

# Review on BS-VI norms and Particulate Matter emission of diesel engines

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## ABSTRACT

The new BS-VI norms which will bring down the NO<sub>x</sub>, HC & PM values for diesel and petrol engines. For diesel engines will have less no. of NO<sub>x</sub>, HC + NO<sub>x</sub> & PM values. The emissions from the engines will be measured in a different way than the traditional method; it will be done by use of a particulate counting machine, which will be counting the particulate matters that are coming out of the exhaust of the engines. Particulate matter consists of 3 major sub-types i.e. soot, insoluble part, and soluble part. For reducing Particulate Matter emission of diesel engines, Diesel Particulate Filter (DPF) is used. In this review paper we are focusing on composition of diesel exhaust gases, Particulate matter types, Need and evolution of BS-VI engine norms, Techniques used for measurement of emission from engines and Diesel Particulate Filter. Future scope involving Real time Driving Emissions is also discussed in this review paper.

## 1. Introduction

There are combustions taking place in engines along with various chemical reactions, which are further transmitted to tail pipe where they are exposed to the atmosphere through the exhaust. [1]

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

1. Gases
2. Particles.

Gases emissions are combination of various gases which are combination of gases like NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub> etc. Particles which come out of the exhaust are called as particulate matter which is further classified into soot, insoluble part and soluble part. Soot is formed from unburned fuel, Hydrocarbons and other available molecules that may condense on or be absorbed by soot depending on surroundings. Vehicular emission is a major contributor to the worsening air quality of Indian Cities. Emission of Gases and Particulate Matter (PM) is taking toll on people's health. For this purpose ARAI (Automotive Research Association of India) has introduced norms which will bring the amount of hazardous emissions coming out of the exhaust to a bare minimum. ARAI has been playing a crucial role in assuring safe, less polluting and more efficient vehicles. [1].

ARAI provides technical expertise in R & D, testing, certification, homologation and framing of vehicle regulations. It was first introduced as 2000 norms, which was later renamed as Bharat Stage 2 (BS-II). The current norm in action being BS-IV which is enforce since April 2010. Now more stringent norms are put into place which will bring down the amount of hazardous emissions drastically. This emission norm which is BS-VI, will be effective for all original equipment manufacturers (OEM) from April 2020. [3]

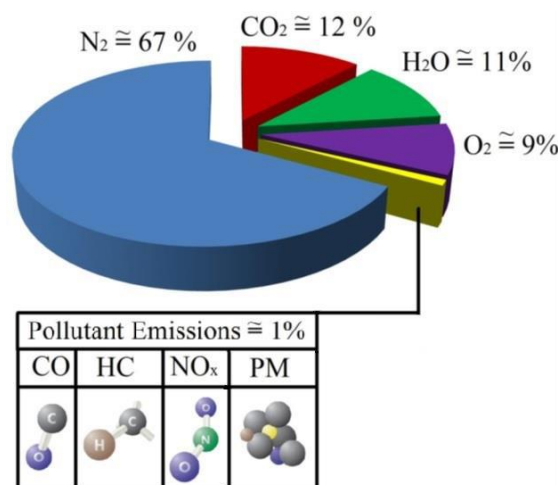


Fig 1:- The compositions of diesel exhaust gas [1]

## 2. Particulate Matter

They may be originated from the agglomeration of very small particles of partly burned fuel, partly burned lube oil, ash content of fuel oil, and cylinder lube oil or sulfates and water. Most particulate matters are resulted from incomplete combustion of the hydrocarbons in the fuel and lube oil. In an experimental study, typical particle composition of a heavy-duty diesel engine is classified as 41 % carbon, 7 % unburned fuel, 25 % unburned oil, 14 % sulfate and water, 13 % ash and other components. [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]

**2.1 Types of Particulate Matter (PM)**

1. PM<sub>10</sub>
2. PM<sub>2.5</sub>

Particulate Matter includes sulphates, nitrates, black carbon metals (cadmium, copper, nickel, zinc) and hydrocarbons. Biological components such as allergens (pollen, dust mites) and microbial components (fungi). [6]

**2.2. Sources**

- These particles come in many sizes and shapes and can be made up of hundreds of different chemicals.
- Most particles found in the atmosphere as a result of complex reaction of chemicals such as SO<sub>2</sub>, NO<sub>x</sub> which are pollutants emitted from power plants industries and automobiles. [6]

