A

Dissertation Report

On

Regeneration of Diesel Particulate Filter Installed on Mahindra 4 Cylinder 2.1 Liter Diesel Engine

Submitted in Partial Fulfillment for the Award of Degree of

Master of Technology in Energy Engineering

By

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CERTIFICATE

This is certified that the dissertation report entitled **"Regeneration of Diesel Particulate Filter Installed on Mahindra 4 Cylinder 2.1 Liter Diesel Engine"** prepared by **Pushkar Chandra** (ID-2013PME5136), in the partial fulfillment of the award of the Degree **Master of Technology** in **Energy Engineering** of Malaviya National Institute of Technology Jaipur is a record of bonafide research work carried out by him under my supervision and is hereby approved for submission. The contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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DECLARATION

I **Pushkar Chandra** hereby declare that the dissertation entitled **"Regeneration of Diesel Particulate Filter Installed on Mahindra 4 Cylinder 2.1 Liter Diesel Engine"** being submitted by me in partial fulfillment of the degree of **M. Tech. (Energy Engineering)** is a research work carried out by me under the supervision of **Prof. Dilip Sharma,** and the contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma. I also certify that no part of this dissertation work has been copied or borrowed from anyone else. In case any type of plagiarism is found out, I will be solely and completely responsible for it.

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2013PME5136

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Abstract

The emission norms for I.C. engines are becoming stringent day by day, to meet out these emission norms in existing engines there is a need to modify them. This modification may either be in the form of combustion improvement technology or an after treatment technology. It is difficult to meet the emission norms only by the combustion improvement technologies. An after treatment technology also plays an effective role in curbing down the emissions. Particulate Matter (PM) form a major emission in C.I. Engines. It has been a challenge to trap these PM since last few years due to their adverse effect on human health. Diesel Particulate Filter (DPF) emerged as a promising technology to filter these particulate matters from the engine emissions with filtration efficiency around 90-95%.

With the accumulation of particulate matter on the DPF, backpressure in the exhaust line increases. This increased back pressure affects the performance of the engine. So the DPF must be regenerated by burning off these accumulated PM and to keep the back pressure under acceptable limit. The regeneration of DPF can be done by two methods. In first method, the DPF must take out from exhaust line and the accumulated carbon is burned by some means. On the other hand in second method, the DPF is regenerated by keeping it in the exhaust line and raising the temperature of the exhaust gas by accelerating the vehicle or by injecting some fuel in the exhaust line. It will burn the accumulated carbon particles hence bring the backpressure down within the acceptable limit.

The experiment was performed on a Euro1, 4 cylinder, 2.1 l diesel engine with a wall flow, uncoated Diesel Particulate Filter. The effect of DPF on engine emissions and performance was analyzed. The choked DPF was regenerated by 2 methods as discussed. The regeneration has been done at various level of back pressure and emissions during the regeneration were measured. Result shows that DPF causes 94% reduction in the smoke opacity with a 3% decrease in brake thermal efficiency. The back pressure came down to 6 kPa from 10 kPa on regeneration. An increase in the emission of NO_x, CO_2 was observed during regeneration.

Table of Contents

List of Figures

List of Tables

Abbreviations

DPF	-	Diesel Particulate Filter
PM	-	Particulate matter
FBC	-	Fuel borne catalyst
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
DOC	-	Diesel oxidation catalyst
DI	-	Direct injection
H_2	-	Hydrogen
HC	-	Hydrocarbon
BPT	-	Balance point temperature
CPSI	-	Cells per square inch
LPG	-	Liquefied petroleum gas
LDV	-	Light-duty vehicle
NO	-	Nitrogen oxide
NO_2	-	Nitrogen dioxide
NOx	-	Oxides of nitrogen
O_2	-	Oxygen
PPM	-	Parts per million
SO_2	-	Sulfur dioxide
SOF	-	Soluble organic fraction
^oC	-	Degrees Celsius
ECU	-	Electronic control unit
BTE	-	Brake thermal efficiency
BSFC	-	Brake specific fuel consumption

CHAPTER 1

INTRODUCTION

Diesel engines are mainly used in on road and off-road vehicles such as trucks, buses and special vehicles (building machines, municipal car parking, agriculture machines generators etc.) because of their reliability and energy efficiency. The main disadvantages of these different types of vehicles are the harmful emission of particulate matter (PM) and nitrogen oxides (NO_x). Nitrogen oxides (NO_X) and particulate matter (PM) emission control from diesel engines is far more complex and requires the implementation of relatively new technologies involving fuel injection control, air management, after treatment and system integration. The relative composition of these emissions is a complex function of fuel properties, fuel additives, Engine specifications, maintenance level and the engine load. TAN Pi-qiang et al. carried out a study to understand the effect of fuel properties on diesel engine exhaust emissions. They found through experiments that the emission level decreases with decrease in fuel aromatic content. With cetane number ascending, the exhaust smoke, PM & HC emissions decline while NOx & COx emissions have very small change. According to the German Federal Environmental Agency (UBA), 49% of the particulate matter and dust 43% of the nitric oxide in road traffic are emitted by diesel engines.

The concern for human health from exposure to diesel engine exhaust arose in mid – 1900s . Due to the increasing number of automobiles, emission levels increased and the concern for human health also increased. This leads to the development of emission regulations and research to improve the technologies for emission reductions.

1.1 Diesel engine combustion

Combustion in diesel engine completes in four phases: such as ignition delay, premixed combustion, mixing controlled combustion and late combustion. In diesel engine air is compressed during compression stroke due to which its temperature and pressure is increased then liquid fuel is injected into the engine cylinder where it evaporates and mixes with the air. After the short ignition delay period, the spontaneous ignition starts and initiates the combustion, which raises the in-cylinder pressure to a much higher level. The burned products along with those unburned are then discharged into the after-treatment system, before being emitted to the atmosphere.

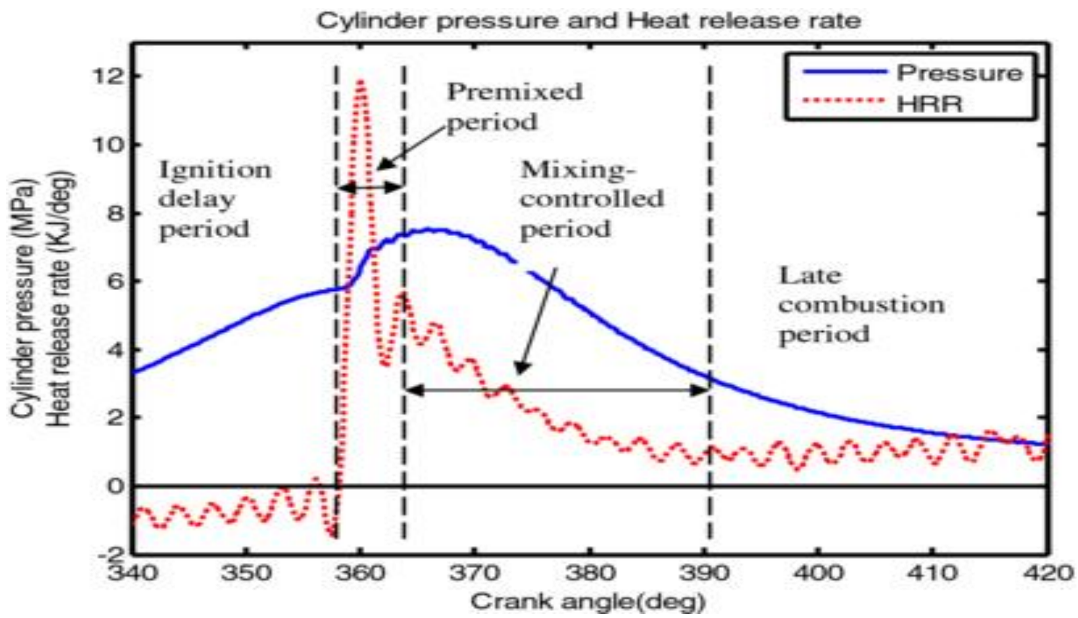


Fig.1.1 Combustion process in diesel engines [16]

1.2 Emission Regulations

In order to mitigate the adverse effects of pollutants on human health and environment, there are certain laws on emission standards, which limit the amount of each pollutant in the exhaust gas coming out of an automobile engine. Emission regulations set specific limits to the amount of pollutants that can be released into the environment with minimal hazardous effects on the environment.

Bharat stage emission standards are emission standards formulated by the Government of India to regulate the output of air pollutants from internal combustion engine equipment, including motor vehicles. The first emission norms were introduced in India in 1991 for petrol and 1992 for diesel vehicles. These were followed by making the Catalytic converter mandatory for petrol vehicles and the introduction of unleaded petrol in the market. Indian standards are now based upon the Euro norms. On 29 April 1999 the Supreme Court of India ruled that all vehicles in India have to meet Euro I or India 2000 norms by 1 June 1999 and Euro II will be mandatory in the NCR by April 2000.

The details of Euro norms adapted to Indian conditions are given in the following table:-

Stage	**Year**	**CO**	**HC+NOx**	**NOx**	**PM**
		gm/km			
Euro I	1992	2.72 – 3.16	0.97 – 1.13	-	0.14 – 0.18
Euro II	1996	1.0	0.7 – 0.9	-	0.08 – 0.10
Euro III	2000	0.64	0.56	0.50	0.05
Euro IV	2005	0.5	0.3	0.25	0.025
Euro V	2011	0.5	0.23	0.18	0.005
Euro VI	2014	0.5	0.17	0.08	0.005

Table 1.1 Emissions Regulation for diesel engine passenger cars [17]

1.3 Diesel particulate matter

The Diesel particulate matter (PM) emitted by the diesel engine consist mainly of [18]

1. Solid particles: carbonaceous soot particles and inorganic ash particles.

2. The soluble organic fraction (SOF): volatile soluble organic compound, originating from unburned fuel and lubricating oil, nucleated as particles or adsorbed on solid particles.

3. Sulphuric acid and sulphate particles originating from SO_3.

These airborne solid particles contained in the PM are feared to cause bronchi tic asthma and lung cancer. Particulate matters are determined by its sampling method. PM sampling includes drawing a sample of exhaust gases from the vehicle’s exhaust system, diluting it with air, and filtering through sampling filters. The mass of particulate emissions is determined by the weight of PM collected on the sampling filter but there are many changes in the procedure, for example using a different type of sampling filter or different dilution parameters, may produce different results.

These particulate matter emitted by the diesel engine can be controlled by Diesel particulate filter (DPF). The DPF can effectively control the solid particles component of diesel PM such as soot and ash particles. However it may not be effective at controlling the SOF or sulphuric acid/sulphate component, which may need to be controlled using other means.

1.4 Diesel particulate filter

It is also called ‘particulate trap’. Diesel particulate filter is a device use to filter out solid particulate component from particulate matter such as soot and ash particles when diesel exhaust flows through it. It has high filtration efficiency up to 90-95%. It is a porous substrate which physically captures the PM as exhaust gas flows through it. The substrate material for DPF mat be ceramic wall flow monolith or sintered metal or metal fibers or ceramic and metal form. But ceramic wall flow monoliths are widely used at the current time. These filters are also called ‘ceramic wall-flow filter’.

1.5 Principle of Operation

A DPF consist of a porous filter substrate which physically capture the PM as the exhaust gas passes through the substrate. Wall flow filter are most widely used filter. In this honeycomb type particulate filter alternate channels are closed at one end and open at opposite end. The exhaust gas flows in open channels and since the same channel is closed from the other end so the exhaust gas is forced to flow from the porous wall between two channels. The solid carbon particles stuck in this filtration medium and the gaseous emission escape to the atmosphere.

