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Diesel Vehicle Emission Controltechniques for Upcoming Indian Emission Legislation

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ABSTARCT: *Due to stringentemissionregulationsintroduced by the Indian government, emission control of diesel vehicle has become mandatory for every automobile vehicle manufacturer. Diesel powered vehicles are preferred due to higher thermal efficiency and lower fuel consumption. Diesel engine inherently emits more oxides of Nitrogen and particulate matters. It is not always possible to control in-cylinder NOx and Particulate below emission legislation limit. Hence exhaust after-treatment system plays vital role in controlling vehicle tailpipe emissions. In this paper, overview of NOx and PM control technologies were discussed.The two technologies effective for controlling NOx emission from diesel engine are EGR(Exhaust Gas Recirculation) and SCR(Selective Catalyst Reduction).First method became popular due to easy of adaptation and no additional infrastructure requirement. The use of high pressure EGR cooler helps NOx reduction up to about 60%. Diesel particulate filters (DPFs) have become most important due to their ability to trap 98% particulates but they require special arrangement to burn the trapped soot.*

Keywords:- *Diesel Engines, EGR, coated DPF, Emissions, Soot, NOx, Catalytic oxidation, SCR.*

I. INTRODUCTION

Currently India follows Bharat stage 4 (BS4) emission norms in major cities and BS3 norms in rest of India. There is a proposal to introduce Bharat stage 5 (BS5) norms tentatively from 2014-15 onwards.

Table 1 shows the comparison of BS4 and BS5 emission legislation for vehicle category N1 class 3 of vehicle with vehicle gross vehicle weight up to 3.5 ton.

Table 1: Comparison of BS4 and BS5 emission norms for N1 class 3 of vehicle

Emission Norms	CO (g/km)	HC+NOx (g/km)	NOx (g/km)	PM (g/km)	PM (Nb/km)
BS4	0.74	0.46	0.39	0.06	NIL
BS5	0.74	0.36	0.28	0.0045	6 x 10^*11*
% less	No change	22	28	93	New method

Significant reduction of NOx (28%) and PM (93%) is required for BS5 as compared to BS4 emission norms. In addition to this, a new concept of particulate number count measurement is introduced. Due to requirement of simultaneous reduction of NOx and particulate matter,it calls for major modifications in engine design like its EGR (exhaust gas recirculation system) and exhaust after-treatment system packaging close to engine.

There were several methods designed by engineers to reduce the soot & NOx production as well as emission in diesel engines. Most successful of them include the introduction of conventional catalytic oxidizer, DPF (Diesel Particulate Filter), EGR (Exhaust Gas Recirculation), Closed coupled catalytic soot filters, HCCI (Homogeneous Charge Compression Ignition), SCR PM Metalit®, etc.

The DPF is the most successful of them all for controlling soot, which has almost 98% efficiency. It traps the soot particles in the emission.The existing DPF technology has also been improved to cDPF(coated Diesel Particulate Filter), which uses catalyst for breaking down the soot particles at low temperatures. One of the concepts is the homogenous charge compression ignition (HCCI) which is based on the simultaneous ignition of a highly diluted premixed air-fuel mixture throughout the combustion chamber. This significantly reduced NOx-soot trade-off but increased the HC and CO emissions. It reduces the engine efficiency slightly but has significant reduction in soot & NOx emission. Close to HCCI combustion conditions are obtained by early fuel injection. It corresponds to combustion in an area with an equivalence ratio leaner than 1 and a temperature lower than 2200 K.The only concern in HCCI combustion is the controlling of cylinder pressure due to the changes in the ambient condition of air.

Partial Premixed Charge Compression Ignition (PCCI) is also a possibility for low emission combustion. In this method, fuel is injected early in the compression stroke which forms a premixed lean mixture over a long mixing period. This results in low NOx & soot emissions, but increase in the amount of fuel injected beyond a certain level results in knocking.The engines using multiple-pulse injection have significant reduction in soot & NOx production than conventional single-pulse injections. With high pressure, multiple injections (two or more injection pulses per power cycle), the soot-NOx trade-off curves of a diesel engine is shifted closer to the origin.

In the new EGR system, high pressure EGR cooler is used with the provision of cooling bypass valve for engine. In the exhaust after-treatment system, the normal diesel oxidation catalyst (DOC) was replaced with DOC+ cDPF (coated diesel particulate filter). Diesel particulate filters are capable to restrict 98% soot particles from the exhaust gas. This technology is sufficient to meet proposed BS5 emission norms in India.

II. DIESEL PARTICULATE FILTER (DPF)

Introduced in 1980, DPF was commercially standardized to fit on a passenger car in 2000 by PSA Peugeot Citroën. DPF traps the particulate matter and by thermal regeneration converts it into water and CO_2. Modern DPFs exhibit very high filtration efficiencies, but they need to be regenerated periodically to prevent their clogging. As typical diesel exhaust conditions are not hot enough to initiate and maintain particulate (soot) oxidation, active (engine) means are employed to raise the exhaust gas temperature up to the point that particulate oxidation can be self-sustained in the filter at fast enough rates (>650° C). To achieve the oxidation of soot particles at lower temperatures (250° – 550° C), a number of direct and indirect catalytic measures can be employed ranging from fuel additives, generation of reactive species, catalytic combustion of post-injected fuel and filter coatings promoting soot oxidation. So modern trends in passenger car DPF are now focusing on the complete elimination of DPF servicing i.e. ash removal. Requirements for robust on-board monitoring and control for these modern technologies generate the need for efficient algorithms which are implementable in computationally limited engine control units (ECUs) and which will provide accurate knowledge of the state of the emission control system during vehicle operation, and which can be used in control loops for management of the integrated powertrain-emission control system.

