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Performance and Emissions Analysis of a Diesel-Engine Generator Using Producer Gas-Diesohol Oil in Dual Fuel Mode

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Abstract

Energy is essential to economic growth of developing countries and emerging economies. In Thailand, energy consumption is increasing continuously. Biofuels have been interesting to increase the energy saving, because they are available and cheap. Therefore, this research is to present about the performance and emission characteristics of an agricultural engine to use the dual fuel mode compared with the primary fuel mode. Dual fuel is the use of diesohol oil, produced from 90 percent of diesel oil and 10 percent of anhydrous ethanol and ethyl acetate, while it is combined with producer gas by increasing the flow rate from 76 to 85 lpm. Producer gas is generated from the charcoal biomass by using a small downdraft gasifier. In engine testing, speed is adjusted from 1,000 to 1,600 rpm at full load. Results show that the use of diesohol oil and producer gas on dual fuel mode has the increase of fuel saving and electrical efficiency and the decrease of SEC to compare with mode of diesohol oil only. For measuring the exhaust gas temperature and the CO and HC emissions, they are increased with increasing producer-gas flow rate on dual fuel mode. In addition, this research found that using Diesohol+PG85 lpm has the both characteristics of engine better than the use of diesel oil only.

Keywords: Diesohol, Producer gas, Engine performance, Emissions

1 Introduction

Energy is an important key for the economic growth of developing countries and new economies. In Thailand, energy consumption has increased steadily to drive the agriculture and transportation sectors because the main energy comes from the petroleum oils to use for the diesel engines, which are applied in producing the electricity of farms and driving the tractors, water pumps, heavy machineries etc. From this reason, several researchers are developing the new energy resources, such as alcohols, biodiesels and biomasses, to apply with the diesel engines Sutheerasak et al. (2017).

Alcohols and biodiesels are an alternative fuel applied for the diesel engines to decrease the main fuel consumption and the exhaust gas emissions, such as carbon monoxide (CO), hydrocarbon (HC) and black smoke, because they are made from the edible and non-edible plants and there is the oxygen (O_2) concentration which leads to better combustion as discussed in Kumar et al. (2013). Ethanol is one of the best alcohols used now to replace fuel, because it is produced from the agricultural plants in countries. For applying ethanol with the diesel engines, Kumar et al. (2013) discusses that using ethanol blended with diesel oil by the emulsion method called that diesohol oil. It increases the cetane number which led to more complete combustion. While biodiesels are synthesized from the vegetable oils and alcohols by the trans-esterification method, this method has more complexly than emulsion method. Moreover, biodiesels has higher fuel viscosity than diesohol oil.

Biomasses cannot use with the diesel engines directly, because they are the solid material. However, they can be converted to the gaseous fuel by the gasification method called that producer gas or syngas. It is generated from a thermo-chemical process, which converts the solid fuel based carbonaceous materials into carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2) and methane (CH_4). Currently, the producer gas becomes the alternative fuel that has been interesting to reduce an increasing demand for energy and high levels of hazardous emissions as discussed in Bates and Dölle (2017).

From 2015 to 2017, Mahgoub et al. (2015) and Bates and Dölle (2017) concluded that using syngas was secondary fuel for the internal combustion engines. If it was applied with the gasoline engines, it could ignite directly. Using this gave lower thermal efficiency than the use of primary fuel of these engines, because it had lower fuel heating value than. In addition, it had to investigate the lubricant and tar quantity. To compare with the diesel engines, they had to use the compressing ignition. Therefore, producer gas was used as fuel in the diesel engines by using the mode of dual fuel in which primary fuel was used as the pilot fuel and producer gas was introduced through the intake manifold of engine by using the box mixing or carburetor. Because, this technique was non-complex and reduced the quantity of tar, it cannot destroy the various parts within these engines.

