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Characterization of diesel engines fueled by dual fuel syngas gasification refused derived fuel (RDF) and dexlite

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Abstract

The increasing energy demand is accompanied by a decrease in fossil energy, it is necessary to develop alternative fuels. Refuse derived fuel (RDF) which is a processed product from urban solid waste (MSW) can be used as alternative energy using gasification technology. The application of the three-stage gasification technology made from RDF is able to produce syngas with a tar content below 100 mg/Nm3, so that it can be used in internal combustion engines with dual fuel diesel technology. This research was conducted experimentally with the aim of knowing the performance characteristics of a diesel engine using duel fuel syngas as a result of gasification of RDF and dexlite. The test was carried out with a constant rotation of the diesel engine at 2200 RPM with varying electrical loads starting from 500 Watts to 7000 Watts with 500 watt intervals. Blower is added to supply combustion air with mass flow rate variation: 0.0068 kg/s; 0.0073 kg/s; 0.0078 kg/s; 0.0083 kg/s; and 0.0088 kg/s. The research data measured the amount of dexlite that can be substituted with syngas, the specific value of fuel consumption, thermal efficiency, and engine operating temperature. The test results obtained that the dual-fuel system can substitute the highest dexlite of 43.45%, The results of this study can be used as a reference for the development of the use of dual fuel engines.

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Keywords

Diesel engine, refused derived fuel, dexlite

Introduction

Fossil fuels are the main source of energy for humans. The increase in the use of fossil fuels has eroded the amount of fossil fuel reserves in the world, so to overcome the limitations of fossil fuels, alternative fuels have been developed [1], [2], [3]. The increase in population and human activities also produces a relatively large amount of waste.

Areas with dense population, such as in big cities, of course produce large volumes of waste. Based on data from Indonesian Environmental Statistics [2, 3] that the production of municipal waste in Indonesia was 39,665 tons/day in 2019. Refuse Derived Fuel (RDF) is combustible waste and separated from the non-combustible parts through the process of counting, sifting and air classification. RDF is produced by mechanically separating the combustible fraction and the non-combustible fraction from the waste [4].

The technology that can be used to convert biomass into alternative energy without producing emissions is gasification [5]. This is the process of converting solid materials containing carbon or biomass into gas [6] [7]. The syngas produced by the gasification process can be applied to internal combustion engines [8]. Engines that use two different types of fuel are known as dual fuel. Dual fuel engine is an engine that has been modified to accept gaseous fuel that is fed into the engine intake channel or injected directly into the engine combustion chamber. Research on the dual fuel syngas system as a result of biomass gasification has been carried out by several researchers with different gasification feedstocks and pilot fuels.

The system used in this research is Combustion Air Gas Integration. This system works by mixing gas with air before entering the combustion chamber [9]. The research was conducted experimentally with a dual fuel system, syngas from refuse derived fuel (RDF) briquette gasification and biodiesel by installing a blower at the intake to increase the Air Fuel Ratio (AFR). From this study, it was found that the maximum loading of the dual fuel biodiesel and syngas system can reduce biodiesel consumption by 43.26% from the single fuel condition. The thermal efficiency value of a dual fuel system with a blower has increased by 54% from the standard single fuel biodiesel. The average dual fuel Air fuel ratio (AFR) increased by 14% at maximum blower usage. In this study, variations in loading were carried out to determine the effect on the performance characteristics of dual fuel with syngas produced from RDF gasification, so that it is expected to be able to get the best syngas character from the downdraft gasifier.

Methods

Research scheme

This experimental research uses a Diamond brand diesel engine model DI1100L which is connected to an electric generator brand Dong Feng model ST-10. The electric generator will be loaded with lamp loads at 500watt intervals. Syngas will be flowed into the intake channel on the diesel engine. Figure 1 is a picture of the research scheme and measurement parameters.

