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Strategy to Meet Euro IV Emission Norms on Common Rail Sports Utility Vehicle

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ABSTRACT

One of the key factors driving the automotive world is emission regulations. Zero emissions, clean engine concept are some buzz words being used extensively in the automotive industry. Stringent emission regulations throughout the world mean that automotive manufacturers have to pay attention to minimizing engine out emissions. Electronic engine management systems allow flexibility in controlling injection parameters & provide a means for optimizing engine performance.

This paper presents work carried out on a 2.49L common rail direct injection diesel engine to achieve Euro IV emission targets. Without after-treatment devices, it is difficult for engine management alone to meet Euro IV and further stringent emissions. To overcome this, two type of after-treatment technologies are adopted by OEM's

- Selective Catalyst Reduction
- Diesel Particulate Filter

Huge amount of research is being done on the application, cost aspect and availability of component samples for series production. PM - NOx trade-off is always a challenge to researchers for emission optimization on diesel engines. With cooled EGR & oxidation catalyst, the same can be brought under control. Common rail technology allows for multiple injections and immense control over engine parameters. This allows for extreme fine-tuning of combustion parameters.

The present paper deals with application work done on a Common Rail Sports Utility Vehicle to meet Euro IV emission norms.

Keywords: Cooled EGR, Oxidation catalyst, pilot injection

INTRODUCTION

Many automobile manufacturers are keen to upgrade their vehicles to meet the stringent Euro IV legislative targets. This paper commences with a general overview of the methodologies to meet Euro IV. Later it is devoted to a specific approach adopted to ensure Euro IV compliance of a sports utility vehicle with a reference mass more than 1750 kg and with an engine incorporating the common rail diesel injection system.

ENGINE SPECIFICATION

The engine specifications are given in table 1.

Table 1: Engine specification

Engine type	4 cylinders, 2 valves / cylinder
Displacement	2.49L
Rated Power	108 hp @ 3800 rpm
Fuel Injection System	Common Rail, BOSCH Gen 2

STRATEGIES TO MEET EURO IV

Euro IV compliance calls for precise control and optimization of injection and combustion parameters. Euro IV emission regulations are more stringent as compared to Euro III (50 % reduction in NOx and 40% reduction in PM). Refer table 2.

Table 2: Emission legislation limits

	Euro III	Euro IV	$\triangle$ (%)
HC, gm/km	-	-	-
Nox, gm/km	0.78	0.39	50.00
HC + NOx , gm/km	0.86	0.46	46.51
CO, gm/km	0.95	0.74	22.11
PM, gm/km	0.10	0.06	40.00

To reduce diesel engine emissions, researchers are carrying out work in different areas. Strategies adopted for achieving Euro IV and beyond are shown in Fig. 1.

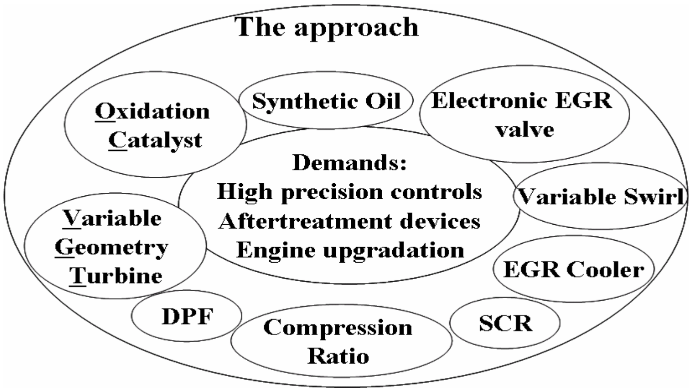


Figure 1: Strategies to reduce emission levels

As emission norms become more stringent, the PM – NOx trade-off becomes more critical. For upgrading a Euro III engine to a Euro IV compliant engine, one approach is to reduce NOx levels by introducing more EGR and control PM by using a Diesel Particulate Filter (DPF). This route necessitates a complex regeneration strategy resulting in increased development time & higher fuel consumption. Refer Fig. 2.

