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Experimentation & Simulation of Dual Fuel (Diesel-CNG) Engine of Off Road Vehicle

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ABSTRACT

The paper consists of experimentation & simulation of dual fuel (Diesel-CNG) engine of off road vehicle. It is novelty to introduce first time in India. The tractor engine consists of 4 cylinder, 4 stroke, direct injection naturally aspirated engine. Existing tractor engine is converted into dual fuel mode and tests are conducted. Diesel engine was successfully converted to dual fuel mode and simulation in GT power was validated with experimental tests performed on test bed. Simulation in GT power i.e. engine modeling for diesel as well as dual fuel engine includes 1D thermodynamic analysis of combustion & performance parameters. The results were obtained by maintaining the performance of diesel engine by testing engine with Nα mode (N-Engine speed, α- Throttle). Six different cases were taken by varying speed of engine. Results show that the engine operation is more economical on the pure diesel mode at lower speed; however, at higher speed dual-fuel operation is better. BSFC is lower for dual fuel mode compared to diesel by 8%. Volumetric efficiency of dual fuel engine is lower as compared to diesel engine by 5%, PM concentration under dual fuel operation is lower compared to normal Diesel operation. CO and HC emissions levels are considerably higher compared to normal Diesel operation. Hence, CO and NOx are reduced with aftertreatment devices such as DOC and EGR respectively. Dual fuel engine effectively meets the emission norms and is compatible for off road vehicles.

Keywords: Experimentation, Simulation, GT power, Diesel-CNG

INTRODUCTION

The dual fuel CI engine has been employed in a number of applications utilizing various gaseous fuels due to their cleaner nature of combustion compared to conventional liquid fuels. Natural gas seems to be an excellent candidate because of its worldwide usage. It has a high octane number; therefore, it is suitable for engines with relatively high compression ratio. Moreover, it mixes uniformly with air, resulting in efficient combustion and a substantial reduction of emissions in the exhaust gas. Dual fuel technology can be applied on conventional direct injection (DI) diesel engines with minor modifications. Furthermore, dual fuel combustion using natural gas is a technique that results in the reduction of both pollutants NO and soot, which is extremely difficult to achieve in DI diesel engines. Dual fuel engines also contribute to the reduction of carbon dioxide emissions due to the low C/H ratio [1-2].

- Simulation of base diesel engine and its validation by testing the diesel engine for baseline diesel tests.
- Conversion of diesel to dual fuel mode.
- Simulation for dual fuel mode and its validation by testing the dual fuel engine
- Optimization of CNG fuel quantity in dual fuel mode.
- Analysis of the results

TOPIC BACKGROUNDAND LITERATURE REVIEW

Global warming, environmental pollution and exhaustion of fossil fuels are seriously issued throughout the world. Also, emission restriction is strengthening in the country and research work about alternative fuels is actively processing. There are two methods to apply natural gas at existing diesel engine [4].

1. CNG dedicated method and CNG
2. Diesel dual fuel method

CNG Dedicated Method
Uses: Spark ignition after premixing intake air and CNG in mixer at intake.
Advantage: Reduces PM by pre-mixture combustion
Drawbacks: Power & Thermal Efficiency decreases due to lowering of compression ratio, Increase in remoulding cost [6].

CNG/Diesel Dual Fuel Method
Uses: Existing diesel engine without remoulding. In dual fuel mode, air and fuel (i.e. CNG) premix in intake & compression ignition occurs by diesel pilot injection. Thus it has characteristics of otto cycle as well as diesel cycle.
Advantages of dual fuel mode: Ignition timing control is easy as ignition starts by diesel injection, Remoulding period is saved, Initial cost is cheaper [6].

What is Dual fuel?
A dual-fuel system is capable of using two types of fuel at the same time in a mixture. It usually cranks up on one type of fuel, and a governor built into the system gradually adds the secondary fuel source until the optimal mixture of the two fuels is achieved for efficient running [2].

