Diesel car emissions & emission control technologies to meet Bharat Stage VI norms

Sagar D. Rudrabhate[1], S.V.Chaitanya [2], Nilesh V. Deshpande[3], Adarsh Choudhary[4]

[1] Student. M.E (Auto- II nd year) AISSMS COE, Pune, Maharashtra, India,
[2] Asst Professor, Dept. of Mechanical Engineering, AISSMSCOE, Pune, Maharashtra, India
[3] Product Engineer-Manager, CTCI, Pune, Maharashtra, India
[4] Senior Product Design Engineer, CTCI, Pune, Maharashtra, India

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Abstract - *Emission legislation requirements has brought different challenges & opportunities to automotive field. The challenge is to meet the stringent emission regulations as well as to satisfy customer requirements in terms of fuel economy, oil consumption, maintenance & NVH. Cost to customer is unavoidable consideration while designing any new engine or it's variant. These challenges have turned in to opportunities for design & development individual to come up with a better product. Modern engines not only meet emission regulations but also should meet customer expectations. Bharat Stage VI emission norms is supposed to be implemented in India from 2020 where emission limits have become very stringent. In addition to emission norms, vehicle manufactures have to comply On Board Diagnostics norms. The paper gives insight on proposed emission norms for Diesel cars. Paper also focus on causes & control of pollutants. Selection of emission control technologies & general methodology to meet emissions is also mentioned*.

Key Words: **Unburned Hydrocarbon (UBHC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Particulate Matter (PM) ,Bharat Stage VI (BS-VI),**

1. INTRODUCTION

Selection of on engine combustion technology & aftertreatment divices is an important decision.It is not only important to meet the emission legislation requirements but it is also important to consider the parameters like packaging within existing space of an automobile. Effectiveness of emission reduction in terms of UBHC/CO/NOx/PM. Effect on back pressure & fuel economy, size & cost of the after treatment device, maintenance & serviceability aspect of the after treatment device.

To optimise the car in order to meet the Bharat Stage VI norms, vehicle has to be optimised in areas such as Engine, transmission, fuel injection system, after treatment system, all types of electronic controls, rolling resistance, gross vehicle weight. Car is made to run on the rolling Chassis Dynamometer for 1220 seconds on Indian Driving Cycle & exhaust gas sampling is done by the exhasut gas anlalyser which are highly accurate.

2. EMISSION NORMS

Table -1: BSI V & BS VI legislation limits for M class Diesel vehicles [6]

Category	Emission limits (g/km)				
	CO	HC	NOx	HC	PM
BS IV	0.5	---	0.25	0.3	0.025
BS VI	0.5	---	0.2	0.25	0.005

2.1 Emission measurement method & equipment

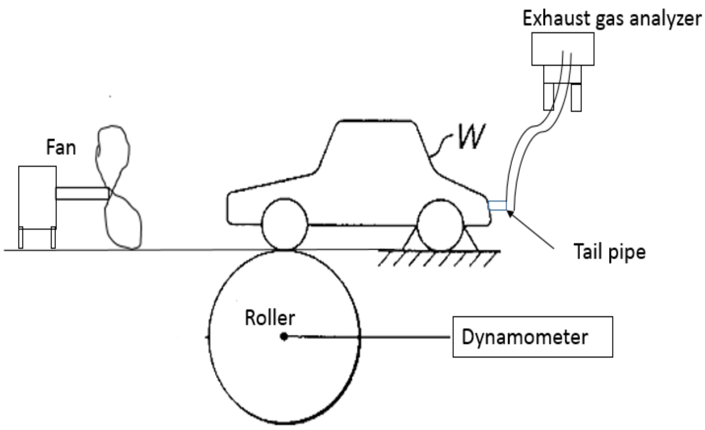

Figure 1: Rolling Chassis Dynamometer & gas analyzer

Car driver will follow the indian driving cycle & vehicle will run into various speeds in different gears as per the cycle.Gas anaslyser will collect the samples of the exhaust gas.Rolling resistance will be applied to the vehicle with the help of the dyanamometer.Fan speed gets changed as per the speed of the vehicle to simulate real life condition.Humidity & temperature are maintained. Following instruments are used to major the pollutants.