1. Design

The most common design of diesel particulate filter is the wall-flow monolith. It is an extruded, usually cylindrical ceramic structure made of the ceramics of higher and more precisely controlled porosity with many small, parallel channels running in the axial direction. The filter media is ultimately packaged into steel container which is installed in the exhaust system of the vehicle. The DPF can be packaged as a stand-alone unit resembling a catalytic converter but usually of bigger size.

Diesel Particulate Filter Materials and Configurations

Ceramic

Oxide ceramics

• Cordierite	• Extruded honeycomb wall-flow monoliths
• Mullite	• Foam monolithic blocks and plates
• Aluminium titanate (tialite)	

Non-oxide ceramics

• Recrystallized silicon carbide	• Extruded honeycomb wall-flow monoliths
• Silicon-bonded silicon carbide	• Fibrous felts
• Silicon nitride	

Metallic

• Sintered metal powder	• Pleated wall-flow sheets
• Metal fiber	• Fibrous felt elements and cartridges
• Metal foam	• Sheets and cartridges

Fig. 1: Cutout of Catalyzed DPF for Urban Bus *(Courtesy of Nett Technologies)*

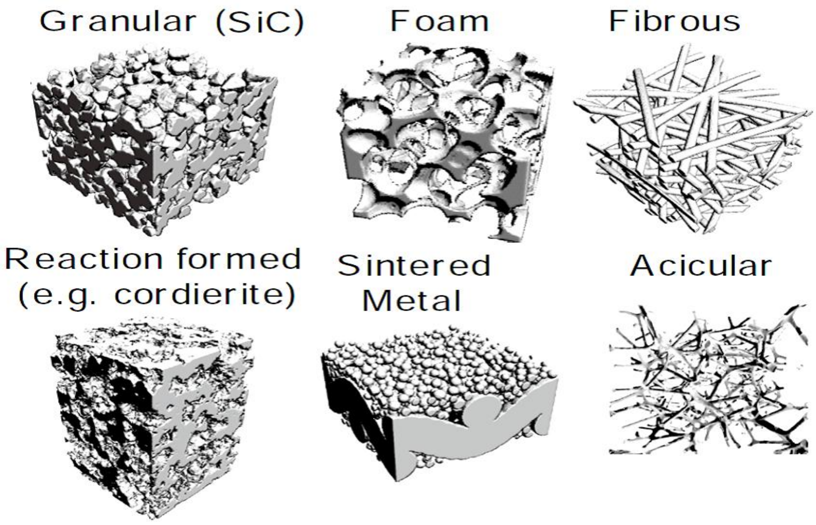
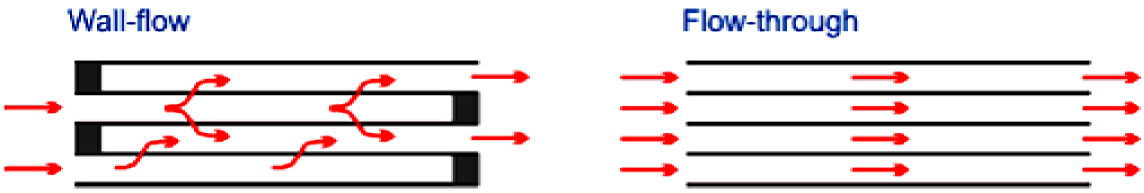


Fig. 2: Computer reconstruction of various types of porous filters

2. Filtration Mechanism

The design of diesel filter monoliths has beenderived from automotive, "flow-through" catalyst substrates. There are, however, two importantdifferences between these structures: (1) the wall-flow monoliths are made of ceramics of higherand more precisely controlled porosity
(2) adjacent channels in the wall-flow filters arealternatively plugged at each end, thus forcing the gas to flow through the porous walls which actas a filter medium.
The flow pattern difference between the flow-through and the wall-flowsubstrate is illustrated in Figure.



Filters, depending on the type of the barrier, may be divided into

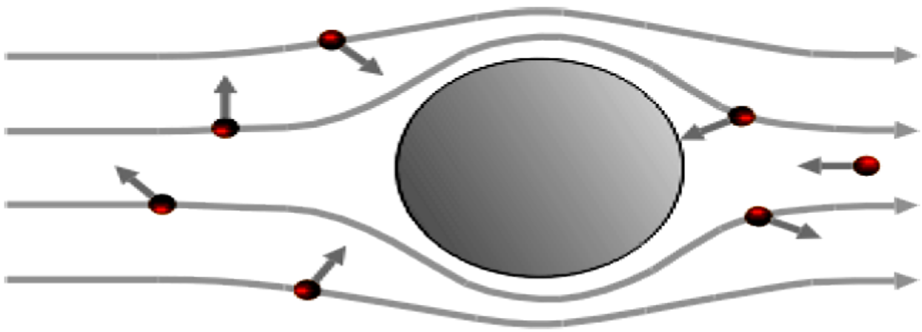
(1) Deep-bed filters

(2) Surface-type filters.

