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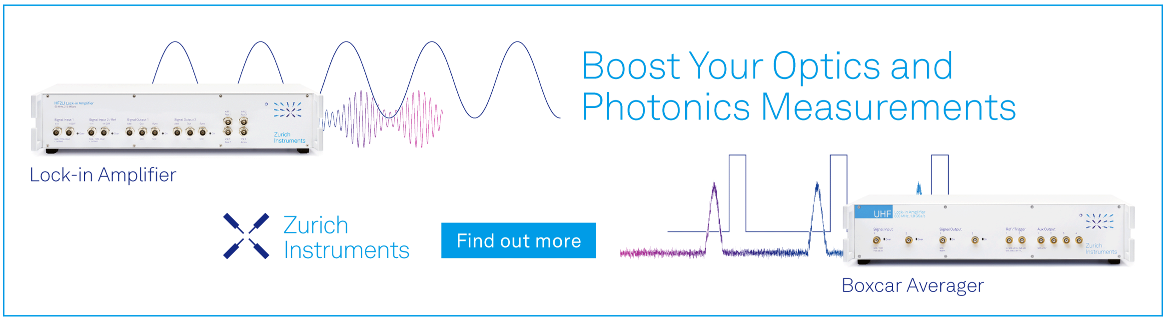

Development of a Low-Cost Biogas Filtration System to Achieve Higher-Power Efficient AC Generator

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Abstract. The paper focuses on the development of a low-cost biogas filtration system for alternating current generator to achieve higher efficiency in terms of power production. A raw biogas energy comprises of 57% combustible element and 43% non-combustible elements containing carbon dioxide (36%), water vapor (5%), hydrogen sulfide (0.5%), nitrogen (1%), oxygen (0 – 2%), and ammonia (0 – 1%). The filtration system composes of six stages: stage 1 is the water scrubber filter intended to remove the carbon dioxide and traces of hydrogen sulfide; stage 2 is the silica gel filter intended to reduce the water vapor; stage 3 is the iron sponge filter intended to remove the remaining hydrogen sulfide; stage 4 is the sodium hydroxide solution filter intended to remove the elemental sulfur formed during the interaction of the hydrogen sulfide and the iron sponge and for further removal of carbon dioxide; stage 5 is the silica gel filter intended to further eliminate the water vapor gained in stage 4; and, stage 6 is the activated carbon filter intended to remove the carbon dioxide. The filtration system was able to lower the non-combustible elements by 72% and thus, increasing the combustible element by 54.38%. The unfiltered biogas is capable of generating 16.3 kW while the filtered biogas is capable of generating 18.6 kW. The increased in methane concentration resulted to 14.11% increase in the power output. The outcome resulted to better engine performance in the generation of electricity.

INTRODUCTION

Energy is a necessary demand for further economic progress and in providing a standard vitality for the community. Due to the fast increment depletion of energy in industry and in commercial in the recent years, a big deficiency on the currently used resources such as the natural gas, fossil fuels, coal and crude oil are now prevailing. Thus, the need for searching possible substitute resources of energy is now very active [1-2].

Renewable energy systems are considered as a favorable key that plays an essential part in solving the issue on sustainable resources as it provides clean and efficient power as it electrifies considerable extent of population [3-4]. Energy sources that are considered renewables are those that are naturally and continually refilled by nature such as solar, hydro, wind and biogas and are very environment-friendly due to the fact that these resources produce no carbon emissions.

One considerably promising renewable energy is the biogas, and this is obtained from various biomass substrates being animal manure, municipal waste, wheat straw and food waste through biochemical process called anaerobic digestion (AD) [3, 5]. Anaerobic digestion is a process involving the absence of oxygen on the organic substances [3]. Biogas is one example of the concept of Waste-to-Energy that is now currently being studied globally as an effort to make renewable energy as replacement to expensive fuels and provide compensation on the increasing demand in energy. Generating electricity from biogas requires an upgraded and quality methane gas and it can be

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achieved through several stages of filtration to remove unwanted gases. Methane is the principal element of the biogas concentration that should be high and significant in concentration. This paper covered the different experimentations conducted where the main objective was to construct a low-cost biogas filtration system to achieve higher power efficient AC generator.