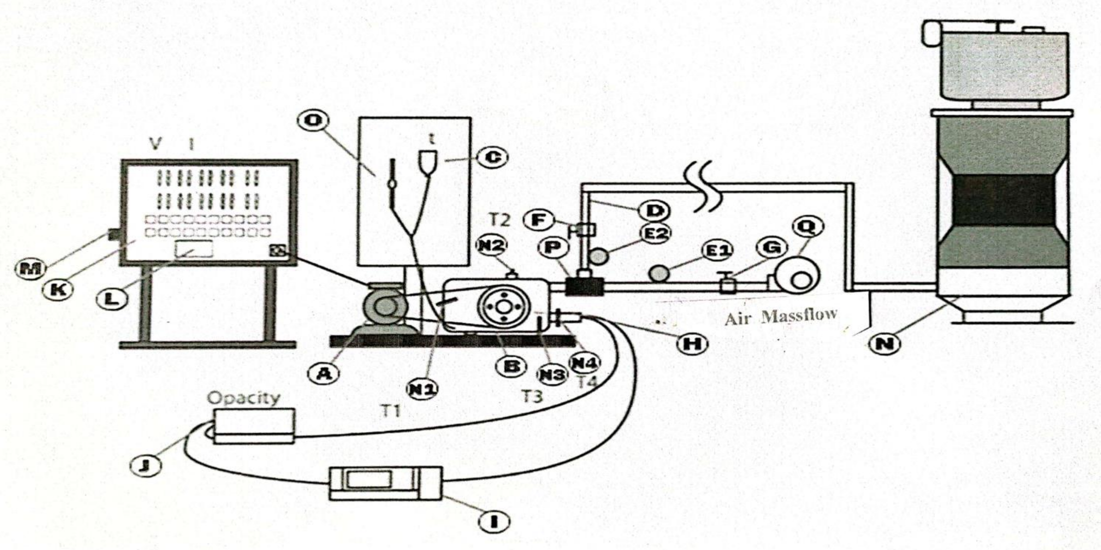

Figure 1. Research Scheme and Measurement Parameters

Information:

A. Generator
B. Diesel engine
C. Volumetric pipette
D. Intake line from reactor
E1. Pitot intake
E2. Intake valve of reactor
F. Free air intake valve
G. Exhaust
H. Stargas Analyzer
I. Stargas Analyzer
J. Smoke meter
N1. Engine temperature thermocouple
N2. Radiator temperature thermocouple
N3. Oil temperature thermocouple
N4. Exhaust temperature thermocouple
K. Lamp load
L. Ampere Scale
M. Display
N. Reactor
O. Volumetric Pipette
P. Mixer
Q. Blower

Measuring tool

1. Volumetric pipette

Volumetric pipette is used to measure the amount of fuel that will be used by a diesel engine. The volumetric pipette used has a capacity of 10 ml.

2. Tachometer

The tachometer is used to measure the rotational speed of the diesel engine. The tachometer used in this study is a tachometer with the Economic Non-Contact Pocket Optical Tachometer KRISBOW type.

3. Thermocouple logger

The Thermocouple Logger is used for logging temperature data from the thermocouple which will be inputted into the software on the computer. The thermocouple logger used in this study is a Vasco lab thermocouple logger model DAQ-517.

4. Pitot tube and digital manometer

The mass flow rate is measured through the pitot tube (Figure 2) in the pipe section. The mass flow rate value is obtained by calculating the difference between the pressures (δp) which can be seen on the digital manometer. The following is a schematic of the pitot tube:

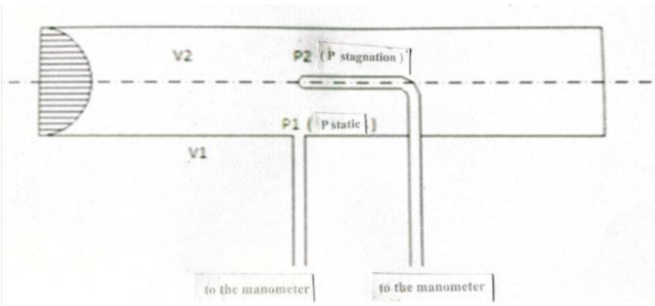

Figure 2. Pitot Tube

5. Smoke meter

Smoke meter is used to measure the smoke opacity of exhaust gases produced by diesel engines. The smoke meter used is an OTC Type 495 smoke meter. In this test, the STARGAS 898 gas analyzer is used as a reader.

6. Power meter display

Power meter Display is used to determine the amount of voltage and current generated by the diesel engine generator. Power meter Display used is a voltmeter type SELEC type MV305 and ammeter type SELEC type MA302

Fuel

Diesel fuel used is dexlite fuel obtained from PT. Pertamina Persero and syngas are obtained from the gasification of Refuse Derived Fuel (RDF) with a three-stage downdraft gasifier producing an LHV of 4448 kJ/Kg (Table 1).

