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Emission Development on Six Cylinder Diesel Engine to Achieve CPCB-II Emission norms with Mechanical FIE System

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Abstract

Diesel engines are commonly being used for power generation due to its higher thermal efficiency and it is better-quality fuel consumption compared to gasoline engines.CPCB-II emission norms, which are the most stringent limits in the world for this category of diesel engines up to above 75 kW. An enginemanufacturer has a big challenge to achieve stringent emission norms with least modification. In engine design to reduce manufacturing and developments cost.Research work carried out to achieve the norms for the power ratings (1500 rpm and 115 kW).Optimization such as of EGR flow rate and injector nozzles (which includes nozzle type, no. of holes, hydraulic through flow, spray cone angle, nozzle tip protrusion etc.) and turbocharger, appropriate injection timing with mechanical fuel injection pump etc.To have a better trade-off between NOx-PM and NOx-BSFC, carrying out tests on 5.7-liter six cylinder turbocharged diesel engine.

Keywords:*CPCB-II, Turbocharged, EGR, engine optimization, Injector Nozzle, Mechanical FIE.*

1. Introduction

Indian Ministry of Environment and Forests-Central Pollution Control Board (CPCB) has proposed new emission limits for diesel genset engine. Diesel engines are the most powerful and efficient thermal engine, the diesel engines are comprehensively making use of in almost all on road and off road applications.

Indian emission norms for stationary gensets engine are upgraded from CPCB I to CPCB II. These revised emission norms call for a significant change in emission limits. CPCB II emission norms call for 62% reduction in NOx+HC and 33% reduction particulates for engines above 75 kW up to 800 kW power range compared to existing CPCB I emission norms. CPCB II norms are more stringent as compared to European Stage IIIA and CEV BS III.

This paper present experimental work carryout to achieve stringent emission norms and fuel economy, The major challenge in meeting the proposed norms is with minimum cost impact to the customer. This paper deals with the strategies to meet CPCB-II emission norms by appropriate selection of engine hardware and optimization of injection parameters, EGR flow rate, turbocharger, mechanical fuel injection pump, high pressure pipe, static injection timing, intercooler to achieve emission performance without major changes in the engine configuration and cost impact for above 75 kW power rating engines. All above different combinations tested during engine optimization trials and configurations with optimum result selected as the final configurations.

Table1. Emission norms comparison between CPCB-Stage I and CPCB-II

Power range (kW)	**CPCB-I Stage I - Existing**				
	Emission Limit (g/kWh)				**Smoke (1/m)**
	NOx	**HC**	**CO**	**PM**	
Up to 800 kW	9.2	1.3	3.5	0.3	0.7
	10.5				
Fuel Spec: Less than 500 ppm Sulfur diesel					
Power range (kW)	**CPCB-I Stage II - Proposed**				
	Emission Limit (g/kWh)				**Smoke (1/m)**
	NOx +HC		**CO**	**PM**	
Up to 19 kW	7.5		3.5	0.3	0.7
More than 19 up to 75	4.7		3.5	0.3	
More than 75 up to 800	4.0		3.5	0.3	
Fuel Spec: Less than 350 ppm Sulfur diesel					

This engine emission has developed for genset applications and used test cycle (5 mode cycle

Emission test (as per ISO 8178 Type D2).The main challenging task to reduce Nox as well as reduce particulate matter both results are trade-off, and The direct injection diesel engine is one of the most efficient thermal engines known. The use of diesel engines for road applications has been widely extended during the last decade due to their relatively lower fuel consumption when compared to spark ignition engines. For this reason, DI diesel engines are widely used for heavy-duty applications and especially for the propulsion of Generators & Tractor. Even though the efficiency of these engines is currently at a high level, there still exist possibilities for further improvement. On the other hand, there are problems associated with its use that result from the relatively high values of particulate emissions and NOx values. Furthermore, that NOx also contributes to the greenhouse effect. Environmental concerns have led to progressively more stringent emission regulation for diesel engine. Keeping this in view, the government of India keeps regulations on the exhaust emission level of engines from time to time. Currently applicable emission norms for GENSET in India are Central Pollution Control Board (CPCB)- 1 and proposed CPCB - 2 emission norms will be applicable from July 2014, for Generator up to 19kw, >19kw.CPCB-II engine are smoother as compare to CPCB-I due to performance related hardware has changed and optimized the better combustion. The motive of the present work is to present an experimental investigation aiming towards meet the desired engine performance and emission levels for development of 125kva diesel genset engines to this problem in cost effective way so that the minimum design modification is required in the existing engine and to reduce the lead-time. Tests were conducted under various operating conditions like Full / part throttle performance test, 5 mode cycle Emission test (as per ISO 8178 Type D2).