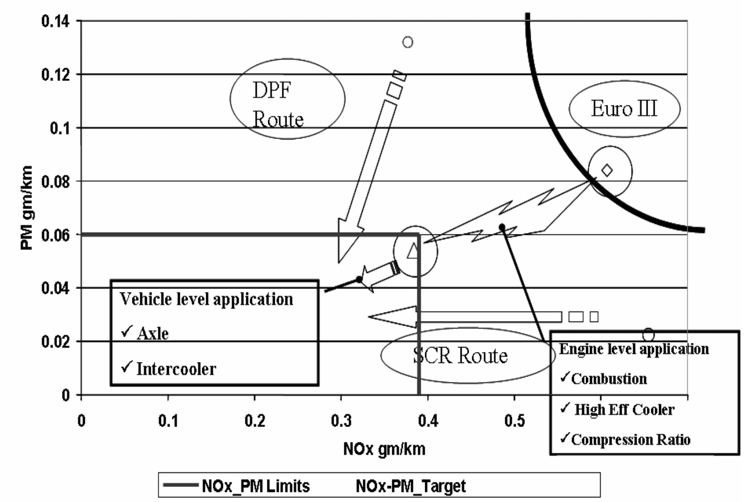


Figure 2: General approach for Euro IV compliance

Another approach is to minimize PM by combustion optimization and use Selective Catalyst reduction (SCR) for NOx reduction. Refer Fig. 2. This route dictates the usage of urea and has complex packaging & serviceability in passenger vehicles. Both these strategies increase the development time and have cost implications.

METHODOLOGY

Existing engine with common rail diesel technology, which meets Euro III emissions, was selected as a base engine. The challenge was to have minimum changes in hardware.

Figure 3 represents the strategy followed in this paper and it advocates using an oxidation catalyst, improved heat transfer capacity EGR cooler and optimization of combustion parameters. With proper hardware selection and optimization of engine calibration, it is possible to meet Euro IV legislative targets. Further, vehicle level hardware optimization and application leads to achievement of engineering targets. Reduced drive train friction was one of the areas which were explored during development.

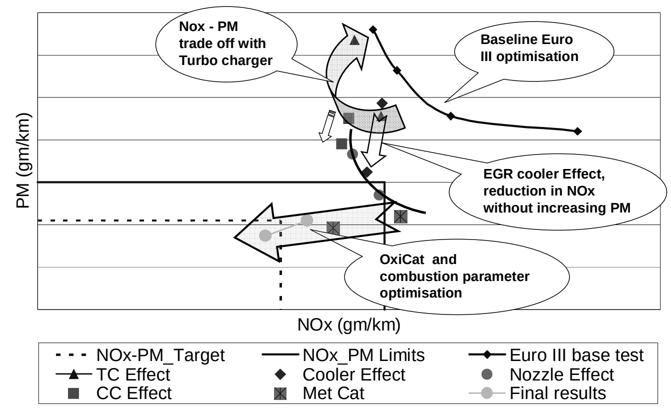


Figure 3: EURO IV methodology

ENGINE HARDWARE SELECTION

Following key parameters were addressed.

- Reduction in compression ratio
- Turbocharger
- Injectors
- EGR cooler
- Oxidation catalyst
- Injection parameters

Compression ratio was reduced by 4% by reducing the swept volume, while piston bowl volume was retained. This resulted in lower NOx at high speeds and loads. Slight increase in HC and CO was observed at low engine speeds. Strategy adopted was to first reduce NOx to the engineering target and then optimize other emissions without deteriorating NOx.

It is always desirable to have minimum possible engine-out emissions. A clean burning engine leads to

- Reduced dependency on after-treatment devices
- Lower cost of after-treatment devices
- Easier EOBD calibration for eventuality of failure of after-treatment system

Critical components affecting engine-out emissions are turbocharger, injectors and EGR cooler. Performance should be individually aligned with overall system requirements for optimal combustion. Evaluation of different hardware and injection strategies was carried out on an engine dynamometer to achieve full load performance and optimize part load emissions. Subsequently, vehicle level optimization was done by optimizing EGR cooler, oxidation catalyst and injection parameters. The following chapters deal with optimization done using above mentioned hardware. For each hardware component, injection parameters were optimized for better performance and emissions.

TURBOCHARGER

The existing Euro III configuration included a traditional waste-gate turbocharger. In order to reduce complexity within the control unit and development time, it was decided to experiment with different turbine geometries of a waste-gate turbocharger rather than using a variable Geometry Turbine (VGT or VNT).

