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# Experimental study on diesel engine coupled with a catalytic converter run on dual-fuel mode using biogas produced from agricultural waste

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# Experimental study on diesel engine coupled with a catalytic converter run on dual-fuel mode using biogas produced from agricultural waste

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**Abstract**. This work studied experimentally the performance and exhaust gas emission of a diesel engine coupled with a catalytic converter run on dual-fuel mode using refined biogas resulted from agricultural waste. The content of methane on the biogas is 70%. The experiments were carried out at constant load 1500 kW. The engine rotation varies from 1000 rpm to 1500 rpm. The biogas flow rate varies from 0 to 6 L/min. The output power of the engine operated on dual-fuel mode is better than the engine operated with pure diesel. The brake thermal efficiency of the diesel engine with flow rate of 2 L/min and 4 L/min is better than diesel only. The specific fuel consumption of the diesel engine operated on dual-fuel mode is higher than pure diesel mode. The opacity number of the engine operated on dual-fuel mode is better than pure diesel mode. However, the CO number and HC number of the engine operated on dual-fuel mode are higher than pure diesel mode. The diesel replacement ratio is within the range 15.6% % to 74.8%. It is recommended to run the present diesel engine in dual fuel mode with biogas flow rate 2 L/min - 4 L/min.

## 1. Introduction

Greenhouse gas (GHG) emissions is a big problem for the globe. It will result in global warming and climate change to the globe. To avoid the globe from catastrophe, GHG emission must be mitigated. Many countries have committed to decreasing GHG emission. Indonesia has released the new target to reduce its emission by 29% from level business-as-usual by 2030 using own budget and it can be increased up to 41% using international supports [1]. One of the promising mitigation actions is to level up the renewable energy utilities. There is a strong worldwide commitment to reduce fossil fuel utilization and replacing with renewable energy sources. Several renewable energy sources can be used to replace fossil fuel such as solar energy [2–23], bioenergy [24 – 29], wind energy, and hydropower.

One of the promising mitigation actions for reducing GHG emission by increasing renewable energy utilization is employing biogas to power engines. Biogas is a significant source of biofuel resulted from anaerobic biodegradation of organic materials such as agricultural wastes which are present abundantly in the rural areas. Such areas typically employ diesel engines for agricultural industrial, transportation, and small-scale power plant. Two methodologies can be employed to

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operate a diesel engine with biogas. The first method is changing the diesel engine to spark engine and run it in pure biogas mode [30, 31] and the second one is dual-fuel mode (diesel-biogas). In the first mode, the CI needs extreme modifications, because the CI engine must be converted into spark ignition engine. The literature shows that CI engine can be operated 100% on biogas with performance comparable with diesel fuel. However, this method will be a problem when the biogas is absence or far from sufficient, the converted CI engine is not easily turned back into pure diesel mode.

In this study, we focus on powering diesel engine with biogas in dual-fuel mode. In this mode, after the compression stage, the charge consisted of biogas and fresh air, a small amount of diesel fuel, called the pilot is put in the chamber. The pilot fuel gets self-ignited and then it becomes the firing source for the initiated biogas fuel. The advantage of a diesel engine operated in dual-fuel mode is it can be operated with a wide variety of gaseous fuels without any significant machine changes [32]. When the biogas is empty or far from sufficient, it is easily put back into pure diesel operation mode. In spite of the fact that a diesel engine run on dual-fuel mode shows its practical use, there are still many problems need to be investigated. The challenges include how to increase the performance and to make the exhaust gases friendly to the environment.

To solve the first challenge, several studies on the improvement of performance diesel engine operated on dual-fuel mode have been reported in the literature. Bedoya et al. [33] studied the effect of mixing system and pilot diesel fuel quality on the performance diesel engine run on dual-fuel mode. Cacua et al. [34] reported the investigation oxygen-enriched air to improve the engine performance. Makareviciene et al. [35] investigated the impacts of methane compositions in a big diesel engine four stokes and four cylinders when operated under dual-fuel (diesel-biogas) mode.

