Performance Investigation of a Small Engine Fueled with Producer Gas and Diesel in Dual Fuel Operation

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Abstract

Producer gas from biomass gasification can be used as a substitute fuel in diesel engines. In this work, performance of a small diesel engine operated on producer gas/ diesel dual fuel mode was investigated. Experimental tests were carried out on an 8.2 kW, single cylinder, naturally aspirated, diesel engine coupled to a 5.0 kW dynamometer. A downdraft gasifier was used to generate producer gas from charcoal as feedstock. Engine speed and load were varied between 1200 – 2000 rpm, and 1.0 – 3.5 kW, respectively. Engine torque, power, specific fuel consumption, diesel replacement rate, and thermal efficiency were evaluated. The dual fuel operation was compared against that with only diesel. It was found that the maximum diesel replacement rate of more than 75 % could be realized at 1400 rpm. Brake specific fuel consumption was in a range between 190 – 222 g/kWh. Efficiency of about 22 % was obtained, compared to 27 % from diesel operation.

***Keywords**:* Biomass gasification, Compression ignition, Engine testing, Renewable energy, Small engines

1. Introduction

Escalating oil price and scarcity of fossil fuels coupled with exploding population have resulted in serious energy crisis. Sustainable technology that utilizes renewable energy sources should be developed to replace fossil fuels. Thailand is an advancing agro-industrial country. There are many biomass resources, especially agricultural residues such as wood chips, charcoal, rice husks, rice straws, corn cobs, sugar canes, etc available. But, at present, they are not largely utilized.

Biomass converted to producer gas via gasification is of great interest because the fuel gas can be used directly in engines. Gasification is an irreversible thermo-chemical process, by which feedstock is thermally decomposed. The end products are principally in gaseous form. The resultant producer gas is composed of hydrogen (H_2), carbon monoxide (CO), methane (CH_4), carbon dioxide (CO_2) and nitrogen (N_2) with a mean calorific value of about 3.0 – 8.0 MJ/Nm^3. The main advantages of gases as fuel over liquid or solid fuels are that (i) gases burn with higher efficiency than the solid or liquid fuels, (ii) they have a higher rate of heat release (iii) the rate of energy output is easily controlled and adjusted, and (iv) gaseous fuels with good energy utilization can be used for power sources.

Earlier studies reported that producer gas has been tried in two types of existing four stroke engines. Spark ignition, (SI) gasoline engines were operated directly as gas engines and compression ignition, diesel engines were operated on gas and diesel as dual-fuel engines. The first type was generally with lower compression ratio (CR), hence, low efficiency and power output. Munoz et al. [1] reported test results on an SI engine fueled with producer gas at a CR of 8.2:1. Power de-rating of 50% was observed, caused by unsuitability of a gas dosage equipment and low heating value of producer gas used. Sridhar et al. [2] used producer gas on an SI engine converted from diesel engine. Its CR was adjusted to 17:1. They found that increasing CR resulted in decreasing tendency of ignition timing. Maximum thermal efficiency was 21 %. Mustafi et al. [3] reported work using synthetic gas from aqua-fuel on an SI engine at CR between 8:1 and 11:1. They found that syngas affected de-rating of 23 %, compared to natural gas. Higher torque was obtained with increasing CR. Papagiannakis et al [4] reported work using producer gas on an SI engine at a CR of 11:1. They found that the engine ran well. The engine output was similar to natural gas engine. But, the specific fuel consumption was more than natural gas engine by 47 %. Dasappa et al [5] studied the use of producer gas on 100 kW, SI engine coupled to a generator at a CR of 9.7. They found that maximum thermal efficiency was 18 %.

As far as duel fuel operation was concerned, earlier studies on this topic was found to be favorable. Uma et al. [6] used producer gas in a diesel engine on dual fuel mode. They achieved the maximum diesel replacement in a range of 67-86 %. Low emissions of sulphur dioxide (SO_2), hydrocarbons and oxides of nitrogen were reported, compared to diesel mode. Singh et al. [7] tested performance of a diesel engine on dual fuel mode. The maximum diesel replacement of 63% was observed. Brake powers were found to decrease marginally. Ramadhasc et al. [8] presented results from a producer gas fed to a 5.5 kW diesel engine. Specific energy consumption reported for both wood chips and coir pith as fuels were 18 MJ/kWh, compared with about 15 MJ/kWh from diesel. They reported a maximum of 72 % diesel replacement at 50% load. Dasappa et al. [9] used producer gas and diesel on a 68 kW diesel engine, reporting an average diesel replacement of about 75 % with an overall efficiency of 22 %. Lekpradit et al. [10] investigated effect of advanced injection timing on dual fuel operation. They found that increasing advance of the injection timing led to lower diesel consumption, but increase in overall efficiency and diesel replacement. Dussadee et al. [11] reported test results on dual fuel in a 32 kW diesel engine. They achieved a maximum diesel replacement of 60 % with an overall efficiency of 20 %.