The turbocharger is one of the means to improve engine performance. For improvement in BMEP at low speeds, reduction in turbine inlet area by 15 % (Turbocharger B) was tested. This resulted in reduction of flow losses and increased air excess ratio at low speeds and higher BMEP. Air excess ratio was improved by 3 – 6 % which resulted in an improved SFC by 6 % and 40 – 50 % in smoke at full load and low engine speeds. However, due to reduced turbine inlet area, pumping losses increase at high engine speeds, resulting in deterioration in SFC as well as high exhaust temperatures. This was compensated by flexibility in injection timing and injection pressure. Advancing injection timing and increasing rail pressure helped to achieve engine performance comparable to the turbine with higher inlet area. At high speed SFC deteriorated by 4% and smoke by 12% as compared to turbocharger A. Refer Fig. 4 and 5.

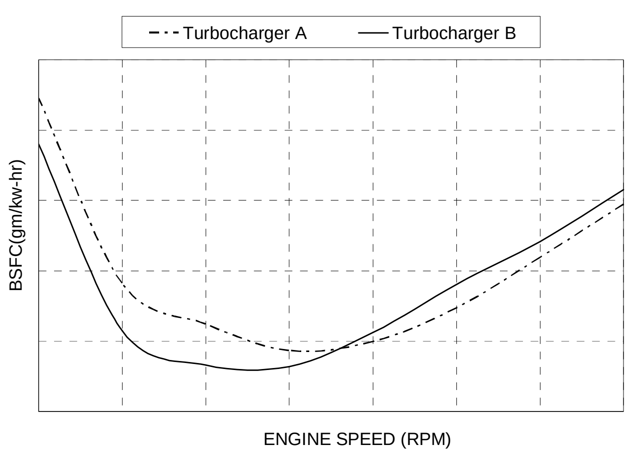


Figure 4: BSFC comparison for turbochargers

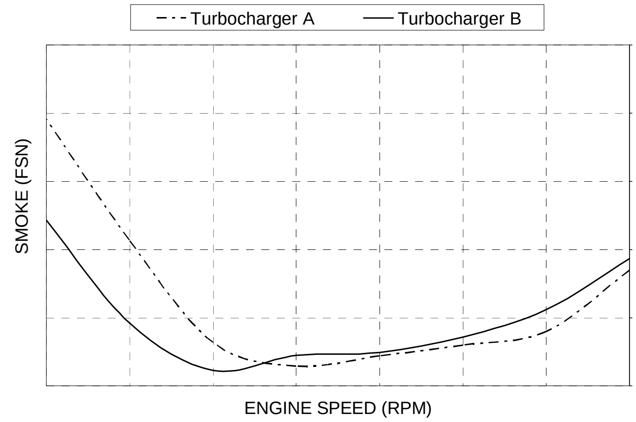


Figure 5: Smoke comparison for turbochargers

Turbochargers were also evaluated on vehicle for emissions. Lower turbine inlet area (Turbocharger B) increased the exhaust backpressure and subsequently higher EGR flow rate resulted in better NOx reduction at high speeds and loads. Refer Fig. 6.

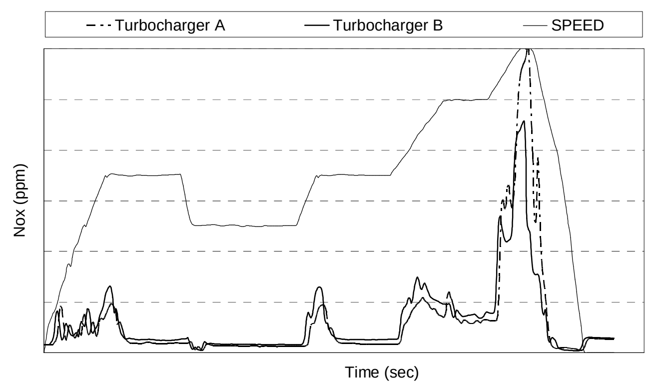


Figure 6: NOx traces - comparison of turbochargers

For the improved levels of smoke and SFC at low speeds, better NOx emissions at higher speeds, turbocharger B with lower turbine inlet area gains advantage over turbocharger A.

INJECTORS

Emission performance of a diesel engine is influenced heavily by the injectors. For an injector, through-flow of diesel in unit time for a pre-defined injection pressure and the number of holes in the injector nozzle govern the quality of atomization.

It was theorized that using injectors with reduced through-flow and increased number of holes would result in finer atomization, leading to better combustion. Finely atomized fuel promotes formation of good air-fuel mixture which helps to reduce hydrocarbon and particulate emissions [1].

