Performance of a small compression ignition engine fuelled by liquified petroleum gas

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Abstract. In this work, a small air cooled single cylinder of diesel engine with a rated power of 2.5 kW at 3000 rpm is tested in two different modes. In the first mode, the CI engines run on diesel fuel mode. In the second mode, the CI engine run on liquified petroleum gas (LPG) mode. In order to simulate the load, a generator is employed. The load is fixed at 800 W and engine speed varies from 2400 rpm to 3400 rpm. The out power, specific fuel consumption, and brake thermal efficiency resulted from the engine in both modes are compared. The results show that the output power of the CI engine run on LPG fuel is comparable with the engine run on diesel fuel. However, the specific fuel consumption of the CI engine with LPG fuel is higher 17.53% in average in comparison with the CI engine run on diesel fuel. The efficiency of the CI engine with LPG fuel is lower 21.43% in average in comparison with the CI engine run on diesel fuel.

1. Introduction
Green House Gases (GHGs) emission is a big problem for the world in the next decades. To avoid the catastrophe, many countries have committed on reducing their GHGs emission. The Government of Indonesia (GoI) has released its target on reducing GHG emissions by 26% from level business as usual (BAU) by 2020 and it can be increased up to 41% by international aid [1]. Recently, the GoI revised the target emissions reduction to 29% of BAU scenario by 2030. The source of emissions can be divided into 5 sectors, they are energy, waste, industrial and process, agricultural, and forestry. According to inventory in 2010, total Indonesian GHGs emission was 1,334 MTon CO2e. The BAU scenario in 2030 is 2,869 MTon CO2e. The emission target by 2030 is 2034 MTon CO2e or reduction of 834 MTon CO2e. Energy sector, individually, has a target of 314 MTon CO2e. It is 11% of the total reduction target. The energy sector includes all activities of burning fossil fuel and fugitive emissions. One of the strategies to achieve this target is promoting renewable energy fuel and or converting liquid fuel into gas fuel which has a lower CO2 emission [2]. In Indonesia, the main consumption of fossil fuel is diesel oil which is used in compression ignition (CI) engines [3]. The CI engines are mainly used in heavy machineries such as truck, agricultural engines, marine, and power plants. Thus, reducing diesel oil consumption will reduce GHGs
emissions significantly. On the other hand, in Indonesia fossil fuel (gasoline, diesel and kerosene) is still subsidized and it becomes a load for the GoI budget. These facts suggest that reducing diesel oil consumption in CI engines will give a significant impact on mitigation GHG emissions and it will help the GoI in reducing fossil fuel subsidy.

There are two methodologies that can be used to reduce diesel fuel in the CI engines. The first method is dual-fuel mode. Here, the diesel fuel is reduced and substituted by gas. The second method is gas fuel mode. In this method, the original CI engine is converted into spark ignition engine and fuelled by gas fuel such as biogas and liquified petroleum gas (LPG). In the CI engine with dual-fuel mode, after compression stroke, the compressed of fuel gas and fresh air, a number of diesel fuel, called the pilot, is injected to the combustion chamber [4,5]. In this work, we focus on the study of a CI engine run on pure gas. The CI engine is converted into spark ignition engine and fuelled with LPG. Several studies related to a CI engine fuelled with gas fuel have been found in literature. Chandra et al. [6] reported a study on the performance evaluation of a 5.9 kW CI stationary engine which is converted to spark ignition. The CI engine run on three different gas fuels. They are compressed natural gas (CNG), methane enriched biogas (Bio-CNG) and biogas produced from bio-methanation of Jatropha and Pongamia oil seed cakes. The composition of the methane-enriched biogas was 95% CH₄- 3% CO₂ and the biogas is 65% CH₄- 32% CO₂. The results showed that the methane-enriched biogas showed almost similar engine performance as compressed natural gas in terms of brake power output, specific gas consumption and thermal efficiency. Lee et al. [7] reported an experimental study on a 30kW biogas power generation enhanced by using waste heat to preheat inlet gasses. The effect of preheating the inlet gas to different temperature was investigated by employing a waste-heat recovery system. The results showed that power generation increases with increasing biogas methane concentration, except when excess air ratio less than 0.85. However, thermal efficiency increased with increasing methane concentration only when excess air higher than 0.95, although, on the relatively rich side, there was no benefit. The improved generator performance obtained by preheating the inlet gas was apparent when the excess air ratio is relatively high, such as bigger than 1.3. Homdoung and Tippayawong [8] reported a study on an agricultural CI engine, single cylinder, four strokes, indirect injection engine, 598 cc, and compression ratio of 22. The CI engine was converted into spark ignition engine and operated 100% on producer gas. The results showed that maximum brake thermal efficiency of 23.9% was obtained. The smoke density of the engine was lower than the diesel engine; however, CO emission was higher with similar HC emission. The same strategy was also used by [9, 10], converting an original CI engine into spark ignition engine and fuelled with biogas.

