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Research Article

Implementation of Bharat Stage VI norms for small and medium duty CI engines

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Abstract

The emissions from the internal combustion engine are a major threat to the environment and thus needs to be controlled and kept a close watch on. India has decided to jump directly to BS VI after BS IV leapfrogging BS V. This paper mentions a few methods by which the target can be achieved and newer and better methods to achieve BS VI target. The changes that can be made to meet the stringent norms are either in the engine architecture, air handling system, after-treatment devices etc. But a sure shot method for the conversion of existing engines is still not present and is a major gap in the study and requires immediate attention.

Keywords: *Bharat Stage (BS) norms, ECM (Engine control module), VGT (Variable geometry turbo), Swirl ratio (SR), DLLA (sac type) and DSLA (sac less type), LNT (lean NO_X trap), cDPF (catalytic diesel particle filter)*

1. Introduction

While the fact that automobiles are major contributors to environmental pollution is hardly new, highly visible signs of pollution such as smog, low visibility and respiratory ailments have given a sense of urgency to the need to control vehicular emissions. These emissions impose a major threat to ecosystem and are a cause of many deaths each year. Currently, emission standards for motor vehicles in India are at BS IV level. The Indian government has decided to advance the standard for cleaner on-road vehicles and leapfrog to Bharat Stage-VI emission norms countrywide by April 2020.According to the Centre for Science and Environment, the move to Bharat Stage-VI will bring down Nitrogen Oxide emissions from diesel cars by 68 per cent and 25 per cent from petrol engine cars. Cancer causing particulate matter emissions from diesel engine cars will also come down by a phenomenal 80 per cent.

Vehicular emissions are a real menace in today's times, as the number of vehicles on the road increases so will the by-products emitted by them. The emission norms around the world are continuously changing and getting stringent with every revision. India is on its way to make its emission norms at par with that prevailing in the developed nations, thus in February 2016 India has decided to leapfrog the Bharat Stage V (BS V) norms and move directly to BS VI after BS IV which is major change in the norms and is hugely appreciated by the automobile fraternity globally.

2. Methodology

The methods which can be used to reduce the emissions from any engine is based on the simple physics of combustion. Any fuel burning engine requires mainly two components to perform the task of combustion, viz., air and fuel thus the major control over the combustion process can be achieved by controlling the amount of fuel and air which the system is consuming. Apart from the fueling system and the air handling the systems, other methods for controlling the rate of combustion is by the method of close monitoring of the engine parameters and feedbacks received from the system, thus the introduction of electronics into the engine. The ECM can control the exact amount of fueling that should be provided to the engine at any given instant thus maintaining the conformity of performance of the engine.

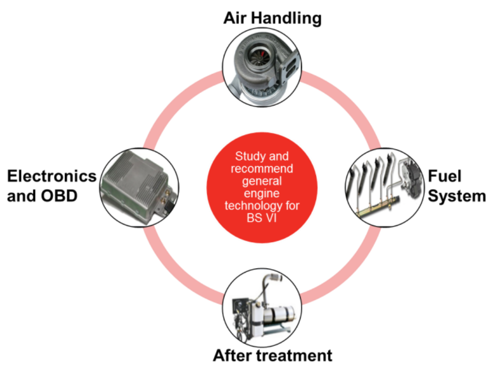

Fig.1 Levers for controlling engine combustion

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2.1 Air handling

The general CI engines have a stoichiometric ratio of the range to 16:1 to 18:1, but the practical engines run much leaner say at 22:1 to 24:1 ratios, thus the amount of oxygen present at any given instant in the combustion chamber is higher than what is actually required for complete combustion of fuel. If during such a stage the temperature of the combustion chamber increases above say 1280˚C, the formation of NO_X is promoted at a very high rate thus increasing the emissions.

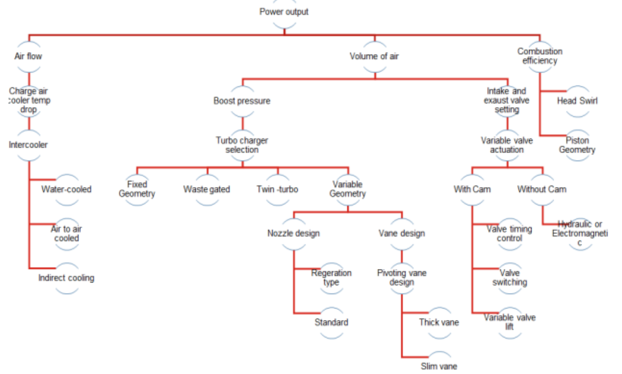

Fig.2 Parameter tree for Air-handling

The component that has a major impact on the intake air for the engine is the turbocharger as most of the engines today have switched to turbocharging instead of natural aspiration due to downsizing and emission restrictions. The selection of turbochargers is a vital and important in any new engine architecture design.