Injector with lower through flow was tested for full load performance and it resulted in marginal improvement in smoke levels as compared to an injector with higher through flow. However, atomization is expected to be better with increased number of holes. Subsequently, the lower through flow injector with increased number of holes was tested and it helped to improve smoke levels by 20 – 25 % at full load. Refer Fig. 7.

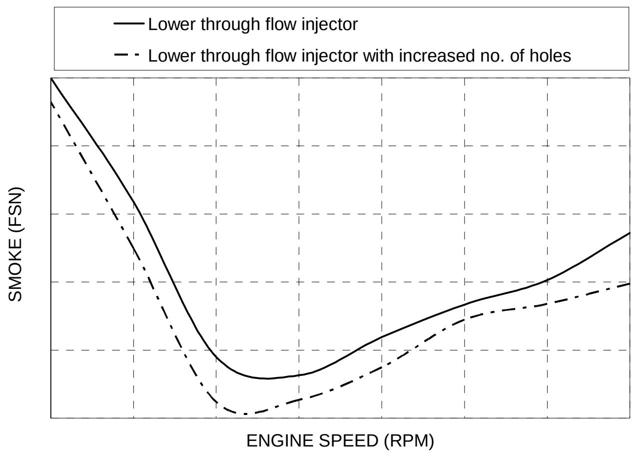


Figure 7: Lower through flow injector - Smoke comparison with increased number of holes

Despite smoke improvement on engine test bed, lower through flow injector showed marked rise in PM on vehicle. Refer Fig. 8. One hypothesis is fine atomization of fuel particles results in reduction in wet particulates, which normally get oxidized in the oxidation catalyst. The increased dry particulates, which pass through the after-treatment devices lead to an increase in overall PM.

Figure 8 shows that lower through flow injector is able to digest more EGR, resulting in reduced NOx emissions.

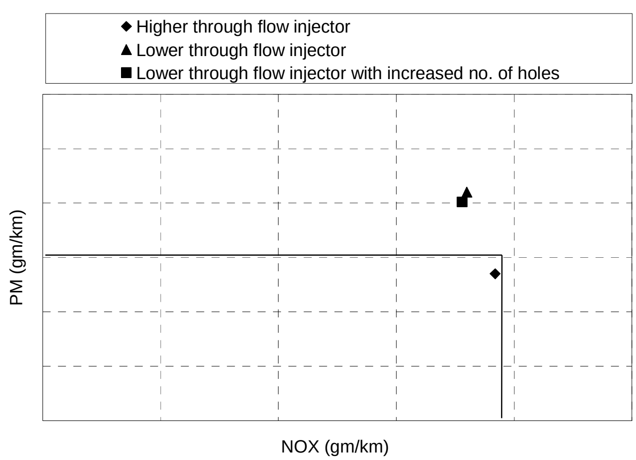


Figure 8: Emission performance of injector with different through flow

EGR COOLER

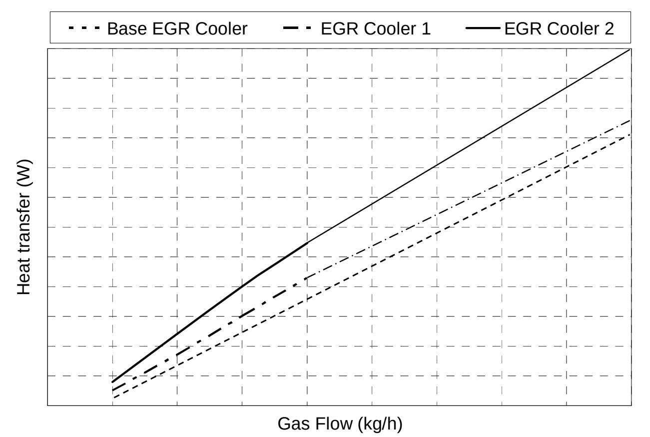
Use of hot EGR will help in reduction of NOx but at the cost of PM. By cooling EGR both NOx and PM can be reduced [1].

EGR cooler is a technological breakthrough which results in reduction of NOx as well as PM. The exhaust gas is cooled before being mixed with the intake air. As a result, the temperature of the intake mixture is lowered, leading to cooler combustion. Cooling EGR prior to mixing with the intake air, lowers the combustion temperature by removing the preheat potential. At the same time it also increases the inlet air charge and hence the oxygen-to-fuel ratio [2]. The slight increase in the available oxygen due to cooling may raise the flame temperature, but this is beneficial for soot control [2]. As the bulk intake charge density is higher with cooled EGR, the volumetric efficiency is increased which in turn reduces the pumping work, leading to an improvement in specific fuel consumption [3].

