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Full Length Research Paper

Performance and emission characteristics of compression ignition (CI) engine with dual fuel operation (diesel + compressed natural gas (CNG))

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The main objective of this work is to study the performance and emission characteristics of compression ignition (CI) engine using compressed natural gas (CNG) for the following conditions. (i) At constant speed by varying injection pressure and load (ii) Dual fuel combustion phenomenon. The conventional fuels like petrol and diesel for internal combustion engines are getting exhausted at an alarming rate, due to tremendous increase in the vehicular population. Further, these 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 engines are un-burnt hydro carbons (UBHC), CO, NOx, smoke and particulate matter. In view of this and many other related issues, these fuels will have to be replaced by alternative and eco-friendly fuels. A 4-stroke, single-cylinder, vertical, stationary diesel engine has been considered for the purpose of experimentation. It is modified suitably to run on the dual fuel mode. CNG gas-air mixer is incorporated on the intake side of the engine. The fuel injection system is also altered so that it injects only the pilot fuel. The engine performance is better on CNG compared to pure diesel up to engine loads of about 75.67%.

Key words: Dual-fuel, emissions, compressed natural gas (CNG), performance.

INTRODUCTION

There is an urgent need to save the conventional fuels like diesel and petrol, so as to reduce the oil import bills of an oil-dependent country and also to mitigate the menace of the environmental pollution. These fuels will have to be replaced by suitable alternative fuels like alcohols and various gaseous fuels (Ghazi, 1980). Among various gaseous fuels, compressed natural gas (CNG), liquid petroleum gas (LPG) and hydrogen are prominent. Dual-fuel operation is found to be one of the prominent methods of conserving diesel and petrol (Dong et al., 2001; Carlucci et al., 2008). Natural gas is found in Free State beneath the earth crest at high pressures and more commonly in association with the crude oil as the most volatile fraction (Mohamed, 2004). About 60% of the natural gas is produced along with the crude oil as an associated gas and rest as the free gas. It primarily consists of methane (about 80 to 90% by volume), and small quantities of other hydrocarbons like ethane, butane and paraffin's and other gases like CO_2 and N_2 (Anyogita et al., 2004). Natural gas has a good potential as substitute fuel for internal combustion engines. It may contain some impurities like hydrogen sulphide and moisture, in small proportions (Anyogita et al., 2004; Talal et al., 2010). It is normally stored in the gaseous form at a high pressure of about 200 bar for transportation. Natural gas is usually shipped in the liquefied form. The composition of natural gas varies from well to well and at the given production well it also varies from time to time (Papagiannakis et al., 2009). Typical composition of natural gas by volume is: Methane 87.3%, Ethane 7.1%, Propane 1.8%, Butane 0.7%, Nitrogen 2.2% and Carbon Dioxide 0.9%.

Experimental set-up

A single-cylinder, 4-Stroke, water-cooled, vertical, stationary diesel

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Abbreviations: **CNG,** Compressed natural gas; **CI,** compression ignition; **LPG,** liquid petroleum gas.