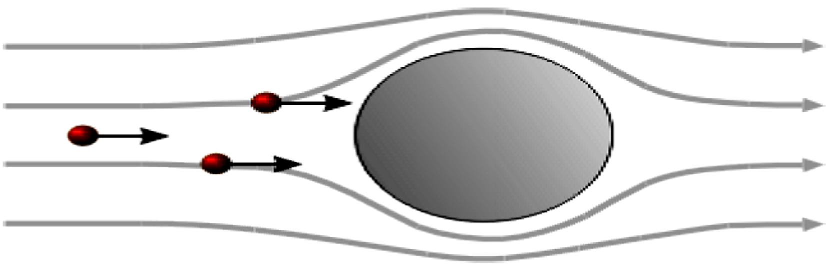
In the deep-bed filters, the mean pore size of filter media is bigger than the mean diameter of collected particles. The particles are deposited on the media through a combination of depth filtration mechanisms which are driven by various force fields. In the surface-type filters the pore diameter is less than the particle diameter. The particles are deposited on the media through sieving.

The main deposition mechanisms in DPF are Brownian diffusion, Depth filtration and direct interception, while thermophoresis can be important in the presence of temperature gradients. The depth filtration relies on three mechanisms of aerosol deposition [Perry 1984]:

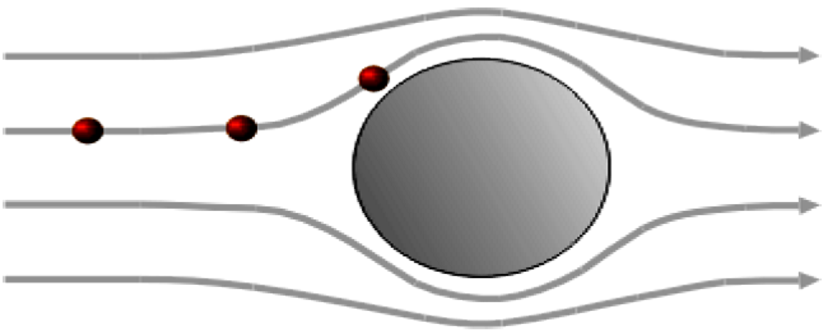
- Diffusional deposition



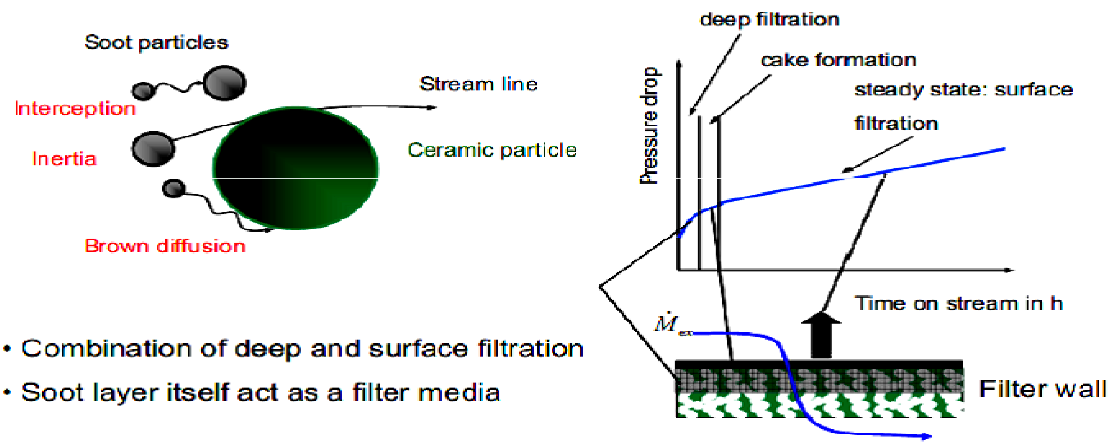
- Inertial deposition



- Flow-line interception.



There is also a mechanism developed which combines deep bed and surface filtration mechanisms. In this mechanism, soot layer itself acts as a filter media. It has advantages of both.



a. THERMAL REGENERATION

DPF is designed to hold only a certain quantity of soot. If the filter becomes overloaded, the particulates create an obstruction to the gas flow, which results in increased pressure drop and may lead to clogging of the filter. Therefore, the filter system has to provide reliable regeneration mechanisms to ensure problem free operation. The soot holding capacity in most filter systems is sufficient only a few of days of engine operation. The temperature of the exhaust gases plays an important role in the filter regeneration. Generally soot gets converted to water & CO_2 at temperatures > 650° C. But exhaust gases do not have such a high temperature. To achieve regeneration, there are following ways -

Active Regeneration Measures

External means

- Fuel burners (full and partial flow)
- Electric heating (upstream or embedded in the filter)
- Microwave heating
- Injection of combustibles (e.g. fuel) in the exhaust
- Injection of catalytic and/or reactive species in the exhaust (e.g. H_2O_2)
- Generation of reactive species (e.g. non-thermal plasma)
- Electrochemical filter reactor

Engine means

- Exhaust gas recirculation
- Post-injection of fuel
- Decrease of boost pressure
- Intercooler bypass
- Injection timing retard

Passive Regeneration Measures

- Catalytic means
- Fuel-borne catalysts
- Catalytic filter coatings
- Reactive species generation

To carry out the thermal regeneration process, mainly passive methods are used. Some of the popular catalysts used are platinum, platinum-palladium alloy, etc. This new development in CDPF (Catalytic Diesel Particulate Filter) aims at achieving:
(i) some soot oxidation activity under moderate exhaust temperature to prolong as much as possible the intervals between fixed regenerations, exploiting direct (i.e. through oxygen transfer) as well as indirect (through NO_2 generation) soot oxidation;
(ii) reduced soot ignition temperatures compared to non-catalyzed filters to allow for energy savings during regeneration;
(iii) tolerance to ash accumulation.