Carbon Monoxide (CO) will be measured by Non Dispersive Infra Red analyzer.Carbon Dioxide (CO_2) measurement is done by Non Dispersive Infra Red analyzer. Chemiluminiscent detector measures Nitrogen Oxides (Nox). Flame ionisation detector measures Hydrocarbon

(HC).Particulate Matter (PM) measurement is done by PTFE (Poly tetra fluro Ethylene) filter paper method.

3 CAUSES & CONTROL OF POLLUTANTS

HC gets produced due to too rich Mixture, too lean Mixture operating temperatures below Ignition, poor atomization-Large Fuel Droplet Size, higher Crevice volumes.

HC can be controlled by increasing compression ratio, reduced quench area, reduced dead volumes, optimum injection timing, rapid needle closing – no dribble, no secondary or after injection ,high injection pressure, ring pack optimisation & oil consumption control.

CO formation is mainly due to incomplete combustion of carbon containing fuels, inadequate oxygen availability and low cycle temperature.

CO can be controlled by Combustion chamber optimisation, high air-fuel ratio – high excess air, turbocharging, multi-valve configuration, swirl optimisation, controlled wall wetting , optimum injection duration, reduce late burning Higher compression ratio, higher cylinder temperatures.

Nox formation is mainly due to high temperature in combustion chamber i.e more than 1300 ° C, excess air. Nitrogen Oxides (NOx) is a representation of mono Nitrogen oxides & resultants are different Nitrogen Oxides.

$N2 + O \rightarrow NO + N$

$N + O2 \rightarrow NO + O$

$N + OH \rightarrow NO + H$

NOx control is done by retardation of injection start, low swirl , Catalytic reduction , Water/Steam injection, Lowering excess air operation , Staged combustion, Lowering pre-heat air temperature, Exhaust gas recirculation (EGR),Selective Catalytic Reduction (SCR),Selective Non Catalytic Reduction (SNCR),Lean NOx trap(LNT).

All components, excluding water, collected on a prescribed filter after dilution with air at a temperature below 51.7 deg C, are called Particulate Matter (PM). Most have a fine particle size distribution (<2.5µm) however ultra-fine (<0.1 µm) particles are also present. Most important constituents are larger molecular Polycyclic Aromatic Hydrocarbons (PAHs) and nitro-PAH compounds. Inadequate air – high soot, poor combustion. Sulphur in fuel Aromatics are causes of PM formation.

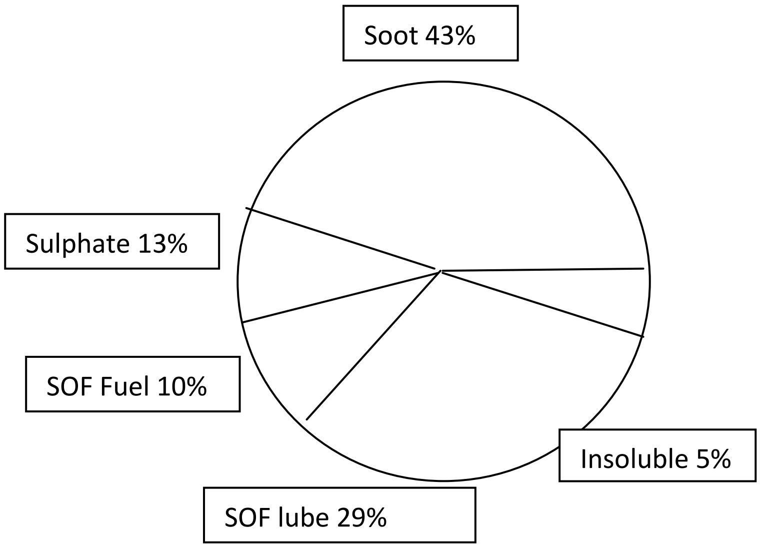

Figure -2: Contents of PM

PM is controlled by soot control, high injection pressures, combustion improvement and swirl optimization & Sulphur control in fuel.

