PAPER • **OPEN ACCESS**

Experimental study of filtration behavior of diesel particulate filter in a diesel engine to meet BS-VI emission norms in INDIA

To cite this article: Gurkamal Nain Singh and Rabinder Singh Bharj 2019 *J. Phys.: Conf. Ser.* **1276** 012078

IOP Conf. Series: Journal of Physics: Conf. Series **1276** (2019) 012078 doi:10.1088/1742-6596/1276/1/012078

Experimental study of filtration behavior of diesel particulate filter in a diesel engine to meet BS-VI emission norms in INDIA

Gurkamal Nain Singh[1*] & Rabinder Singh Bharj[1]

[1]Department of Mechanical Engineering, Dr B R Ambedkar National Institute of Technology, Jalandhar-144011, Punjab, India

*Email: gurkamaln.15.phd@nitj.ac.in

Abstract. Due to upcoming Bharat Stage -VI emission norms, emission control has to become mandatory for every vehicle in India. Bharat Stage-VI are the stringent emission norms to be introduced by the Indian government for controlling the vehicle exhaust emissions. Diesel powered vehicles are more popular because of its high thermal efficiency, lower fuel consumption, and lower CO_2 emission compared to the petrol engine. Although, diesel-powered vehicles produce more oxides of nitrogen and particulate matter. Diesel particulate filter (DPF) is the new technology to abate the particulate matter. In this paper, a DPF was installed into the exhaust of a single cylinder direct injection diesel engine. In order to investigate the filtration efficiency of DPF and its effect on fuel economy, indicated power and emission characteristics, experiments were conducted on a single cylinder diesel engine test rig. Results showed that after installing the DPF on the engine exhaust there was more than 90% reduction in particulate matter, while specific fuel consumption was increased by about 4% and indicated power was decreased by approximate 2KW.

1. Introduction

Diesel engine plays a key role in global transportation. High fuel economy and efficiency make diesel engine more attractive compared to other power source engines. Diesel engines are used for several purposes as power generation, farming, construction and industrial activities [1]. Moreover, diesel engines have a big market share of light-duty vehicles. But, the nature of its combustion process, it produces more particulate matter and NOx compared to the petrol engine and this leads to rising health concerns [2]. To reduce the tailpipe emission, the Indian government has pronounced to enforce the hardest emission standards norms of BS-VI from the current BS-IV by April 2020 via bouncing BS-V standard, the proposed standard limits are as shown in Table 1. Diesel powered vehicles are more responsible for the generation of air pollution, especially NOx and particulate matter. In order to comply with this stringent emission legislation, significant further progress is required in diesel engines. Stringent Indian emission norms enforce vehicle manufacturer to use an exhaust after-treatment system in diesel vehicles. Diesel particulate matter is more concern pollutant among various deleterious pollutants, which have an adverse effect on human health. Diesel particulate filter (DPF) is the most effective particulate matter abatement device, which was first introduced in the year 2000 in Europe. It has approximately 97% filtration efficiency [3]. Philip G Blackman et al. [4] carried out the study on emission control to achieve Euro IV and Euro V on heavy duty vehicle. Some researchers have studied hexagonal and square diesel particulate filters under controlled and uncontrolled catalyzed regeneration. The cell structure of the particulate trap determines the pressure drop in the substrate channel wall. The square cell is widely used in commercially available DPF, which is worldwide accepted because of easier manufacturing and lower cost. Honeycomb monolith with a hexagonal cell structure offers a lower pressure drop compare square cell structure [5]. Ohra et al. [6] found that the filtration efficiency improved from 80% to 92% by reduction the mean pore diameter of 25 to 15 micrometer. While T.Mizutani et al. [7] reported that filter means pore size smaller than 15-micrometer result in 100% efficiency. They also found that the filtration efficiency decreases on increasing mean pore size up to 20% and after it, there is no change in filtration efficiency. Cordierite ($2MgO.2Al_2O_3.5SiO_2$) is the most extensively used ceramic material for extruded monolithic substrates [8]. Cordierite has a set of exceptional properties including high porosity, low thermal expansion, high thermal shock resistance, and a tailored microstructure. Cordierite has the advantage of the choice of cell shape and size, wall porosity and microstructure through advanced ceramic substrate technology. Ceramic monoliths are prepared from synthetic cordierite [9]. There are several challenges related to upgradation of automotive engineering from BS IV to BS VI out of which technology upgradation in conforming to BS IV to BS VI is an essential task which is under progress. In BS VI standards, first time, a particle number (PN) emission limit is to be introduced for diesel engines. This standard will further reduce the PM emission limits and to achieve these limits, all diesel cars will need to be fitted with particulate filters [10]. Till now DPF was not fitted to diesel vehicle in India but due to BS-VI norms, DPF will become mandatory to a heavy vehicle. So, this study is about knowing the filtration behavior of DPF and its effect on the performance of the diesel engine.