The objective of this study was to investigate performance of a small engine fueled with producer gas and diesel in dual fuel mode without modifying the engine. This is to reduce diesel fuel requirement.

2. Experimental

2.1 Apparatus

The engine setup is schematically shown in Fig. 1, consisting of a gasification system and a diesel engine adapted to operate in the diesel and dual fuel modes. The gasification system was configured to operate on different biomass materials as fuels. It consisted of a gas generator, a gas cooler and a gas filter. The other elements of the package were a water treatment plant for closed-loop water recirculation system. The specification of gasifier used is given in Table 1. The engine used in this work was a naturally aspirated, 8.2 kW, small diesel engine. It was a four-stroke, single cylinder, compression ignition engine with bore and stroke of 92 and 90 mm, respectively. Compression ratio used was 21:1. The engine was coupled to a 5 kW dynamometer. The Y-shaped carburetor was used in dual fuel operation with producer gas to enable mixing of gas with intake air. Specifications of the engine are given in Table 2.

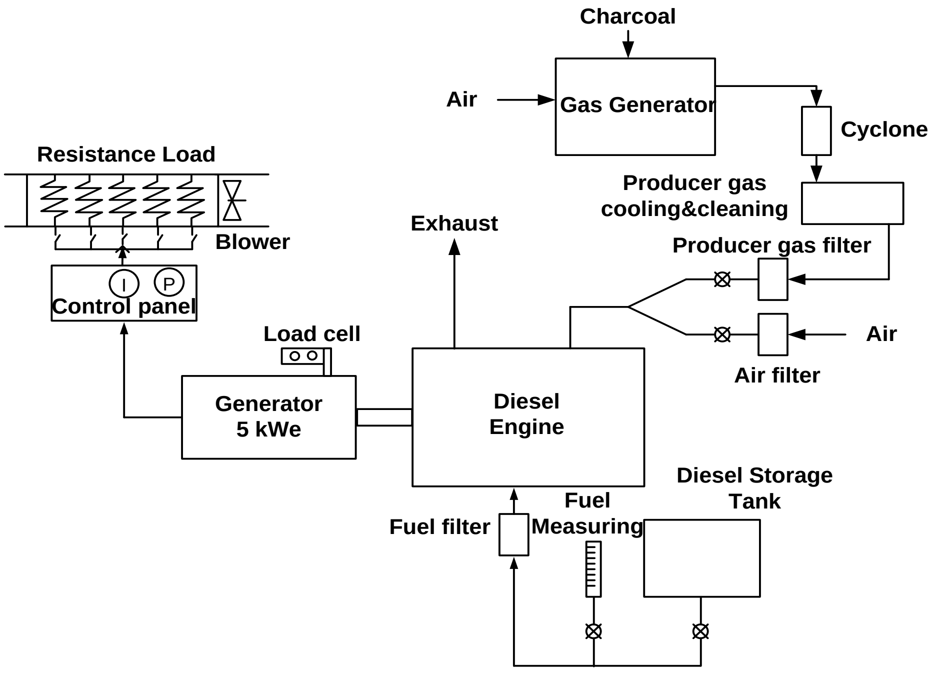

Fig. 1 Schematic diagram of producer gas engine test rig used in this study

Table. 1 Specification of the gasifier

Type of gasifier	Downdraft, batch feeding
Feeding	Manual
Fuel consumption	5 kg/h
Hopper capacity	30 kg
Gas cooling	Water
Biomass size	10 mm (minimum) 50 mm (maximum)

Table. 2 Specifications of the small diesel engine

Parameters	Specification
Type	indirectly injected, 4S, single cylinder, engine
Engine rating (kW)	8.2
Bore (mm)	92
Stroke (mm)	90
Displacement (l)	0.598
Compression ratio	21
Alternator rating (kW)	5
Rated output (kW)	5.0 @ 1500 rpm
Rated speed (rpm)	2400
Loading device	Electrical generator