**2.3. Harmful Effects of Particulate Matter**

- Particulate Matter contains microscopic solids or liquid droplets that are so small that they can be inhaled and cause serious health problems , because they can get deep into lungs , and some may even get into blood stream. [6]
- Fine particles (PM<sub>2.5</sub>) are the main cause of reduced visibility (haze) in our country.
- As Particulate Matter gets deep into the lungs and blood stream, it can cause blood cancer and lung cancer. [6]
- Delhi has earned the unenviable distinction of becoming the city on Earth this month, as air quality has reached epically bad proportions.
- On November 8, pollution surged so high that some monitoring stations reported an Air Quality Index of 999, way above the upper limit of the worst category, Hazardous.
- (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]

**2.4. Health effects due to pollutants emitted through exhaust**

Exposure to such particles can affect both lungs and heart. Numerous scientific studies have linked particle pollution exposure to a variety of problems, 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]

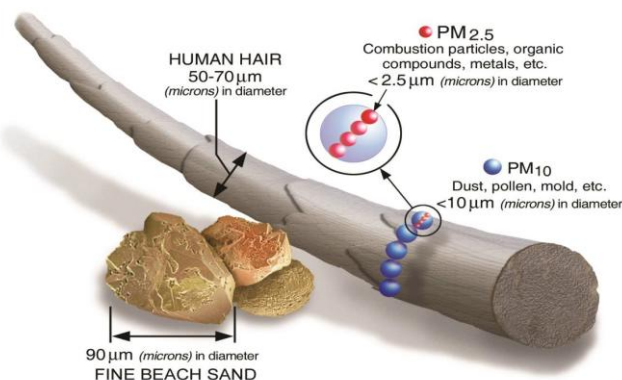


Fig 2:- Size of Particulate Matter compared to human hair. [6]

**2.5. 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]

**3. Timeline of Bharat Stage (BS)**

Bharat stage emission standards (BSES) are emission standards instituted by the Government of India to regulate the output of air pollutants from internal combustion engines and Spark-ignition engines equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment & Forests and climate change. The standards, based on European regulations were first introduced in 2000. Progressively stringent norms have been rolled out since then. All new vehicles manufactured after the implementation of the norms have to be compliant with the regulations. In 13 major cities, Bharat Stage IV emission norms have been in place since April 2010 and it has been enforced for entire country since April 2017. In 2016, the Indian government announced that the country would skip the BS-V norms altogether and adopt BS-VI norms by 2020. In its recent judgment, the Supreme Court has banned the sale and registration of motor vehicles conforming to the emission standard Bharat Stage-IV in the entire 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)

**4. BS-IV**

1. Effective and in force from April 2010.
2. It had reduced value of CO, NO<sub>x</sub>, HC and Particulate Matter as compared to BS-III.

Vehicular emission is a major contributor to the worsening air quality of Indian cities. Emission of NO<sub>x</sub>, SO<sub>2</sub>, CO<sub>2</sub> and Particulate Matter is taking a toll on people’s health. In October 2016, India signed the Conference of Protocol also known as the Paris Climate Agreement. Being a signatory to the agreement, India is obligated to bring down the carbon footprint by 33-55% from the levels recorded in 2005 in the next 12 years. This warranted the need for a stricter norm that could reduce the emissions considerably and put India on track to meet the Paris agreement goals. Ideally, BS-V would have been rolled out by 2021 and BS-VI in 2024 but leapfrog to Bharat Stage VI norms by 2020 had to be planned because of the carbon footprint obligations. A carbon footprint is historically defined as the total emissions caused by an individual, event, organization, or product, expressed as carbon dioxide equivalent. [7]

**4.1 Reasons for skipping BS-V**

Switching from one Bharat stage (BS) to another Bharat stage (BS) is not an easy task. It required huge capital investment in refineries and Automobile industries. Various new units and revamp of existing units required. So if India switches from BS-IV to BS-V then a new set of projects are required. And from BS-V to BS-VI will require another new set of projects. Hence it is not economical. [7]

**5. BS-VI**

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

BS-VI emission standards are defined for category M and N vehicles with gross vehicle weight (GVW) not exceeding 3,500 kg. Vehicle types in these categories include light-duty passenger and commercial vehicles. Emission standards are set separately for vehicles equipped with spark ignition (SI) and compression ignition (CI) engines, and vary both in terms of the types of pollutants that are regulated as well as the levels at which emission limits for commonly regulated pollutants are set. In both cases, emission limits are numerically equivalent to Euro 6 standards for similar engine types. [3]