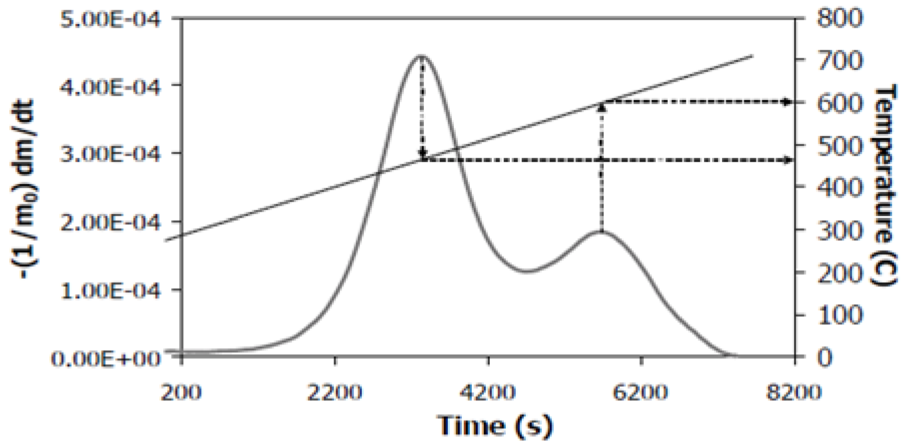


Fig. 3: Soot oxidation rate on catalyzed filter

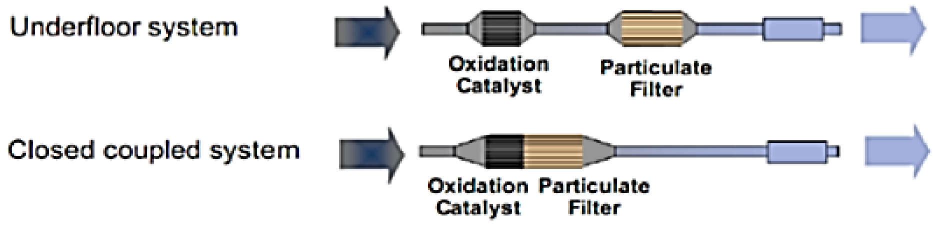


Fig. 4: Position of DPF system in a vehicle

III. EXHAUST GAS RECIRCULATION

It is used in diesel engines to reduce the NOx content of emission. It works by recirculating a portion of exhaust gas back to engine cylinders, which replaces some of excess oxygen in the pre-combustion mixture. Because NOx forms when a mixture of nitrogen & oxygen is subjected to high temperature, lower combustion chamber temperatures caused by EGR reduces the amount of NOx generated. A sophisticated version of EGR was introduced by Chrysler in 1973.

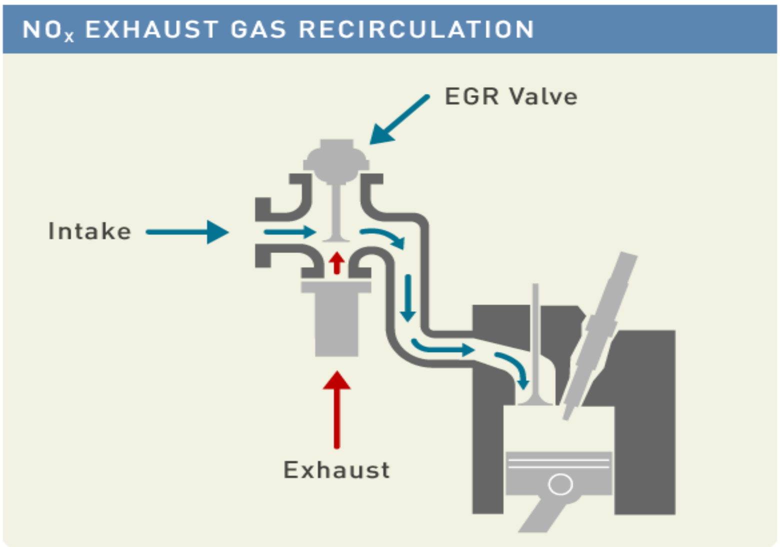


Fig. 5: Exhaust Gas Recirculation Schematic

1. Modifications in conventional EGRto modern High pressure cooled EGR

The effect of injection timing on low temperature combustion process and emissions when investigated via three dimensional computational fluid dynamics (CFD) procedures in a DI diesel engine using high EGR rates, the results showed that when EGR was increased from low levels to levels corresponding to reduced temperature combustion, soot emission after first increasing, was decreased beyond 40% EGR and got the lowest value at 58% EGR rate. Soot and NOx emissions were simultaneously decreased at advanced injection timing before 20.5 ºCA BTDC in conjunction with 58% cooled EGR rate in comparison to baseline case.