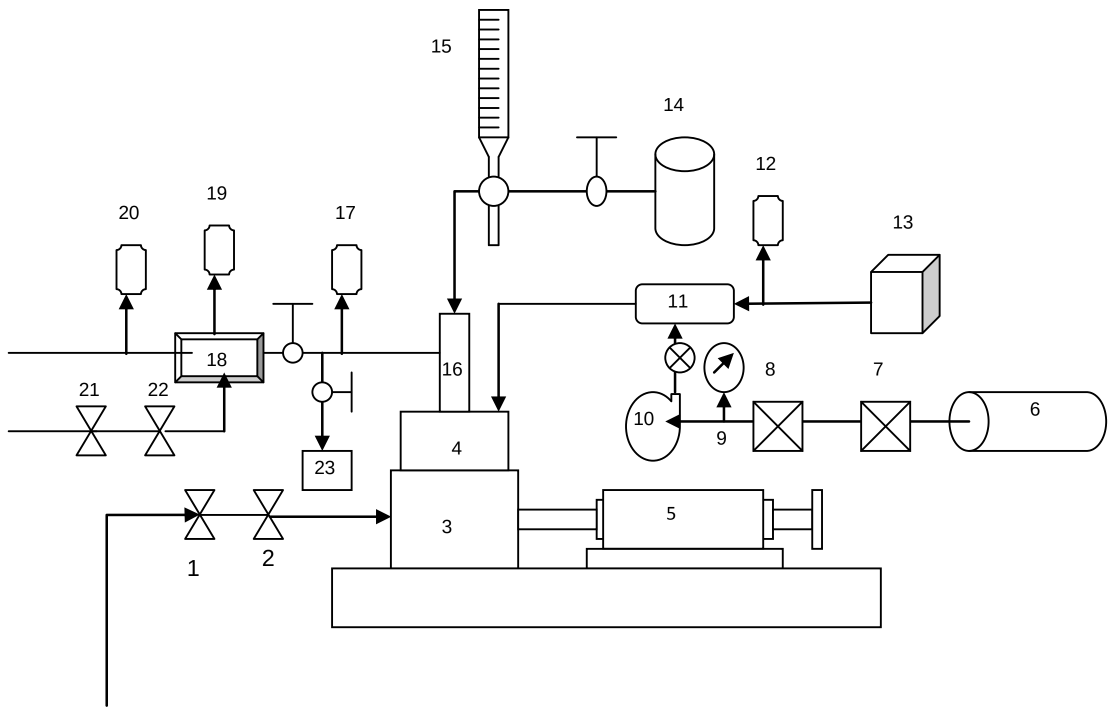

Figure 1. Layout of experimental set up, [1. Cooling Water flow meter 2. Inlet water temperature Sensor 3. Engine block 4. Cylinder head 5. Hydraulic Dynamo meter 6. CNG cylinder 7.On/off valve, 8. Solenoid valve 9. Pressure gauge 10. Regulator 11. Gas-air mixer 12. Manometer 13. inner box 14. Fuel tanks 15. Diesel flow measuring unit 16. Fuel injection system 17. Exhaust gas temperature sensors at inlet calorimeter 18. Calorimeter, 19. Calorimeter outlet water temperature sensors 20. Temperature at outlet calorimeter 21. Calorimeter water flow meter 22. Calorimeter inlet water temperature sensor 23. Emissions analyzer point].

engine of 3.7 kW rated power is considered for the purpose of experimentation. The experiments are conducted on diesel engine with diesel and dual fuel at different injection pressures of 180, 210 and 240 bars. A hydraulic dynamometer is used for loading the engine. The experiments intended to investigate the engine performance and emission levels with diesel and dual fuel (natural gas + diesel).

In the experimentation, load, pilot fuel quantity, fuel injection pressure and speed are the parameters selected for variation. Initially, the engine is operated on the diesel baseline mode at a constant speed of 1500 rpm at different loads. At each operating condition, dynamometer load, air flow rate, fuel flow rate, exhaust gas temperature and cooling water flow rate are recorded, tabulated and plotted. Then the engine is operated on the dual fuel mode at different loads for different injection pressures. The amount of diesel pilot fuel is kept constant while the engine speed is controlled by increasing the flow rate of natural gas to the engine until the specified engine speeds are obtained. All the experimental data for engine loads are recorded, tabulated and plotted. In the calculations of energy contributions of diesel and CNG, the lower calorific value of diesel is taken as 43626 kJ/kg while that of CNG is taken as 47132 KJ/kg. The layout of experimental set up is shown in Figure 1.

RESULTS AND DISCUSSION

The effect of fuel injection pressure on the engine performance and emission characteristics are investigated at different engine loads. The summary of the outcome is dealt in the following sections: Figure 2 shows the variation of exhaust gas temperature with brake power. From the figure, it is observed that the exhaust gas temperature is increased with increase in brake power. This reveals that more amount of dual fuel being consumed per hour compared to diesel. From the Figure 3, it is observed that initially with increasing brake power, the brake specific fuel consumption of dual fuel and diesel are decreased and then increases with increase in brake power. The brake specific fuel consumption with dual fuel is less than that of diesel throughout the range of brake power at all injection pressures. This is mainly due to the combined effects of relative fuel density, viscosity and calorific value of the dual fuels. From Figure 4, it was observed that initially with increase in brake power, the brake thermal efficiency of the engine is increased with both dual fuel and diesel. The brake thermal efficiency obtained with dual fuel is higher than that of diesel at all injection pressures.

