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Effect of Pilot Fuel Quantity on the Performance and Emission of a Dual Producer Gas – Diesel Engine

Pisarn Sombatwong, Prachasanti Thaiyasuit and Kulachate Pianthong*

Department of Mechanical Engineering, Faculty of Engineering, Ubon Ratchathani University, Ubonratchathani 34190, Thailand

Abstract

Quantity of pilot fuel is an important parameter for controlling the combustion process in a dual fuel engine. However, very few researches have investigated this effect in details in a dual producer gas-diesel engine. In this study, the combustion characteristics, engine performances, and exhaust gas emissions are investigated. The single cylinder, direct injection, diesel engine coupled with dynamometer is used as the engine test bed. The producer gas is generated from 50 kW_{th} double throat downdraft gasifier using charcoal as the raw material. In the test, the engine speed is constant at 1500 rpm while the bmep loads are varied between 0 - 535 kPa. Three pilot fuel quantities being 0.22, 0.29 and 0.35 kg/h are supplied. Experimental results show that the increasing amount of pilot fuel improves thermal efficiency and reduces the CO emission at low engine load conditions. However, the diesel saving is always decreased when the pilot fuel quantity exceeds its optimum condition.

Keywords: Pilot fuel; Producer gas; Dual fuel engine; Combustion characteristics; Engine performance

1. Introduction

Producer gas (sometime called synthesis or syngas) is one of the potential alternative fuel to replace fossil fuels in the internal combustion engine. The producer gas may be used as an alternative fuel in compression ignition (CI) engine as a partial substitute for diesel in dual fuel mode, and in spark ignition (SI) engine as a producer gas alone mode. In dual fuel CI engine operating with producer gas as main fuel with small amount of liquid diesel fuel as an ignition source, the gaseous fuel is inducted along with the intake air and is compressed like in a conventional diesel engine. The mixture of air and gaseous fuel does

* Corresponding author. Tel.: +66-4535-3300; fax: +66-4535-3308.
E-mail address: k.pianthong@ubu.ac.th (Kulachate Pianthong)

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not auto-ignite due to its high autoignition temperature [1]. A small amount of diesel fuel is needed to inject near the end of the compression stroke to act as a source of ignition for compressed gas-air mixture. The pilot liquid fuel, which can be injected by the conventional diesel injection equipment, normally contributes only a small fraction of the engine power output. Using pilot diesel injection, gaseous fuels can be very conveniently used in the dual fuel mode in existing diesel engines, without any major modification. This makes dual fuel engine flexible to switch back to diesel mode easily [1-3].

The quantity of the pilot diesel fuel injection is usually fixed for a given engine. At full load, its amount represents less than 10% of the total amount of energy to the engine [2]. In most dual fuel operating systems, the engine power output is controlled by changing only the amount of the primary gaseous fuel added to the air during the induction stroke. Thus, at constant speed, the change of the amount of the gaseous fuel results to a change of the inducted combustion air, since the total amount of inducted mixture is kept constant.

Many research studies [1-11] have reported that, under dual fuel operation, the poor utilization of the gaseous fuel, observed at low loads, results in poorer engine performance and higher concentrations of carbon monoxide emissions compared to values observed under normal diesel operation. Recently, many researchers have studied the performance and emission characteristics of the dual engines fueled with producer gas - liquid fuels. Some researchers used alternative liquid fuels as a pilot fuel such as rice bran oil [5-8], Honge oil [8-10], biodiesel [7-9], and rubber seed oil [10]. Their studies showed that stable engine operations are possible with producer gas without any modifications to either engines or its operations. NO_x emission of dual fueling is lower than that of diesel fueling operating under the same operation. There were reports in [5-11] that producer gas were used in standard diesel engine in dual fuel mode operation and the diesel saving up to 70% had been obtained. It was reported in [8] that the power derating of engines, observed in dual fuel mode, was between 20 and 30%.

