

A Review of BS-VI Standards and Particulate Matter Emission from Diesel Engines

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ABSTRACT

The new BS-VI standards will reduce NO_x, HC, and PM levels in diesel and gasoline engines. Diesel engines will have fewer NO_x, HC + NO_x, and PM levels. The emissions from the engines will be measured in a different way than in the previous approach; particle counting equipment will be used to count the particulate materials that come out of the engines' exhaust. Particulate matter is classified into three types: soot, insoluble portions, and soluble parts. A Diesel Particulate Filter (DPF) is used to reduce particulate matter emissions from diesel engines. In this review article, we will look at the makeup of diesel exhaust gases, different forms of particulate matter, the need for and evolution of BS-VI engine standards, techniques for measuring engine emissions, and the Diesel Particulate Filter. This review study also discusses the future scope of real-time driving emissions.

KEYWORDS: *Bharat Stage-VI Norms, Particulate Matter, Diesel Particulate Filter, Real time Driving Emissions*

INTRODUCTION

In engines, combustion occurs along with numerous chemical processes, which are then transferred to the tail pipe and exposed to the atmosphere via the exhaust.

[1]

These are called tail pipe emissions which can be classified into two major categories:

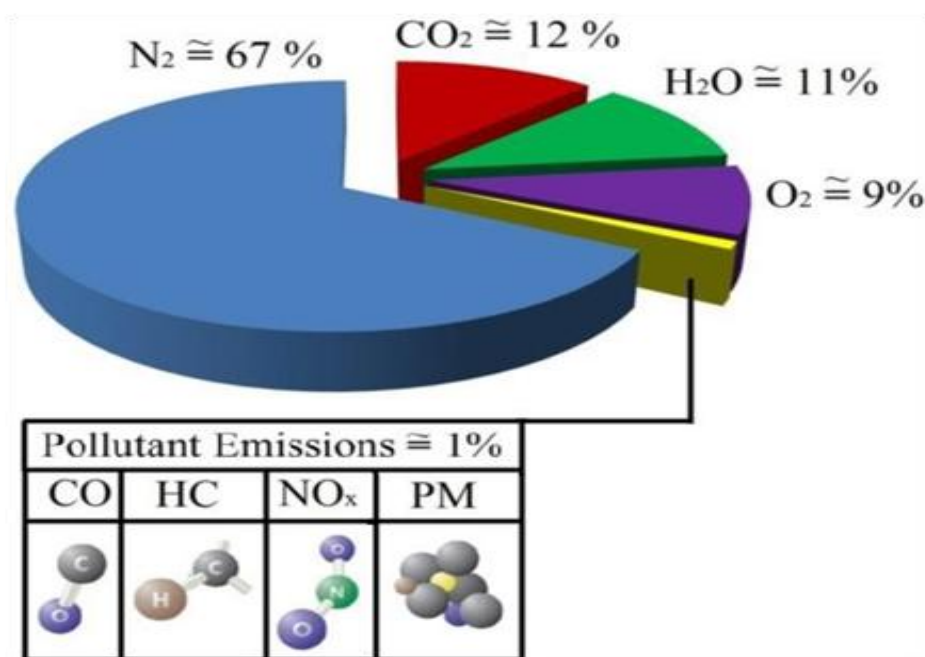
1. Gases
2. Particles.

Gas emissions are a mixture of several gases such as NO_x, SO₂, CO₂, and others. Particulate matter refers to the particles that escape from the exhaust and is further categorised as soot, insoluble portion, and soluble part. Soot is created by unburned fuel, hydrocarbons, and other accessible molecules, which may condense on or be absorbed by soot depending on the environment.

Vehicle emissions are a key factor in India's deteriorating air quality. People's health is suffering as a result of gas and particulate matter (PM) emissions. To that end, the ARAI (Automotive Research Association of India) has enacted regulations that would reduce the quantity of dangerous pollutants flowing from the

exhaust to a minimal minimum. ARAI has been instrumental in ensuring safe, less polluting, and more efficient automobiles. [1].

