Performance Comparison of Diesel and Dual Syngas-Diesel in Compression-Ignition Engine

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Abstract

Compression-ignition engine or diesel engine is widely used in remote area as a driven machine for multi-proposes such as driving the generator or pump. However, the use of diesel engine has constrained especially in remote area where the availability of diesel fuel is limited. Therefore biomass becomes as an alternative fuel resource because it is easily accessible in each local area. Unfortunately, solid fuel like wood chips or wood-charcoal is unable to use in diesel engine directly. A gasification process is needed to convert solid fuel to syngas. However, a lower of heating value and the different fuel composition of syngas can cause the effect on combustion efficiency and the engine performance. This study is to investigate the possibility on the use of syngas in diesel engine by concerning on energy efficiency, environment and economic aspects. In this study, a 42-kW gasifier operated with wood-charcoal was used to produce a gas fuel. Comparison between using pure diesel fuel and mixed fuel of syngas and diesel fuel was investigated and the engine performance was tested with a dynamometer. The results shown that mixed fuel of diesel and syngas from wood-charcoal gasifier can be operated in the diesel engine. Using mixed fuel gave the effect on a lower of engine efficiency but it can achieve to reduce the cost of operation as well as the reduction of emission from the exhaust.

***Keywords**:* Gasifier, Biomass, Diesel engine, Syngas

1. Introduction

Demand of energy consumption has continuously increased as well as the increase of fossil fuels prices. Therefore, renewable energy such as wind energy, solar energy, and bioenergy is concerned to compensate the restriction of energy resources. Bioenergy is delivered from organic matter or biomass (a fuel that contains carbon as a major compound). Biomass is considered as a source of natural energy storage which is locally available and the price is quite low. Biomass such as the scrap of agricultural material or the waste from the agricultural industry can be converted and stored in the different forms such as solid fuel, liquid fuel, and gas fuel in order to comfortable use.

In remote area where is off-grid connection and limits the source for electricity generation, diesel engine is the most technology selection in there even its unit cost of electric generation is considerably high as compared with wind or solar energy. This is because the electric energy from diesel engine is quite consistency, not time dependent and seasonal constrain. However, delivery diesel fuel to the remote area may loss in the energy security. Therefore, the compromise between locally supply and technology available have been considered by many researchers. Unfortunately, solid fuel like wood chips or wood-charcoal is unable to use in diesel engine directly. Therefore, a gasification process has been introduced due to its process can change the state of solid fuel into gas phase. Then it can be conveniently used and easily controlled in the thermal process.

Vinay et al. [1] studied the application of mixed fuel between syngas from wood chips with mustard oil cakes and diesel fuel in four-cylinder engine. They found that even the use of mixed fuel resulted to the reduction of thermal efficiency about 5.45%, but it achieved to decrease NO_x emission up to 18.6%. However, using only primary biomass, i.e. wood chips, as feedstock can cause the trouble on high level of tars production. Hence the mixed feedstock between coconut shells with charcoal was introduced to lower a level of tars generation to apply in the internal combustion engine [2]. Rajvanshi, A.K. et al. [3] also introduced syngas from acacia wood chips mixed with diesel oil applied in diesel engine. They found that the use of syngas could save diesel fuel by 50-70% and the saving was increased as the engine load increased.

Therefore, the paper is to investigate the possibility on the application of syngas generated from 42-kW gasifier in a compression-ignition engine. Charcoal was used as a raw material instead of wood chips to burn in the gasifier of this study in order to reduce the tars production. Comparison between using pure diesel fuel and mixed fuel of syngas and diesel fuel was investigated in the viewpoint of energy efficiency, environmental, and economic aspects.

2. Gasification

Gasification is a process which can convert organic material into a syngas. The process of gasification differ from the typical combustion because oxygen available in the gasifier is limited the amount in order to occur the partial oxidation process. Syngas or synthesis gas composes with combustible gases such as carbon monoxide (CO), hydrogen (H_2), methane (CH_4), and non-combustible gases i.e. nitrogen (N_2), with less amount of carbon dioxide (CO_2). However, the composition of syngas can be variety depending on the type of feedstock and the operation condition in the gasifier. Gasification process has four sub-processes, as shown in **Fig. 1**:

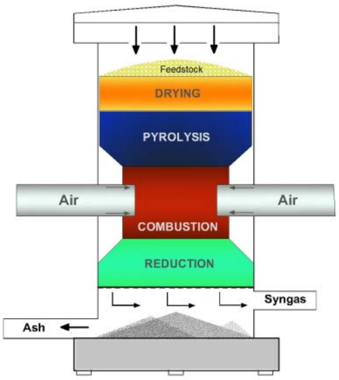

Fig. 1 Downdraft gasifier

Drying is a process to drive off the water from the solid biomass by using the waste heat from other processes. Temperature of this zone is ideally requested about 100-160°C depended upon the kind of feedstock.