A number of studies of using producer gas in dual fuel mode have been carried out. Brenneisen et al. (2013), Yadav (2013), Rich et al. (2016), Sutheerasak et al. (2017) and Singh and Mohapatra (2018) investigated the performance and emissions characteristics of the diesel engines by using the various engine speeds and loads. Producer gas was generated the gasifiers by using biomasses (such as sugarcane bagasse, carpentry waste, woods, waste wood chips, jatropha seeds, press cake and wood pellets) combined with diesel oil on dual fuel mode to compare with mode of using diesel oil only. Results demonstrated that there were the increase of thermal efficiency, the decrease of energy consumption and the increase of emissions (such as CO, HC and black smoke).

In addition, Bargat et al. (2012), Nayak and Acharya (2014), Nayak (2014), Hadkar and Amarnath (2015) and Yaliwal et al. (2016) had operated on dual fuel mode by using the producer gas and alternative fuels, such as biodiesels and vegetable oils, to reduce the exhaust gas emissions of diesel engine. However, the use of these oils had the effects on stability of engine operation because these oils had more fuel viscosity than diesel fuel. Consequently, they gave lower engine performance than mode of using diesel fuel only. On the other hand, diesohol oil has lower fuel viscosity than biodiesel oil but there are no research to study the using producer gas and diesohol oil on dual fuel mode. Therefore, the objective of proposed work is to present about the investigating characteristics of engine, such as performance and emissions, from using diesohol oil and produce gas operated on dual fuel mode for comparing with using the diesohol and diesel oils only.

2 Materials and Methods

2.1 *Producer gas*

Producer gas is generated from a producing gas system by using a charcoal ignited within a small downdraft gasifier (1). Specifications of the gasifier are shown in Table 1 (a) and Figure 1, which indicates a set-up experiment of the system of producing syngas fuel. First, charcoal about 6 kg from a weighing scale is fed into the small downdraft gasifier through the top. Air is entranced at the side of gasifier by using a blower (2) to accelerate the reaction time of gasification process.

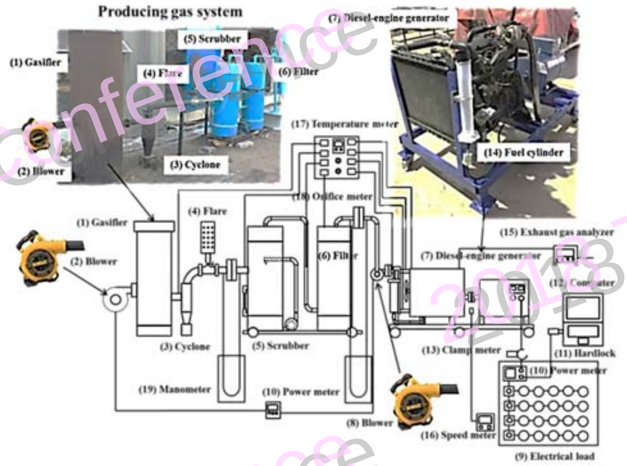

Figure 1 Schematic of experimental setup.

Next, charcoal is transformed to the hot producer gas and it is sent to a cyclone (3) to trap the solid particles. Then, the gas is investigated the ability of burning producer gas from a flare (4) and the gas is entered to a wet scrubber (5) to decrease its temperature and the quantity of tar. However, the cooled gas into the wet scrubber has the humidity in various quantities. To reduce the moistness, the gas is entranced to a sandbed filter (6) to clean again. Finally, the gas is inducted by the blower (8) to compress into a Y-shape mixing chamber and an intake manifold of diesel-engine generator (7). Properties of producer gas are shown in Table 1 (b). For measuring the producer-gas flow rate in each point, the concentric orifice plate (18) and the U-tube manometer (19) are applied in this research.

Table 1 Gasifier specification and Producer gas.

a. Gasifier specification	
Item	**Description**
Type of gasifier	Closed top
Maximum Capacity (kW_{th})	75
Rate charcoal consumption (kg/h)	5 to 6
Maximum rate gas flow (m^3/h)	96 (Charcoal)
Calorific Value (MJ/kg)	29.60
Biomass size (mm)	10 to 30
Efficiency (%)	70 to 75
Equivalence ratio	0.12 to 0.16
b. Producer gas properties	
Properties	**Description**
Hydrogen (%vol)	7.5±2.5
Carbon monoxide (%vol)	29.5±1.5
Carbon dioxide (%vol)	1.5±0.5
Methane (%vol)	1.5±0.5
Nitrogen (%vol)	57.5±2.5
Calorific value (MJ/Nm^3)	5.08±0.48