Parameter	Fixed geometry	Waste gated turbocharger	Variable geometry	Turbo two-staging
Low engine speed boost	Low	Medium	High	High
Transient response	Low	Medium	High	Mediu m
Driving EGR flow	Low	low	High	Mediu m
Flexibility over pressure ratio	Low	Medium	High	Mediu m
Engine braking	Low	Medium	High	Low
Complexity	Low	Medium	Medium	High
Cost	Low	Medium	High	Expens ive

Fig.3 Comparison of different types of turbochargers

As it is evident from Fig 4. the pressure ratio that can be achieved from the variable geometry turbo (VGT) is the highest even at lower mass flow of air, means that it can produce higher boost pressures even at lower engine speeds thus providing better transient response Fig 5. for the engine when fitted with this type of turbo.

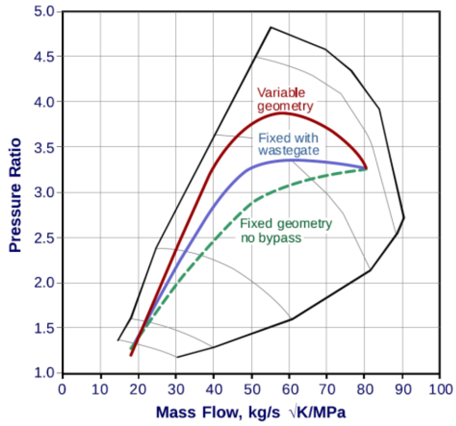

Fig.4 Mass flow v/s Pressure ratio

The other method for controlling the air flow is the selection of intake air filters for fresh charge induction, but the intake depression achieved by the filter is not a constant value and thus cannot be relied upon completely, as it increases with clogging.

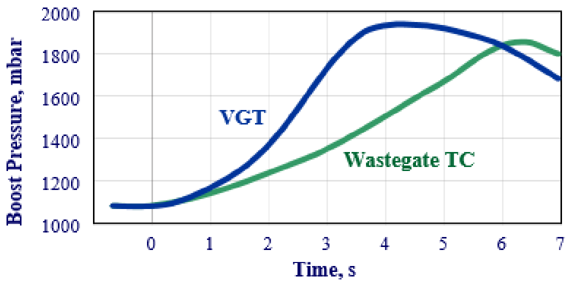

Fig.5 Time v/s Boost Pressure (transient response)

2.2 Fuel handling system

The other and probably the most complex system for controlling the combustion is the fueling system. Any component of the fueling system, if not compatible with the other will cause tremendous rise in the emissions, for example, if the injector is of the a particular cone angle which causes the fuel spray to hit the cylinder liner will cause the soot to shoot up tremendously, or if the swirl on the cylinder head is very high and causes the fuel to mix in a very turbulent manner will cause the swirl ratio (SR) to be very high hence increasing the contribution in NO_X formation. Also the spray pattern of the nozzles play an important role for the complete atomization of the fuel and through mixing with the fresh charge.

The type of injector nozzle influences the total HC in the emissions. DLLA (sac type) causes some fuel to drip even after the End of Injection, thus increasing the amount of residual fuel in the piston bowl which will eventually cause the HC concentration to increase in the exhaust gases. DSLA (sac less type)overcomes the problem of fuel drip but the fuel reserve and the injection pressure is comparatively lower than DLLA nozzle.

Parameters	BS IV Compatible Nozzle Properties	Recommendation for BS VI Nozzle	Effect on Emission & Performance
No of Holes & Spray	7 holes	Based on Bore and Stroke , Should be increased	NOx , Soot to be monitored
Hole Geometry	Cylindrical Holes	Conical Hole	Atomization and mixing
Sac Geometry	DSLA / DLLA	DSLA	DSLA (VCO)
Seat Geometry	DSLA / DLLA	DSLA	DSLA (VCO)

Fig.6. Nozzle parameters and their effects

2.3 After treatment devices

The engine out emissions can only be controlled by after treatment devices. The new BS VI norms are so stringent that without the use of after-treatment devices, it is impossible to meet the emission regulations (even BS IV uses after-treatment devices). The newer and improved versions of after-treatment devices are being tested for use in BS VI conversion experiments.

In order to assess the potential of different after-treatment strategies to meet future BS VI emission norms for an Ultra-light Commercial Vehicle (U-LCV) powered by small displacement Single Cylinder Diesel Engine concepts, a set of EATS (Exhaust Gas After-treatment Systems) concepts has been investigated (refer to Figure 7).

