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Effect of fuel injection pressure on full load performance of diesel-producer gas dual fuel engine

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Abstract

An attempt is made to compare usage of different biomass to generate producer gas and then to study the performance and emissions from a dual fuel engine run on diesel and producer gas from different biomass. The experiments are conducted at different fuel injection pressures. The open top, down draft gasification system is used to generate producer gas through bio-gasification process. A compression ignition engine was allowed running on fossil diesel (FD), fossil diesel and producer gas (FD+PG) dual fuel mode. In dual fuel mode, the producer gas from different biomass viz., babul wood, mango wood and casuarinas wood used each time during experimentation. The emission levels for each mode were measured. The dual fuel mode was found environmentally benign in terms of emissions; nitrous oxides (NOx) and smoke density (SD) levels are found to be much lower compared to conventional diesel engine exhaust.

Keywords: Dual-fuel engine, fossil diesel (FD), producer gas (PG), emissions.

Introduction

The global energy consumption is predicted to double by 2030 and quadruple by 2100. This will put strains on the existing supply systems, increasing the risk of international conflicts over fossil fuels. Fossil fuel extraction is expected to peak during the current decade. Due to this, the conventional fuels especially petrol and diesel for internal combustion engines, are getting exhausted at an alarming rate. In order to conserve the fossil fuels or to plan for survival of technology in future it is essential to plan for alternate fuels. Further, these conventional fuels cause serious environmental problems as they release toxic gases into the atmosphere at high temperatures and concentrations. Some of the pollutants released by the internal combustion engines are HC, CO, NOx, smoke and particulate matter. In view of this and many other related issues, these fuels will have to be replaced completely or partially by less harmful alternative, eco-friendly and renewable fuels for the internal combustion engines. In this context usage of bio-gasification technology for power generation applications at a number of industrial sites in India and abroad is being encouraged, as this good old technology helps in reducing pollution.

Combustion of fossil fuels is one of the main energy conversion mechanisms throughout the world for power generation applications especially the automobile systems. Many technologies are being directed to mitigate the atmospheric pollution caused while burning the fossil fuel. Usage of gaseous fuels is one of such method (Holm, 2006). The producer gas generated by a thermo-chemical conversion of biomass (bio-mass gasification) is a promising fuel from the environmental protection point of view.

Gasification is the process of converting solid/liquid fuel in to gaseous fuel. It involves the utilization and conversion of biomass in an atmosphere to produce a medium or low calorific value gas. Gasification is a form of pyrolysis, carried out at high temperatures. The ratio of oxygen to biomass is typically around 0.3. The resulting gas, known as producer gas, is a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide and nitrogen. Biomass gasification is one of the upcoming biomass conversion technologies developed in order to produce a combustible gas mixture (called producer gas) using agro-residues (Tester *et al.,* 2006). It can be effectively utilized for decentralized power generation and thermal applications. Gasification of lignocelluloses biomass allows transforming its physical and chemical properties into a new fuel much more suitable to obtain mechanical energy in a process described a time ago (Ramadhas *et al.,* 2006).

Partial combustion of biomass in the gasifier generates producer gas that can be used for heating purposes and as supplementary or sole fuel in internal combustion engines. The utilization of producer gas in the diesel engine in dual fuel operation is an established technology for conservation of fossil diesel (FD). Producer gas could be used in CI engine, without any modification in the engine. However, it cannot replace the FD completely. FD replacements up to 70–90% have been achieved in the dual fuel mode. Because of its poor ignition characteristics some minimum amount of FD is required to start the ignition (Yamane & Shimamoto, 2002). A typical composition of producer gas generated by biomass gasification on volumetric basis is given in Table 1 (Yamane & Shimamoto, 2002). The performance of an internal combustion engine depends on engine parameters like injection timing, fuel injection pressure, compression ratio, ignition delay etc. (Prakash *et al.,* 1999; Abd Alla *et al.,* 2000; Cinar *et al.,* 2003; Torregrosa *et al.,* 2006).

In the present study, an attempt is made to utilize the fossil diesel (FD), fossil diesel and producer gas (from

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different biomass) in dual fuel mode and the engine performance and emissions were analyzed. The experiments were conducted at different fuel injection pressures.