2.2 *Diesohol oil*

Diesohol oil is synthesized by the emulsion process at Chemical Engineering Department, Faculty of Engineering, Burapha University. Reactants use the diesel oil, anhydrous ethanol (which is a clear, colorless and homogeneous liquid free from suspended matter and consisting of at least 99.9% ethanol by volume at 15.6 °C) and ethyl acetate (which is used in a chemical emulsifier) by the electromagnetic machine. Ratio of diesel oil: anhydrous ethanol: ethyl acetate is 90:5:5 %vol. Next, there is the testing of fuel properties of diesohol compared with diesel oil shown in Table 2.

Table 2 Fuel properties.

Properties	Diesohol	Diesel
Viscosity @ 40 °C (mm^2/sec)	1.86	2.84
Density @ 15 °C (kg/m^3)	831	843
Flash point (°C)	13	69
Heating value (MJ/kg)	43.14	44.03

2.3 Experimental setup

The experiments are carried out on an engine, which is the three-cylinder diesel engine to use the four-stroke, water-coolant and direct-injection system, with specifications shown in Table 3. It is connected with an AC generator 20±5 kW_e on the stand. Loads added to the engine use the electric lamps (9). Recording data of output electrical power to depend on the electrical load is analyzed from a power meter of richtmass RP-96EN (10) through the clamp IMARI-CT100/1A by converting the signal into the richtmass RS485 with USB data converter and hardlock (11) for RP series to connect with a computer (12). In addition, there is the calibration of power-meter parameters with a clamp meter (13). For recording the fuel flow rate to calculate the fuel consumption rate, a fuel cylinder (14) is applied in this research. Intake air flow is measured from the orifice plate (18) and the U-tube manometer (19). Temperatures (such as coolant, air intake, exhaust gas and producing gas system) are recorded from the temperature meters (17). Carbon monoxide (CO) and hydrocarbons (HC) emissions are analyzed from the MOTORSCAN: 8020 eurogas emission analyzer (15) by using IR Bench (Infrared measuring) method.

Table 3 Agricultural engine specification

Item	Description
Model	John Deere 3029DF150
Engine Type and aspiration	In-line, 4-stroke, low speed
Number of cylinder (cyl)	3
Displacement (L)	2.9
Bore x Stroke (mm)	106 x 110
Compression ratio	17.2 : 1
Power (kW)/ speed (rpm)	43 /2,500
Torque (N.m)/ speed (rpm)	191 /1,600

2.4 Experimental procedure

Engine performance testing is carried out at the automotive biofuels and combustion engineering research laboratory in Faculty of Engineering, Burapha University. First, engine is warmed up about 15-20 min by using the diesel oil and then the engine testing starts up by adjusting engine speed at 1,000±50 rpm until 1,600±50 rpm by using fully electrical load. After speed and load are steady in these conditions, there is the record of parameters, such as the electrical power, the fuel consumption rate by recording the time of using 20 ml of fuel, temperatures (such as coolant, air intake, exhaust gas and producing gas system) and exhaust gas emissions, such as CO and HC. Next, fuel is converted to diesohol oil and used the same conditions as the diesel oil testing after that there are the record of parameters to compare with diesel oil.

While the mode of diesohol oil is completed, there is the start of dual fuel mode by closing valve of the flare (4) in the producing gas system to send the producer gas into the instruments (such as a cyclone, a wet scrubber and a sandbed filter). Next, producer gas is sucked by blower (8) into the Y-shape mixing chamber to increase the producer-gas flow rate from 76 to 85 lpm while diesohol oil is injected in normal injection timing of the engine. In this mode testing, there is the use of same condition as the using mode of diesel oil and diesohol oil only after that there are the record of parameters to compare with both oils. Finally, all results from using the dual fuel mode and the mode of only diesel oil and only diesohol oil are applied to analyze the performance and emission characteristics.

