Investigation of Supercharging Producer Gas in Dual Fuel Mode on the Performance and Emissions of a Diesel-Engine Generator

Ekkachai Sutheerasak, Worachest Pirompugd, and Surachai Sanitjai

***Abstract*—The objective of proposed work is to present about engine performance and emissions analysis of a diesel engine using the diesel fuel and the supercharging producer gas in dual fuel mode compared with only diesel fuel mode. Producer gas is generated from a small downdraft gasifier 75 kW using a charcoal as the primary fuel. Results of performance and emissions at engine speed 1,600 rpm show that using diesel fuel and supercharging producer gas at various flow rates in dual fuel mode increase the electrical power and electrical efficiency and decrease the energy consumption. Carbon monoxide, hydrocarbons and black smoke emissions increase with increasing producer-gas flow rate. Compressing producer gas at 125 lpm indicates that there is the highest diesel saving at 40% on engine speed of 1,200 rpm.**

***Index Terms*—Producer gas, supercharging, performance, emissions.**

I. Introduction

Thailand used the renewable energies up to 9.0 Mtons in 2015, while they increased from previous year to 11.9 percent of alternative energies. Those energies mainly came from using biomasses. Since 2015 to 2036, the policy of energy ministry requires to increase the use of biomasses more than 20-25 percent of renewable energies. First target is the use of producer gas or syngas fuel generated from biomasses on a thermo-chemical gasification process with internal combustion engines [1].

Diesel engines are widely used in agricultural farms and small factories. To reduce the use of diesel fuel and high levels of hazardous emissions from the engine, researchers study the using producer gas with diesel engines in the dual fuel mode in which diesel fuel is used as the pilot fuel and producer gas is introduced through a carburetor to mix with air before entranced to intake manifold. Because, this way is uncomplicated method, it helps in diesel fuel saving and there are lower cost and non-modifications [2], [3].

A number of studies of the use of producer gas in dual fuel mode have been carried out. Reference [1] used wood pellet to generate the producer gas introduced to the intake manifold by compressing producer gas from 46 to 64 lpm and diesel fuel was injected into the engine as primary fuel. The maximum diesel saving was 34% at engine speed 2,200 rpm and producer gas flow rate 64 lpm. Reference [4] produced the syngas fuel from the jatropha seeds and press cake by testing with the small diesel engine at constant speed and various loads. Diesel consumption decreased 52.7% and the exhaust gas emissions, such as carbon monoxide (CO) and carbon dioxide (CO_2) emissions, increased with increasing load. Reference [5] investigated the performance and emissions of a dual-fuel engine at constant speed and various loads by using diesel fuel combined with producer gas, which it was generated from sugarcane bagasse and carpentry waste, by using the gas flow rate 5.07 Nm^3/h. Diesel consumption decreased 45.7% and there was the increase of emissions, such as CO and hydrocarbons (HC). Reference [6] studied the performance and emission characteristics of the dual-fuel diesel engine by changing compression ratio from 12 to 18 at constant speed and full load. Diesel fuel was injected in normal timing, and syngas fuel produced from the sawdust and cotton stalks and it was entranced to intake manifold at constant gas flow rate. Using compression ratio from 16 to 18 had the decrease of diesel fuel consumption from 57.14 to 64.30%. Moreover, the use of higher compression ratio had higher engine performance and lower emissions than the use of lower compression ratio in dual fuel mode.

In addition, Reference [7] increased the ratio of hydrogen mixed with producer gas as secondary fuel while diesel fuel was injected into the engine as primary fuel at constant speed and various loads. Increasing hydrogen combined with producer gas gave the combustion characteristics better than the use of only producer gas combined with diesel fuel on dual fuel mode. Reference [8] studied the performance characteristic of the dual-fuel engine by changing the composition of syngas fuel at constant gas flow as secondary fuel while pilot diesel fuel was primary fuel, and Researchers [9], [10] investigated the performance, combustion and emission characteristics of diesel engine from using the constant producer gas flow rate combined with diesel fuel or biodiesel oil.

From many different types of literature reviews, producer gas flow rate is one of the most important keys that can control the diesel saving and engine characteristics. However, previous researched mainly focused on the effect of constant gas flow rate on the engine characteristics. The objective of proposed work is to present about the study of performance and emissions characteristics of the diesel-engine generator in dual fuel mode from increasing producer gas flow rate by supercharging and diesel fuel which is injected into the engine as primary fuel.

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II. Methodology

A. Producer Gas

Producer gas was 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 I and Fig. 1, which indicates a set-up experiment of the system of producing syngas fuel.