Table 1. Constituents of producer gas.

Gas	Volume
Carbon monoxide	18-22%
Hydrogen	15-19%
Methane	1-5%
Hydrocarbons	0.2-0.4%
Nitrogen	45-55%
Water vapor	4%

Materials and methods

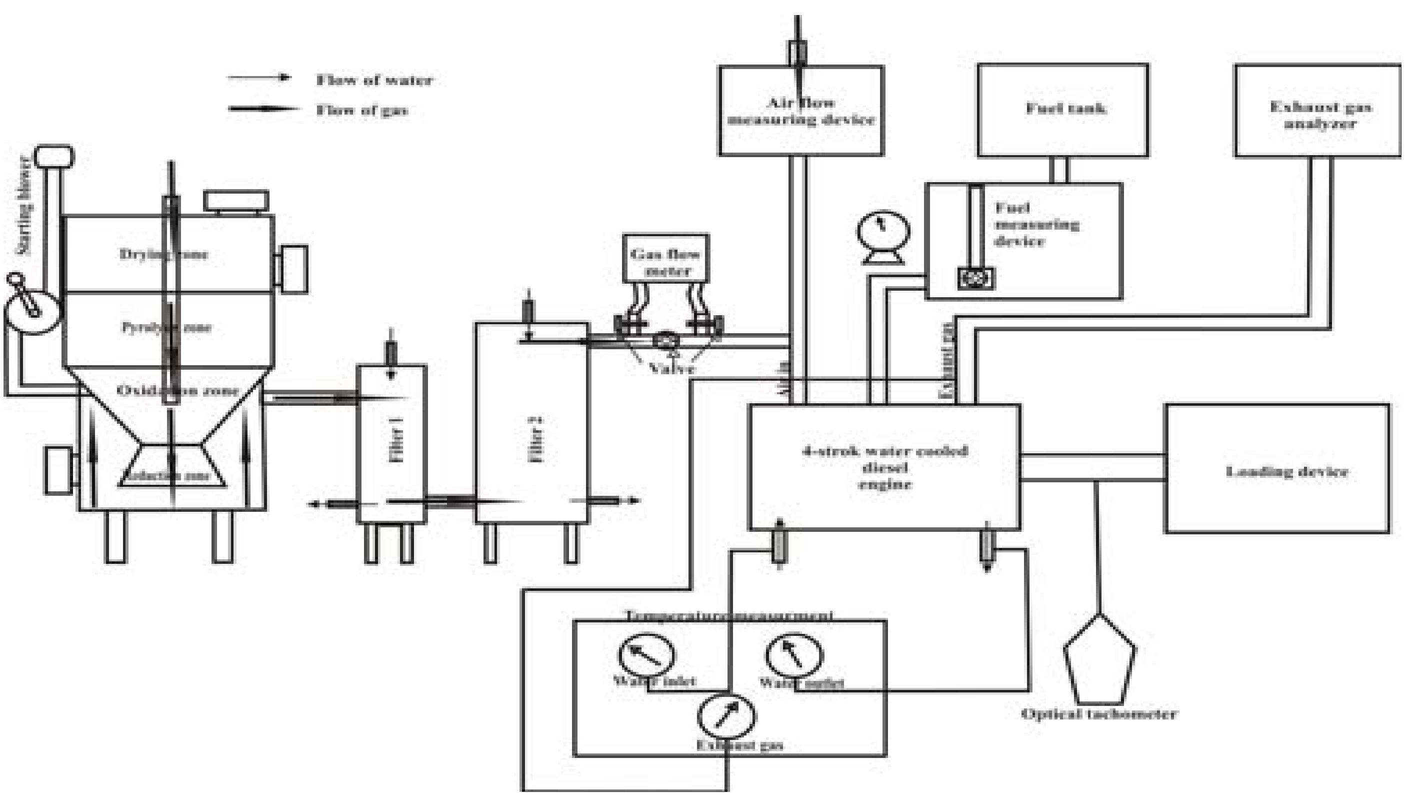
Biomass is recognized as one of the major potential sources for energy production which includes agricultural residues, energy crops, wood waste, coconut shell, bagasse and food processing residues. In this work, simple wood pieces available locally are used as feedstock for the biomass gasifier. Different types of wood selected are babul wood, mango wood and casuarinas wood. Wood pieces with approximate size of 5 cm long and 3 to 4 cm diameter are used as gasifier feedstock. fossil diesel, fossil diesel and producer gas from babul wood (FD+PG babul) in dual mode, fossil diesel and producer gas from mango wood (FD+PG mango) in dual fuel mode and fossil diesel and producer gas from casuarinas wood (FD+PG casuarinas) in dual fuel mode are used as fuels in single cylinder, CI engine to generate baseline data for the study. The CI engine used for the study was Kirloskar, single cylinder, four-stroke diesel engine. The engine was made to run on fossil diesel, next on dual mode using fossil diesel and producer gas, different woods each time. In each mode operation the fuel injection pressure is changed to study the effect of fuel injection pressure on the performance and emissions of the engine on diesel alone mode and dual fuel modes.

