Use of Producer Gas from Wood Pellet on Dual Fuel for a Diesel-engine Generator

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***Abstract*— This research aims to use producer gas from wood pellet producing from a small gasifier in dual fuel mode for a diesel-engine generator. The engine was tested at speed 1,800 rpm and different loads. Results show that the use of diesel combined with producer gas at 55 lpm resulted in an increase of diesel saving to 23%. Electrical efficiency and energy saving increased to 3% and 13% as compared with diesel, respectively. Producer gas increasing more than 55 lpm led to the addition of black smoke to 30%, and there was more soot within the combustion chamber than diesel.**

***Index Terms*—producer gas, diesel engine, performance, emission**

I. Introduction

Producer gas (PG) is generated from biomasses by thermo-chemical gasification, as consisting of carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4) [1]. PG could not ignite within diesel engines, because the auto-ignition temperature of PG was typically above 500℃ [2]. Reference [3] presented the use of dual fuel mode because of non-modified engines and low cost. Diesel was injected at normal timing, while PG was secondary fuel mixed to air before sent into an intake manifold. References [1-4] compressed PG generating from charcoal by using a small downdraft gasifier as combined with primary oils, such as diesel, diesohol, and biodiesel, resulting in the decrease of primary fuels to 30% at a flow rate of PG 125 lpm. Engine efficiency found on dual fuel mode with PG produced from wood chips and corn cobs was similar to that on diesel mode [5]. Researchers [6-7] modified a diesel engine using PG generated from biomasses, such as sugarcane bagasse, carpentry waste, sawdust, and cotton stalks, by using a medium-sized downdraft gasifier, while maximum diesel saving attained was 64% at a compression ratio 18:1. Prior studies on the dual fuel between PG and diesel for non-modified diesel engines indicating that the slight decrease of engine performance while the diesel consumption was reduced to 40% as compared with diesel [8-11].

As studying the literature reviews, charcoal is the best because of lower humidity and little tar, but it is expensive in Thailand. Biomasses, particularly plant residues and wood chips, have been interesting to reduce the natural combustion problem leading to the release of CO_2. However, they are suitable for large gasifiers because of a variety of packing sizes. There are presently machines that process these biomasses into the wood pellet, but the study of PG, as produced from wood pellets in dual fuel mode for diesel engines, had some parts. The objective of the proposed work is to present the study of performance characteristics of a diesel-engine generator using dual fuel between diesel and increasing flow rate of producer gas generated from the wood pellet by using a small downdraft gasifier at a constant speed 1,800 rpm and different loads.

II. Methodology

A. Producer Gas as a Potential Fuel

Producer gas was generated from the wood pellet as fed on the top of a small downdraft gasifier [Specification, maximum capacity, 29 kW_{th}; wood pellet consumption, 6 kg/hr; maximum flow rate, 67 m^3/hr; diameter of wood pellet, 8 mm; length of wood pellet, 30mm; efficiency, 75%] while the air was entranced at the side by adjusting an inverter showing in Fig. 1. After the wood pellet became to the PG, it was entered into a cyclone, a heat exchanger, and a flare to test the flame ability. Next, it was sent into a wet scrubber and a sandbed filter to clean producer gas, and it was tested the flame ability again. At the same time, the PG sample was taken to analyze the gas components by using gas chromatography, as shown in Table I. PG sample as produced from wood pellet comparing with charcoal shows that H_2 content was increased to 6%, while CO content was decreased to 8.5%, but CO_2 content was added to 9%. Therefore, the PG generated from wood pellets has a better flame ability property due to higher H_2 content.

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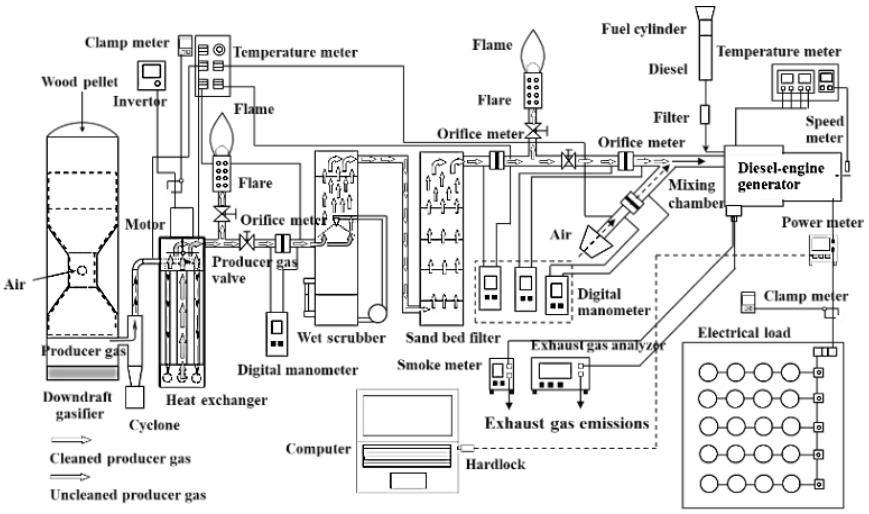