TABLE I: Gasifier Specification

Item	Description
Type of gasifier	Closed top downdraft
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

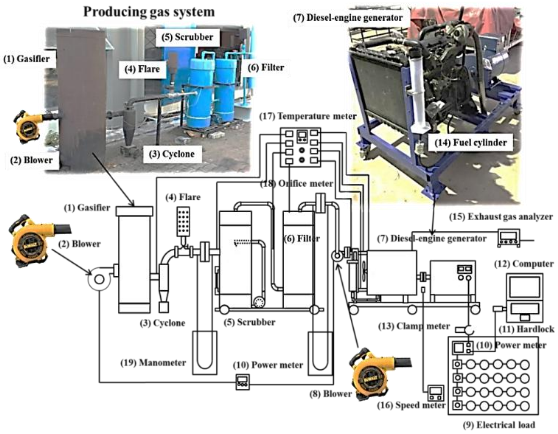

Fig. 1. Schematic of experimental setup.

First, charcoal about 6 kg from a weighing scale was fed into the small downdraft gasifier through the top. Air was entranced at the side of gasifier by using a blower (2) to accelerate the reaction time of gasification process. Next, charcoal was transformed to the hot producer gas and it was sent to a cyclone (3) to trap the solid particles. Then, the gas was investigated the ability of burning producer gas from a flare (4) and the gas was entered to a wet scrubber (5) to decrease its temperature and the quantity of tar. However, the cooled gas into the wet scrubber had the humidity in various quantities. To reduce the moistness, the gas was entranced to a sandbed filter (6) to clean again. Finally, the gas was 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 II. 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 II: Producer Gas Properties

Properties	Volume percentage
Hydrogen (%)	7.5±2.5
Carbon monoxide (%)	29.5±1.5
Carbon dioxide (%)	1.5±0.5
Methane (%)	1.5±0.5
Nitrogen (%)	57.5±2.5
Calorific value (MJ/Nm^3)	5.08±0.48

B. Experimental Setup of Diesel-Engine Generator Testing

The experiments were carried out on a four-stroke three cylinder direct injection (DI) diesel engine, with specifications shown in Table III. It was connected with an AC generator 20±5 kW_e by using electric lamps in adding the electrical load (9). Recording data of output electrical power to depend on the electrical load was 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 was the calibration of power-meter parameters with a clamp meter (13). For recording the diesel flow rate to calculate the diesel saving, a fuel cylinder (14) was applied in this testing. For analyzing concentration of exhaust gas emissions, such as CO and HC, they were measured from MOTORSCAN: 8020 eurogas emission analyzer (15) by using Infrared measuring method. For measuring black smoke, MOTORSCAN: 9010 opacity meter/smoke detector (15) was applied in this experiment.

TABLE III: Engine Specification

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

C. Experimental Procedure

Diesel-engine generator testing was carried out at the automotive biofuels and combustion engineering research laboratory in the Department of Mechanical Engineering, Faculty of Engineering, Burapha University, the engine was firstly warmed up about 15-20 min. Room temperature in the engine performance testing was determined at 30±2 °C and all experiments were recorded in the period of 50 to 100 hours by reference from the standard of engine testing [1]. After engine operation was constant, experiments started up by adjusting engine speed from 1,000 to 1,600±50 rpm and fully electrical load by using only diesel fuel and set the amount of fuel at 20 ml for investigating the diesel consumption rate.

In this time, there was the measurement of temperatures (such as coolant, air intake, exhaust gas and producing gas system) from temperature meter controller (17) and then there was the measurement of exhaust gas emissions, such as CO, HC and black smoke. After finishing in only diesel fuel mode testing, there was 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 was compressed by blower (8) into the Y-shape mixing chamber to increase the producer-gas flow rate from 76 to 125 lpm while diesel fuel was injected in normal injection timing of the engine. In this mode testing, there was the same condition as well as on only diesel fuel mode at same speed and full load. Finally, all experiments from using dual fuel and only diesel fuel mode were applied for analyzing the engine performance characteristics.

III. Results and Discussion

A. Diesel Consumption Rate

Diesel consumption rate (DCR) is calculated from amount of diesel fuel at 20 ml divided by real time at engine speed from 1,000 to 1,600±50 rpm at full load. This investigation uses the dual fuel mode, which is the use of diesel fuel as primary fuel and supercharging producer gas from 76 to 125 lpm as secondary fuel, compared with only diesel fuel mode shown in Fig. 2 on the left side.