Experimental setup

A Kirloskar CI engine, with single cylinder, water cooled direct injection with rated output of 3.7 kW at constant speed of 1500 rpm was used for the study. An open top downdraft gasifier is selected in the study for generating of producer gas. It generated producer gas with less tar content and reduces the amount of high molecular weight hydrocarbons and particles as compared to the updraft gasifier (Ramadhas, 2006). The schematic diagram of gasifier-CI engine assembly and experimental setup is shown in Fig. 1.

The experimental setup includes downdraft gasifier, filter, gas cooler and diesel engine with loading device. Wood pieces of 3-4 cm in diameter and approximately 5 cm length were used as feedstock for gasification. The wood fed from the top of the gasifier at regular frequency and partial combustion is initiated. The partial combustion of biomass in the gasifier generates producer gas. This producer gas is allowed to enter the gas cooler passing through the gas filter. The valves are arranged in the pipeline to control the producer gas flow rate. A turbojet air flow meter is used to measure the air flow rate. The performance and emission tests are carried out in liquid mode and dual fuel mode, at different load conditions and at various fuel injection pressures. The dual fuel mode of

Fig. 1. Schematic diagram of experimental set up: assemble of gasifier & CI engine



operation is carried out by mixing producer gas-air mixture to the combustion chamber of the engine through inlet manifold. The flow rate of the liquid fuel was measured on volumetric basis. AVL gas analyser was used for the measurement of emissions. Smoke level is measured using a NPM-SM-11B NETEL (Hartridge) diesel smoke measuring system. A plenum chamber and manometers are used to measure the flow rate of producer gas. Experiments were conducted on the engine at full load with varying fuel injection pressures. The fuel injection pressures selected are 180 bar, 210 bar and 240 bar. The performance parameters like fuel consumption, fuel flow rates, thermal efficiency are calculated and compared for different fuel modes viz., fossil diesel, fossil diesel and producer gas dual fuel mode. Similarly emissions of the engine at different fuel modes and fuel injection pressure conditions were measured during the trails and compared.

Results and discussion

The engine performance along with emission characteristics at full load and different fuel injection pressure conditions viz., 180 bar, 210 bar and 240 bar of the engine are observed, while operating the engine with fossil diesel (FD), FD+PG babul, FD+PG mango and FD+PG casuarinas dual fuel modes.

Performance

Brake thermal efficiency (BTE): It can be seen in Fig. 2 that the brake thermal efficiency of the engine on fossil diesel mode is higher compared to all dual fuel modes of operation at all fuel injection pressure conditions considered. The brake thermal efficiency of the engine on fossil diesel mode at 240 bar fuel injection pressure is 42.74%, whereas on fossil diesel and producer gas from babul wood dual fuel mode, the BTE is 37.9%. For FD+PG mango, and FD+PG casuarinas modes of operation the brake thermal efficiency are 34.84% and 35.32% respectively. The brake thermal efficiency of the engine on dual fuel mode is lesser compared to fossil diesel mode because of the lower calorific value of producer gas. The producer gas contains more combusted mixture. Further, due to less supply of oxygen in dual fuel mode of operation, it leads to incomplete combustion of fuel and hence lower brake thermal efficiency.