Modes of Operation of Dual Fuel Engines
The premixed dual-fuel engine is basically a conventional compression ignition engine of the diesel type where the injection of some liquid fuel, often in quite small dosages, is used to provide the source for ignition. The cylinder charge is made up mainly of lean mixtures of a gaseous fuel and air. There are a number of variations of this mode of operation, such as having the gaseous fuel injected at very high supply pressures directly into the engine cylinder so that the fuel burns into the wake of the earlier injected and already ignited liquid fuel jet [2].

Thipse *et al* [7], states the methodology and outcomes of the recent experimental research work carried out for development of dual fuel diesel CNG engine for SUV application. The existing diesel SUV engine is converted to conventional dual fuel mode. Natural gas is fumigated in the intake manifold and the mixture of CNG and air is compressed in the compression stroke which is then ignited due to auto-ignition of the diesel fuel spray. The quantity of diesel in this case can vary from 100% to 20% and this strategy is preferable on engine which does not have electronically controlled diesel injection. Engine performance and emissions test were studied by carrying out test on chassis dynamometer. Base diesel performance parameters were studied for full and part throttle performance. Dual fuel kit development and diesel replacement strategy with base line diesel engine test was conducted. Engine is tested for dual fuel mode by adapting the GSR (20%, 40%, 60%, and 80%) strategy at different speed and load conditions and all performance data is recorded for analysis.

Thipse *et al* [8], states the methodology and outcomes of the recent experimental research work carried out for development of dual fuel diesel CNG engine for SUV application. They throw light on present limitations and drawbacks of dual fuel engines and proposed methods to overcome these drawbacks. A parametric study of different engine operating variables affecting performance of diesel-CNG dual fuel engines vis-à-vis base diesel operation is also summarized for a four-cylinder engine. In their work existing diesel SUV engine is converted to operate on CNG & diesel simultaneously with no changes in the engine compression ratio, cylinder head, or basic operation as a diesel cycle engine. They discussed the two methods of dual fuel engines i.e. Conventional Dual Fuel and Pilot Ignited Natural Gas Diesel (PINGD). They also discussed the merits and demerits of the dual fuel technology and issues regarding the same.

Lim *et al* [9] states the methods of converting dual fuel engine and discussed the remoulding of existing diesel engine into dual fuel mode. In this study, Injection of diesel with high pressure by CRDI and injecting CNG at intake port for pre-mixing. Results showed that dual fuel mode satisfied torque and power with conventional diesel mode. CNG alternating ratio over 90% was obtained in all operating range. PM emissions were found lower by 94% than diesel mode. But NO_X emissions were found higher. CO_2 is found decreased. HC & CO were found increasing compared to diesel mode. Experimental work was carried out on 4 cylinder, 2.5L direct injection diesel engine using CRDI system. Dual fuel mode was obtained by injecting CNG in pre-mixing intake system. For supplying CNG to in-cylinder as main fuel, CNG fuel supply tank, pressure regulator, emergency shut out valve of solenoid form were equipped. MPI (multi point injection) method was used. When supplying CNG, pressure was maintained 8 bar using two regulators for decompression. Two ECU's were used for engine control.

Chougule *et al* [10] states the performance parameters to examine BSFC using GT suite. A 59 kW diesel engine has been converted to dual fuel keeping same compression ratio. They had found improvement in fuel economy. Closed loop lambda control system and lean combustion are incorporated in engine to achieve performance targets. Initially experiments were conducted for base diesel engine on engine dynamo for performance parameters. Experimental test data and design data of base diesel engine are used as input in GT-Suite to predict the performance of base diesel engine. Calibration and optimization is carried out to get close results. Simulation of dual fuel engine is done using GT-Power. Dual fuel simulation results were compared with base diesel engine simulation results and targeted values. The deviation of simulated results for base diesel engine under all operating conditions is found to be less than 10% for Torque and 5% for BSFC. Simulation results showed that by utilization of natural gas, the BSFC is increased by 13% and 9% for 50% and 70% load respectively as compared to base diesel engine results by keeping brake power same. Fuel economy is increased by 10% in dual fuel engine. CNG is the main fuel and Diesel as pilot fuel for dual fuel operation.

SIMULATION METHODOLOGY

Methodology of project includes 1D simulation of engine i.e. Engine modelling in GT Power software.