Given the widespread dieselization of the Indian light-duty fleet, reductions in allowable pollutant emission rates for vehicles equipped with CI engines are among the most significant aspects of the BS VI proposal. Fuel types include diesel, gasoline, and hydrogen. A key aspect of the fuel specifications is a limit on the maximum allowable sulfur content in gasoline and diesel fuels of 10 Particulate Matter. Especially for diesel engines, low sulfur fuels are necessary for the application of advanced emission control technologies, such as DPFs, which will be required to meet BS-VI emission standards. [3]

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

BS-VI emission standards for larger goods movement and passenger transport vehicles are defined separately under the proposed BS-VI regulation for category M and N vehicles with GVW exceeding 3,500 kg. Importantly, emission standards for these vehicle categories cover heavy-duty vehicles, which are

estimated to be the largest on-road source of PM and NO<sub>x</sub> emissions in India. Both the pollutants included in the BS-VI regulation for heavy-duty vehicles and the mass emission limits for these pollutants follow Euro-VI specifications. In addition, a comparison of BS-IV and BS-VI NO<sub>x</sub> and PM emission limits for heavy-duty diesel vehicles is presented in Figure 1. [3]

From an air quality and human health perspective, perhaps the single most important aspect of the BS-VI regulation is the tightening of the PM emission limit and introduction of a PN limit for heavy-duty diesel vehicles. As shown in Figure1, the PM standard for these vehicles is reduced by 50% and 67% from BS-IV levels as measured on steady-state and transient dynamometer test cycles, respectively. The more stringent PM standard is accompanied by a particle number emission standard of 8x10<sup>11</sup>/kWh for steady-state cycle testing and 6x10<sup>11</sup>/kWh for transient cycle testing. As was the case for light-duty diesel vehicles, these steps will likely force manufacturers of heavy-duty engines sold in India to utilize DPFs to control PM emissions from BS-VI emission level engines. Given the importance of heavy duty diesel vehicles as a source of PM emissions and the large PM and PN control efficiencies offered by DPF systems,7 these restrictions should greatly reduce the PM emissions burden of on-road vehicle in India. [3]

World-Harmonized Not-To-Exceed (WNTEx) Also, in-service conformity testing is required to show that emissions performance is maintained over the useful life of the engine. In-service conformity factors, which define allowable emissions above regulated emission limits, are set for gaseous pollutants. As was the case for light-duty vehicles, BS-VI OBD requirements will be introduced in two stages, with BS-VI

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]



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

Note all regulated pollutants are not shown here. An independent BS-IV NO<sub>x</sub> limit is not defined for three-wheeled vehicles. Shown here is the combined NO<sub>x</sub>+HC limit equal to 0.380 g/km. [3]

## 6. Techniques used for measurement of emissions from engines

### 6.1 AVL Smoke Meter Machine

The AVL Smoke Meter is a filter-type smoke meter for measuring the soot content in the exhaust of diesel and related internal combustion engines. It has become an industry standard for developing modern engines. The filtered soot causes a blackening of the filter paper, which is measured by a photoelectric measuring head and the result is analyzed by a microprocessor. The determined values are the Filter Smoke Number (FSN) and the soot concentration in  $\text{mg}/\text{m}^3$ . The AVL smoke meter uses the filter paper method to determine the filter smoke Number and soot concentration in  $\text{mg}/\text{m}^3$ . The variable sampling volume and the thermal exhaust conditioning ensure and extremely high reproducibility and a wide range of applications. The instrument can be used not only on large engines but also on light duty engines independent of their generation. In additions, raw exhaust measurements (e.g. Upstream a DPF) or measurements up to 5000m altitude can be carried out by using derive options. [5]

