Efficiency Analysis of Spark Ignition Biogas Genset for Electricity Power Generation

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***Abstract*—This research studied the influence of the ratio of load and maximum power of genset and usage time to the efficiency of electricity energy conversion using biogas as fuel. The experiment was done in Biogas Power System installed by Puslit Telimek LIPI in Baiturrahman Islamic Boarding School, West Java, Indonesia. The electricity energy was generated using modified Spark Ignition gasoline genset so that it can be fueled with 100% biogas. Genset efficiency was calculated based on genset load and thermal power of biogas consumed by the genset. The result showed that the genset efficiency is increased with the increasing of load and maximum power ratio. Usage time also significantly decreased the genset efficiency for biogas fuel without CO_2, H_2S, and water purification. For 5 kW new genset with 40% load, the average efficiency can reach 42.20%. Genset 2.5 kW with usage time 8 years has lower average efficiency as much as 11.76% for 40% load and 5.50% for 20% load. The efficiency of new genset is significant high, so that SI genset very potential to be implemented in a biogas system. To reach higher efficiency, purification process is needed especially to remove the CO_2, H_2S, and H_2O.**

***Index Terms*—Efficiency; Biogas; Energy Conversion; Spark Ignition Genset.**

I. INTRODUCTION

In 2014, Puslit Telimek LIPI installed biogas power system in Pondok Pesantren Baiturrahman, one of Islamic Boarding School in Ciparay District, West Java, Indonesia. The installation was supported financially by WAITRO and ISESCO. The students in this boarding school are approximately 500 people. Besides education program, Baiturrahman Boarding School also conducts some entrepreneur programs including rearing cows to fulfill the customer's demand. The presence of students and cows in this school contributes to the production of food waste, feces, and cow manure that can be used as raw materials for biogas production. Although the biogas system was designed to co-digest cow manure, feces, and food wastes, its operation is limited to co-digest human feces and cow manure only. At present, food waste has not been used as raw material. Food waste is one the main substrates of raw material for biogas production in Indonesia due to its high availability and the simple process [1] of anaerobic digestion to convert the organic compounds in these materials into biogas.

The utilizations of biogas have been largely developed as fuel for electricity power generation, and biogas power systems have been installed in some areas in Indonesia such as in Majalengka, Situbondo, Ciparay, Bengkulu, and NTB. Biogas has a high potential to be used as fuel for electricity power generation due to the high calory value and the electricity energy can be generated using various methods. According to [2], it can be generated using internal combustion engine, gas turbine, and steam turbine through Rankine Cycle. The utilization of biogas as fuel in internal combustion engine is a reliable technology and has been long time established [3]. The electricity power can be generated using gasoline (spark ignition) engine or diesel (compression ignition) engine. For diesel engine, dual fuel system can be applied with minor modification [4]. However, due to the significant different of autoignition temperature of biogas and diesel fuel, complicated modification is needed to use biogas as a 100% fuel [5]. On the other hand, for SI engine, with simple modification in the fuel system [6], the energy conversion process can be fueled with 100% biogas.

Due to the different type of energy source, the utilization of biogas as fuel in CI or SI engine will influence the engine performance. The present of other component together with methane in biogas such as H_2S, that was highly toxic [4] can cause corrosion to the engine and metal parts [7] and probably affect the engine performance. Component, chemical, and physical characteristic of biogas was in correlation with the operational problem on the engine [8]. Corrosion of engine components due to acidic attack, carbon deposits on engine surfaces, inadequate engine lubrication, higher engine friction and excessive wear are the operational problems that may exist in the utilization of biogas [4]. Long usage time may also influence the efficiency, due to some conditions that may arise during other parts of the year [5].

This research is an experimental study of the efficiency of energy conversion in the utilization of biogas as fuel for electricity power generation in Baiturrahman Boarding School, West Java Indonesia. The electricity energy is generated using modified gasoline spark ignition generator set (genset) so that it can be operated using biogas 100%. During the energy conversion process, some heat loss may occur due to friction or some heat loss to environment that influence the genset efficiency. Data about efficiency of biogas genset is needed in the design of biogas power system. This data can be used to determine the potency of electrical power based on the availability of raw materials, and the amount of raw material to generate certain electrical power, as well as for calculation in the design of biogas genset.