Table 1. Composition of syngas from gasification of Refuse Derived Fuel (RDF) Volume Percentage (%)

	Volume Percentage (%)
CO	22.68
H2	11.54
CH4	0.00
CO2	8.45
O2	5.43
N2	51.90

Research variation

The variation of this research is the intake air mass flow rate is used as a variable that is regulated using a blower. The mass flow rate in the first variation is 0.0068 kg/s, 0.0073 kg/s, 0.0078 kg/s, 0.0083 kg/s and 0.0088 kg/s. The load given to the machine also varies, starting from 500-Watt to 7000-Watt for each variation with increasing loading done gradually with 500-Watt intervals.

Data calculation

The calculation of the power (Ne) produced by the diesel engine is carried out using the following equation:

$$Ne = \frac{V x\ l\ x\ Cos\varphi}{\eta_{generator}\ x\ \eta_{transmisI}} \quad (1)$$

The value of V is the voltage (Volts) and I is the current (Amperes) obtained from measurements using a power meter display is worth 0.9 and 0.95 [10].

Torque (Mt) is a measure of the engine's ability to produce work, or mathematically written as:

$$\text{Mt} = \frac{60\ X\ Ne}{2\pi n} \quad (2)$$

Where Ne is the power (Watt) obtained in equation (1), n is the engine speed (RPM).

Brake Mean Effective Pressure (bmep) is a piston working stroke caused by the working pressure of the combustion process of the air and fuel mixture. The amount of this pressure varies throughout the piston stroke. Changes in pressure on the piston are averaged so that the value is constant which makes the work value the same. The pressure is said to be work per cycle per piston stroke volume, or mathematically written as:

$$\text{bmep} = \frac{\text{NexZx60}}{\text{A x l x n x i}} \quad (3)$$

Where Ne is the power obtained in equation (1), A is the piston cross-sectional area (m2), l is the stroke length of the piston (m), i is the number of cylinders in the engine, n is the engine speed (RPM), and z is the type of stroke. Of the engine, in this case z is 2 because the engine is 4 strokes.

Specific fuel consumption (sfc) is the amount of fuel used in the engine to produce an effective power of one hp for one hour. The calculation of specific fuel consumption is carried out using the following equation:

$$\text{Sfc} = 3600\ \frac{\dot{\text{m}}\text{bb}}{\text{Ne}} \quad (4)$$

With is the use of material (kg) at a certain time (seconds) and Ne is the power obtained in equation (1).

The calculation of dexlite substitution in diesel engines is carried out using the following equation:

$$\text{Subtitution} = \frac{\dot{\text{m}}\ dexlite_{single} - \dot{\text{m}}\ dexlite_{dual}}{\dot{\text{m}}\ dexlite_{single}} \times 100\% \quad (5)$$

Where $\dot{\text{m}}\ dexlite_{single}$is the mass of dexlite fuel (kg/s) used during single fuel operation and $\dot{\text{m}}\ dexlite_{single}$ is the mass of dexlite fuel (kg/s) used during dual fuel operation.

Result and Discussion

Power

The generator set unit is operated at constant rotation at 2200 RPM to produce a stable voltage at 220 V. Figure 3 illustrates the amount of power generated by the engine in single fuel conditions using dexlite and dual fuel syngas & dexlite conditions with variations in the intake mass flow rate study air 0.0068 kg/s, 0.0073 kg/s, 0.0078 kg/s, 0.0083 kg/s, 0.0088 kg/s.