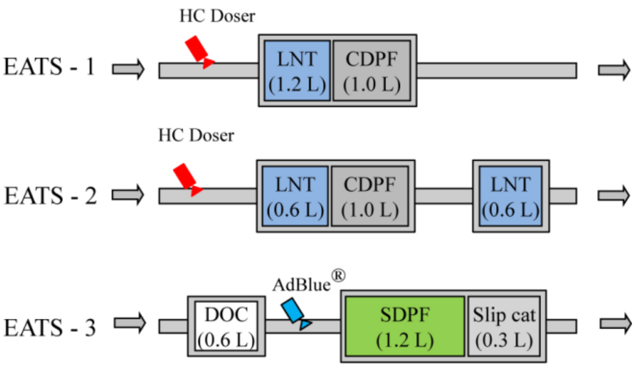

Figure 7 Layouts of the exhaust gas after-treatment system (EATS) investigated in present study for meeting BS VI legislation. (EATS-1: single stage close coupled LNT, EATS-2: dual stage LNT and EATS-3: SCR coated DPF with a NH3 slip cat)

3. Experiment engine and procedure

For the understanding of the application a case study has been selected from a paper by Om ParkashBhardwaj,*et al.* titled Comparative Study to Assess the Potential of Different Exhaust Gas After-treatment Concepts for Diesel Powered Ultra-Light Commercial Vehicle Applications in View of Meeting BS VI Legislation, from SAE Technical Paper series. For the present application, a brief description of the vehicle application is provided in table below:

Parameter	Specification
Engine Displacement	550 ~650 cc; NA ; Single Cyclinder
Maximum torque	39.5 Nm @ 1500 - 1700 rpm
Maximum Power	11.7 kW @ 3700 rpm
Vehicle Test Mass	~ 850 kg
Transmission	4 speed manual transmission

Fig.8. Base engine specifications

For the above vehicle application, the Bharat Stage VI regulations would require a tailpipe NOx emission limit of 80 mg/km. In order to meet this stringent requirement, various scenarios are simulated to ascertain which amongst the various options for the OEM's can be realized to achieve a good calibration for the given emission limits.

The boundary conditions for the simulations are described below:

- The exhaust after-treatment catalysts simulated in the study were aged for ~160,000 kms.
- The impact of deSOx on the catalysts is not considered.
- The Ki factor for DPF/SDPF regeneration is not taken into account
- The DPF regeneration behavior, and thereby, soot oxidation using thermal or passive regeneration is not simulated
- Impact on the catalyst due to fuel impurities over the aging process is not considered.
- To ensure a robust emission compliance, an engineering margin of ~ 20 % was targeted with respect to the legislation limit for the tailpipe NOx, 80 mg/km.

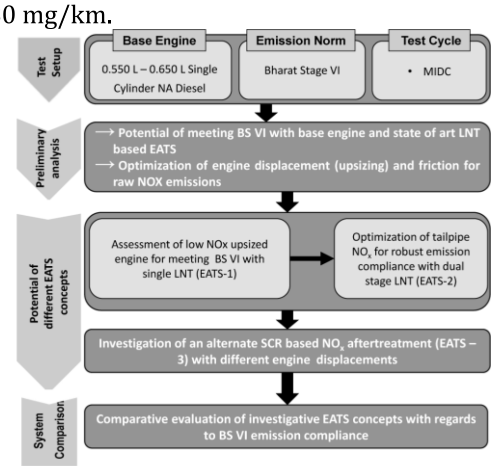

Figure 9. Methodology and approach used for the analysis of emissions compliance strategies using various engine and after-treatment concepts

A state-of-the-art 550 cc single cylinder naturally aspirated engine is considered as the base to start the investigation for meeting the BS VI legislation for this application. The limitations for the maximum EGR rate at full load result in high engine out NOx of 229 mg/km in the MIDC cycle for this engine. For the application, the maximum vehicle speed during the MIDC is 60 km/h. Due to the low power-to-weight ratio, higher vehicle speeds are not possible with the considered powertrain.

Subsequently, an evaluation of the tailpipe emissions for this engine, when fitted with a single LNT and a catalyzed DPF, is performed in order to assess the proximity to target tailpipe NOx emissions. At first, different volumes of the LNT catalysts are used in order to estimate an appropriate volume of the after-treatment system for fulfillment of the BS VI legislation. Figure 11 shows the results from the simulations comparing the tailpipe NOx emissions for LNT + cDPF based exhaust after-treatment systems (varying the volumes of the LNT catalyst from 0.6 to 1.2 L). As expected the LNT catalyst with 1.2 L volume provided maximum NOx conversion (99 mg/km tailpipe NOx) due to higher NOx load storage capability. It also offers maximum residence time for the exhaust gases in the catalyst amongst the four tested volumes. The NOx conversion efficiency while going from 0.6 L to 1.2 L varies in the range of 40 to 57 % respectively.