The pilot fuel quantity is one of the most important variables that can control the performance and emissions of dual fuel engine. However, previous works only focused on the performance and emissions at the maximum diesel saving. Also very few researches about the effect of pilot fuel quantity in producer gas-diesel have been done. The main aim of this work is to investigate the effect of pilot fuel quantity on the performance and emissions of a single cylinder, direct injection diesel engine modified to operate under dual fuel mode. Producer gas generated from downdraft gasifier is used as primary fuel and a pilot amount of diesel fuel is used as an ignition source. Two sets of measurements are conducted, the first one is using diesel fuel only (normal diesel operation) and the second one is running under dual fuel conditions at various engine operating conditions. Results from this study will be valuable information for improving the engine performance and exhaust emission at specific operating conditions under dual fuel mode.

2. Materials and Methods

The schematic diagram of experimental setup is shown in Fig.1. This consists of a diesel engine, a gasifier with cooling and cleaning system, dynamometer and controlling system. The engine tests were conducted on a four-stroke single cylinder, direct injection, naturally aspirated diesel engine. Detailed specification of the engine is given in Table 1. An eddy current dynamometer was directly coupled to the engine, and the engine load was measured from the controller. The double throat downdraft gasifier was specifically designed and developed by the Research and Service on Energy Centre (RSEC) of Ubon Ratchathani University to match with the engine. The specification of the gasifier is given in Table 2. The biomass fuel (charcoal) was fed into the gasifier through the top opening, while the air is supplied to the gasifier by using a blower. The partial combustion of biomass in the gasifier provides producer gas, which enters the gas cooling and passes through cleaning unit. Properties of the producer gas is given in Table 3.

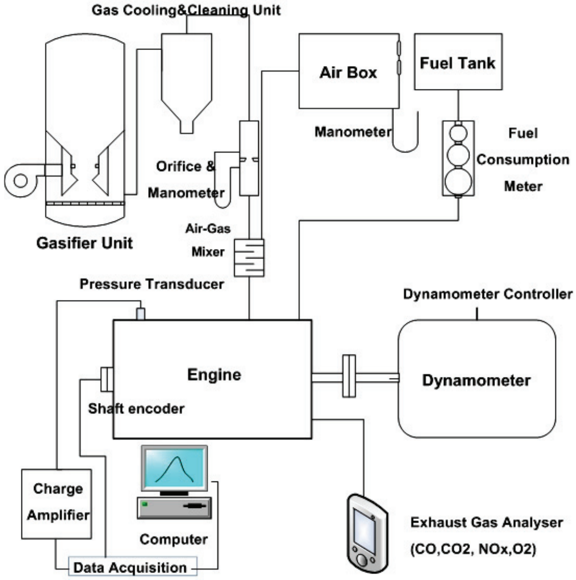


Fig. 1. Schematic diagram of the experimental setup

Table 1. Specification of the engine

Item	Description
Model	Mitsubishi D-800
Bore x Stroke	82 x 78
No. of cylinder	1
Piston displacement	411 cc.
Maximum output	5.884 kW / 2400 rpm
Maximum torque	25.5 N-m / 1900 rpm
Compression ratio	18:1

Table 2. Specification of the gasifier

Item	Description
Type of gasifier	Double throat downdraft (Imbert type) [12]
Capacity	50 kW_{th}
Fuel consumption	6 kg/h (Charcoal)
Biomass size	10 mm – 30 mm
Efficiency	70 %

Table 3. Properties of producer gas

Gas	Percentage
CO	27 - 32.3 %
H2	3.2 - 4.2 %
CH4	0 %
O2	0.04 %
N2	57 - 62 %
Calorific value	4.2 – 4.6 MJ/Nm3

A glass burette with 30 ml volume capacity and a stopwatch were used to determine the amount of fuel consumption. Orifices and manometers were used to measure the air and gas flow rate separately. The exhaust gas temperature and exhaust emissions were measured and determined using K-type thermocouple and HM 5000 exhaust gas analyzer, respectively. Specification of the exhaust gas analyzer is given in Table 4.