ARAI provides technical knowledge in R&D, testing, certification, homologation, and automotive regulatory development. It was initially announced as 2000 standards, but was subsequently renamed Bharat Stage 2. (BS-II). The current standard in use is BS-IV, which has been in effect since April 2010. More severe regulations are now in place, which will dramatically reduce the quantity of dangerous pollutants. This emission standard, known as BS-VI, will go into force for all original equipment manufacturers (OEM) in April 2020. [3]



PARTICULATE MATTER

They may have formed as a result of the aggregation of extremely minute particles of partially burnt fuel, partially burned lubricating oil, ash content of fuel oil, cylinder lube oil, or sulphates and water. The majority of particulate matter is produced by incomplete combustion of hydrocarbons in gasoline and lubricating oil. A typical particle composition of a heavy-duty diesel engine is 41% carbon, 7% unburned fuel, 25% unburned oil, 14% sulphate and water, 13% ash and other components, according to an experimental investigation. [6]

Diesel particulate matters are typically spheres about 15 - 40 nm in diameter, and approximately more than 90 % of PM is smaller than 1 μm in diameter. The formation process of PM emissions is dependent on many factors as the combustion and expansion process, fuel quality (sulfur and ash content), lubrication oil quality, and consumption, combustion temperature, exhaust gas cooling. Particulate matter emissions from diesel engines are considerably higher (six to ten times) than from gasoline engines. Diesel particle emissions can be divided into three main components: soot, soluble organic

fraction (SOF), and inorganic fraction (IF). More than 50 % of the total PM emissions are soot that is seen as black smoke. [6]

Types of Particulate Matter (PM)

1. PM10
2. PM2.5

Sulphates, nitrates, black carbon metals (cadmium, copper, nickel, zinc), and hydrocarbons are examples of Particulate Matter. Allergens (pollen, dust mites) and microbiological components are biological components (fungi). [6]

SOURCES

- These particles can be hundreds of different compounds and come in a variety of sizes and forms.
- The majority of particles seen in the atmosphere are the product of complicated chemical reactions, such as SO₂, NO_x, which are pollutants generated by power plants, industry, and cars. [6]

Harmful Effects of Particulate Matter

- Particulate Matter is made up of tiny solids or liquid droplets that are so minute that they may be breathed and cause major health concerns since they

can reach deep into the lungs and even into the bloodstream. [6]

- The major cause of impaired vision (haze) in our nation is fine particles (PM_{2.5}).
- When particulate matter enters the lungs and bloodstream, it can cause blood and lung cancer. [6]
- New Delhi has achieved the awful distinction of being the most polluted city on the planet this month, with air quality reaching epic proportions.
- On November 8, pollution levels reached such high levels that several monitoring stations reported an air quality index of 999, well beyond the top limit of the worst category, hazardous.
- (An extra-sensitive air quality instrument at the US embassy measured 1,010, as shown in the chart

below.) (An extra-sensitive air quality instrument at the US embassy got a reading of 1,010, as you can see in the chart below.) [6]

Health effects due to pollutants emitted through exhaust

Exposure to such particles can harm both the lungs and the heart. Numerous scientific studies have connected particle pollution to a wide range of issues, including:

- Premature death in people with heart or lung disease.
- Non – fatal heart attacks.
- Irregular heartbeat.
- Aggravated Asthma.
- Decreased lung function.
- Increased respiratory symptoms, such as irritation of the airways, coughing or difficulty in breathing. [6]