Typically, a catalytic converter is employed to reduce the bad impact of the combustion engine in general. The catalytic converter has been proposed to reduce the emission of a combustion engine since 1975. The catalytic converter converts harmful exhaust gases into a safe compound that can be emitted to the atmosphere and cause less damage to the environment. Rezk et al. [36] reported the effects of the catalytic converter position on the performance and hydrocarbon emissions of a gasoline engine. Michel et al. [37] studied the optimization fuel consumption and pollutant emissions of gasoline-hybrid electric vehicle equipped with catalytic converter. Irawan et al. [38] explored the optimum design of manganese-coated copper catalytic converter on gasoline motor. Those literature are focused the gasoline or spark ignition engines.

The above studies are only focused on a spark engine coupled with a catalytic converter in a gasoline engine. However, only limited studies on a diesel engine coupled with a catalytic converter. Vallinayagam [39] reported a study on emission decrease from diesel engine fueled by pine oil biofuel using selective catalyst reduction and catalytic converter. Lozhkin and Lozhkina [40] proposed a mathematic model of catalysis process in the mode of heat rejection. The model was validated to a catalytic converter with storage device diesel engine of the city bus. Recently, Ambarita [24] reported the study on the effect of catalytic converter on the performance and emissions of a diesel engine run in dual-fuel mode using raw biogas.
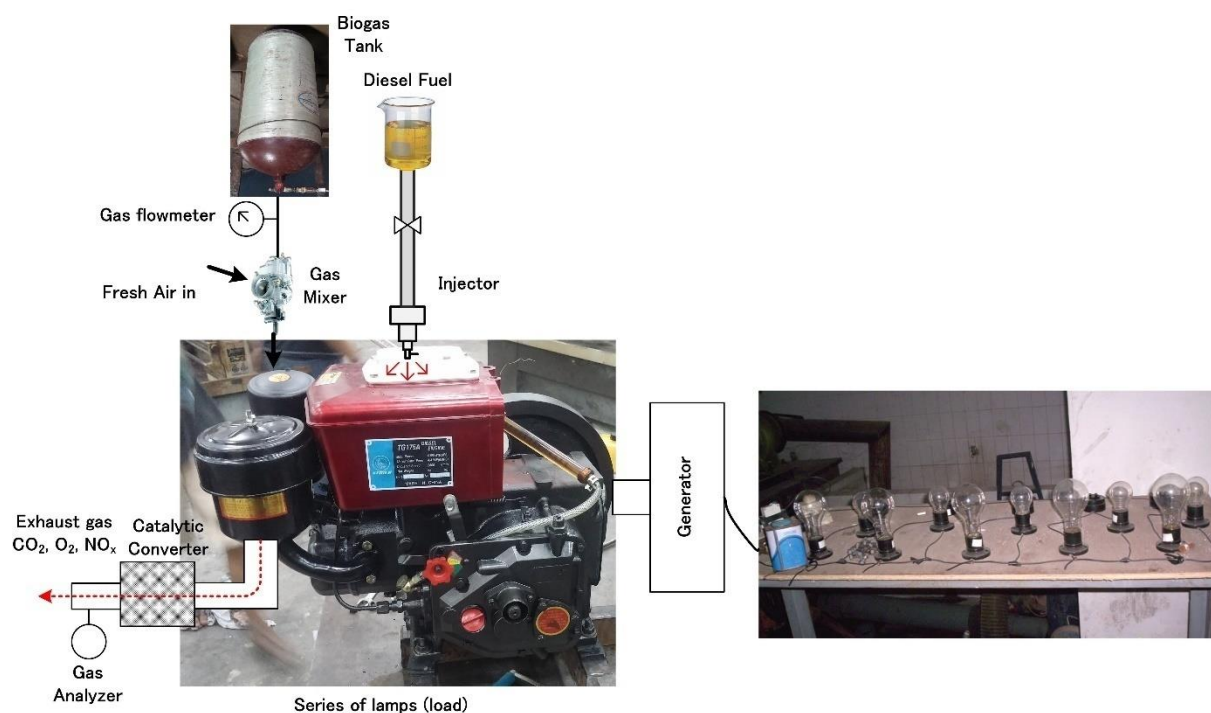
In this study, a diesel engine run on duel-fuel mode coupled with a catalytic converter will be investigated. The biogas will be refined. The objective is to explore the effect of catalytic converter on the performance and emission characteristics of the diesel engine when it is run in dual-fuel mode using methane enriched biogas.The results are expected to supply the necessary information to reach GHG emission target and to provide technology in supporting energy for sustainable development which is safe for human health.

