RESEARCH ON STEPS TAKEN TO MEET BSIV EMISSION NORMS WITH SINGLE CYLINDER AIR COOLED DIESEL ENGINE & CONVENTIONAL INJECTION SYSTEM

Rahul Katariya[1], Ashok. J. Keche[2]
[1]M Tech. Scholar - Mechanical, MIT, Aurangabad, India
[2]Associate Professor, Mechanical Engineering Department, MIT, Aurangabad, India

ABSTRACT
Single cylinder diesel engines are highly fuel efficient & hence are widely used in small 3 & 4 wheelers in India. All 4 wheelers being sold in India should comply Bharat Stage IV (BSIV) emission norms. Current single cylinder air cooled diesel engines meets BSIII emissions. However it is difficult to meet stringent BSIV emission norms on the vehicles powered with single cylinder air cooled engine due to its inherent design limitations. With this research, a systematic attempt is made to upgrade single cylinder air cooled, diesel engine from BSIII to BSIV emission norms on small 4 wheeler vehicle using simple & cost effective mechanical fuel injection system. This covers changes made in hardware including combustion chamber redesign, nozzle selection, increase in injection pressure, low compression ratio, retarded injection timing, use of EGR, glow plugs & exhaust aftertreatment to achieve BSIV emission with minimum 10% margin for all the pollutants.

KEYWORD: *Diesel engine, Emissions, Combustion Design, Compression ratio, EGR*

I. INTRODUCTION

With the increasing number of vehicles especially vehicles driven by diesel engines, the pollution levels are also increasing. These high levels of pollutants in the earth's atmosphere are contributing to a large extent to global warming. Also hazardous pollutants are affecting human lives too. In order to control the pollution levels, government of each country is imposing stringent emission norms. In India such regulations on emission limits are termed as `Bharat Stage' emission followed by a post fix indicating the level of emissions.

Currently in India BSIV emission norms are introduced in April 2013.Single cylinder diesel engines are highly fuel efficient & hence are used widely in many small 3 wheelers & 4 wheelers in India as an affordable public / goods transport. But to meet emissions on these engines is very difficult due to its inherent design limitations and BSIV emissions are a way out of this problem as they pose stringent limits on pollutants.

For over three decades, there have been strong developments in the areas of FIE, fuel injection strategies and after treatment to reduce engine out emissions. Various researches indicate that high pressure fuel injection system helps not only to improve the performance, but also to reduce the emissions of direct injection (DI) diesel engines [1]. Very limited references are available on ways to meet the BSIV emissions on single cylinder air cooled diesel engines.

Objective of this work is to select the optimum hardware to meet BS IV emission norms with single cylinder air cooled diesel engine without compromising performance, fuel economy.

This paper will take through the emission technologies used for meeting the BSIV emissions on single cylinder diesel engine. The emission technologies required to meet the BIV emission norms on single cylinder air cooled diesel engine are different than those used on other multicylinder engines due to its inherent design limitations.

This report consists of overview of engine and vehicle specifications, information on emission driving cycle & emission limits, advances in diesel engine technologies, challenges with single cylinder air cooled diesel engine, summary of the test results with change in hardware and conclusion.

Table 1: Engine Specifications

Parameter	**Specifications**
Displacement, cc	435 to 500
No. of cylinders & Aspiration	1; Naturally aspirated; DI
Fuel	Diesel
Type of cooling	Air cooled
No. of valves / cyl.	02; Vertical
Rated Power	6.2 kW to 7 kW @ 3600 rpm
Max. Torque	20 Nm to 23 Nm @ 2200 rpm
BSFC at Power point, g/kWh	285
BSFC at Max. torque point, g/kWh	250
Emission Compliance	BSIII
Engine weight	50 to 55 kg
Fuel injection system	Mechanical FIE

Table 2: Vehicle Specifications

Parameter	**Specifications**
Application : 4 Wheeler	
Kerb Weight, kg	600 to 700
Payload, kg	500
GVW, kg	1100 to 1200

1.1 Emission driving cycle:

In India, emission driving cycle viz ECE + EUDC 90 [5] is defined by the regulatory authorities for the vehicles below 3.5 T payloads.

