of data.

1. Design and development stage. During the design stage, the amount of biogas produced in BA Gonzales Integrated Farm Builder and the problems they encountered in using raw biogas in their generator were considered. It also includes engineering calculations, design specifications of the system components, and lay out of the proposed system. In the development stage of the water scrubber system, system components and material specifications were considered. Durability and availability of materials were taken into consideration during the fabrication of the system.

2. Preliminary testing stage. The preliminary testing stage involves establishing different parameters necessary in the operation and evaluation of the system. These are the percent composition of raw biogas, working pressure, scrubbing time and the amount of water to be used.

3. Final gathering of data. During the final gathering of data, the performance of the biogas scrubber system was evaluated in terms of scrubber efficiency and percent increase of methane.

Method of determining the composition of biogas

The sample of raw biogas which was collected from BA Gonzales Integrated Farm Builder was contained in rubber balls and transported to the laboratory. To ensure that these contain only biogas, they were filled then emptied three times before the final collection of the samples. The composition of the raw biogas was determined in terms of percent by volume: % CH_4, % CO_2, % N_2 and %H_2S using gas chromatograph of the Philippine Institute of Pure and Applied Chemistry (PIPAC).

A methane analyzer of the Department of Science and Technology (DOST) was also used in determining the main composition of biogas, the methane. The analyzer was used on-site. It was connected to the biogas source through a hose, and shows readings after detecting the biogas.

Method of determining the working pressure

The working pressure was determined by the capacity of the ring blower and the amount of pressure required by the generator to supply the appliance, machines and others that needed electricity.

Method of determining scrubbing time

The scrubbing time was recorded from the time the raw biogas entered the system until the process was completed with an output of clean biogas on the gas dryer which was indicated by the pressure gauge.

Method of determining amount of water

The amount of water was determined by trial and error. Several water levels (25%, 50%, 75%) were tested and the water level with no water passing through the gas dryer, and resulted in the system's good performance, was chosen.

Methods of testing performance parameters

After establishing these parameters and achieving a successful trial test run, final gathering of data was conducted. During this stage, the performance of the biogas scrubber system was evaluated in terms of scrubber efficiency and percent increase of methane.

Method of determining the scrubber efficiency

Scrubber efficiency (SE) was determined by the ratio of the summation of the percentage composition of biogas contaminants before scrubbing minus the summation of percentage of composition of biogas after scrubbing to the summation of the percentage composition of biogas contaminants before scrubbing. The efficiency was computed using the equation:

$$\mathrm{SE} = \left[\frac{(\%\mathrm{CO_2} + \%\mathrm{N_2} + \%\mathrm{H_2S})_{\text{raw biogas}} - (\%\mathrm{CO_2} + \%\mathrm{N_2} + \%\mathrm{H_2S})_{\text{clean biogas}}}{(\%\mathrm{CO_2} + \%\mathrm{N_2} + \%\mathrm{H_2S})_{\text{raw biogas}}}\right] \times 100$$

Method of determining the percent increase of methane.

The percent increase of methane was determined by the ratio of the difference of the percent methane of clean biogas and raw biogas to that of percent CH_4 of raw biogas. In equation form:

$$\%\ \text{increase} = \left[\frac{(\%CH_4)_{clean\ biogas} - (\%CH_4)_{raw\ biogas}}{(\%CH_4)_{raw\ biogas}}\right] \times 100$$

The composition of the clean biogas that was used in the determination of the percent increase of methane and in calculating the scrubber efficiency was obtained through laboratory testing conducted by PIPAC.

3. RESULTS AND DISCUSSION

3.1 System components

Figure 1 shows the biogas scrubber system. The major components of the system are the body frame, ring blower, water pump, scrubber, stripper, flash tank, and dryer. The frame assembly was made from 1 ½" x 1 ½" x 1/8" angle bar. This serves as the foundation and base support for the whole system. A 1 hp ring blower with 60 Hertz, 220 voltages was used whose function is to regulate the flow of raw biogas that would enter the system. A 0.5 hp water pump installed in the system is used to pump the water that is used in the process. The scrubber is where the purification process happens. It has a length of 6.43 ft and diameter of 0.86 ft. The stripper used in the system has a length of 5.58 ft. and a diameter of 0.89 ft. This is where stripping or depressurizing with air occurs. The flash tank is installed adjacent to the water pump with a length of 1.8 ft and is used to filter the water during the process. The gas dryer installed in the system has a length of 2.53 ft and a diameter of 0.66 ft whose function is to absorb the moisture content of the purified biogas.