In order to move from Euro III to Euro IV, it was worthwhile to investigate effects of EGR coolers with increased heat transfer capacity. Refer Fig. 9.

Figure 9: Heat transfer comparison for EGR coolers

These EGR coolers were tested for engine-out emissions for different steady state vehicle speeds. Temperature drop across the cooler for EGR cooler 2 was 36 % better than the base EGR cooler at 100 kmph, resulting in lowered mixture temperature and subsequently had the least NOx emissions. Refer Fig. 10.



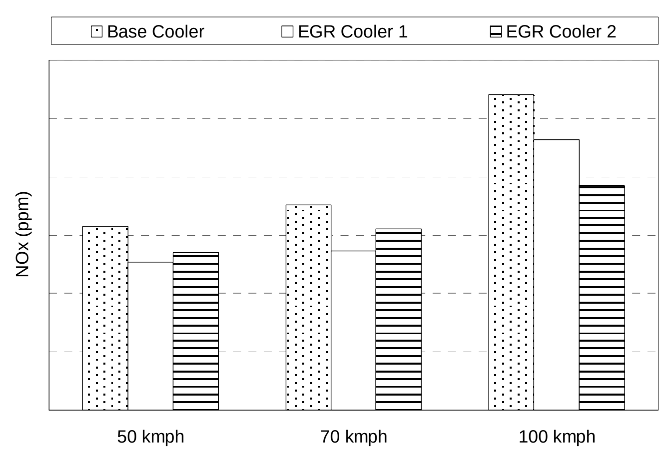


Figure 10: NOx emission – EGR cooler comparison

Also, the pressure drop with EGR cooler 2 was found to be 24 % better than base EGR cooler and hence lower EGR flow into the intake manifold resulted in smoke reduction. The improvement on the engine test bed is confirmed by vehicle emission results. Figure 11 shows the vehicle emission results for different EGR coolers.

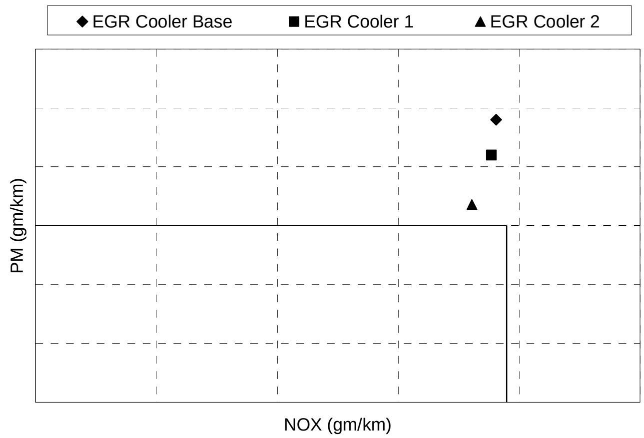


Figure 11: Vehicle mass emission – EGR cooler comparison

SELECTION OF AFTER-TREATMENT SYSTEM

The use of noble metal catalytic converters in the exhaust system reduces hydrocarbon emissions by burning a portion of the gaseous hydrocarbons and those bound to soot (particulates) using the oxygen in the exhaust gases.[3]

EGR cooler leads to a slight increase in CO and HC. With cooled EGR, the ignition delay increases and thereby more fuel is available for re-ignition period. Lower charge temperature reduces the fuel vaporization and mixing rate and leads to increase in HC and CO levels [4]. Close couple catalyst and under floor oxidation catalyst were tried out for reducing the unburnt hydrocarbons. Different combination of precious metal loading and brick combinations were tested.

By using close couple (CC) catalyst, there is increase in exhaust backpressure and VOF (Volatile Organic fraction) is reduced by almost 20%. VOF has an effect on the oxidation of particulate in oxidation catalyst. Due to reduced VOF, CC is not able to convert HC and CO. Figure 12 represents the effect of closed couple catalyst on HC and CO emissions. HC and CO conversion with CC is negligible. Close couple with bigger diameter may be better, but due to packaging constraints it was not tested. Under floor oxidation catalyst along with higher volume and different loading were tested, resulting in better HC and CO emissions as compared to close couple application.