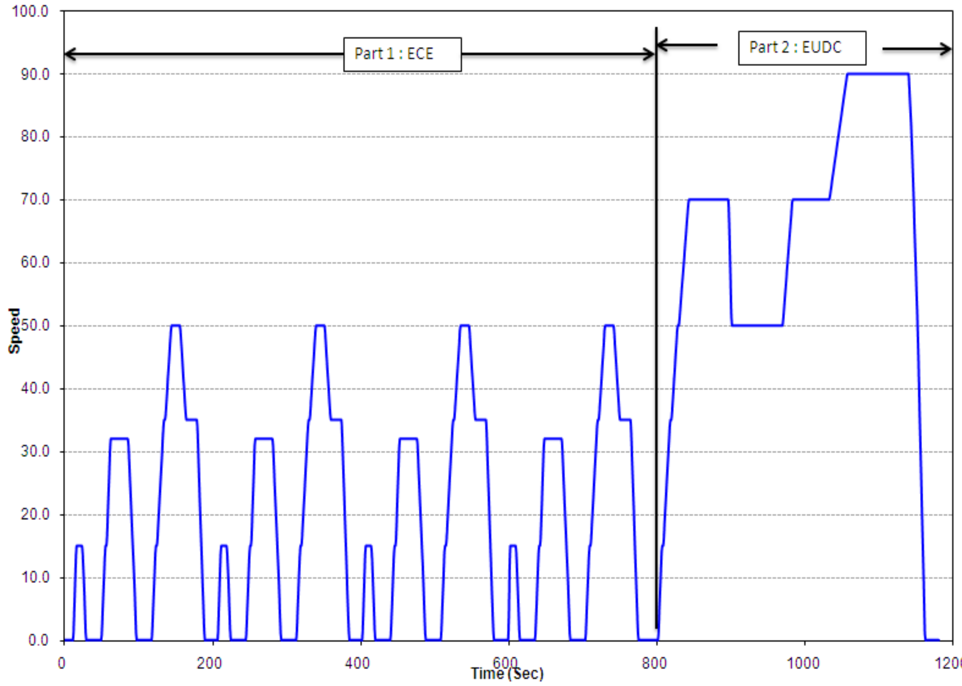

Figure 1: Emission Driving Cycle

1.2 Emission Limits

Below table & the chart followed shows the emission limits for various pollutant for BSIII & BSIV. Chart also shows how & when different emission limits are imposed In India.

Table 3: Emission limits: BSIII & BSIV [5]

	CO g/km	NOX (g/km)	HC+NOX (g/km)	PM (g/km)
BSIII	0.64	0.5	0.56	0.05
BSIV	0.5	0.25	0.3	0.025

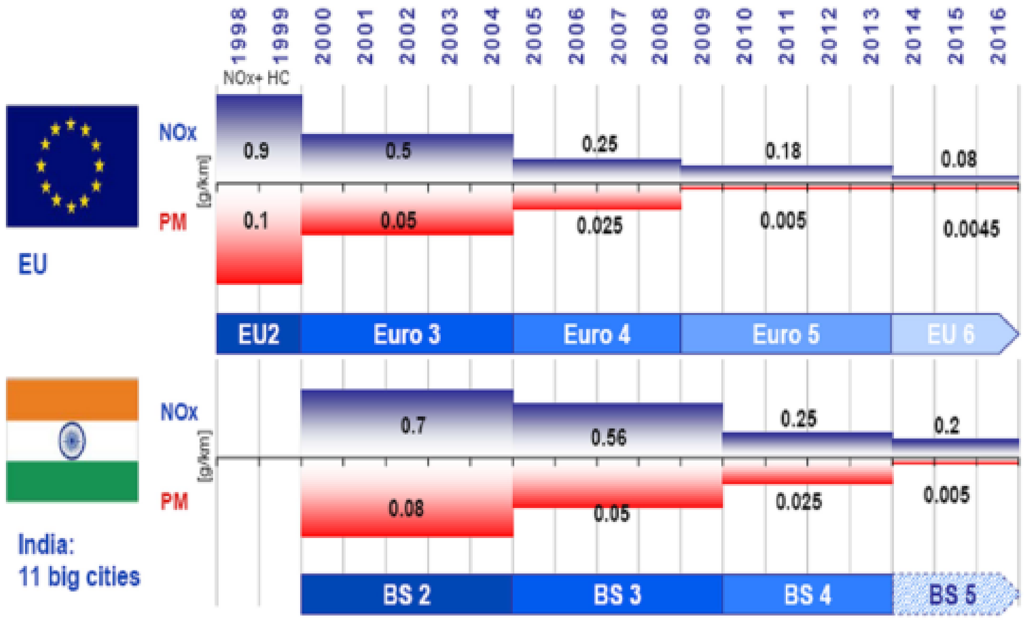

Figure 2: Stages of implementation of Emission Limits

1.3 Advances in Diesel Engine Technology

Engine manufacturers worldwide have developed a variety of emission-reduction technologies to minimize diesel emissions which includes:

- Common rail fuel injection [7]
- Combustion chamber design
- Electronic engine control [8]
- Exhaust gas recirculation
- Improved air handling
- Use of 4 valves with vertical injector
- Cooled EGR
- Turbocharging
- Aftertreatment : Diesel oxidation & particulate oxidation catalyst
- Use of glow plugs

Most of the above mentioned technologies are used on multi-cylinder engines.