The brake thermal efficiency of all modes of operation is increased with increase in fuel injection pressure. For instance, the brake thermal efficiency on fossil diesel (FD) mode at 180 bar fuel injection pressure is 35.71%, at 210 bar the BTE is raised to 37.82% and at 240 bar it is raised to 42.74%. Similarly on dual fuel mode of FD+PG babul, the brake thermal efficiency at 180bar, 210bar and 240 bar are 33.16%, 35.24% and 37.9% respectively. Similar trend can be observed with other modes of operations also. This may be due to reason that, as the fuel injection pressure increases the pilot fuel particle size might have decreased, which contributes for the effective combustion of charge due to the finer spray formed in the combustion chamber.

Fig. 2. Effect of injection pressure on brake thermal efficiency in dual fuel mode with different combinations of producer gas at full engine load.

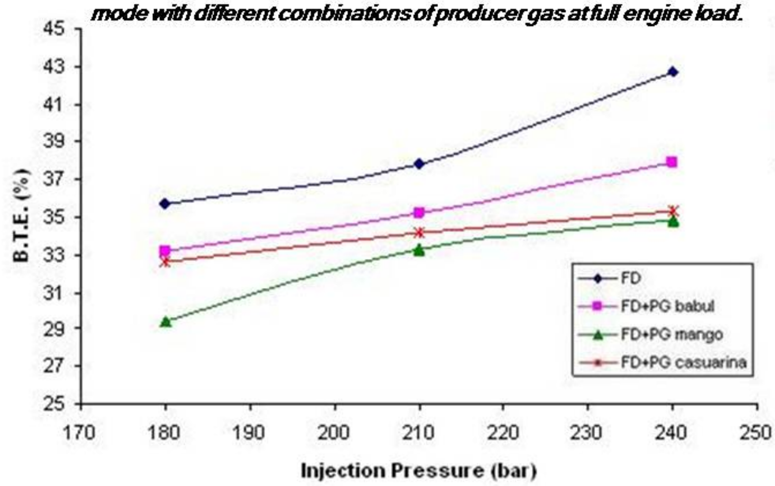


Fig. 3. Effect of injection pressure on exhaust gas temperature in dual fuel mode with different combinations of producer gas at full load.

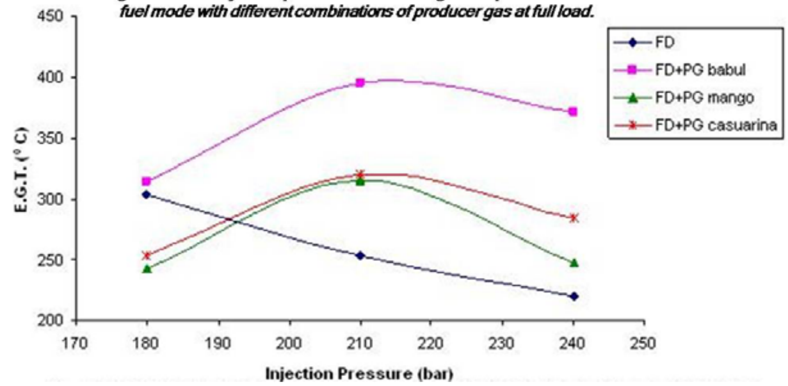


Fig. 4. Effect of injection pressure on CO emission in dual fuel mode with diesel and various producer gas combinations at full load.

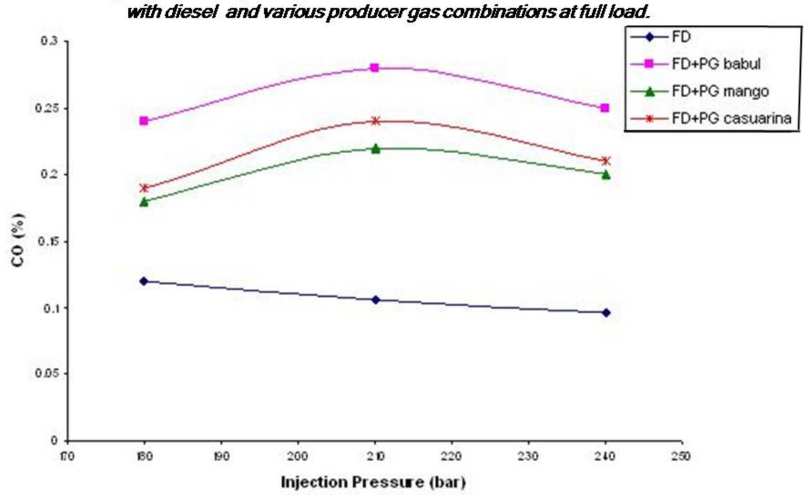


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Fig.5. Effect of injection pressure on HC emission in dual fuel mode with diesel and various producer gas combinations at full load.