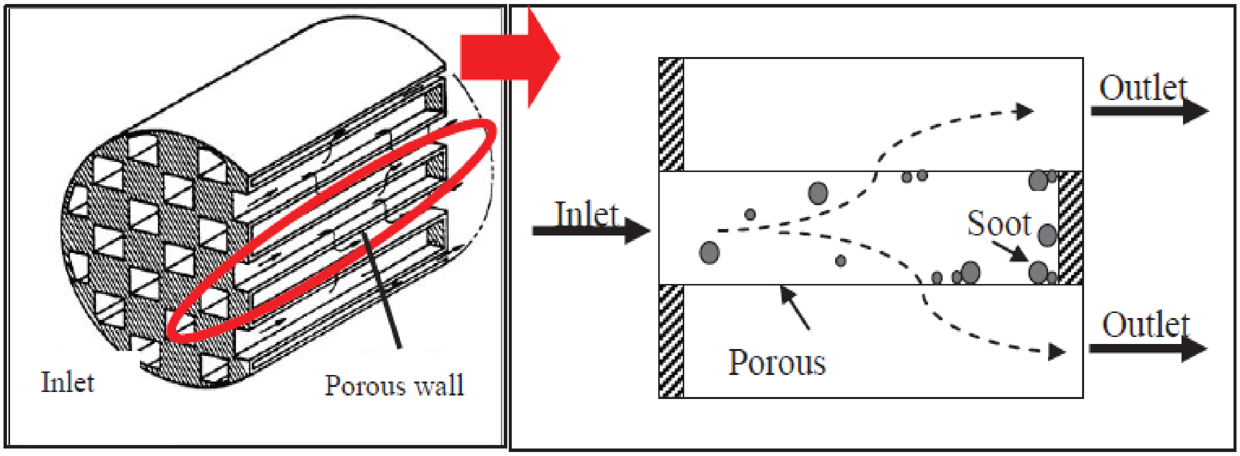


Fig. 1.2 A wall-flow monolith honeycomb design (L), Detail inside view (R)

1.6 The Filtration Process

The DPFs function by physically capturing and withholding the PM suspended in the exhaust gas as this passes through the porous filter substrate. Filtration can be divided into deep bed filtration where the PM is captured and withheld throughout the depth of the substrate material, and surface filtration where the PM is captured on the surface of the substrate material and lead to formation of the filtration cake.

The performance of the DPF is measured in terms of its filtration efficiency which can be define as the ratio of the rate at which PM is collected by the filter to the rate at which PM enters the filter. It is also important to consider the pressure drop that arises in the DPF due to the resistance that the porous material of the filter substrate and the particle deposit in the filter present to the exhaust gas passing through the filter. The pressure drop gives rise to a backpressure of equal magnitude in the exhaust system which results in a fuel economy penalty for the engine. The pressure drop depends on the permeability of the filter substrate material and the permeability of the soot deposits.

Usually, filter substrate having an open pore structure (large pore size) have low filtration efficiency and low pressure drop whereas filter substrate having a closed pore structure (small pore size) have high filtration efficiency and high pressure drop. The efficiency of the surface or cake filtration may reach very high value since the particulate deposits themselves act as a filtration medium for other PM.

1.7 The regeneration process

The regeneration process is of critical consequence to the durability of the DPF because during this process DPF can be exposed to high temperature that damage the substrate material and result in the DPF failure. Therefore, although the primary function of a DPF is to filter the PM in the exhaust gases, DPF regeneration is the most important issue in the DPF research and development.

During the regeneration process, the accumulated soot deposits in the filter is oxidized to gaseous products to prevent further built up of these deposits and an excessive backpressure in the exhaust system. The soot can be oxidized by oxygen (O_2) thermally or catalytically using a soot oxidation catalyst and can also be oxidized by nitrogen dioxide (NO_2) if this is present in sufficient quantities.

The oxidation of the soot by oxygen can be proceed via two reaction paths:

$C + O_2 \rightarrow CO_2$

$C + \frac{1}{2} O_2 \rightarrow CO$

Thermal oxidation of soot by oxygen occurs at temperature above the soot ignition temperature of approximately 550-600°C whereas catalytic oxidation of soot by oxygen using a soot oxidation catalyst can occur at lower temperature.

Oxidation of soot by NO_2 occurs primarily via one reaction path:

$C + NO_2 \rightarrow CO + NO$

Oxidation of soot by NO_2 can occur at significant lower temperature compared to oxygen. Engine out NO_x emission usually consist mostly of NO and little NO_2. However, the NO_2 fraction can be increased according to the reaction.

$2\ NO + O_2 \rightarrow 2\ NO_2$

The conversion of NO to NO_2 is kinetically controlled at lower temperature and therefore initially increases with temperature. However, above a certain temperature NO conversion decreases progressively due to thermodynamic limitation. The platinum catalyst used to promote NO to NO_2 oxidation also exhibit comparable activity for SO_2 to SO_3 oxidation and prone to inhibition by SO_2 and can result in the formation of sulphate particle. Therefore, they have to be used with very low sulphur fuel.

The regeneration process can be viewed as a dynamic process in which the difference between the rate of soot accumulation due to filtration and the rate of soot removal due to oxidation determines whether the mass of the soot in the filter is increasing or decreasing. The rate of soot accumulation due to filtration depends on the soot emission rate of the engine and the filtration efficiency of the filter. The rate of soot removal due to oxidation depends on the oxidation reaction rate which in turn depends strongly on the temperature of the filter. In general the oxidation reaction rate increases with increasing temperature and therefore at high exhaust gas temperature the rate of soot removal due to oxidation tends to be higher than at low exhaust gas temperature. Therefore, depending also on the rate of soot accumulation due to filtration, and all else being equal, at low exhaust gas temperature the soot mass load tend to be increasing whereas at sufficiently high exhaust gas temperature the soot mass load tends to be decreasing.

The exhaust gas temperature of the diesel engine is usually below the soot ignition temperature of approximately 550-600°C. Therefore, to regenerate the DPF it is necessary to facilitate soot oxidation catalytically at the exhaust gas temperature encountered under typically engine operating condition or to facilitate soot oxidation thermally by increasing the temperature of the soot to above its ignition temperature.

The soot can be oxidized at temperature below its ignition temperature using a soot oxidation catalyst and using catalytically generated $NO_{2.}$ In principle this can enable the filter to regenerate at lower temperature. However the degree to which this is possible also depends greatly on the exhaust temperature dynamics under typical engine operating condition.

Alternatively, the filter can be regenerated by actively increasing the temperature of the soot to above its ignition temperature. This may involved the use of engine management methods to increase the temperature of the exhaust gas and/or other methods to increase the temperature of the exhaust gas or the filter.

It is noted that if a regenerating filter is operated at low exhaust gas temperature for prolonged time or if the time between regeneration of filter is too long then the soot mass load may increase sufficiently to enable uncontrolled regeneration. In this event, because of large soot mass load, the heat release from the soot oxidation reaction is sufficient to raise the temperature of the filter to above the soot ignition temperature and therefore to sustain the thermal oxidation of the soot until all the soot is oxidized. The heat release may be so large that the temperature of the filter exceeds the melting temperature of the substrate material or the substrate cracks because of exceedingly high thermal stresses.

1.8 Classification of regeneration system

When diesel particulate matter are deposited on the filter then back pressure increases which results in decrease in engine performance and engine may be reach in Stalling condition so it is necessary to clean the filter by oxidizing the carbon particles .

There are two approaches by which particulate matter may be burn off.

1. **Active Regeneration**
2. **Passive Regeneration**

The active regeneration refers to regeneration that heats the internal temperature of DPF to burn PM with the help of external energy. The passive regeneration refers to regeneration that uses the energy from exhaust of diesel engine. In order to realize passive regeneration, catalysts are commonly used to decrease burning temperature of PM.

1.8.1 Active Regeneration-:

In this type of regeneration, the temperature of exhaust gases increases up to 550-600˚C. When the oxidation starts, the exothermic reaction sustain the combustion of soot particles which can increases thermal stresses and filter may be melted or damage. So the different type of pressure sensors is used for monitoring the pressure drop across the filter by obtaining signals. The exhausts gas temperature increases by following techniques.

- Use of electric heater upstream of the filter
- Use of burner upstream of the filter
- Regeneration with Fuel Additives

- Catalytic Coating of Trap Material
- Continuously Regenerating System (CRT)

Use of Electric Heater Upstream Of the Filter

In this type of regeneration the carbon particles gets burn off by electrically operated heater. The power is supplied for heater by the engine alternator. It needs a high battery back-up and all the process is to be done while vehicle in garage. This type of method has been used until now for stationary electrical regeneration of particulate traps, but it is not practicable in mobile applications because its higher energy demand.

Use of Burner Upstream Of the Filter

A diesel fuel burner is placed in the exhaust in front of the diesel particulate filter for regeneration. This type of system can perform at all engine speed and loads.

Two types of system may be used-

- Burner full-flow system
- Burner by-pass system

In full-flow type system, the total exhaust gas is to be heated to about 540˚C. A large air pump is required & high burner fuel consumption is needed. It is very complex to control the burner fuel flow to maintain safe levels of the gas temperature at inlet of DPF are necessary.

In by-pass type system a small part of exhaust is allowed to flow through the diesel particulate filter for regeneration. In this system small air pump is required. The fuel consumption by the burner is low as compared to full-flow type.

Regeneration with Fuel Additives

This type of regeneration enables to oxidize the particulate matter collected in the trap at low temperature as 300-400˚C. Various types of fuel additives such as Fe, Ce, Mn, Zn, CU, Pt and Pb are used diesel particulate filter for regeneration.

Two types of fuel additives have recently been classified as very promising. The first one is a cerium based additive and second one is Fe-additive. In these additives, metal oxides are used as substances with a catalytic activity. This type of regeneration is very efficient and economic.

Catalytic Coating of Trap Material

The trap material can be coated with catalytic active substances which is as efficient as fuel additive. It seems to be possible to reduce the oxidation temperature of the soot about 200˚C.

Continuously Regenerating System (CRT)

This type of system consists of an oxidation catalyst and particulate trap. Diesel exhaust gas first passes through the catalyst where carbon monoxide (CO) and hydrocarbons (HC) are converted at a temperature range of 200 to 600˚C. Also nitrogen monoxide (NO) is converted into NO_2. This NO_2 converts the carbon (C) in the particulate filter into Carbon dioxide (CO_2). Consequently NO_2 will be reduced again to NO. This type of regeneration occurs at a temperature range 200 to 450˚C. This method has not yet found large scale application as the CRT-system only works with sulfur- free diesel fuel (below 10 PPM) so called “city diesel”.

1.8.2 Passive regeneration

Engine throttling

The combustion increases due to throttling of air which in turn reduces air flow and overall air fuel ratio in results the exhaust gas temperature increases. The main disadvantage of this technique is the increase in the engine pumping losses which in results in loss of fuel efficiency.

Another it decreases oxygen concentration in the exhaust and for oxidation 2-5% of oxygen in the exhaust is necessary. Under normal cruising condition, throttling is unable to increase the exhaust temperature to the levels needed for regeneration.

It can be work only higher loads and also increases HC, CO & smoke emission. It has limited success.

CHAPTER 2

LITERATURE REVIEW

2.1 Diesel particulate size distribution

Diesel particulates have a bimodal size distribution which involves small nuclei mode particles and larger accumulation mode particles. Most of diesel particle mass is contained in the accumulation mode. On the other hand, most of the particle number uses to found in the nuclei mode. Although the exact composition of diesel nanoparticles is not known, it is believed that they are composed primarily of condensates (hydrocarbons, water, and sulfuric acid). Spark ignited engines also emit numbers of small particles which are comparable to those from diesel engines. Ambient particulate matter is generally divided into the following categories based on their aerodynamic diameter. The aerodynamic diameter is defined as the diameter of a 1 g/cm^3 density sphere of the same settling velocity in air as the measured particle.