2. EXPERIMENTAL SETUP

Experiments were carried out on six-cylinder diesel engine (Rating 115 kW @ 1500 rpm), engine tested on test cell with all standard condition with instrumentations and the Engine setup with Instrumentation required for measuring & data acquisition during the emission test on engine dynamometer. The experimental measurements for the present investigation were performed to the achieve emission target.

The major task in the present experimental work is to evaluate the performance and emissions on diesel engine for genset application, used software to execute the emission test results. Hence, this engine selected for the present research. All test data captured during test and emission.

This paper deals with the strategies applied and experimentation details to meet the proposed CPCB Stage-II emission limits. The criticality increases exponentially for new versions. The experimental investigations carried out on various capacities turbocharger diesel genset engines.

Table.2. Engine Specification

Configuration	Base Engine (CPCB-I)	Upgraded Engine (CPCB-II)
Power	75 KW	114.9 KW
Type of Aspiration	Turbocharged	Turbocharged
No. of Cylinder	6	6
Swept Volume	5. 67 Ltr.	5. 67 Ltr.
Bore X Stroke	97X128	97X128
FIP	Bosch, A2000	Bosch, A4000
SIT	9 deg. BTDC	9 deg. BTDC
Injector	P-Type	P-Type With K-Factor
EGR	Without EGR	With EGR

Eddy Current Dynamometer: Eddy current dynamometer is a device, which is used to measure moment of force (torque) and power of the engine.

Emission Gas Analyzer: This analyzer used to measure the engine exhaust emission raw gases in ppm like HC, NOx, CO, CO2, and O2 etc.

Smoke Meter: Smoke meter is a device which used to measure smoke (FSN) of engine exhaust, smoke instruments measure optical properties of diesel smoke and used AVL 415S Smoke meter.

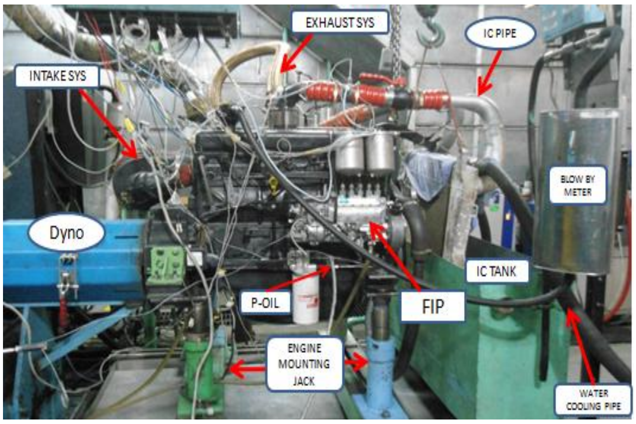


Fig.1. Experimental setup and instrumentations.

Fuel meter: Used AVL 735S/753C fuel meter to measured fuel flow rate, AVL Fuel mass flow meter is a high precise and continuous fuel consumption measurements system, which is worldwide.

Data Acquisition System: For studying the processes inside the cylinder, a data acquisition system used. This used for analyzing the measured cylinder pressure data and combustion parameters with variations in the crank angle other parameters.

3. STRATEGY TO MEET CPCB II EMISSION NORMS

Choosing the most significant hardware from a wholescope of options is difficult to meet the requirements in an efficient and effective manner. The following combinations tried out during engine optimization trials to achieve optimum results.