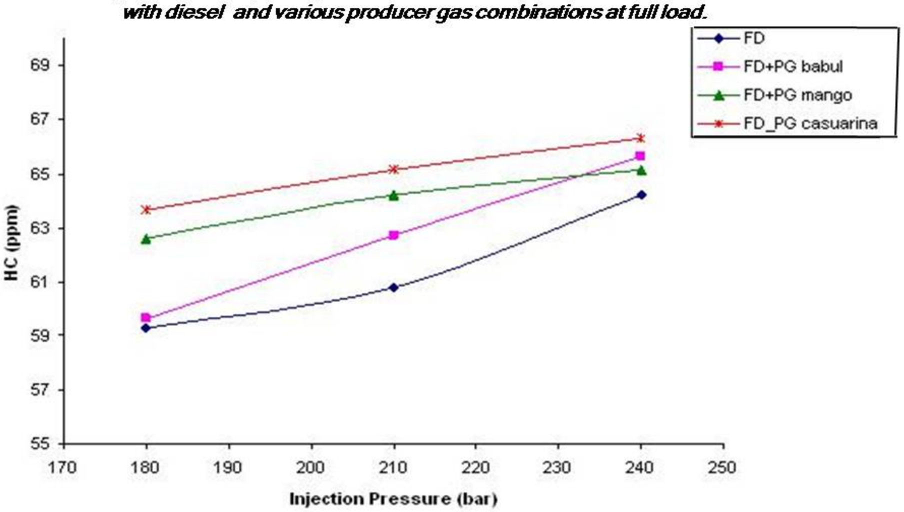
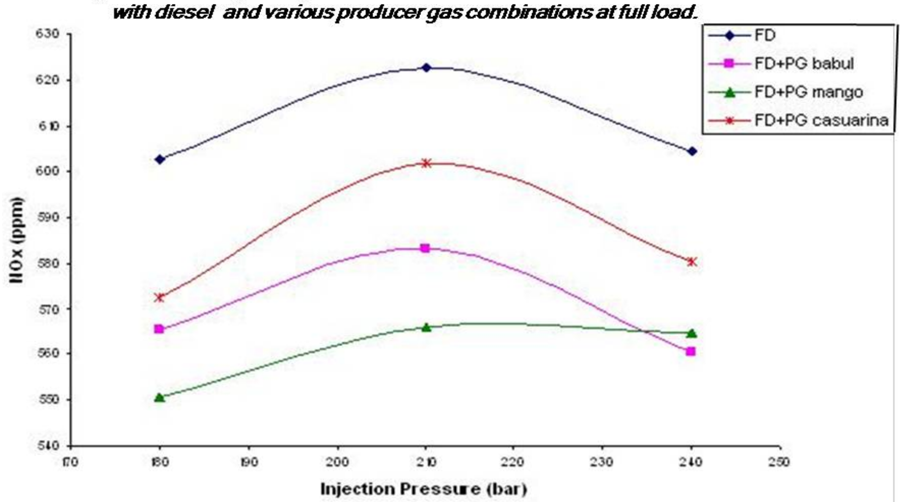


Fig.6. Effect of injection pressure on NOx emission in dual fuel mode with diesel and various producer gas combinations at full load.