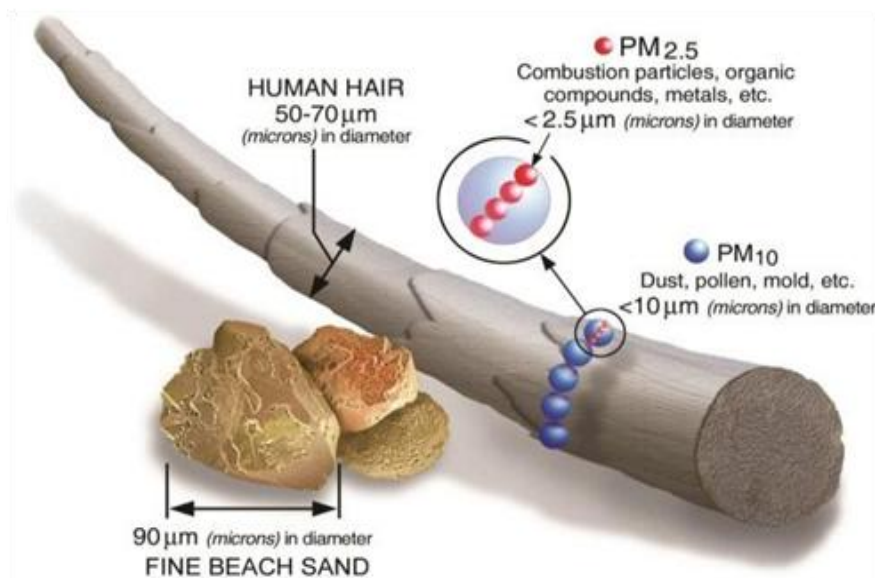


Fig 2:- Size of Particulate Matter compared to human hair. [6]

Environmental damage

Particles can be carried over long distances by wind and then settle on ground or water. Depending on their chemical composition, the effects of this settling may include:

- Making lakes and streams acidic.
- Changing the nutrient balance in coastal waters and large river basins.
- Depleting the nutrients in soil.
- Damaging sensitive forests and farm crops.
- Affecting the diversity of ecosystems.
- Contributing to acid rain effects. [6]

Timeline of Bharat Stage (BS)

Bharat Stage Emission Standards (BSES) are emission regulations established by the Indian government to limit the production of air pollutants from internal combustion engines and spark-ignition engine equipment, including motor vehicles. The Central Pollution Control Board, which is

part of the Ministry of Environment, Forests, and Climate Change, sets the criteria and schedule for implementation. The standards, which were based on European legislation, were first implemented in 2000. Since then, increasingly strict standards have been implemented. All new cars constructed following the adoption of the requirements must be compliant. Bharat Stage IV emission regulations have been in place in 13 major cities since April 2010, and they have been implemented throughout the nation since April 2017. The Indian government declared in 2016 that the country would abandon BS-V standards in favour of BS-VI standards by 2020. The Supreme Court has ruled that the sale and registration of motor vehicles meeting the Bharat Stage-IV emission standard will be prohibited in the whole country from April 1, 2020. [7]

Table- 1 Timeline of Bharat Stage (BS)

Standard	Reference	Date
Bharat Stage II	Euro 2	1 April 2005
Bharat Stage III	Euro 3	1 April 2010
Bharat Stage IV	Euro 4	1 April 2017
Bharat Stage VI	Euro 6	April 2020 (Proposed)

BS-IV

1. Effective and in force from April 2010.
2. It had reduced value of CO, NO_x, HC and Particulate Matter as compared to BS-III.

Vehicle emissions are a key factor in India's deteriorating air quality. People's health is suffering as a result of NO_x, SO₂, CO₂, and Particulate Matter emissions. In October 2016, India ratified the Conference of Protocol, widely known as the Paris Climate Agreement.

As a party to the accord, India is required to reduce its carbon footprint by 33-55% from 2005 levels over the next 12 years. This justifies the need for a higher standard, which may significantly decrease emissions and put India on track to fulfil the Paris accord targets. Ideally, BS-V would have been implemented by 2021, and BS-VI by 2024.

However, a jump to Bharat Stage VI standards by 2020 was required due to carbon footprint commitments. Historically, a carbon footprint is defined as the total emissions created by an individual, event, organisation, or product, represented in carbon dioxide equivalent. [7]

Reasons for skipping BS-V

It is not a simple process to transition from one Bharat stage (BS) to another. It necessitated significant capital expenditure in refineries and the automobile industry. Several new units and a reworking of old ones are necessary. As a result, if India transitions from BS-IV to BS-V, a new set of projects would be required. And the transition from BS-V to BS-VI will necessitate a new set of initiatives. As a result, it is not cost-effective. [7]

BS-VI

Category M and N Vehicles with GVW < 3,500 KG (Light- duty Vehicles)

The BS-VI emission rules apply to category M and N cars with a gross vehicle weight (GVW) of less than 3,500 kg. These vehicle types include light-duty passenger and commercial vehicles.

Emission standards for cars equipped with spark ignition (SI) and compression ignition (CI) engines are determined independently, and they differ in terms of both the categories of pollutants controlled and the levels at which emission limits for commonly regulated pollutants are set. Emission limitations in both situations are quantitatively identical to Euro 6 criteria for similar engine types. [3]

Given the substantial dieselization of India's light-duty fleet, one of the most significant parts of the BS VI plan is the reduction in permissible pollutant emission rates for cars equipped with CI engines. Diesel, gasoline, and hydrogen are all fuel kinds. A crucial feature of the fuel requirements is a restriction of 10 ppm on the maximum permissible sulphur content in gasoline and diesel fuels.

