Use of dual fuel between B10 and increasing syngas on the performance and emissions of a diesel-engine generator

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Abstract. The research is to study the use of diesel mixed to 10% biodiesel (B10) combined to increasing syngas from 76 to 125 lpm in dual fuel mode with a diesel-engine generator. In engine test, the speed was adjusted from 1,000 to 1,600 rpm. Syngas was produced from a downdraft gasifier, as the charcoal was used to the primary fuel. Results indicate that the use of B10 and increasing syngas on dual fuel gave higher engine performance than using B10, but the emissions were enormously increased with increasing syngas. However, the use of B10 and syngas at 125 lpm increased the fuel saving to 30.77% and 27.20%, and the electrical efficiency added to 13.90% and 10.59% as compared with B10 and diesel respectively. Dual fuel between B10 and syngas at 125 lpm can apply to the diesel-engine generator in the future.

1. Introduction
In Thailand, the electrical power is very necessary and influential on the driving economy and the living human as produced from the power plant. In the countryside, it was mainly produced from a diesel-engine generator to use in the subsistence of agriculturists. Diesel prices are increasing continuously and the engine pollutants are creating the environmental problem, nowadays. Biodiesel and biomass become to an alternative energy for the agriculturists. Biodiesel is mixed to diesel in ratio of 5 to 7% replacing to diesel nowadays. In the future, the policy of energy ministry need to increase the amount of biodiesel up to 10% to reduce the carbon monoxide (CO) and hydrocarbons (HC) [1]. Biomass is converted to the syngas, a fuel gas mixture consisting primarily of the carbon-hydrogen content as produced by using a gasifier. However, it cannot ignite in the diesel engines because of the high self-ignition temperature. Therefore, the use of dual fuel mode is the basic technique because of the non-modified engine [2].

A number of studies of using syngas on dual fuel have been carried out. Some researchers [2, 3] studied the use of syngas and diesel on dual fuel, the engine performance was changed and the emissions were increased. Other researchers [4-7] tested the performance and emissions of diesel engines using speeds and loads. Syngas generated from biomasses combined to biodiesels, produced from plant oils and methanol. As operating under different biodiesel blends until using pure biodiesel combining to syngas, the engine emissions, especially CO and HC, were decreased but the engine performance was dropped with increasing biodiesel. Blend of biodiesel is more than 10% leading to the engine performance dropped and the fuel injection system damaged [1, 8]. Previous researches mainly focused on biodiesel synthesized from vegetable oils in countries and methanol, which was expensive. On the contrary, this research produced the biodiesel from palm oil and ethanol derived from the fermentation
2. Methods and Materials

2.1. Preparing syngas and B10

First of all, the syngas was generated from a downdraft gasifier sent to the producing gas system consisting of a cyclone, a wet scrubber, and a filter tank. Specifications of the gasifier, the producing gas system, and the diesel engine test are shown in figure 1 and table 1. Before the syngas was sent into a diesel engine, the gas sample was taken to analyse the gas components, such as hydrogen (H\textsubscript{2}), carbon monoxide (CO), carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}), nitrogen (N\textsubscript{2}) and calorific value (CV), by using a gas chromatography as shown in table 2.

![Figure 1. Schematic of the experimental setup.](image)

| Table 1. Downdraft gasifier specification. |
|------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Fuel            | Maximum capacity (kW\textsubscript{th}) | Rate consumption (kg/h) | Maximum gas flow (m\textsuperscript{3}/h) | Calorific value (MJ/kg) | Thermal efficiency (%) | Equivalence ratio |   |
| Charcoal        | 75\pm0.1         | 5.5\pm0.5           | 96\pm1           | 29.6\pm0.1        | 72.5\pm2.5         | 0.14\pm0.02     |   |

| Table 2. Syngas properties. |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Fuel | H\textsubscript{2} (%vol) | CO (%vol) | CO\textsubscript{2} (%vol) | CH\textsubscript{4} (%vol) | N\textsubscript{2} (%vol) | CV (MJ/m\textsuperscript{3}) |
| Syngas         | 7.5\pm2.5       | 29.5\pm1.5       | 1.5\pm0.5       | 1.5\pm0.5       | 57.5\pm2.5       | 5.08\pm0.48     |

Syngas was increased the gas flow rate by a supercharger compressed into a Y-shape mixing box, and absorbed by a turbocharger. For measuring the flow rate of syngas and air, the flow conditioning was installed before the mixing box, and a venturi tube and a digital manometer were applied in this
research. For producing B10, the reactants were the diesel and biodiesel, the palm oil ethyl ester. Ratio of diesel and biodiesel was 90:10 %vol, while the mixture process was studied from the researcher [1]. Next, there was the fuel properties test under various ASTM procedures, such as the temperature of pour point (T_p), cloud point (T_c), and flash point (T_f), the density, and the viscosity, as shown in table 3.