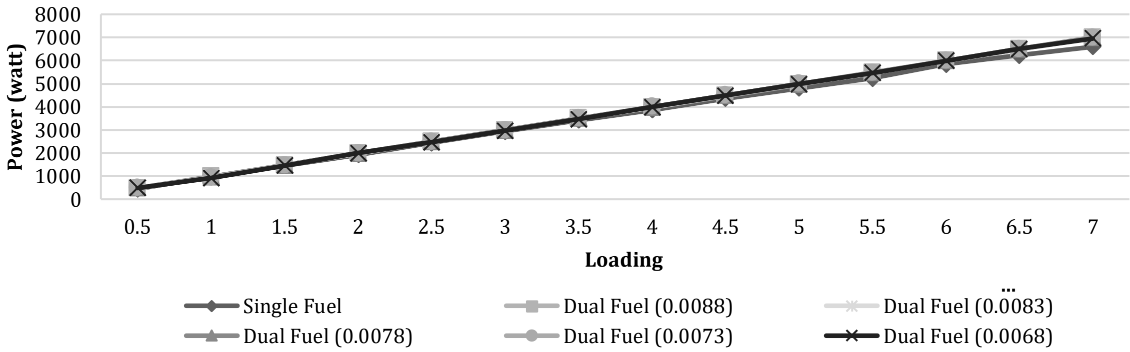

Figure 3. Graph of comparison of power to loading

Figure 3 shows that each variation has the same trend line between the power and load ratio, namely the power produced always increases as the load increases. This is caused by the engine speed being maintained consistently and the suitability of the air mass flow rate entering the combustion chamber with the air requirements to completely burn the fuel entering the combustion chamber in each variation.

The linear trendline in Figure 3 is in accordance with previous studies as shown by the results of research [11-13]. The linear trendline occurs because changes in the current and voltage values produced by the generator are also relatively small because the engine speed is kept constant at 2200 rpm by controlling the dexlite fuel intake using the governor mechanism.

Specific fuel consumption (sfc)

Sfc is the fuel consumption used by the engine to produce 1 kW of power for one hour. Figure 4 below is a graph of the sfc comparison of the condition of the single fuel engine and the condition of the dual fuel engine.

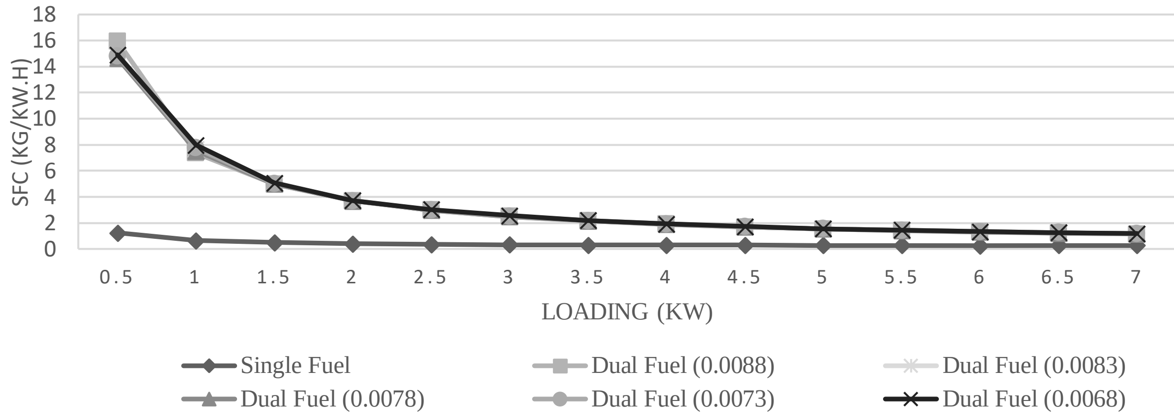

Figure 4. The comparison of sfc to loading

Figure 4 shows that the sfc values for all conditions decreased with increasing loading. At low load, the fuel entering the combustion chamber does not burn completely so that the engine produces low power. The sfc graph for a single fuel system is lower than that for a dual fuel system. This is because the amount of fuel that enters the combustion chamber every time in a dual fuel system is more than that of a single fuel system.

In the dual fuel engine condition, the syngas consumption is kept constant due to the constant flow of air through the venturi mixer for each loading, so the syngas mass flow rate does not change. However, with the addition of a constant load and mass flowrate of syngas, the dexlite consumption time decreases. So, the value of sfc decreases with increasing load, at the same mass of air flow.

The trendline in Figure 4 is in accordance with previous studies as shown by the results of the study [11, 12, 13]. The shape of the trendline decreases exponentially because the greater the addition of the air mass flow rate, the syngas mass flow rate will increase, so that the dexlite mass flow rate is getting smaller because syngas makes combustion in the combustion chamber bigger. If the combustion is large, the governor will automatically reduce the dexlite fuel flow rate. Based on the sfc formulation, the increasing syngas mass flow rate will cause the sfc dexlite to decrease. As the syngas mass flow rate increases, the dexlite mass flow rate will decrease and this factor causes the sfc to decrease.