- 1D simulation of engine for baseline diesel engine
- Testing of engine on base diesel engine
- Conversion of diesel to dual fuel mode
- Simulation of engine for dual fuel engine
- Testing of engine on dual fuel mode

Inlet Manifold

Discretizing a manifold, the discretization length should be about 0.4 times the bore diameter in the intake system. Hose diameter is 41.5 mm, Length is 293.1mm, wall temperature is 300K, Volume is 443 mm * 53 mm * 83 mm = 487189.25 mm^3

Exhaust Manifold

Discretizing length is 0.55 times the bore diameter in the exhaust system. Hose diameter is 37 mm, Length is 356 mm, wall temperature is 300K, Volume is 356 mm * 80 mm * 37 mm = 86016.807 mm^3.

Dual Fuel Engine Simulation

Dual fuel engine is modelled with CNG injector at the intake port. CNG mixes with air at the port and charge enters the engine at suction stroke.

Optimization: Experimental methodology:

A test matrix was prepared with variation of speed and load on which engine was tested under normal diesel and then dual fuel mode with gas supplement ratios of 20%, 40%, 60%, 80% and maximum with stable operation.

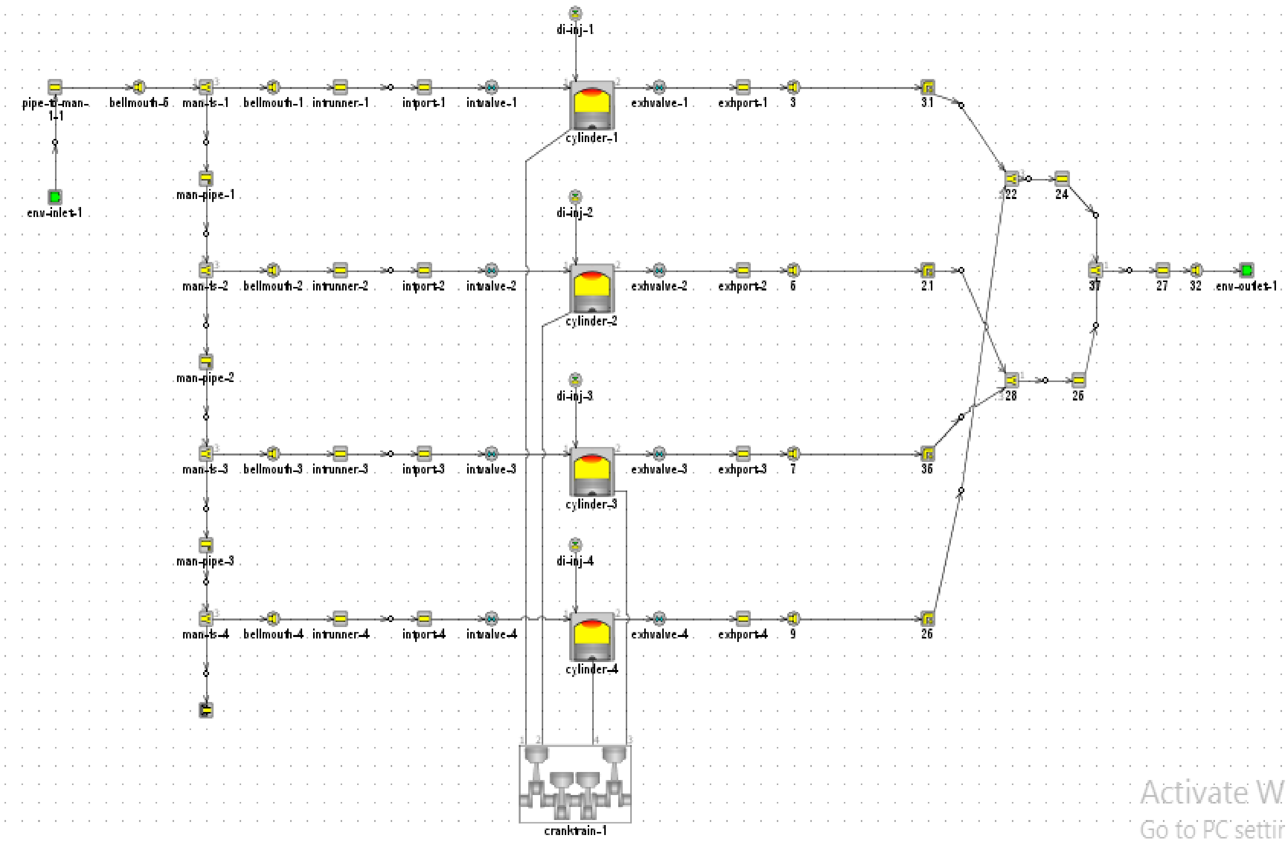

Fig. 1 Diesel Engine Model

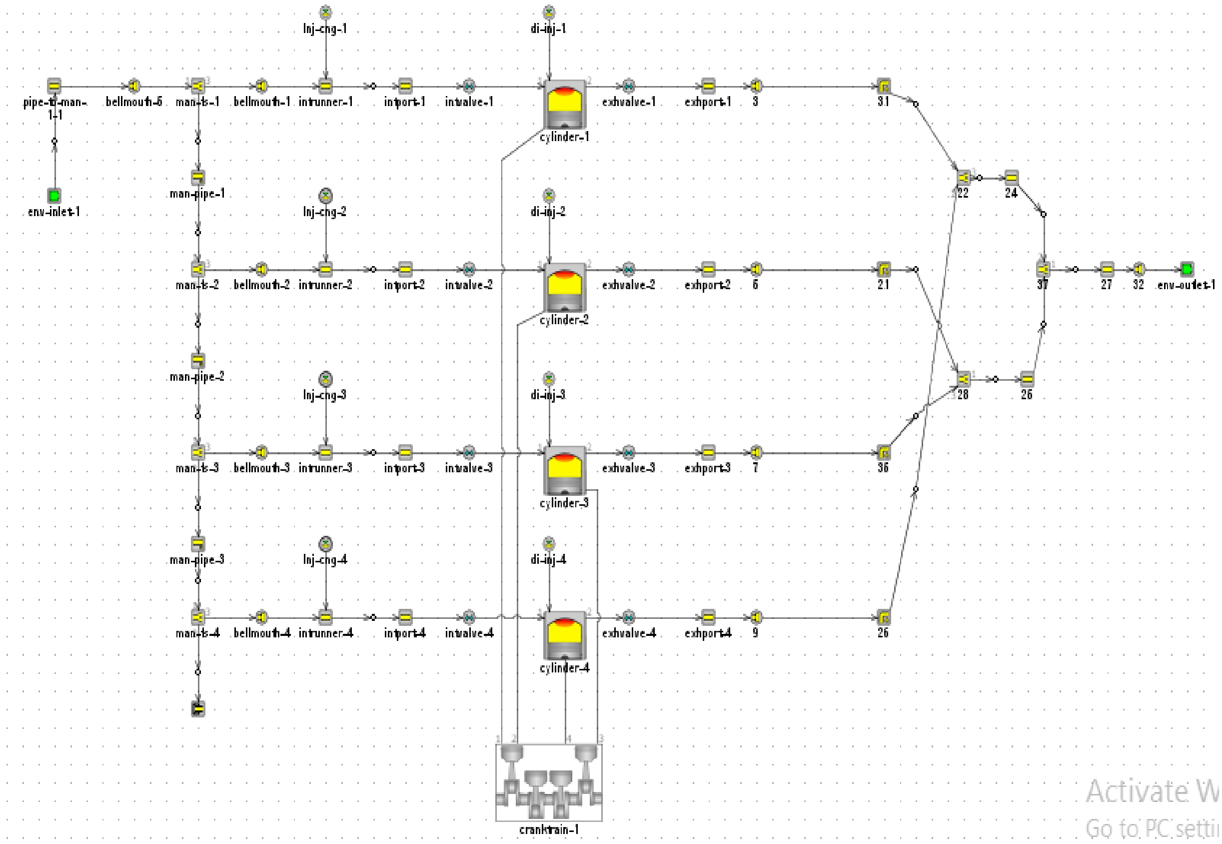

Fig. 2 Dual Fuel Engine Model

EXPERIMENTATION

Engine Specifications

Table -1 Engine Specifications

Name	Specification
Engine type	4 stroke water cooled DI Diesel engine
Displacement	3000 cc
Aspiration	Naturally aspirated
No. of cylinders	4
Bore * stroke	90.9*120 mm
Compression Ratio	18.5
Max Power	33.5 kW @ 2000 rpm
Max Torque	186 N-m @1400 rpm