The study focuses on a low-cost filtration system for the elimination of the main contaminants or so-called the non-combustible gases such as the carbon dioxide, hydrogen sulfide, and water vapor. This filtration allows the increase of methane present in the composition that leads to a higher power efficient AC generator. The system makes use of cost-effective materials to construct a favorable filtration system.

Water scrubber is one filtration system that may be used to remove carbon dioxide and hydrogen sulfide traces as these are more soluble in water than methane. Silica gel is another filter that has a good ability of absorbing water vapor. Sodium hydroxide is another filter best in removing elemental sulfur and suppressing considerable quantity of carbon dioxide. Iron sponge was used for the elimination of hydrogen sulfide. And, activated carbon may be used for further reduction of carbon dioxide.

BIOGAS COMPOSITION ASSESSMENT

Raw biogas energy contains several different types of gases and may vary depending on the biomass waste used. The use of a methane gas analyzer concluded the two major constituents of the biogas, these are the combustible methane sites (57%) and 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%) [2-3, 6-7].

Carbon dioxide causes greenhouse effect and has a negative effect on human health. Hydrogen sulfide (H_2S) is odorous, toxic and the cause of corrosion in the system. H_2S will increase the possibility of various operational problems in engines, turbines, compressor, etc. Also, water vapour (H_2O) causes corrosion in the system and would react with other gases [10-11].

Methane is a compound of hydrocarbon and carbon elements. Since carbon compounds are interlinked with each other, the reduction percentage of one gas is the increase of another [1, 8]. Hence, the superior presence of non-combustible elements in the biogas composition leads to the reduction of electric power yield. Biogas comprises of a large percentage of unfavourable impurities that threaten the electric power yield and restricts its compression ability and offers a mechanical damage on the system. Indeed, it is essential to implement the several methods on cleaning, filtering, and upgrading the biogas through the separation and elimination of contaminants [7, 9].

DESIGN OF FILTRATION SYSTEM

This filtration system consists of six stages for raw biogas purification. The raw biogas enters its first filtration, which is the water scrubber for the removal of CO_2 and trace of H_2S. The second and fifth stages are filled with silica gel, this substance has a very effective characteristic of absorbing water vapor. The third stage is for further elimination of H_2S, the filter is filled with iron sponge. Fourth stage is designed for the removal of elemental sulfur that is formed after the H_2S and iron sponge got in contact and the removal of CO_2 as well, this is filled with the solution of sodium hydroxide and water. The last filtration contains activated carbon and designed for further elimination of CO_2 and trace of H_2S. Figure 1 shows the six stages of the designed filtration system together with its components and dimensions.

