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Performance and Emission Characteristics of Supercharged Biomass Producer Gas-diesel Dual Fuel Engine

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Abstract: The performance and emission characteristics of supercharged producer gas-diesel dual fuel engine has been investigated and evaluated. In this study, producer gas, which was generated from gasifier and intake air, were injected separately and mixed at the engine's intake manifold. Experiments were carried out at a constant injection pressure and flowrate of both producer gas and air. The performance and emission characteristics of dual fuel engine were investigated by supercharged producer gas-diesel dual fuel, premixed producer gas-diesel dual fuel and diesel fuel at constant engine speed and different loads. It was found that by supercharging the producer gas-diesel dual fuel mixture, the diesel fuel substitution and brake thermal efficiency were slightly increased and there is a reduction in carbon monoxide emission and specific energy consumption as compared to premixed producer gas-diesel dual fuel. The main reason is because relatively complete combustion occurred due to more air utilization, which increases in engine volumetric efficiency under these conditions. Therefore, the experimental results indicate that the supercharging is an effective way on improvement of combustion characteristics and at the same time a reduction of unburned gas emissions in dual fuel producer gas-diesel operation.

Key words: Dual fuel engine, gasification, port injection, producer gas, supercharging

INTRODUCTION

Global concern on environmental issues and the fast depletion of the petroleum reserves have imposed a great strain on developed countries to find an alternative sources of fuels in diesel engines for substitution of diesel fuel. Biomass is one of the renewable energy resources, which is capable of displacing large amounts of solid, liquid and gaseous fossil fuels. The solid biomass materials can be conveniently used as an alternative fuel through a process known as gasification. Historically, gasification is an old technology that has been disappeared soon after the Second World War when petroleum became easily available. Today, due to the increase of fuel prices and the environmental concern, there is renewed interest on this old technology. Gasification, basically is the process of converting solid fuel into a gaseous fuel through a thermo-chemical conversion process. The process involves the utilization and conversion of biomass in an atmosphere by using air or steam as a gasifying agent to produce a low or medium heating value gas. The generated gas, known as producer gas is a combination mixture of combustible and non-combustible of Carbon Monoxide (CO), Hydrogen (H_2), Methane (CH_4), Carbon Dioxide (CO_2), Nitrogen (N_2) and water vapor (H_2O).

The gasification process also produces fine dust, ash and condensable compounds of tar which must be cleaned and removed if the producer gas is intended to be used in the Internal Combustion (IC) engines (Sridhar *et al*., 2005a). The percentage composition of producer gas obtained by different researchers on volume basis over the last three decades are shown in Table 1.

Producer gas is one of the potential alternative fuel to replace fossil fuels in the IC engines. The producer gas can be used as an alternative fuel in Compression Ignition (CI) engine as a partial substitute for diesel in dual fuel mode, and Spark Ignition (SI) engine in producer gas alone mode (Shashikantha and Parikh, 1994). In the SI engine fueled only by producer gas, spark plug is used as

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Table 1: Percentage composition of producer gas

Gas constituents	(2)	(3)	(4)
CO	15-30	15-25	24.04
H_2	10-20	15-20	14.05
CH_4	2-4	1-3	2.02
CO_2	5-15	10-15	14.66
N_2	45-60	40-50	43.62
H_2O	6-8	1-2	1.61

an igniter. However, in the dual fuel engine, partial of diesel oil is still required to start the ignition for combustion process. The main reason is because the producer gas that contained carbon monoxide as a main constituent has comparatively much lower flame velocity, thus requires longer time to ensure the complete combustion (Mohod *et al*., 2003).

A major problem associated with producer gas engines are loss of power or power derating. There is a general perception that the most possible reason is because of lower heating value of producer gas itself or lower energy content of producer gas-air mixture. This statement could be true for naturally aspirated IC engines fuelled by producer gas (Roy *et al*., 2009). It was reported that almost 35% power loss is expected due to the lower energy content of producer gas-air mixture (Wood Gas as Engine Fuel, 1986).