Table 1. BS IV and BS VI Emission Standards for Medium Duty Automotive Diesel Vehicles [11]

Pollutant Type (In g/Km)						
Stage	CO	HC	HC+NOx	NOx	PM	PN
BS IV	0.50	-	0.30	0.25	0.0250	-
BS VI	0.50	-	0.17	0.08	0.0045	6.0 x 10^11

Note: CO-Carbon monoxide; HC-Hydrocarbon; NOx-Oxides of Nitrogen; PM-Particulate Matter; PN-Particulate Number.

2. Experimental setup and research method

Diesel particulate filter was tested on exhausted gases produced by single cylinder engine fired with diesel and coupled with an eddy current dynamometer. The engine was water-cooled, indirect injection, four strokes, and single cylinder diesel engine. The eddy current dynamometer is equipped to control the engine at the desired speed/load combination. Detailed specifications of the engine are given in Table 2.

Table 2. Diesel engine specification

Maker	Kirloskar
Model	TV1
Type	Four stroke, water cooled, Diesel engine
Number of cylinder	Single
Bore and stoke	8705mm×110mm
Compression ration	17.5:1
Cubic capacity	661
Rated power	5.2 kw@1500 RPM

In experimental work, DPF which is made of cordierite material was equipped in the exhaust of diesel engine. Diesel particulate filter consists of a stainless steel cylinder that holds the ceramic honeycomb filter. Inlet pipe of filter housing connected to exhaust manifold of the diesel engine. White cement is used to fill the gap between the housing pipe and substrate to ensure no escape of exhaust gas go through the gap as shown in figure 1.

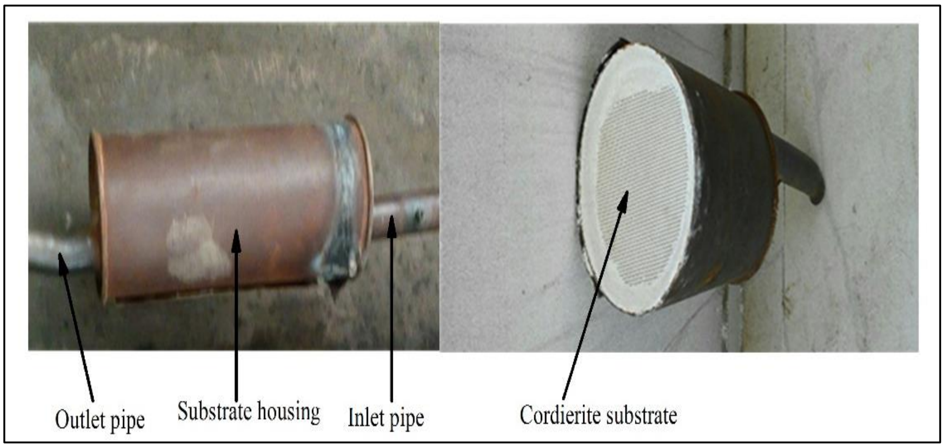

Figure 1. Assembly of Diesel Particulate Filter

Indicated power, specific fuel consumption, and smoke are taken into consideration from diesel engine setup. AVL 437 was used to measure the smoke percentage in the exhaust gas. The principle of measuring smoke from AVL 437 is based on extinction of light beam by scattering and absorbing by the smoke indefinite length of the tunnel. The diesel engine was connected to the DPF system. When a steady state was achieved, engine performance readings were taken at various loads. The experimental setup is shown in figure 2.

