Adaptation of a Gasoline-Fueled Conventional Engine into a Purified Biogas-Fueled Engine for Power Generation

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Abstract

A Kubota AE3500 spark ignition engine was modified for a purified biogas operation. Provision was done for the inlet of the purified biogas, adjustment of the spark plug gap setting and assessment of the ignition timing. The purification process of the biogas was also done by attaching two-drum purification system arranged in series into an existing semi-continuous biogas digester. One drum is for the removal of CO_2 and the other for removal of H_2S. The purified biogas-fueled engine was tested for smoothness in operation, overall thermal efficiency and specific fuel consumption. Tests were conducted at different loads, rpm, fuel inlet pressure and air fuel ratio. Gas analyses at the inlet and exhaust were conducted in every experimental run. Results indicate that with proper engine modification and biogas purification, a purified biogas is a very good engine fuel alternative.

Keywords: biogas, alternative fuel, biogas purification, conventional engine modification

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The consistent increases in fossil fuel usage in the past has made alternative energy sourcing an important concern of the world today. Otherwise, it is only a matter of time before fossil fuel reserves run out. In the Philippines, this concern is partly addressed through the Engineering Research and Development for Technology (ERDT) scholarship program where MSU-IIT is a delivering institution. This paper is a requirement in a form of a thesis on renewable or alternative energy of this program.

The use of renewable energies like biogas requires the development of new designs or the modification of existing ones. This thesis is an example of the latter. This work is an adaptation of a gasoline-fueled Kubota AE3500 spark ignition engine that would allow its operation to work with biogas, that involves modification of engine parts. Prompted by the study of Aquino (2010) which produced raw biogas from hog wastes through a designed digester, this study seeks to purify the produced biogas to fuel a modified and adjusted chosen engine to enable it to generate power.

The biogas technology has been steadily developed within the last fifty years from small individually-designed units to industrial plants with sophisticated boundary technology. The development, however, has largely taken place only on the side of biogas production and anaerobic waste treatment. The utilization of the biogas has just recently been given more attention as larger and more sophisticated biogas systems require or depend on a sensible utilization of the larger gas quantities. In this study however, utilization of biogas in adapting the SI engine into a biogas-driven engine is not intended for a large-scale use but only for household utilities such as for lighting domestic fuels for burners used in kitchen and other appliances or backyard farming utilization like small water pumps for small farm irrigation.

Objectives of the Study

This study aims to achieve the following objectives:

1. To purify the produced raw biogas to improve its fuel value.
2. To determine what possible engine modification and/or adjustments should be done in order to allow engine operation work with biogas fuel.

3. To compare the performance and determine attendant factors of performance of the chosen SI engine before modification (baseline performance on gasoline) and after modification (performance on biogas) in terms of the usual parameters of efficient engine performance.
4. Based on the determined factors, to present recommendations for better engine performance (efficiency) on purified biogas fuel.

Methodology

Purification of Produced Biogas

In this study, the produced biogas from the study of Aquino (2010) was utilized. His digester is a semi-continuous flow type which allows the feeding of organic matter and its removal once digested, thus in turn allows a continuous supply of biogas.

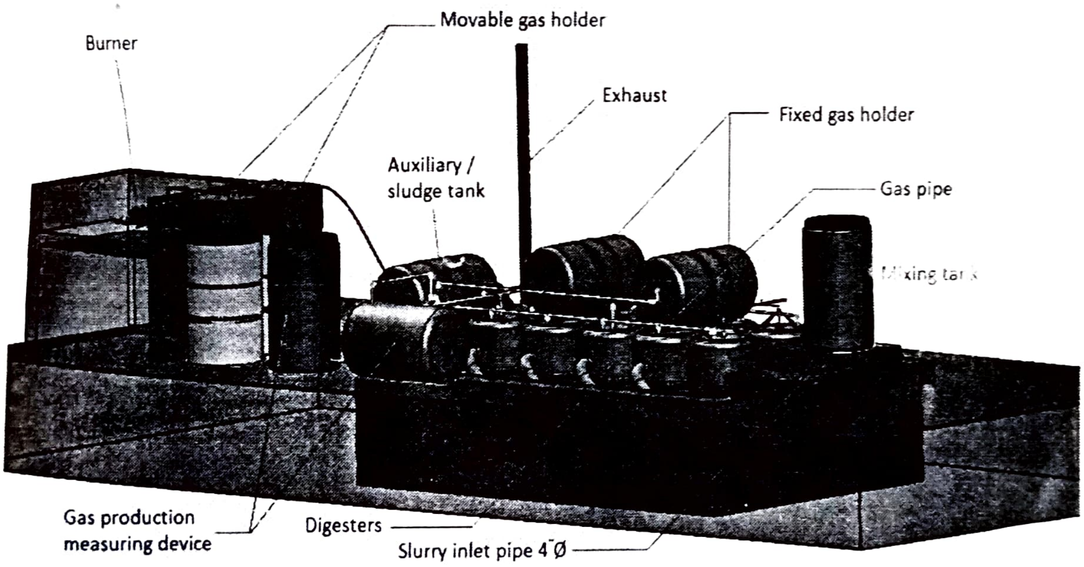

Figure 1. Sectional View of a Semi-Continuous Type of Aquino's Digester.

Installation of CO_2 Scrubber Tank (Drum 1)

The CO_2 may be scrubbed off the biogas by the use of a carbon dioxide scrubber. It consists of a tank with stirrers to evenly mix the lime with the water inside the tank. When the biogas from the digester bubbles through the limewater, the CO_2 component is absorbed. The residue may be removed from the bottom and may be used as potash fertilizer or soil conditioner.