Low sulphur fuels, particularly for diesel engines, are essential for the use of modern emission control technology such as DPFs, which will be required to achieve BS-VI emission regulations. [3]

Category M and N Vehicles with GVW > 3,500 KG(Heavy-duty Vehicles)

The proposed BS-VI rule for category M and N vehicles with a GVW greater than 3,500 kg defines different BS-VI emission criteria for heavier goods transportation and passenger transport vehicles.

Importantly, new vehicle emission regulations apply to heavy-duty vehicles, which are anticipated to be India's greatest on-road source of PM and NOX emissions. The pollutants contained in the BS-VI rule for heavy-duty vehicles, as well as their mass emission restrictions, adhere to Euro-VI criteria. Figure 1 also shows a

comparison of BS-IV and BS-VI NOX and PM emission restrictions for heavy-duty diesel vehicles. [3]

The tightening of the PM emission limit and the introduction of a PN limit for heavy-duty diesel vehicles is possibly the single most important component of the BS-VI regulation in terms of air quality and human health.

Figure 1 shows that the PM standard for these cars is decreased by 50% and 67% from BS-IV levels, respectively, when evaluated on steady-state and transient dynamometer test cycles.

The tougher PM standard is supplemented by particle number emission standards of 81011/kWh for steady-state cycle testing and 61011/kWh for transient cycle testing. As with light-duty diesel cars, these measures will very certainly compel manufacturers of heavy-duty engines marketed in India to use DPFs to limit PM emissions from BS-VI emission level engines.

Given the importance of heavy duty diesel cars as a source of PM emissions and the considerable PM and PN control efficiencies given by DPF systems, these

limits should significantly lower India's on-road vehicle PM emissions burden. [3]

Not-To-Exceed World Harmonization (WNTe) In-service conformity testing is also necessary to demonstrate that emissions performance is maintained during the engine's useful life.

Gaseous pollutants have in-service conformance factors that determine allowed emissions over authorised emission limits. The BS-VI OBD

regulations will be implemented in two stages, as they were for light-duty cars.

1. OBD applicable for new models on April 1, 2020 and all models on April 1, 2021 and BS-VI.
2. OBD applicable beginning April 1, 2023. [3]

Note all regulated pollutants are not shown here. An independent BS-IV NOX limit is not defined for three-wheeled vehicles. Shown here is the combined NOX+HC limit equal to 0.380 g/km. [3]