Exhaust gas temperature (EGT): Fig. 3 shows the variation of exhaust gas temperature with the fuel injection pressure for FD mode, FD+PG babul dual fuel mode, FD+PG mango dual fuel mode and FD+PG casuarinas mode at full load condition. From the Fig. 3 it can be seen that the exhaust gas temperature of the engine on fossil diesel mode is lesser compared to all dual fuel modes of operation at higher fuel injection pressure conditions considered. The exhaust gas temperature of the engine on fossil diesel mode at 240 bar fuel injection pressure is 220^{0}C, whereas on fossil diesel and producer gas from babul wood dual fuel mode, the EGT is 372^{0}C. For FD+PG mango and FD+PG casuarinas modes of operation the exhaust gas temperature are 248^{0}C and 284^{0}C respectively. The exhaust gas temperature of the engine on dual fuel mode is higher compared to fossil diesel mode at higher fuel injection pressures because of the higher replacement of FD with PG and excess energy supply to the engine.

It is also observed that the exhaust gas temperature of all dual fuel modes of operation are increased with increase in fuel injection pressure from 180 bar up to 210 bar and then it is decreased slightly at 240 bar injection pressure. Whereas, on fossil diesel (FD) mode of operation, it is observed that the exhaust gas temperature decreased with increase in fuel injection pressure. For instance, the exhaust gas temperature on fossil diesel (FD) mode at 180 bar fuel injection pressure is 303^{0}C, at 210 bar the EGR is lowered to 253^{0}C and at 240 bar it is further lowered to 220^{0}C. Similarly, on dual fuel mode of FD+PG babul, the exhaust gas temperature at 180bar, 210bar and 240 bar are 314^{0}C, 395^{0}C and 372^{0}C respectively. Similar trend can be observed with other dual fuel modes of operations also.

Emission study

Carbon monoxide emission: Fig. 4 shows the variation of carbon monoxide (CO) emission with fuel injection pressure for fossil diesel (FD) mode, FD+PG babul dual fuel mode, FD+PG mango dual fuel mode and FD+PG casuarinas mode at full load condition. It may be observed from the figure that CO emission for fossil diesel (FD) mode of operation is lesser compared to all dual fuel modes of operation at higher fuel injection pressure conditions considered. The CO emission of the engine on fossil diesel mode at 240 bar fuel injection pressure is 0.096%, whereas, on fossil diesel and producer gas from babul wood dual fuel mode, the CO emission is 0.25%. For FD+PG mango, and FD+PG casuarinas modes of operation the CO emission are 0.2% and 0.21% respectively. The CO emission of the engine on dual fuel mode is higher compared to fossil diesel mode at all fuel injection pressures because of the mixture of producer gas – air flow to the engine reduces the amount of oxygen required for complete combustion. This creates incomplete combustion and increase in the CO emissions. It is also observed that the CO emission of all dual fuel modes of operation are increased with increase in fuel injection pressure from 180 bar up to 210 bar and then it is decreased slightly at 240 bar injection pressure. Whereas, on fossil diesel (FD) mode of operation, it is observed that, the CO emission decreased with increase in fuel injection pressure. For instance, the CO emission on fossil diesel (FD) mode at 180 bar fuel injection pressure is 0.12%, at 210 bar the CO emission is lowered to 0.106% and at 240 bar it is further lowered to 0.096%. Similarly, on dual fuel mode of FD+PG babul, the CO emission at 180bar, 210bar and 240 bar are 0.24%, 0.28% and 0.25% respectively. Similar trend can

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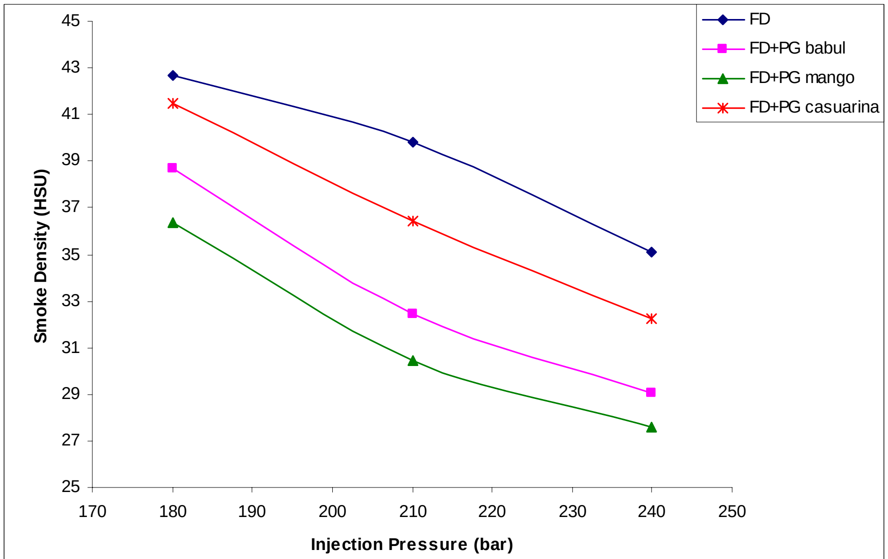

