The Effect of Biogas Pressure in the Performance and Emission of Spark Ignition Engine

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Abstract. Biogas is a renewable energy which can be used for fuel in the internal combustion engine and produce electricity by using a generator. On a small scale, electricity generation from biogas is important and attractive for special purposes especially for the areas which are not connected to the main electricity network or which are plenty of sources of biomass waste. Therefore, the purpose of this study is to investigate the performance and emissions of the internal combustion engine using the biogas fuel. The study was conducted by a simulation using ASPEN HYSYS and by experiment. The biogas pressure was varied from 0 to 4 barg. The results show that the highest power and efficiency were obtained at 700 W and 14.2%, respectively. The use of pressurized biogas can increase efficiency by 1%. Low CO and HC emissions and high CO₂ emissions indicate that combustion occurs completely.

1. Introduction

Alternative fuels such as biogas as a substitute for fossil fuels have been developed for many years. In areas with problems of some animal manures and biomass wastes, we can try to overcome them by processing them into biogas. The well-known processing process is carried out by anaerobic digestion (AD) [1]. The processing of natural dyes from indigofera plants and cow dung by AD technique has also been carried out by previous studies [2, 3].

The use of biogas to generate electricity has also been carried out [4-6]. On a fairly large scale, the power plant from biogas with a capacity of 685 kW was able to supply 10% of the city's electricity needs [6]. On a large enough scale, the choice of power plants can be done between the gas turbine or gas engine. Meanwhile, for small scale less than 10 kW, the main selection is done on the gas engine using an internal combustion engine (ICE).

Various attempts have been made to improve the performance of ICE using biogas fuels. Some important variables that affect to the performance of biogas engines are the ratio of methane and CO₂ in biogas [7], combustion mode, and air fuel ratio [7] where the engine used is diesel type. While the use of Otto engines has also been investigated where the variables investigated were the compression ratio [8] and swirl [9]. Unfortunately, the influence of biogas pressure itself is rarely examined even though it is predicted that the biogas pressure can increase the density and therefore the energy entering to the combustion chamber also increases. The use of pressurized biogas in an ICE may certainly affect the
performance and emissions quality of ICE. So that, the purpose of this research is to investigate the performance and emissions of ICE when using biogas fuel at various biogas pressures.

2. Methods

Biogas is produced from the AD reactor where Indigofera plant waste was mixed with cow dung. Biogas characteristics have been reported previously [3]. Biogas was then flowed into the internal combustion engine which was connected to the electric generator.

The ICE has 4 stroke, 1 cylinder, and 160 cc. The compression ratio is 8.5:1. The engine is equipped with an automatic voltage regulator (AVR) so that the AC voltage is 220 V with a frequency of 50 Hz. The loads from the generator were obtained from electric lamps. The amount of biogas that enters the ICE was measured using the gas meter. The electric energy produced was then measured with a DL69-2047 digital multi meter.

The ICE performance is expressed in terms of power and efficiency. The efficiency of the ICE generator system can be calculated as the ratio between the output power and the fuel flow rate multiplied by the lower heating value of the fuel used [10] as written in Equation 1.

\[ \eta = \frac{P}{(m \times LHV)} \]  

Specific fuel consumption (sfc) is the ratio between the amount of fuel used (kg) and the energy produced (kWh), or equal to the ratio between the instantaneous fuel flow rate and the power produced [10] as follows.

\[ sfc = \frac{m}{(P \times t)} \]  

HYSYS ASPEN simulation was used to investigate in more detail the combustion process of biogas in the ICE. The software has various modules than can be combined to provide a full representation of various reactors. However, ICE modules are not available in ASPEN HYSYS. Therefore, the ICE model was constructed and composed of a compressor module, a RGibbs reactor, and two turbines. The compressor module was used to simulate the compression stroke with 80% isentropic efficiency. The RGibbs reactor module was used to simulate combustion stroke in the combustion chamber. The amount of energy produced in the combustion process was then flowed into the turbine module to represent the expansion stroke. Air and biogas were mixed by the mixer before being put into the compressor as can be seen in Figure 1. The power and efficiency can then be calculated by ASPEN HYSYS and compared with experimental results.

![Figure 1. The process scheme of ICE in ASPEN HYSYS](image)

To provide the pressurized biogas, the compressor was vacuum first and the biogas was streamed to the compressor. The pressurized biogas was then flowed into the mixer and flowed into the ICE. Biogas
pressure was varied from 0 to 3 barg. To see whether biogas pressure affected to the power and efficiency of ICE, an analysis of variance of one variable was carried out [11].