Figure 5 shows the variation of volumetric efficiency with diesel and dual fuel at the injection pressures 180 bar, 210 bars and 240 bar and conclusions drawn between them are given below. The volumetric efficiencies of dual fuel at injection pressures of 180 bars and 240 bars are lower up to 75% load compared to

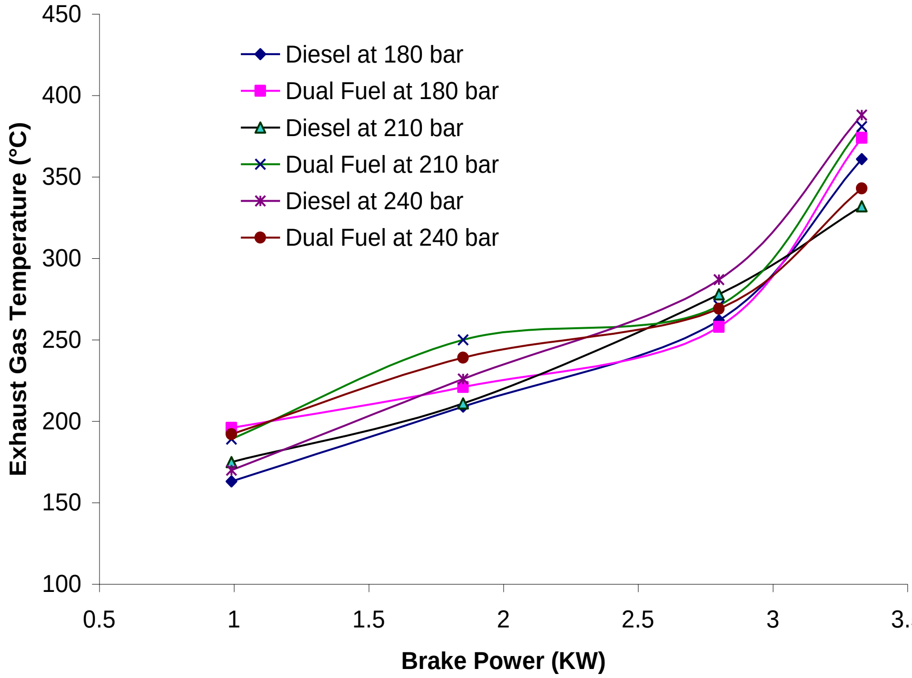

Figure 2. Brake power versus exhaust gas temperature with dual fuel operation.

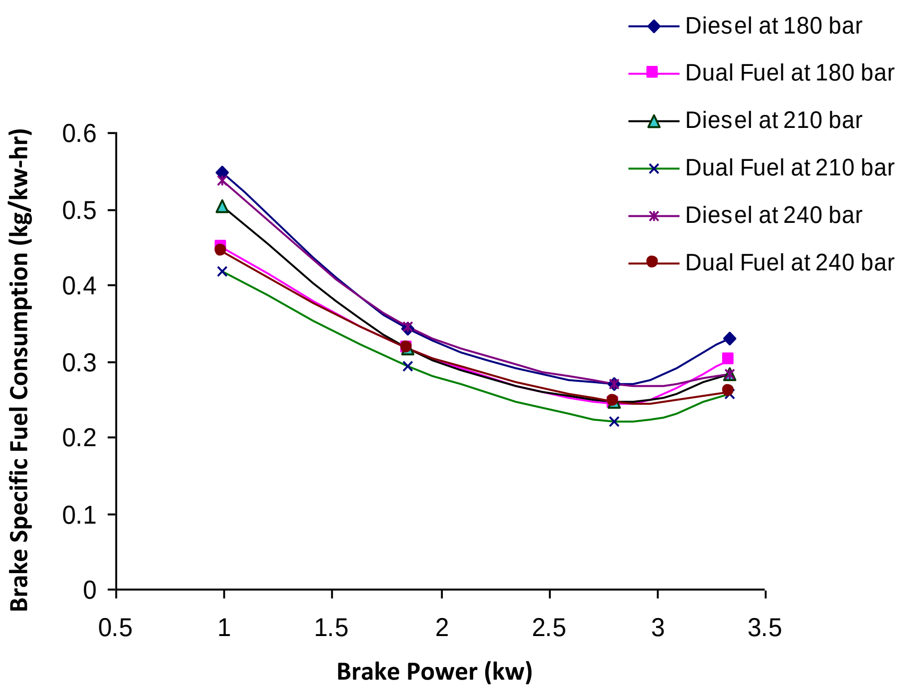

Figure 3. Brake power versus brake specific consumption with dual fuel operation.

diesel and increases tremendously at the engine load of 90% due to engine knocking.