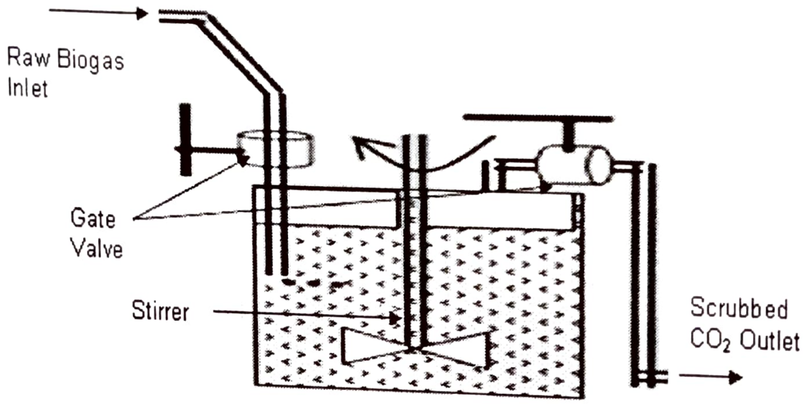

Figure 2. CO_2 Scrubber Tank (Drum 1)

Installation of H_2S Scrubber Tank (Drum 2)

A practical way to remove the H_2S is by passing the biogas through iron fillings in an enclosed container. Hydrogen sulfide is very corrosive and may even cause the embrittlement of metal; hence, it is essential that it be removed from the biogas.

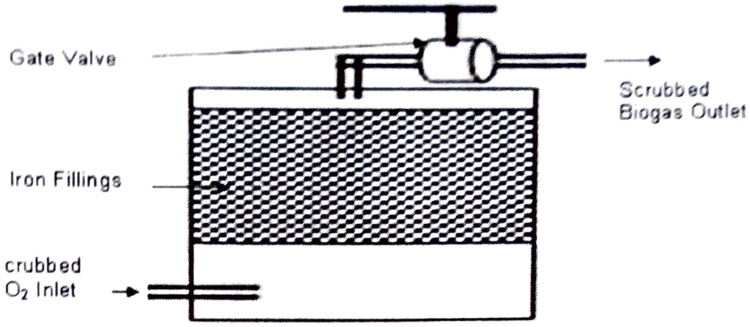

Figure 3. H_2S Scrubber Tank (Drum 2)

Installation of Gas Tank Storage Holders (Drums 3a and Drum 3b)

These two gas tank holders shall serve as the storage of a maximum of 0.4 m^3 of produced purified biogas from the digester.

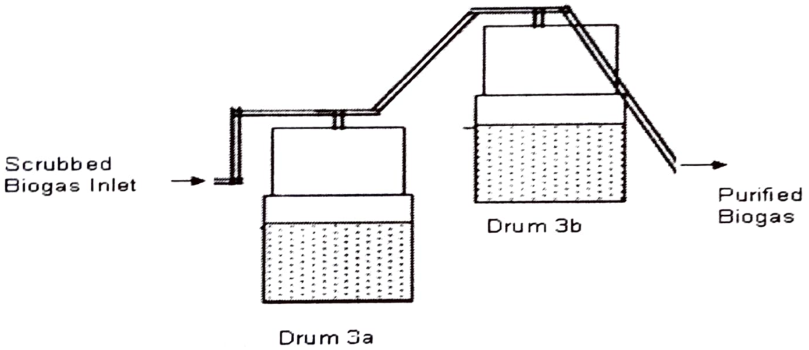

Figure 4. Gas Tank Storage Holders (Drums 3a and 3b)

Appropriate Modification

Appropriate modifications of the chosen engine and adjustments of the spark plug gap setting are necessary in order to allow its operation work with biogas fuel.

Modification of the fibra spacer of the chosen engine involves abricating a new and stronger fibra spacer with provision for biogas inlet as shown in Figure 5.

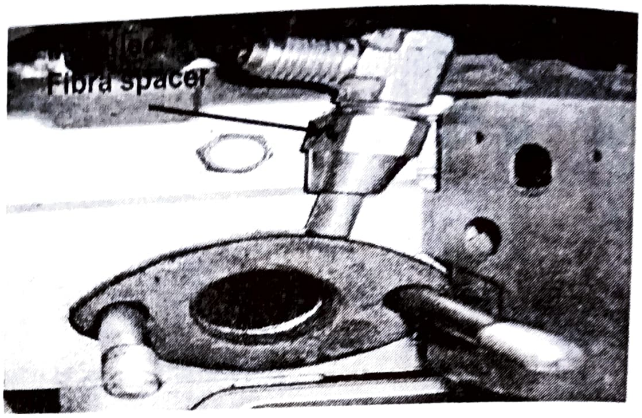

Figure 5. Modified Fibra Spacer

Adjustment of the Spark Plug Gap Setting

Adjustment of the spark plug gap settings is also necessary to ensure that the engine would run properly.

The manufacturer's manual on gasoline fuel spark ignition Kubota engine carries with it a 0.6 mm spark plug gap setting. However, the same engine on biogas fueling requires a higher spark plug gap setting because of the high octane rating of biogas, which needs a longer ignition time (http://www.powerarc.com/sparkplug.htm).

Ignition Timing Assessment

The natural characteristics of biogas having only 60.5% methane, and 35% CO_2 contents and traces of other components would cause delay in ignition. Thus, there is a need to assess the original ignition timing for biogas fueling.

Power Output Measurement

The power output from the engine is monitored through the built-in input of the generator.

The output of voltage, current and rpm are factors to calculate the power output of the generator set.

Comparative Performance

Existing standards are used in profiling comparative performance, of the chosen SI engine before modification (baseline performance on gasoline) and after modification (performance on biogas) in terms of smoothness in operation, overall thermal efficiency, and specific fuel consumption.

Factors that Account for the Difference in Performance

Data on the efficiency of engine performance were gathered from literature review (Maramba, 1978; Kapadia, 2006; Mitzlaff, 1988; Tambong, 1992; Souza, 2006 and Gupta, 1996) and from actual experience during experimentation for this paper.

Results and Discussions

Purification of the Produced Raw Biogas

Operating a conventional gas-driven engine with a biogas fuel initially requires purification of produced biogas to obtain a quality of biogas fuel suitable to run an engine. Hence, the first activity done was to purify the produced biogas of Aquino (2010) to be utilized as engine fuel for this study. Figure 6 shows this purification process and Figure 6a shows its result.