Figure 1. Schematic of experimental setup

TABLE I. PRODUCER GAS PROPERTIES

Properties	Producer gas	
	Wood pellet	Charcoal [1]
Hydrogen (%vol)	13.5±3.5	7.5±2.5
Carbon monoxide (%vol)	21.0±3.0	29.5±1.5
Carbon dioxide (%vol)	10.5±1.5	1.5±0.5
Methane (%vol)	1.5±0.5	1.5±0.5
Nitrogen (%vol)	52.5±2.5	57.5±2.5
Calorific value (MJ/m^3)	4.76±0.12	5.08±0.48

After finishing the PG property study, PG and air was sent to a mixing chamber as combined with diesel injected into a diesel-engine generator [Model, Mitsuki: 5GF-ME; cylinder, 1 cyl; capacity, 406 cm^3; power (max.), 3.5 kW$_{ele}$ @ 1,800 rpm; compression ratio, 17.5:1]. Electrical power (P$_{ele}$) was added by the electric lamps, as measured from a power meter connecting with the richtmass RS485, USB data converter, and hardlock shown on a computer. Temperatures, such as coolant, air intake, exhaust gas, and producing gas system, were investigated from the K-type thermocouple as connecting with the temperature meters. For measuring the exhaust gas emissions, especially nitric oxide (NO) and black smoke, they were investigated from the Cosber: KWQ-5 Automotive emission analyzer and the Cosber: KYD-6 Opacimeter showing in term of black-smoke intensity.

B. Experimental Procedure

First of all, the diesel-engine generator was warmed up about 15 minutes, and the ambient temperature was determined at 30±3 °C. After the engine was stable, experiments were started by using diesel alone, while all experiments were recorded in 100 hours [1]. The engine was run at 1,800±50 rpm, and the electrical load was increased from 20 to 100%. Diesel was fixed at 20 ml to calculate the diesel consumption, and temperatures and emissions were measured from instruments. After finishing the mode of diesel alone, dual fuel mode was started by using PG increasing from 42 to 64 lpm. While diesel (D) was injected at normal timing, the PG was studied at 42, 46, 50, 55, and 64 lpm. Terms were shown as D+PG42, D+PG46, D+PG50, D+PG55, and D+PG64 lpm. For testing dual fuel mode, there was the same condition with the mode of diesel alone. Final, parameters of engine performance from using dual fuel between diesel and increasing producer gas (D+PG), such as electrical power, diesel consumption, emissions, etc., were compared with the mode of diesel alone.

III. RESULTS AND DISCUSSIONS

A. Electrical Power

Electricity generation in this research is investigated from the output electrical power from using fuels in the diesel-engine generator, as shown in Fig. 2.

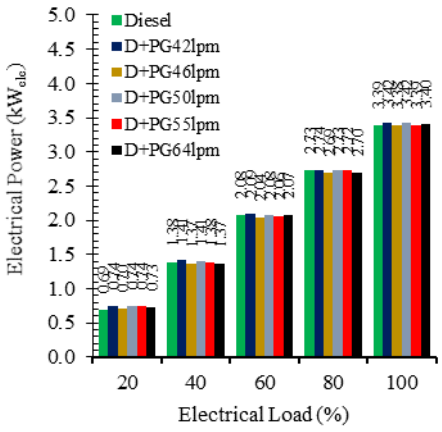


Figure 2. Electrical power as different loads.

Electrical power is increased as increasing loads, while the use of dual fuel between diesel and producer gas (D+PG) as increasing from 42 to 64 lpm gave the electrical power similar to using diesel since this test was performed at equally electrical load.

B. Diesel Consumption

The use of D+PG led to the decrease of diesel consumption (DC), showing in Fig. 3, while PG increased to 55 lpm resulted in the reduction of DC to 0.36 lpm at maximum load.

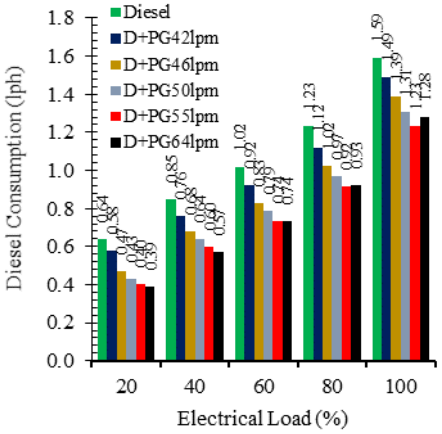


Figure 3. Diesel consumption as different loads.