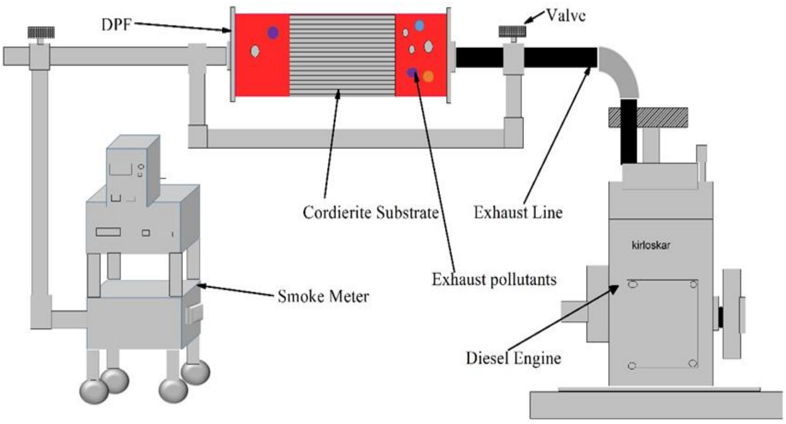

Figure 2. Schematic diagram of the experimental setup

3. Result and discussion

3.1. DPF effect on fuel economy

The trend for specific fuel consumption (SFC) with respect to varying load with and without DPF while engine running at constant speed (1400rpm) are shown in figure 3. It is clear from the figure, at a constant speed and higher loading condition SFC was decreased without using DPF. This is due to higher combustion efficiency at higher loads. But, when DPF is installed to exhaust stream 5% increment was noticed under the same experimental conditions. These were attributed to the increased exhaust back pressure which results in more presence of exhaust gas inside the combustion chamber. It is well known that more presence of exhaust gas led to the more pumping losses and deterioration of the combustion process. These effects turn into a decrease in combustion efficiency.

IOP Conf. Series: Journal of Physics: Conf. Series **1276** (2019) 012078 doi:10.1088/1742-6596/1276/1/012078

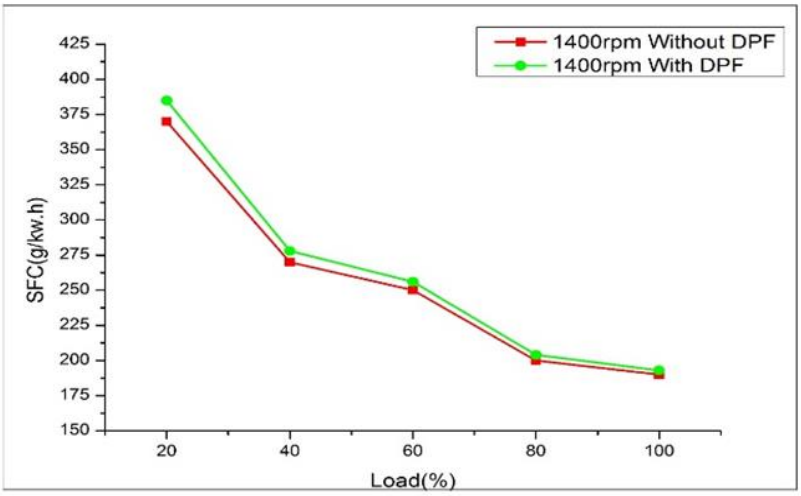

Figure 3. Specific fuel consumption with respect to Load

3.2. Smoke emission analysis

Figure 4 shows the smoke opacity which is increasing with load at a constant speed (1400rpm). The smoke emission level from engine exhaust without fitment of DPF is increasing with increase in load because of incomplete combustion in the engine cylinder. Incomplete combustion leads to increase the level of soot in the engine exhaust. But, when DPF is installed to the exhaust stream the level of smoke was decreased drastically. The decrease in the smoke emission after the installation of DPF shows the filtration effect of this device. The soot gets trap in the honeycomb structure of the filter by allowing gases to flow through its porous wall material. The efficient working of DPF filtration can be seen in Figure 4.