Soot is a mass of impure carbon particles resulting from the incomplete combustion of hydrocarbons i.e Carbon & Ash, Soot is formed due to high Temperature, inadequate air – high soot, lack of Oxygen. Soot is controlled by reduced wall wetting, good atomization, enhanced mixing by re-entrant bowl shape & distribution of fuel in combustion chamber, Intake swirl optimization further brings down the soot percentage.

Tradeoff between HC, NOx & PM is very important while meeting emission norms for any car..

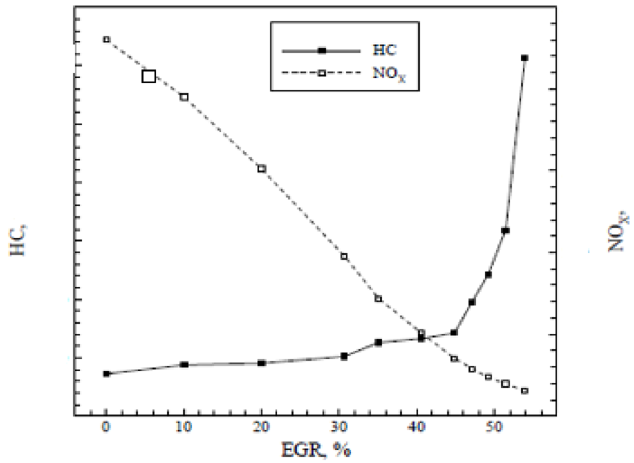

Figure -3 : HC/NOx Vs EGR rate [7]

The amount of EGR mixing puts limits on engine power. More than 30% mixing of EGR is not advisable as it brings down maximum engine power. Figure 2 shows that with increase in percentage of EGR, HC emissions goes up & NOx levels comes down

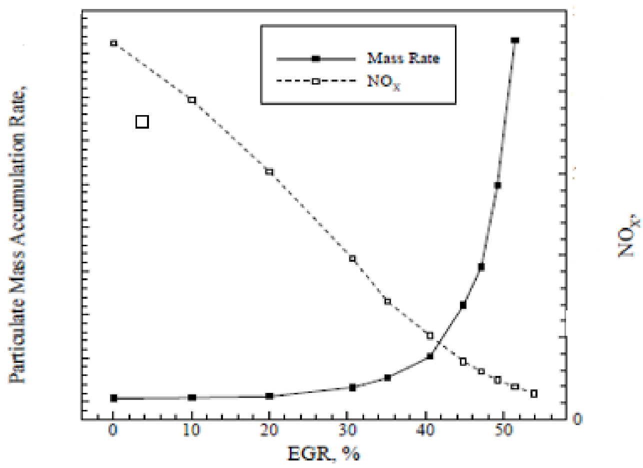

Figure -4 : PM/NOx Vs EGR rate [7]

Figure 4 shows general tradeoff between NOx & PM. PM trap is often used to bring down the Particulate Matter values. Fuel injection timing needs to be retarded to bring down the peak combustion temperatures. It adversely affects the maximum power & specific fuel consumption (SFC). Higher swirl ratio is recommended for EGR engine for proper mixing of air & exhaust gas. Piston bowl design can be modified for proper mixing & combustion. Diesel Oxycat is required to bring down HC & CO values. Precious metals like Platinum/Palladium/Rhodium works as catalyst in Oxycat & performs the oxidation. With increase in % of EGR, PM emissions goes up. & hence tradeoff is required.

4. COMBUSTION PROCESS & EMISSION CONTROL

Combustion process can be divided into three categories which ultimately affects the exhaust emission of the car.
Pre-combustion parameters are fuel quality, turbocharging & intercooling, swirl & ambient conditions to a limited extent.

During combustion piston bowl, crown & skirt design piston ring design, fuel injection timing, fuel pressure, fuel injection rate, injector design-Spray pattern , hole diameters, number of holes, angle of holes, combustion temperature control, cam timing, number of valves per cylinder are the critical factors to meet Bharat Stage VI norms & long durability targets.