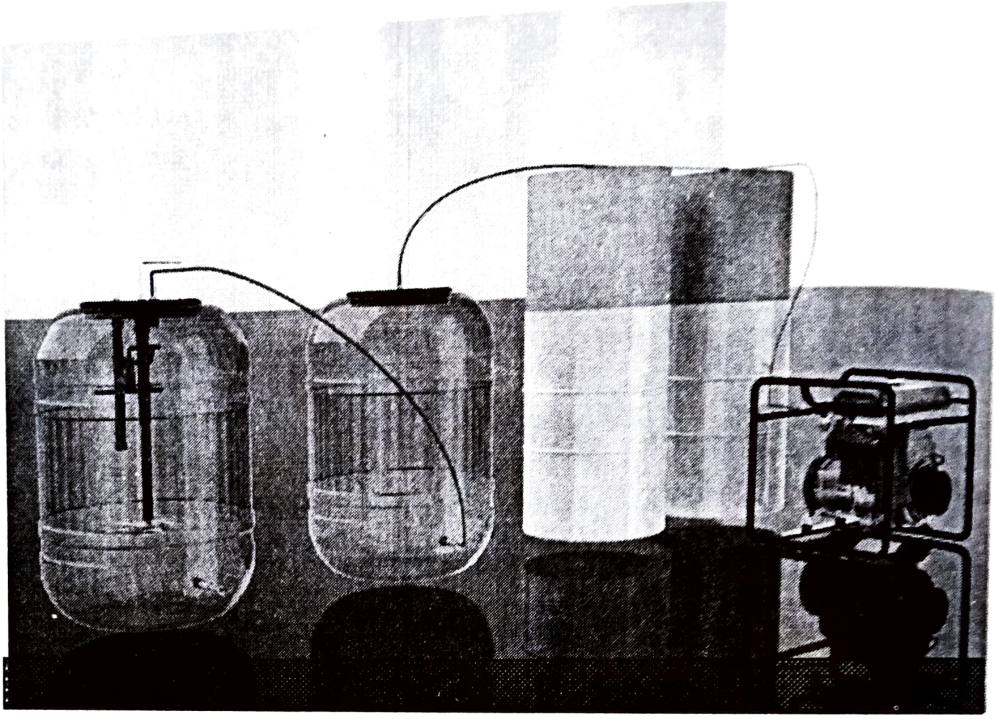

Figure 6. A Photo of the Actual Purification System Consists of the Drum A (CO_2 scrubber), Drum B (H_2S Scrubber), Gas Holders (Drums 3a and 3b) and Engine.

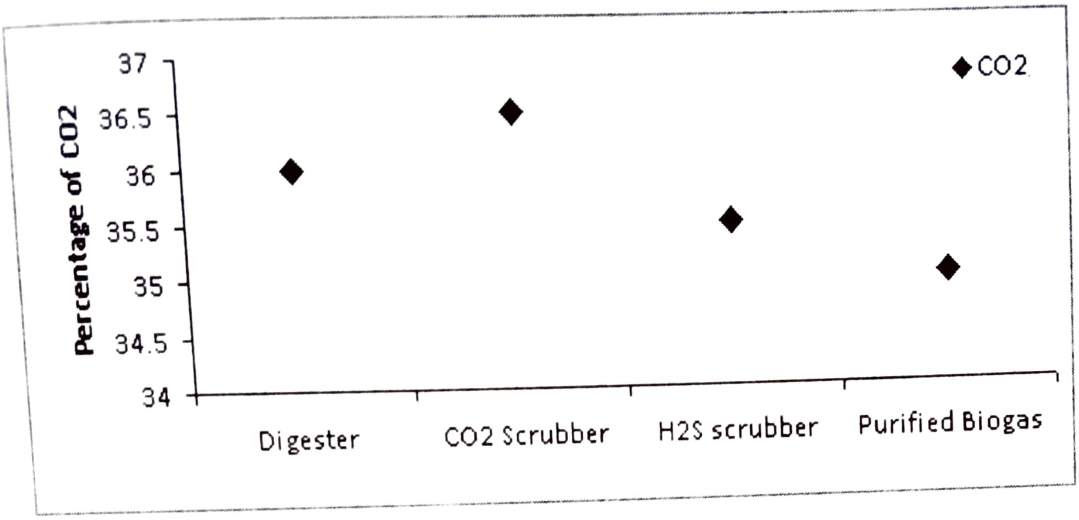

Figure 6.a. Decrease of CO_2 Content during Purification

Decrease of CO_2 content during purification result is unexpected and seems to negate the findings of B. Z. Shakhashiri (1983) because normally CO_2 content should be decreasing after scrubbing. The rather increasing trend in this study could be because the other components of the raw biogas such as the O_2, CO and H_2S have been either reduced or totally eliminated as they may have been absorbed in the process of subjecting the raw biogas to the CO_2 scrubber. However, there is already a decreased amount of CO_2 scrubber output in the H_2S scrubber and in the gas holder stage. This is expected because even if the H_2S scrubber is intended to reduce or eliminate only the H_2S content, it also reduced or eliminated the CO_2 content.

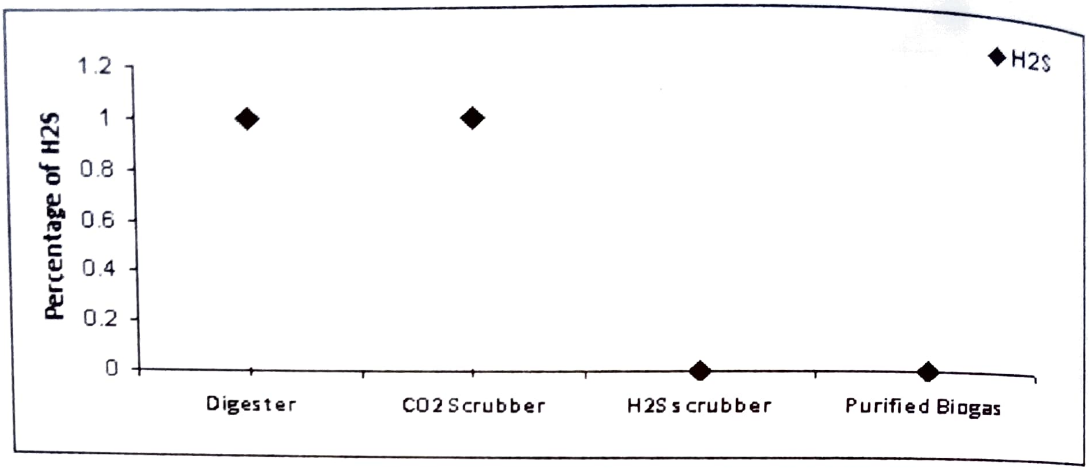

Figure 6.b. Decrease of H_2S Content during Purification

The other purification process done was through the use of the H_2S scrubber. This H_2S content is highly corrosive and must be reduced or completely removed from the biogas fuel to increase the life span of the used engine.