Mechanical FIE –Use Mechanical fuel injection system to achieve stringent emission norms, mechanical A4000 FIP used to required fuel injection pressure and fuel quantity. The fuel-injection system supplies the diesel into engine. The fuel-injection pump generates the required fuel pressure for injection and delivers the fuel at the required rate. The fuel pumped through a high-pressure fuel line to the nozzle, which injects it into the engine's combustion chamber. The combustion processes in a diesel engine are primarily dependent on the quantity and manner in which the fuel introduced into the combustion chamber.The in-line fuel-injection pump used all over the world in medium-sized and heavy- duty trucks as well as on marine and fixed- installation engines. It is controlled either by a mechanical governor, which may be combined with a timing device, or by an electronic actuator mechanism. In contrast with all other fuel-injection systems, the inline fuel-injection pump lubricated by the engine's lubrication system. For that reason, it is capable of handling poorer fuel qualities. The fuel injection equipment must be able to achieve precise control of fuel metering. Bosch, A4000 FIP used instead of existing A2000 FIP in order to increase the pump end pressure & indirectly increasing the peak combustion pressure, which increase the power as compare existing engine rating 75 kW, and optimizing the appropriate fuel pressure, which helps in reducing the NOx emission from the engine exhaust. NOx can also be decrease by changing other parameter like after treatment devices but these devices increases the cost and lead-time of the system.

Standard in-line fuel injection pumps - the range of standard in-line fuel injection pumps currently produced encompasses a large number of pump types. They are used on diesel engines with anything from 2 to 12 cylinders and ranging in power output from 10-to200 kW per cylinder. They are equally suitable for use on direct-injection (DI) or indirect-injection (IDI) engines.

EGR System-EGR is the most extensively used techniques for reducing NOx formation during combustion. NOx reduction in combustion chamber of engine, exhaust gas is presence in gaseous form and It is having latent heat and carbon contains to which are reacts with fresh air and fuel in combustion chamber. Transform the chemical reaction, which formation the emission, exhaust gas recirculation (EGR) used to reduce formation nitrogen oxide (NOx), external or internal EGR system works by recalculating a portion of an engine's exhaust gas back to the engine cylinders. In a diesel engine, the exhaust gas replaces some of the excess oxygen (from air flow) in the pre-combustion mixture. The NOx formation mainly when the mixture of nitrogen and oxygen is subjected to high temperature, NOx formation due to high combustion temperature, When EGR supply into engine combustion chamber, it dilute the air fuel ratio and decrease the combustion pressure and temperature caused by reduce the NOx formation in combustion chamber, EGR decrease combustion pressure which result decrease the engine power and efficiency, Most modern engines now require exhaust gas recirculation to meet NOx. In modern diesel engines, the EGR gas is cooled with a heat exchanger ie.EGR cooler. Since diesels always operate with excess air, they advantage from EGR rates as high as 40% (at idle, when there is otherwise a large excess of air) in controlling NOx emissions. Exhaust recalculated back into the cylinder can increase engine wear as carbon particulate wash past the rings and into the oil. Exhaust gas-largely carbon dioxide and water vapor-has a higher specific heat than air, so it still serves to lower peak combustion temperatures. However, adding EGR to a diesel reduces the specific heat ratio of the combustion gases in the power stroke. This reduces the amount of power that can be extracted by the piston. EGR also tends to reduce the amount of fuel burned in the power stroke. This is evident by the increase in particulate emissions that corresponds to an increase in EGR Particulate matter (mainly carbon) that are not burned in the power stroke is wasted energy. The most familiar is a diesel particulate filter in the exhaust system, which cleans the exhaust but reduces fuel efficiency. Since EGR increases the amount of PM that must be dealt with and reduces the exhaust gas temperatures and available oxygen, these filters need to function properly to burn off soot. Automakers inject fuel and air directly into the exhaust system to keep these PM filters from becoming blocked up.