On engine emission control techniques are Combustion optimization, Cooled Exhaust Gas Recirculation (EGR), Variable Geometry Turbocharging, High Pressure Common Rail Fuel System, very precise Electronic Controls, Split Injection/injection rate control, HCCI (Homogeneous charge compression ignition)

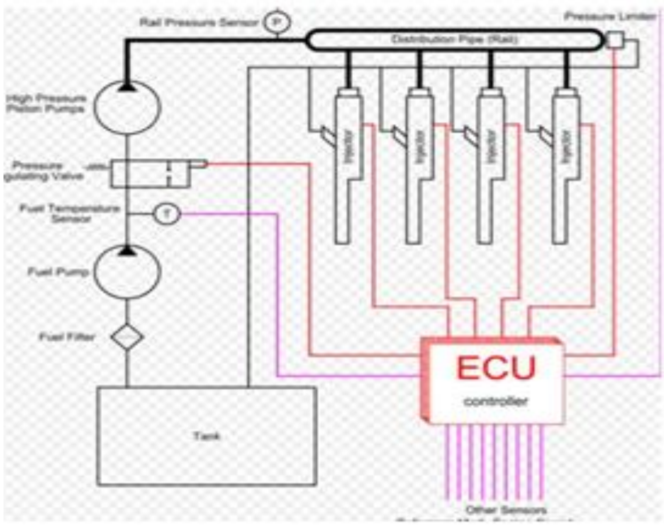

Figure 5: Common rail fuel injection & electronic controls [8]

In common rail fuel system, fuel is extracted from tank & after filtration, fuel is pressured to very high pressures such as 1400-1800 bars & pressure is maintained with the help of common rail. Fuel is injected into combustion chamber as per the command from electronic control unit (ECU).

Use of crank speed sensor, rail pressure sensor, accelerator pedal sensor, coolant temperature sensor, oil pressure sensor, delta pressure sensor ,temperature & manifold pressure sensor, exhaust manifold pressure sensor, water in fuel sensor, metering valve are typical name of electronic controls used to control the emissions.

High level accuracy in terms of fuel injection, data monitoring & control, quick close loop feedback system is possible with the help of electronic controls. Transmission control unit is also required for better synchronization between engine, transmission & vehicle.

5. EMISSION CONTROL BY EGR & AFTER TREATMENT

Some portion of exhaust gas is recirculated from exhaust manifold to EGR cooler.The percentage of the EGR is being decided based on the calibration strategy (for part load & full load operating conditions) to meet the required emission norms.

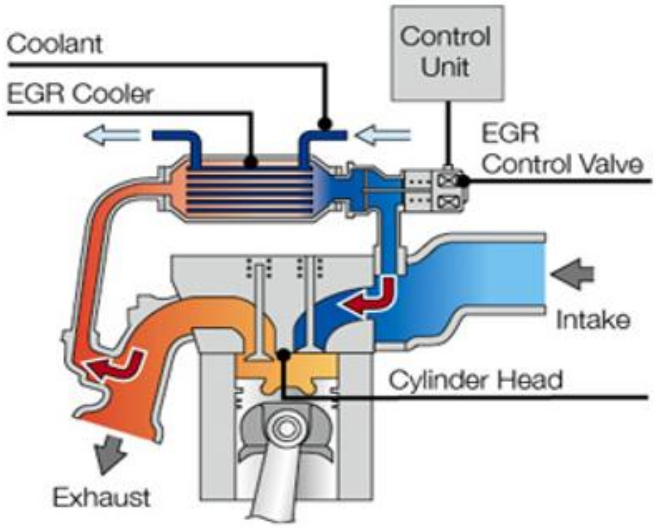

Figure 6: Working of EGR system [8]

The EGR cooler brings down the temperature of exhaust gas by exchanging the heat with engine coolant.The EGR control valve regulates the ammount of exhaust gas going to engine based on the calibration strategy.Exhaust gas is mixed with intake air before going to combustion chamber.Mixing of exhaust gas limits the fresh oxygen in the charge & hence reduces the combustion temperature.Reduced combustion chamber brings down NOx levels.

To accomodate EGR cooler & EGR valve, exhaust manifold requires modification. Addition of air & intake mixing device,temparature & pressure sensor,EGR mass flow sensor ,coolant in & out pipe lines for EGR cooler needs to be done.Engine cooling system needs to be modified.Radiator on vehicle needs to be redesigned to serve more heat rejection as 20~30% more coolant gets cirulated through EGR cooler w.r.t non EGR engine. Cylinder head & block requires modification to meet additional coolant flow requirements. Piston design change, addition of Particulate Matter trap, Diesel Oxycat may require in addition to EGR system to meet overall emission requirements of HC, NOx, CO & PM for BSVI norms.