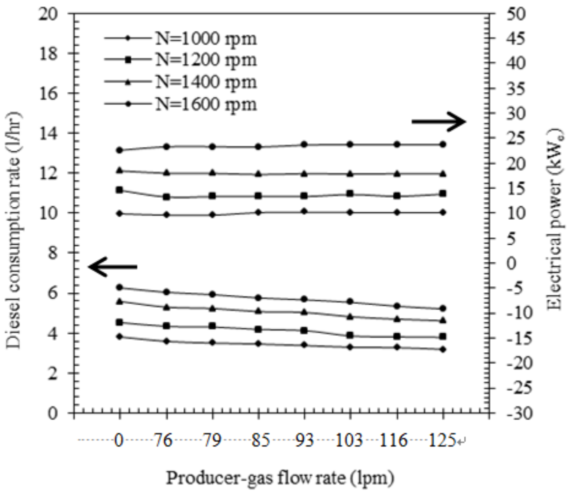

Fig. 2. DCR and electrical power with different gas flow rates.

It can be seen that the compressing producer gas causes the DCR to decrease at all engine speeds. To consider at maximum speed of 1,600 rpm, the DCR decreases from 16.74 to 32.54% to compare with only diesel fuel mode. Moreover, this research can be found that the DCR goes up to 40% at engine speed 1,200 rpm and producer-gas flow rate 125 lpm, while this result is compared with Reference [5] demonstrates that there is more diesel consumption rate than 5.7%. In addition, this is consistent with Researchers [1]-[6] because there is more amount of energy supplied by the gaseous fuel with increasing producer-gas flow rate. To keep total energy constant, diesel consumption rate must be decreased.

B. Electrical Power

Fig. 2 on the right side shows the results of electrical power with increasing producer-gas flow rate and engine speed. Results indicate that using diesel fuel and supercharging producer gas in dual fuel mode give the electrical power similar to only diesel fuel mode at all speeds. To consider the engine speed 1,600 rpm at flow rate 76 to 125 lpm, the electrical power from using the compressing producer gas on dual fuel mode increases from 3.15 to 5.06% compared with only diesel fuel mode.

This is consistent with research work of Reference [5] because the increase of producer gas quantity is the increases of hydrogen concentration within fuel before it is reacted with air. This result becomes the rich mixture combustion, while there is the effect on the use of insufficient oxygen in the combustion process [1]-[5].

C. Electrical Efficiency

Fig. 3 on the left side indicates that using diesel fuel and compressing producer gas in dual fuel mode increases electrical efficiency (which was calculated from the ratio of electrical power and all the energies supplied to the engine) with adding speeds. While the maximum electrical efficiency is at the engine speed 1,600 rpm, it increases from 35.54 to 41.97% to use producer-gas flow rate from 76 to 125 lpm. To compare with only diesel fuel mode, electrical efficiency increases from 6.13 to 12.56%. This is consistent with Reference [10] because supercharging producer gas is to impinge with air within the Y-shaped mixing chamber to help better turbulence and air-producer gas mixing.

As a result, the start of combustion is faster to improve the electrical efficiency. In addition, the use of dual fuel mode has lower energy input than using diesel fuel mode because producer gas has lower heating value than diesel fuel. Although there is the increasing multiplication of the blower power and efficiency, the electrical power from testing has similarly value. Results show that the use of dual fuel mode has higher thermal efficiency than using diesel fuel mode only [1]-[9].

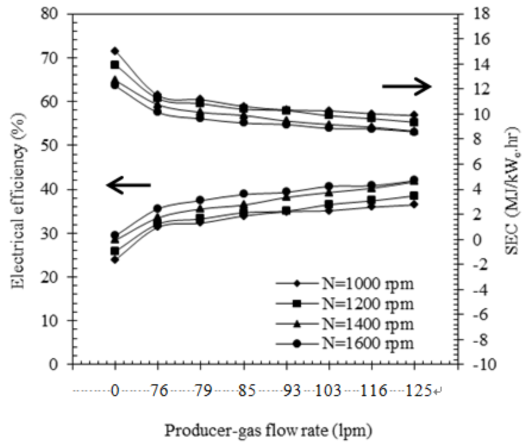

Fig. 3. Electrical efficiency and SEC with different gas flow rates.

D. Specific Energy Consumption

Fig. 3 on the right side observes that supercharging producer gas combined with diesel fuel in dual fuel mode decreases the specific energy consumption or SEC (which was calculated from the ratio of all the energies supplied to the engine and electrical power) in all engine speeds.

To consider the engine speed 1,600 rpm, the SEC from using the compressing producer gas on dual fuel mode decreases from 17.25 to 29.93% compared with only diesel fuel mode. Because the SEC is inversely proportional to the electrical efficiency, this efficiency increases with increasing producer gas flow rate and then the SEC decreases in accordance with corresponding flow rate of producer gas also [1]-[3].