High Measurement resolution ( $0.001\text{FSN}$  or  $10\mu\text{g}/\text{m}^3$ ) and low detection limit ( $0.002\text{FSN}$  or  $20\mu\text{g}/\text{m}^3$ ). Filter paper has various properties. The important parameters are wet strength, porosity, particle retention, volumetric flow rate, compatibility, efficiency and capacity. There are two mechanisms of filtration with paper; volume and surface. By volume filtration the particles are caught in the bulk of the filter paper. By surface filtration the particles are caught on the paper surface. The paper used for fuel filters is a paper with controlled porosity, which is pleated and wound to cartridges. The raw material for filter paper used in fuel filters are made of a mixture of hardwood and softwood fibers. The basis weight of the paper is  $50 - 80 \text{ g}/\text{m}^2$ . [5]

#### Measuring Principle

A variable, but exactly defined sampling volume is sampled from the engine's exhaust pipe and passed through clean filter paper inside the device. The filtered soot causes a blackening of the filter paper, which is measured by a photoelectric measuring head and the result is analyzed by a microprocessor. When determining the soot content, not only the paper blackening (PB) has to be taken into account, also the volume of exhaust drawn through filter paper is important (effective sampling length  $L_{\text{eff}}$ ) [5]

$\text{FSN} = \text{PB}$  for  $L_{\text{eff}} = 405\text{mm}$  (length of column of exhaust referred to 1 bar and  $250\text{C}$ )

Effective Length = (Sample Volume – Dead Volume – Leak Volume)/ Filter Area

$$\text{PB} = (100 - \text{Rr})/10$$

$$\text{Rr} = \text{Rs}/\text{Rf} \cdot 100\%$$

PB - Paper Blackening.

Rs - Reflectometer Value of the sample.

Rf - Reflectometer Value of non-blackened filter paper.

Rr - Relative brightness of the sample. [5]



Fig 4:- AVL smoke meter machine [5]

### 6.2 Particulate Counting Machine

AVL, the world leader in the field of emissions particulate measurement, has developed the AVL Particle Counter, a compact, flexible and easily integrable device to measure particle number concentrations of diluted exhaust gas in reliable and compliant way. The AVL Particle Counter consists of a conditioning component (volatile particle remover VPR) and the actual particle number counter (PNC). The VPR consists of first dilution step (particle number diluter 1), an evaporator tube, and a secondary dilution (particle number diluter 2). The PNC is n-butanol based condensation particle counter with a cutoff diameter of  $23\text{nm}$ . [5]

#### Working Principle

All the commonly used clean room airborne particle counters, regardless of manufacturer, work on a light scattering principle. Essentially, this means that they utilize a very bright light source to illuminate the particles. [5]

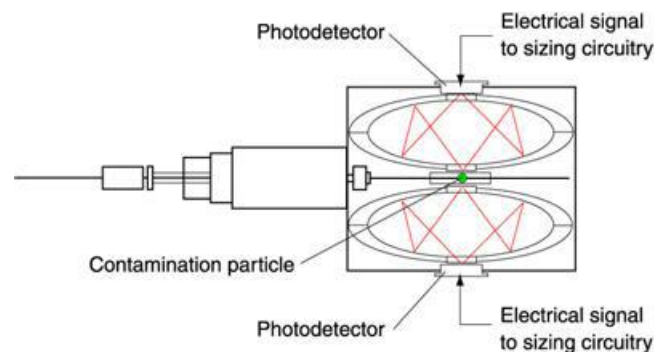


Fig 5:- As entrained particles in the air pass through the laser beam, the laser light interacts with particles and is scattered. [5]

The clam shapes in the diagram are mirrors. They are silvered so that the reflecting surface is inside. As the light scatters, it is picked up by these mirrors, which focus the scattered light on to one or more photo-detectors. The photo-detector converts the burst of light energy from each particle into a pulse of electrical energy. Light 'scattering' is a general term and is composed of various different physical phenomena. [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 non-volatile particles
PNC measuring range	0 to 10,000 cm <sup>3</sup> up to 50,000 cm <sup>3</sup> 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