II. CHALLENGES WITH SINGLE CYLINDER ENGINES

Perhaps India is the only country using single cylinder air cooled diesel engines for 4 wheeler automotive application. Following factors makes it difficult to meet BSIV on single cylinder, air cooled, mechanically governed diesel engines:

- Inherent design limitation – Air cooling leading to poor heat dissipation & limitations on BMEP & peak pressures, Mechanical governing with limited or no control injection based on load demand.
- High fuel economy expectations – Same or better than BSIII version
- Low cost targets – Minimum increase over BSIII configuration
- Stringent limits on pollutants – 50% reduction over BSIII emission limits
- Serviceability – Easy, less tedious and with minimum electronics.

In spite of above challenges, following technologies were adopted for attempting to meet stringent norms of BSIV emissions.

2.1 Injection timing retard

An important step towards achieving engineering targets for emissions for any diesel engine is selection of optimum injection timing [2][3]. For mechanically governed engines this becomes further critical to find trade off between Nox & PM with optimised injection timing. The retarded injection timing helps to reduce Nox, but at the penalty of increase in fuel consumption and particulate matter. [9][10]

For the subject engine, the static injection timing was retarded by ~2^0 to achieve considerable reduction in Nox. The combustion properties of this engine are such that it required ~ 2 to 3 degrees of retardation in static injection timing each for meeting emissions from BSII to BSIII and from BSIII to BSIV.

2.2 Injection pressure increase

Retarded injection timing results in substantial loss in fuel economy. Reasons for this loss in fuel economy are attributed to the loss in peak combustion pressure that leads to reduced cycle work (area between the combustion diagram and the compression diagram in figure 4) [2] [6]. To compensate for the loss of work (power) more fuel is provided to produce the desired work and this leads to more fuel consumption.

To compensate for this loss, increasing peak injection pressure by ~20 to 40% has a significant improvement in fuel consumption. High injection pressure can be obtained through faster injection cam profiles or reduced diameter nozzles. This increases the overall injection rate that can be used to shorten the duration of fuel injection. An increased injection rate allows a delay in the initiation of fuel injection, similar to retarded injection timing, causing lower peak combustion temperatures and reduced NOx formation. Increasing the injection rate tends to reduce the PM and fuel economy penalties of retarded injection timing, because the termination of fuel injection is not delayed.

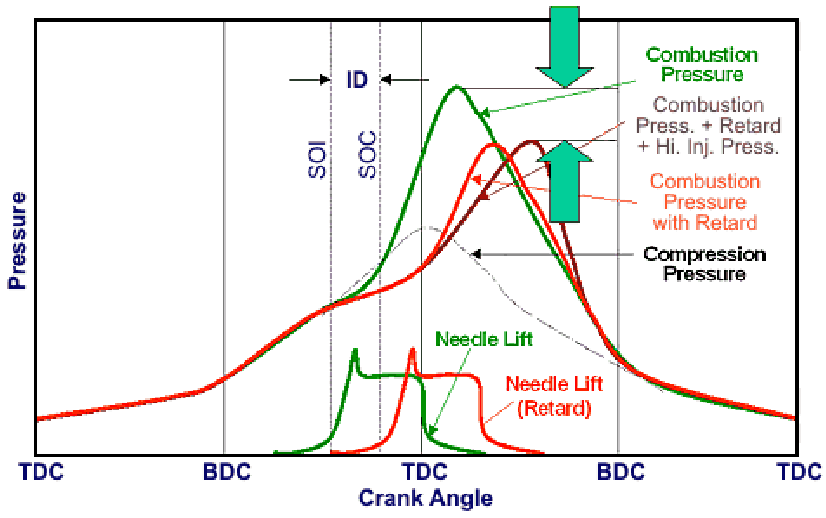

Figure 3: Effect of high injection pressure

For the engine for research, the injection pressure was increased by 20% by modifying the fuel injection pump cam lobe profile. Also the nozzle hole diameter was reduced by 25 microns to facilitate further reduction in emissions.

2.3 Exhaust gas circulation

Almost all modern diesel engines uses exhaust gas recirculation (EGR) to reduce Nox formation during combustion process. The principle of EGR is relatively simple. Exhaust gas, being already burned, is essentially inert [3] [4]. If some of this exhaust gas is introduced into the intake manifold (recirculated) along with air and fuel, it won't participate in the combustion reactions. However, the exhaust gas can absorb some of the heat produced, thereby lowering the cylinder temperature. Since NOx production is favoured strongly by higher temperatures, EGR reduces NOx emissions substantially [11].