Particulate emissions

Particulate matter (PM) is a mixture of solid and liquid particles in the exhaust gas. PM contained in the exhaust gas of diesel engines is carbon particles. The measurement of particulate matter used in this study uses a smoke meter which tests the optical properties of exhaust gases.

The measured opacity of the machine has a downward trend when it enters loading 1.5 to d. 3.5 kW and then will increase when loading 4 kW on single fuel engine conditions and the same trend on engines in dual fuel conditions. This indicates fuel combustion in the load range of 1.5 to d. 3.5 kW can burn both dexlite and syngas fuel in conditions that are close to optimal conditions so that the measured opacity of the exhaust gas is low.

The increase in opacity at loading 4 kW and so on indicates that the fuel mixture in the engine is in a rich condition so that the combustion occurs is not perfect and produces a higher carbon content than conditions in the range of 1.5 to d. 3.5 kW.

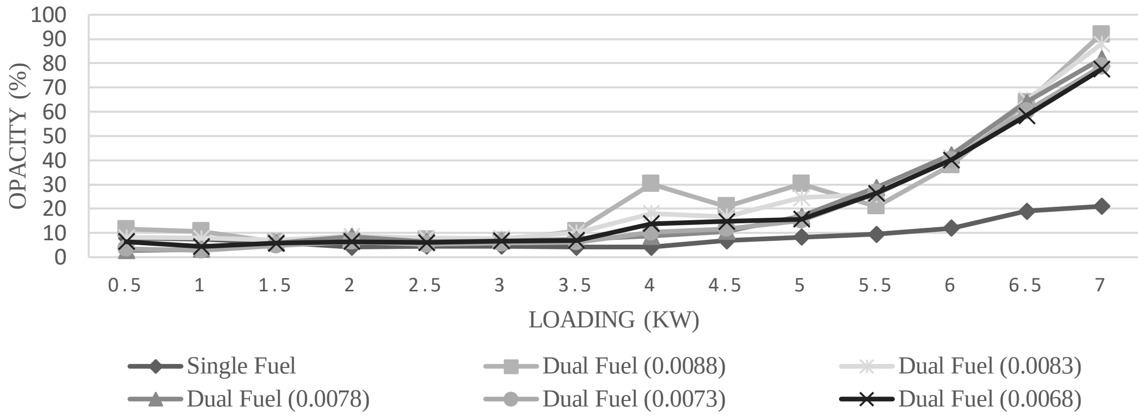

Figure 5. The comparison of the opacity of the diesel engine to the loading

This higher carbon content gives rise to dark colored exhaust gases. The opacity of the exhaust gases also increases when the engine is operated with a dual fuel system. Theoretically [14], for a dual fuel system, the addition of gas fuel to a diesel engine has a lower opacity value than the single fuel system. When compared to the actual data with the theory, the curve of the actual data is the opposite of the theory. Referring to Figure 5 that the ratio of air to fuel for combustion of a dual fuel system occurs in conditions that are rich in fuel, or it can be called a shortage of intake air. So that the combustion that occurs in the combustion chamber is not perfect and causes a high carbon content. The higher opacity under dual fuel conditions, especially at 4 kW loading, indicates that the higher loading is accompanied by the need to produce more power, more fuel is needed but at 4 kW loading, the combustion that occurs causes a high carbon content in the exhaust gas.

Air Fuel Ratio

The comparison chart of Air Fuel Ratio (AFR) shows that the air intake mass flow rate of 0.0068 kg/s is the lowest AFR condition, while the single fuel engine condition is the highest condition. This shows that the amount of fuel is more than the amount of air that enters. This results in a fuel-rich mixture. For standard conditions according to Heywood [15], ideally the AFR for diesel engines is in the range of 18≤ AFR 80. This means that the single fuel test has met the standard diesel engine AFR requirements.