Table 3. Properties of diesel and B10.

| Fuel  | T_p (°C) | T_c (°C) | T_f (°C) | Density (kg/m^3) | Viscosity (mm^2/s) | CV (MJ/kg) |
|-------|----------|----------|----------|------------------|--------------------|------------|
| Diesel| -8       | 7        | 45       | 821              | 2.9                | 44.36      |
| B10   | -0.5     | 8        | 81       | 839              | 4.03               | 42.86      |

2.2. Experimental setup of the engine test
The experiments were carried out on a four-stroke diesel engine [Model, John Deere 3029DF150; engine type and aspiration, direct injection and turbocharger systems; cylinder, 3 cyl; capacity, 2.9 L; power (max.), 43 kW @ 2,500 rpm; compression ratio, 17.2:1]. It was connected with an AC generator by using the electric lamps to increase the engine load. Electrical power was measured by a power meter and a clamp by converting the signal into the richtmass RS485 with USB data converter and hardlock connected with a computer. Temperatures were investigated from the thermocouple connected with the temperature meters. For measuring the exhaust gas emissions, such as CO_2, CO and HC, they were analysed from the MOTORSCAN: 8020 eurogas emission analyzer.

2.3. Experimental procedure
First, the engine was warmed up about 15-20 minutes. After engine was stable, experiments were started up by using diesel and then B10. Speed was started at 1,000±50 rpm and then it was increased from 1200±50 to 1,600±50 rpm. The amount of both oils was determined at 20 ml to study the fuel consumption. Parameters, such as flow rates, power, temperatures and emissions, were recorded. Next, syngas was increase to 76 lpm and sent to mix with air in the mixing box. The mixture was, then, sent into the turbocharger and the engine cylinder where the B10 was separately injected at the normal timing. Again, the engine performance test conditions as well as the recorded parameters would be the same as those for both oils. After finish using the flow rate of 76 lpm, others flow rates would, then, be introduced and the same conditions and parameters would be recorded. All the gas flow rates used in this study were 76, 79, 85, 93, 103, 116, and 125 lpm.

3. Results and Discussions
The performance and emissions tests were conducted on diesel engine at dual fuel i.e. B10 (B10) as primary fuel and syngas (SG) was added at 76 lpm, 79 lpm, 85 lpm, 93 lpm, 103 lpm, 116 lpm and 125 lpm as secondary fuel respectively. Terms were shown as B10+SG76 lpm, B10+ SG79 lpm, B10+SG85 lpm, B10+SG93 lpm, B10+SG103 lpm, B10+SG116 lpm and B10+SG125 lpm, while the flow rates of syngas indicated after SG.

Figure 2 on the right side indicating the electrical power increases with increasing speed. Use of B10 has lower electrical power, as decreased to 2.67% compared with diesel at 1,600 rpm because of lower fuel heating value than diesel [1, 8]. Use of dual fuel between B10 and increasing syngas (B10+SG) from 76 to 125 lpm shows that the electrical power increases with increasing syngas, as increased from 1.53 to 5.57% compared with B10 at 1,600 rpm. Moreover, the use of B10+SG125 lpm gives higher electrical power than diesel. Results are similar to the researcher [2], because the increasing syngas led to the increases of the carbon-hydrogen concentration before reacting with air. As a result, the combustion phenomena became to the fuel-rich mixture combustion. Figure 2 on the left side showing the fuel consumption rate (FCR) increases with increasing speed. Use of B10 has higher FCR, as increased to 5.16% compared with diesel at 1,600 rpm due to lower calorific value than diesel [1, 8]. For increasing syngas combined to B10, the FCR decreases with increasing syngas as reduced from 18.51 to 30.77% compared with B10 at 1,600 rpm. Results are similar to the researchers [2] since the
increasing syngas on dual fuel has replaced more primary fuel led to the start of combustion faster and the pilot B10 was decreased. In addition, the use of B10+SG125 lpm has lower FCR than diesel showing that it has more fuel saving than diesel.

Figure 3 on the right side demonstrating the electrical efficiency increases with increasing speed, whereas the maximum efficiency occurs at 1,400 rpm. For using B10 compared with diesel, the electrical efficiency decreased to 2.09% because of higher fuel consumption and lower fuel heating value than diesel [1, 8]. For using B10+SG, the electrical efficiency increases with increasing syngas as increased from 6.63 to 13.90% compared with B10 at maximum efficiency. Results are consistent with the researchers [2, 3] since the primary fuel was burned quickly after syngas was ignited. Next, the increasing syngas had accelerated the burning rate very rapidly. As a result, the pilot B10 was dropped with increasing gas flow rate. Moreover, the use of B10+SG125 lpm gives higher electrical efficiency than diesel while it reduces the limiting of B10 which had lower efficiency than diesel.