Engine Components

- Starter motor: Electrical motor for cranking engine.
- Air Filter: Filters the intake air from unwanted particles.
- Mechanical Fuel Injection Pump: Bosch Inline FIP with governor as governing mechanism.
- Fuel filter: Filters fuel from tank. Two filters with coarse and fine filters.
- Oil Filter: Filters lubrication oil.
- Alternator: Charges the battery.
- Coolant pump: Pumps water for cooling.

Engine Connections

- Dynamometer: Eddy current dynamometer
- Data Acquisition System: Collects all data from sensors.
- Emergency stop throttle: For stopping the engine

RESULTS & DISCUSSION

Validation of P-θ Diagram:

- The graph shows the P-θ diagram of diesel engine where the simulation results are validated with experimental results for rated rpm i.e. 2000 RPM.

- Maximum pressure achieved was 63.32 bar at 6º after TDC.
- Diesel fuel injection timing was 6º before TDC and ignition delay period was for almost 2.3º.

Diesel Engine

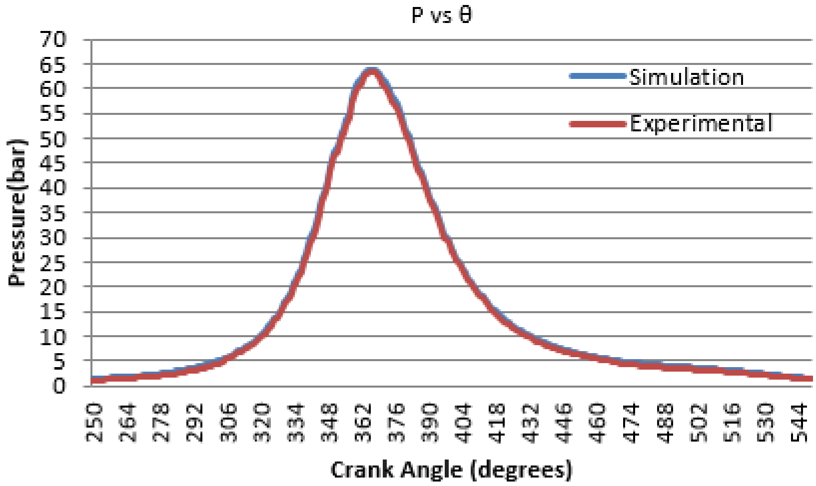

Fig.3 P-θ diagram for 2000rpm

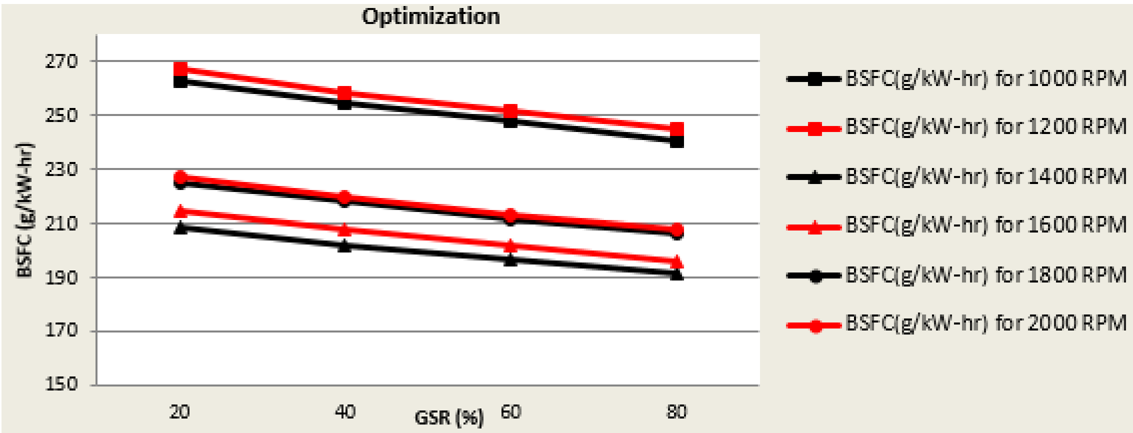

Fig. 4. BSFC vs GSR

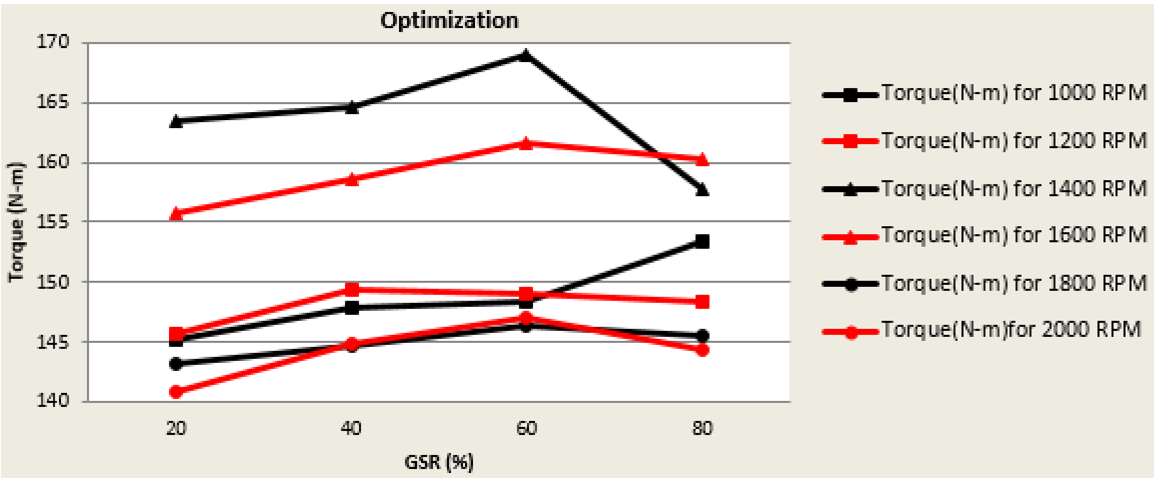

Fig. 5 Torque vs GSR

Optimization of Fuel Flow

- Optimization of CNG flow in case of dual fuel engine is obtained by varying the term Gas Supplement Ratio (GSR).
- Test trials were carried on the engine dynamometer to determine the minimum diesel quantity required for running in dual mode.
- Minimum BSFC is obtained at approximately 60% substitution rate of diesel.
- At the same time, torque value is set to the value of performance of diesel engine.

Validation of P-θ Diagram

- Graph 8 shows the optimization of CNG fuel flow to retain torque of diesel engine. From graph, at 60% substitution rate of diesel, torque value is retained.
- Optimization table shows the values varied from 1000 RPM to 2000 RPM for different GSR varying from 20% to 80%.
- It was observed that for keeping same Engine RPM and Torque, there is drop in Engine characteristics (Load) after 80% substitution of Diesel fuel.
- So that Diesel Flow rate corresponding to 80% substitution of Diesel is considered as critical flow rate.

Dual Fuel Engine

- The graph shows the P-θ diagram of dual fuel engine where the simulation results are validated with experimental results for rated rpm i.e. 2000 RPM.
- Maximum pressure achieved was 64.82 bar at 8^o after TDC.
- Diesel fuel injection timing was 6^o before TDC and ignition delay period was for almost 4^o.