Fig.7 Effect of Injection Pressure on SD emission in dual fuel mode with Diesel and various Producer Gas combinations at Full Load

be observed with other dual fuel modes of operations also.

Hydrocarbon emission: Fig. 5 shows the variation of hydrocarbon (HC) emission with fuel injection pressure for fossil diesel (FD) mode, FD+PG babul dual fuel mode, FD+PG mango dual fuel mode and FD+PG casuarinas mode at full load condition. It may be observed from the figure that HC emission for fossil diesel (FD) mode of operation is lesser compared to all dual fuel modes of operation at all fuel injection pressure conditions considered. The HC emission of the engine on fossil diesel mode at 240 bar fuel injection pressure is 64.23 ppm, whereas on fossil diesel and producer gas from babul wood dual fuel mode, the HC emission is 65.65 ppm. For FD+PG mango, and FD+PG casuarinas modes of operation the HC emission are 65.12 ppm and 66.31 ppm respectively. The HC emission of the engine on dual fuel mode is higher compared to fossil diesel mode at all fuel injection pressures. This may be due to the lower charge temperature and air-fuel ratio, resulting in slower combustion and allowing small quantities of fuel to escape the combustion process.

It is also observed that the HC emissions of all modes of operation are increased with increase in fuel injection pressure. For instance the HC emission on fossil diesel (FD) mode at 180 bar fuel injection pressure is 59.3 ppm at 210 bar it is raised to 60.8 ppm and at 240 bar it is further raised to 64.23 ppm. Similarly on dual fuel mode of FD+PG babul, the HC emission at 180 bar, 210 bar and 240 bar are 59.63 ppm, 62.74 ppm and 65.65 ppm respectively. Similar trend can be observed with other dual fuel modes of operations also. This may be attributed to leaner fuel air mixture during combustion period as the fuel injection pressure increases, and probably some of the fuel remains in the injector nozzle sac volume and escapes the combustion, which produces higher HC.

Oxides of nitrogen emission: The major pollutants from the exhaust of a diesel engine are oxides of nitrogen and smoke. Fig. 6 shows the variation of oxides of nitrogen (NOx) emission with fuel injection pressure for fossil diesel (FD) mode, FD+PG babul dual fuel mode, FD+PG mango dual fuel mode and FD+PG casuarinas mode at full load condition. It may be observed from the figure that NOx emission for all dual fuel modes of operation is lesser compared to fossil diesel (FD) mode of operation at all fuel injection pressure conditions considered. The NOx emission of the engine on fossil diesel mode at 240 bar fuel injection pressure is 604.3 ppm, whereas on fossil diesel and producer gas from babul wood dual fuel mode, the NOx emission is 560.42 ppm. For FD+PG mango, and FD+PG casuarinas modes of operation the NOx emission are 564.61 ppm, and 580.42 ppm respectively. The NOx emission of the engine on dual fuel mode is considerably lower compared to fossil diesel mode at all fuel injection pressures. The formation of NOx is because of presence of organic nitrogen in the air, which is more incase of fossil diesel mode. Whereas producer gas does not have organic nitrogen it has only atmospheric nitrogen, which inorganic nitrogen. Due to this the NOx emission for all dual fuel mode of operation are less compared to fossil diesel mode of operation.

It is also observed that the NOx emission of all modes of operation are increased with increase in fuel injection pressure from 180 bar up to 210 bar and then it is decreased at 240 bar injection pressure. For instance, the NOx emission on fossil diesel (FD) mode at 180 bar fuel injection pressure is 602.6 ppm, at 210 bar, the NOx emission is raised to 622.4 ppm and at 240 bar it is lowered to 604.3 ppm. Similarly, on dual fuel mode of FD+PG babul, the NOx emission at 180 bar, 210 bar and 240 bar are 565.32 ppm, 583.27 ppm and 560.42 ppm respectively. Similar trend can be observed with other dual fuel modes of operations also. NOx emission depends upon combustion chamber temperature which may be more at 210 bar fuel injection pressure due to optimum fuel air mixture for combustion.