- PM_{10}—particulates of an aerodynamic diameter of less than 10 µm
- Fine particles of diameters below 2.5 µm
- Ultrafine particles of diameters below 0.1 µm or 100 nm
- Nanoparticles, having diameters of less than 50 nm

Figure 1.2 shows the distribution of diesel exhaust particulates. A logarithmic scale is used for particle aerodynamic diameter. Usually all diesel particulates have sizes of significantly less than 1 µm. As such, they represent a mixture of fine, ultrafine, and nanoparticles.[12]

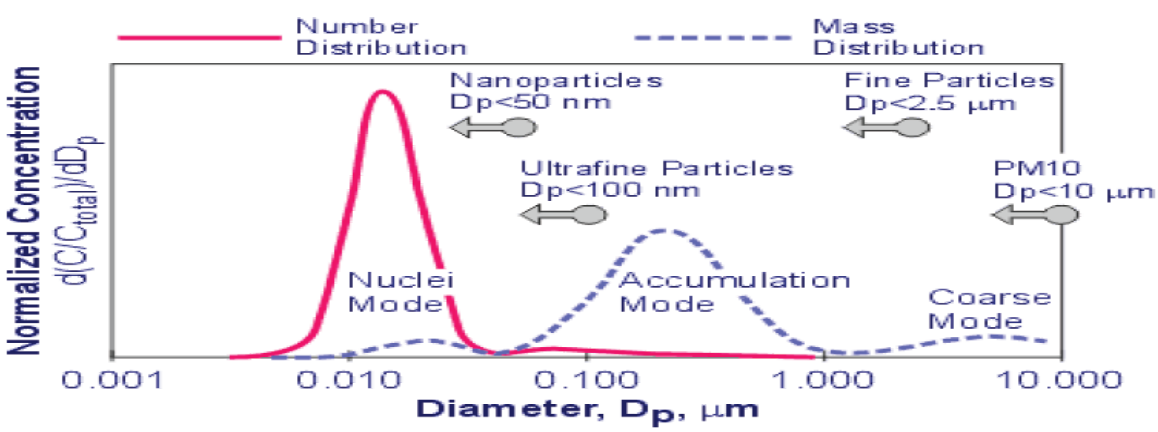


Fig.2.1 Diesel particle size distribution [13]

Abdul et.al. [2]

They measured the particle concentration and size distributions in the exhaust of a turbocharged, after cooled, direct-injection diesel engine. They found upstream of filter size distribution has bimodal, log normal structure consisting of a nuclei mode with a geometric number mean diameter in the 10-30 nm range and accumulation mode in the range of 50-80 nm. Nearly all the particulate matter found in the tailpipe before dilution is present as solid carbonaceous agglomerated and a small amount of metallic ash. There also may be a significant quantity of volatile organic compounds in the gas phase at exhaust temperatures that are transformed to diesel particulate matter (DPM) by nucleation, adsorption, and condensation as the exhaust dilutes and cools.

Bergmann et al. (2009) [11]

An experiment was conducted on a 2 litre turbo-charged common-rail direct injection diesel vehicle equipped with a catalyzed Silicon Carbide (SiC) wall-flow DPF. The vehicle was running on a Euro 4 certified diesel fuel (<10 ppm sulphur). Their experiments included both real-world chasing of the vehicle on a high-speed test track but also measurements on a chassis dynamometer. Regeneration was investigated at constant speed of 100 km/h. The size distribution of the emitted particles was measured in real time with a TSI's Engine Exhaust Particle Sizer (EEPS), which during the lab experiments was sampling directly from the tailpipe using a dilution system designed to mimic ambient dilution. Both tests revealed a formation of a distinct nucleation mode peaking at approximately 10 nm. This nucleation mode was almost 3 orders of magnitude larger than the background distribution. The latter was similar to that measured during non-regenerating conditions, being lognormal in shape with a peak at a much larger size (60-100 nm).

Mokhri et al. (2012) [8]

The analysis on a DPF using simulation approach specifically on soot filtration was reviewed. The paper discussed about the flow pattern and velocity, size of soot particles, pressure drop and also soots cake growth. They found that the area starting from the middle towards the end of the channel is the area where most soot particles are deposited based on the axial velocity of the exhaust gas and the soot cake increases the filtration efficiency and also pressure drop. The growth of soot cake thickness starts at the end of the channel and increases constantly along the channel.

2.2 Effect of Diesel Particulate Filter on engine emissions

Gangel et al. [1]

They described the effect of the Diesel Particulate Filter on engine emissions. The test was conducted on two heavy duty vehicles. It was a undermine study during the working period of the vehicles. In each case, diesel exhaust gas emissions were measured during mine production duty cycle with and without the filter and fuel borne catalyst. The exhaust back pressure and temperature were also measured. The results indicate a 61% reduction in CO, 65% increase in NO_2, 92% reduction in DPM. The amount of NOx (NO+NO_2) remains same. The ash from filter was also analyzed for various chemicals in order to develop a methodological to clean the filter.

Tzamkiozis et al. (2010) [12]

They examined the impact of the emission control and fuel technology development on the emissions of gaseous and, in particular, PM pollutants from diesel passenger cars. Three cars in five configurations in total were measured, and covered the range from Euro 1 to Euro 4 standards. The emission control ranged from no after treatment in the Euro 1 case, an oxidation catalyst in Euro 2, two oxidation catalysts and exhaust gas recirculation in Euro 3 and Euro 4, while a catalyzed diesel particle filter (DPF) fitted in the Euro 4 car. Both certification test and real world driving cycles were employed. The results showed that CO and HC emissions were much lower than the emission standard over the hot-start real-world cycles. However, vehicle technologies from Euro 2 to Euro 4 exceeded the NOx and PM emission levels over at least one real-world cycle. The NOx emission level reached up to 3.6 times the certification level in case of the Euro 4 car. PM were up to 40% and 60% higher than certification level for the Euro 2 and Euro 3 cars, while the Euro 4 car emitted close or slightly below the certification level over the real-world driving cycles. PM mass reductions from Euro 1 to Euro 4 were associated with a relevant decrease in the total particle number, in particular over the certification test. This was not followed by a respective reduction in the solid particle number which remained rather constant between the four technologies at 0.86 $*10^{14}$ km^{1} (coefficient of variation 9%).

Lapuerta et al. (2012) [13]

They conducted an experiment on a modern common-rail diesel engine equipped with diesel oxidation catalyst and diesel particulate filter. The engine was fuelled with EN-590 diesel fuel and run in a highly emissive operating mode selected among those reproducing the New European Driving Cycle. During the test the intake/exhaust conditions, intake charge, injection and combustion timing, fuel consumption and regulated emissions were measured. It was observed that the EGR (exhaust gas recirculation) ratio decreased from 30% down to 21%, shifting the combustion process away from its design parameters. In consequence, nitrogen oxides emissions increased around 60% along the test, compromising the objectives of the emission regulations. A 4% increase in fuel consumption throughout the test was measured. An energy balance revealed that such penalty was caused by increased pumping losses and, especially, by higher energy losses via exhaust gas temperature and engine coolant.

2.3 Regeneration of Diesel Particulate Filter

Okubo et al. (2008) [6]

They investigated the fundamental characteristics of PM oxidation by O_3 injection. The plasma regeneration experiment was carried out using a small diesel engine generator (219 ml and 1 kW). Most black carbon soot in the channel are continuously burned and removed at very low temperature of 250°C. The lowest consumed O_3 per unit PM mass is 10.1 g (O_3) /g (PM). The regeneration rate is 2.56 g/h in maximum. The continuous regeneration could be possible during the engine operation. It was estimated that a heavy-weight vehicle with the ozone injection DPF regeneration system can meet the new regulation by using electric power of 0.25% of the engine output.

Lance et al. (2012) [7]

They conducted a experiment to study the efficiency benefits and materials issues associated with the electrically-assisted diesel particulate filter (EADPF) device developed by General Motors (GM).They developed a DPF technology that utilizes electrical power to heat the DPF for regeneration, thereby greatly reducing the “fuel penalty”. The experiment was conducted on a 1.9 liter, 4 cylinder general motor diesel engine. DOC was installed before the DPF. They achieved a filtration efficiency of 95%. The regeneration time was reduced by 75%. A 50% fuel penalty reduction was achieved.

Bach et.al (2012) [14]

They developed and tested particulate filter with combined regeneration of fuel additive and electrical heating. They found that trap regeneration take place at low exhaust gas temperature of about 270˚C. During urban traffic, exhaust gas temperature of modern turbo-charged diesel engine is below 200˚C. The passive method with fuel additive is not sufficient to provide trap regeneration during low engine speed/load conditions. They found that continuous regeneration take place at exhaust gas temperature above 400˚C. With fuel additive the energy required for heating is reduced because the required heating capacity is lower than 2KW. In results they also found trap is able to collect more than 90% of all particulate emissions and works in all practical condition of the engine.

Seiyama et al. (2013) [4]

They regenerated the particulate filter with the help of sliding discharge on the insulator plate of mica plate. Prior to the regeneration experiment, 600L of diesel exhaust from a diesel generator operated at 90% rated load was filtered by the DPF. Discharge plasma reactor based on sliding discharge, which is a kind of surface discharge generated on an insulator by applying DC-superimposed AC high voltage, was employed to oxidize soot collected on the DPF. The experiment was carried out under low load and temperatures between 100 and 190 degree C. Experimental results show that soot was oxidized by generating sliding discharge on the surface of DPF. There was no thermal damage of the DPF. Energy efficiency, which is defined as the amount of oxidized soot per electric energy dissipated in the sliding discharge, increased with increasing the temperature as well as concentration of oxygen in the test gas. Small amount of Ag_20 was used which increased the energy efficiency of soot oxidation significantly. On the contrary, excessive amount of Ag_20 resulted in lower energy efficiency than that of DPF without Ag_20. Probably because the sliding discharge was not generated favorably due to high conductivity resulted from metal Ag. Effect of temperature and oxygen concentration on the oxidation efficiency was observed and time change of pressure loss across the DPF was also observed.

2.4 Emission during regeneration

Dwyer et al. (2010) [10]

They conducted an experiment with collaboration of California Air Resources Board (CARB) and the Joint Research Center of the European Commission (JRC). In the experiment, the emission and the particulate matter mass were measured with the PMP (Particulate Measurement Program) which is 20 times more sensitive than the traditional method. Uncoated silicon carbide wall flow DPF with cerium based fuel borne catalyst was installed on a Peugeot 407, 4 cylinder, 2l turbocharged, direct injection diesel passenger car. The regeneration event is triggered by the pressure drop. Because the actual regeneration event is strong function of the driving pattern therefore, a test was designed to trigger the regeneration event, and the vehicle was driven on the dynamometer with three back to back 50-min runs at a constant speed of 75mph (120 km/h). Gaseous and total particle number emissions were recorded using the Horiba analyzer bench and the TSI Engine Exhaust Particle Sizer (EEPS). PM filter samples were also collected on three TX40 filters with 50 min sampling time for each filter. The DPF regeneration event occurred during the last run of a second series of three 50-min runs. The gaseous emissions increase sharply during the initial engine cold start, and they decrease and become stable through most of the steady state run. The beginning of the DPF regeneration event was indicated by the sharp rise in the emission concentrations at approximately 9000 sec. into the cycle, and gaseous emissions increase significantly due to generation of an engine exotherm and subsequent regeneration. It was estimated that the period of DPF regeneration event lasted approximately 9 min.

Quiros et al. (2014) [15]

Their work specifically evaluated PM mass emissions during regeneration by measurements from the following instruments: TSI Dust Trak DRX 8533, TSI Engine Exhaust Particle Sizer 3090 (EEPS) and TSI Scanning Mobility Particle Sizer 3936L88 (SMPS), filters by gravimetric analysis, and for one test a Dekati Mass Monitor 230-A (DMM). Active regeneration by fuel injection upstream of the DPF began with the Soot Combustion Regime, where PM emissions had account median diameter (CMD) of >30 nm and some faint gray smoke was observed flowing from the tunnel. During brief moments of the Soot Combustion Regime, the Dust Trak DRX reported more than half of the mass was >1 μm. As active regeneration continued, after treatment inlet temperature increased to >500 ^{0}C, beginning the Fuel Combustion Regime, defined conversely where the CMD of the emissions was <30 nm. Under both regimes, discrepancies were observed between EEPS and SMPS size distributions and improved agreement was attained after performing a post-hoc EEPS correction procedure. The accuracy of the DMM was equivocal; the average DMM emissions rate was within five percent of the gravimetric filter, but the mass distribution was substantially shifted relative to SMPS and EEPS distributions. Uninterrupted parked active regeneration resulted in13g PM emissions from the 2007MY and 1.8g PM from the 2010MY based on filter measurements. The PM mass emissions rates, based on measurements from real-time instruments, show that the contribution of Soot Combustion Regime to total regeneration emissions decreased from 75% to 5% between the 2007 and 2010MY.