As a result, diesel saving was increased to 22.67% because increasing PG led to ignition timing quickly, causing a decrease of pilot-diesel injection [1-5]. However, PG added more than 55 lpm led to the addition of DC because of the increase of incomplete combustion from using excessive PG than necessary increasing total energy input (Q_{in}) to generate the electricity as same as the use of diesel alone [6, 8].

C. Electrical Efficiency

Electrical efficiency (EE), the ratio of P_{ele} to Q_{in}, was the best on 80% load showing in Fig. 4. Use of D+PG was higher EE than diesel alone, as increased to 3.12% using D+PG up to 55 lpm due to increasing PG leading to the decrease of pilot-diesel injection and Q_{in} [1].

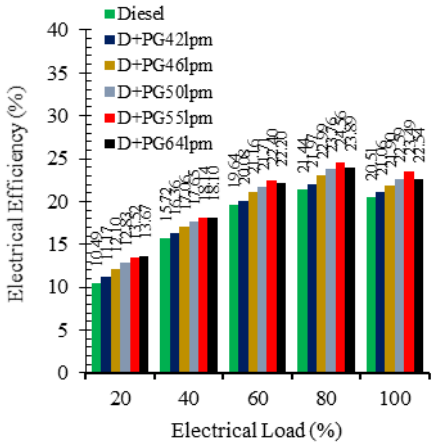


Figure 4. Electrical efficiency as different loads.

However, when PG was added more than 55 lpm led to the decrease of EE to 0.67% because of the incomplete combustion from using too much PG, causing the increase of heat losses [5, 8].

D. Specific Energy Consumption

Fig. 5 investigates the level of specific energy consumption (SEC), the ratio of Q_{in} to P_{ele}, as decreased to 2.13 MJ/kW_{ele}.hr using D+PG as added to 55 lpm because of the reduction of Q_{in} continuously from increasing PG [1-5].

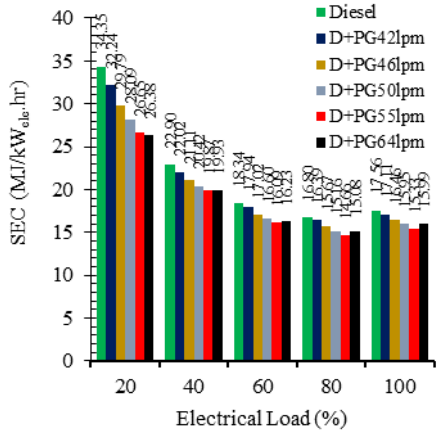


Figure 5. SEC as different loads.

While PG was increased more than 55 lpm, SEC level was higher because there was the addition of heat losses as using too much PG [5, 8].

E. Nitric Oxide Release

Some pollutant as highly released from the diesel engines is the nitric oxide (NO), because the concentration of NO emission is depended on the air content [9-11]. Fig. 6 shows the release of NO as reduced with increasing PG. Use of D+PG up to 64 lpm decreased the level of NO to 139.04 ppm because the flow rate of air and PG was sent into the intake manifold simultaneously, but the flow rate of PG was higher than the air flow rate. Therefore, there was not enough air to burn with diesel and many PG, causing the increase of incomplete combustion leading to the reduction of NO continuously [6-11].

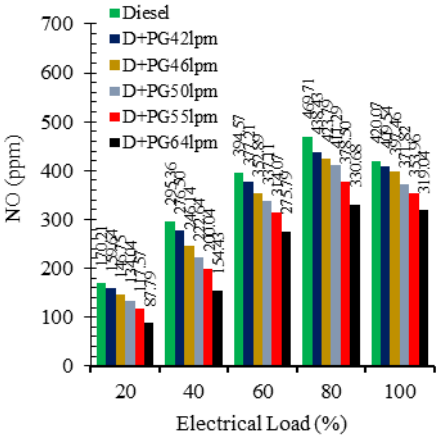


Figure 6. NO release as different loads.

F. Black-smoke Release

Black smoke as released from diesel engines is the crucial problem as shown in term of diesel particulate matter emissions which are usually emitted in case of PM2.5 causing the destruction of human health in Thailand. This research measures the level of black smoke from the black-smoke intensity, as shown in Fig. 7.

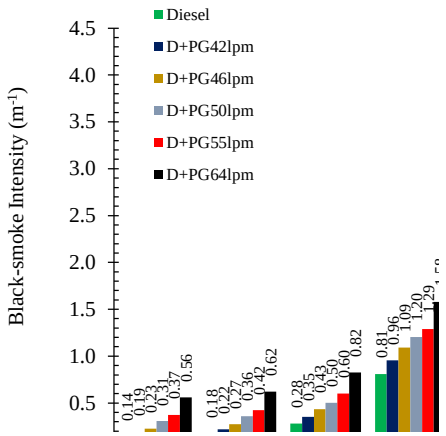


Figure 7. Black-smoke intensity as different loads.