3.2 Results of preliminary testing

This section presents the results of preliminary testing regarding the composition of the raw biogas, the operating pressure, the scrubbing time, and the amount of water needed in the scrubber.

The established working pressure of the system is 4.6 psi. The scrubbing time is found to be 6. 243 seconds and the amount of water needed in the scrubber should be 25% to 50% of its volume. These established values were used in the final testing of the system.

3.3 Biogas composition

Table 1 presents the result of gas chromatography of raw biogas, or the biogas before the treatment process. It was analysed in terms of % CH_4, % CO_2, % N_2 and %H_2S.

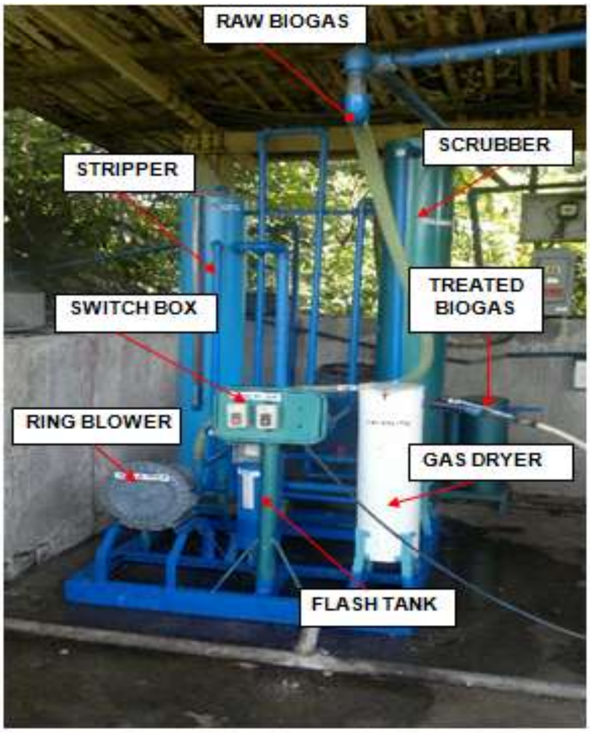

Figure 1. The biogas scrubber system.

Table 1. Biogas composition before treatment of biogas system.

Components	Percentage Composition (%)	Typical percentage composition (%)
CH_4	56.75	55-65
CO_2	30.1	30-45
N_2	3	0-10
H_2S	ND	0-3

*ND = Not Detected; minimum detectable amount for H_2S = 0.1%

The data show that the biogas produced from BA Gonzales Integrated Farm Builder contained 56.75 % CH_4, 30.1 % CO_2, 3 % N_2 and < 0.1 % H_2S. The raw biogas contained sufficient amount of methane. The result shows that the composition of the gathered biogas prior to treatment is comparable to the typical biogas percentage composition of 55 % - 65% CH_4, 30% - 45% CO_2, 0% - 10% N_2, and 0% - 3% H_2S. The results obtained from the Report of Analysis conducted by Philippine Institute of Pure and Applied Chemistry (PIPAC), are only from approximately 89.95 % of the total composition of biogas. The gap was due to the presence of other impurities not accounted in the analysis.

3.4 Working pressure

The working pressure was determined by installing a pressure gauge before the raw biogas entered the system and after the biogas passed through the gas dryer. Table 2 summarizes the pressure measured in the system and considered as the working pressure in different parts of the system. The working pressure of the system ranges from 4.6 psi to 14.7 psi. The system pressure and outlet gas pressure operates at 4.6 psi while the gas and liquid inlet pressure are at 8 psi and 14.7 psi, respectively.