2.5 Performance characteristics analysis

In this research, the power output is shown in value of the electrical power. Engine performance analysis (Heywood (1988)) is determined from thermal efficiency and specific energy consumption. This can be calculated as follows:

$$\eta_{ele} = \frac{P_{ele}}{\dot{m}_f HV_f + \dot{m}_{PG} HV_{PG} + P_{pump}\eta_{pump}} x100 \quad (1)$$

$$\eta_{pump} = \frac{\dot{V}_{PG}\Delta p_t}{102P_{pump}} x100 \quad (2)$$

$$SEC = \frac{\dot{m}_f HV_f + \dot{m}_{PG} HV_{PG} + P_{pump}\eta_{pump}}{P_{ele}} \quad (3)$$

Where

η_{ele} : Electrical efficiency (%)
η_{pump} : Pump efficiency (%)
SEC : Specific energy consumption (MJ/kW_e.h)
P_{ele} : Electrical power (kW_e)
P_{pump} : Pump power (kW_e)
$\dot{V}_{PG}$: Volume flow rate of producer gas (m^3/sec)
$\dot{m}_f$: Fuel flow rate (kg/sec)
$\dot{m}_{PG}$: Mass flow rate of producer gas (kg/sec)
Δp_t : Total differential pressure (mm_{WC})
HV_f : Heating value of fuel (MJ/kg)
HV_{PG} : Heating value of producer gas (MJ/Nm^3)

3 Results and Discussion

In the agricultural engine testing from 1,000 to 1,600±50 rpm at full load using the dual fuel mode, which is the use of diesohol oil (Diesohol) is primary fuel and the flow rate of producer gas (PG) is increased at 76 lpm, 79 lpm and 85 lpm as secondary fuel respectively. Terms are demonstrated as Diesohol+PG76 lpm, Diesohol+PG79 lpm and Diesohol+PG85 lpm respectively. Results from the testing are described below.

3.1 Fuel consumption rate

Figure 2 shows that the fuel consumption rate (FCR) increases with increasing speed. Using dual fuel mode by increasing producer-gas flow rate from 76 to 85 lpm to combine with diesohol oil has less FCR than the mode of diesohol oil only. Because the mixing of diesohol oil and producer gas is ignited very quickly with increasing gas flow rate, leading to increasing specific energy output. To keep total energy constant, fuel consumption rate must be decreased (Mahgoub et al. (2015), Bates and Dölle (2017) and Singh and Mohapatra (2018)).

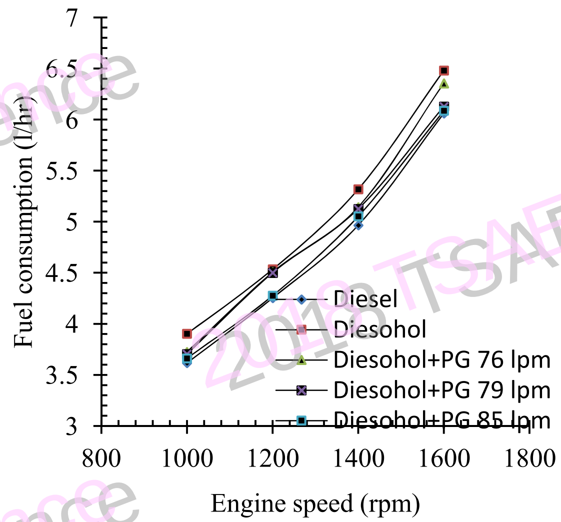

Figure 2 Fuel consumption rate with increasing speed and producer gas flow.

Considering at maximum speed at 1,600 rpm from using fuels such as Diesohol, Diesohol+PG76 lpm, Diesohol+PG79 lpm and Diesohol+PG85 lpm, FCR equals 6.48, 6.35, 6.13, 6.09 lph respectively and decreased from 1.94 to 6.09% to compare with the Diesohol. This research found that using Diesohol+PG85 lpm has the FCR equaled to mode of diesel oil only. Because diesohol oil has less heating value than diesel oil, increasing producer-gas flow rate combined with diesohol oil improves the combustion efficiency and decreases the pilot diesohol oil quantity (Kumar et al. (2013), Mahgoub et al. (2015), Bates and Dölle (2017) and Singh and Mohapatra (2018)).