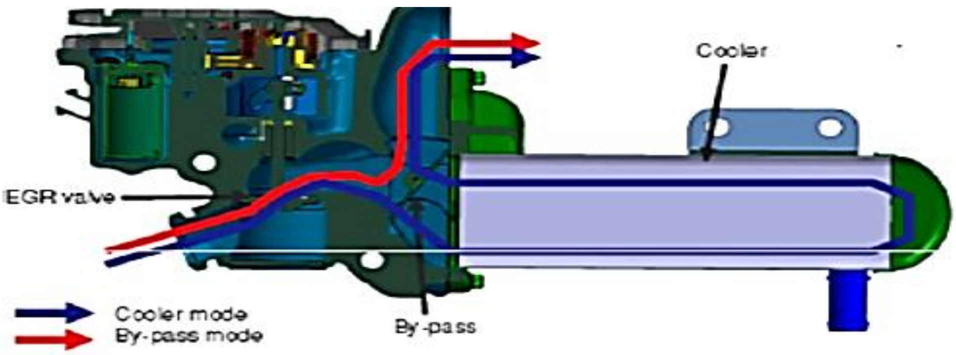


Fig. 6: Construction of Exhaust Gas Recirculation System

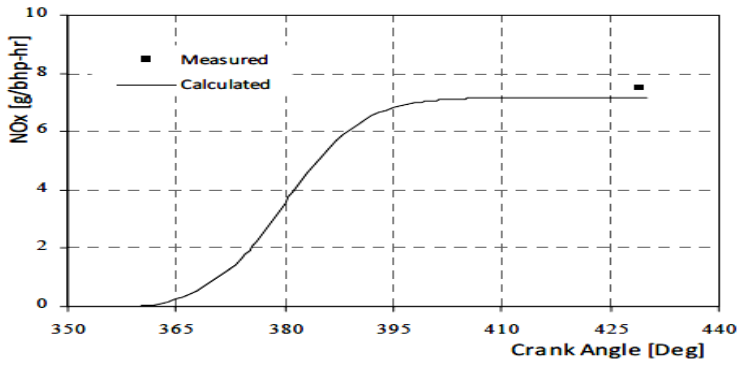
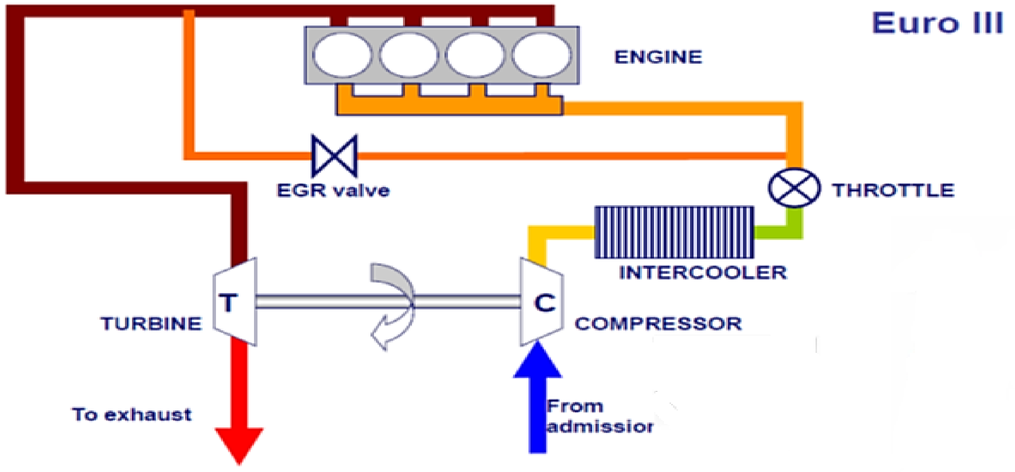


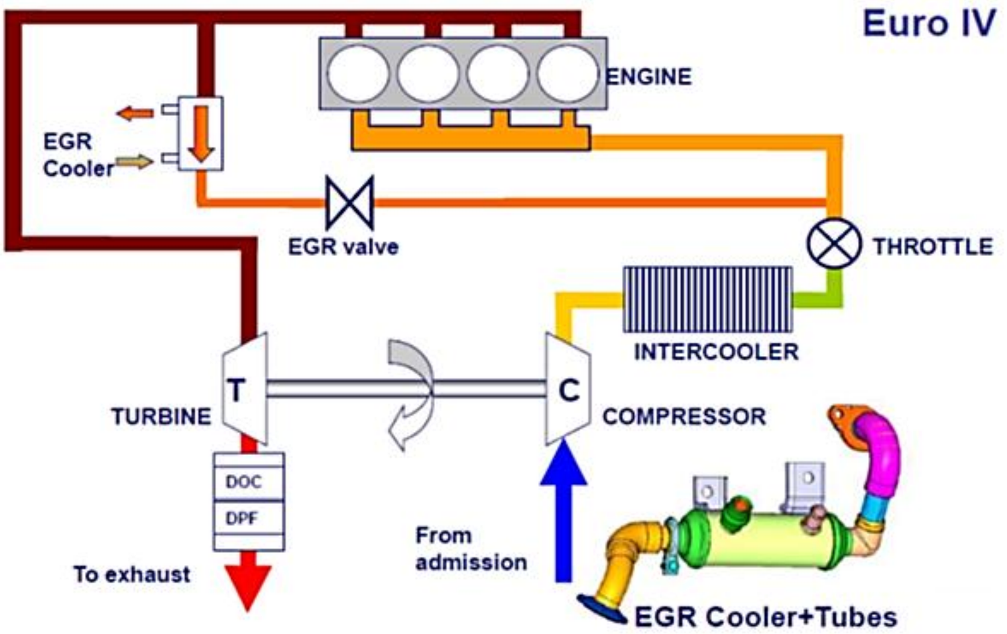
Fig. 7: Comparison of calculated and measured NO*x* emission

Some of the EGRs recommended by Euro Norms are as shown in fig.