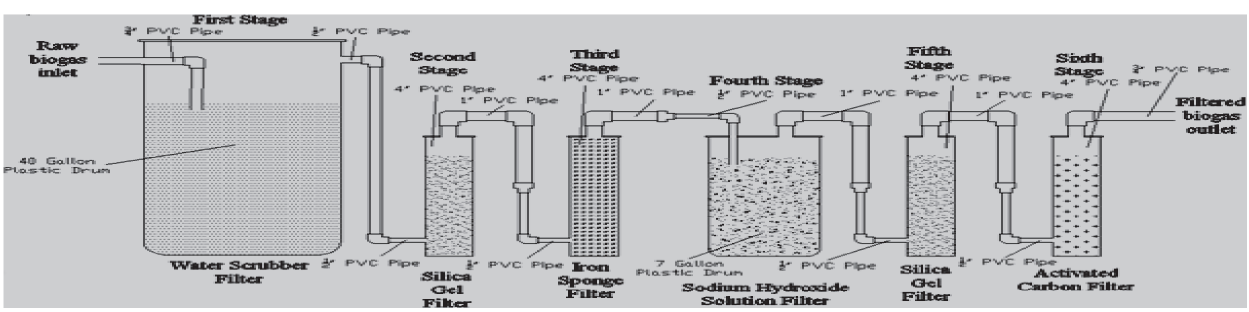

FIGURE 1. Biogas filtration system

Water Scrubber Filter

Greater concentration of CO_2 in the biogas composition decreases the heating rate of the gas, restricting economic possibility to consumption, drop the power production and could be source of corrosion on the pipelines and engines [7, 9]. In [7], water scrubbing is the cheapest and simplest method of upgrading the biogas. This method involves the substantial adsorption of CO_2 and a quantity of H_2S.

The first stage of the filtration system was the carbon dioxide filtration using water scrubber. A 40-gallon container was used. The PVC inlet was installed on the left side of the container and one-inch of it was submerged in water to allow the gas to bubble and leave the CO_2 in the water. The PVC outlet was installed on the other side of the drum utilizing one-half inch PVC pipe intended to increase the pressure of the biogas flow. The amount of water used was 30 gallons covering three-fourth of the total volume of the drum.

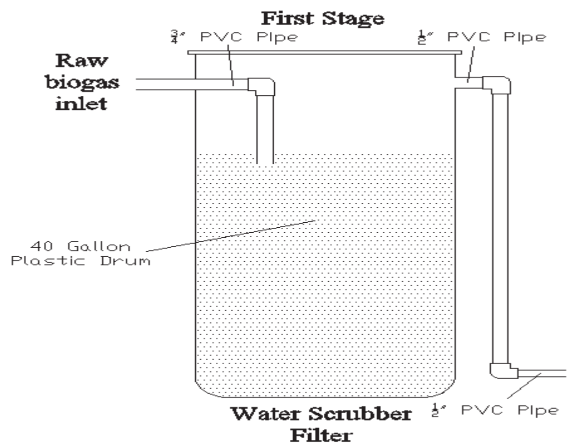

FIGURE 2. Design of water scrubber filter

Silica Gel Filter

Biogas is indeed constituted with water vapor since it is driven from solid or liquid fractions with high moisture concentration. Temperature and pressure plays an important factor on the measurable amount of water vapor. Even though water vapor sites a small percentage of the raw biogas, this cannot be neglected as it is considered to be contaminant of the system. Several methods are applied in treating raw biogas [10].

The silica gel filter was used twice in the system and was placed after the water scrubber and sodium hydroxide solution filters. The filter executed the chemical drying method in its basic way which is the adsorption. Each container rising to 23.5-inch and 4-inch in diameter was filled with 2 kilos of silica gel which reaches to around three-fourth of its total volume.