Specific energy consumption (SEC), the sum of energy consumption from syngas and B10 per the electrical power, shows that it decreases with increasing speed indicating in figure 3 on the left side. Use of B10 has higher SEC than diesel, as increased to 7.61% at maximum efficiency. This is similar to the researcher [1] because of more fuel consumption than diesel. For using B10+SG, the SEC decreased with increasing syngas as decreased from 17.11 to 29.01% compared with B10 at maximum efficiency. Use of B10+SG125 lpm has lower SEC than diesel. Results are consistent with the researchers [2, 3], because the calorific value of syngas was lower than B10. Although the increase of syngas would replace this oil very much, but the total input energy supplied to this engine was decreased. As a result, the SEC was decreased with increasing syngas.

Figure 4 on the right side observes that the increasing speed leads to the increase of the exhaust gas temperature (EGT). Use of B10 has higher EGT than diesel, as increased to 9°C at maximum efficiency. This is similar to the researcher [1] due to the oxygen (O₂) content within B10 led to better complete combustion. For using B10 and increasing syngas on dual fuel, the EGT increases with increasing syngas as increased from 50 to 99°C compared with B10 at maximum efficiency. Use of B10+SG125 lpm has higher EGT than diesel. Results are similar to the researchers [2-5] explained from the syngas properties which had the CO₂ and CO contents (table 2), while they were combined to B10 burned with O₂ content becoming to the fuel-rich mixture combustion. It changed the combustion phenomena in the diffusion combustion, which led to the increase of burning temperature. Figure 4 on the left side indicates that the
release of carbon dioxide (CO₂) increases with increasing speed. Use of B10 has higher the CO₂ release, as increased to 0.65 %vol compared with diesel at maximum efficiency. Because the O₂ content in the B10 improved higher combustion efficiency, it was more complete combustion [1]. Increasing syngas combined to B10 leads to the increase of CO₂ level. CO₂ was increased from 1.13 to 2.32%vol compared with B10 at maximum efficiency. Moreover, the use of B10+SG125 lpm gives higher CO₂ level than diesel very much. Results are similar to the researchers [2-5] because of the fact that the generated syngas consisted of both CO and CO₂ quantities (table 2). While increasing syngas combined to B10 reacted with O₂ content within this chamber, innumerable content of C was burned with O₂ content. At a result, there were the increase of combustion temperature and the steep rise in the release of CO₂.

Figure 4. Exhaust gas temperature and CO₂. Figure 5. CO and HC emissions.

Figure 5 on the left side demonstrates that the carbon monoxide (CO) decreases with increasing speed. Use of B10 reduces the CO emission to 0.08 %vol compared with diesel at maximum efficiency, which is confirmed by the researcher [1] because of the O₂ content in the B10 which resulted in a more complete combustion. However, the using B10 combined to increasing syngas has the opposite effect, because the CO emission increases with increasing syngas as increased from 0.50 to 0.81%vol compared with B10 at maximum efficiency. Use of B10+SG125 lpm releases the CO more than diesel. Results are consistent with the researchers [5-7], because the syngas consisted of both CO and CO₂ quantities and the more syngas sent to the engine decreasing the amount of O₂ required for complete combustion. As a result, the unburned syngas was increased and the CO emission was enhanced. Figure 5 on the right side indicates that the emission of hydrocarbon (HC) increases with increasing speed. Use of B10 is lower HC emission, as decreased to 5 ppm compared with diesel at maximum efficiency. This may be due to the O₂ content in the B10 led to more complete combustion [1, 8]. However, the use of B10 and increasing syngas on dual fuel have negative effects. HC emission increased from 11 to 27 ppm compared with B10 at maximum efficiency. Moreover, the HC emission from using B10+SG125 is higher than using diesel very much. Results are similar to the researchers [4-7]. The cause of increasing HC emission is explained from the direct result of incomplete combustion, since the increasing syngas led to the decrease of air flow sent to the engine cylinder. The high syngas content in combining to B10 injection will be burned with the less amount of O₂. Therefore, the greater insufficient amount of O₂ in the combustion will increase the formation of more CO and HC emissions.
4. Conclusion
Use of B10 combined to increasing syngas up to 125 lpm gives higher engine performance than the use of B10 only, while the use of this dual fuel can reduce the limiting of B10. For the advantage of using B10+SG125 compared with B10, the electrical efficiency increased to 13.90%, the SEC decreased to 29.01%, and the fuel saving increased to 30.77%. In case of the release of pollutants, the use of B10 and increasing syngas in dual fuel mode increases the level of CO, HC and CO₂ with increasing syngas. Moreover, the use of B10+SG125 has more engine emissions than the use of B10 very much. Use of B10 gives lower engine performance than diesel, but the use of B10+SG125 can increase the engine performance higher than the use of diesel. To compare B10+SG125 with diesel, the electrical power increased to 2.76%, the electrical efficiency increased to 10.59%, and the fuel saving increased to 27.20%. Therefore, the B10+SG125 can use to be the alternative energy with the diesel-engine generator for the subsistence of agriculturists in the future.

5. References
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