II. EXPERIMENTAL

This research was conducted to study Biogas Power System in Baiturrahman Boarding School, West Java,

Indonesia, especially the power generation unit that converts the combustion heat of biogas to electricity energy. Figure 1 shows the cow's corrals, biogas digester unit, and biogas generator set in the system.

Figure 1: Biogas system in Baiturrahman Islamic Boarding School

Biogas from the digesters was sent to the generator set through the conditioning unit to generate electricity. Biogas flowmeter was installed between the conditioning unit and the generator set to measure the biogas consumption. The generator set was used to generate certain amount of power. Gas sample for methane content analysis was taken from the conditioning unit using Chromathography Gas. The scheme of experimental set up was presented in Figure 2.

The potency of thermal power of biogas can be calculated based on biogas consumption by genset to generate a certain amount of power. If the rate of biogas consumption by genset is denoted as Vb (l/s), the consumption of biogas in gmol/s, Fb, can be calculated using ideal gas equation, as follow:

$$F_b = \left(\frac{P.V_b}{R.T} \right) \quad (1)$$

with P is the biogas pressure (atm), R is the ideal gas constant (0,082 l. atm/gmol.K), and T is the biogas temperature (K). If the methane content of biogas is denoted as Cb_1 (% volume), the potency of thermal power of biogas flow to genset can be calculated according to the methane content and heat of the combustion of methane in biogas as much as 802620 joule/gmol at 298, 15 K [9], as follows:

$$P_T = \left(\frac{C_{b_1}}{100} . F_b . \Delta H_c \right) \quad (2)$$

with P_T is the thermal power of biogas consumed by the genset (watt).

If the genset load is P_b (watt), the genset efficiency, (η, %), can be calculated by divided the load with the biogas thermal power, as follows:

$$\eta = \left(\frac{P_b}{\frac{C_{b_1}}{100} . F_b . \Delta H_c} \right) \times 100\% \quad (3)$$

III. Results and Discussion

Analysis of genset performance in this research was done to study the influence of ratio of load and genset maximum power, and usage time of genset, on the genset efficiency (or the efficiency of energy conversion process in the genset). Analysis was done based on rate of biogas consumption by genset in certain electricity power load. The genset efficiency was calculated using equation 1 until 3.

A. Influence of Load and Maximum Power Ratio

Experiment was conducted using genset 2.5 kW with eight years of usage time. The variation of load was 0.5 kW and 1 kW or in ratio of load and maximum power about 1/5 and 2/5 (20% and 40% load). The result of the experiment is presented in Table 1.

Table 1 shows that the efficiency of genset increases with the increasing of load and maximum power ratio of genset. This result is in accordance with the research done by [6], in which the efficiency increased with the increasing of genset load, since the load did not exceed the maximum power of genset. The biogas consumption in Table 1 shows a lower reading in the higher ratio of load and maximum power. The average genset efficiency of 11.76% for 40% load was higher than the average efficiency of 5.50% for 20% load. In the maximum ratio of load and genset power, the efficiency estimated could reach more than 20%. Therefore, to obtain higher efficiency, it is suggested that the genset operates in the maximum load or in the higher load so that the heat loss to environment is lower. Furthermore, because the genset used in this experiment is an old genset, which has been used for eight years, the efficiency of new genset will probably be higher.

B. Influence of genset usage time

The influence of usage time on the genset efficiency was studied using two gensets with different usage time and maximum power. The first genset was genset 2.5 kW with usage time eight years, and the second genset was new genset with maximum power 5 kW. Experiments were done in the same load and maximum power ratio as much as 2/5 or in 40% load. The load installed in the 5 kW genset was 2 kW and for 2.5 kW genset the load was 1 kW. The result of experiment and calculation of genset efficiency are presented in Table 2.