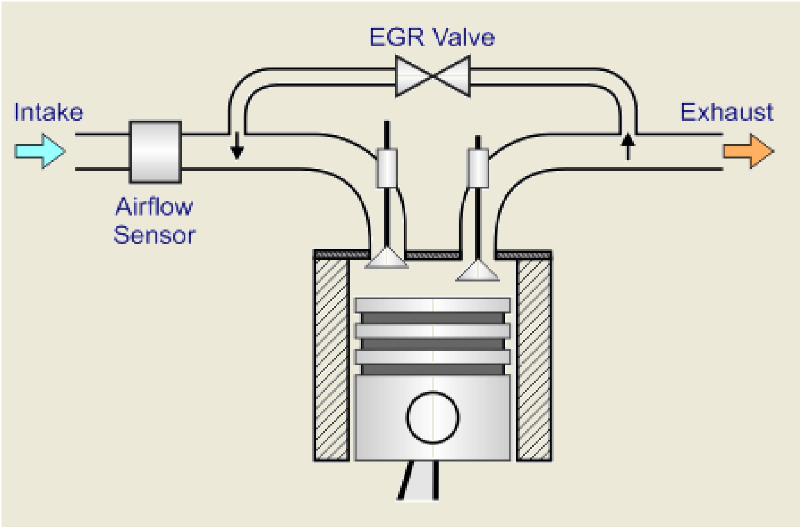

Figure 4: Schematic of exhaust gas recirculation

EGR coolers are commonly installed to cool the EGR gases prior to mixing with fresh air. This further reduces the Nox emissions and also particulate matter. But the subject engine, being an air cooled engine, there is no possibility to use an EGR cooler. But the EGR pipe was routed such that the air stream of cooling air passing over the cylinder head and crankcase fins can be made pass over the EGR pipe to lower the temperature to some extent.

The electric progressive EGR with feedback was used for precise control of EGR actuation. EGR rate was controlled by a 3D map being governed by throttle position and engine speed as an input. The throttle position was sensed by a potentiometer and the engine speed was measured by converting the flywheel mounted alternator frequency to engine speed. Oil temperature was one of the important inputs to give signals to ECU for exhaust gas recirculation.

The glow duration of glow plugs installed in the fresh air path was also controlled through EGR ECU to facilitate the pre glow & post glow for HC & PM reduction.

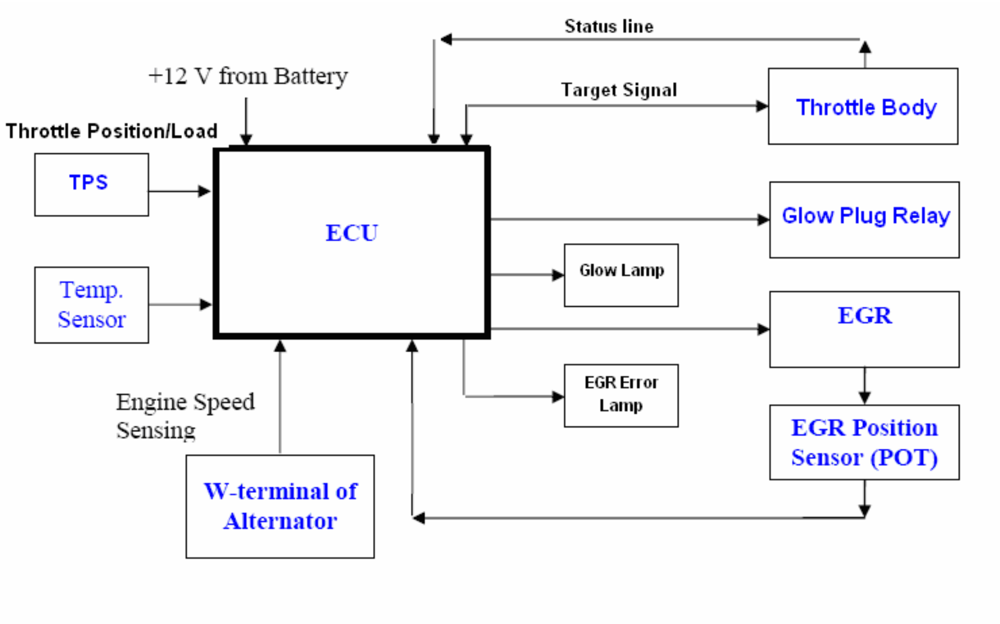

Figure 5: EGR ECU with system diagram

2.4 Exhaust after treatment

The automotive industries including suppliers are taking significant efforts from last decade to reduce CO, HC and particulate emissions. Development of new after treatment technologies includes diesel oxidation catalyst (DOC), particulate filters (POC). Conversion efficiency and light off temperature of DOC and POC depends on lot many parameters like cross section, length, cell density, washcoat formulation, exhaust flow velocity, exhaust gas temperature etc.
For subject engine, a combination of single canned DOC & POC with mounting close to the engine was selected for meeting specially PM reduction. Higher cell density selected to increase the back pressure which further helped to increase the EGR rates for Nox reduction.