The above literatures show that study on CI engine run on gas fuel in order to decrease the diesel oil and GHGs emission has come under scrutiny. However, study on CI engine fueled with LPG has receive less attention. In this study, the performance of a small CI engine converted into spark ignition engine and fueled with LPG is investigated experimentally. The main objective here is to explore the performance characteristics of the CI engine if it is fueled with LPG. The performance of the CI engines run on LPG and diesel fuels are compared. The results are expected to supply the necessary information on development of alternative solutions for reducing GHGs emission in energy sector.

2. Method and equipment
In this study, a CI engine purchased from Indonesian market is used in the experiment. The commercial name of the engine is KAMA Model YL170F with rated power of 2.5 kW and
2.8 kW at engine speed 3000 and 3600 rpm, respectively. The type of the engine is an air cooled single cylinder four-strokes with dimension of stroke and bore is 70 mm and 55 mm, respectively. It is categorized as a small CI engine with a weight of 27 kg and typically found it is used by Indonesia small farmer. The specifications of the tested CI engine are presented in Table 1.

| No | Parameter                | Value                                         |
|----|--------------------------|-----------------------------------------------|
| 1  | Commercial name/model    | KAMA Diesel Engine YL170F                     |
| 2  | Number of cylinder/stroke| Single-cylinder/4 strokes and Vertical        |
| 3  | Cooling system           | Air cooled                                    |
| 4  | Bore × Stroke            | 70 mm × 55 mm                                 |
| 5  | Maximum power            | 3.8 kW at 3600 rpm                            |
| 6  | Rated power              | 2.5 kW at 3000 rpm and 2.8 kW at 3600 rpm     |
| 7  | Engine weight            | 27 kg                                         |
| 8  | Overall dimension        | 330 × 376 × 415                               |

2.1. Engine modification
In order to perform the study, an experimental apparatus has been designed and developed as shown in Figure 1. It consists of a unit of the tested CI engine, generator, series of lamps, LPG tank, gas mixer, and measurements apparatus. As stated in the previous section, the CI engine is tested in two different operation modes. In the first mode, the CI engine is tested without modification. The diesel fuel is used. In the second mode, since the gas fuel is used, several modifications are made. Cylinder head of the engine is modified by changing the nozzle and replaced it with spark plug. A gas mixer has been designed and developed in order to mix the fresh air with biogas. Here, an intake manifold is employed to inject the mixture into the engine.

![Figure 1. Experimental apparatus](image)

A crank angle signal is employed to detect the engine speed signal. The signal is used to regulate the combustion timing. In order to regulate the pressure of the LPG fuel before
injected to the engine, a gas regulator is used. Pressure of the LPG when it is mixed with fresh air is measured using a manometer. The engine speed is measured using a tachometer. An ignition coil connected with a power supply (battery) and crank angle signal is used to determine the combustion time.