Table 4. Specifications of exhaust gas analyzer

Gas	Range	Resolution&Accuracy
HC	0 - 10,000 ppm	10 ppm ±2%
CO	0 – 10 %	0.01% ±2%
CO_2	0 – 20 %	0.01% ±2%
O_2	0 – 25 %	0.01% ±2%
NO_x	0 – 5000 ppm	1 ppm ±2%

The in-cylinder pressure was measured with a piezo-electric pressure transducer (6052C, Kistler) coupled with a charge amplifier. In each test, the combustion pressure data was measured over 100 cycles and recorded by Dewesoft 6.6 software with a sampling interval of 0.2° crank angle (CA) to ensure accurate ignition timing and phasing of heat release. The obtained in-cylinder pressure data were averaged over the crank angle to eliminate the effect of cycle-to-cycle variations and then calculated to the heat release rate for the analysis of combustion characteristics.

A series of experiments were conducted in this study using diesel fuel and producer gas-diesel dual fuel. All tests were conducted by starting up the engine with diesel fuel only. For dual fuel experiments, the operation started 30 minutes after the gasifier started up. The engine was initially run at no load using diesel fuel. Then, torques of 2.5, 5, 7.5, 10, 12.5 and 15 Nm were selected and each load was applied at a constant engine speed of 1500 rpm. Three values of pilot fuel quantities which are 0.22, 0.29 and 0.35 kg/h were used in each test. The cooling water temperature was maintained at 80 °C to reduce the variation in the test result. The performance and emission characteristics of dual fuel engine were investigated at various pilot fuel injection quantity and loads.

In producer gas-diesel dual fuel operation at various loads condition, the supply of producer gas was adjusted manually to keep constant speed while pilot fuel quantity was fixed. At various loads, the amount of air or gas entering into the engine was varied by the rotation of the air and gas valves. This gives the variation in air-fuel ratio of the mixture that used to calculate diesel saving.

3. Results and Discussions

3.1. Combustion characteristics of Single and Dual-Fuel Modes

The heat release rate of the fuel causes a variation of gas pressure and temperature within the engine cylinder. In-cylinder pressure and crank angle data over the compression and expansion strokes of the engine operating cycle can be used to obtain quantitative information on the progress of combustion. The data from 100 consecutive cycles were recorded. From these, the mean cylinder pressure trace is estimated. The net heat release rate is determined by applying the first law of thermodynamics [13] using the following Eq. (1).

$$\frac{dQ_n}{dt} = \frac{\gamma}{\gamma - 1} p \frac{dV}{dt} + \frac{1}{\gamma - 1} V \frac{dp}{dt} \tag{1}$$

Where dQ_n/dt is the net heat release rate and γ is the ratio of specific heats, c_p/c_v. An appropriate range for γ for diesel heat release analysis is 1.3 to 1.35 [13].

Fig. 2(a) and 2(b) show the effect of producer gas quantity on the cylinder pressure and the heat release rate for dual fuel mode of operation at constant speed and pilot diesel of 1500 rpm and 0.22 kg/h, respectively. It can be observed that combustion starts later for higher gas amount comparing to the diesel operation in Fig. 3(a). and Fig. 3(b). In a dual fuel engine, peak pressure depends on the combustion rate in initial stages, which in turn is influenced by the amount of fuel taking part in the premixed combustion phase. The premixed or uncontrolled combustion phase is governed by the ignition delay period and by the mixture preparation during the delay period. Thus, slow burning nature of producer gas during the ignition delay period are reasons for this trend of peak pressure.