After subjecting the output biogas from the CO_2 scrubber to H_2S scrubber, a zero H_2S content yield was obtained (Figure 6.b).

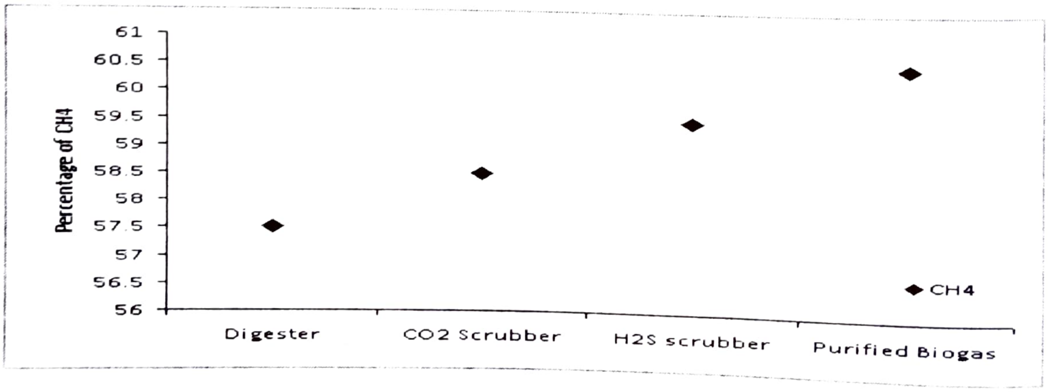

Figure 6.c Methane Content during Purification Process

Methane content during purification process at the digester stage, methane content of raw biogas is 57.5%. After passing through the CO_2 scrubber the percentage of methane content increased to 58.5%. In the

H_2S scrubber stage, methane further increased to 59.5%, until a level of 60.5% was reached at the gas holder stage.

The produced purified biogas is therefore free of H_2S and has 60.5% methane content ready for utilization as fuel for the chosen engine in this study. The yield is then stored inside the two gas holders. Each holds a maximum capacity of 0.2 m^3 of purified biogas.

Modification and Adjustment of the Chosen Kubota AE3500 with Built-in Generating Set

While it is possible to run a gasoline-fueled engine with an alternative biogas fuel, appropriate modification of the engine and necessary adjustments of the spark plug gap setting should be done to set the engine suitable for biogas operation (Kapadia, 2004; Souza, 2006).

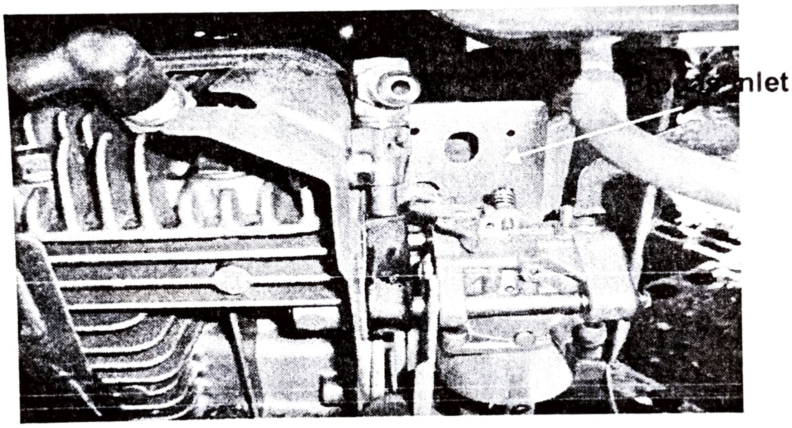

Figure 7. Modified Fibra Spacer of a Kubota AE3500 Engine with Built-in Generating Set

a. Modification

To allow the chosen engine work with purified biogas fuel the fibra spacer of the engine was modified for this purpose (Figure 7). The original fibra spacer was replaced with a fabricated one having a 7.0 mm hole bored at the middle top portion of spacer. This design is to accommodate the 6 mm inside diameter inlet tube of the purified biogas stored in the gas holder. This allows the biogas fuel to pass through at the right time of need after engine start up with gasoline.

Adjustment of the Spark Plug Gap Setting

There is also a need to adjust the spark plug gap setting of the engine, given a 60.5% methane content of the produced purified biogas and given a computed compression ratio of 5.539 of the Kubota engine used in this study.

As a step towards providing efficient biogas utilization as fuel in operating an engine, literature suggests that the compression ratio should be below the range of 10-12 to avoid engine knock (Mitzlaff, 1988).

The manufacturers suggest the use of cooler plugs for gaseous fuels such as biogas, however, Jewell, W. J., et al. (1986) recommends the use of a hotter plug for biogas. He declares that spark gaps between 0.017 and 0.030 inch proved to be adequate with no noticeable difference in performance within this range. Similarly, Walsh et al. (1988) used Champion J-6 spark plugs with a spark gap of 0.025 inch with good performance and service intervals above 1000 hours.

Hence, during the actual experimentation for this paper, three replicate adjustments of the sparkplug gap setting were done (Table 1).

Table 1. Adjustment of Spark Plug Gap Setting

Spark Plug Gap Settings	Status of Engine Start-up
0.5 mm (0.020”)	Engine start, but weak
0.6 mm (0.025”)	Engine starts better, but still lacks power
0.7 mm (0.027”)	Engine starts well. Produces needed power.