- **Pyrolysis** is a process to heat the biomass with controlled amount of oxygen at the temperature about 450-600°C. Char and some of combustible gases are produced as well as the release of volatile gases and tars during the pyrolysis process.
- **Combustion** is a process that the products from pyrolysis zone react with a limited of oxygen to generate CO_2, H_2O and heat which the temperature is quite high at 900-1,200°C.
- **Reduction** is a process where the carbon reacts with the water vapor at the temperature up to about 600-900°C to produce combustible gases or syngas.

Currently, there are several types of gasifier available for commercial use such as updraft gasifier, downdraft gasifier, fluidized bed gasifier, and etc. depended on the purpose of the use. In this study, downdraft gasifier or co-current gasifier was introduced because the downdraft gasifier design all tars have to pass the hot bed of char and have the residence time to more or less complete burn the tars. Therefore, the amount of tars is much lower than the updraft gasifier. Syngas containing some of tars is not preferable to combust in the engine.

3. Experimental setup

Fig. 2 shows the schematic diagram of the gasifier connected with the gas cleaning system and the set of test engine. Air from the ambient was sucked into the gasifier by the startup blower. About 1-kg of ignited charcoal was fed into the combustion zone, and then the next 10-kg charcoal in which its size was controlled at 1”x1” consequently loaded at the top of the gasifier. The gasifier has the capacity to produced syngas in the range of 4–30 Nm^3/h at 5-42 kW power capacity. This system also consisted of the cleaning system: cyclone was used to separate the particle and dust, gas cooler was used to reduce the temperature of syngas which in turn some tars were condensed, and filter which used charcoal as filter material was to remove the tars. The cleaning system was required to separate various impurities contained in the syngas before further used in diesel engine in order to avoid deposits, corrosion, and erosion occurring in the engine. All components were set on the rig as shown in **Fig. 3**.

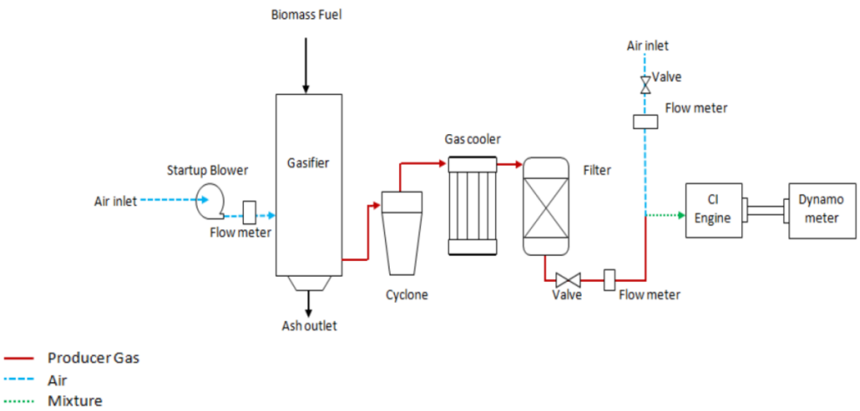

Fig. 2 Flowdiagram of the downdraft gasifier connecting with the cleaning system and the test engine

Fig. 3 The rig of downdraft gasifier

In this study, a single cylinder, four stroke air-cooled, direct injection diesel engine was used to validate the possibility used of syngas in diesel engine. The detail specification of the engine was summarized in **Table 1**.

Table 1 Diesel engine specification

Parameter	Specification
Model	ETQ 186FG
Type	Four-stroke, direct injection
Max. output (kW)	6.3
Bore (mm)	80
Stroke (mm)	70
Fuel tank capacity (L)	15
Cooling system	Air-cooled

The engine performance and emission test were performed on a single cylinder four-stroke diesel engine. The experiment were conducted with two fuel modes, i). pure diesel fuel mode, and ii). dual fuel mode which was the mixed fuel between diesel and syngas. Then the comparative study on the effect of syngas to the engine operation in the viewpoint of efficiency, economic, and emission was investigated. The experiement were conducted by controlling the engine operation at fixed speed of 1,800 rpm, 1,900 rpm, 2,000 rpm, 2,100 rpm, and 2,200 rpm and applying with two different fuel modes. The parameters studied consisted of torque, brake power, brake specific fuel consumption, engine efficiency, and the release of emission gases.

4. Results and discussions

4.1 Engine performance

Preliminary testing on the gasifier operation was found that synthesis gas was initiated after the process started in the next 15 min. By loading 11 kg of charcoal into the gasifier, the time requirement to burnout the feedstock was about 300 minute, while only 210 minute was the available period to use the benefit from the synthesis gas at which the production rate was 0.35 l/s.