3.2 Electrical efficiency

Figure 3 indicates that the electrical efficiency increases with adding speed. Using dual fuel mode at various producer-gas flow rates combined with diesohol oil has higher electrical efficiency than the mode of diesohol oil only. It causes from the start of combustion quickly because there is the increase of producer-gas flow rate. From this reason, there is the decrease of pilot diesohol oil quantity with increasing producer-gas flow rate. Moreover, using dual fuel mode has lower total energy input than using mode of diesohol oil only while this reason leads to increase electrical efficiency (Sutheerasak et al. (2017), Mahgoub et al. (2015), Bates and Dölle (2017),Yadav (2013) and Hadkar and Amarnath (2015)).

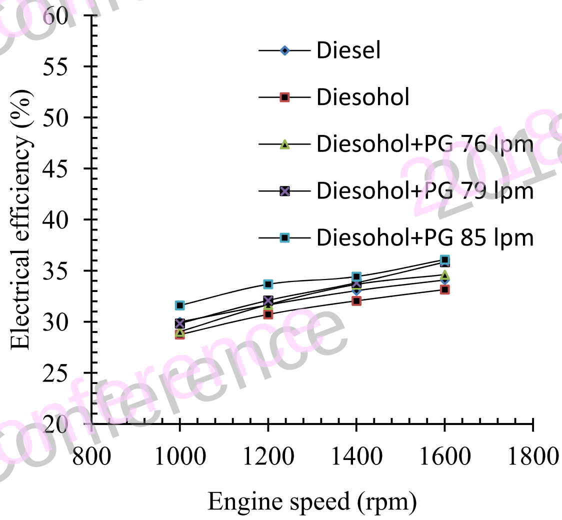

Figure 3 Electrical efficiency with increasing speed and producer gas flow.

Considering at maximum speed from using Diesohol, Diesohol+PG76 lpm, Diesohol+PG79 lpm and Diesohol+PG85 lpm, electrical efficiency equals 33.14, 34.61, 35.85 and 36.08% respectively and added from 1.47 to 2.94% to compare with Diesohol. In addition, this research found that using Diesohol+PG85 lpm has the increase of electrical efficiency up to 1.99% to compare with mode of diesel oil only. Because diesohol oil and producer gas have less heating value than diesel oil, increasing producer-gas flow rate combined with diesohol oil improves the combustion efficiency and decreases the pilot diesohol oil quantity (Kumar et al. (2013), Bates and Dölle (2017) and Mahgoub et al. (2015)).

3.3 Specific energy consumption

Figure 4 observes the specific energy consumption (SEC) reduces with increasing speeds. Using various flow rates of producer gas on dual fuel mode have lower SEC than the mode of diesohol oil only. Considering at maximum speed from using Diesohol, Diesohol+PG76 lpm, Diesohol+PG79 lpm and

Diesohol+PG85 lpm, SEC equals 10.86, 10.40, 10.04 and 9.98 MJ/kW$_e$.h respectively and reduced from 4.24 to 8.15% to compare with Diesohol.

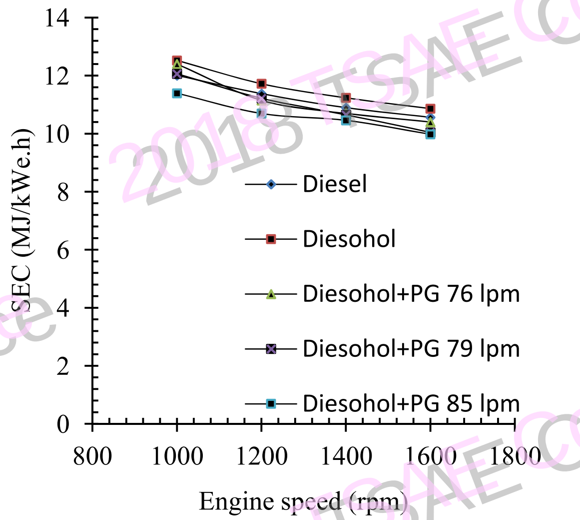

Figure 4 Specific energy consumption with increasing speed and producer gas flow.