The calculation result in Table 2 shows that the efficiency of 5 kW new genset could reach more than 40%, with the average efficiency about 42.20%. This value reached almost

four times the efficiency of 2.5 kW genset with eight years of usage time, and with the average efficiency about 11.76%. There was a significant difference of the genset efficiency between the new genset and the old genset with eight years of usage time because the utilization of biogas in Baiturrahman Boarding School did not through CO_2, H_2S, and water removal seriously.

Figure 2: Scheme of experimental set up

Table 1
Efficiency Based on Load and Maximum Power Ratio (Genset Power = 2.5 kW, Biogas Pressure = 3 kPa, Biogas Methane Content = 42.32%)

Load	Time, minute-	Biogas consumption rate, m^3/minute	Biogas thermal power, kW	Genset efficiency, %
20%	0-1	0.04	9.39	5.33
	1-2	0.04	9.39	5.33
	2-3	0.04	9.39	5.33
	3-4	0.038	8.92	5.61
	4-5	0.036	8.45	5.92
	Average efficiency			5.50
40%	0-1	0.037	8.68	11.52
	1-2	0.036	8.45	11.84
	2-3	0.037	8.68	11.52
	3-4	0.035	8.21	12.17
	Average efficiency			11.76

Table 2
Efficiency Based on Genset Usage Time (Biogas Pressure = 3 kPa, Load = 40%, Biogas Methane Content = 42.32%)

Genset maximum power, Usage time	Time, minute-	Biogas consumption rate, m3/minute	Biogas thermal power, kW	Genset efficiency, %
5 kW, 0 year	0-1	0.02	4.69	42.61
	1-2	0.02	4.69	42.61
	2-3	0.02	4.69	42.61
	3-4	0.02	4.69	42.61
	4-5	0.021	4.93	40.58
	Average efficiency			42.20
2,5 kW, 8 years	0-1	0.037	8.68	11.52
	1-2	0.036	8.45	11.84
	2-3	0.037	8.68	11.52
	3-4	0.035	8.21	12.17
	Average efficiency			11.76

With the present of H_2O, CO_2 will react with H_2O to form carbonic acids [10] that cause the corrosion to equipment. Further, the presence of H_2S and water vapour in biogas [4] will also damage the engine since these materials are very corrosive. Therefore, purification process for CO_2, H_2S and H_2O is fundamentally needed in the utilization of biogas in engine, particularly for transportation [11] and electricity power generation, so that the life time of the engine can be longer. On the other hand, because the efficiency will be higher with the increasing of power load [6], it is possible for the efficiency to increase in the higher load. For the maximum load, it is estimated that the average efficiency can reach up to 80% for new genset and 20% for 8 years usage time genset. The result shows that SI engine biogas genset performed well, and after the purification process, biogas has a high potential to be used as fuel in electricity power generation.

The average efficiency of new genset in this research was 42.20%, and it was higher than the dual fuel genset fueled with biogas. Further, the diesel fuel was 23% [4] and it was also higher than the biogas spark ignition engine in previous research as much as 10.5710% for load 100 watt [12] and 11.0996% for load 200 watt, using genset 850 watt. The lower efficiency of previous research derived from using spark ignition engine [12] could be caused by the lower load and maximum power ratio about 2/17 and 4/17 (11.8% load and 23.5% load). The result was lower than the load and maximum power ratio in this research, that was about 2/5 (40% load). In the lower load, the genset efficiency will also be lower.

From the calculation, it is known that the efficiency of new genset was significantly high so that the spark ignition biogas genset is very potential to be used in biogas power system. To reach higher efficiency, it is suggested to add equipment to remove CO_2, H_2S, and H_2O in the system, and it has the potential to obtain higher performance in the system.

IV. Conclusions

Genset efficiency will increase with the increase of load and maximum power ratio. In the higher load, the efficiency will also be higher. The usage time will significantly decrease the efficiency in the utilization of biogas without

purification process due to the present of corrosive compounds such as CO_2, H_2S, and H_2O. The average efficiency of 5 kW new genset in 40% load can reach 42.20%. Genset 2.5 kW with eight years of usage time has lower average efficiency about 11.76% in 40% load and about 5.50% in 20% load. Since the efficiency of new genset is significantly high, it it highly potential to implement spark ignition genset in biogas power system, and purification process is needed to increase the genset efficiency.

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