Figure 6 shows that there are significant differences between the AFR of the single fuel system and the dual fuel system. In single fuel operation, the greater the load, the lower the AFR value. The dual fuel system has a very low AFR because when the engine is running on a dual fuel system, the mass flow rate of air entering the combustion chamber is almost half that of the engine when operated with single fuel. When operating in a single fuel state, the engine vacuum attracts a mixture of air and dexlite. Whereas in a dual fuel system, air must share a place with syngas. With the increase in the total mass flow rate of fuel (syngas and dexlite), the AFR becomes much smaller.

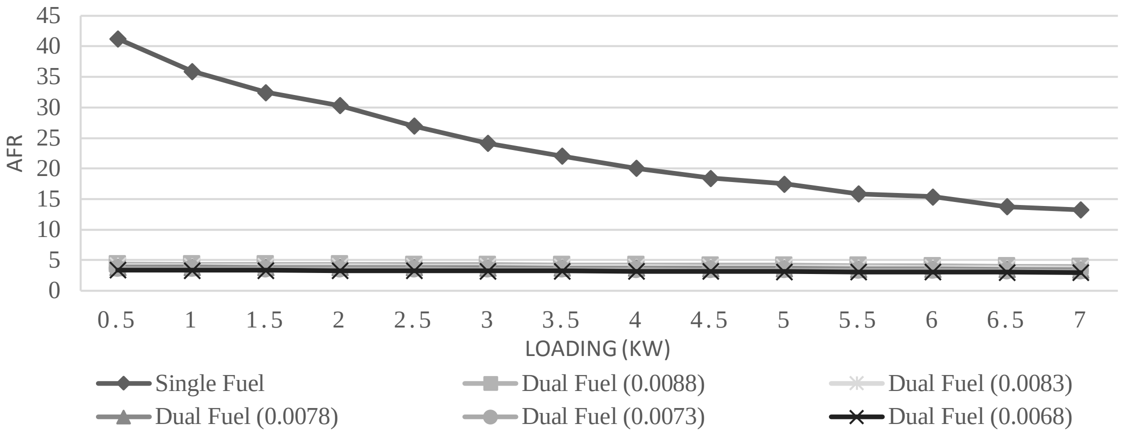

Figure 6. Engine AFR comparison to loading

In the single fuel state, as the load increases, the AFR gets richer. This is because the need for the engine to produce more power requires more fuel supply. Meanwhile, the mass flow rate of air that can pass through the intake manifold tends to remain the same.

Dexlite substitution

The addition of syngas to diesel engines aims to replace some of the dexlite fuel consumption. Below is a graph of the comparison of the percentage of substitution against loading.

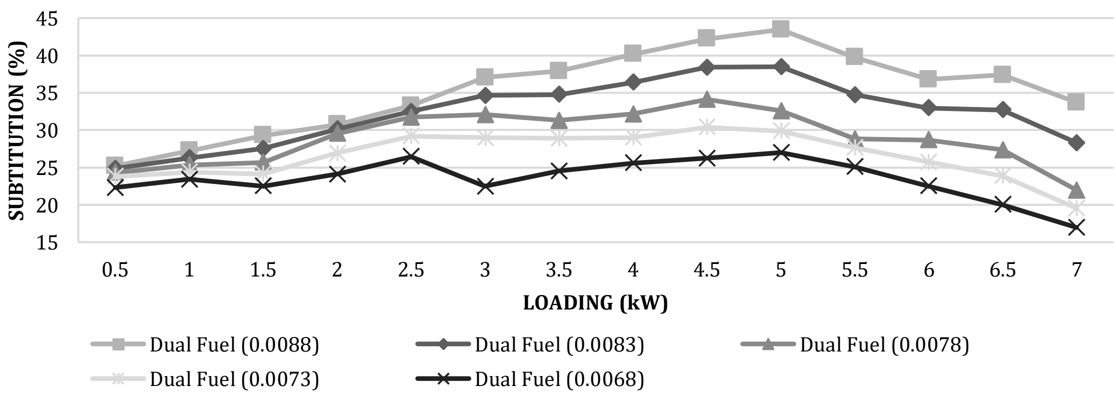

Figure 7. Comparison of dexlite substitution against loading

Figure 7 shows that the trend increases as the load increases and then decreases after reaching a certain point. This indicates that the presence of unburned syngas at low loading then also burns along with the increase in load. Syngas substitution appears to decrease when the load exceeds 5 kW. This indicates that the LHV of the syngas is insufficient to meet the power requirements so that the governor of the engine will adjust the consumption of dexlite fuel to be added. The largest syngas substitution was observed at the mass flow rate of the air intake of 0.0088 kg/s. The biggest substitution occurs at high blower pressure due to the use of a mixer in the form of a venturi in the intake channel. The greater the pressure measured in the intake channel, the greater the vacuum in the venturi so that more syngas will enter and mix more perfectly with the air.