2.2 Test procedures

The test conditions were at ambient pressure of 0.92 kPa; air density of 1.1 kg/m^3. Ambient temperature during the testing period was 32 ± 3 $^\circ$C. A load bank was connected to test the engine generator set. Measurements on current, voltage, frequency and fuel consumption were carried out. The static pressures were monitored using water tube manometers. The feedstock used for gasification was charcoal with moisture content between 12 to 15 % dry basis. It was fed to the gasifier through the top opening. Air entered at the combustion zone and producer gas generated left near the bottom of gasifier at the temperature of about 500 - 600 $^\circ$C. Hot producer gas was allowed to pass through the cooler where its temperature was reduced to ambient level. The cooled gas was then passed through the filter to remove tar and other particulate matter.

At the start, the engine was operated in diesel mode until stable, usually after 30 min. It was then switched to duel fuel mode where producer gas was fed and mixed with intake air. Amount of producer gas was adjusted by means of a control valve.

2.3 Data analysis

Agilant 6890 gas chromatography was used to measure mole fractions of CO, H_2, CH_4, CO_2 and N_2 in the producer gas. They were found to be CO at 18 ± 2%, H_2 at 14 ± 2%, CH_4 at 1 ± 0.5%, CO_2 at 12 ± 2%, and balancing N_2. Tests were carried out at varying engine speeds and loads between 1200 – 2000 rpm, and 1.0 – 3.5 kW, respectively. The producer gas and airflow rates were measured using gas meters. The engine torque, brake power, specific energy consumption, diesel consumption, diesel replacement rate, and thermal efficiency were evaluated. The dual fuel operation was then compared with only diesel.

3. Results and Discussion

3.1 Dual fuel operation

The gasifier was able to work continuously. The small engine was operated smoothly on dual fuel mode. The temperature of input producer gas was in a range of 35 - 40 $^\circ$C. The flow rate of producer gas was in a range of 5 to 40 m^3/h.

3.2 Engine torque

Fig. 2 shows engine torques of dual fuel mode of operation, compared with diesel fuel operation at various engine outputs. The engine torques of dual fuel mode was found to be slightly lower than diesel mode, by about 2 % on average. Reduction of engine torque was observed due to lower volumetric efficiency during intake, hence insufficient air to complete combustion. Generally, the volumetric efficiency of diesel fuel mode was about 85 – 90 %, but the dual fuel mode had actual volumetric efficiency of lower than 70 %.

3.3 Brake power

Fig. 3 shows engine brake powers of dual fuel mode of operation, compared with diesel fuel operation at various engine speeds. The engine brake powers of dual fuel mode were observed to be similar to diesel mode, in a speed range of 1200–1600 rpm. Between 1800–2000 rpm, dual fuel operation showed lower brake powers than diesel mode. Decrease of brake power at high engine speeds may be due to insufficient oxygen available to complete the combustion [11]. The brake powers of dual fuel mode and diesel mode were between 0.68 – 6.33 kW, and 0.69 – 6.37 kW, respectively.

3.4 Specific energy consumption

Fig. 4 shows variation of specific energy consumption with engine speeds. The specific energy consumption from dual fuel mode of operation was found to be higher than that from diesel mode at all engine speeds. At higher producer gas flow, specific energy consumption was higher. Patterns of specific energy consumption for both modes in a range of 1200 - 1400 rpm were rather constant, but increased between 1600-2000 rpm. At 1500 rpm, specific energy consumption was at minimum. The specific energy consumption in dual fuel and diesel modes at 1500 rpm were 17.7 and 18.7 MJ/kWh, respectively.

3.5 Diesel consumption

Diesel consumption at various engine speeds is shown in Fig. 5. The diesel consumption in dual fuel mode was observed to be lower than diesel mode for all engine speeds. Minimum diesel consumption in dual fuel mode was about 100 g/kWh at 1500 rpm, while for diesel mode operation, it was 360 g/kWh at engine speed of 1800 rpm.

3.6 Diesel replacement rate

Diesel replacement rate under various engine speeds was calculated from diesel consumption in diesel mode and dual fuel mode. The results are shown in Fig. 6. Use of producer gas in dual fuel mode of operation was found to reduce the consumption of diesel at all engine speeds, as expected. The maximum diesel replacement rate was 75 % at engine speed of 1400 rpm. The diesel replacement rate was found to decrease with increasing engine speed. The lowest replacement rate was 58 % at engine speed of 2000 rpm.