EGR reduces the NOx emission by four ways:

A) Dilution Effect: The dilution of the intake charge with EGR reduces the mass fraction with oxygen. This lower oxygen mass fraction is the dilution effect. Adding together EGR to the intake air flow charge also affects average properties of the intake charge such as the specific heat capacity and molecular mass introducing other effects.

B) Thermal Effect: - EGR contains water and CO2, both of which having higher specific heat capacities than fresh air mass. The effect of amplified heat capacity is the thermal effect. The nitrogen in the air is replaced with inert gas helium to study the effect in separation. Intake air mass dilution with EGR simultaneously introduces the dilution and thermal effect. The oxygen mass fraction in the intake air needs to be held constant to avoid interference from dilution effect.

C) Chemical Effect: - A quantity of the diluents gases may disconnect or actively participate in chemical reactions during the combustion progression, this is the chemical effect. One way to isolate the chemical effects is to replace nitrogen in the air with argon while the diluents is present this maintains a constant average charge heat capacity and oxygen concentration in the intake charge relative to the undiluted. This avoids interference from the thermal and dilution effect. However, it is not used in this project.

D) Add mass effect: - If adding diluents into the intake charge results in an increased mass flow rate, an additional effect is introduced. This added flow has an additional heat capacity due to its mass. The EGR used is 18 mm diameter EGR orifice tube in which the exhaust gases flows from the exhaust to intake due to pressure difference between Exhaust and Inlet system.

This EGR has a disadvantage that at full load EGR is not required but due to pressure difference the exhaust gases flows to the inlet and reduces the power and fuel efficiency at full load.

EGR Cooler – To reduce EGR gas temperature (From 550 °C to 125 °C).The heat absorbed from the combustion process is proportional to EGR rate, its specific heat, and the difference between combustion and EGR temperatures. Therefore, cooling the EGR stream allows for greater heat absorption from the combustion process, which leads to a lower rate of NOx formation. In addition, EGR cooler occupies less volume in the inlet system. Lower EGR volume displaces a smaller fraction of fresh filtered intake air, thus displacing less O2, which helps maintain combustion efficiency.

High Pressure Pipe –High-pressure pipe designed to sustain high fuel injection pressures, high-pressure pipe is used between fuel injection pump to injector to maintain fuel pressure, and high-pressure pipe internal diameter reduces from 2 mm to1.8 mm to increase the fuel pressure. Diesel fuel injection pressures in diesel engine plays a vital role for engine performance and emission treatment of combustion. Manufactured from special low-carbon steel as international standards, Special coating avoided corrosion and rust, High quality basic seamless steel tube, standardized inner bore diameter and fine finish ensuring smooth fuel flow and fuel pressure conforms to the OEM specification.

NTP (Nozzle Tip Protrusion) – Nozzle Tip Protrusion (NTP) plays a vital role in air fuel interaction. NTP adjusted such that fuel spray hits the piston bowl at the lip or the entry of the bowl.

Too low NTP may result in spray hitting the cylinder wall, the results show that a lower NTP led to slightly faster heat release, and too high value may result in insufficient charge mixing.

It may be noted that the NTP should be closely paired with injection timing. Effect of NTP on emissions is shown in Figure 2 and 3. [4].

Nozzle tip protrusion (NTP) is having wide scope for optimization for the combustion system. The influence of the variation in NTP on NOx and PM emissions, as well as BSFC

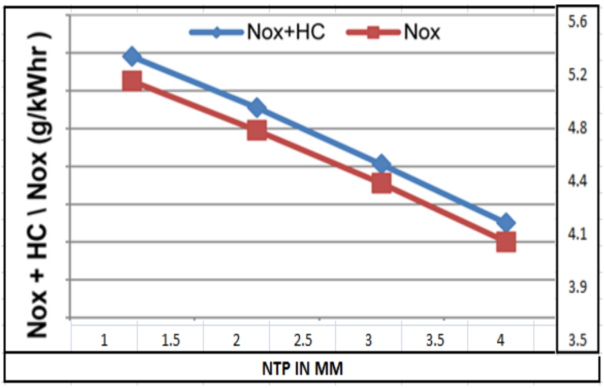


Fig.2. Effect of NTP on NOx+ HC and NOx emissions.