Flue temperature operational characteristics

The operating temperature is a benchmark for the condition of the diesel engine when operating. The operating temperature will be represented by the oil temperature, exhaust gas temperature and engine temperature measured.

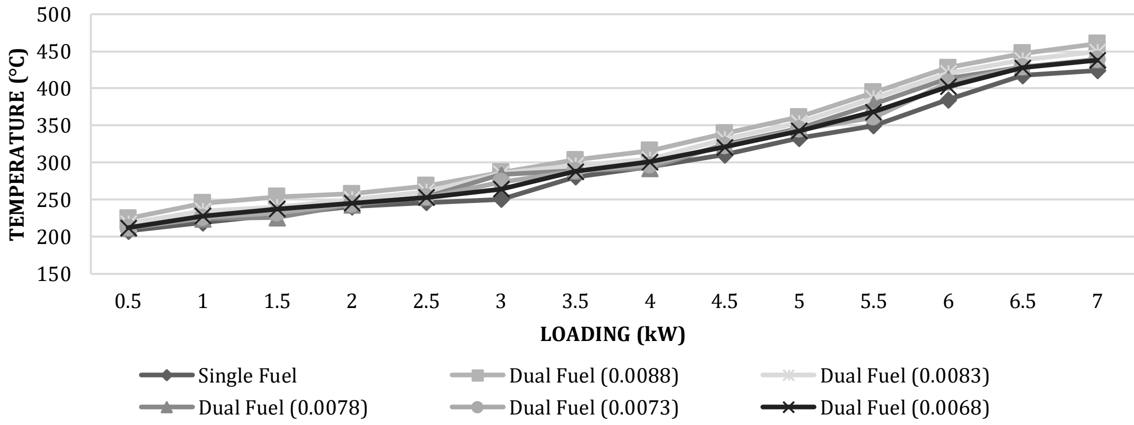

Figure 8. Engine oil temperature comparison with loading

Figure 8 shows that as the load applied to the engine increases, the temperature of the oil will increase. This is related to the function of the oil that works as a lubricant from the piston in the engine. The more quantity of fuel that is converted by the engine by the combustion process into heat energy released, it will increase the oil temperature. The oil will absorb the heat released from the combustion in the cylinder. The greater the quantity of fuel used, the higher the heat energy produced. In a dual fuel diesel system with the addition of syngas, it will provide an additional LHV value from the fuel entering the engine. The addition of the LHV value will cause additional heat energy generated in combustion so that the oil temperature in the dual fuel system will tend to increase when compared to a single fuel diesel engine.