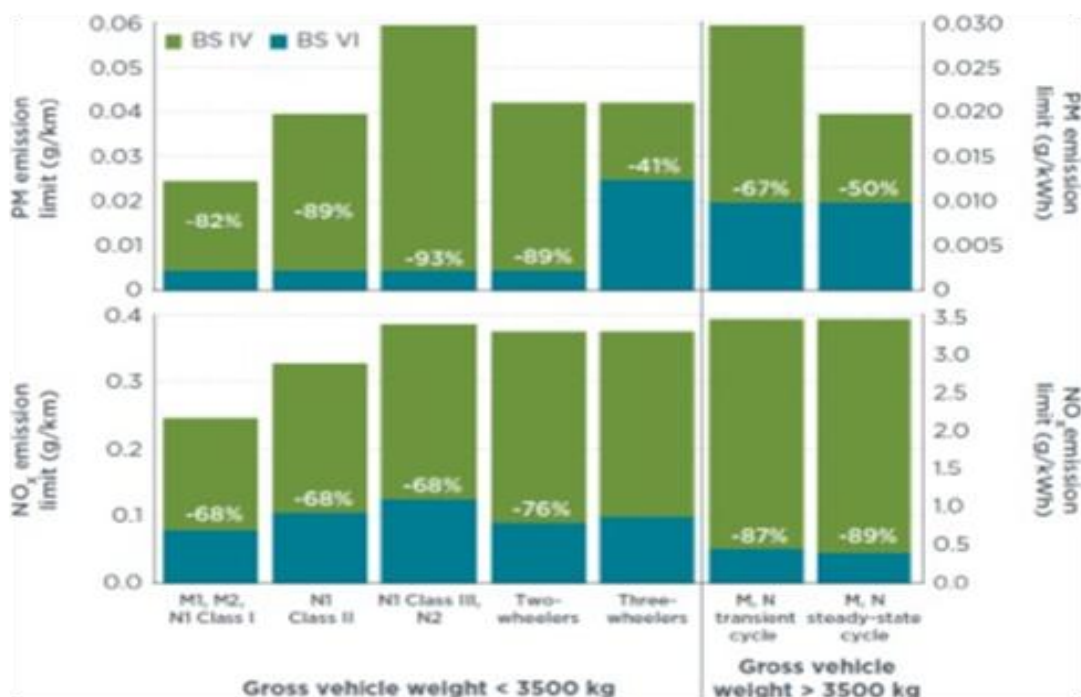


Fig 3:- BS-IV and BS-VI emission limits for compression ignition vehicles. [3]

Techniques used for measurement of emissions from engines

AVL Smoke Meter Machine



Fig 4:- AVL smoke meter machine [5]

The AVL Smoke Meter is a filter-type smoke metre used to measure the soot level of diesel and similar internal combustion engines' exhaust. It has become a de facto industry standard for the development of contemporary engines. The filtered soot causes the filter paper to blacken, which is detected by a photoelectric measuring head and evaluated by a microprocessor. The calculated values are the filter smoke number (FSN) and the soot concentration in milligrammes per cubic metre (mg/m³).

The filter paper technique is used by the AVL smoke metre to measure the filter smoke number and soot concentration in mg/m³. The variable sample capacity and thermal exhaust conditioning enable good

repeatability and a broad variety of applications. The instrument is applicable not just to big engines but also to light-duty engines of any generation. Furthermore, raw exhaust measurements (for example, upstream of a DPF) or measurements up to 5000m altitude can be performed by employing derivation options. [5]

Low detection limit (0.002FSN or 20ug/m³) and high measurement resolution (0.001FSN or 10ug/m³). The quality of filter paper varies. Wet strength, porosity, particle retention, volumetric flow rate, compatibility, efficiency, and capacity are critical factors. With paper, there are two filtration mechanisms: volume and surface. Particles are collected

in the bulk of the filter paper using volume filtration. Surface filtration traps particles on the paper's surface. The paper used in gasoline filters is a regulated-porosity paper that is pleated and coiled into cartridges. Filter paper used in gasoline filters is manufactured from a combination of hardwood and softwood fibres. The paper's basic weight ranges from 50 to 80 g/m². [5]

Measuring Principle

Inside the device, a variable but precisely specified sampling volume is drawn from the engine's exhaust pipe and passed through clean filter paper. The filtered soot causes the filter paper to blacken, which is detected by a photoelectric measuring head and evaluated by a microprocessor. When estimating the soot concentration, not only must the paper blackening (PB) be considered, but also the volume of exhaust sucked through the filter paper (effective sampling length L_{eff}) [5].

$$FSN = PB \text{ for } L_{eff} = 405\text{mm}$$

(length of column of exhaust referred to 1 bar and 250C)

$$\text{Effective Length} = (\text{Sample Volume} - \text{Dead Volume} - \text{Leak Volume}) / \text{Filter Area}$$

$$PB = (100 - R_r) / 10$$

$$R_r = R_s / R_f \cdot 100\%$$

PB - Paper Blackening.

R_s - Reflectometer Value of the sample.

R_f - Reflectometer Value of non-blackened filter paper. R_r - Relative brightness of the sample. [5]

Particulate Counting Machine

The AVL Particle Counter, designed by AVL, the world leader in emissions particulate measurement, is a compact, versatile, and readily integrable instrument for measuring particle number concentrations of diluted exhaust gases in a reliable and compliant manner. The AVL Particle Counter is made up of two parts: a conditioning component (volatile particle remover, VPR) and a particle number counter (PNC). The VPR is made up of three parts: a first dilution step (particle number diluter 1), an evaporator tube, and a secondary dilution step (particle number diluter 2). The PNC is a condensation particle counter based on n-butanol with a cutoff diameter of 23nm. [5]