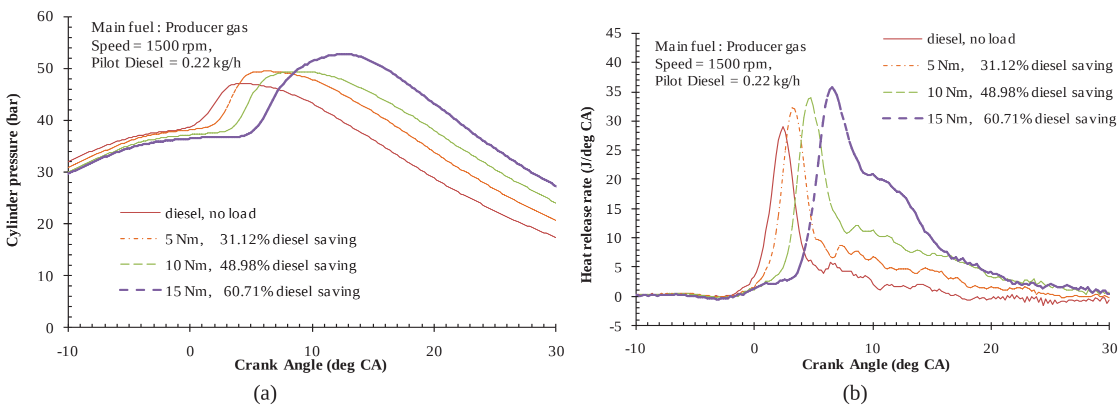
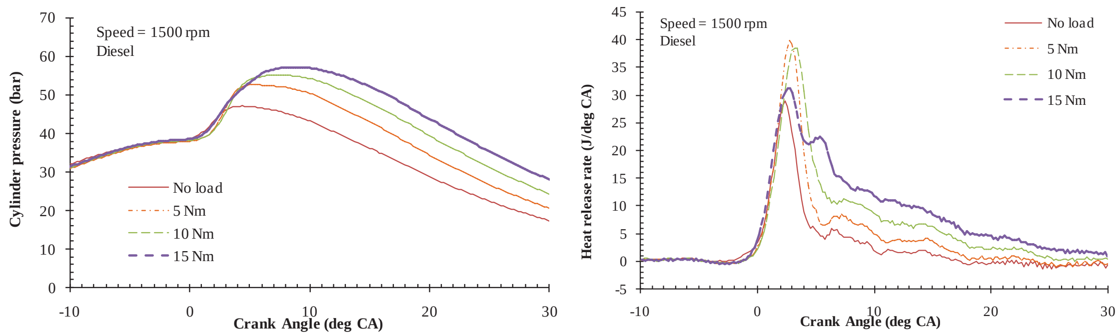


Fig. 2. Effect of producer gas quantity on (a) the cylinder pressure and (b) the heat release rate with the dual-fuel mode at a pilot fuel quantity of 0.22 kg/h at various loads

The ignition delay in dual fuel operation strongly depends on the type of gaseous fuel and their concentrations in the cylinder charge. Diesel-producer gas dual fuel operation shows longer ignition delays compared to diesel operation. The reason for such an increase in ignition delay is due to the large amount of producer gas fuel in the intake and compression process. It results from the increase of the ignition delay period which leads to a rapid increase of the total heat release curve during the premixed controlled combustion phase a fact that improves the fuel conversion efficiency since the duration of combustion becomes shorter.

A study by M.P. Poonia et al. [3] has found that, with larger pilot diesel, the combustion of the gaseous fuel is better leading to higher mass fraction burnt and higher brake thermal efficiency in dual mode as compared to the corresponding diesel operation. They explained that in the first stage of combustion the heat is mainly released due to premixed burning of part or whole of the pilot quantity in addition small part of gas entrained in the spray. In the second stage by auto-ignition of gas-air mixture in the close vicinity of pilot spray and diffusive burning of the remaining pilot fuel whereas in the third stage heat is released due to burning of gas-air mixture by flame propagation initiated from spray zone are responsible for heat release.



(a) (b)

Fig. 3. (a) cylinder pressure and (b) heat release rate with the diesel mode at constant engine speed (1500 rpm) at various loads

3.2. Performances of Single and Dual-Fuel Modes

3.2.1. Diesel Saving

The diesel saving in dual fuel mode operation is shown in Fig. 4. The use of producer gas in dual fuel mode operation reduces the consumption of diesel fuel at all engine loads. The maximum diesel saving is 64.21% at the pilot diesel of 0.22 kg/h and Brake Mean Effective Pressure (BMEP) load of 535 kPa. The diesel saving was decreased at higher pilot diesel quantity. This phenomenon was due to the mixture being richer at high pilot diesel and high engine loads.