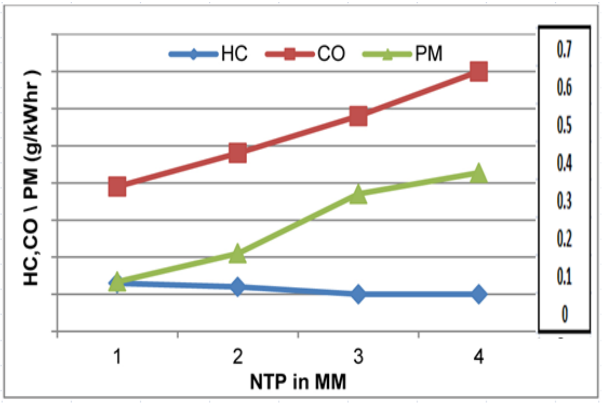


Fig.3. Effect of NTP on HC, CO and PM emissions

Injector Nozzle Hydraulic Through Flow-Through flow of injection quantity and numbers of hole of fuel injection for better atomization of fuel, fuel injection spray pattern. The nozzle injects the fuel into the combustion chamber of the diesel engine. It is a determining factor in the efficiency of mixture formation and combustion and therefore has a fundamental effect on engine performance, exhaust-gas behavior and noise. In order that nozzles can perform their function as effectively as possible, they have to be designed to match the fuel-injection system and engine in which they are used. The nozzle is a central component of any fuel-injection system. It requires highly specialized technical knowledge on the part of its designers. The nozzle plays a major role in shaping the rate-of-discharge curve (precise progression of pressure and fuel distribution relative to crankshaft rotation).Optimum atomization and distribution of fuel in the combustion chamber, and Sealing off the fuel-injection system from the combustion chamber. Because of its exposed position in the combustion chamber, the nozzle is subjected to constant pulsating mechanical and thermal stresses from the engine and the fuel-injection system. Thefuel flowing through the nozzle must also cool it. When the engine is overrunning, when no fuel is being injected, the nozzle temperature increases steeply. Therefore, it must have sufficient high-temperature resistance to cope with these conditions.

Injection timing –Optimization of fuel injection parameters static injection timing (SOI) and injection duration. Ignition delay is of two parts, physical delay and chemical delay. Physical delay is the atomization, vaporization, mixing with air and the chemical delay is the pre-combustion reactions which lead to the auto ignition. The physical component is affected by the injection pressure, air density and air flow characteristics. Injection timing will largely affect the chemical delay as it is dependent on the temperature and pressure of the charge when the fuel is injected. Advancing the injection timing will increase the chemical delay as the temperature and pressure are lower. This means that the ratio of premixed combustion is increased thus resulting in sharp increase in pressure and temperature in the cylinder. This results in higher NOx formation and soot gets reduced as the ratio of diffused combustion is lower. Here we observe reduction in HC and CO as the time available for combustion is longer. NOx emissions increase dramatically, when the in cylinder temperature and the Air-fuel Ratio (AFR) increase, whereas PM emissions increase at a rich AFR and lower temperatures. Generation of NOx and PM is a local phenomenon, so the local AFR and temperature at each point of the cylinder are of relevance to the generation of emissions.

Turbocharger Selection -The selection of a proper turbo charger enables to minimize the engine out smoke and to reduce the exhaust gas temperature and better fuel economy as well as better torque curve and improving engine performance. Required airflow to complete combustion of fuel and turbocharger increase the volumetric efficiency of engine. Matching an engine to a turbocharger to achieve well efficient turbocharger operation on a various range of engine speed is a complicated and compromising procedure. Matching large airflow turbine to improve the performance on higher engine speed, the exhaust turbine energy will be inadequate to operate the turbine at high sufficient speed to provide the charge to combustion fuel. This can result lower smoke and fuel consumption, matching a low air flow turbine to an engine develop the performance at low engine speed and output in excessively high boost pressure at high engine speed.
The optimization of turbocharger in work, the required air flow, boost pressure, boost pressure ratios, intake manifold temperatures & turbine inlet temperatures are estimated, accordingly three turbochargers were selected jointly in consultation with the turbocharger supplier. Sufficient database was scrutinized to arrive at the estimations.