Ignition Timing

After careful assessment and with the given different load conditions of without load, 500 watts, 1,000 watts, and 1,500 watts, the original ignition timing was maintained instead of adjusting it for biogas fueling. This is because the engine worked well during trials. In addition, the original timing had to be maintained to avoid the complexities that would be incurred in returning back from biogas to gasoline fueling as soon as the engine is stopped.

Power Output Measurement

Inlet pressure should first be determined to measure the power output of the engine.

Table 2. Comparative Inlet Pressure on Engine at Different Conditions

Different Engine Conditions	RPM at Different Inlet Pressure on Engine		
	4.5 cm of H_20	5.5 cm of H_20	9.5 cm of H_20
Idling	775.13	1467:43	1724.57
w/o load	3672.90	3633.34	3623.45
w/ 500W load	3643.23	3603.67	3623.45
w/ 1000W load	3613.56	3524.55	3603.67
w/ 1500W load	3524.55	3405.87	3554.22

The 9.5 cm of H_20 pressure inlet for biogas was chosen for this study. Results (Table 2) show that with the inlet initial test pressures of 4.5 cm of H_2O and 7.5 cm of H_2O, rpm trouble occurred at lower pressure. When the gas holder was half full, a little adjustment to the gate valve was necessary to correspond to the gas requirement input of the engine. With additional pressure at a 9.5 cm of H_2O, rpm normalized. Here, the engine did not have to exert additional effort in sucking the biogas from the gas holder.

The yield purified biogas of 0.2 m^3 stock in each of the two gas holders could run the chosen engine 11.70 mins at an average volume flow rate of 0.000570 m^3/s at 1500 watts load.

Having modified the fibra spacer, adjusted the spark plug gap setting, assessed the ignition timing, and determined the inlet pressure, the chosen Kubota AE3500 engine with built-in generator is now set for baseline performance profiling at 0.7mm gap setting and at 9.5 cm of H_2O inlet pressure at a 60.5% Methane purified biogas fuel.

Operation of Kubota Engine in 60.5% Purified Biogas Fuel

The yield of purified biogas with 60.5% methane content was used to operate the chosen engine through this following procedure.

Initial start up of engine was done using gasoline. As soon as engine started well, the gasoline valve was quickly closed to accommodate the biogas fuel replacement. However, the biogas inlet was opened only soon after the gasoline in the reservoir was used up to avoid the mixture of fuels. When engine start up stalled, the biogas fuel inlet was gradually opened at the same time slowly closing the throttle valve so that the engine will not stop while waiting for rpm to stabilize.

In the case of start-up failure, initial step was repeated. When successful, adjustments were done with the accelerator and with the throttle valve to reach at a desired air/fuel ratio.

To increase rpm, without load corresponding adjustment in the biogas inlet and in the throttle valve was done, in such a way that throttle valve was almost closed to allow efficient biogas flow for sustained engine start. For further load increase, adjustment of biogas inlet was continuously done until rpm stabilized.

As maximum load of 1500 watts was applied, biogas inlet valve was gradually closed while slowing down the accelerator maintaining a stable rpm. At this point, the gasoline gate valve was gradually opened to make the engine run back on gasoline fuel again. By the time, rpm stabilized on gasoline fuel, the biogas gate valve was slowly closed. Rpm of gasoline was allowed to stay for a few minutes before finally shutting the engine off to exhaust residues of biogas inside the combustion chamber of the engine to avoid rust.

Comparative Baseline Performance Profile

For comparative performance profile, the baseline performance of the chosen engine run with gasoline is recorded in comparison with the biogas fuel.

The Orsat Gas Analyzer was used to get the baseline performance of the Kubota AE3500 engine in all identified parameters using gasoline as fuel. This data served as basis for obtaining the comparative performance of the same engine when fueled with biogas as shown in Figure 8 and corresponding figures.

Equivalence Ratio:

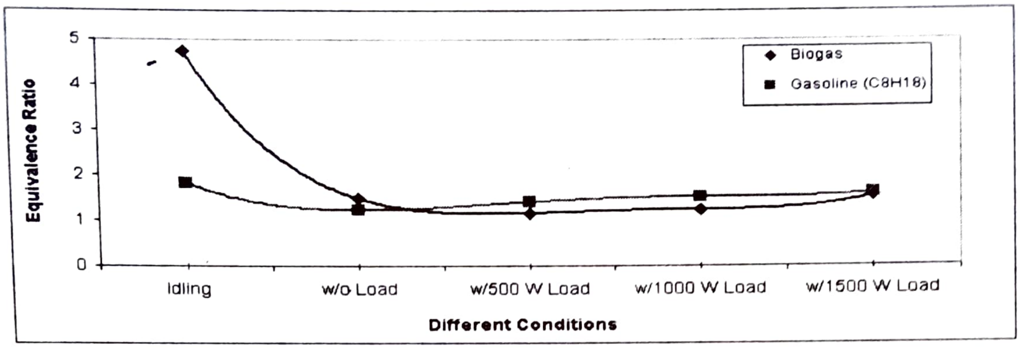

Figure 8a. Comparative Engine Performance in Purified Biogas Fuel at 9.5 cm. of H_2O Inlet Pressure and Gasoline Fuel in Terms of Equivalence Ratio

The figure shows variation of equivalence ratio from idling mode of engine to without load and to different loads. There is a decreasing pattern from idling state to full rpm without load. When subjected to increasing load, there is an increasing pattern of equivalence ratio for both gasoline and biogas fuels.

This result conforms to the result of Kapadia, 2004 which reports that manual control of the operating air-fuel ratio was done so as to maintain the speed of the engine close to 3000 rpm. It was observed that the engine could be operated in a very narrow band of equivalence ratios. Operation at richer ratios could not be achieved.