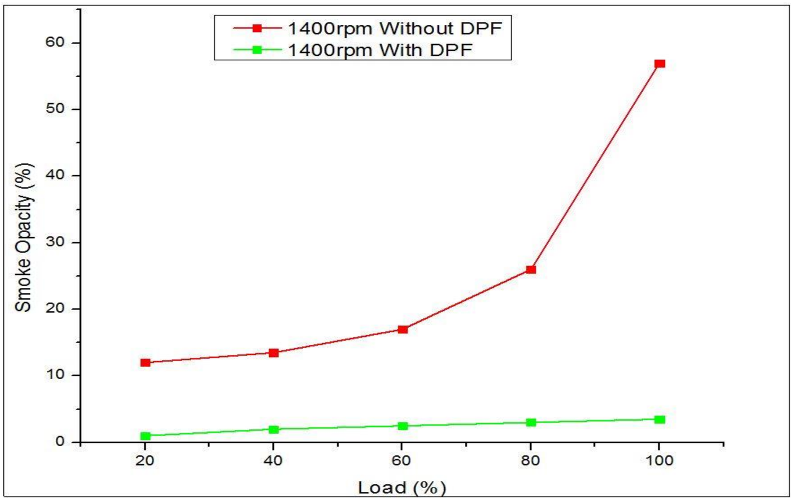

Figure 4. Smoke Opacity with respect to Load

3.3. DPF impact on NO_X formation

NOx emission was increased with the rise in load at a constant speed (1400 rpm) as it can be seen in Figure 5. The reason behind is: as load increases the average air-fuel ratio of the gas mixture decreases due to an increase in cylinder temperature which leads to an increase in NOx formation. Whereas when

DPF was installed to exhaust stream negligible increase in NOx formation was observed, it can be due to the back pressure developed in engine cylinder which raises the in-cylinder temperature resulting in a slight rise in NOx formation. On account, the NOx level was increased with the DPF in exhaust stream which was approximately 1% compared to the exhaust measured without DPF.

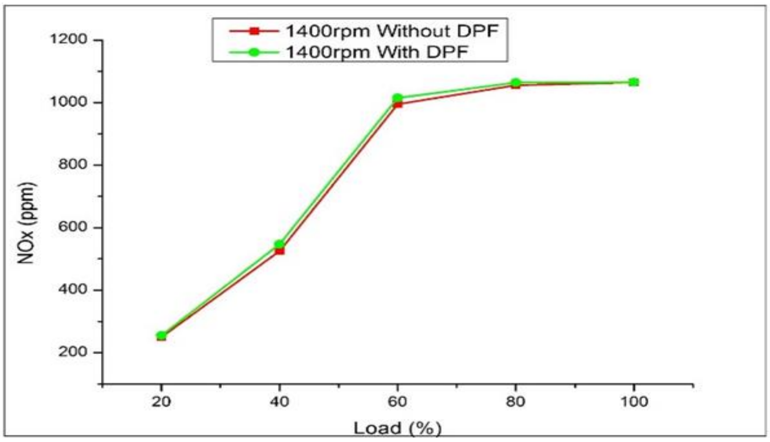

Figure 5. NOx emission with respect to load

3.4. DPF filtration efficiency characteristics

AVL437 smoke meter has been used to evaluate DPF filtration efficiency. To measure smoke opacity, AVL smoke meter uses the light to detect smoke activity in specific channel length. In order to know the DPF filtration efficiency, smoke opacity with and without DPF is measured. DPF filtration efficiency formula can be described as.

$$\eta = \frac{c1-c2}{c1}$$

Where C1 and C2 are smoke opacity measured by smoke meter before and after installing the DPF respectively. It is observable from figure 6 that efficiency increases gradually with increasing load. This is because as the load is increased, the exhaust gas temperature, air flow viscosity will be increased and soot particle will do a Brownian movement that spread more strongly.