At 210 bar injection pressure, the volumetric efficiency of the engine is increases as the load increases, this trend has continued up to 75% of load and then decreases up to 90% of the load, similarly the trend has been decreases up to 50% of the load and then increases up to 75%, further decreases up to 90% of the

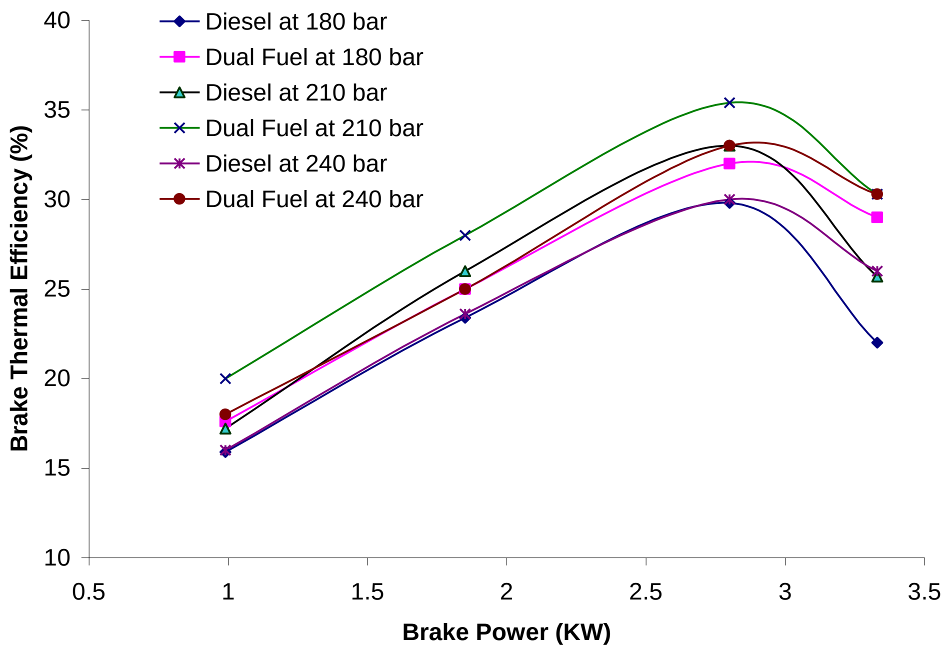

Figure 4. Brake power versus brake thermal efficiency with dual fuel operation.

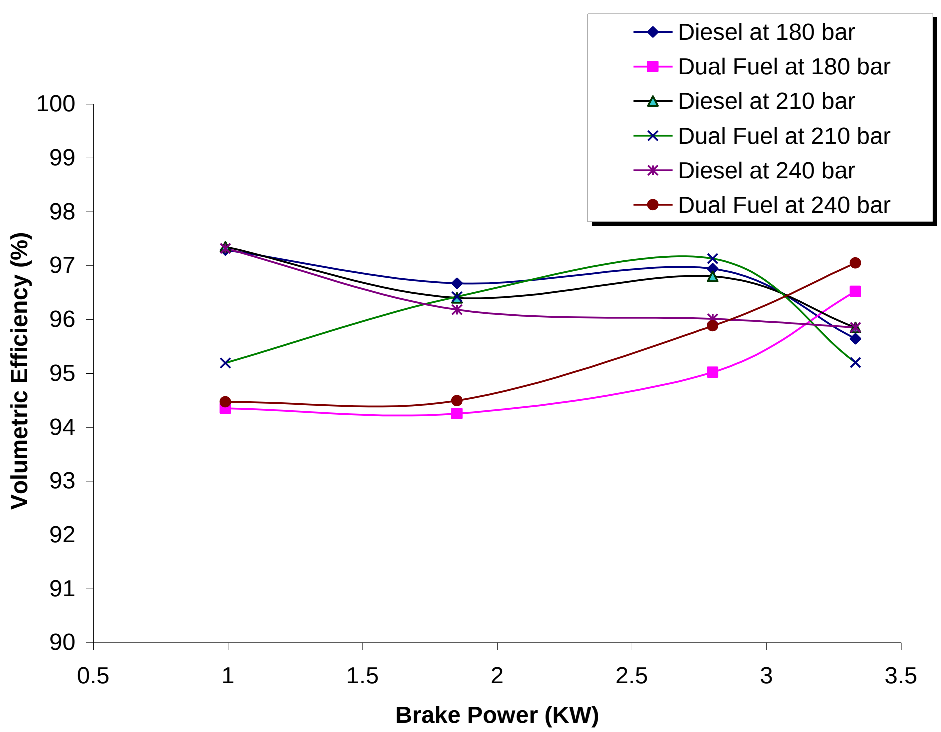

Figure 5. Brake power versus volumetric efficiency with dual fuel operation.