2.5 Balance point temperature

Balance Point Temperature is an important parameter for the DPF regeneration test. The BPT is defined as the temperature at which the soot accumulation rate is equal to the soot oxidation rate or at which slope of delta-p (kPa/min) is equal to zero. Only when inlet temperature is higher than BPT, the DPF began regeneration. Therefore, BPT is an important indicator for the DPF regeneration test.

Liu et al. [5]

They described the Balance Point Temperature, which is the temperature at which the soot accumulation rate is equal to the soot oxidation rate or the point at which the slop of pressure drop is equal to zero. The Diesel Engine was used for test is BORA 1.9 TDI Engine with the SiC wall-flow trap DPF. DOC is installed in front of the DPF and LPG injection and control system is installed. This system can inject LPG into the exhaust pipe to increase the engine-exhaust gas temperature. The traditional method of determining BPT is obtained by estimating, the disadvantage of the method is inaccurate. This study first researches the relationship between delta-P and DPF inlet temperature, and calculates the BPT by a quadratic equation. The result of the BPT is 357℃.

Buono et al. (2011) [9]

The experiment was conducted on a modern, electronic controlled fuel injection diesel engine. The engine was fuelled either with petroleum ultralow sulphur fuel or with biodiesel: Break even temperature (BET) was evaluated for both fuels. Results showed that on average, the BET is lower for biodiesel than for diesel fuel. The final goal was to characterize the regeneration process of the DPF device depending on the adopted fuel, taking into account the different combustion process and the different nature of the particulate matter. Overall the results suggest significant benefits for the use of biodiesel in engines equipped with DPFs. A Break Even Temperature (BET) procedure has been employed for evaluating the Diesel Particulate Trap performance with both fuels. In the case of Biodiesel, the tailpipe soot concentration, when the EGR was turned off, resulted to be approximately 50% lower than the diesel fuel, while NOx emissions were higher, in variable percentage depending on the engine running conditions. The experimental tests results highlighted that the regeneration strategy which is normally used for diesel fuel, is not well suited if the engine is fuelled with biodiesel. In fact to improve the exhaust gas temperature behaviour, it was necessary to decrease the amount of injected fuel by post-injection.

2.6 Aging factor of DPF

Xinyun et al. (2011) [3]

The experiment was conducted on a Foton BJ1049V9JD6-SB light duty diesel vehicle with FBC, burner and DOC to adapt to high sulfur in China. An aging test of 60,000 km and environmental compatibility test is carried out in different zones i.e. in cold zone, tropical zone and plateau. Result shows aging of DPF endorse filtration efficiency because of change microstructure. The filtration efficiency of DPF increases rather than decreases along with the travel distance. With the difficulty during the ignition of burner in the cold zone, reliability and fuel economy of the system may be influenced and in plateau, with the help of subsidiary air pump, the burner works smoothly with burning performance better than in flat lands. The results reflect strong adaptability of regeneration device and discover the main difficulty for system application, which refers to overproof emissions due to aged DOC.

2.7 STATEMENT OF THE PROBLEM

The present work was undertaken to develop a system with the following objectives:

- To study the effect of Diesel Particulate Filter on engine emissions and performance.
- To regenerate the Diesel Particulate Filter.
- To measure the emission during the regeneration of DPF.

CHAPTER 3

EXPERIMENTAL SETUP

3.1 Introduction

An experimental setup was developed to study the effect of Diesel Particulate Filter and for its regeneration. The experimental setup consisted of a diesel engine coupled with eddy current dynamometer and Diesel Particulate Filter. To measure the air flow rate, air was introduced in the engine through an air box. Fuel supply system consisted of fuel tank and a Burette meter, to measure the fuel flow rate. Thermocouples were placed at various places on engine. For measurement of exhaust emissions (CO, CO_2, O_2, HC, and NOx) AVL gas analyzer was used. For measurement of smoke emission AVL smoke meter was used. The Schematic diagram of experimental setup is shown in fig.

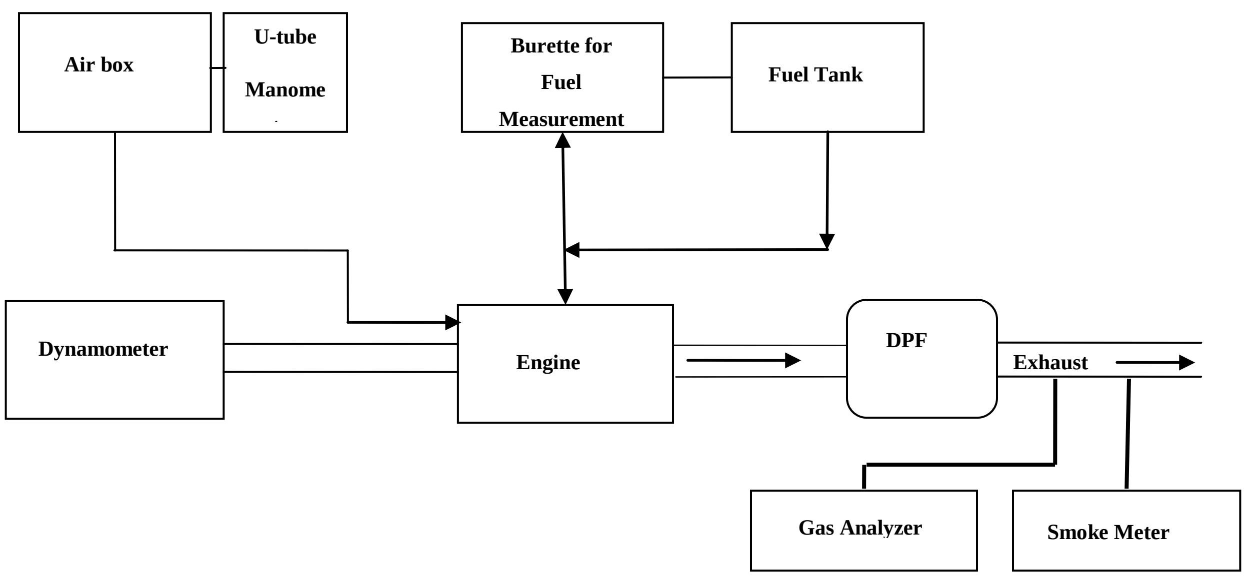


Fig.3.1 Schematic diagram of Experimental setup

3.2 Engine

The experiment was conducted on a Mahindra 2.1liter diesel engine. The complete specification of the engine is given in the table.

No. of cylinder	4
Cylinder block	Cast iron
Cylinder liner	Removable wet type
Bore (mm)	90
Stroke (mm)	83
Compression ratio	22.4/1
Cubic capacity(cm^3)	2112
Crank shaft	Forged steel,5-bearimg journal
Cooling	By water
Lubrication	Pressure lubrication
Connecting rods	Forged steel
Main bearing	Aluminum tin
Piston	Aluminum
Cylinder head	Aluminum with turbulence chamber
Camshaft	Chilled casting,3 bearing
Valves	Overhead rocker arm operated
Timing	Gear operated
Maximum BHP	62 at 4500 RPM
Maximum torque	12.3 kg. m.(89 lb.ft.) at 2000 RPM
Operating cycle	4-stroke (order: 1-3-4-2)
Cylinders	In line arrangement

Table 3.1 Specification of Mahindra multi-cylinder engine

3.3 Dynamometer

SAL make Eddy Current Dynamometer was used to apply the resisting torque on the engine. It has maximum torque 351.28 N-m. Value of current can be changed manually to change the torque. The value of current, torque and engine RPM can be read on a digital meter. Satisfactory supply of water was provided for cooling purpose of dynamometer. Recommended water supply pressure at the inlet was 1 kg/cm^3 or 10 m. head.

3.4 Fuel Flow Measurement

To measure the volumetric flow rate of fuel (diesel) burette method was used. In this method a glass burette was connected to the fuel tank and engine with help of a Tee valve as shown in Figure. There are three position of Tee valve.

1) Horizontal- In this valve position the fuel flows directly from the fuel tank to the engine.

2) Vertically downward- In this the fuel flows from the fuel tank to the burette.

3) Vertically upward- In this the fuel flows from the burette to the engine.

The fuel return line is connected with another burette to make the air out of the fuel line. So that time taken by engine to consume a fixed volume of the fuel was measured with the help of stopwatch. The burette also helps to let us know the fuel level in the fuel tank. The photographic view of fuel measurement with burette method as shown in fig.

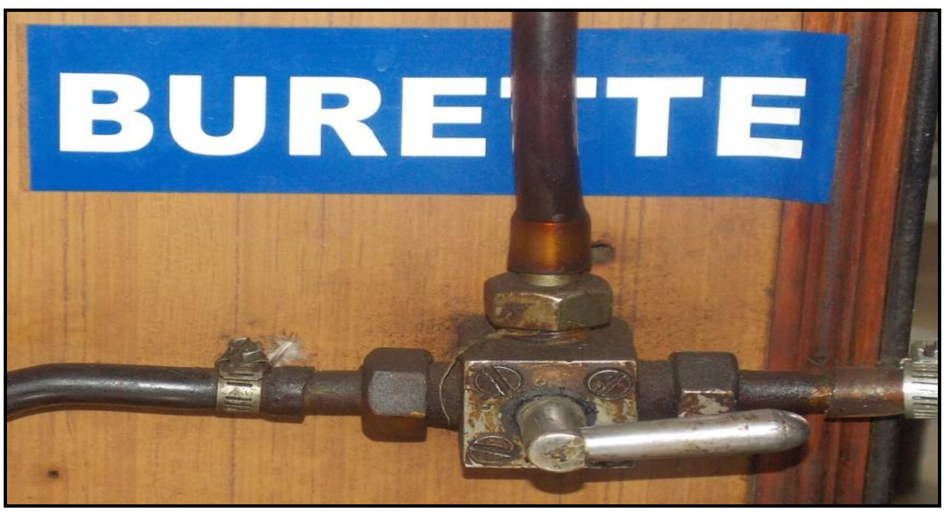


Fig.3.2 Fuel measuring system (by burette method)

Formula for measuring the mass flow rate of fuel is

Mass flow rate of fuel = Volume flow rate * Density of fuel

3.5 Temperature Measurement

Various K type thermocouples are placed at different places to measure the temperature of exhaust gases, cooling water inlet and outlet o run the engine under control condition. The K type thermocouple is inexpensive, and a wide variety of probes are available in its −200 °C to +1350 °C range.

3.6 Exhaust Emissions Measurement

The emissions were measured at different torque values with and without of diesel particulate filter. The table gives the emission constituent and their measuring unit.

S. No.	Constituent	Unit
1.	Carbon mono-oxide (CO)	% volume
2.	Carbon dioxide (CO_2)	% volume
3.	Oxygen (O_2)	% volume
4.	Unburned hydro-carbon (HC)	PPM
5.	Nitrogen oxides (NOx)	PPM
6.	Smoke	% opacity

Table 3.2 Component in the exhaust emission

The first five gas were measured by the AVL DIGAS 4000 LIGHT. The AVL 437 SMOKE METER was used to measure the smoke opacity in the exhaust gases. The AVL DIGAS 4000 LIGHT and AVL smoke meter is shown in the fig.

Fig.3.3 AVL DIGAS 4000 LIGHT

Fig.3.4 AVL 437 SMOKEMETER

3.7 Diesel Particulate Filter (DPF)

The fresh DPF was used for the experiment study. The glass wool was filled around the DPF in its casing to make it tight in the casing as well as the glass wood acts as a insulator to prevent heat loss from casing to environment. The figure of fresh DPF and DPF fitted in its casing is shown in the figure.