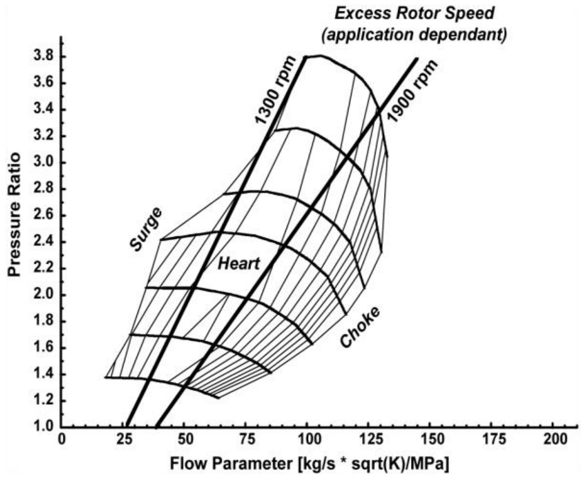


Fig.4. Optimized compressor map.

In turbocharger measured the turbine speed by speed sensor which is increase the turbine speed then increase the high mass air flow supply to the engine and decrease turbine speed decrease the mass air flow supply to engine, turbine speed depends on the exhaust gas pressure or exhaust gas energy. Non waste gate turbocharger is used in this application, Selection of turbocharger based on desire torque curve as well as achieves targeted BSFC and smoke limit, necessary adequate amount of EGR flow from exhaust to required boost pressure and exhaust manifold pressure which allow the EGR drive.

Intercooler-Intercooler is simply a heat exchanger mechanical device, which reduces the temperature of the compressed intake air mass, as a result of this volumetric efficiency of the engine is increased, intercooler makes density of air more oxygen rich air to the engine allowing more fuel to be burn thus improving combustion and giving more power. Due to Retard in fuel injection timing & EGR the power is reduced and specific fuel consumption is increased. Intercooler reduced the temperature of compressed air from 145 deg. C to 45 deg. C, Higher temperature of air decreased the performance and power of the engine due to incomplete combustion, and pressure drop depends on the intercooler size.
Load Sensing Principle- Estimating load on an internal combustion engine using only engine crank pickup sensor as an input.This technology has wide applications in control of internal combustion engines. One such application is Exhaust Gas Recirculation (EGR) control. It is well known that if amount of recalculated exhaust gas in an IC engine is varied as a function of both engine speed and load on engine, better engine performance (as measured in terms of emissions and specific fuel consumption) can be obtained, as compared to varying the amount of recalculated exhaust gas based only on engine speed. Using load estimation technology, such better engine performance to be obtained using only engine crank pickup sensor as an input to EGR control Electronic Control Unit (ECU).Test Setup Description. Overall objective of the tests was to demonstrate ability of EGR

ECU to distinguish between different loads on the engine using only crank sensor as an input. The setup used during the tests on the engine dynamometer.

A magnetic pickup unit (MPU) was used as a crank pickup sensor. Output of this sensor was interfaced with EGR ECU. It should be noted that EGR ECU also serves as the ECU for Electronic Governor. The ECU implements digital signal processing methods on signal obtained from crank pickup sensor, and forms an estimate of load on engine (hereafter called Load Index).It was possible to operate the dynamometer in torque control mode (where a specified torque is applied to engine) or in speed control mode (where engine speed is regulated by dynamometer at a specified value).Following two sets of tests were conducted as a part of demonstration exercise. Torque controlled by dynamometer, speed controlled by mechanical governor. In this mode, torque on engine was controlled at various points between part load and rated load conditions for the engine. Variation of Load Index computed by EGR ECU as a function of engine load torque was studied. Speed controlled by dyno, torque controlled by manual fueling adjustment. In this mode, engine speed was regulated at a fixed value (1800RPM) using the dynamometer. Engine torque was varied manually by changing effective fuel rack position. Variation of Load Index computed by ECU as a function of engine load torque studied. Observations torque controlled by dynamometer,, speed controlled by mechanical governor: As mentioned earlier, in this test, load was imposed on engine using the dynamometer. The fueling, and hence engine speed, was controlled by mechanical governor. Thus, for a given load, engine speed was determined by mechanical governors droop characteristics.