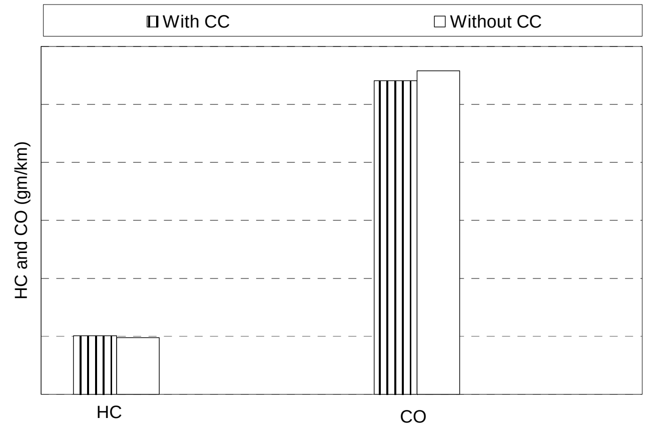


Figure 12: Effect of closed couple catalyst on HC and CO emissions

OPTIMIZATION OF INJECTION PARAMETRS

Optimization of injection parameters plays a vital role in NOx-PM trade off in diesel engine. The timing advance and retardation is limited by the structural durability and smoke respectively.

Optimization of injection parameter includes

- Main Injection Timing
- Number of pilot injection
- Pilot quantity & separation

MAIN INJECTION TIMING

Main injection timing plays critical role in NOx-PM trade-off as well as in HC and CO formation. Generally it is observed that with retarded injection timing, NOx reduces and PM increases. With cooled EGR, best balance between the lower charge temperature and ignition delay can be achieved with retarded timing. This results in NOx as well PM reduction. The main injection timing was retarded at all steady state speeds to reduce NOx. However, while timing retardation beyond TDC helps in emission reduction, the probability of misfiring during acceleration increases. To avoid this, timing was retarded up to TDC only.

PILOT INJECTION

Common rail offers flexibility in number of injection and freedom to choose the start of injection. In pilot injection, a small quantity of the fuel is injected prior to the main injection. With proper selection of number of injections, NOx-PM trade-off can be taken care of. Pilot separation, i.e. time period between the start of pilot and start of main injection, also plays a vital role. At higher speed, pilot injection significantly reduces ignition delay, which leads to increased soot levels. This can be seen from the Fig. 13. The rate of pressure drop across the filter paper in dilution tunnel was monitored for this purpose.

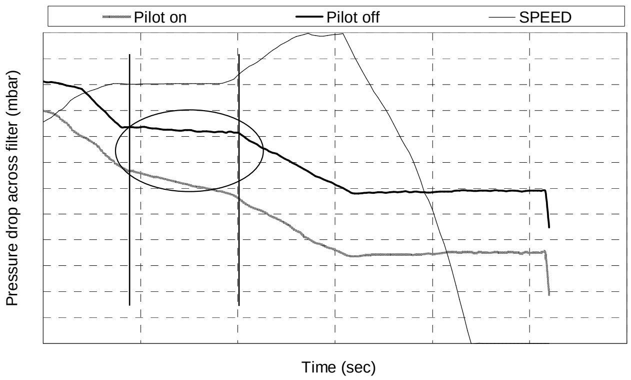


Figure 13: Pressure drop comparison across filter for pilot on & pilot off condition

With improved EGR cooler efficiency, intake temperatures were much lower as compared to Euro III application. Pilot separation was reduced for reduction in HC and CO formations in cold conditions. Refer Fig. 14 and 15.