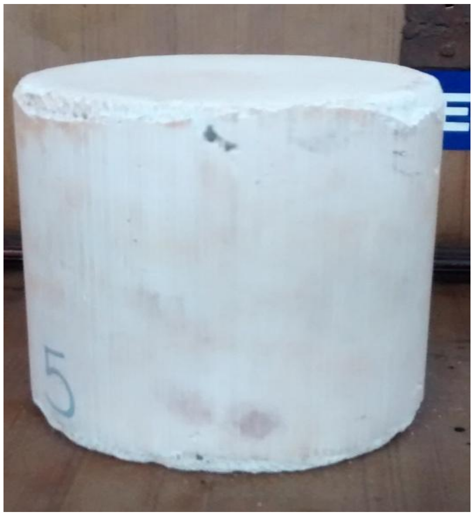


Fig. 3.5 Fresh DPF

Fig.3.6 Cross- sectional view

(a) **(b)**

Fig. 3.7(a), (b). DPF fitted in its casing with the glass wool

3.8 EXPERIMENTAL PROCEDURE

A series of experiments were conducted out to find out the effect of Diesel Particulate Filter on engine emission and performance. First the engine was run without Diesel Particulate Filter (DPF) at constant RPM with different resisting torque. Different emission measurement, smoke measurement, fuel flow rate were measured. After that DPF was installed in the exhaust line and the same reading were again taken to find out the effect of DPF on engine emission and performance. The experimental setup is shown in the figure.

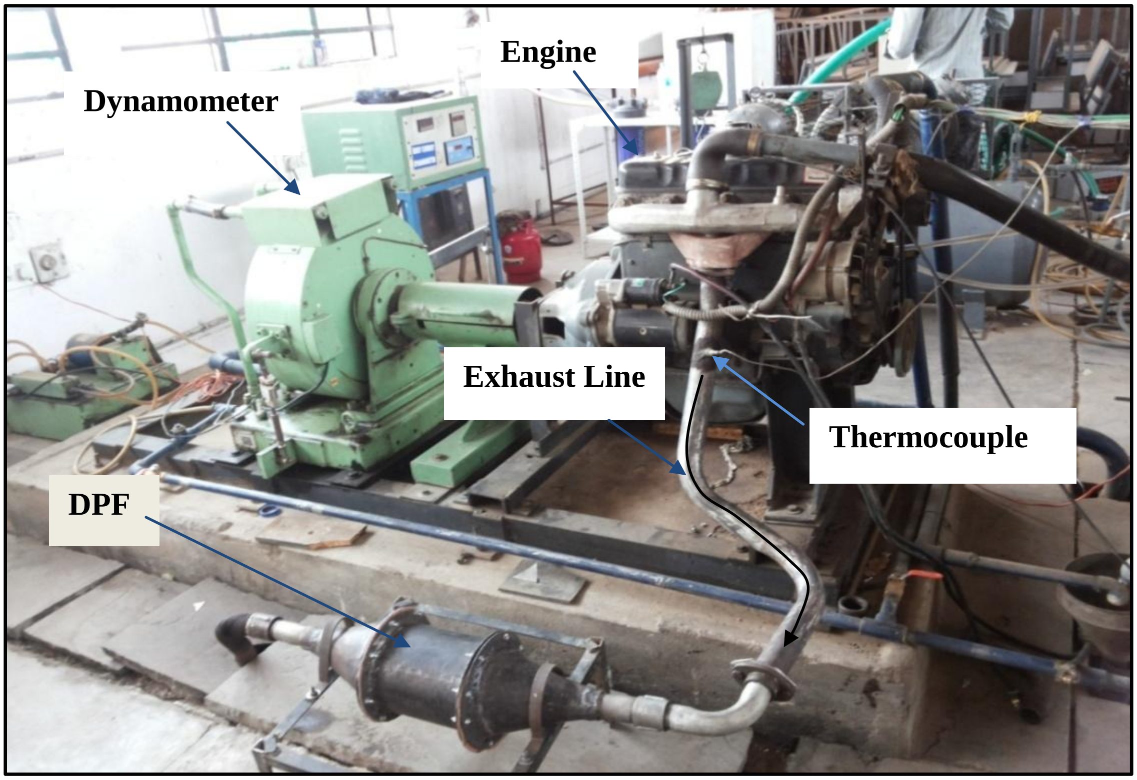


Fig.3.8 Experimental setup

This is the experimental setup for the first objective i.e. to know the effect of DPF on engine emission and performance. Some modifications were done on the existing setup to make it suitable for the second objective i.e. to regenerate the DPF.

CHAPTER-4

EFFECT OF DIESEL PARTICULATE FILTER ON ENGINE EMISSION AND PERFORMANCE

After developing the complete experimental setup, experiment was conducted. The measurement of different emissions and performance parameter were taken. In this chapter the effect of DPF on engine emissions and performance is discussed.

4.1Effect of DPF on engine emissions

4.1.1 Smoke opacity

Smoke contain ultrafine particle commonly called soot or PM which are harmful to human health and environment. The purpose of diesel particulate filter is to trap these solid carbon particles before emitting in to the atmosphere. Here it is observed that after installing the Diesel Particulate Filter, there is a drastic reduction in the smoke opacity. 94% reduction was observed in the smoke opacity. The variation of smoke opacity with different torque is shown in the figure.

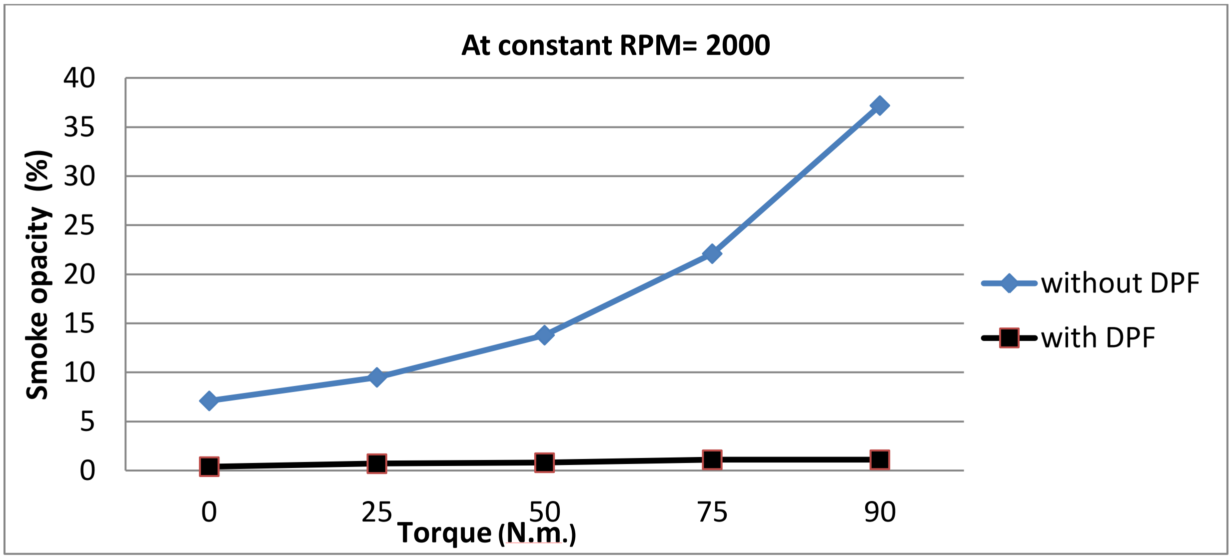


Fig.4.1. Smoke opacity at different torque with and without DPF

4.1.2 Emission of CO

CO results from the incomplete combustion of fuel. Figure shows the concentration of CO in the exhaust gas, with and without DPF. It is clear from the figure that the emission of CO reduces after installing the DPF in the tail line. 16% reduction was measured**.**

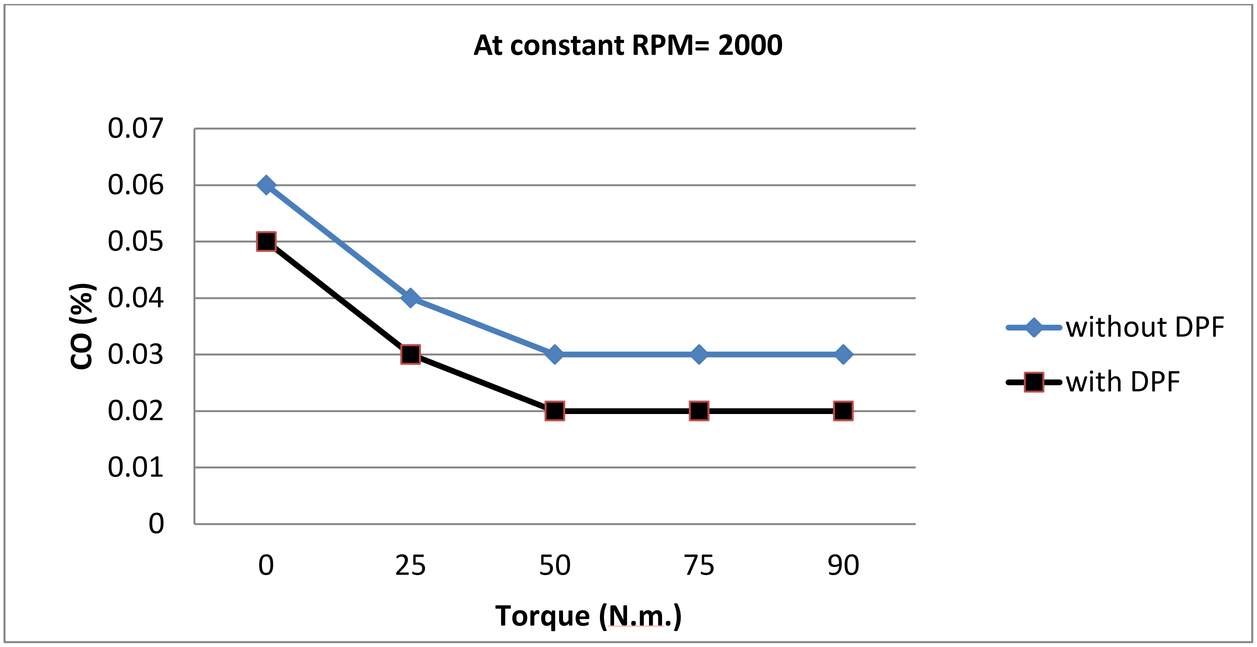


Fig.4.2 CO emission at different torque with and without DPF

4.1.3 Emission of CO_2

CO_2 results from the complete combustion of fuel. The concentration of the CO_2 in the exhaust gas, with and without DPF is shown in the figure. It can be observed from the figure that there is an increase in the emission of CO_2. On an average the increase in CO_2 emission is around 10%.

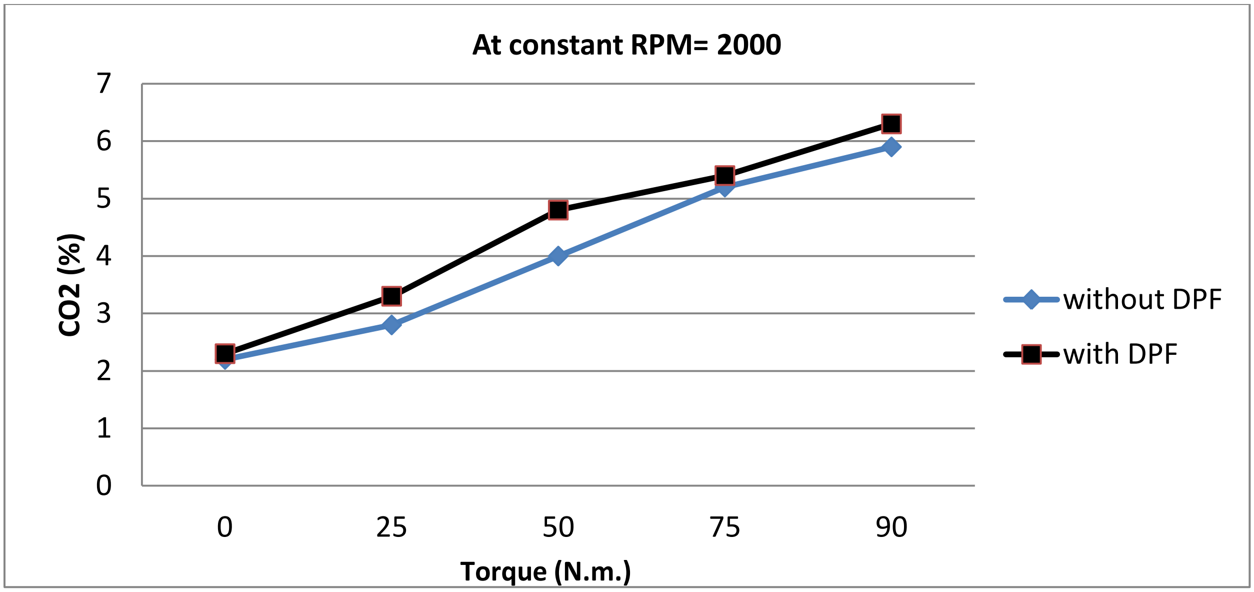


Fig.4.3 CO_2 emission at different torque with and without DPF

4.1.4 Emission of O_2

The concentration of oxygen in the exhaust gas is shown in the figure. It is clear from the figure that the concentration of oxygen decreases while operating with DPF. There is 24% reduction in the O_2 concentration.