In addition, using Diesohol+PG85 lpm has the decrease of SEC at 5.53% compared with mode of diesel oil only. Because the SEC is inversely proportional to the electrical efficiency, if this efficiency is added with various flow rates, the SEC decreases in accordance with corresponding these flow rates also (Sutheerasak et al. (2017) and Yadav (2013)).

3.4 Exhaust gas temperature

Figure 5 shows that the exhaust gas temperature increases with adding speed. Using the increase of producer-gas flow rate in this mode has higher the exhaust gas temperature than mode of diesohol only. Because using diesohol oil and increasing quantity of producer gas on dual fuel reacted with oxygen in combustion chamber are rich mixture, they have too much fuel and not enough air in the cylinder. From this reason, they have higher late of combustion than using diesohol oil only which leads to higher exhaust gas temperature (Bates and Dölle (2017), Hadkar and Amarnath (2015) and Yaliwal et al. (2016)).

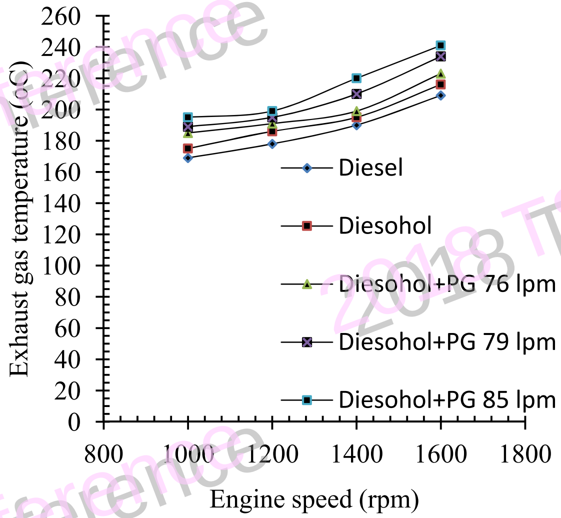

Figure 5 Exhaust gas temperature with increasing speed and producer gas flow.

Considering at maximum speed from using Diesohol, Diesohol+PG76 lpm, Diesohol+PG79 lpm and Diesohol+PG85 lpm, exhaust gas temperature equals 216, 223, 234 and 241 °C respectively and increased from 7 to 25 °C to compare with Diesohol. For using the Diesohol+PG85 lpm to compare with mode of diesel oil only, exhaust gas temperature increases at 32 °C because diesohol oil has the O_2 concentration and using producer gas on dual fuel mode is quickly the start of combustion. Both reasons lead to the increase of burning temperature and exhaust gas temperature (Kumar et al. (2013), Hadkar and Amarnath (2015) and Yaliwal et al. (2016)).

3.5 Carbon monoxide emission

Figure 6 indicates that carbon monoxide (CO) emission increases with increasing speed. To consider the increase of producer-gas flow rate in dual fuel mode by comparison with mode of diesohol oil only, it has more the CO emission than mode of diesohol only. Because there is the incomplete combustion from the rich mixture combustion, leading to the presence of elevated levels of CO emission (Bates and Dölle (2018), Mahgoub et al. (2015), Hadkar and Amarnath (2015) and Yaliwal et al. (2016)).

At maximum speed from using only diesohol oil and diesohol oil combined with increasing producer gas flow rate from 79 to 85 lpm, CO emission equals 0.23, 0.35, 0.38 and 0.45%vol respectively and added from 0.12 to 0.22%vol to compare with using diesohol oil only. For using the Diesohol+PG85 lpm to compare with mode of diesel oil only, CO emission increases at 0.17%vol because using dual fuel mode is the rich mixture combustion, this reason may lead to the incomplete combustion in the mixing-controlled combustion phase (Kumar et al. (2013), (Bates and Dölle (2018), Mahgoub et al. (2015), Hadkar and Amarnath (2015), Yaliwal et al. (2016) and Heywood (1988)).