In order to simulate the load, a generator with commercial name Brushless is employed. The generator is a self-exciting, 2-poles, single phase. Specifications of the generator are as follows. The rating frequency, rating voltage, rating power, and power factor are 50/60 Hz, 110-240 V, 0.8 – 1.1 kVA, and 1.0, respectively. The electricity from the generator is used to light a series of lamps which can be operated at load 400W and 800W. The diesel oil is purchased from PERTAMINA the government oil retailer in Indonesia. Before used, the LHV of the diesel oil is tested. The LHV and density of the diesel fuel is 42.64 MJ/kg and 0.82 kg/m³, respectively. The LPG used in this study is produced by PERTAMINA and retailed in the Indonesian market. It consists of 30% Propane and 70% Butane. The heating value and density at atmosphere are 48.8 MJ/kg and 1.71 kg/m³, respectively. The temperature is measured using thermometer type of KW 06-278 Krishbow with an accuracy range of ±0.5% ± 1°C. The load of electricity is measured using a Multi tester Meter CD800A. The revolution speed of the CI engine is measured using Tachometer.

The experiments are performed in two modes. In the first mode the CI engine is run on pure diesel. Here the load is fixed at 800 W and engine speed varied from 2600 rpm to 3400 rpm. For every engine speed, when the CI engine is stable, the measurement is carried out for 5 minutes. Electric power, fuel, temperature, and engine speed are measured. In the second mode, the CI engine is converted into spark ignition mode, the LPG from the tank is mixed with the fresh air in the mixer. The pressure of the LPG from the tank is decreased to 1.8 bar by using gas regulator. The same measurements with the pure diesel are performed. Every test is replied for three times and the measurement is averaged.

2.2. Problem formulation

To carry out the analysis, performance parameters are formulated. The used performance of the CI engine is discussed in term of electric power output, efficiency and specific fuel consumption. These parameters are elaborated in the following.

The resulted power \( P_e \) (Watt) of the CI engine is calculated by using the voltage and electric current resulted by the generator. The below equation is used.

\[
P_e = V \times I
\]  
(1)

where \( V \) [Volt] and \( I \) [Ampere] are voltage and current resulted by the generator, respectively. The next parameter is efficiency. It is defined as electric power resulted by the generator divided by total energy from the fuel burn in the CI engine. For the first mode, the CI with pure diesel fuel, it is calculated by using equation (2).

\[
\eta = \frac{P_e}{m_{\text{diesel}} \times H_{\text{diesel}}}
\]  
(2)

where \( H_{\text{diesel}} \) [kJ/kg] is the heating value of the diesel fuel. On the other hand, in the second mode, converted CI engine with LPG fuel, the efficiency is given by

\[
\eta = \frac{P_e}{m_{\text{LPG}} \times H_{\text{LPG}}}
\]  
(3)

where \( H_{\text{LPG}} \) [kJ/kg] and \( m_{\text{LPG}} \) [kg/s] is the heating value and mass flow rate of the LPG, respectively. The next comparison parameter is specific fuel consumption (\( \text{sfc} \) [g/kWh]). It is
a ratio of fuel consumption to the useful energy. Here, it can be viewed as how many gram of fuel is needed to produce 1 kWh of electrical energy. For diesel operation mode, it is given by:

\[ \text{sfc}_{\text{diesel}} = \frac{m_{\text{diesel}} \times 10^3}{P_e} \] ........ (4)

While for LPG fuel mode it is given by:

\[ \text{sfc}_{\text{LPG}} = \frac{m_{\text{LPG}} \times 10^3}{P_e} \] ........ (5)

Using the above formulated parameters, the performance of the CI engine is analyzed.

3. Results and Discussions
The results will be discussed in 4 subsections, they are output power, total efficiency, specific fuel consumption, and after test visualization of the combustion chamber.

3.1. Output power
The output power is calculated using the measured voltage and the current of electricity as formulated in equation (1). The electric power as a function of engine rotation speed for both diesel fuel and LPG fuel are shown in Figure 2. As a note, the load is fixed at 800 W. It can be seen clearly that, for both modes, the output power increases with increasing engine speed increases. The output power of the CI engine run on pure diesel is similar with the CI engine run on LPG fuel at the same speed. This figure reveals that the CI engine can be run with LPG fuel with output power comparable with the same engine run on pure diesel mode.