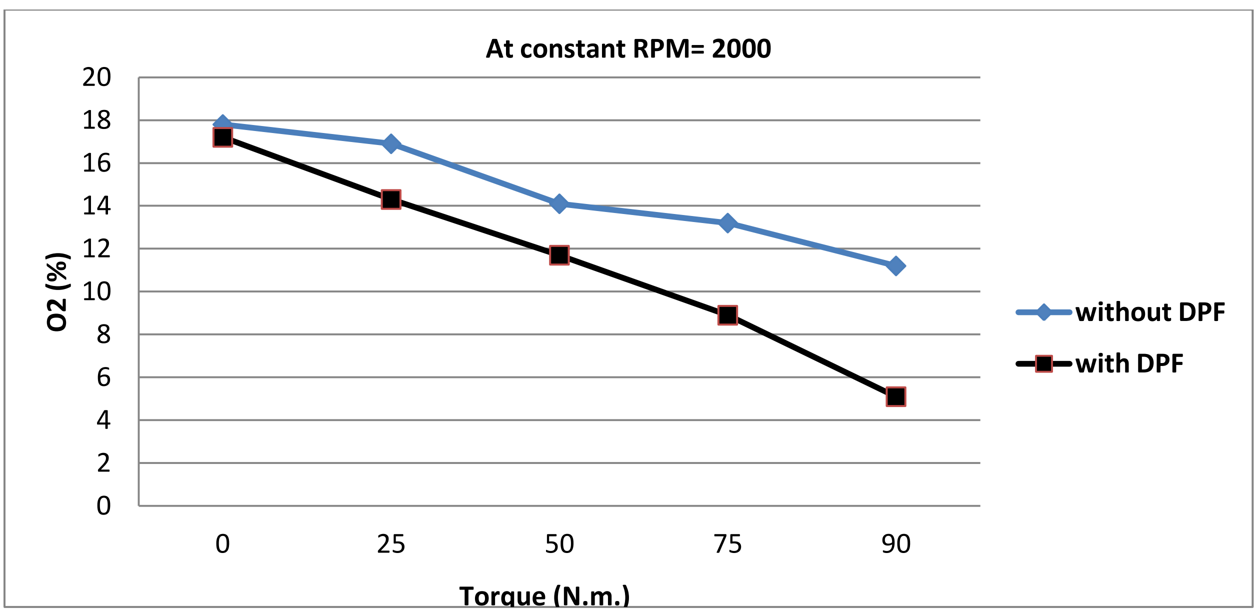


Fig.4.4 O_2 emission at different torque with and without DPF

4.1.5 Emission of NOx

NOx formation in an engine is primarily a function of reaction temperature, availability of oxygen and time duration. The concentration of NOx in the exhaust gases with and without DPF is shown in the figure. After installing the DPF there is 11% increase in the NOx emission.

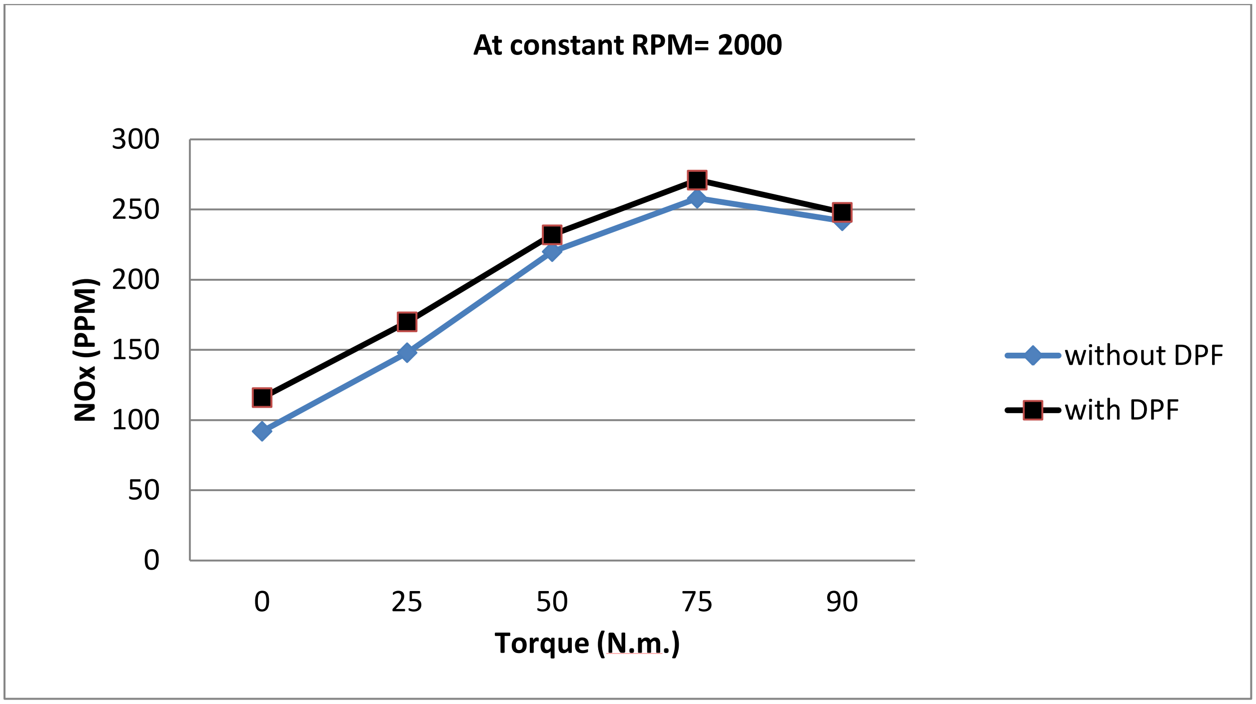


Fig.4.5 NOx emission at different torque with and without DPF

After installing the DPF in the tail pipe, it causes a backpressure in the exhaust line which keeps on increasing with the running time of the engine. This backpressure affects the engine performance in such a way that to produce the same power with DPF the engine burns more fuel. This leads to an increase in the temperature of combustion chamber. Due to which CO converts into CO_2 and percentage of CO in the exhaust gases decrease whereas CO_2 increases. And the oxygen concentration decreases. This high temperature is also the main cause of increase in the emission of NOx.

4.2 Effect of DPF on engine performance

4.2.1 Brake specific fuel consumption

DPF causes a backpressure in the exhaust line due to which engine consumes more fuel to produce the same amount of power. Due to which the BSFC increase. At low torque the BSFC is same as in case of without DPF, but as the torque increases the BSFC also increases. The average percentage increase in the BSFC is 4%. Figure shows the variation of BSFC with different resisting torque.

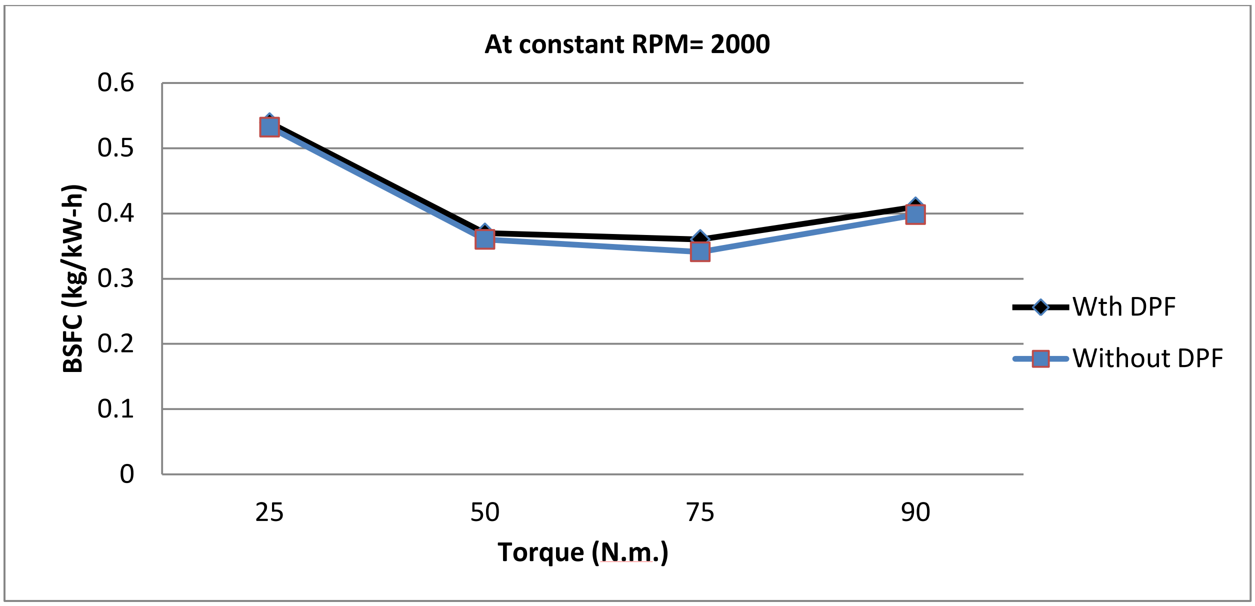


Fig.4.6 Brake specific fuel consumption at different Torque with and without DPF

4.2.2 Brake thermal efficiency

The figure shows the variation of brake thermal efficiency with different resisting torque values. It is clear from the figure that at low value of torque the brake thermal efficiency is same with and without DPF, but as the torque increases the brake thermal efficiency starts to decrease because BSFC increases. A reduction of 3% was observed in brake thermal efficiency.