Comparison of Diesel and Dual Fuel Mode

- Comparing diesel with dual fuel mode, dual fuel mode delays in combustion due to gaseous nature & high auto-ignition temperature of CNG.
- Peak pressure in case of dual fuel mode is almost equal to the diesel mode since it does not harm the engine structures, transmissions systems and knocking effect is eliminated.
- Comparing diesel with dual fuel mode, brake power is retained by dual fuel mode as with diesel mode.
- Performance of the dual fuel engine is similar to the diesel engine.
- The graph shows the fuel efficiency of the diesel engines and dual fuel engines.
- Comparing the two graphs, at full load, the mixing of CNG with air meet or exceed the fuel efficiency performances of the diesel engine i.e. BSFC is lower for dual fuel mode compared to diesel by 8%.
- Volumetric efficiency of dual fuel engine is lower as compared to diesel engine.
- It decreases by 5% compared to diesel engine.
- Lower volumetric efficiency and slow combustion is observed.
- CNG being a gaseous fuel, displaces the incoming air in the cylinder, this in turn, reduces the volumetric efficiency as well as the net amount of energy going inside the cylinder.

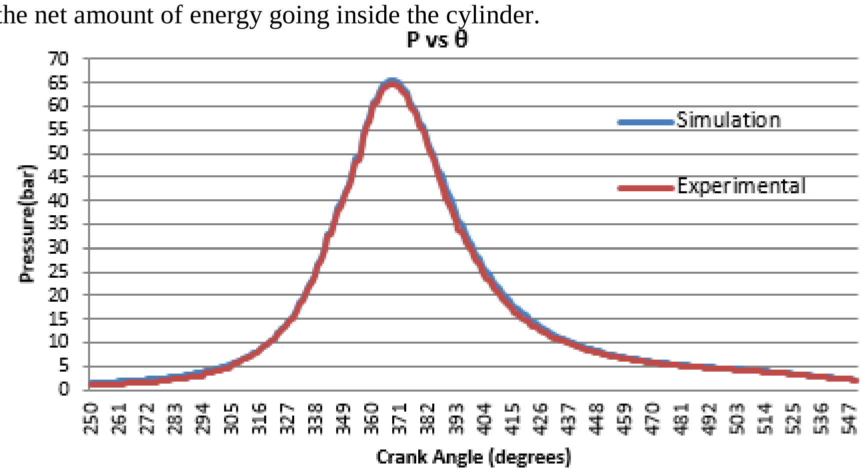

Fig. 6 P-θ Diagram for rated rpm (i.e. 2000) for 60% GSR

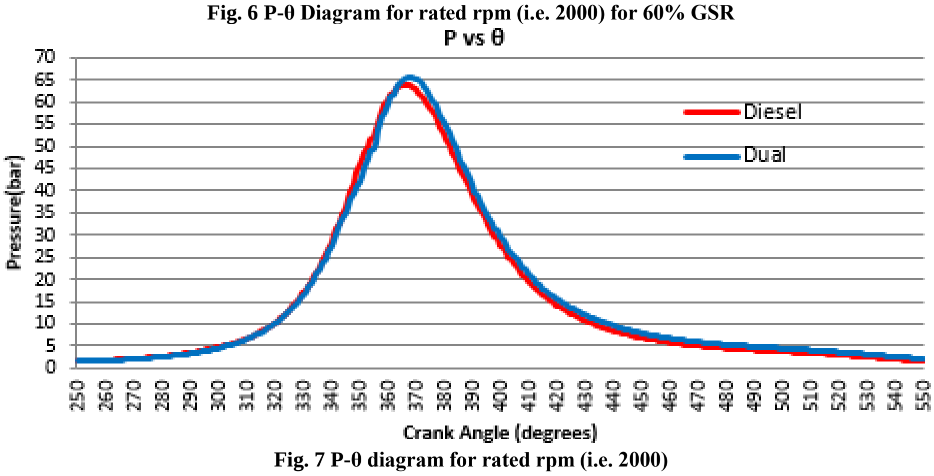

Fig. 7 P-θ diagram for rated rpm (i.e. 2000)