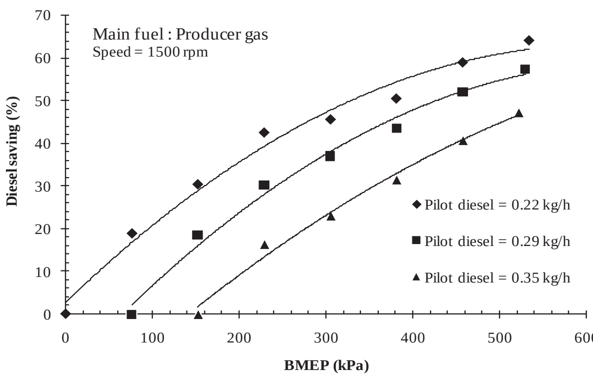


Fig. 4. Variation of Diesel saving with BMEP

3.2.2. Brake Thermal Efficiency (BTE)

The main disadvantages of the dual fuel combustion are its negative impact on engine efficiency and carbon monoxide emission compared to normal diesel operation [2]. Fig. 5. shows the variation of brake thermal efficiency of the engine operated on diesel fuel and dual fueled producer gas-diesel with respect to the BMEP. The brake thermal efficiency of dual fuel engine is always lower than that of diesel fuel, in which the maximum efficiency achieved by diesel fuel was 33.4%. In dual fuel operation, the maximum brake thermal efficiency was 26.65% at pilot diesel of 0.35 kg/h and BMEP load of 458.37 kPa.

The thermal efficiency of large pilot quantity is greater than that of small pilot quantity. This is due to the increase of the pilot diesel fuel results in greater energy release on ignition, improved pilot injection characteristics, a large number of ignition centers requiring shorter flame travels and a higher rate of heat transfer to the unburned gaseous fuel-air mixture [1].

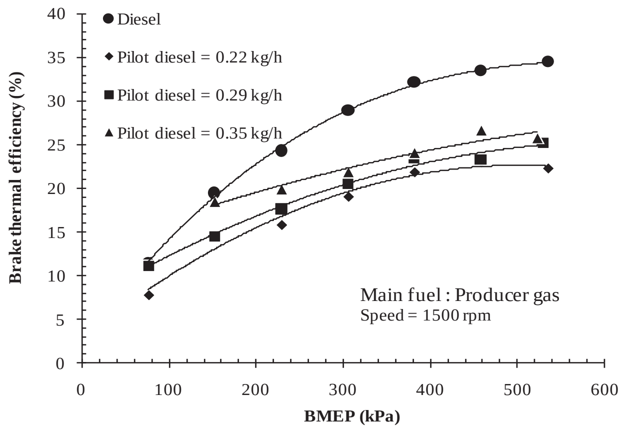


Fig. 5. Variation of BTE with BMEP

3.2.3. Brake Specific Energy Consumption (BSEC)

In dual fuel operation, specific energy consumption is preferred to compare the performance of two type of fuels that having different calorific values and density [11]. Specific energy consumption is calculated based on fuel consumption and calorific value to the brake power of both diesel and producer gas. It was found that the specific energy consumption in dual fuel mode operation is higher than that of diesel mode in all operating conditions as shown in Fig. 6. Increase in specific energy consumption indicates that the efficiency reduces in the dual fuel mode.

The increase of pilot diesel fuel amount leads to an improvement of the brake specific energy consumption compared to the one observed under lower pilot fuel quantity mode. The use of larger pilot fuel quantity leads to a higher total heat release rate during the premixed controlled combustion phase. It results to an increase of the cylinder charge temperature, which affects positively the combustion rate of diffusion phase since it becomes more efficient [2].