Next, the engine testing was conducted on the dynamometer by using two different fuel modes. The result of engine performance found that the increase of engine speed trended to decrease engine torque and brake power for both fuel modes, as shown in **Fig. 4**. It implies that the use dual fuel of syngas mixed with diesel fuel can compensate the torque and brake power of the engine as well as the use of pure diesel. The result can be also noticed that the use of dual fuel at low engine speed about 1800-2000 rpm can provide higher engine torque and brake power as compared with using pure diesel fuel. When considering on the fuel consumption of pure diesel mode and dual fuel mode as presented in **Fig. 5**, it can be obviously noticed that the increase of torque and brake power of diesel engine at low engine speed related to more fuel consumed. **Table 2** shows the mass flow rate ratio of diesel-to-syngas at various engine speeds operation.

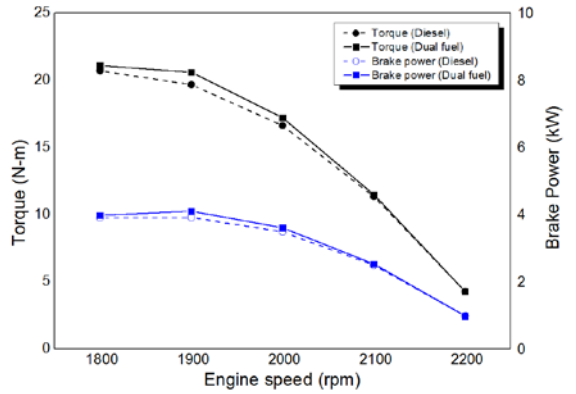

Fig. 4 The relation between engine speed with torque and brake power in two fuel modes

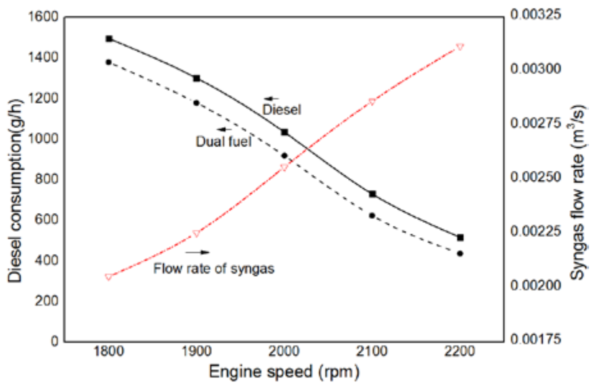

Fig. 5 The variation of fuel consumption with respect to engine speeds

Table 2 Diesel-to-Syngas mass flow rate ratio at various engine speeds

Engine speed (rpm)	Diesel : Syngas
1,800	1 : 5.78
1,900	1 : 6.21
2,000	1 : 7.13
2,100	1 : 9.26
2,200	1 : 12.02

It was difficult to compare the fuel efficiency of each case by using the fuel consumption term, therefore, brake specific fuel consumption (BSFC) was applied as the ratio of burn fuel per a shaft output. In dual fuel mode, BSFC was calculated from the fuel consumption and the calorific value of both diesel and syngas. **Fig. 6** presents the BSFC of engine when using pure diesel mode and dual fuel mode in various engine speeds. The result shows that BSFC of both cases trended to decrease as engine speed increased. At the speed of 2,100 rpm, engine provided the minimum of BSFC, and then it turned to increase as increasing the engine speed which was corresponded to the trend of engine efficiency as shown in **Fig. 7**. BSFC in diesel mode was found to be higher than that of dual fuel mode at all conditions about 9-15%. It can obviously notice that the use of syngas in diesel engine was acceptable when the engine operated at low speed because the engine efficiency could be kept as same level as the engine run with the conventional fuel. However, the use of synthesis gas might not be appreciated to operate at high engine speed because the efficiency of engine in dual fuel mode was dropped significantly as compared with the conventional mode.