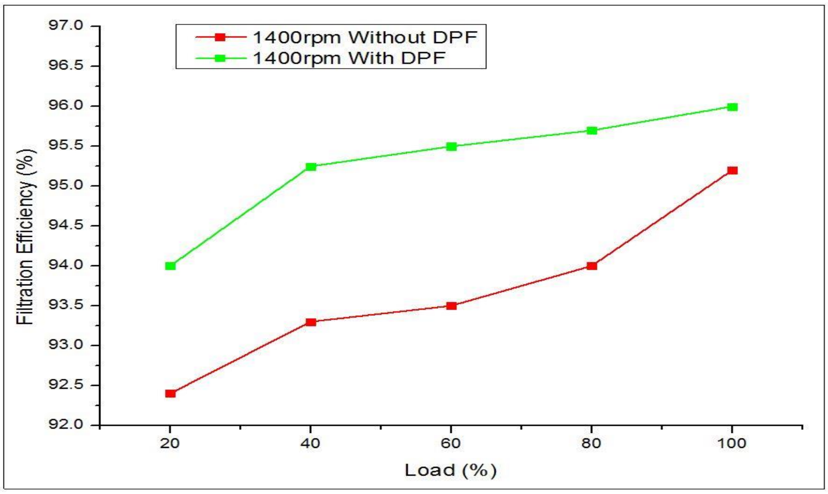

Figure 6. Filtration efficiency with respect to Load

IOP Conf. Series: Journal of Physics: Conf. Series **1276** (2019) 012078 doi:10.1088/1742-6596/1276/1/012078

3.5. DPF influence on Indicate power

Engine indicated power decreases when DPF is installed to engine exhaust as it is shown in figure 7. This is because of increased back pressure which leads to thermodynamic changes in the combustion process. The pressure drop of DPF is increased as soot particle from a diesel engine is accumulated at filter wall. DPF installing leads to decrease in 2 kW power.

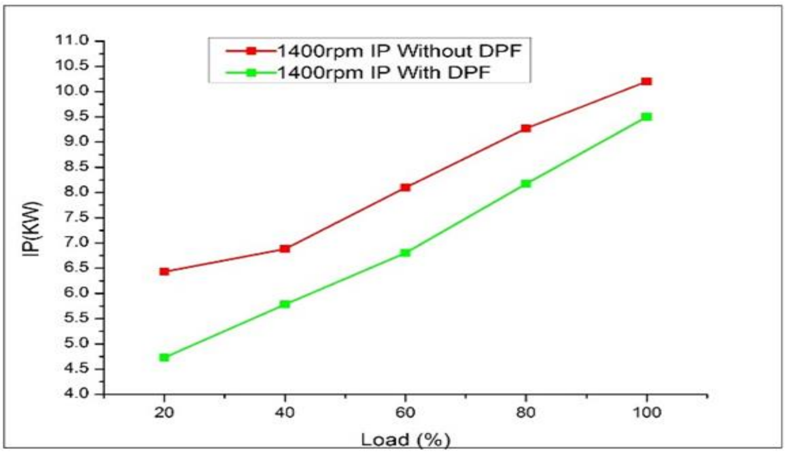

Figure 7. Indicate power with respect to load

3.6. Engine speeds effect on PM

It can be seen from figure 8 that smoke percentage increases as speed increases. These results show that the speed vs. smoke trend also is similar to load vs. smoke. It is well known that engine speed has an impact on particulate emission of diesel engines. When engine speed is increased, the air-fuel ratio decreases to the same extent. Due to which, incomplete combustion leads to more soot or smoke formation. Further, when the engine speed is increased time available for combustion decreases which are responsible for soot formation. From the figure, it can be concluded that there is no significant effect on DPF filtration efficiency as speed is varied.