![Figure 2. Output power of the CI engine at load 1500 W](image)

3.2. Specific fuel consumption
Figure 3 shows the specific fuel consumption (sfc) as a function of engine speed. The specific fuel consumption can be viewed as a parameter to show how effective the heat energy in the fuel can be converted into power. Here, it is the ratio of fuel to electrical energy. The lower sfc is the better. The figure shows that sfc decreases with increasing engine speed. In the first mode, the highest and the lowest sfc is 0.59 and 0.98 kg/kWh, respectively. On the other hand, in the second mode, highest and the lowest sfc is 1.16 and 0.69 kg/kWh, respectively. These values suggest that sfc in the first mode is better than in the second mode. As expected, the CI engine run in pure diesel mode is better than the engine converted into spark ignition
engine. This is because the present CI engine is originally designed for being operated with diesel fuel. All of the system is designed for optimum operation for diesel fuel. Thus, operating the CI engine without any modification to improve the combustion process made the engine less effective.

![Engine speed vs. specific fuel consumption](image1.png)

**Figure 3.** Engine speed vs. specific fuel consumption

3.3. Efficiency

In this study, the calculated efficiency is different from thermal efficiency. In the thermal efficiency, the output will be measured as brake power. Here, the efficiency is calculated using the electric output power from the generator. The efficiency for both cases are shown in Figure 4.

![Engine speed vs. Efficiency](image2.png)

**Figure 4.** Engine speed vs. Efficiency

It can be seen in the figure that efficiency increases with increasing engine speed. As a note, the present engine has rated power of 2.5 kW and 2.8 kW at engine speed 3000 and 3600 rpm, respectively. In the experiment, the used load is only 800 W. It is far below the rated power. Thus, the present CI engine is operated far from its optimum efficiency. Thus,
the efficiency still far from its maximum value. The comparison of the CI engine with pure diesel and LPG shows that efficiency of the CI engine run on diesel mode is higher than efficiency of the LPG fuel. In the diesel fuel, the efficiency varies from 8.5% to 14.1%. In the LPG fuel, the efficiency varies from 6.7% to 11.2%. These values suggest that efficiency of the CI run on diesel fuel is higher than LPG fuel. The average difference is 21.5%. It’s because the CI engine is originally designed for diesel fuel. All of the system is designed for optimum operation for diesel fuel. Thus, operating the CI engine without any modification to improve the combustion process made the engine less efficient. The similar trend also shows by the specific fuel consumption.

3.4. After test visualization

The last parameter compared here is after test visualization. The photograph of the cylinder head of the engine before tested, after tested with diesel fuel and after tested with LPG fuel are shown in Figure 5. It is shown clearly, that the cylinder head of the engine is very clean before it is tested. After tested with diesel fuel, there was significant carbon deposition on the cylinder head. This fact clearly shown in Figure 5(b). However, the carbon reside is significantly lower in the cylinder head when the engine tested with LPG fuel, as shown in Figure 5(c). These carbon deposition reveals that operating the CI engine with LPG fuel make the engine cleaner and it can be operated longer. Thus, it needs less maintenance cost.

![Visualization of cylinder head before and after tested](image)

Figure 5. Visualization of cylinder head before and after tested

4. Conclusions

The performance of a small CI engine has been tested in two difference fuels. In the first mode, the diesel fuel is used and in the second mode LPG fuel is used. In the second mode, the CI engine is converted into spark ignition engine by replacing the oil pump into spark plug. The conclusions are as follows. The output power of the CI engine run on LPG fuel is comparable with the engine run on diesel fuel. However, the specific fuel consumption of the CI engine with LPG fuel is higher 17.53% in average in comparison with the CI engine run on diesel fuel. The efficiency of the CI engine with LPG fuel is lower 21.43% in average in comparison with the CI engine run on diesel fuel. It is suggested to increase the efficiency of
the CI engine run on LPG fuel by further modification in compression ratio and fuel injection system.

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