7. Emission control system of Particulate Matter for diesel engine vehicles

7.1 Diesel Particulate Filter (DPF)

DPFs have been applied in the production of vehicles since 2000. They are used to remove PM emissions from the exhaust gas by physical filtration and usually made of silicon carbide (SiC) honeycomb structure. The plugged channels at each end force the diesel particulates matters through the porous substrate walls, which act as a mechanical filter. As soot particles pass through the walls, they are transported into the pore walls by diffusion where they adhere. [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 designed to have an optimum porosity, enabling the exhaust gases to pass through their walls without much hindrance, whilst being sufficiently impervious to collect the particulate species. This provides highly efficient surface filtration for the following 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 periodically applied to DPFs in which trapped soot is removed through a controlled oxidation with O<sub>2</sub> at 5500C or higher temperatures. In an active generation of DPF, Particulate Matter is oxidized periodically by heat supplied from outside sources, such as an electric heater or a flame-based burner. Unlike in the active regeneration, in passive regeneration of DPF, the oxidation of Particulate Matter's occurs at the exhaust gas temperature by catalytic combustion promoted by depositing suitable catalysts within the trap itself. Particulate Matter is oxidized by an ongoing catalytic reaction process that uses no additional fuel. Under a temperature range between 200 and 4500C, small amounts of NO<sub>2</sub> will promote the continuous oxidation of the deposited carbon particles. [1]

In passive regeneration, the entire process is very simple, quiet, and effective and fuel efficient, that is, neither the vehicle operator nor the vehicle's engine management system has to do anything to induce the regeneration of the DPF. [1]

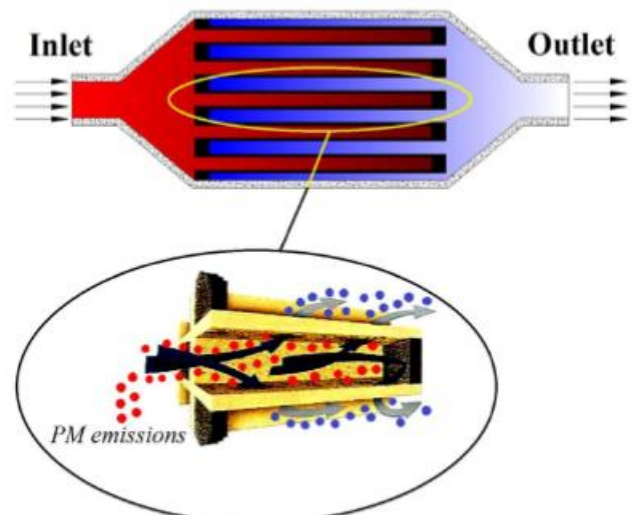


Fig 7:- DPF Working [1]

8. Future Scope

8.1 RDE (Real-Time Driving Emissions)

The Real Driving Emissions (RDE) test measures the pollutants, such as NO<sub>x</sub>, emitted by cars while driven on the road. RDE does not replace the WLTP laboratory test, but complements it. RDE ensures that cars deliver low emissions over on-road conditions. Europe is the first region in the world to introduce such on-road testing, marking a major leap in the testing of car emissions. Under RDE, a car is driven on public roads and over a wide range of different conditions. Specific equipment installed on the vehicle collects data to verify that

legislative caps for pollutants such as NO<sub>x</sub> 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)

To measure pollutant emissions as the vehicle is being driven on the roads, cars are fitted with Portable Emission Measuring Systems (PEMS) that provide a complete real-time monitoring of the key pollutants emitted by the vehicle (ie NO<sub>x</sub>). [6]



Fig 8:- Real time testing cycle [6]

## 9. Conclusion

There are combustions taking place in the engine, which are further transmitted to the tail pipe where they are exposed

to the atmosphere through the exhaust. This article reviews the characteristics of main pollutant emissions from diesel engines and control technologies of these pollutant emissions with standards and regulations. As for PM emissions, the reasons of PM emissions are agglomeration of very small particles of partly burned fuel, partly burned lube oil, ash content of fuel oil and cylinder lube oil or sulfates and water. These pollutant emissions have harmful effects on environment and human health. To control these pollutant emissions as desired is only possible with after treatment systems. Diesel exhaust after treatment systems includes DPF. With the after treatment emission control systems, it is possible to reduce the damage of the pollutant emissions on air pollution, to meet emission standards and requirements, and to prevent the harmful effects of pollutant emissions on environment and human health. In addition to this there is a major change in measuring of the particles coming out of the exhaust. Older techniques included of measuring the smoke coming out of the tail pipe, which was conducted by use of AVL smoke meter. Now this procedure is conducted by counting of the particles coming out of the tail pipe as discussed earlier. Now as stringent norms are imposed by the ARAI which will be effective from April 2020, causing any vehicles produced after that deadline with older norms entirely absolute. Hence the new BS-VI norms will bring much needed reduction in the emissions in the exhaust of the vehicles.

## 10. Acknowledgement

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