## 2. Method

### 2.1. Experimental setup

Figure 1 depicts the schematic diagram of the designed experimental setup. It comprises of a small diesel engine, a generator, a series of lamps, biogas container, gas mixer, and measurements sensors. The used diesel engine is typically employed to power a mini tractor in Indonesian agriculture. The

specifications of the diesel engine are explained as follows. It is a single-cylinder four strokes engine and designed for diesel fuel. The engine has the highest output power of 4.86 W with a weight of 65 kg. The Bore and Stroke of the engine are 75 mm and 80 mm, respectively. The rated output of the diesel engine is 4.41 kW at a rated speed of 2600 rpm. The compression ratio of the engine is 23:1. A catalytic converter, which is typically used for motorbike purchased in the Indonesian market, is coupled to the CI engine. It is a three-way, Pt-Rh, honeycomb structure catalytic converter.



**Figure 1.** Experimental Apparatus

In this study, the biogas is made of biodegradation of Palm Oil Mill Effluent (POME) by using digester. The biogas digester belongs to PTPN III an Indonesian government-owned Palm Oil Company. The type of the biogas digester is anaerobic mesophilic. The biogas is refined and stored in a particularly designed tank by using a compressor. The methane content of the biogas is 70%. As a note, raw biogas without treatment has methane content of 60%. The methane content of the biogas is estimated using Gas Chromatography. The diesel fuel is obtained from PERTAMINA the fuel retailer in Indonesia belong to the government. Before tested, low heating value (LHV) of the diesel fuel is investigated using a bomb calorie meter. The LHV is 42.64 MJ/kg. The heating value of the biogas will be calculated using the formula suggested by Ludington [41].

The diesel engine is coupled with a single-phase synchronous generator by employing a pulley. The generator specifications are depicted in the followings. The grading frequency, grading voltage, and maximum power are 50/60 Hz, 115-230 V, and three kVA, respectively. The generator is employed to power a series of lights. The features of the exhaust gas such as opacity is characterized using engine smoke meter and HC and CO are characterized by using gas analyzer. The model of the engine smoke meter is HD-410 with main specifications are as follows. The measuring range, absorption coefficient, oil temperature, and operation temperature are 0.00-100%, 0.00 - 21.42 m-1, 0 - 800 rpm, 0 - 100ºC, and of -10ºC - 40ºC, respectively. The model of Gas Analyzer is HG-510 with features as follows. The measurement ranges of CO and HC are 0-9.99% and 0-9999 ppm, respectively. The temperature is collected using thermometer sensor KW 06-278 Krishbow. The

accuracy range is$\pm0.5\% \pm 1^oC$. Multitaster Meter CD 800Ais used to measure electric charge. Tachometeris employed to measure shaft rotation speed of the CI engine.