3.7 Thermal efficiency

Thermal efficiencies of both diesel and dual fuel mode of operation are shown in Fig. 7. Thermal efficiency of dual fueled engine was found to be lower than those of diesel engine for all engine speeds. Reduction in thermal efficiency was due to higher producer gas flow rates and lower calorific value of producer gas. Higher percentage of producer gas in the gas–air mixture may reduce the amount of fresh air entering the engine combustion chamber. Maximum thermal efficiencies of dual fueled and diesel engine were calculated to be 22 and 27 %, respectively. Both were achieved at engine speed of 1600 rpm.

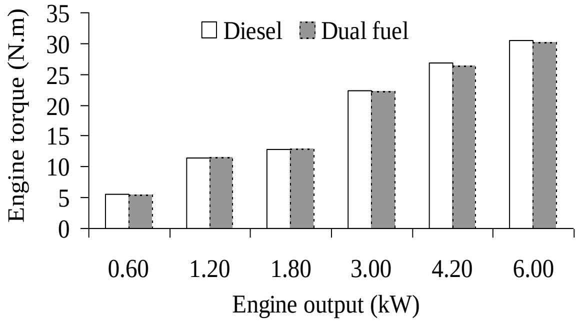

Fig. 2 Comparison of engine torque

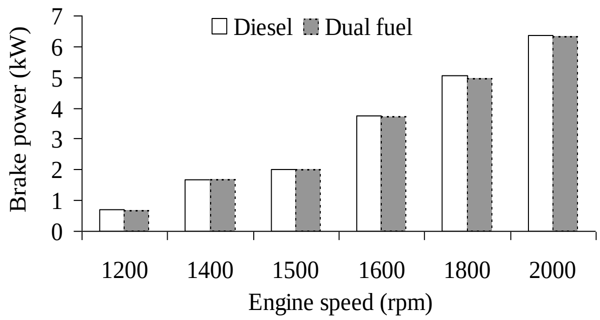

Fig. 3 Comparison of engine brake powers

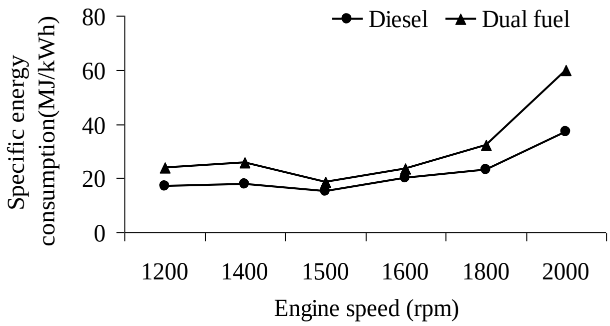

Fig. 4 Comparison of specific energy consumption

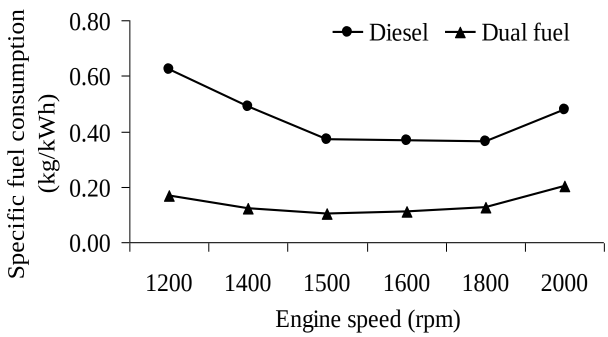

Fig. 5 Comparison of diesel consumption

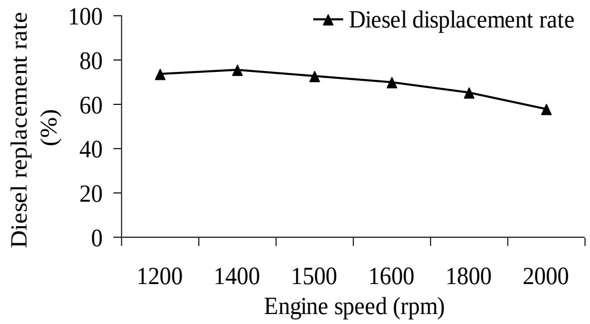

Fig. 6 Diesel replacement rate in dual fuel mode

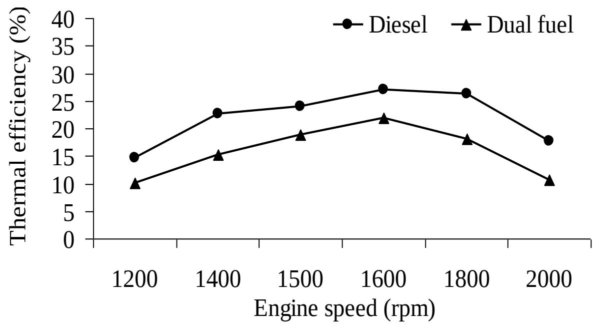

Fig. 7 Comparison of engine thermal efficiency

4. Conclusions

It was shown that unmodified diesel engine was capable of successful running in dual fuel mode of operation with biomass derived producer gas. Important findings on the performance of a small diesel engine in dual fuel mode of operation using producer gas were highlighted in the present paper.

The engine torque and brake power in dual fuel mode operation were slightly lower than those in diesel mode at all engine speeds.

The specific energy consumption in dual fuel mode of operation was higher than that of diesel mode at all engine speeds. But, the diesel consumption in dual fuel mode was much lower than diesel mode at all engine speeds. Maximum diesel replacement rate and thermal efficiency of dual fuel operation were 75 and 22 %, respectively.

5. Acknowledgment

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6. References

[1] Munoz, M., Moreno, F., Morea-Roya, J., Ruizb, J., and Arauzob, J. (1999). Low heating value gas on spark ignition engines, Biomass and Bioenergy, vol. 18, August 1999, pp. 431-439.