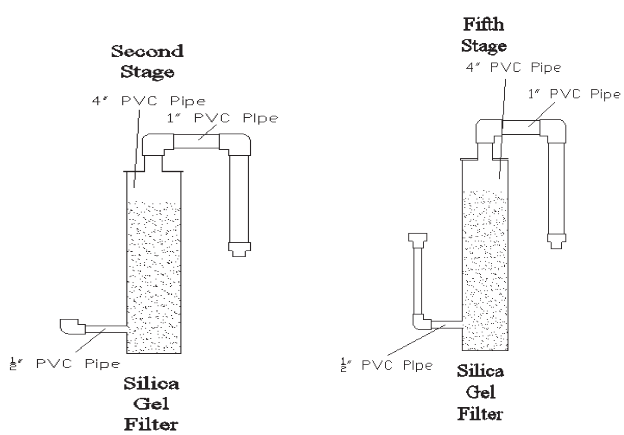

FIGURE 3. Design of silica gel filter

Iron Sponge Filter

In [11], one of the unwanted gases that make up raw biogas is the hydrogen sulfide and must be eliminated due to its corrosiveness and toxicity. Equipment damage, environment and user hazard is possible if hydrogen sulfide is still present when biogas is burned. Also, this produces sulfur dioxide, which is very hazardous to the environment. In this study, the method used to eliminate the hydrogen sulfide from the raw biogas was the dry oxidation process in which the use of iron oxide was implemented. The iron oxide used was in the form of iron sponge or steel wool and was placed after the silica gel filtration column to counteract the rusting of the iron sponge. The hydrogen sulfide filter was a cylindrical plastic container, 23.5-inch in height and 4-inch in diameter. On the inlet, a PVC pipe of one-half inch in diameter was used and was positioned at the bottom of the column. The outlet used a 1-inch in diameter and was fitted at the top of the column. The whole container was filled with iron sponges.

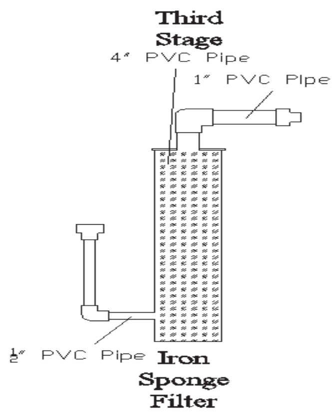

FIGURE 4. Design of iron sponge filter

Sodium Hydroxide Solution Filter

Whenever the untreated biogas gets in contact with iron materials, iron oxide is formed into elemental sulfur. The fourth stage was designed to remove the formed elemental sulfur and carbon dioxide from biogas by the use of a water and NaOH. The biogas will enter from the top of the column containing the NaOH solution and allowed to bubble and as a result, the formed elemental sulfur and carbon dioxide are removed. This process involves the base and the acid compounds. Water acts as the base and NaOH as the strong acid. When water is mixed with NaOH, a vast quantity of heat is made because of exothermic reaction. The raw biogas can only pass the solution when heat has vanished.

The fourth stage of the filtration system uses a seven-gallon container with an inlet pipe of ½-inch in diameter and an outlet pipe of 1-inch in diameter, both are located on top. The container contains a solution of 10 liters of water and 900 grams of sodium hydroxide pellets. Figure 5 shows the design of the sodium hydroxide solution filter.

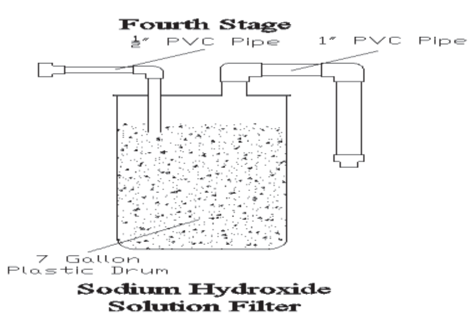

FIGURE 5. Design of sodium hydroxide solution filter

Activated Carbon Filter

The last stage of the filtration system was the activated carbon filter. Activated carbon is commonly known for its CO_2 and H_2S removal ability. This was placed after the silica gel filter since this must not be exposed in wet state and too much hydrogen sulfide concentration. Figure 6 shows the design of the activated carbon filter. The filter is a PVC pipe, 27.5-inch in height and 4-inch in diameter. On the inlet, a PVC pipe of ¾-inch in diameter was used and was positioned at the bottom of the column, while the outlet used a 1-inch in diameter and was fitted at the top of the column. The amount of activated carbon covered the total volume of the filter.