Working Principle

Regardless of vendor, all frequently used clean room airborne particle monitors operate on a light scattering basis. This essentially implies that they spotlight the particles with an extremely powerful light source. [5]

Mirrors are used to represent the clam forms in the figure. They are silvered on the interior so that the reflecting surface is visible. As light scatters, it is captured by these mirrors, which concentrate the dispersed light onto one or more photo-

detectors. The photodetector turns each particle's flash of light energy into an electrical pulse. Light "scattering" is a broad word that encompasses a variety of physical processes. [5]

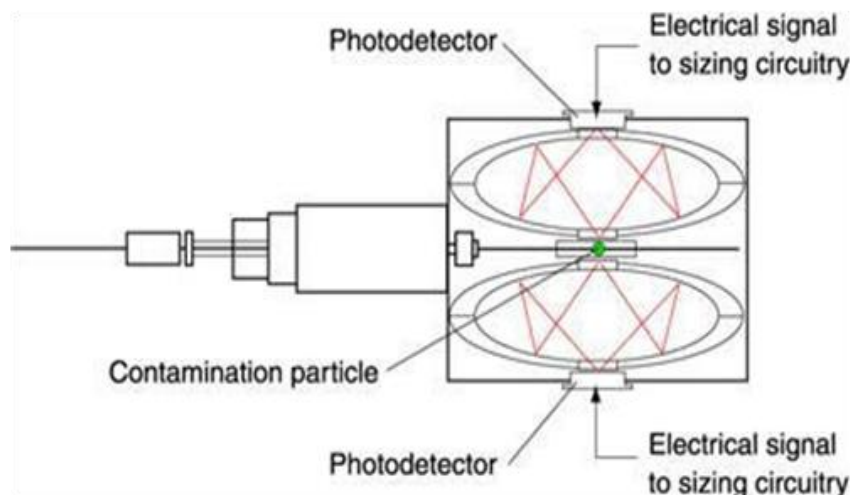


Fig 5:- As entrained particles in the air pass through the laser beam, the laser light interacts with particles and is scattered. [5]



Fig 6:- AVL Particulate counting machine [5]

SPECIFICATIONS

Table- 2 Specifications of AVL particulate counting machine [5]

Parameters	AVL Particle Counter
Measurements	Particle number concentration of Particle number concentration of non-volatile particles
PNC measuring range	0 to 10,000 cm ³ up to 50,000 cm ³ in single count mode
PNC (90) rise time	<5 sec
Operation temperature	5°C to 25°C
Maximum sampling temperature	< 52°C
Pressure differential between measurement channel and ambient	+/- 20 mbar
Temperature evaporation tube	350°C
Power supply	90 - 240 VAC, 50/60 Hz, ~1kW
Dimensions	482 (19) x 445 (10HU) x 650mm
Weight	~46 kg

Emission control system of Particulate Matter for diesel engine vehicles

Diesel Particulate Filter (DPF)

DPFs have been used in car manufacturing since 2000. They are typically built of silicon carbide (SiC) honeycomb structures and are used to eliminate PM pollutants from exhaust gases by physical filtering. The diesel particles are forced through the porous substrate walls, which operate as a mechanical filter, by the closed channels at each end. Soot particles are transferred into the pore walls by diffusion as they pass through the walls. [1] This filter has a large of parallel mostly

square channels. The thickness of the channel walls is typically 300–400 nm.

The filter walls are built with an optimal porosity, allowing exhaust gases to move through without minimal resistance while remaining impermeable enough to catch particle species. This results in highly efficient surface filtration for the subsequent operating phase. [1]

However, excessive saturation must be prevented. As the filters accumulate Particulate Matter, it builds up backpressure that has many negative effects such as increased fuel

consumption, engine failure, and stress in the filter. To prevent these negative effects, the DPF has to be regenerated by burning trapped Particulate Matter. [1]

Types of Regeneration in DPF

There are subsequently two types of regeneration processes of DPFs commonly referred as:

1. Active regeneration
2. Passive regeneration.

Active regeneration can be used on DPFs on a regular basis to remove stored soot by controlled oxidation with O₂ at temperatures of 550°C or higher. Particulate matter is oxidised on a regular basis in the active DPF production by heat provided from outside sources, such as an electric heater or a flame-based burner.