Selective Catalytic Reduction (SCR) is one more popular technique to bring down the emissions levels of NOx. SCR can be used in addition with EGR. NOx limits of BS VI emission norms can be met if these two techniques used at a time on car.

Diesel Oxidation Catalyst, SCR catalyst, Urea injection system, Urea tank & Dosing unit addition, plumbing for Urea injection, mixer arrangement, inlet & outlet NOx sensor gets added in exhaust system if SCR path is followed.

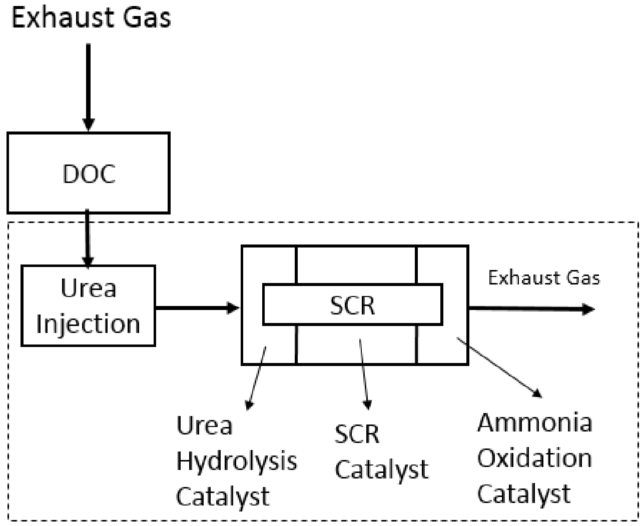

Figure 7: Working of SCR system

Reaction shown helps for complete oxidation of the exhaust gases & creates $C0_2$, H_20 & N_2 which helps to meet Bharat Stage VI emission norms.

Diesel Oxycat (DOC)	2NO + O2 → 2NO2
	2CO + O2 → 2CO2
	4HC + 3O2 → 2CO2 + 2H20
Urea Hydrolysis Catalyst	(NH2)2CO + H2O → CO2 + 2NH3
SCR Catalyst	4N0 + 4NH3 + O2 → 4N2 + 6H20
	NO + NO2 + 2NH3 → 2N2 + 3H20
	2NO2 + 4NH3 + O2 → 3N2 + 6H2O
Ammonia Oxidation Catalyst	4NH3 + 3O2 → 2N2 + 6H20

6. ON BOARD DIGNOSTICS (OBD II)

Meeting BS VI Emissions norms will not be a only tasks to manufactures but they have to comply Indian OBDII norms. OBDII helps to detect the malfunctioning in exaust emissions of car.In case of malfunctioning, it generates fault code with the help of Electronic Control Unit (ECU).Fault code is displayed on the Dashboard to the driver in terms of Malfunction Indication Lamp (MIL).Driver is supposed to go the dealer to resolve the emission fault code.

Otherwise, corrective actions like car shut down or de rate in power will take place to avoid the non compliance to the emissions after certain hours of running after the generation of fault code.

Fault code will also help to technician to fix the problem in the car in less time.

7. METHODOLOGY

Following is the generic method to meet BS VI emissions

Existing engine specifications / emission norm meeting capability/norms

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Packaging space for after treatment packaging & engine packaging

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Legislation requirement of IOBD II & Performance requirements like fuel economy

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Finalization of emission control strategy & subsequent design/calibration changes supported by Analysis

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Validation & BS- VI emission trials on prototype

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Type approval by government certified agency

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Start of production (SOP)

8. CONCLUSIONS

Use & combination of on engine & after treatment emission control techniques decides the 'Strategy'

Every vehicle manufacture (OEM) decides its own strategy depends up on many parmameters such as cost, packaging space, other performance parameters like fuel economy, transient performance, acceleration, gradeability

Reliability, consistency in meeting emission norms on mass production vehicles, time lines makes the emission compliance more challenging

Most of the car manufactures are geared up & working on product modifications to meet for BSVI norms compliance

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