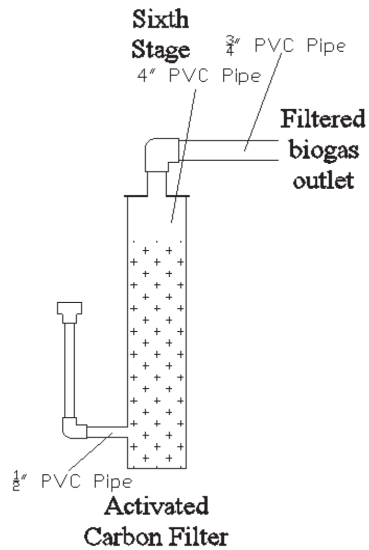

FIGURE 6. Design of the activated carbon filter

EVALUATION OF THE FILTRATION SYSTEM

The evaluation was conducted to monitor the efficiency of the constructed filtration system. Table 1 displays the outcome of the evaluation on methane concentration for untreated and treated biogas. The result showed that the design was effective in reducing the concentration of the unwanted gases. The methane completes the 57% of the total raw biogas composition before filtration to 88% after filtration system. The system was able to eliminate 72% of the non-combustible constituents.

TABLE 1. Evaluation of the methane content

Biogas	Biogas Flow Rate (Nm^3/sec)	Methane Content (%)	Methane Flow Rate (Nm^3/sec)
Unfiltered	5.6%	57%	3.65%
Filtered	5.13%	88%	4.7%
72% elimination of non-combustible constituents			

Evaluation of the Electrical Performance of the AC Generator

Table 2 shows the evaluation of the electrical performance of the 20kW-AC generator whose parameter is the general power output of the generator in kilowatt using the unfiltered biogas and the filtered biogas. Considering the unfiltered biogas as fuel for the generator, the average power output was 16.3 kilowatts. The filtered biogas, as fuel for the generator, was able to produce an average power output of 18.6 kilowatts. There was an increase of 14.11% in the generation of the power output. The generator became 91.5% efficient using the filtered biogas system. The result clearly shows the effectiveness of the filtration system if the generated power output is to be considered.

TABLE 2. Evaluation of the electrical performance of the AC generator

Biogas	Average Generator Power Output (using 20kW AC Generator)
Unfiltered	16.3 kW
Filtered	18.6 kW
14.11 % increase in the generation of the power output	

Cost Analysis

The materials used to construct the filtration system were matched to the strategic technologies that are readily available in the market to verify that the designed structure is low-cost and efficient. Table 3 illustrates the comparison of the total cost consumed in the construction of the design filtration system to the available filtration system in the market.

The total amount consumed in the design and construction of the filtration system, making use of all materials available like the PVC pipe and container was PhP 20,000.00. One available filtration system in the market is the Camda China Biogas Upgrading System and this cost to about PhP 50,000.00 to PhP 500,000.00. Another biogas filtration system available in the market is the KDCL-50 series Biogas Purifying System and this costs to about PhP 290,000.00 to PhP 750,000.00. The discrepancy in the total cost clearly shows that the developed filtration system is very low cost versus those that are available in the market.

TABLE 3. Cost analysis

Filtration System	Actual Price (PhP)
Developed Filtration System	PhP 20,000.00
Camda China Biogas Upgrading	Php 50,000.00 to Php 500,000.00
KDCL-50 series Biogas Purifying System	PhP 290,000.00 to PhP 750,000.00

CONCLUSION

To achieve better performance of AC generator using methane as its fuel, it is essential to incorporate a filtration system to its. A raw biogas comprises of 57% concentration of the non-combustible elements and only 43% of the combustible methane element. With the integration of the developed filtration system, intended to eliminate the traces of the unwanted gases and to increase the methane concentration, the system was able to reduce these unwanted gases by 72% and thus, increasing the methane concentration to 54.38%. The increased in the methane concentration resulted to the increased of the methane flow rate and was able to eliminate the high corrosive elements that may cause damage to the generator. The increased also resulted to the 14.11% increase in the power output of the generator.

The behaviour clearly shows the dependency of the power output of the generator to the methane concentration and flow rate of the methane to the generator. Thus, the constructed filtration system performed a very convincing result.

The comparison of the total cost consumed in the design and development of the system versus the entire biogas filter available in the market shows a big difference in the cost. The discrepancy clearly shows the low-cost characteristics of the developed system. Overall, the developed filtration system was able to meet all the objectives of the study.

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