### 2.2. Problem Formulation

The performance of the diesel engine is analysed employing the electrical power, thermal efficiency, and specific fuel consumption. The power resulted by the CI engine $P_E$ (Watt) is estimated by

$$P_E = V \times I \tag{1}$$

where $V$ [Volt] and $I$ [Ampere] are the voltage and the current of the electric power by the generator, respectively. Thermal efficiency is the electric power divided by the energy injected to the engine. For the case of CI engine run on diesel only mode, it is given by

$$\eta = \frac{P_E}{\dot{m}_{diesel} \times H_{diesel}} \tag{2}$$

where $H_{diesel}$ is the heating value of diesel fuel. In the case of engine operated in dual-fuel mode, the thermal efficiency is given by

$$\eta = \frac{P_E}{\dot{m}_{dual} \times H_{diesel} + \dot{m}_{biogas} \times H_{biogas}} \tag{3}$$

where, $\dot{m}_{dual}$ [kg/s] and $\dot{m}_{biogas}$ [kg/s] are the mass rate of the diesel fuel and biogas, respectively. Here, $H_{biogas}$ the heating value of the biogas [kJ/kg].

Specific fuel consumption $sfc$ [g/kWh] is fuel consumed by the engine divided by useful energy. It is a parameter to show how many grams of fuel is burnt to result in 1 kWh of electrical energy. In the case of diesel only mode, it is given by the equation below.

$$sfc = \frac{\dot{m}_{diesel} \times 10^3}{P_E} \tag{4}$$

For diesel engine operated on dual-fuel mode it is defined as:

$$sfc = \frac{(\dot{m}_{diesel} + \dot{m}_{biogas}) \times 10^3}{P_E} \tag{5}$$

To express the ratio of diesel fuel substituted by the biogas, the parameter replacement ratio [r] is used. It is defined as reduced diesel fuel consumed when the CI engine tested on dual-fuel mode and when it is tested on diesel only mode. The parameter is given by the below equation.

$$r = \frac{\dot{m}_{diesel} - \dot{m}_{dual}}{\dot{m}_{diesel}} \times 100\% \tag{6}$$

where $\dot{m}_{diesel}$ [kg/s] is the diesel mass flow rate in diesel mode and $\dot{m}_{dual}$ [kg/s] is the diesel mass flow rate in dual-fuel mode.
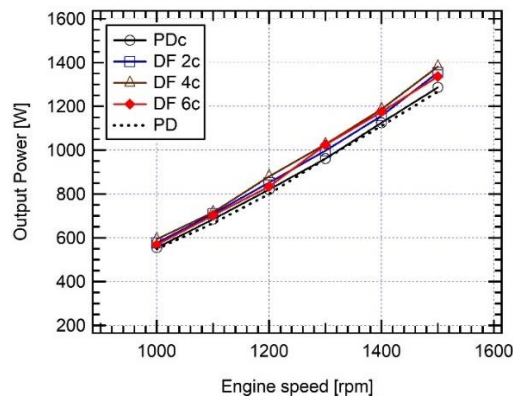
## 3. Results and discussions

In the experiment, the engine speed was operated from 1000 rpm to 1500 rpm and the biogas flow rate was varied from 0 L/min, 2 L/min, 4 L/min and 6 L/min. The load was fixed at 1500 kW. The total number of experiments is 24 tests.
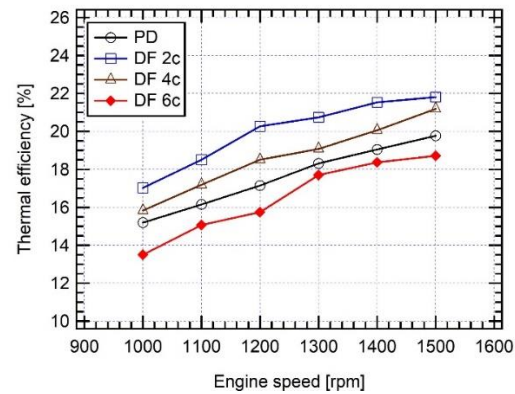
### 3.1. Performance characteristics

Figure 2 depicts the power resulted by the diesel engine as a function of diesel engine speed. The figure shows that the output power of the diesel engine run operated in dual-fuel mode coupled with a catalytic converter is higher than pure diesel mode. This fact suggests that the catalytic converter does not affect the output power of the diesel engine. In addition, There no significant effect of the biogas flow rate to the output power.