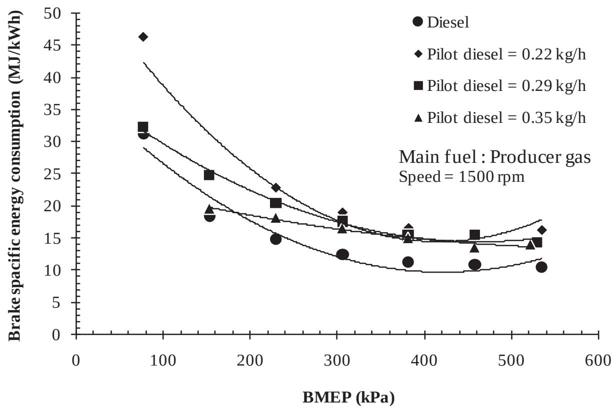


Fig. 6. Variation of BSEC with BMEP

3.3. Exhaust Emission Characteristics of Single and Dual-Fuel Modes

3.3.1. Carbon Monoxide (CO) Emission

Values of the CO emissions are shown in Fig. 7. The CO emission in a producer gas-diesel dual fuel mode is always higher than that of the diesel alone mode at all operations. It is revealed that the increase of pilot fuel amount, keeping the engine load constant, leads to a decrease of CO emissions. A larger pilot fuel quantity provides a greater magnitude of ignition centers with large reaction zones. Moreover the flame propagation path from each ignition center within the charge becomes relatively shorter, and thus, combustion is better. At higher loads, when the gaseous fuel concentration in the air charge is above the lean combustion limit, the frame is able to propagate through most of the combustion chamber unaided, and varying the pilot fuel quantity has little effect.

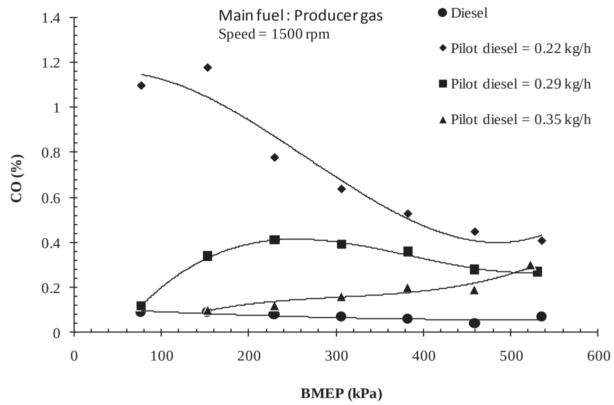


Fig. 7. Variation of CO emission with BMEP

3.3.2. Exhaust Gas Temperature

The variation of Exhaust Gas Temperature (EGT) with respect to BMEP is shown in Fig. 8. It was observed that the exhaust gas temperature of dual fuel mode always higher than that of diesel alone mode due to excess of energy supplied to the engine. Significantly higher combustion rates during the later stages with diesel-producer gas leads to higher exhaust gas temperature.

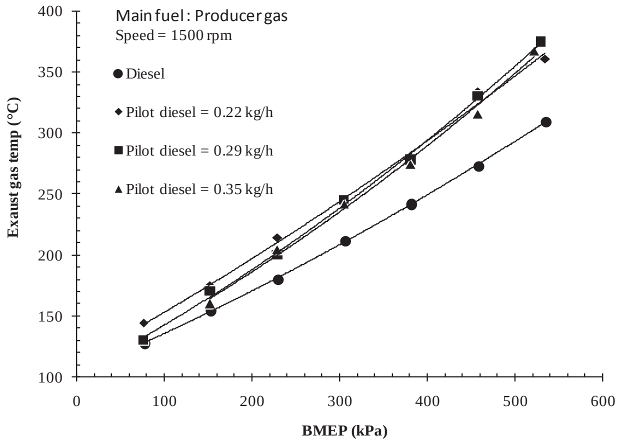


Fig. 8. Variation of EGT with BMEP

4. Conclusion

In this work, an experimental investigation has been conducted to examine the effect of the pilot fuel quantity on the performance and emissions of a dual fuel producer gas-diesel engine, the following conclusions may be drawn.

1) The diesel saving was decreased at higher pilot diesel quantity, may be due to the mixture being richer at high pilot diesel and high engine loads.
2) The engine efficiency and BSEC of producer gas-diesel dual fuel engine can be improved by increasing the amount of pilot fuel.
3) The CO emissions could be reduced by increasing the pilot fuel quantity.

In summary, the dual fuel engine is technically appropriate to run at the high load condition which gives high thermal efficiency and low emissions. However, the high percentage of diesel saving is another important purpose of some users, although it is contradict to the thermal efficiency and emissions. Then, users may have to choose to operate their engines on their purpose. Our results also indicate that the low efficiency in the tested engine comes from the inappropriate cylinder peak pressure which causes by the long ignition delay. Therefore, the optimum injection timing is required in dual fuel engine and should be investigated in the future.

Acknowledgements

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