engine load. The decrease of volumetric efficiency in dual fuel is due to the larger volume of inlet air occupied by the CNG. The variation of NO_X emission with brake power is shown in Figure 6. From the figure, it is observed that the amount of NO_X is increased with increase in brake power for both (diesel and dual) the fuels. The temperature of combustion chamber is also increases with increase in brake power and NO_X formation is

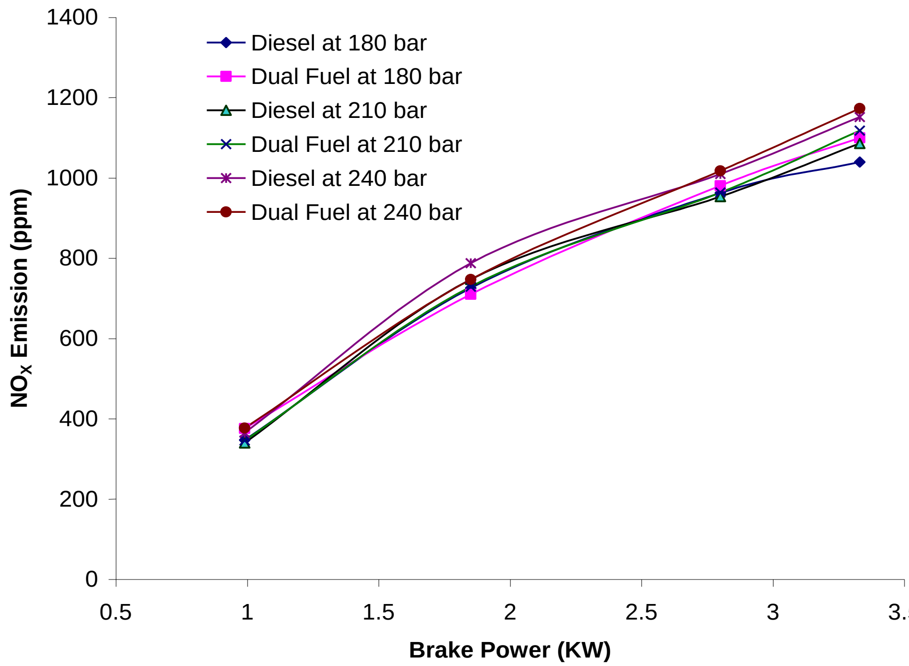

Figure 6. Brake power versus emission of NO_2 with dual fuel operation.

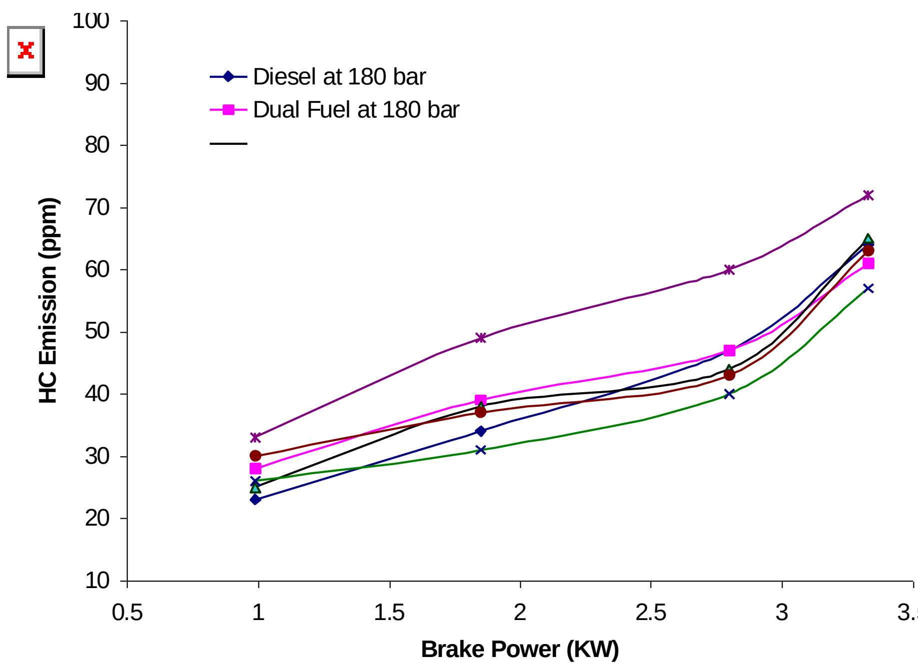

Figure 7. Brake power versus HC emission with dual fuel operation.