2.5 Summary – Hardware selection

Following table summarises the hardware selected for subject research.

Table 4: Hardware Selection

Hardware	Nature of change	Objective
Combustion bowl	Reduced compression ratio	Reduction of NOx
	Bowl geometry	Reduction of smoke & PM
Nozzle	Lower flow rate & different spray cone angle	Reduction of both NOx & PM
Injection cam profile	Increase in plunger velocity & injection pressure	CO, HC, Smoke & PM reduction
Injection timing	Retarded injection timing	NOx reduction
EGR	External progressive EGR (New addition)	NOx reduction
Glow plugs	New addition	For better startability due to low CR
Aftertreatment	Use of catcon & open filter	To reduce CO, HC & PM

III. RESULTS

Since the objective was not only to meet the BSIV emissions, but also to ensure the engine target performance, outcome of the trials conducted during selection of various hardware indicates that the final performance is well within the minimum & maximum target band as shown in graph below.

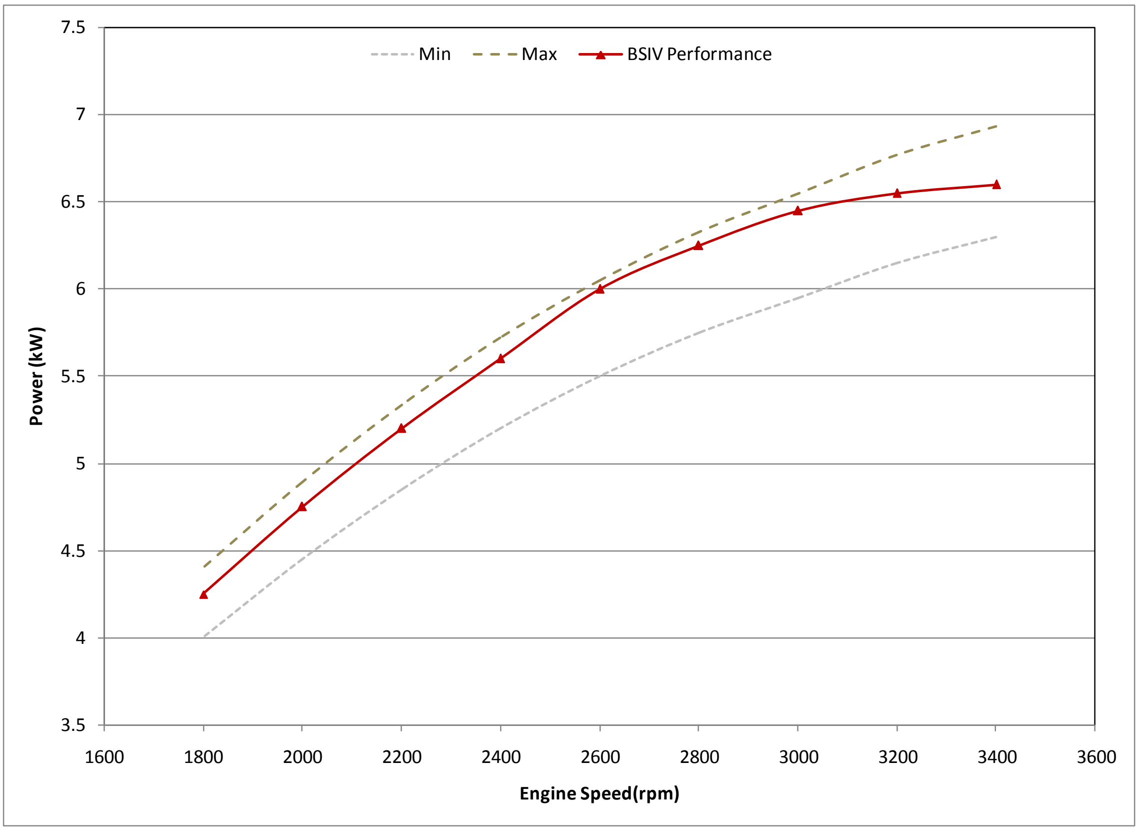

Figure 6: Power Curve_Full throttle performance

As mentioned in 2.1, the injection timing was retarded to reduce the NOx. The retarded injection timing was selected such that there is a sufficient Nox reduction without much penalty on soot. The increase in soot was compensated by increasing the injection pressure as mentioned in 2.2. For the subject engine, the most optimum static injection timing is 7° btdc with higher injection pressure cam. This is represented in figure 7.