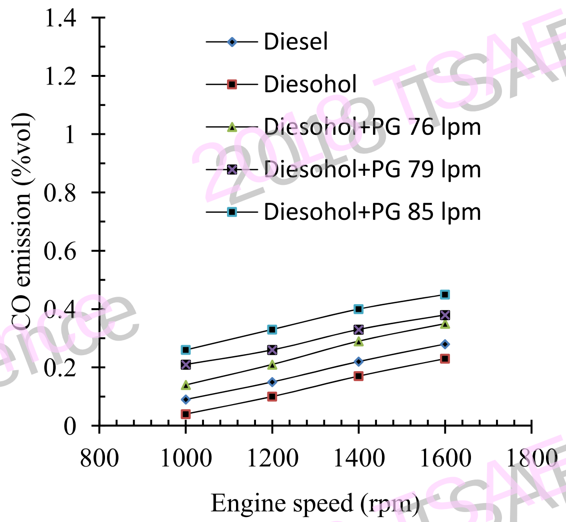

Figure 6 Carbon monoxide emission with increasing speed and producer gas flow.

3.6 Hydrocarbon emission

Figure 7 shows that hydrocarbon (HC) emission increases with adding engine speed. For using dual fuel to have the increase of producer-gas flow rate to combine with diesohol oil, there is more HC emission than the use of only diesohol oil and this result corresponds to the increase of CO emission.

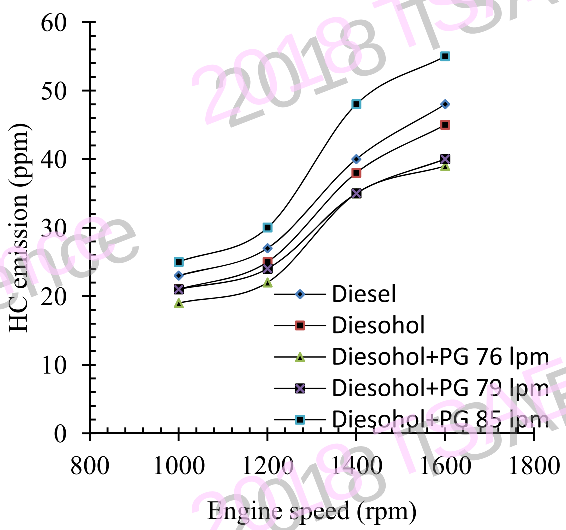

Figure 7 Hydrocarbon emission with increasing speed and producer gas flow.

For using Diesohol, Diesohol+PG76 lpm, Diesohol+PG79 lpm and Diesohol+PG85 lpm, HC emission equals 45, 39, 40 and 55 ppm respectively and increased to 15 ppm to compare with Diesohol. However, this research found that using Diesohol+PG76 lpm and Diesohol+PG79 lpm have lower HC emission than using diesohol and diesel oils only. Use of Diesohol+PG76 lpm and Diesohol+PG79 lpm to compare with only diesel oil has the HC emission to decrease at 6 and 5 ppm respectively. Because diesohol oil has the O_2 concentration, it is reacted with carbon atom in the structure of the fuel mainly (Hadkar and Amarnath (2015), Yaliwal et al. (2016) and Heywood (1988)).

4 Conclusions

From applying producer gas to combine with diesohol oil on dual fuel mode for the agricultural engine summarized as follows:

Increasing flow rate of producer gas combined with diesohol oil on dual fuel mode has the increase of fuel saving to compare with mode of diesohol oil only, while using Diesohol+PG85 lpm has the fuel consumption rate to equal the use of diesel oil only.

Electrical efficiency from the dual fuel which is the use of diesohol oil combined with increasing flow rate of producer gas is higher than using diesohol oil only, while using Diesohol+PG85 lpm gives the electrical efficiency up to 1.99% to compare with using diesel oil only. On the other, use of dual fuel is lower SEC than the use of diesohol and diesel oils only.

Exhaust gas temperature from using producer gas and diesohol oil on dual fuel mode increases with increasing producer-gas flow rate, while using Diesohol+PG85 lpm has higher exhaust gas temperature than the use of diesel oil only.

CO and HC emissions are increased with increasing producer-gas flow rate on dual fuel mode, while the use of Diesohol+PG76 lpm and Diesohol+PG79 lpm have lower HC emission than using diesohol oil only and diesel oil only.

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