According to Dasappa (2001), the primary factors that influencing power output from producer gas engines as are including low heating value of producer gas, low in engine Compression Ratio (CR) and the way of air introduced into the engine's cylinder (Dasappa, 2001). The heating value of producer gas, even though is almost eight to ten times lower than of natural gas, its energy density (stoichiometric air-gas mixture) is only about 20-35% lower than energy density of natural gas (Reed and Das, 1988). This is because the stoichiometric air to fuel ratio for producer gas is 1.2 as compared to 17 for natural gas (Sridhar *et al*., 2001).

For compression ratio, the thermal and mechanical efficiencies in IC engine increases with increase of CR, implying the power output increases with CR under given set of operating conditions. The technique of increasing CR in improving the performance of producer gas engine has been carefully investigated by Sridhar *et al.* (2001, 2005a, b). Therefore, supercharging the engine is seen the other potential factor to improve engine performance, as well as an exhaust emissions. Supercharging is a well known method that could improves the combustion process in diesel engines (Heywood, 1988). Higher intake air pressure and air temperature of the engine reduces ignition delay with a lower rate of pressure rise in the combustion chamber.

The producer gas can be compressed to a higher pressure than atmospheric, due to the fact that the producer gas has poor ignition delay and ignition characteristics (Singh *et al*., 2007). Compressing and storage of producer gas have been tried by number of researchers. Hassan *et al.* (2010) had developed a preliminary investigation on compressed producer gas from downdraft biomass gasifier. It has been reported that a good quality of compressed producer gas with constant pressure and flow rate were obtained throughout the experiment. Ahmed *et al.* (2006) had conducted a study on compressing of producer gas using switch grass as a biomass fuel through gasification process. The producer gas obtained was compressed using an air compressor and stored at 869 kPa of gauge pressure. The compressed producer gas was then converted into ethanol using microbial catalysts. Investigation carried out by Roy *et al.* (2009) on the performance and emission of dual fuel engine fueled by producer gas revealed that the producer gas-air mixture can be supercharged in the engine. The mixture of the gas was kept constant a 200 kPa and the engine speed fixed at 1000 rpm. The producer gas used was a simulated gas, which was prepared by mixing individual gas components to an appropriate proportions of the actual producer gas composition.

Based on literature studies reviewed, it is observed that no such information available on employing producer gas from downdraft gasification under supercharged condition in the IC engine. Therefore, the present study is aimed to investigate the performance and emission characteristics of supercharged dual fuel producer gas-diesel engine fueled by producer gas from downdraft biomass gasifier.

MATERIALS AND METHODS

The experimental setups consisted of a downdraft gasifier complete with cooling and cleaning system, air compressor and a single cylinder direct injection diesel engine. The downdraft gasifier was specifically designed and developed by Bio-energy Group of Universiti Sains Malaysia. The specifications of the downdraft gasifier used are given in Table 2.

The biomass fuel is fed into the gasifier through the top opening, and air is supplied to the gasifier using a rotary blower, in which the capacity was higher than the required airflow rate. Air enters the combustion zone and the producer gas generated goes out near the bottom of the gasifier. Once the steady operation of the gasifier is achieved, the hot producer gas is then allowed to pass through the cyclone, heat exchanger and gas filter for the cleaning and cooling processes as shown in Fig. 1.