4. RESULTS AND DISCUSSION

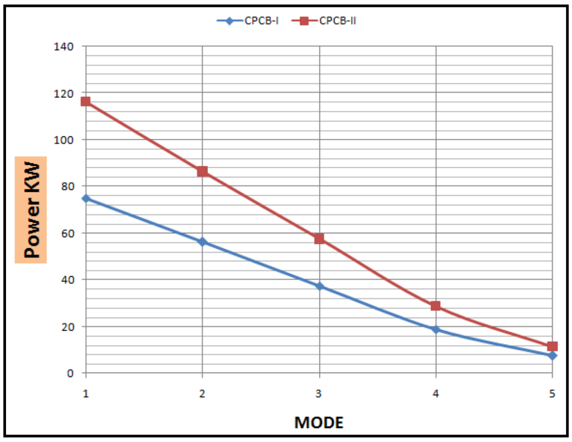


Fig.5. Power comparison between CPCB-I & CPCB- II Rating

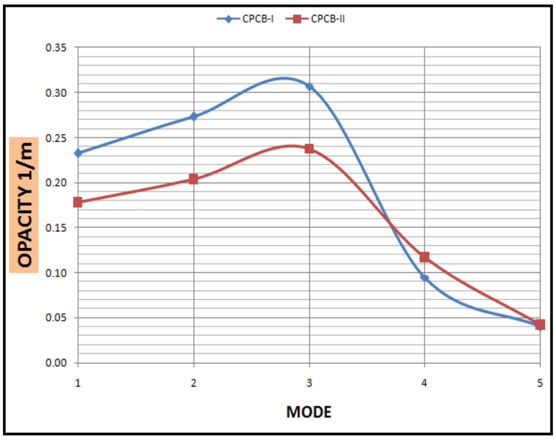


Fig.6. The Opacity comparison between CPCB-I &CPCB-II.

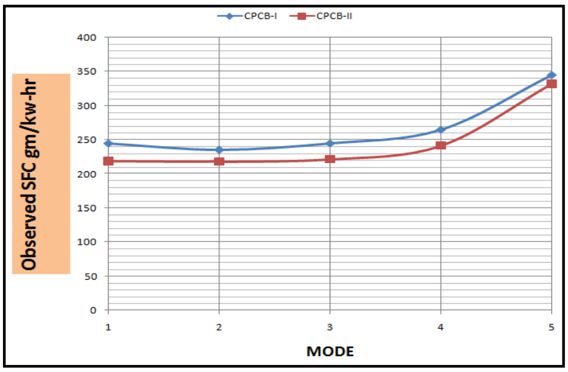


Fig.7. The BSFC comparison between CPCB-I & CPCB-II

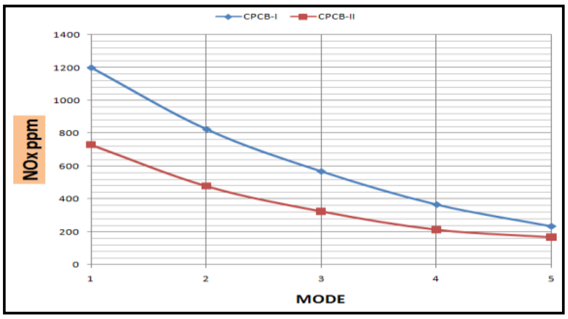


Fig.8. The NOx comparison between CPCB-I & CPCBII.