Calorific Value:

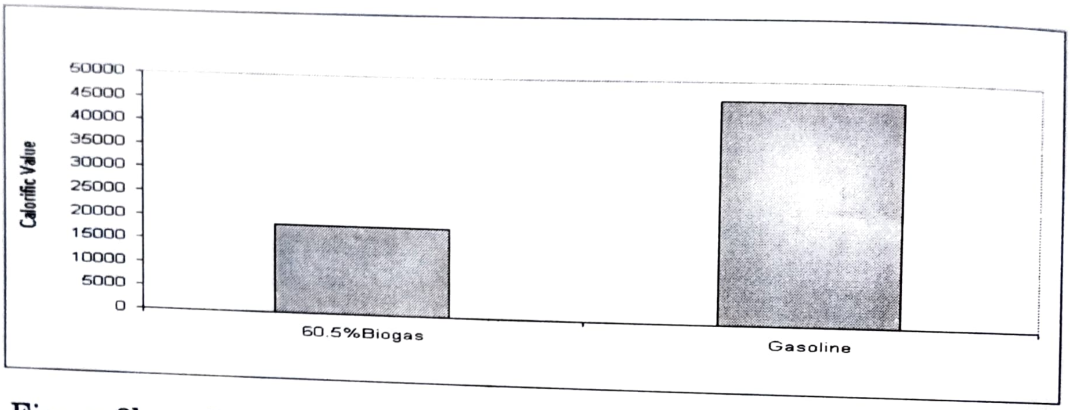

Figure 8b. Comparative Results of Purified Biogas and Gasoline Fuel in Terms of Calorific Value

By the natural composition of the two fuels, gasoline fuel has a higher calorific value than biogas by more than 50%. This could be due to the CO_2 content of biogas which has not been fully eliminated during the purification process. This implies a need for an intensified purification of raw biogas to increase the calorific value of biogas for efficient engine performance.

Volumetric Efficiency:

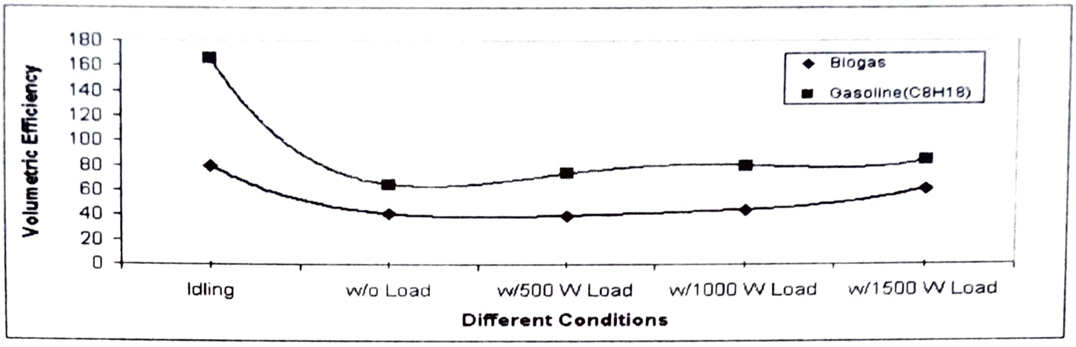

Figure 8c. Comparative Engine Performance in Purified Biogas Fuel at 9.5 cm. of H_2O Inlet Pressure and Gasoline Fuel in Terms of Volumetric Efficiency

In the case of a four-stroke type of engine which is used in this study, volumetric efficiency has a big role in the engine's performance. Because this type of engine has a distinct suction stroke, volumetric efficiency would indicate the engine's breathing capacity. One basic principle in mechanical engineering is that the more air the engine can take in, the better is its power output. Volumetric efficiency is therefore, the volumetric rate of air flow (not mixture flow) into the engine (Ganesan, 2004).

Results show (Figure 8c) that there is a high air flow rate for both gasoline and biogas fuels, a normal profile because the engine does not yet exert any effort and is able to breathe normally. However there is an increasing airflow in both the gasoline and biogas fuels at increasing load although gasoline fuel has better volumetric efficiency than biogas. According to Standards the normal range for volumetric efficiency is 80-85%. Biogas has only 61.40%, a rather relatively low flow rate compared to the 84.06% of gasoline use. This could be attributed to the quality of biogas fed engines during experimentation which has only 60.5% methane. The lesser percentage of air flow into the engine in biogas operation must be because of the presence of the remaining CO_2 in the purified biogas yield. The purer the biogas used, that is, the higher its methane content, the higher could be the air flow rate. In addition, the butterfly valve or choke controlling the carburetor, which should only be at almost close condition to allow biogas to flow into the engine, could also be a factor.

Electrical Power Output:

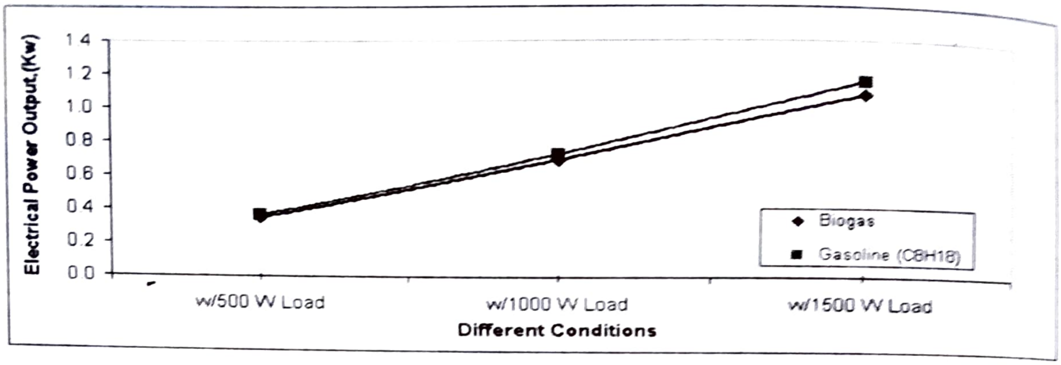

Figure 8.d. Comparative Engine Performance in Purified Biogas Fuel at 9.5 cm. of H_2O Inlet Pressure and Gasoline Fuel in Terms of Electrical Power Output

In electrical power output gasoline fuel has a higher amount of output compared to biogas fuel because of the composition of the two gases. Gasoline fuel has high calorific value of 46,050.33 Kj/kg compared to biogas fuel which has only 18,437.39 Kj/kg.