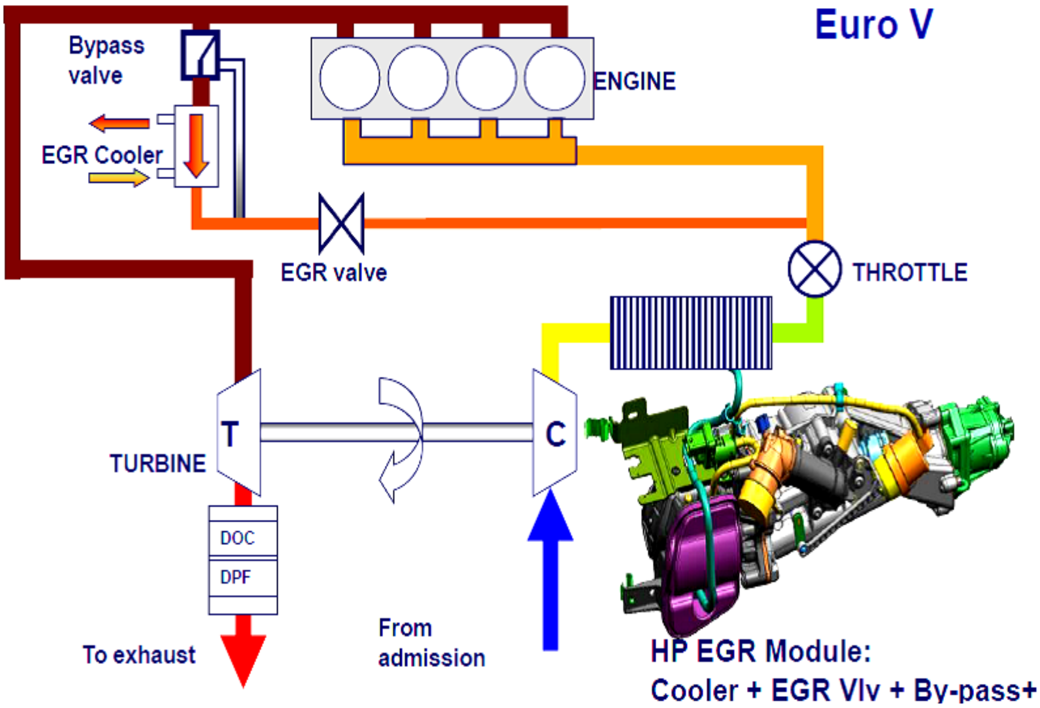
1. Euro III



2. Euro IV



3. Euro V



These Euro Norms were modified for Indian vehicles and named as Bharat Stage (BS).

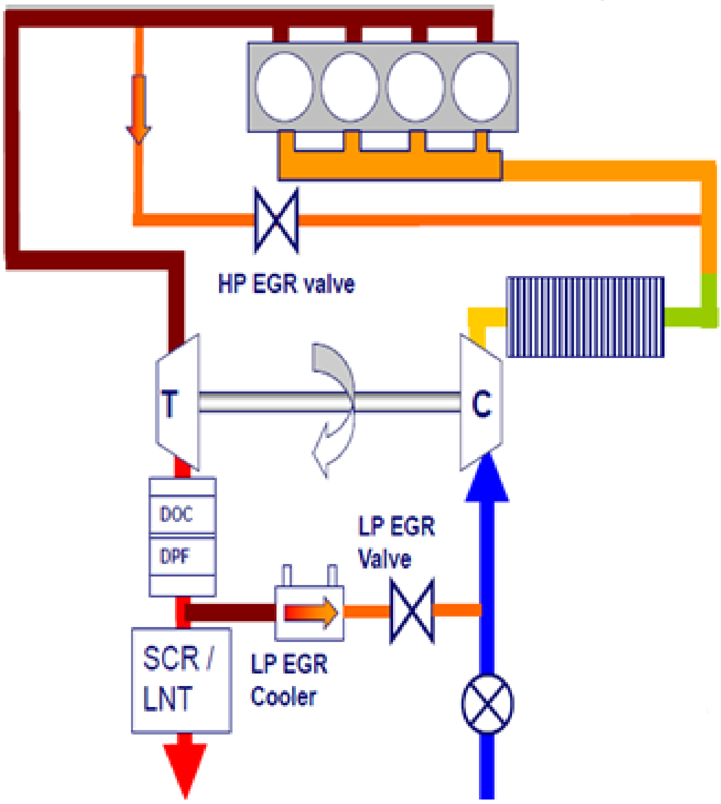
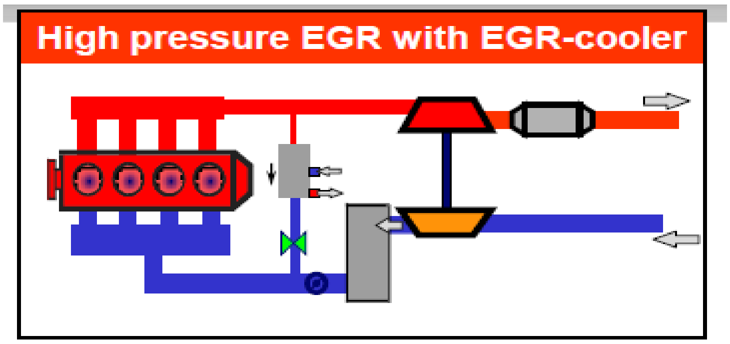