Smoke emission: Fig. 7 shows the variation of smoke density with fuel injection pressure for fossil diesel (FD) mode, FD+PG babul dual fuel mode, FD+PG mango dual fuel mode and FD+PG casuarinas mode at full load condition. It may be observed from the figure that smoke density for fossil diesel (FD) mode of operation is higher compared to all dual fuel modes of operation at all fuel injection pressure conditions considered. The smoke density of the engine on fossil diesel mode at 240 bar fuel injection pressure is 35.12 HSU, whereas on fossil diesel and producer gas from babul wood dual fuel mode, the HC emission is 29.08 HSU. For FD+PG mango, and FD+PG casuarinas modes of operation the smoke density are 27.56 HSU and 32.26 HSU respectively. The smoke density of the engine on dual fuel mode is considerably lesser compared to fossil diesel mode at all fuel injection pressures. It is also observed that the smoke density of all modes of operation is decreased with increase in fuel injection pressure. For instance, the smoke density on fossil diesel (FD) mode at 180 bar fuel injection pressure is 42.65 HSU, at 210 bar it is lowered to 39.8 HSU and at 240 bar it is further lowered to 35.12 HSU. Similarly on dual fuel mode of FD+PG babul, the HC emission at 180 bar, 210 bar and 240 bar are 38.66 HSU, 32.44 HSU and 29.08 HSU respectively. Similar trend observed with other dual fuel modes of operations also. This may be attributed to increase in the amount of gaseous fuel that forms no soot while increasing charge temperature contributes to its oxidation.

Conclusion

The engine was made to run on fossil diesel mode, fossil diesel and producer gas dual fuel mode. Producer gas generated from babul wood, mango wood and casuarinas wood each time to run the engine on dual fuel mode. The experiments were conducted at 3 different fuel injection pressures of 180 bar, 210 bar and 240 bar. The performance and emission of the engine at full load were investigated. The following results were obtained.

- The engine was able to run on 180 bar, 210 bar and 240 bar fuel injection pressures on fossil diesel mode and dual fuel mode.
- The engine was able to run on dual fuel mode with diesel and producer gas generated from babul wood, mango wood and casuarina wood each time.
- The brake thermal efficiency of the engine on all dual fuel modes of operations is less compared to fossil diesel mode.
- The brake thermal efficiency of the engine for all modes of operation increased with increase in fuel injection pressure from 180 bar to 240 bar.
- The exhaust gas temperature of fossil diesel mode is less compared to all dual fuel modes of operation at higher fuel injection pressures of 210 and 240 bar.
- The exhaust gas temperature is increased for fuel injection pressure of 210 bar for all modes of operation. Further increasing the fuel injection pressure resulted in decreasing the exhaust gas temperature.
- CO emission of dual fuel mode of operation is higher compared to that of fossil diesel mode of operation at all fuel injection pressures.
- CO emission increased up to the fuel injection pressure of 210 bar for all dual fuel modes of operation and then decreased slightly at 240 bar injection pressure.
- CO emission decreased with increase in fuel injection pressure from 180 bar to 240 bar for fossil diesel mode of operation.
- HC emissions of all dual fuel modes of operation are higher than the fossil diesel mode of operation at all fuel injection pressures.
- The HC emission increased with increase in fuel injection pressure from 180 bar to 240 bar for all modes of operation.
- NOx emission on all dual fuel mode of operation is lesser compared to that of fossil diesel mode of operation at all fuel injection pressures.
- NOx emission increased at 210 bar fuel injection pressure for all modes of operation and decreased at 240 bar fuel injection pressure.
- Smoke density on all dual fuel modes of operation is lesser compared to that of fossil diesel mode of operation at all fuel injection pressures.
- Smoke density decreased with increase in fuel injection pressure from 180 bar to 240 bar for all modes of operation.

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