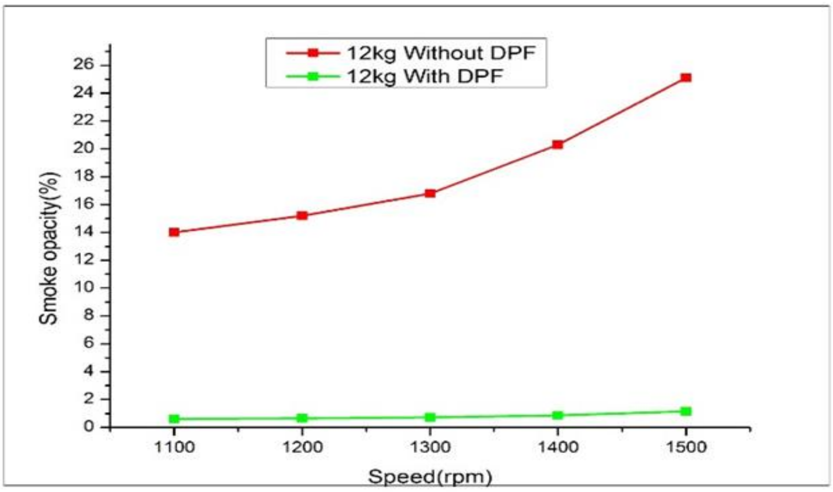

Figure 8. Variation in Smoke opacity with respect to varying RPM

4. Conclusions

The following conclusions can be drawn based on the above experimental results of this study.

- After installing DPF, Indicated power was decreased by 2 KW, while the minute effect on NOx formation.
- Soot was reduced from the tailpipe of the diesel engine by 95% with the installation of DPF.
- DPF causes no adverse effect on fuel consumption after installing the DPF to engine exhaust. It's reduced by 5% fuel consumption which is not a big matter of concern compared to health risk produced by smoke.
- DPF filtration efficiency increases on increasing the load because of Brownian movement that spread more strong at higher load.

Further, the use of DPF as an after-treatment device will involve some challenges; subsequently, the constant flow of soot into the filter would ultimately block it, so it will be essential to regenerate the filtration properties of the filter by burning-off the accumulated particulate on a regular basis. In the process of doing that, there should not be any kind of compromise with fuel efficiency and a good test facility is required to develop a good DPF. There is also the challenge of assembling the after-treatment devices in the limited space without compromising with fuel efficiency. The aggregates of DPF will increase the weight of the vehicle. The additional weight can impact fuel efficiency.

References

[1] Ramanathan V 2007 Global dimming by air pollution and global warming by greenhouse gases *Nucl. & Atm. Aer.* **6** 473-83

[2] Seaton A, MacNee W, Donaldson K and Godden D 1995 Particulate air pollution and acute health effects *Lancet* **345** 176-8

[3] Hawker P, Myers N, Huthwohl G, Vogel H, Bates B, Magnusson L and Bronnenberg P 1997 Experience with a New Particulate Trap Technology in Europe *SAE paper* 970182

[4] Chatterjee S, Walker AP, and Blakeman PG 2008 Emission Control Options to Achieve Euro IV and Euro V on Heavy Duty Diesel Engines *SAE Tech. Pap. Ser.*

[5] Tsuneyoshi K and Yamamoto K 2012 A study on the cell structure and the performances of wall-flow diesel particulate filter *6th Dubrovnik Conf. Sustain. Dev. Energy Water Environ. Syst. SDEWES 2011* **48** 492–99

[6] Ohara E, Busch P and Vogt CD 2007 Filtration Behavior of Diesel Particulate Filters (1) *SAE Tech. Pap. 2007 World Congr. Detroit, MI; United States*

[7] Mizutani T, Kaneda A, Ichikawa S, Kurach H, Vogt CD, Tanka M, Martin A, Fajii S and Busch P 2007 Filtration Behavior of Diesel Particulate Filters (2) *SAE Tech. Pap. 2007 World Congr.*

[8] Saracco G and Fino D 2001 Advances in Environmental and Pollution Control Materials *Mrs Singa. Publ.* **1** 273-85

[9] Johnson JH, Bagley ST, Gratz L and Leddy D 1994 A Review of Diesel Particulate Control Technology and Emission Effects *SAE paper No. 940233*

[10] Bharj RS, Kumar R and Singh GN 2019 On-Board Post-Combustion Emission Control Strategies for Diesel Engine in India to Meet Bharat Stage VI Norms In *Advanced Engine Diagnostics* (pp. 105-125) Springer, Singapore.

[11] Bansal G and Bandivadekar A 2013 Overview of India's vehicle emissions control program. ICCT, Beijing, Berlin, Brussels, San Francisco, Washington.