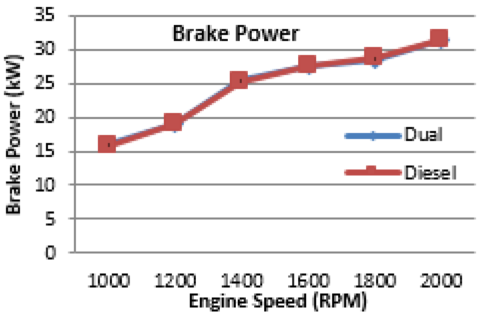

Fig. 8 Brake Power vs Engine Speed

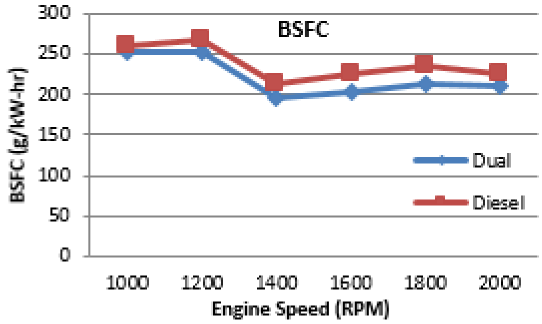

Fig. 9 BSFC vs Engine speed

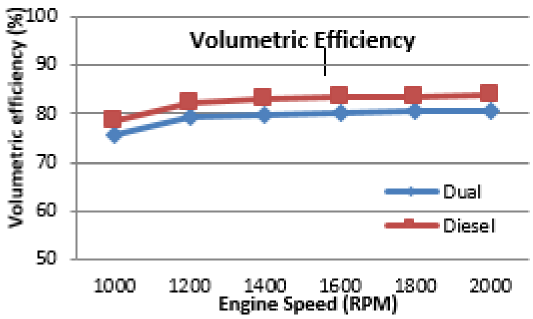

Fig. 10 Volumetric Efficiency vs Engine Speed

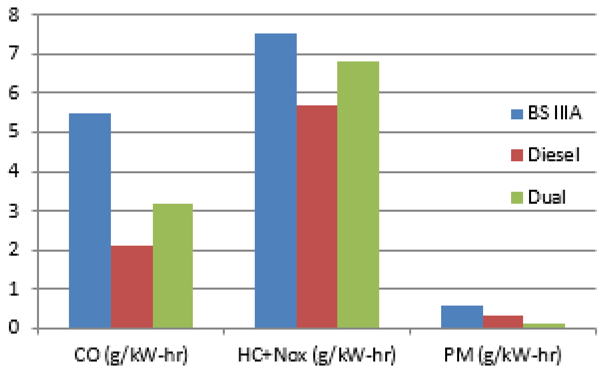

Fig. 11 Emissions without aftertreatment

Emissions

Comparing with BS IIIA emissions norms, following chart gives experimental results of emissions. Following chart shows the comparison of emissions with emission norm BS IIIA. It can be seen from the emission results that all the emission parameters are within the limits.

- There was increase in CO emissions observed about 50% that is because of CH_4 content.
- There was increase in HC as well as NO_X by 20%.
- PM emissions reduced to about 70%.

CONCLUSION

In the present work an experimental investigation has been conducted to examine the effect of dual fuel combustion on pollutant emissions and performance of an existing direct injection diesel test vehicle. The diesel engine has been properly modified to operate under dual fuel operation and its basic configuration has been maintained. The following conclusions have been made from the above work.

- Diesel engine was successfully converted to dual fuel mode and simulation in GT power was validated with experimental tests performed on test bed.
- The engine operation is more economical on the pure diesel mode at lower loads; however, at higher loads dual-fuel operation is better.
- BSFC is lower for dual fuel mode compared to diesel by 8%.
- Volumetric efficiency of dual fuel engine is lower as compared to diesel engine by 5%.
- As far as pollutant emissions are concerned, the use of natural gas under dual fuel operation has a positive effect on PM emissions, and thus, PM concentration under dual fuel operation is lower compared to normal Diesel operation.
- On the other hand, CO and HC emissions levels are considerably higher compared to normal Diesel operation. Their value increases with the gaseous fuel mass ratio and only at high engine load and high natural gas mass ratios a decrease is observed.
- Thus, it seems that dual fuel combustion using natural gas is a promising technique for controlling both NO and soot emissions even on existing DI Diesel engines and requires only slight modification of the engine structure. This is extremely important if we consider the difficulties of controlling both pollutants, NO and soot, on DI Diesel engines.
- Further Development of after treatment solutions for dual fuel engines is required.

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