The engine tests were conducted on a four-stroke single cylinder direct injection diesel engine as detailed

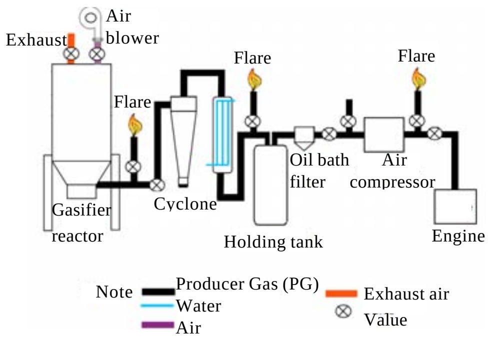

Fig. 1: Schmatic diagram of gasifier system

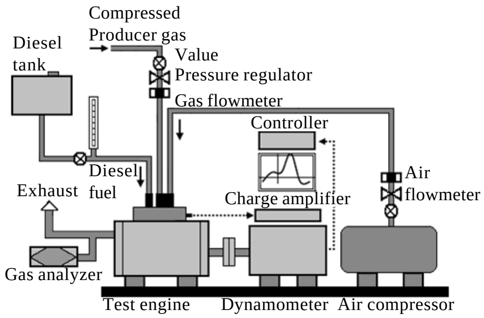

Fig. 2: Schmatic diagram of engine system

Table 2: Specification of the gasifier

Item	Description
Type of gasifier	Downdraft
Fuel consumption	20 kg h^{-1}
Hopper capacity	100 kg
Biomass fuel	Off cut furniture wood
Biomass size	50-100 mm (cubic)
Efficiency	70-75%

Table 3: Specification of the engine

Item	Description
Model	Yanmar L70AE-DTM
Type	Single Cylinder, DI
Capacity	296 cc
Maximum Power	4.9 kW @ 3600 rpm
Compression Ratio	19.1
Injection Timing	14°±1° BTDC
Injection Pressure	19.6 Mpa

specifications are shown in Table 3 and Schematic diagram of engine system is shown in Fig. 2. An electrical eddy current dynamometer was directly coupled to the engine, and the engine load applied was measured from controller. A glass burette with 50 mL volume capacity and a stopwatch were used to determine the fuel consumption. The exhaust emissions and exhaust gas temperature were measured and determined using Kane Automotive Gas Analyzer and K-type thermocouple, respectively. All experimental data required for the evaluation of the performance parameters and exhaust emissions were recorded.

A series of experiments were conducted in this study using diesel fuel only, premixed and supercharged producer gas-diesel dual fuel. All tests were conducted by starting up the engine with diesel fuel only. Experiments for premixed and supercharged conditions, operation were started after 30 min of the gasifier started up. The engine was initially run at full load using diesel fuel to measure the maximum brake power and fuel consumption. Then, engine torques of 3, 5, 7 and 9 Nm were selected and each load was applied at a constant engine speed of 1600 rpm. In supercharged condition, the producer gas from gasifier was compressed before the gas is injected and mixed with compressed air at the intake port of the engine's cylinder as shown in Fig. 4. The supercharged producer gas and air were kept constant at 200 kPa throughout the experiment. Pressure regulator and gas flow meter were used to maintained the required pressure and flowrate of both producer gas and intake air.

In both premixed and supercharged operations, the supply of producer gas was adjusted manually to obtained the maximum percentage of diesel displacement. For all cases, the engine was operated at a standard fuel injection timing of 14° Before Top Dead Centre (BTDC) and standard injection pressure of 196 bar and the experiment for each test was replicated three times.

RESULTS AND DISCUSSION

Brake thermal efficiency: Figure 3 shows the variation of brake thermal efficiency of the test engine operated on diesel fuel, premixed and supercharged dual fueled producer gas-diesel with respect to the Brake Mean Effective Pressure (BMEP). The brake thermal efficiency of dual fueled engine is always lower than of diesel fuel, in which the maximum efficiency achieved by diesel fuel was 25.3%. In the dual fuel operation, the maximum brake thermal efficiencies were recorded as 16.8 and 19.3% in premixed and supercharged dual fuel, respectively. Further increase of engine load will result in decrease of brake thermal efficiency due to lower calorific value of producer gas combusted mixture that enters into the engine.