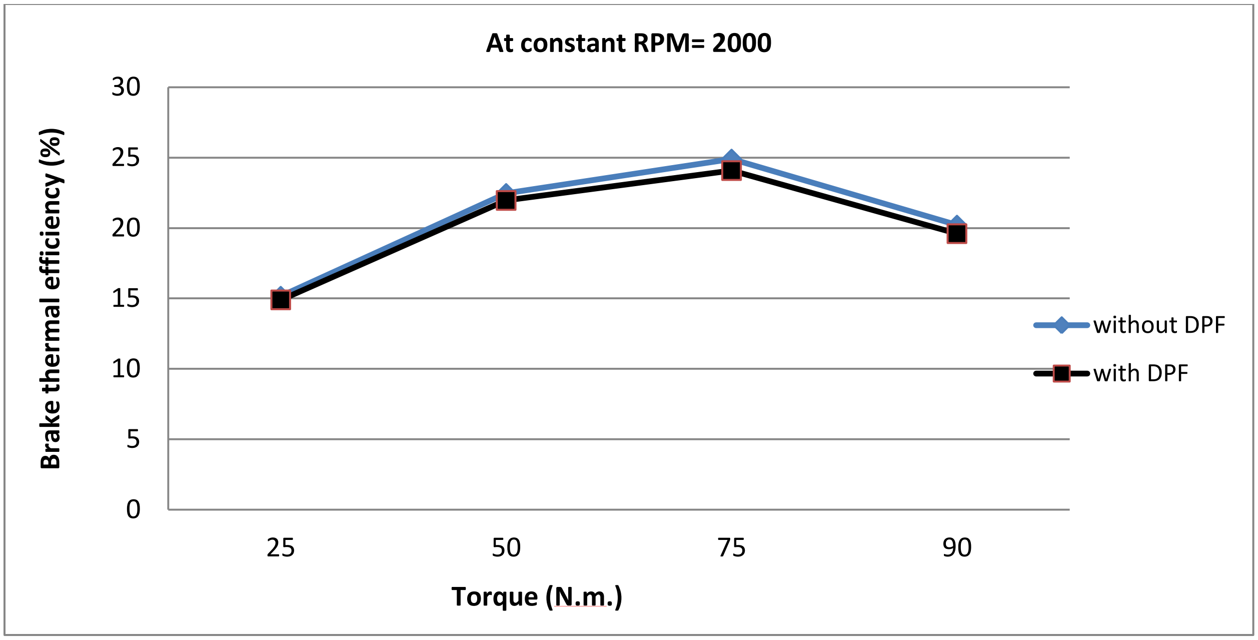


Fig.4.7 Brake thermal efficiency at different Torque with and without DPF

So DPF performed its soul function very efficiently. The filtration efficiency was found to be 94%. It is also having a little effect on other engine emission. The percentage change in the different constituent of exhaust gases and performance parameter is shown in the tabular form below.

S. No.	Constituent	Change
1.	Smoke opacity	94% decrease
2.	NOx	11 % increase
3.	CO	16% decrease
4.	CO_2	10% increase
5.	O_2	24% decrease
6.	BSFC	3% increase
7.	BTE	3% decrease

Table 4.1 Effect of PDF on different parameter

CHAPTER 5

REGENERATION OF DIESEL PARTICULATE FILTER

5.1 Introduction

In the previous chapter we have discussed the effect of DPF on engine emission and performance. But as the engine runs with the DPF, more and more carbon particles accumulates on the filter due to which the back pressure in the exhaust line keeps on increasing which increase the fuel consumption hence lowers the brake thermal efficiency. So this accumulated carbon must be burned off to maintain the pressure drop in the acceptable limit. So in this chapter we will discuss about the regeneration of the Diesel Particulate Filter.

The regeneration of the DPF was done by two methods. In first method of regeneration, the DPF was pulled out from the exhaust line and the accumulated carbon was burned off by some means. Whereas in second method of regeneration the DPF was regenerated by keeping it in the exhaust line. This was the active regeneration of DPF.

5.2 First method of regeneration

A fresh DPF was used to analyze the effect of DPF. When the analysis was done, the chocked DPF was taken out of the exhaust line. The fresh and choked DPF are shown in the figure.

Fig.5.1 Fresh DPF

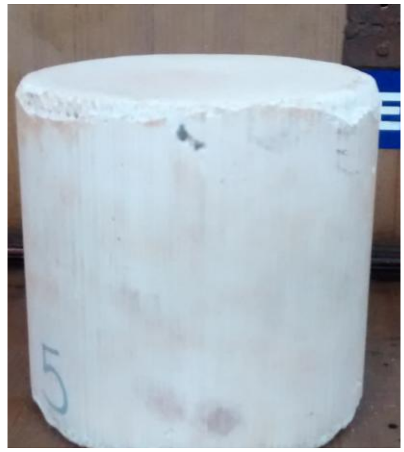
Fig.5.2 Choked DPF

To regenerate the DPF, the accumulated carbon must be burned off. Since the burning temperature of the carbon is around 550-600 degree centigrade. To do so the DPF was taken out from the exhaust line of the engine and put in a muffle furnace. The temperature of the furnace was set at 600 degree centigrade. After 8-10 hours of operation the furnace was turned off. And after 3-4 hours the furnace was opened. The figures of different activities are shown below.

Fig.5.3 Setting up the temperature

Fig.5.4 After 8-10 hours of operation

(a)



(b)

Fig.5.5 (a), (b) DPF after regeneration

So DPF can be fully regenerated passively but it consumes extra time and effort. During this whole time period the engine is in inoperative condition or the engine cannot be run with DPF.

5.3 Second method or Active Regeneration

The DPF can be regenerated actively i.e. without taking it out from the exhaust line. The work to be done to regenerate the DPF is to oxidize the accumulated particulate matter (PM). This can be done by raising the temperature of the exhaust gas, which raises the temperature of PM. Since the temperature of the exhaust gases in the normal operating condition is around 300-400 degree centigrade but the combustion temperature of the PM is around 550-600 degree centigrade. This high temperature can be achieved by injecting the diesel in the exhaust line before the inlet of DPF which raises the temperature of exhaust gases. And when this high temperature gas will go into the DPF, the PM accumulated in the DPF will oxidize and the back pressure will reduce.

5.3.1 Experimental Setup

To regenerate the DPF actively, a setup was prepared. A "diesel Particulate Filter Electronic Control Unit" made by Vembsys Technovation Pvt. Ltd. was used. The ECU includes- control electronics, injection pump, pressure monitoring system and pc connection as depicted in figure. It is used to measure the temperature, back pressure and to inject the diesel in the exhaust line. The actual picture of ECU is shown in figure. And its components are shown in the tabular form.

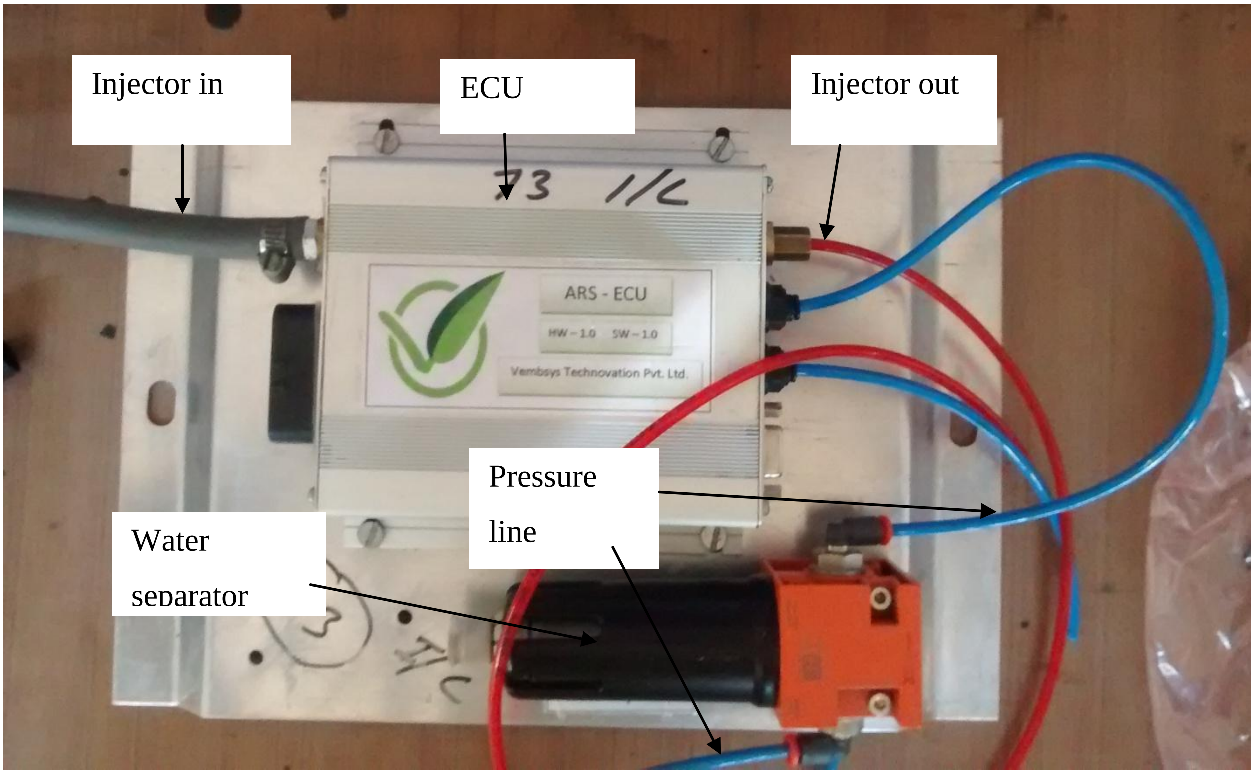


Fig.5.6 The ECU for DPF regeneration

S. No.	Component	Specification
1.	Thermocouple	K type (0-1023^{o}C)
2.	Back pressure sensor	Range: 0-100 kPa (absolute)
3.	Injector	Flow rate: up to .47 l/hr
4.	MIL lamp	Tricolor of LED red , green ,yellow powered by 12V
5.	Water separator	N/A

Table.5.1 Component of ECU and their specification

5.3.2 Working Principle

The DPF ECU takes the power from the 12 volt battery to operate. An optimum control strategy for injection is developed for the regeneration of filter by monitoring different input parameters like temperature and pressure. The ECU and its connection is depicted in figure.

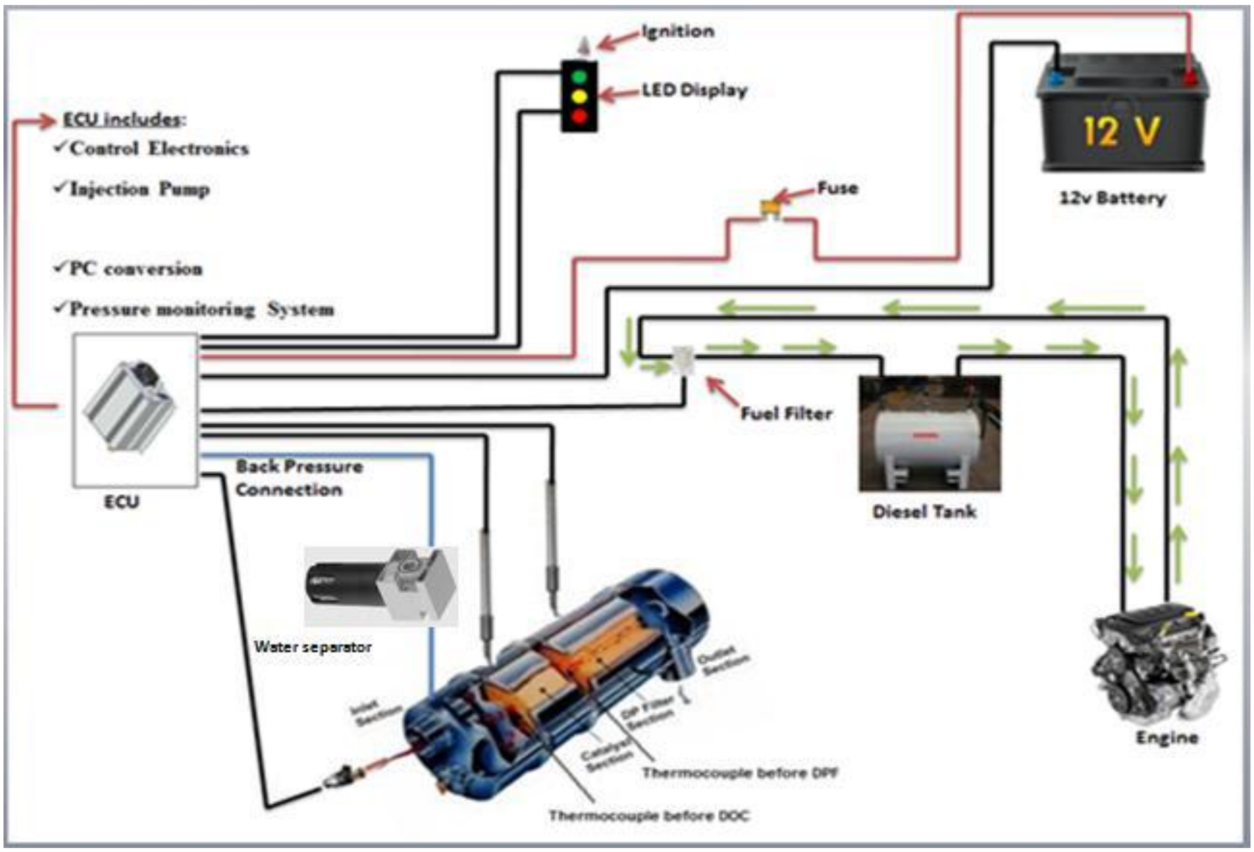


Fig.5.7 ECU and its connection

After installing the ARS software and all the connection of wiring harnesses and communication cables, a screen opens with different parameter. The parameters on the left side of the screen named as “Reactive setting” are given by the user and the parameters on the right side of the screen named as “Reactive status” show the online or actual values. It is shown in the figure. When the actual values meet the preset values, the injector pump starts and injects the fuel for the given time period defined by the user. But somehow in actual the pump didn’t work well so we run the injector pump by manual setting.