[2] Sridhar, H.V., Paul, P.J., and Mukunda, H.S. (2000). Biomass derived producer gas as a reciprocating engine fuel-an experimental analysis, Biomass and Bioenergy, vol. 21, December 2000, pp. 61–72.

[3] Mustafi, N.N., Miraglia, Y.C., Raine, R.R., Bansal, P.K., and Elder, S.T. (2006). Spark-ignition engine performance with ‘Powergas’ fuel (mixture of CO/H2): A comparison with gasoline and natural gas, Fuel, vol. 85, pp. April 2006, pp. 1605–1612.

[4] Papagiannakis, D.T., Rakopoulos, C.D., Hountalas, D.T., and Giakoumis, E.G. (2007). Study of the performance and exhaust emissions of a spark-ignited engine operating on syngas fuel, International Journal of Alternative Propulsion, vol. 1, September 2007, pp. 190-215.

[5] Dasappa, S., Subbukrishna, D.N., Suresh, K.C., Paul, P.J., and Prabhu, G.S. (2011). Operational experience on a grid connected 100 kWe biomass gasification power plant in Karnataka, India, Energy for Sustainable Development, vol. 15, March 2011, pp. 231-239.

[6] Uma, R., Kandpalb, T.C., and Kishorea, V.V.N. (2004). Emission characteristics of an electricity generation system in diesel alone and dual fuel modes, Biomass and Bioenergy, vol. 27, January 2004, pp. 195 – 203.

[7] Singh, R.N., Singh, S.P., and Pathak, B.S. (2006). Investigations on operation of CI engine using producer gas and rice bran oil in mixed fuel mode, Renewable Energy, vol. 32, September 2006, pp. 1565–1580.

[8] Ramadhas, A.S., Jayaraj, S., and Muraleedharan, C. (2007). Dual fuel mode operation in diesel engines using renewable fuels: rubber seed oil and coir-pith producer gas, Renewable Energy, vol. 33, January 2007, pp. 2077–2083.

[9] Dasappa, S., and Sridhar, H.V. (2011). Performance of a diesel engine in a dual fuel mode using producer gas for electricity power generation, International Journal of Sustainable Energy, vol. 1, September 2011, pp. 1–16.

[10] Lekpradit, T., Tongorn, S., Nipattummakul, N., and Kerdsuwan, S. (2009). Study on advanced injection timing on a dual-fuel diesel engine, Journal of Metals, Materials and Minerals, vol. 18, February 2009, pp. 169-173.

[11] Dussadee, N., Kiatsiriroat, T., Homdoung, N., Chaiwong, K., Thararux, C., Kangwankit, S. (2011). Study on power generator system using producer gas with biodiesel, Final report submitted to the Provincial Electricity Authority, Thailand.