Specific energy consumption: In dual fuel mode operation, specific energy consumption is preferred to compare the performance of two type of fuels that having different calorific values and density. 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 of diesel mode at all operating conditions as shown in Fig. 4. For premixed dual fuel, reduction in air flow leads to incomplete combustion and increase the specific energy consumption as compared to supercharged dual fuel mode.

Diesel fuel replacement: The use of producer gas in dual fuel mode operation reduces the consumption of diesel fuel at all engine loads. The percentage of Diesel Fuel Replacement (DFR) varied between 48.3 to 62.2% for premixed dual fuel and 52.8 to 68.2% in supercharged dual fuel engine as in shown in Fig. 5. It was observed that the maximum percentage of diesel fuel replacement was recorded at 40% load for both premixed and supercharged dual fuel mode. Continuous injection of producer gas in supercharged dual fuel increases its density, hence displaced more diesel fuel at the mid load. The diesel fuel replacement was seen decreased at low and high load conditions. This phenomenon was due to insufficient oxygen to complete the combustion at low load, whilst in high load operations insufficient producer gas flow decrease the diesel fuel replacement.

Carbon monoxide emissions: The Carbon Monoxide (CO) emission in a producer gas-diesel dual fuel mode is always higher than the diesel alone mode at all operating conditions as shown in Fig. 6. The higher concentration of CO emission in dual fuel is a result of incomplete combustion, due to insufficient of air required for complete combustion. However, supercharged duel fuel exhibits better performance as compared to conventional premixed dual fuel. This is because the continuous injection of air increased the density of air, therefore increase the combustion efficiency in the engine's cylinder. However, overall CO concentration is still higher than diesel mode.

Nitrogen oxides emissions: The Nitrogen Oxides Emission (NOx) depends very much on the maximum temperature in the engine's cylinder and percentage of load applied. It was observed that the NOx increases with increase in load for all diesel alone and dual fuel modes as shown in Fig. 7. Supercharging the air into the engine cylinder provides more air and causes higher NOx emission in supercharged dual fuel. In diesel alone mode, organic nitrogen in the air is a main cause of the NOx formation. Producer gas do not have organic nitrogen, it has only atmospheric nitrogen, which is inorganic nitrogen (Singh *et al.*, 2007).