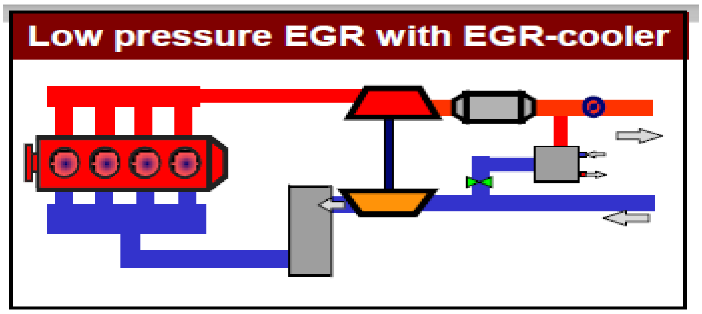
Fig. 8: EGR System

EGRs further have two types

- High pressure EGR



- Low pressure EGR



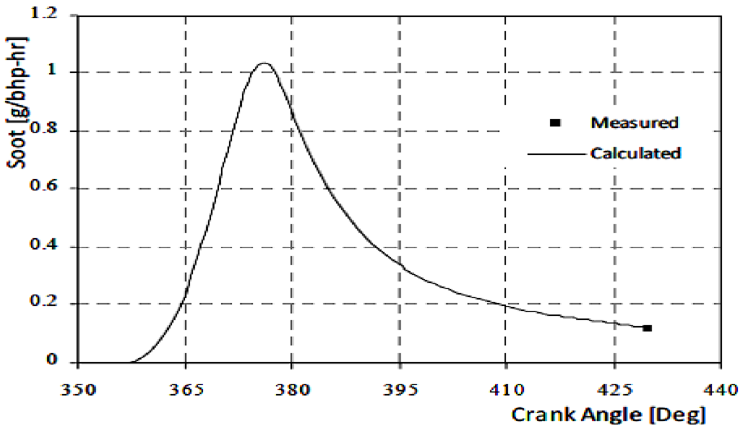


Fig. 9: Comparison of calculated and measured soot emission

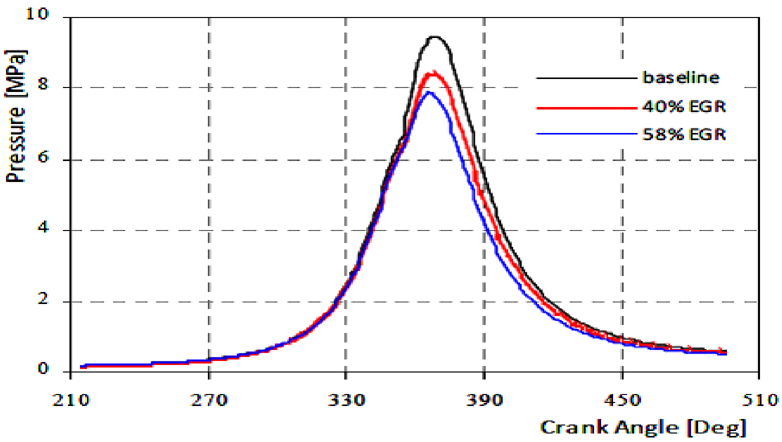


Fig. 10: In-cylinder pressure comparison between different high EGR rate cases and baseline case

It can be seen in Fig. 10 that the in-cylinder peak pressure is reduced with increase of EGR with earlier injection. This is because the use of high EGR ratio reduces further the availability of oxygen. This lack of oxygen in the cylinder charge reduces the combustion rate leading to retarded combustion and thus to lower peak cylinder pressure values thereby reducing NOx production.

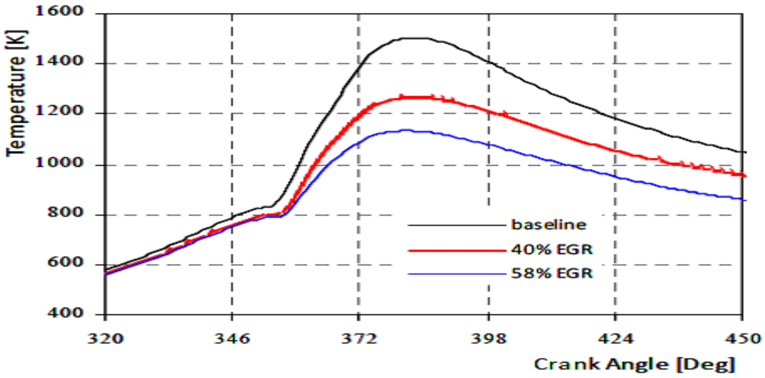


Fig. 11: In-cylinder temperature comparison between different EGR rate cases and baseline case

Operating at 40% and 58% of cooled EGR rate, the maximum value of mean in-cylinder temperature is reduced down to 1269 K and 1132 K, respectively in comparison to 1504 K at the baseline case. This is due to the dilution effect and the thermal effect in conjunction with cooled EGR. The introduction of burnt gases into the cylinder replaces a part of the inlet air and causes a reduction of the oxygen concentration. This effect slows down the heat release rate if large amounts of EGR is used and leads to the reduction in mean in-cylinder temperature. Moreover, during compression and combustion, the inert burnt gases must be heated up together with the rest of the in-cylinder charge. Because the total heat capacity of the charge is higher with burnt gases due to the higher specific heat capacity values of carbon dioxide (CO_2) and water vapor (H_2O), lower end of compression and combustion temperatures are achieved, and heat release rates as well as maximum pressure and temperature are reduced as seen in Fig. 11.