strongly temperature dependent Phenomenon. The NO_X emission for dual fuel is less when compared to diesel. Figure 7 shows the variation of UBHC with brake power. The UBHC is increased with increase in brake power for both (diesel + dual) fuels. It is observed that the emission of un-burnt hydro carbons for dual fuel is less than the diesel fuel. The lean mixture and exhaust gas temperature of CNG are responsible for less un-burnt hydro carbon emission when compared to diesel. The variation of smoke density with the brake power for different fuel injection pressures is illustrated in Figure 8. From this figure it was observed that, the smoke density is increased with an increase in the fuel injection pressure in both the cases that is, with diesel and dual

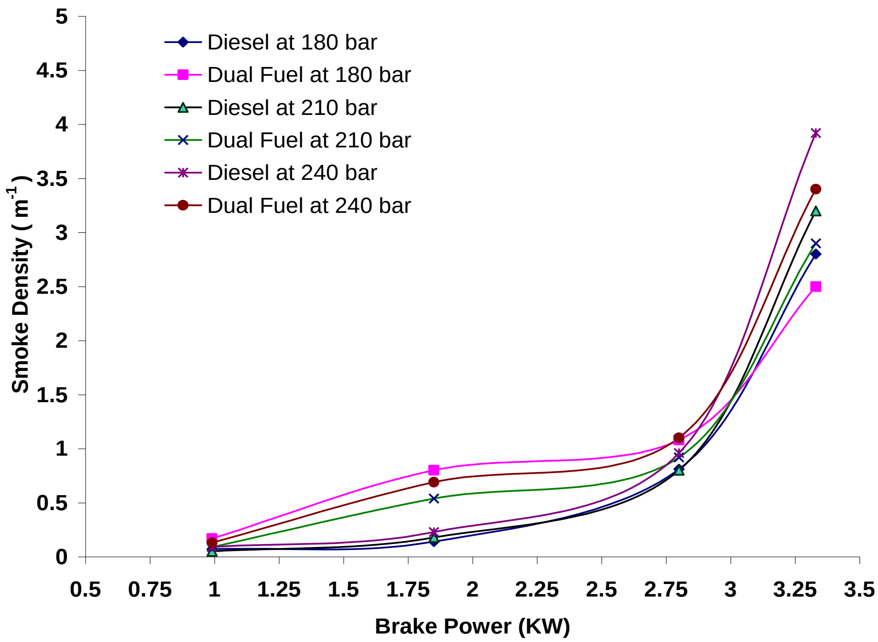

Figure 8. Brake power versus smoke density with dual fuel operation.

fuel. Further, the smoke density is decreased with increase in CNG content at all injection pressures.

Conclusions

Dual fuel operation is more convenient and economical for conserving the precious conventional liquid fuels. A diesel base line engine could be operated on the dual fuel mode with minor changes. The following conclusions have been made from the above work. The exhaust gas temperature for dual fuel operation is higher than diesel at the injection pressures of 180 and 210 bar. The exhaust gas temperature obtained for dual fuel and diesel are 374, 381 and 343°C and 361, 332 and 388°C, respectively. The brake specific fuel consumption with dual fuel is less than that of diesel throughout the range of brake power at all injection pressures. The brake specific fuel consumption is decreasing with increase in load up to 75.67% of rated load and then increasing beyond 75.67% of rated load for both fuel modes. Higher brake thermal efficiency is obtained at 210 bar injection pressure for diesel and dual fuel operations.

The Brake Thermal Efficiency is decreased with increase in Brake Power, when the engine is operated beyond 75.67% rated load. Prior to 75.67% load the Brake Thermal Efficiency is also increased with increase in Brake Power. The volumetric efficiency of dual fuel at 180 bar and 240 bar injection pressure is less up to 75% load compared to diesel and then increases tremendously due to engine knocking. At 210 bar injection pressure, the volumetric efficiency for both fuels is increases up to 75% load and then decreases. This decrease in volumetric efficiency, in dual fuel, is due to the larger volume of inlet air occupied by the CNG. The emissions of NO_X is increased with increase in brake power for both (diesel and dual) the fuels at all injection pressures. The un-burnt hydro carbons are increased with increase in brake power for both (diesel + dual) fuels. The emission of un-burnt hydro carbons for dual fuel is less compared to diesel fuel. The smoke density is increases with increase in brake power at all defined fuel injection pressures for both the diesel and dual fuels.

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