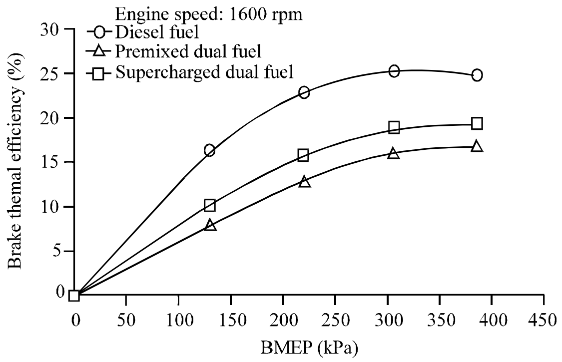

Fig. 3: Variation of the BTE with BMEP

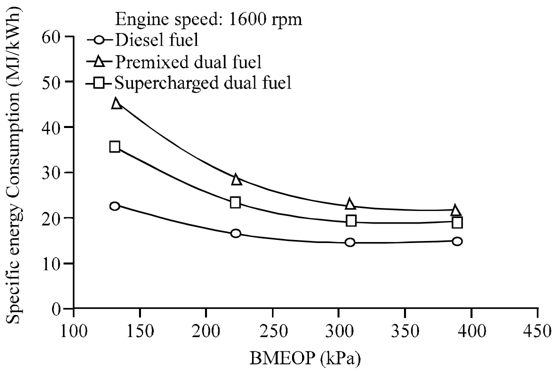

Fig. 4: Variation of SEC with BMEP

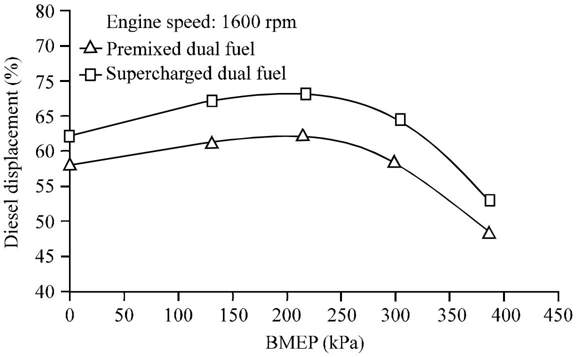

Fig. 5: Variation of DFR with BMEP

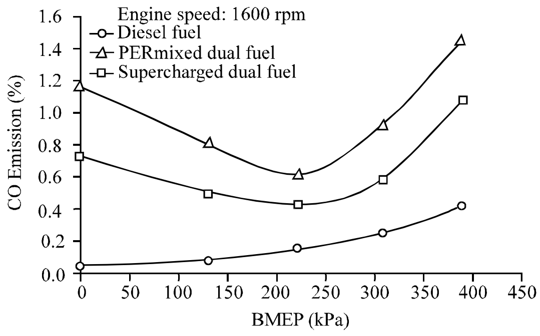

Fig. 6: Variation of CO emission with BMEP

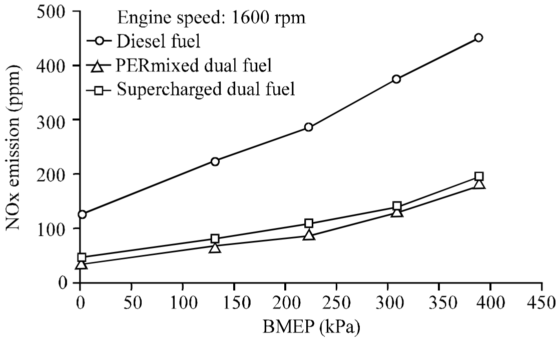

Fig. 7: Variation of No_x emission with BMEP

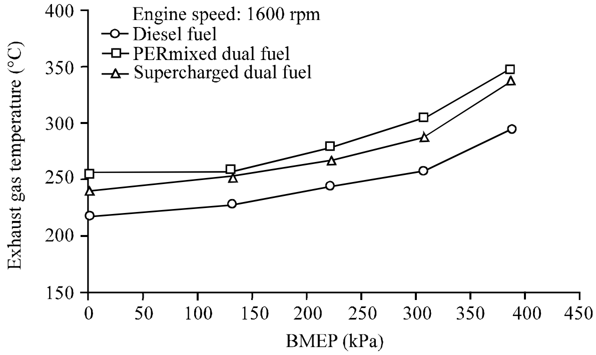

Fig. 8: Variation of EGT with BMEP

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 diesel alone mode due to the excess of energy supplied to the engine. The exhaust gas temperature of supercharged dual fuel mode is seen higher than premixed dual fuel because the density of the fuel mixture entering the engine increases. The higher exhaust gas temperature in the combustion chamber is an indication of increase in NOx emissions.

CONCLUSION

The engine performance and exhaust emission characteristics of supercharged producer gas-diesel dual fuel, premixed producer gas-diesel dual fuel and diesel fuel were experimentally investigated at constant engine speed and various engine load. The study proved that application of supercharger provides increased oxygen content to the engine, and enables sufficient mixing of fuel-air in the combustion chamber. Therefore, some important findings from this study may be summarized as follows:

- The brake thermal efficiency of the engine with supercharged dual fuel was improved 15% higher than of premixed dual fuel
- Higher diesel displacement is achieved in the supercharged dual fuel operation without any engine modification
- Reduction in specific energy consumption in supercharged dual fuel is an indication of better combustion efficiency as compared to premixed dual fuel
- Carbon monoxide emission from supercharged dual fuel is decreased due to an excess of air in the combustion chamber, as compared to premixed dual fuel operation

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