Unlike active regeneration, passive regeneration of DPF involves the oxidation of particulate matter at the exhaust gas temperature by catalytic combustion, which is aided by the placement of appropriate catalysts within the trap itself. A continual catalytic reaction mechanism that consumes no additional fuel oxidises particulate matter. Small concentrations of NO₂ will facilitate the continual oxidation of the implanted carbon particles at temperatures ranging from 200 to 450°C degrees Celsius. [1] The entire process of passive regeneration is relatively easy, silent, effective, and fuel efficient, as neither the vehicle operator nor the vehicle's engine management system has to do anything to induce DPF regeneration. [1]

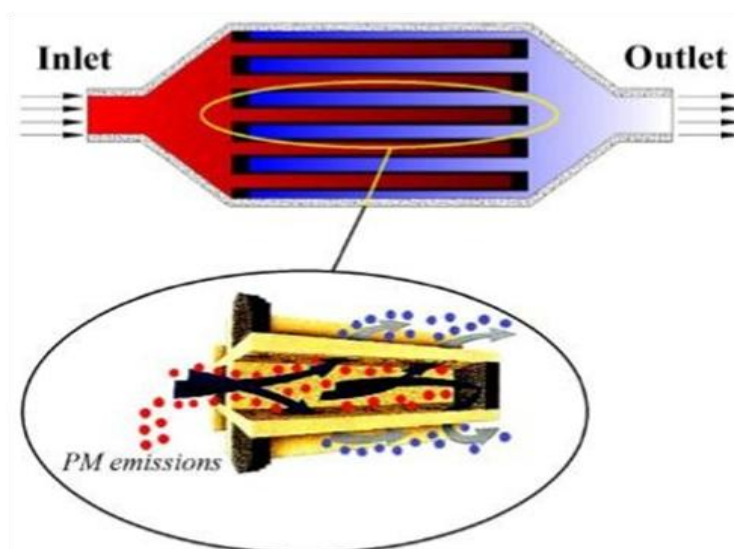


Fig 7:- DPF Working [1]

FUTURE SCOPE



Fig 8:- Real time testing cycle [6]

RDE (Real-Time Driving Emissions)

The Real Driving Emissions (RDE) test monitors the pollutants released by automobiles on the road, such as NO_x. The WLTP laboratory test does not replace, but rather supplements, the RDE. The RDE guarantees that automobiles emit low levels of pollution when driving.

Europe is the first region in the world to use such on-road testing, marking a significant advancement in automobile emissions testing. RDE allows a car to be operated on public roads in a variety of situations. Data is collected by specific equipment put on the vehicle to ensure that regulatory limits for pollutants such as NO_x are not exceeded. [6]

Conditions include:

- Low and high altitudes
- Year-round temperatures
- Additional vehicle payload
- Up- and down-hill driving
- Rural roads (medium speed)
- Motorways (high speed)

Cars are equipped with Portable Emission Measuring Systems (PEMS) that offer comprehensive real-time monitoring of the primary pollutants generated by the vehicle in order to measure pollutant emissions as the vehicle is driven on the road (i.e., NO_x). [6]

CONCLUSION

There is combustion occurring in the engine, which is then transported to the tail pipe and exposed to the atmosphere via the

exhaust. This article examines the characteristics of major pollutant emissions from diesel engines as well as the technology used to manage these pollutant emissions in accordance with norms and regulations. The aggregation of extremely minute particles of partially burnt fuel, partially burned lubricating oil, the ash content of fuel oil and cylinder lube oil, or sulphates and water. These pollution releases impair both the environment and human health. Only after treatment systems allow for the required control of pollutant emissions. A DPF is a component of diesel exhaust after treatment systems. It is feasible to limit the damage of pollutant emissions to air pollution, satisfy emission norms and criteria, and avoid the negative impacts of pollutant emissions on the environment and human health using post-treatment emission control systems. Furthermore, there has been a significant variation in the measurement of the particles coming out of the exhaust. Older procedures included monitoring the amount of smoke coming out of the tailpipe using an AVL smoke metre. This operation is now carried out by counting the particles that exit the tail pipe, as previously explained. Now that the ARAI has established stricter requirements that will be enforced in April 2020, all cars built after that date with

earlier norms will be completely absolute. So, the new BS-VI standards will lead to much-needed reductions in the amount of pollution from vehicles.

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