Figure 3 shows the thermal efficiency of the diesel engine run on dual-fuel mode and pure diesel mode. The figure shows that the highest thermal efficiency is shown by the diesel engine when it fueled with biogas with flow rate of 2 L/min. Increasing the biogas flow rate to 4 L/min will decrease the
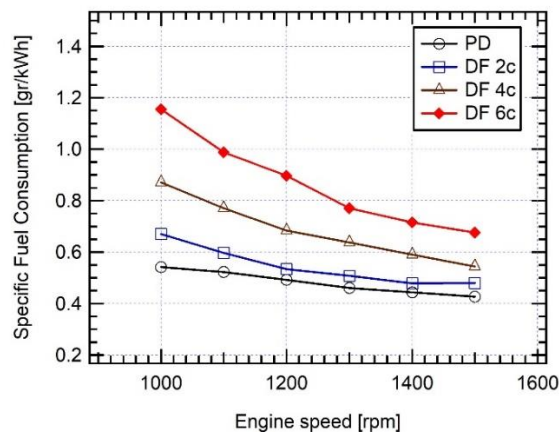
thermal efficiency. The thermal efficiency of the CI engine operated at biogas flow rate 2 L/min and 4 L/min is better than diesel only mode. However, when the biogas flow rate increased up to 6 L/min, the thermal efficiency will be lower than diesel only mode.
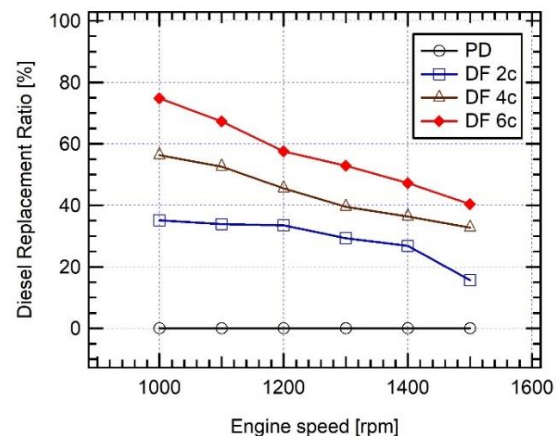


**Figure 2.** Electric Output power



**Figure 3** Thermal Efficiency



**Figure 4.** Specific fuel consumption



**Figure 5.** Diesel replacement ratio

The specific fuel consumption of the engine is shown in Figure 4. As a note, a lower specific fuel consumption is better. It was shown that specific fuel consumption decreases with increasing engine speed. This fact reveals that the diesel engine should be operated at high engine speed. Specific fuel consumption decreases with decreasing biogas flow rate.

*3.2. Exhaust gas emission*
As a note, the objective of installing a catalytic converter to the diesel engine is to reduce negative effect of the exhaust gas. The opacity number of the exhaust gas for all cases are shown in Table 1. The table shows that opacity number of the exhaust gas decrease when the diesel engine run on dual-fuel mode. This is because of some particulates in the combustion chamber decrease by the presence of the biogas.

   Table 2 shows the CO emission number of the exhaust gas. It can be seen that the pure diesel mode results in the lowest CO number. The CO emission decrease with increasing biogas flow rate. Table 3 shows the HC number of exhaust gas. It was shown that the lowest HC number resulted by the engine run on pure diesel mode. This is because the diesel fuel is bunt perfectively. By injecting biogas to the

combustion chamber, some of the hydrocarbon in the fuel was not burnt perfectively. This makes the HC in the exhaust gas is high. Increasing biogas flow rate will increase HC number.