E. Carbon Monoxide Emission

Fig. 4 on the left side shows the change of quantity of CO emission with increasing the amount of producer gas combined with diesel fuel in dual fuel mode. It can be seen that the quantity of CO emission increases with increasing engine speed and producer-gas flow rate. To consider the engine speed 1,600 rpm, the CO emission from using diesel fuel and compressing producer gas on dual fuel mode increases from 0.59 to 0.96 %vol to use producer-gas flow rate from 76 to 125 lpm.

When the use of this mode is compared with only diesel fuel mode, the quantity of CO emission is increased from 0.37 to 0.74 %vol. This is consistent with Researchers [4], [5] because they explain that there is the incomplete combustion due to insufficient amount of oxygen supplied in combustion and then it leads to the presence of elevated levels of CO emission in the exhaust gas emission [2], [3].

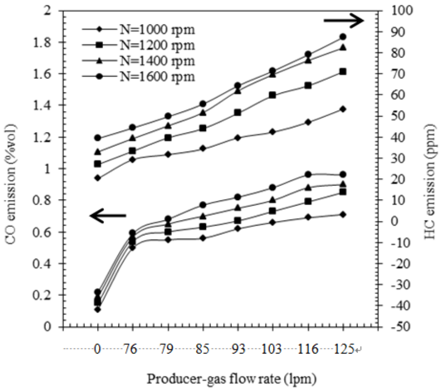

Fig. 4. CO and HC emissions with different gas flow rates.

F. Hydrocarbon Emission

Fig. 4 on the right side observes that the quantity of HC emission increases with adding producer-gas flow rate and engine speed which it is similar with the increase of the amount of CO emission. To consider the engine speed 1,600 rpm, the HC emission from using diesel fuel and compressing producer gas on dual fuel mode increases from 44.33 to 87.33 ppm to use producer-gas flow rate from 76 to 125 lpm.

When the use of this mode is compared with only diesel fuel mode, the quantity of HC emission is increased from 5.00 to 48.00 ppm. This is consistent with Researchers [4], [5] because there is the increasing incomplete combustion as a result of slow burning velocity of producer gas and the decreasing of oxygen percentage very continuously in the mixture with increasing gas flow rate [2], [3].

G. Smoke Opacity

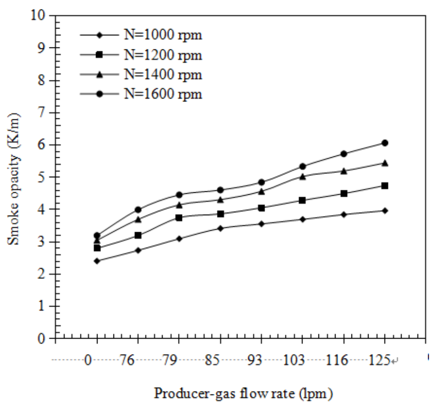

Fig. 5. Smoke opacity with different gas flow rates.

Black smoke in this research is investigated from smoke opacity shown in Fig. 5. It can be seen that the smoke opacity increases with adding the amount of producer gas combined with diesel fuel in dual fuel mode, and this result is similar with the increase of CO and HC emission. To consider the engine speed 1,600 rpm, smoke opacity from using diesel fuel and compressing producer gas on dual fuel mode increases from 4.00 to 6.07 $K.m^{-1}$ to use producer-gas flow rate from 76 to 125 lpm.

When the use of this mode is compared with only diesel fuel mode, the smoke opacity is increased from 0.80 to 2.87 $K.m^{-1}$. This may be due to increasing incomplete combustion as result of rich mixture combustion formed with increasing the quantity of producer gas. As a result, it increases the amount of black smoke, CO and HC emissions [2], [3].

IV. Conclusion

Investigating the performance and exhaust emission characteristics of diesel-engine generator summarized as follows:

- It is clear from the testing that the use of diesel fuel with producer gas in dual fuel mode has the maximum diesel saving is 40% at engine speed 1,200 rpm and producer-gas flow rate 125 lpm.
- Using diesel fuel with supercharging producer gas from volume flow rate 76 to 125 lpm in dual fuel mode compared with only diesel fuel mode improves the engine performance because there are the increase of electrical power and electrical efficiency and the decrease of specific energy consumption at all engine speeds.
- Measuring exhaust gas emissions by using diesel fuel and supercharging producer gas from volume flow rate 76 to 125 lpm in dual fuel mode demonstrates that there is the increase of CO and HC emissions and black smoke with increasing engine speeds.

To further improve the present system, the following suggestions can be adopted in future:

- Modification of the diesel engine to decrease the pilot diesel fuel.
- Using supercharged air combined with compressed producer gas to improve engine performance and to decrease emissions, such as CO and HC emissions and black smoke.
- Using other biomasses to produce the syngas fuel and method of tar removal.
- Study of engine wear from using producer gas combined with diesel fuel in long term.

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