From Fig. 12, firstly, the soot is increased with increasing EGR rate and decreasing air-fuel ratio accompanied with intake charge dilution with exhaust gas and reduction of in-cylinder oxygen concentration. However, when the EGR rate exceeds a critical point, the soot starts to sharply decrease. Therefore, it was shown that the soot emission decreases even in the richer condition. Namely, when EGR rate is increased beyond 40 % EGR, soot emission reduced to lowest value at 58% EGR rate. As a result, for a fixed injection timing and injection pressure and for a given amount of fuel, it can be said that the increase in cooling EGR rate to 58% allows us to achieve the soot emission level close to the baseline case soot engine-out level but it can’t be eliminated completely.

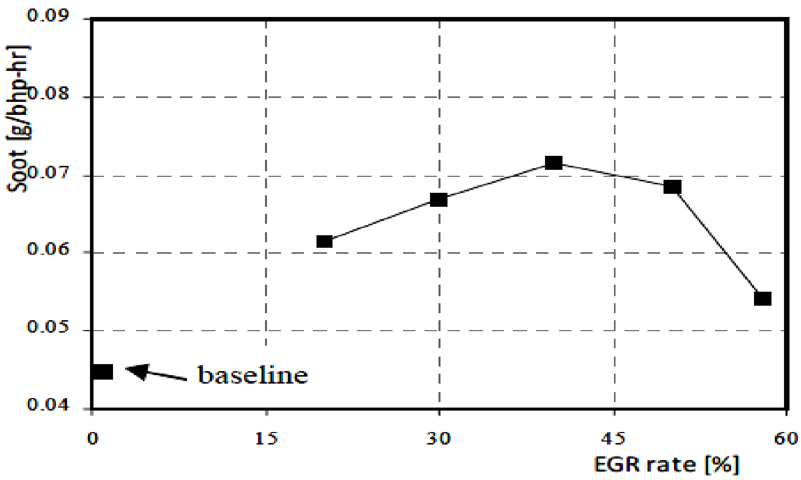


Fig. 12: Effect of EGR rate on soot emission at EVO for SOI at 351.5 ºCA as compared to the baseline case.

From Fig. 13, when the EGR level is increased beyond 40 % EGR, NOx emission reduced to nearly zero at 58% EGR rate.

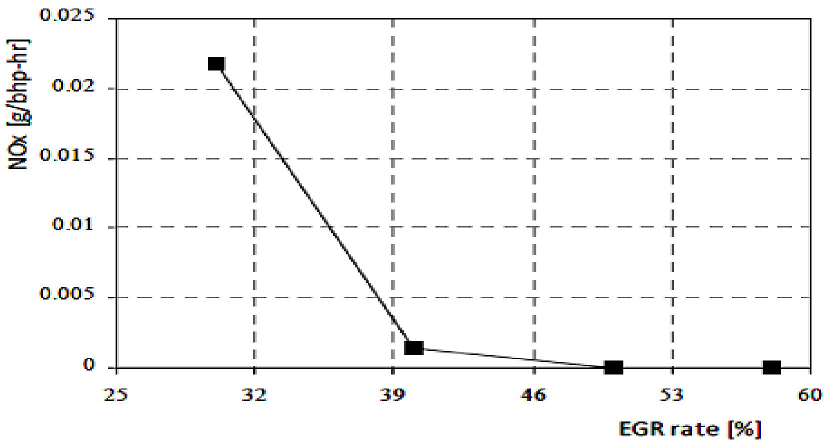


Fig. 13: Effect of EGR rate on NOx emission at EVO for SOI at 351.5 ºCA

2. Drawbacks of EGR

- It reduces temperature of combustion chamber, resulting in less efficient combustion, compromising economy & power.
- EGR also increases the production of soot, which is however masked by the simultaneous introduction of DPF.
- EGR systems can also add abrasive contaminants & increase engine oil acidity, which can reduce engine longevity.

IV. CONCLUSIONS

- ❖ DPF is successfully employed to reduce soot content of the emission. CDPF has efficiency almost 98%, so it is helpful in following the strict emission regulations.
- ❖ EGR, even though having many drawbacks, when coupled with DPF, can be effectively used in vehicles to control NOx production.
- ❖ High cooled EGR rates help in simultaneous reduction of soot as well as NOx, when 40 to 58% EGR is used sacrificing the engine economy a little.

REFERENCES

[1]. Athanasios G. Konstandopoulos, Eleni Papaioannou “Update on The Science and Technology of Diesel Particulate Filters” KONA Powder and Particle Journal No.26 (2008).

[2]. S. Juttu, S. S. Thipse, N. V. Marathe, M. K. Gajendra Babu “Homogeneous Charge Compression Ignition (HCCI): A New Concept for Near Zero NOx and Particulate Matter (PM) from Diesel Engine Combustion” SAE Paper No. 2007-26-020.

[3]. Zhiyu Han, Ali Uludogan, Gregory J. Hampson, Rolf D. Reitz “Mechanism of Soot and NOx Emission Reduction Using Multiple-Injection in a Diesel Engine” SAE Paper No. 960633.

[4]. Sh. Khalilarya, S. Jafarmadar, H. Khatamnezhad, Gh. Javadirad, M. Pourfallah “Simultaneously Reduction of NOx and Soot Emissions in a DI Heavy Duty diesel Engine Operating at High Cooled EGR Rates” International Journal of Aerospace and Mechanical Engineering 6:1 2012.

[5]. W. Addy Majewski “Diesel Particulate Filters” DieselNet Technology Guide 2001.