**Table 1.** Opacity Number

| Engine Speed [rpm] | Biogas Flow rate | | | |
|---|---|---|---|---|
| | Pure Diesel | 2 L/min | 4 L/min | 6 L/min |
| 1000 | 7.7 | 5.2 | 6 | 2.6 |
| 1100 | 9.9 | 9.3 | 6.4 | 5.1 |
| 1200 | 9.4 | 11.6 | 9.6 | 9.6 |
| 1300 | 14.7 | 12.3 | 12 | 13.5 |
| 1400 | 19.1 | 17.8 | 13.7 | 15.9 |
| 1500 | 18.2 | 31 | 15.2 | 18.7 |

**Table 2.** $CO_2$ emission

| Engine Speed [rpm] | Biogas Flow rate | | | |
|---|---|---|---|---|
| | Pure Diesel | 2 L/min | 4 L/min | 6 L/min |
| 1000 | 0.02 | 0.15 | 0.06 | 0.03 |
| 1100 | 0.02 | 0.12 | 0.04 | 0.04 |
| 1200 | 0.02 | 0.11 | 0.04 | 0.04 |
| 1300 | 0.02 | 0.11 | 0.03 | 0.04 |
| 1400 | 0.02 | 0.09 | 0.04 | 0.04 |
| 1500 | 0.03 | 0.02 | 0.04 | 0.04 |

**Table 3.** HC emission

| Engine Speed [rpm] | Biogas Flow rate | | | |
|---|---|---|---|---|
| | Pure Diesel | 2 L/min | 4 L/min | 6 L/min |
| 1000 | 10 | 248 | 162 | 120 |
| 1100 | 6 | 193 | 112 | 115 |
| 1200 | 6 | 170 | 94 | 109 |
| 1300 | 6 | 116 | 82 | 101 |
| 1400 | 6 | 132 | 82 | 98 |
| 1500 | 6 | 145 | 82 | 85 |

*3.3. Diesel replacement ratio*

As a note the aim of using biogas in a diesel engine is to replace diesel consumption. The parameter to explore this objective, diesel replacement ratio is used. This parameter should be treated as how much diesel fuel can be reduced when the diesel engine is tested in dual-fuel mode. If the diesel replacement ratio is high, it means a better operational cost. The diesel replacement ratio at different engine rotation speed for all cases are depicted in Figure 5. The figure reveals that diesel replacement ratio starts from 15.6% % to 74.8%. The minimum diesel replacement ratio is depicted by the engine when it is tested in the dual-fuel mode with a biogas flow rate of 2 L/min with a speed of 1500 rpm. The maximum diesel replacement ratio is depicted by the engine when it is tested in the dual-fuel mode with a biogas flow rate of 6 L/min at an engine speed of 1000.

The diesel replacement ratio reduces as the engine speed increases. This is due to higher engine speed, the fuel burning process occurs at a very limited time. This will affect the mass of biogas that can substitute the diesel fuel. For all cases, increasing biogas flow rate will increase diesel replacement ratio. These facts indicate that using biogas in a diesel engine can decrease diesel fuel consumption significantly.

## 4. Conclusion

In this work a diesel engine coupled with a catalytic converter run in dual-fuel mode has been tested experimentally. The biogas used in the experiment is made of biodegradation of Palm Oil Mill Effluent (POME) by using digester. This POME is known as agricultural waste which has negative impact on the environment. The biogas is refined to increase the methane content. The engine was tested at different engine speed and biogas flow rate. The conclusions of this study are as follows. The output power of the engine run on dual-fuel mode is better than pure diesel mode. Thermal efficiency of the diesel engine with lower biogas flow rate (2 L/min and 4 L/min) is better than pure diesel mode. The specific fuel consumption of the diesel engine run on dual-fuel mode is higher than pure diesel mode. The opacity number of the engine run on dual-fuel mode is better than pure diesel mode. However, the CO number and HC number of the engine run on dual-fuel mode are higher than pure diesel mode. The diesel replacement ratio is within the range 15.6% % to 74.8%. It is recommended to run the present diesel engine in dual fuel mode with biogas flow rate 2 L/min - 4 L/min.

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