RPM:

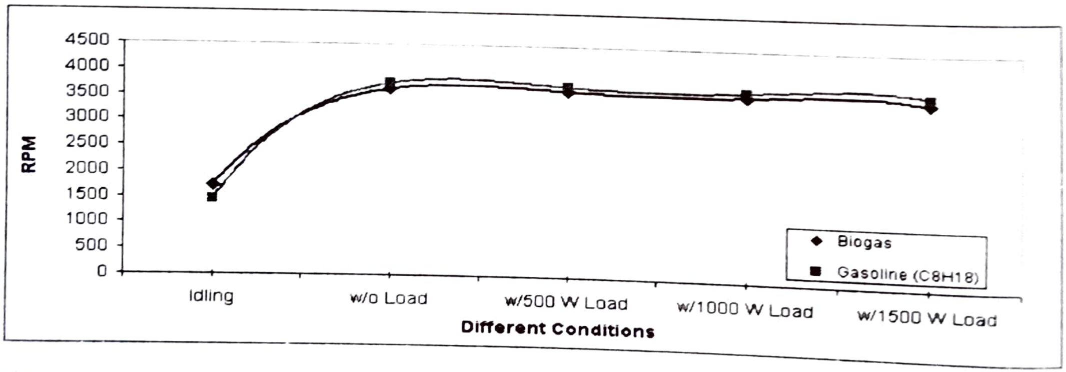

Figure 8.e. Comparative Engine Performance in Purified Biogas Fuel at 9.5 cm. of H_2O Inlet Pressure and Gasoline Fuel in Terms of RPM

At a given load above 3000 rpm (Figure 8.e), the biogas-fueled engine is able to generate needed electrical output only slightly lower than that of a gasoline-fueled engine to run a generating set. This could be attributed to the fact that the chosen engine used in this study was not designed to operate with gaseous fuel like biogas. This behavior of the power drop is consistent with the findings of Pinto (n.d.), citing power reduction of around 10% in biogas compared to the original gasoline fuel.

This result, however, implies that biogas fuel in terms of rpm can approximate the capacity of gasoline fuel.

Air-Fuel Ratio:

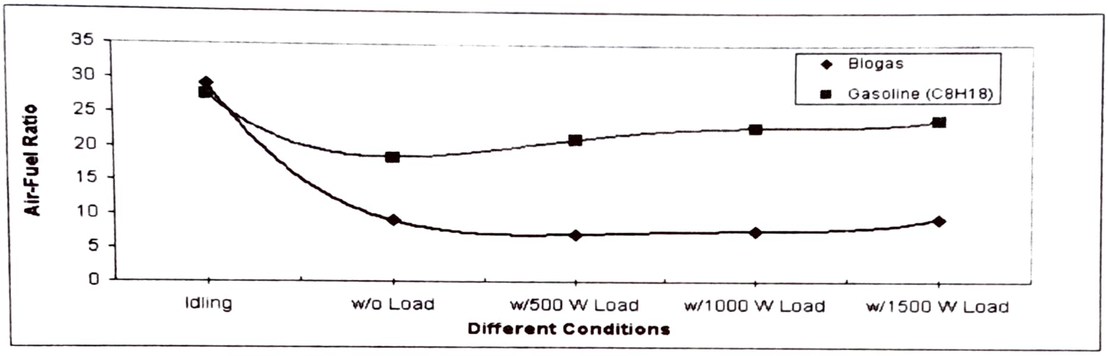

Figure 8.f. Comparative Engine Performance in Purified Biogas Fuel at 9.5 cm. of H_2O Inlet Pressure and Gasoline Fuel in Terms of Air-Fuel Ratio

Figure 8.f shows the actual air-fuel ratio supplied to the engine for both gasoline and biogas in all conditions. Gasoline-fueled engine shows relatively a higher air consumption. This could be due to the fact that gasoline is liquid while biogas is gas. Liquid needs more air to combust the fuel. Gasoline on the other hand only needs less amount of air for combustion.

In his own work, Kapadia (2004) reports on an interesting observation from the experiments that the air-fuel ratio is around 0.8 at maximum load that reduces to 0.6 at low loads for the manifold injection strategy. The air and fuel flow rate control was done manually but the need exists for an automated system to control simultaneously the air and the biogas flow rates.

Overall Thermal Efficiency:

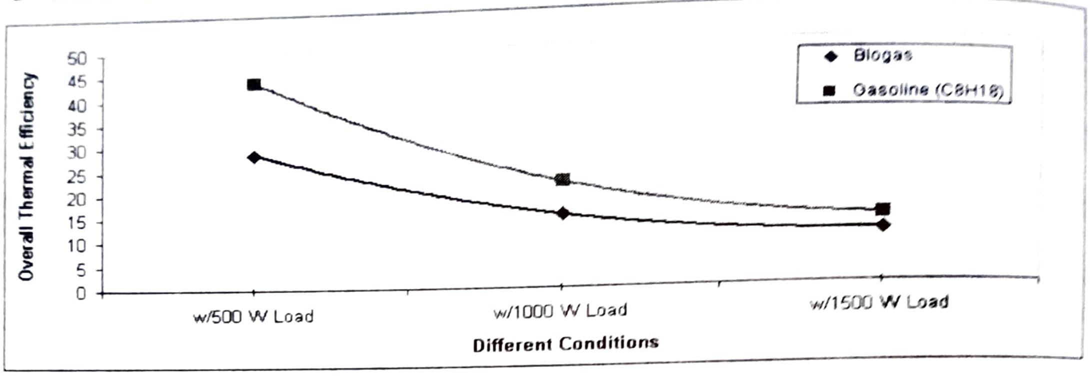

Figure 8.g. Comparative Engine Performance in Purified Biogas Fuel at 9.5 cm. of H_2O Inlet Pressure and Gasoline Fuel in Terms of Overall thermal Efficiency

In this study, overall thermal efficiency was measured in terms of the overall performance of the engine when operated on biogas fuel. Figure 8.g shows that at a lighter load, there is s big gap in terms of engine performance between a gasoline-fueled engine and a biogas-fueled one. Gasoline fuel gives a better engine performance than biogas fuel. However, in heavier loads, both fuels offer reduced engine efficiency. This result is in a parallel pattern for both fuels with biogas at a lower capacity in terms of overall thermal efficiency. The reason for this could be because the two fuels have different calorific values. In addition, the engine used in this study is again not originally designed for biogas fueling.