3. Results and Discussion

The results of the output power and efficiency of the ICE using biogas fuel can be seen in Figure 2. It is noted that the highest power that can be obtained with the pressurized biogas fuel was 700 W at 3 bar pressure and 2400 rpm. Figure 2a shows that the ups and downs of the output power generated at different biogas pressures were influenced by the biogas consumption. In the greater biogas consumption, the power produced was also high. In general, it can be seen that the performance of ICE by simulation resulted a higher output power compared to the power generated from ICE by experiments. It is caused that the simulation was done with a perfect combustion model so that the temperature and pressure of the combustion chamber were higher than the actual temperature and pressure.

![Figure 2](image_url)

**Figure 2.** Power, fuel consumption, and efficiency of ICE

| Source of variation | Sum of Squares | Degrees of Freedom | Mean Square | F0 |
|---------------------|----------------|--------------------|-------------|----|
| Pressure            | 0.096          | 4                  | 0.024       | 41.603 |
| Error               | 0.006          | 11                 | 0.001       |     |
| Total               | 0.103          | 15                 |             |     |

In Figure 2b it can be seen that the highest efficiency of the ICE was 14.2% achieved at a biogas pressure of 3 barg. Improving the efficiency of ICE by increasing biogas pressure is about 1%. The enhancing efficiency of ICE is quite significant from the analysis of variance test as can be seen in Table 1 where the $F_{0.05, 4, 11}$ is higher than 3.36.

With higher biogas pressures, the quality of combustion is better [12] due to the phenomenon that the pressurized biogas has an easier characteristic to ignite. Meanwhile, if the efficiency of ICE found from the study is lower than that of the efficiency of ICE from previous studies, i.e. 26.2% [13]. When compared with the highest efficiency of 23.3% [13] on spark ignition engines made from raw biogas with 65% methane content, the maximum efficiency in this study remains lower.

The sfc of the ICE with the biogas fuel in this study was ranging from 5.37 to 6.73 kg/kWh. Meanwhile, when compared with previous studies on the spark ignition engine with methane-enriched biogas which has a minimum sfc of 0.471 kg/kWh [13], the lowest sfc found in this study remained far higher. When compared with a minimum sfc of 0.651 g/kWh [13] on the ICE with a raw biogas with 65% methane content, the minimum sfc of the ICE in this study was still higher. The reason is because the biogas in this study had 8% methane content and 26% carbon monoxide content. As a result, the energy produced from the burning of the biogas is low so that to produce a high power, a bigger amount of biogas is needed with not too good quality, so that the sfc increases and efficiency decreased.
Figure 3. Flue gas emission from ICE with biogas fuel

Figure 3 shows the exhaust emissions from ICE with the biogas fuel. The CO, CO₂ and O₂ concentrations found in the flue gas were ranging from 0.09 to 0.11%, from 4.8 to 5.3%, and from 11.96 to 12.97%, respectively. Hydrocarbon (HC) content in flue gas was ranging from 866-875 ppm. The higher the biogas pressure, the content of CO and CO₂ was slightly decreasing. The presence of a very low content of CO and HC and a high content of CO₂ indicates that the combustion in the ICE occurs completely. While the high content of oxygen in the flue gas showed that the air to fuel ratio (AFR) mixture of air-biogas that enters the ICE was higher than the stoichiometric AFR. The high AFR can be carefully identified by the analysis with ASPEN HYSYS and it can be seen that the work of compression increased sharply while the input energy tended to be the same so that the net output of work generated from ICE tended to be low. Therefore, besides being influenced by the quality of biogas, the ICE efficiency of 14.2% in this study was also influenced by the high use of AFR.

4. Results and Discussion

The study on the effect of pressure on biogas-based ICE performance and emissions has been conducted. The output power and efficiency have been compared between the results of the experiments and the results of the ASPEN HYSYS simulation. The highest power and efficiency were obtained at 700 W and 14.2%. The use of pressurized biogas can increase the efficiency of ICE by 1%. A low content of CO and HC emissions and a high content of CO₂ emissions indicated that combustion occurred completely. Therefore, it can also been known that the cause of the low efficiency of the engine aside from the biogas quality factor is also influenced by the use of excess air when burning the biogas in the ICE. Therefore, efforts to improve the performance of ICE with biogas fuel can be done by improving the quality of biogas and controlling the proper use of AFR are interesting for future works.

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