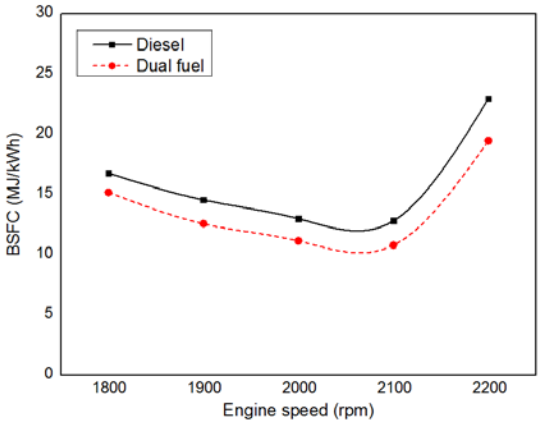

Fig. 6 Effect of engine speed on brake specific fuel consumption

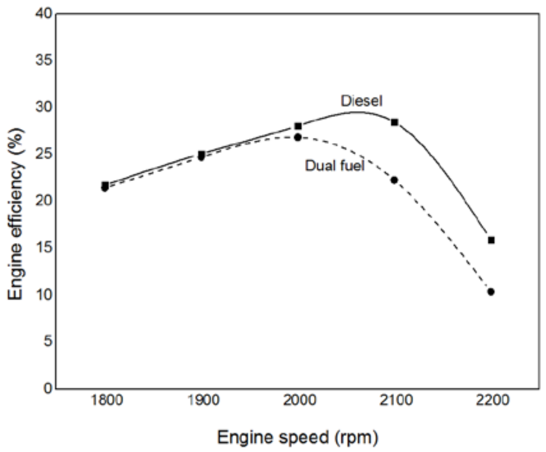

Fig. 7 Engine efficicency at various engine speed

4.2 Emission characteristics

In this study, emission from the engine was measured to reflect the combustion quality of both fuel modes. **Fig. 8** shows the measured temperature of the exhaust gas. The result shows that lower engine speed gave the impact on the increase of exhaust gas temperature, and this value trended to decrease as the engine speed increased. The exhaust gas temperature decreased from 320°C to about 130°C when the speed changed from 1,800 rpm to 2,200 rpm due to higher suction flow of air or syngas into the engine by the faster of engine rotation. Using dual fuel mode resulted into the exhaust gas temperature higher than the engine in diesel mode which can be implied that there were some excess fuel supplied to the engine.

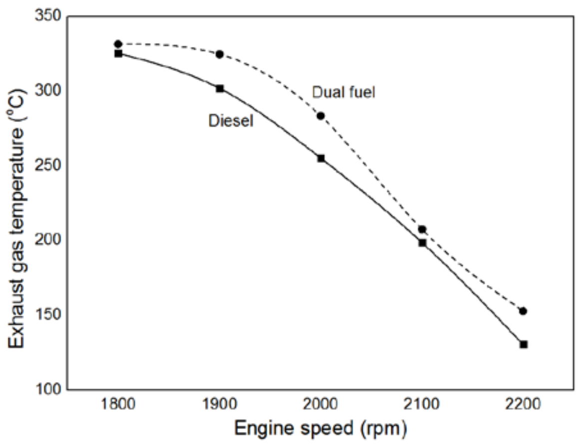

Fig. 8 The temperature of exhaust gas in different fuel modes

The released of CO and NO, as shown in **Fig. 9**, can be obversed that CO was highly emitted from the engine when dual fuel was applied. High CO emission can reflect on the incomplete combustion of poor mixture formation. However, in the case of dual fuel mode operation, high CO released was not only the impact of incomplete combustion, but also the effect of CO contained as a main gas composition in sythesis gas.

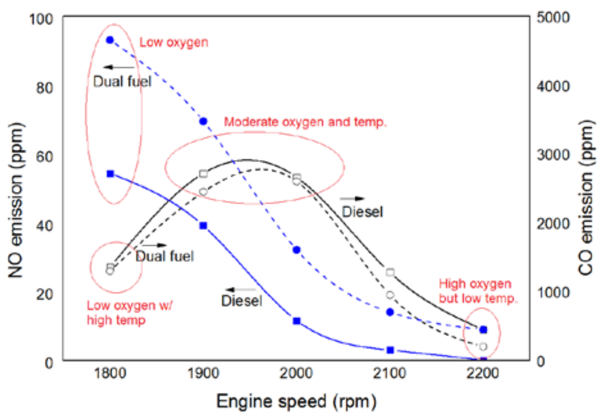

Fig. 9 CO and NO emissions from diesel engine when using two different fuel modes.

Typically, the formation of NO in diesel engine has two main reasons: high temperature and the available of oxygen. In this study, the result was found that NO emissions in both fuel modes were low at low engine speed. These were happened even the exhaust gas temperature considerable high because it dominated by the effect of low level of oxygen rather than the temperature effect. NO emission increased significantly at the engine speed around 1,900-2,000 rpm which caused by the available of oxygen incorporated with high exhaust gas temperature. NO emission trended to decrease as the engine speed increased due to the dominated effect of lower combustion temperature more impact than high level of oxygen. To compare the formation of NO in different fuel modes, it found that the mixed fuel released NO lower than the use of diesel fuel because a portion of air intake into the engine was dominated by syngas.

5. Conclusion

The use of synthesis gas as dual fuel in a compression-ignition engine has the possibility but the appropriate use was at low engine speed because the engine could keep the operation at the same efficiency as the use of diesel fuel. However, syngas was not properly used during high engine speed operation because of the drop of efficiency. The application of mixed fuel in diesel engine can save the use of diesel fuel about 9–15%. In the viewpoint of environment, the use of synthesis gas as dual fuel can achieve to reduce the release of NO, but it cannot success to decrease CO emission. The reason was CO containing in the syngas as a general compound, therefore, it can easily release at the exhaust.

6. References

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