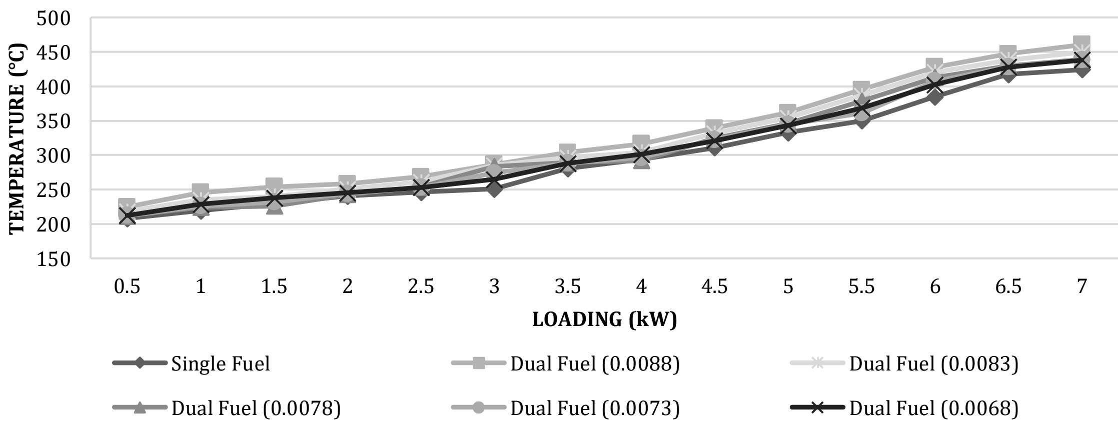

Figure 9. Comparison of engine exhaust gas temperature against loading

From Figure 9, it is known that as the load applied to the engine increases, the temperature of the exhaust gases will increase. This is related to the quantity of fuel converted by the engine in the combustion process into heat energy released. The greater the quantity of fuel used, the higher the heat energy produced. The graph on the mass flow rate variation of 0.0088 kg/s has the highest exhaust gas temperature value. This is caused by the large amount of air that enters the combustion chamber to react the fuel completely. Complete combustion produces higher energy.

Data from engine temperature is used to support data from exhaust gas temperature. Engine temperature is measured by placing a thermocouple on the cylinder head of the engine.

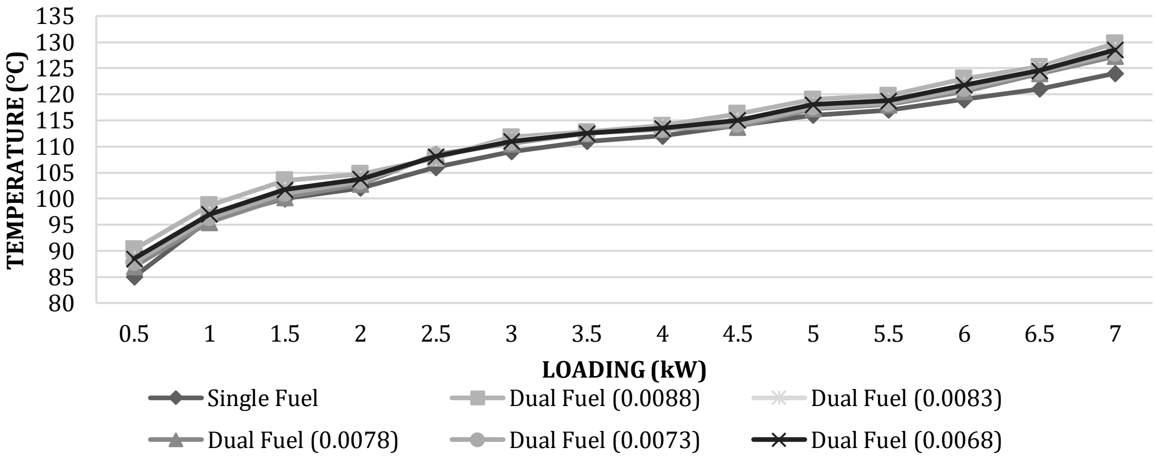

Figure 10. Comparison of engine temperature to loading

Figure 10 shows that as the load applied to the engine increases, the temperature of the engine will increase. This is related to the heat energy released from the combustion chamber channeled to the cylinder wall by convection and then propagates to the surface of the engine block by conduction. The more quantity of fuel that is converted by the engine by the combustion process into heat energy released, it will increase the engine temperature. In a dual fuel diesel system with the addition of syngas, it will provide an additional LHV value from the fuel entering the engine. The addition of the LHV value will cause additional heat energy generated in combustion so that the engine temperature in a dual fuel system will tend to increase when compared to a single fuel diesel engine. The graph on the mass flow rate variation of 0.0088 kg/s has the highest engine temperature value. This is caused by the large amount of air that enters the combustion chamber to react the fuel completely. Complete combustion produces higher energy.

Conclusion

The addition of a dual fuel system to a diesel engine can replace some of the diesel fuel consumption. The addition of syngas produced from refused derived fuel (RDF) gasification will increase the particulate emissions caused by the engine. Apart from the increase in emissions, the AFR in diesel engines with dual fuel systems will experience a significant decrease, so further efforts and research are needed to increase the AFR value. The operating conditions of the diesel engine in the dual fuel system will experience an increase in temperature, both at engine temperature, exhaust gas and oil. The decrease in dexlite fuel consumption in the experiment shows that syngas can generally be a renewable energy source. Gasification from refused derived fuel (RDF) has the potential to be an energy source that can be applied in Indonesia because of its abundance.

Acknowledgments

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