At any rate, as an alternative fuel to generate power for a small-scale operation, biogas, if well purified and if allowed a longer shelf life can approximate the efficiency of gasoline fuel. A 90% purification of biogas is possible given a longer purification duration; for the longer the purified biogas stays in its gas holder the higher methane content is attained.

Specific Fuel Consumption:

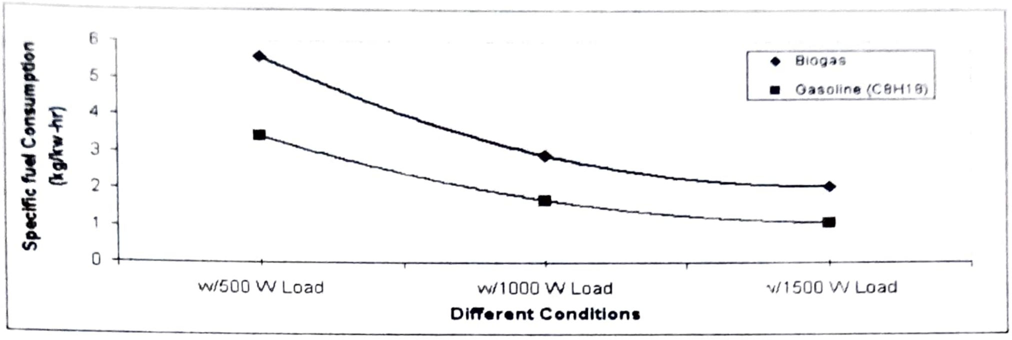

Figure 8.h. Comparative Engine Performance in Purified Biogas Fuel at 9.5 cm. of H_2O Inlet Pressure and Gasoline Fuel in Terms of Specific Fuel Consumption

In fuel consumption, engine on purified biogas fuel consumes more fuel than engine on gasoline fuel (Figure 8.h). But this profile is understandable because biogas fuel is only forcibly introduced by a given fuel inlet pressure of 9.5 cm of H_2O while gas fuel operates on natural aspiration. It also shows that at less load, the engine for both fuels consumes more fuel but as load increases for both fuel consumption decreases.

Factors Accounting for Engine Performance

1. Due to a limited duration for experimentation the purification level of the biogas used in this paper is only 60.5%. The more pure the yield of biogas the better is the efficiency of engine performance. In this study, and with only 60.5% biogas purification level, engine performance in biogas fuel indicates a relatively lower performance than in gasoline fuel.
2. The limitations of efficient biogas utilization are caused by the composition of biogas by its very nature itself.
3. The necessary modification of the engine parts to accommodate biogas fuel could be another factor. In this paper, the butterfly valve or choke for air passage to the carburetor had to be almost closed to allow the biogas fuel to pass through the inlet into the engine. This condition

has adversely affected the volumetric efficiency of biogas fuel which is already lower than that of gasoline fuel.

4. The fact that the engine used in this study is not originally designed for biogas operation could also be another factor. While the engine functions automatically on gasoline fuel, biogas fueling works on manual operation. It has also a low compression ratio of 5.539 which adversely affected engine performance especially in biogas adaptation.

Conclusion and Recommendations

Conclusion

1. The purification process either reduces or eliminates the other biogas components other than CO_2 such as CO and O_2, H_2S and other trace gases.
2. The longer the shelf life of produced biogas, the higher the amount of methane gas is produced and the higher its fuel value.
3. Biogas fuel, if brought to a 100% purification level can approximate the efficiency in performance of gasoline-fueled engine.
4. Modification of some engine parts and corresponding adjustments of spark plug gap setting are necessary to set the engine suitable for biogas operation.
5. The scope of modification of the original engine to make it work with biogas fuel and attendant adjustments needed after modification could also be factors of efficiency in engine performance.
6. On the whole, the alternative biogas fuel could run an engine for a small scale operation. It is worthy of adapting specially in rural communities where raw materials for biogas production abound and are free. Of equal importance is that biogas is environment-friendly. Its raw material is simply recycled from biodegradable waste products such as hog waste and farm waste.
7. The purification level of raw biogas, necessary adjustments of engine parts are factors of engine performance in biogas fueling.

Recommendations

1. More replicate tests should be performed to obtain more accurate base-line data for biogas.
2. There should be longer laboratory time to allow storage of the raw biogas in each of the purification stations to ultimately obtain a high level of purified biogas for use as engine fuel.
3. The result showed that there is a need to improve on the output of the CO_2 scrubber for a more purified biogas.
4. Further study should also be done to determine how long the fabricated H_2S scrubber could stay effective and efficient in eliminating the H_2S content of biogas. This is an important basis in maintaining such scrubber.
5. This study gives way to a more in depth and comprehensive research on technological developments on biogas to graduate from its small-scale utilization to a medium-scale and even on a large-scale level.
6. Future work could involve automatic governing for different load conditions to ensure that the appropriate air-fuel ratio is maintained at each load thus, maximizing efficiency over the entire load range.
7. A study on biogas fuel compression is also recommended for commercial purposes.

Acknowledgement

The writer would like to thank the *Engineering Research and Development for Technology* (ERDT) program and the College of Engineering, MSU-IIT for their financial support to this project.

Recommendations

1. More replicate tests should be performed to obtain more accurate base-line data for biogas.
2. There should be longer laboratory time to allow storage of the raw biogas in each of the purification stations to ultimately obtain a high level of purified biogas for use as engine fuel.
3. The result showed that there is a need to improve on the output of the CO_2 scrubber for a more purified biogas.
4. Further study should also be done to determine how long the fabricated H_2S scrubber could stay effective and efficient in eliminating the H_2S content of biogas. This is an important basis in maintaining such scrubber.
5. This study gives way to a more in depth and comprehensive research on technological developments on biogas to graduate from its small-scale utilization to a medium-scale and even on a large-scale level.
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