As described in 2.3, use of electrical progressive EGR results in considerable reduction in NOx emissions. Same was tested during steady state trials on engine dynamometer and results are plotted on graph in figure 8. The rate of EGR going inside combustion chamber was optimized by varying the EGR valve opening and at the same time recording the soot at various speed & various loads. Such a result at 3000 rpm is shown in figure 10. The map so derived was fine tuned during trials on chassis dynamometer on actual vehicle.

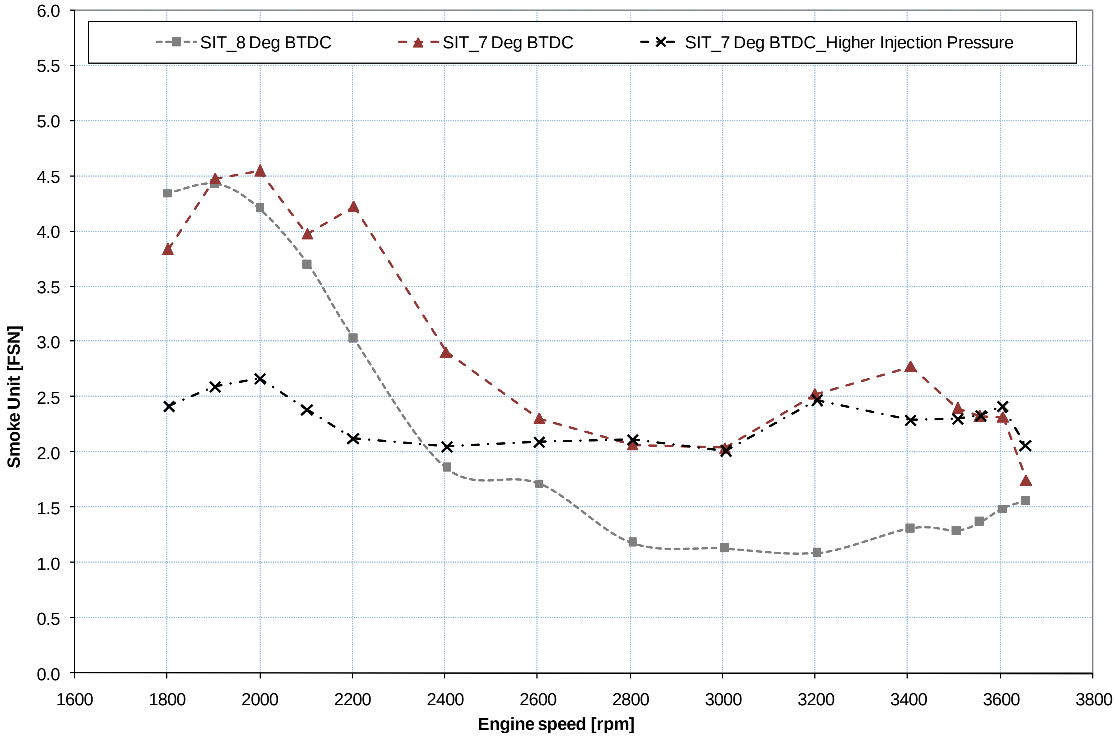

Figure 7: Steady State Trials : Effect of Timing retard

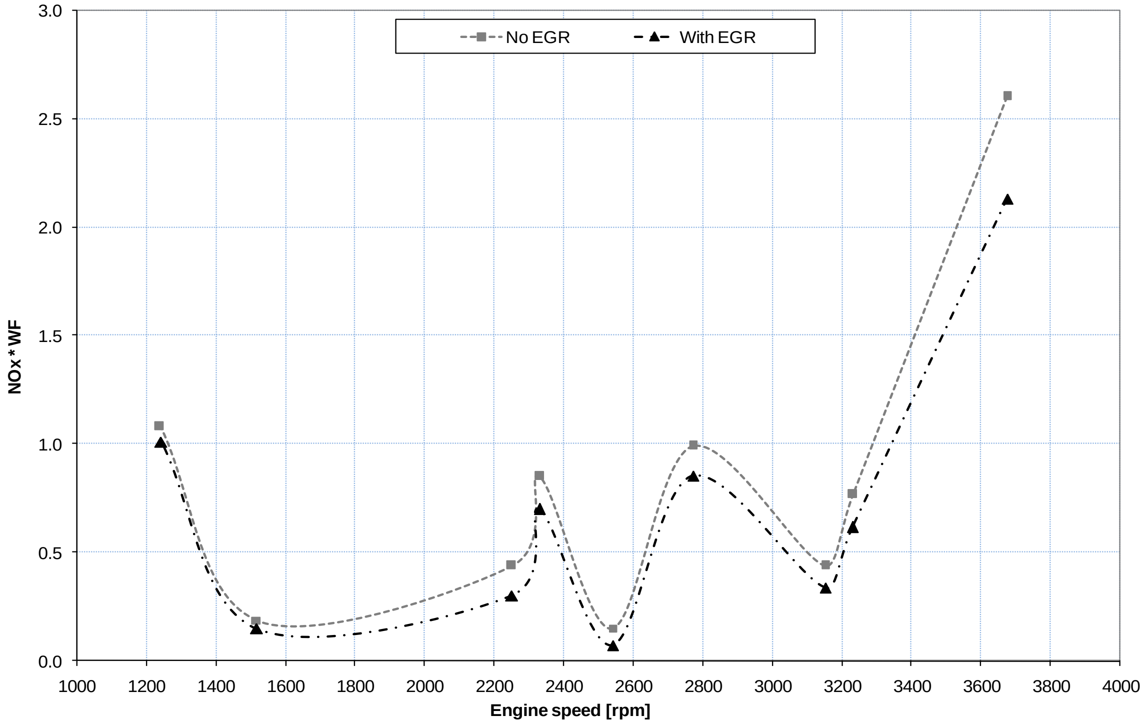

Figure 8: Steady State Trials : Effect of EGR on NOx

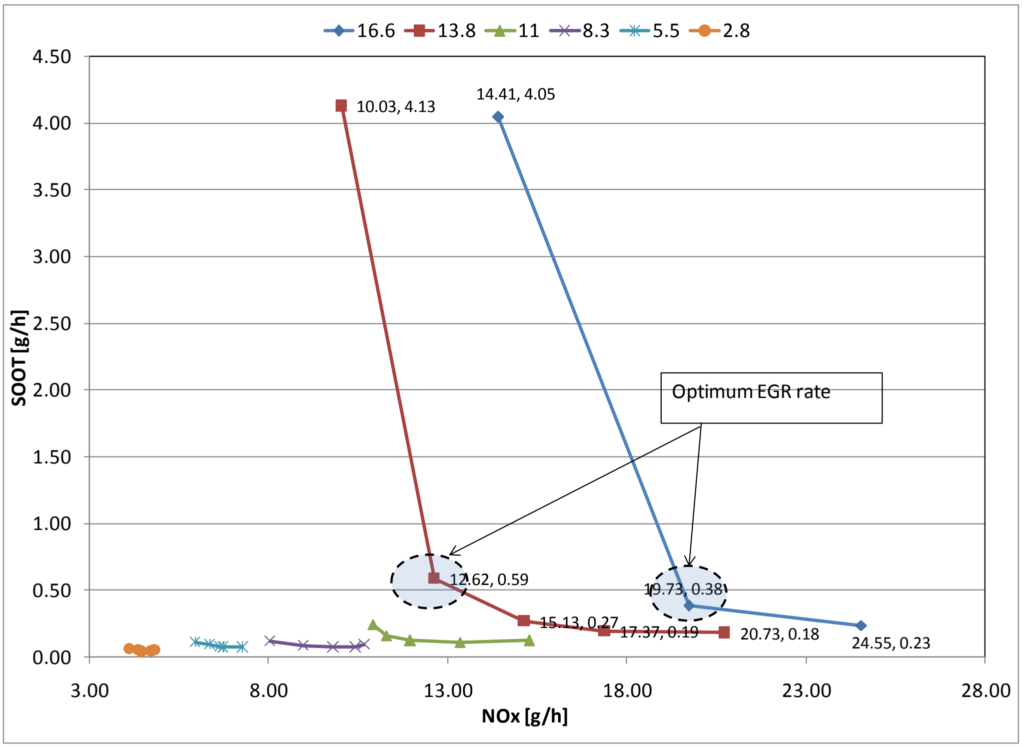

Figure 9: Steady State Trials : EGR Mapping

The final emission trials taken on chassis dynamometer for optimization of EGR rate to meet NOx emissions and selection of after treatment as mentioned in 2.4 for meeting PM emissions achieved the BSIV emissions with considerable margin.