3.5 Scrubbing time

The scrubbing time was determined by recording the time when the raw biogas entered the system until the process is completed with an output of clean biogas passing through the gas dryer. A pressure gauge was installed before and after the process to confirm that the biogas passed through the system. The scrubbing time obtained in the process is 6.24 $\pm$ 0.03 s. This scrubbing time indicates that the biogas can pass through the system and be cleaned in a short period of time.

3.6 Amount of water

The amount of water was determined using trial and error method. Different amount of water levels were used. The water was not allowed to pass through the gas dryer so that the water would not enter into the generator.

Results show that when the water level in the scrubber was 75% to 100%, too much water passed through the gas dryer while at 50% - 75%, some water passes through the gas dryer. When the water level was 0% to 25%, the amount of water was not sufficient to start the scrubbing process. On the other hand, when the water level was 25% to 50%, the system works properly and no water passed through the gas dryer. Thus, this was the best option and was used in the scrubbing process.

3.7 Results of final testing

After obtaining a successful test run, final testing and performance evaluation were conducted. Performance of the system was evaluated in terms of scrubbing efficiency and the percentage increase of the CH_4 component.

Table 2. Summary of the working pressure of biogas scrubber.

Operating Condition	Pressure (psi)
Inlet gas pressure	8
System pressure	4.6
Outlet gas pressure	4.6
Inlet liquid pressure	14.7

Scrubber efficiency was determined by the ratio of the summation of the percentage composition of contaminants of raw biogas minus the summation of the percentage of composition of contaminants of clean biogas to the summation of the percentage composition of contaminants of raw biogas. Table 3 shows the scrubber efficiency of the system. A scrubber efficiency of 68.67% was calculated. It can be noted from the results that CO_2 and N_2 reductions contributed to obtain the scrubber efficiency. H_2S, on the other hand, was not reduced during the process

To test the effectiveness of the developed prototype, the percentage increase of CH_4 was calculated. From the results of the analysis conducted by PIPAC, the percentage increase of CH_4 was 27.70 $\pm$ 2.05%, while the DOST Biogas Analyzer showed the percentage increase of methane was 26.11 $\pm$ 0.88%. There was a slight difference between the two samples using two different gas analyzers in terms of percentage composition of CH_4. The gap was due to the presence of other impurities not accounted in the analysis. Increase in the percentage of methane indicates the upgrading of the biogas.

4. CONCLUSIONS

During the development of the biogas scrubbing using water purification system and accompanying performance tests and laboratory tests, the composition of the raw biogas was found to be 56.75 % CH_4, 30.1 % CO_2, 1 % N_2 and less than 0.1 % H_2S. The biogas scrubber system is comprised mainly of the body frame, ring blower, water pump, scrubber, stripper, flash tank, and dryer. The scrubber and stripper are made of polyvinyl chloride (PVC). The inlet gas pressure was 8 psi, the system and outlet gas pressure was 4.6 psi, and the inlet liquid pressure was 14.7 psi. The recorded time of scrubbing has an average of 6.243 seconds. The amount of water in the scrubber has a range of 25 to 50 percent of the scrubber volume. The treated biogas was composed of 72.45 % CH_4, 10.2 % CO_2, traces of N_2, and H_2S was not detected. The average percent increase of CH_4 analyzed by PIPAC and by DOST Biogas Analyzer was 27.70 $\pm$ 2.05% and 26.11 $\pm$ 0.88%, respectively. The scrubber efficiency is 68.67 %.

Table 3. Results of determining the scrubber efficiency.

Contaminants	Raw (%)	Clean (%)	Efficiency
CO_2	30.1	10.2	
N_2	3.0	0.1	
H_2S	0.1	0.1	
Total	33.2	10.4	68.67%

5. RECOMMENDATIONS

Based on the findings, the authors recommend the conduct of further studies and consultation with experts to improve the efficiency of the biogas scrubbing system. Automation of the operation of the system may also be employed to minimize human intervention and for safety purposes.

6. ACKNOWLEDGEMENT

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