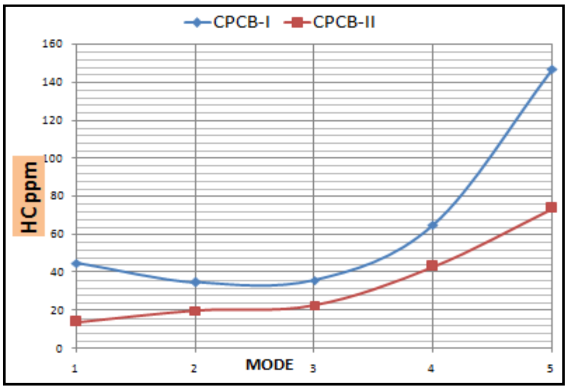
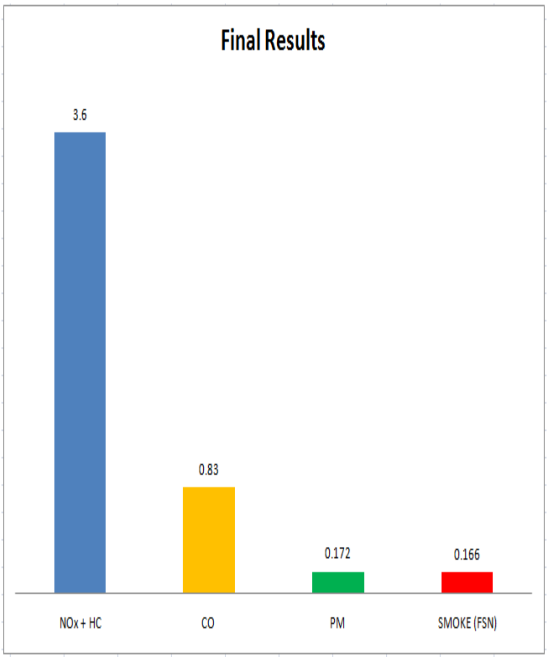


Fig.9. The HC comparison between CPCB-I & CPCBII.

Table.3. Actual results V/s Engg. Targets

Emission Parameter	CPCB-II Limits	Engg. Target	CPCB-I Results	Iteration -I (A4000 FIP & K-Fac Inj.)
Nox + HC (g/KWh)	4.0	3.5	7.23	3.60
CO (g/KWh)	3.5	2.5	1.1	0.83
PM (g/KWh)	0.2	0.15	0.251	0.172
Smoke (m-1)	0.7	0.56	0.541	0.166

From above figures 5. It can be seen that the Power requirement in CPCB-II is high because during this rating calculation customer has demanded 10% overload Power at rating speed i.e.1500 rpm. Hence there is 10 % power rise in CPCB-II engine rating as compared to CPCB-I rating.
Also from figures 6, 7, 9 it can be seen that there is drastic improvement in Smoke, BSFC and HC this is because of use of K- Factor Injector & Fig. 8 shows improvement in Nox& this is observed because of use of A4000 FIP.



5. CONCLUSION

Stringent CPCB-II Emission limits have been achieved with mechanical fuel injection system. Emission limits for NOX + HC are decreased by 50.20 % as compared to baseline limits. Also there is very large margin for Carbon Monoxide (CO) – 24.54%, Particulate Matter (PM) - 31.47% & Smoke- 69.31%.CO External cooled EGR has play a significant role t o decrease NOX, and the external EGR system is low cost due simple design on and off type EGR valve are used and A4000 pump i.e. high fuel pressure as compare to A2000 FIP which lead to decrease PM, smoke and fuel consumption. Results Smoke and CO emission is decreased due to use of K-Factor injector and PM emission are increased due to retarded injection timing. Some of the Particulate matter is oxidized during exhaust stroke but the amount of oxidation of fuel is very less, Turbocharger optimization for better torque and better fuel efficiency with low smoke and PM as well as targeted EGR drive.

6. ACKNOWLEDGEMENTS

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