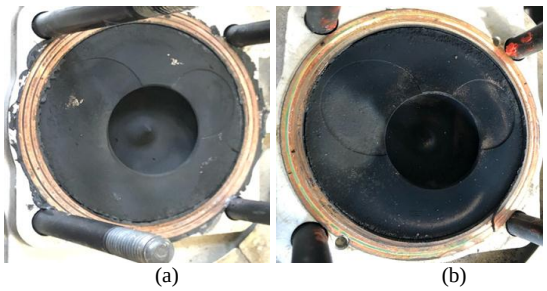
Use of D+PG up to 64 lpm increased the level of black-smoke intensity to 0.77 m^{-1} leading to the addition of black-smoke quantity to 30.33% because there was an increase of UHC and CO leading to the release of black smoke enormously [1-6].

G. Investigation of Soot within the Combustion Chamber

After finishing the diesel-engine performance test in 100 hours referring from SAE J1312 (JAN90) and SAE J1349 (JUN90), there is the test of using producer gas from wood pellet on dual fuel with a diesel-engine generator comparing with the use of diesel in another one, which has the same engine data. Both diesel engines are tested at the same conditions, while experiments of engine test are recorded in 200 hours as referred with SAE J1940 (JUN89) and JIS B8018 (1989). After completing the engine test, there is the open of cylinder head of both engines to take the photographs of soot as attached to various parts, such as intake and exhaust valves, piston head, combustion chamber, etc., as shown in Fig. 8 and Fig. 9.

(a) (b)

Figure 8. Intake and exhaust valves of (a) diesel engine using diesel alone and (b) diesel engine using D+PG.



(a) (b)

Figure 9. Piston head of (a) diesel engine using diesel and (b) diesel engine using D+PG.

Results of using D+PG, which generated from wood pellet, comparing with diesel within the both diesel-engine generators showing that the diesel engine using D+PG had more soot within combustion chamber than another one using diesel. Because the use of D+PG as increased to 64 lpm led to the addition of UHC and CO enormously, they were formed during the incomplete combustion process resulting to the formation of soot as attached to various parts, such as intake and exhaust valves, piston head, combustion chamber, etc [8, 9]. However, this research indicating that the use of producer gas from wood pellet on dual fuel for the diesel-engine generator does not have the amount of tar on the various parts of engine. Therefore, producer gas produced from wood pellet is suitable for alternative fuel as combined with diesel or other oils in the future.

IV. Conclusions

Using dual fuel between diesel and PG generated from wood pellet in a small downdraft gasifier as increased from 42 to 64 lpm is compared with diesel alone, while the diesel-engine generator is tested at speed 1,800 rpm and different loads in 100 hours and 300 hours. Results are summarized as follows:

- PG from wood pellet has the gas components similar to PG from charcoal, while PG generating from wood pellet has higher H_2 content and lower CO content than charcoal.
- The use of PG from wood pellet combining to diesel in dual fuel mode does not affect the change of electrical power. The use of PG up to 55 lpm resulted in an increase in diesel saving to 23%. Electrical efficiency was increased to 3%, and energy saving to 13% compared with diesel alone. However, the use of PG was more than 55 lpm leading to the addition of incomplete combustion.
- Investigation of NO and black smoke levels using dual fuel mode indicating that the release of NO was decreased to 139 ppm, but the black-smoke quantity was increased to 30% as compared with diesel alone at 80% load using dual fuel between diesel and PG at 64 lpm.
- Preliminary examination of the wear parts showing that both diesel-engine generators using diesel and dual fuel between diesel PG at 64 lpm have a little wear. However, the diesel engine using PG on dual fuel has more soot within the combustion chamber than another one using diesel. Contrarily, this research indicating that the use of PG from wood pellets on dual fuel for the diesel-engine generator does not have the amount of tar on the various parts of the engine.
- The results of the present study provide the ideas for further study improvement. The combustion characteristics and other emissions, such as CO_2, CO, and UHC, from using dual fuel between diesel and PG as generated from the wood pellet and the increase of PG up to 64 lpm should be studied. Next, new research should investigate the engine wear in the long term.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Ekkachai Sutheerasak is the first author and a corresponding author who conducted the research, performed engine performance tests and analyzed the data. Worachest Pirompugd designed a wet scrubber. Wirogana Ruengphrathuengsuka and Surachai Sanitjai generated and analyzed the properties of syngas. All authors wrote their respective sections and approved the final version.

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