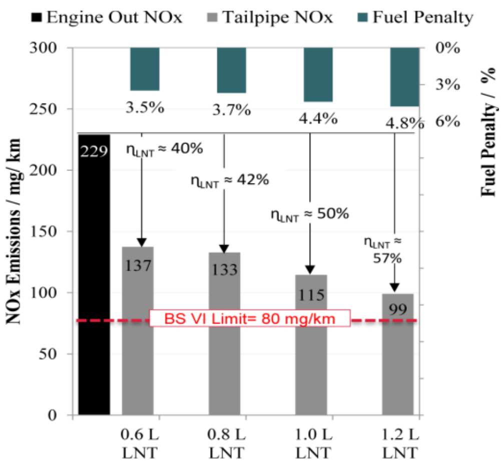

Figure 10. Performance of the different volumes of LNT catalyst with the 550 cc base engine configuration in cold start MIDC. Due to high engine out NOx emissions and the limited conversion performance of LNT at high temperatures, a tailpipe emission limit of 80 mg/km could not be met with base engine concept

While the 1.2L LNT performs the maximum deNOx, it also requires more reducing agent for regenerating the LNT. To maintain optimum performance of the LNT, its relative NOx load (actual load to maximum allowable load), must be maintained at low level through more frequent regeneration events. While the 0.6L LNT required around 5-6 rich events per cycle as directed by the LNT coordinator, the overall time for regeneration in the cycle lasted around 12 sec. while the 1.2L required only 2 events but their durations resulted in an overall regeneration time of around 18 sec. during the cycle. The fuel penalty for the 0.6L and 0.8L LNT was calculated to be in the range of ~3.5 - 3.7% while that of 1.0L and 1.2L were found to be around 4.4 % and 4.8 % respectively. However, all four catalyst volumes could not meet the BS VI legislation limit of 80 mg/km. Hence, an additional reduction of engine out NOx emission is mandatory in order to meet the legislation with a sufficient margin of safety.

Conclusions

This study analyzed the strategies to meet upcoming stringent exhaust gas emission norms (BS VI) in ultra-light commercial vehicle (U-LCV) applications powered with single cylinder - natural aspirated (SCE-NA) Diesel engines. Although, the emission concepts and technologies required for meeting BS VI targets are quite matured and already being successfully applied in EU and US markets for over a decade, the application specific challenges (i.e. base engine technology, full load operation in cycle etc.) and Indian market specific boundary conditions (i.e. fuel quality, specific climatic and driving conditions, road qualities and cost aspects etc.) would require extensive efforts to get market specific tailored solutions. To meet this goal, the SimEx powertrain simulation tool from FEV enables a simultaneous optimization of the multiple sub-systems considering engine thermodynamics, controls, transmission system, gear shifting strategy and exhaust after-treatment.

The base engine (550cc SCE-NA) selected for the present study was able to fulfill BS IV engine out NOx emissions (229 mg/km) in MIDC with a maximum speed of 60km/h. The study was conducted in two main phases.

In the 1st phase, the base engine technology was optimized in terms of friction reduction and cylinder volume right-sizing. An increase of cylinder volume to 650cc along with friction reduction measures resulted in ~ 20 % decrease of engine out NOx emissions as compared to the BS IV base engine without sacrificing the fuel consumption and full load performance.

In the 2nd phase of this study, different configurations of NOx after-treatment concepts were analyzed for meeting BS VI norms (i.e. 80 mg/km NOx). The results suggest following key conclusions:

- A state of the art single stage LNT system (i.e. LNT + cDPF) in conjugation with right-sized low friction engine (engine out NOx = 183 mg/km) shows a potential to bring-down the tailpipe NOx into the BS VI window (72 mg/km), but with insufficient engineering margins.
- The single stage LNT configuration (close coupled position) showed a limited conversion performance, mainly due to high temperature

peaks seen from the beginning of the cycle as a result of the full load engine operation in a significant part of MIDC.

- To ensure a more robust emission compliance, an innovative dual stage LNT system (i.e. LNT + cDPF + LNT) was investigated by keeping the total LNT system volume similar to single stage LNT. This system shows a good potential to meet the legislation by bring the tailpipe NOx down to 66 mg/km (i.e. approx. 20 % engineering margin).
- The dual LNT concept might lead to slightly more fuel penalty during the regeneration of its downstream LNT as a result of the consumption of reducing species by the oxygen storage capacity of cDPF. Moreover, this concept will require further validation due to possible challenges to ensure a successful de-sulphation of downstream LNT.
- Therefore, a final selection of the after-treatment strategy will depend significantly on the application specific boundary conditions (i.e. base engine technology, performance, robustness, cost.

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