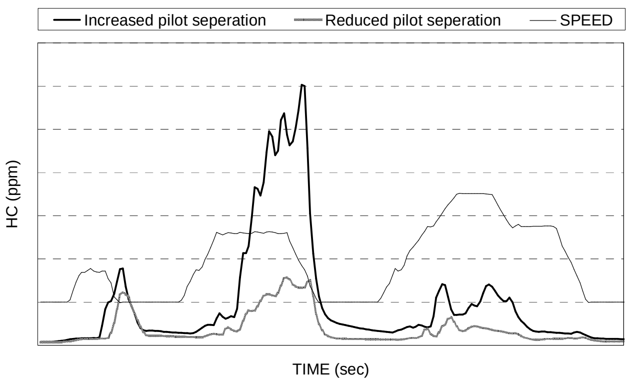


Figure 14: Effect of pilot separation on HC emissions

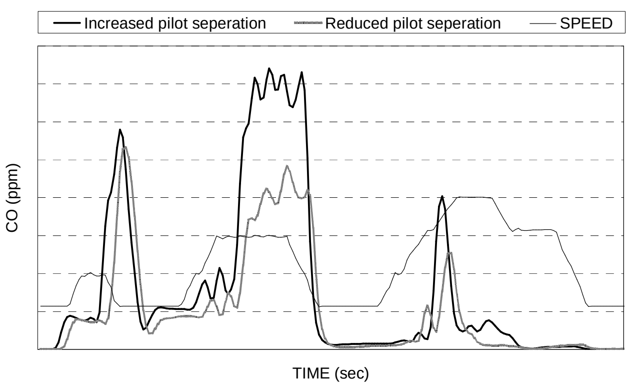


Figure 15: Effect of pilot separation on CO emissions

Pilot quantity was increased for further reduction in HC and CO. During the engine emission development, it was also observed that increasing pilot quantity leads to reduction in ignition delay, particularly at lower speeds and loads. This improved HC and CO emissions by 30% and 25% respectively. Refer Fig. 16

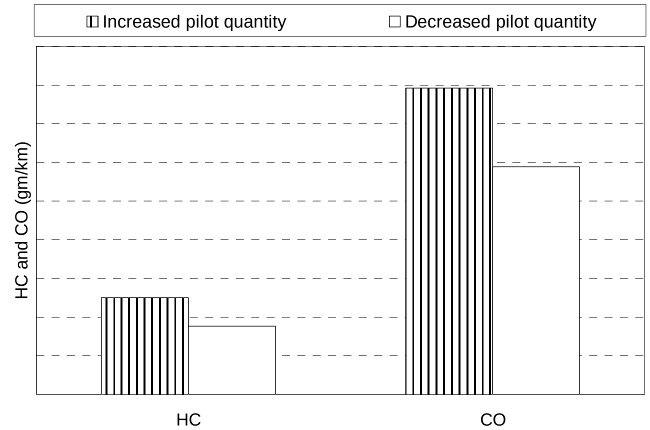


Figure 16: Effect of pilot quantity on HC and CO during emission cycle

FINAL CONFIGURATION

Based on the above evaluation, the final configuration chosen was as follows

- Turbocharger B
- EGR Cooler_2
- Higher through flow injector
- Metallic oxidation catalyst
- Low Friction axle

With the above configuration, consistency evaluation was done on three production vehicles and was compared with the development vehicle. Refer Fig. 17

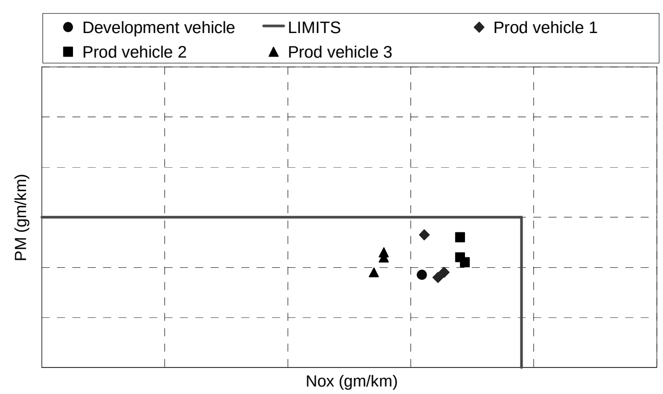


Figure 17: Consistency for production vehicles

CONCLUSION

- Based on the trials conducted, authors conclude that it is possible to meet Euro IV emission norms with sufficient margin by optimization of cooled EGR, oxidation catalyst and injection optimization.

- A selection of turbocharger with smaller turbine inlet area helps in improving BMEP at low speeds. Smaller turbine inlet area has negative effect on high engine speeds, which is compensated by higher injection pressure and flexible injection timing.

- NOx-PM trade-off can be better handled by cooled EGR. Depending upon the strategy of combustion optimization, PM can be reduced for same level of NOx or vice versa.

- Cooled EGR has negative effect on CO & HC, this is compensated by increasing the pilot quantity at low engine speeds along with optimized oxidation catalyst.

- With cooled EGR and pilot quantity application, proper balance between ignition delay and combustion temperature can be achieved for better NOx-PM trade off. However the authors feel more work needs to be done for better understanding of the subject.

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