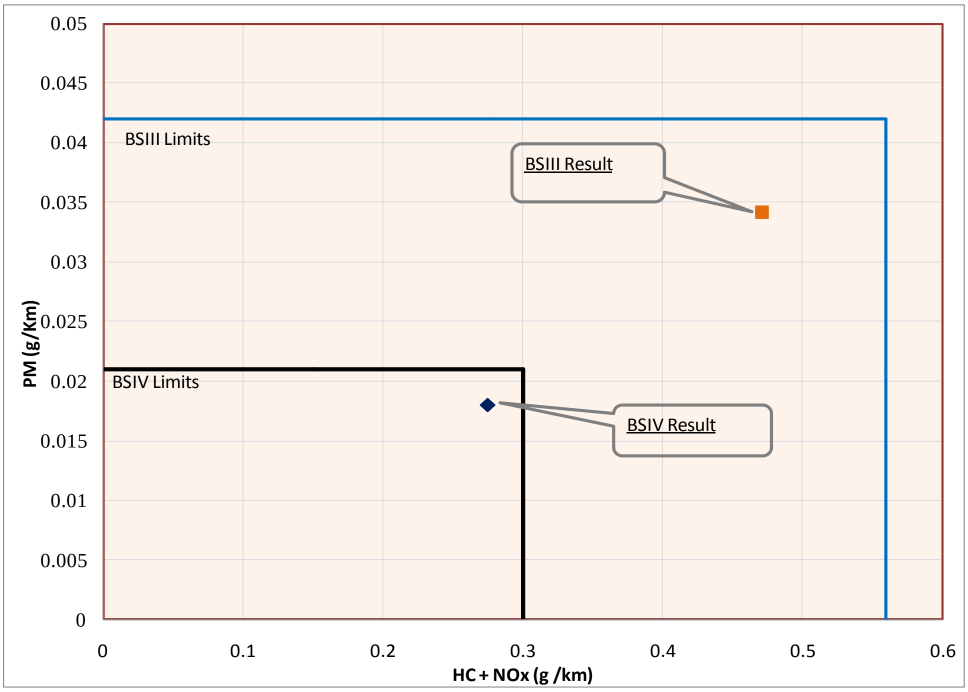

Figure 10 : Emission test results

IV. CONCLUSIONS

Being air cooled and mechanically governed, meeting BSIV emissions on single cylinder diesel engine is really challenging, although it is not impossible. Proper selection of hardware as summarized below meets the stringent BIV emission norms on small 4 wheeler vehicles.

- Retarded injection timing reduces Nox by 20%, but at the same time it increases the fuel consumption, HC and particulate matter.
- 20% increase in injection pressure and reduced hole diameter nozzles, regains the fuel consumption and also reduces PM levels by more than 20%.
- With electrical progressive EGR and air cooled exhaust gases, further Nox reduction is achieved which brings Nox within 10% of margins over limits.
- Selection of DOC & open filter combination along with glow plugs reduces CO/HC and PM levels such that PM margin is more than 40%.

REFERENCES

[1]. Parker, R.F., 1976, **Future Fuel Injection System Requirements of Diesel Engines**. SAE (USA) Paper No. 760125
[2]. **Diesel Technology Forum** – *www.dieselforum.com*
[3]. **Manufacturers of Emission Control Technologies** – *www.engine-manufacturers.org*
[4]. **U.S. Environmental Protection Agency** – *www.epa.gov/otaq*
[5]. MoRTH/CMVR/**TAP 115 - 116**
[6]. **Bosch Handbook**
[7]. Keshav Varde and Takashi Watanabe (2000), **Characteristics of High Pressure Spray and Exhaust Emissions in a Single Cylinder DI Diesel Engine**, Seoul 2000 FISITA World Automotive Congress Paper No F2000H235
[8]. R. Govindaraju and K.R. Govindan (2012**), Impact of Low Cost Embedded Control on Single Cylinder Diesel Engine**, European Journal of Scientific Research, Paper No ISSN 1450-216X Vol.84 No.1
[9]. T Fang, Robert Coverdill and Robert White, **Air – fuel mixing and combustion in a small bore direct injection diesel engine using a retarded injection strategy**,
[10]. Laguitton, Crua, Cowell and Gold, **The effect of compression ratio on exhaust emissions from a diesel engine**
[11]. Shabbir Sheikh, Gokhale, Thatte and Gandhi (2011), **Efficient Approach for Optimization of Piston Bowl Shape, Compression Ratio and EGR for DI Diesel Engine**, SAE Paper No. 2011-24-0013.

AUTHORS BIOGRAPHY

Rahul Katariya is a student of 2nd year M Tech in department of Mechanical Engineering, MIT, Aurangabad, India

Ashok J. Keche is working as Associate Professor, Mechanical Engineering Department, MIT, Aurangabad, India