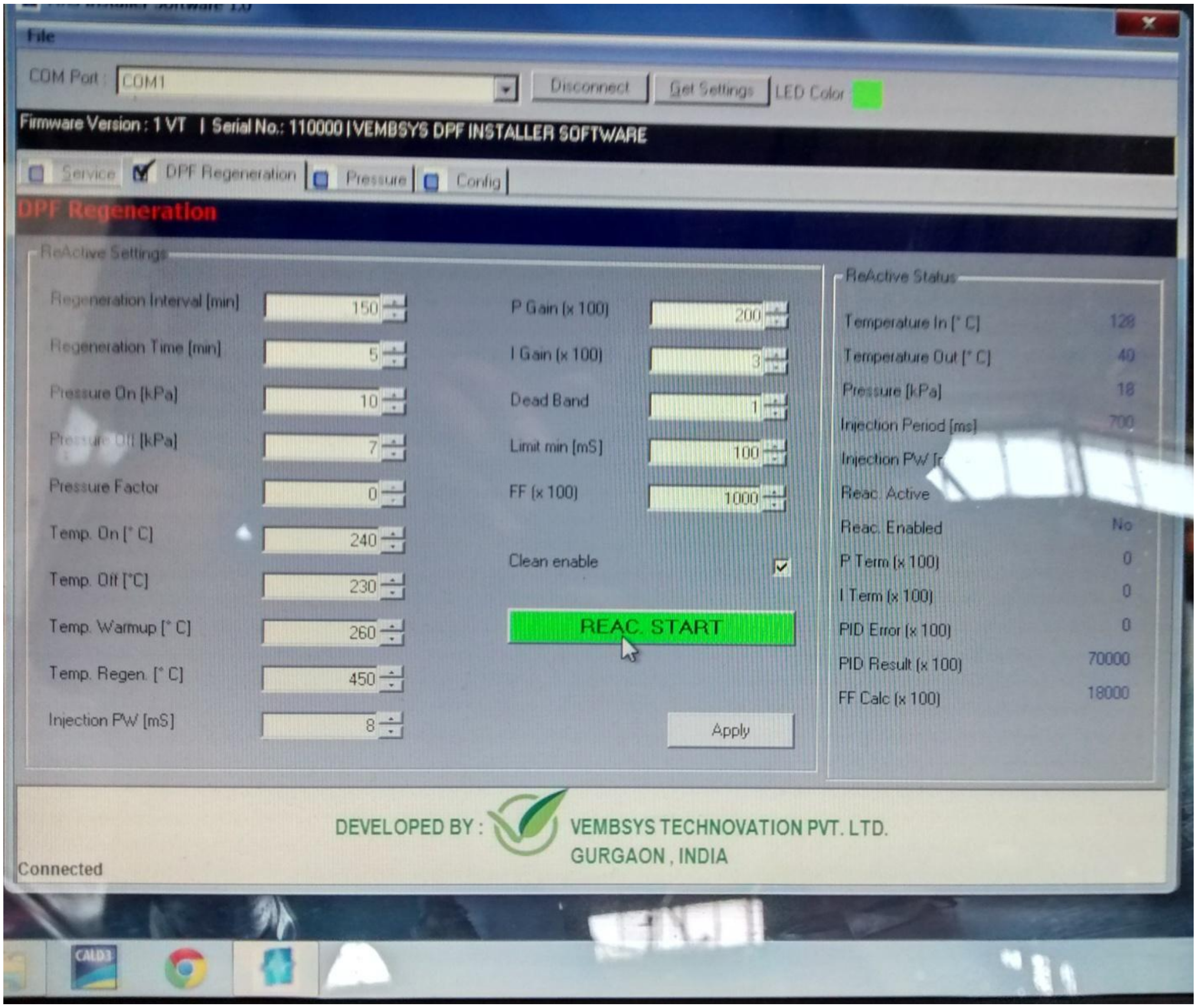


Fig.5.8 Different online parameter for DPF regeneration

5.3.3 Experiment Procedure

After developing the whole setup for DPF regeneration, the engine was run at 2500 RPM and 50N.m. torque. The increase in backpressure with time was measured and plotted. The injector pump was operated manually. The DPF was regenerated at different backpressure and the reduction in backpressure was measured. Fresh air was supplied in the exhaust line for better combustion of injected fuel. The actual experimental setup is shown in the figure.

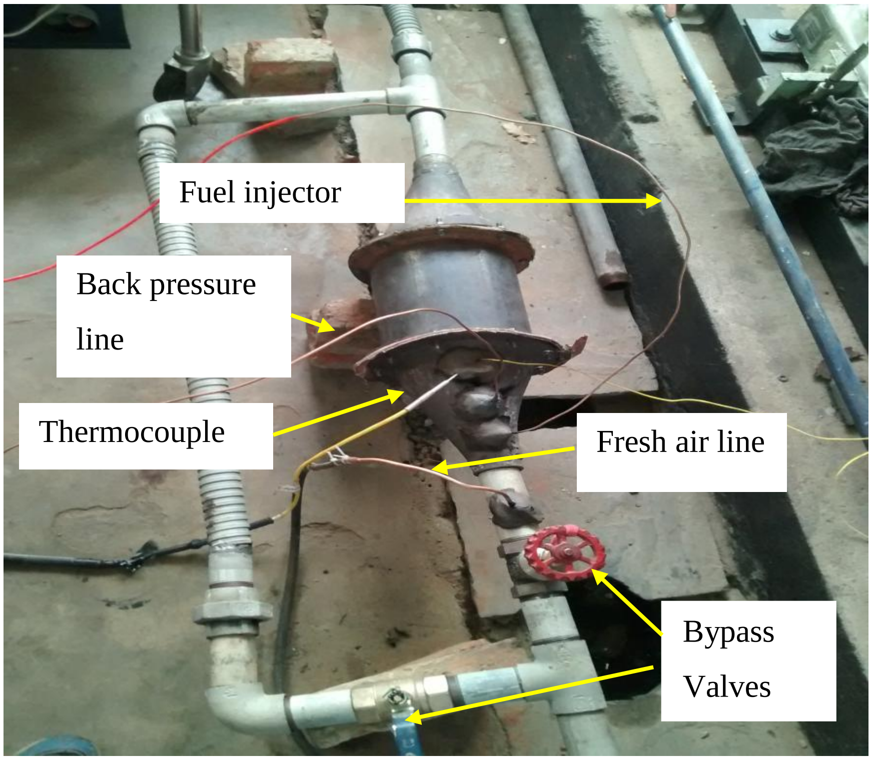


Fig.5.9 Arrangement for different measurement

Fig. 5.10 Actual Experimental Setup

5.4 Results

The engine was run at 2500 RPM and 50 N.m. torque. The back pressure started increasing with the engine operating time. The trend of increasing back pressure with the time is shown in the figure.

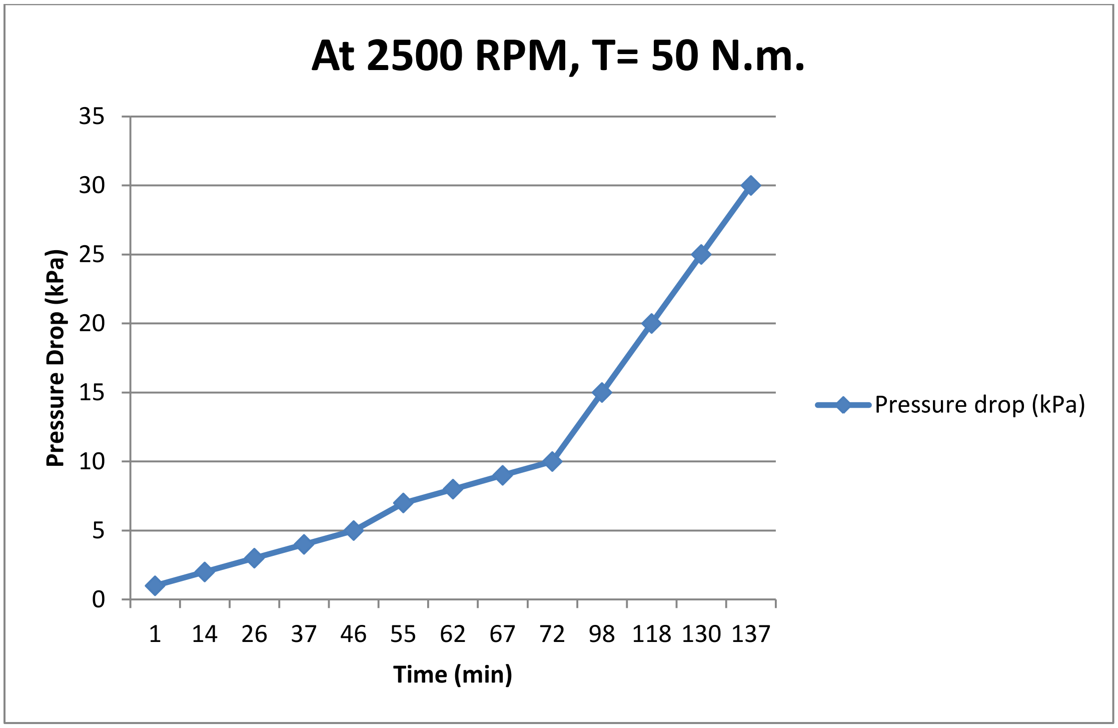


Fig.5.11 Trend of back pressure with time

The regeneration of DPF was done at different value of back pressure and the reduction in the back pressure was analyzed. The duration of fuel injected was 5 minutes from fuel injector at a rate of 0.43 l/hr. The fresh air was supplied from an air compressor at a rate of 2.52 kg/hr. The following analysis has been done.

1st regeneration

The 1st regeneration was done when the back pressure was 10kPa. The fuel injection took place for a time period of 5 min. After the injection stop, the back pressure came down to 6kPa. Emissions during the regeneration were measured..

2nd regeneration

The 2nd regeneration was done when the back pressure was 15kPa. The fuel injection took place for a time period of 5 min. After the injection stop, the back pressure came down to 13kPa.

3rd regeneration

3rd regeneration took place when the back pressure was 20kPa. Same amount of fuel and air were supplied. The back pressure reduced to 19kPa.

4th regeneration

4th regeneration was done when the backpressure was 25kPa. After fuel injection, the back pressure reduced to 24kPa.

5th regeneration

5th regeneration took place when the back pressure was 30kPa which remain 30kPa after the regeneration.

The regeneration attempt and reduction in backpressure is shown in the tabular form below.

Regeneration attempt	Back pressure (kPa)	
	Before Regeneration	After Regeneration
1st	10	6
2nd	15	12
3rd	20	19
4th	25	24
5th	30	30

Table.5.2 Pressure Drop in different regeneration attempts

The most successful regeneration event was the first one where the backpressure reduced from 10kPa to 6kPa. Whereas the reduction in back pressure is less when done at higher backpressure. The emissions of different gases and smoke opacity were measured before and after each regeneration event. Emission from the engine and back pressure was also measured during the1st regeneration period.

5.4.1 Emission before and after the regeneration event

5.4.1.1 Emission of CO

The concentration of CO decreases as it was before the regeneration at low value of back pressure, but it is same before and after at higher value of the backpressure. It can be shown in the figure.

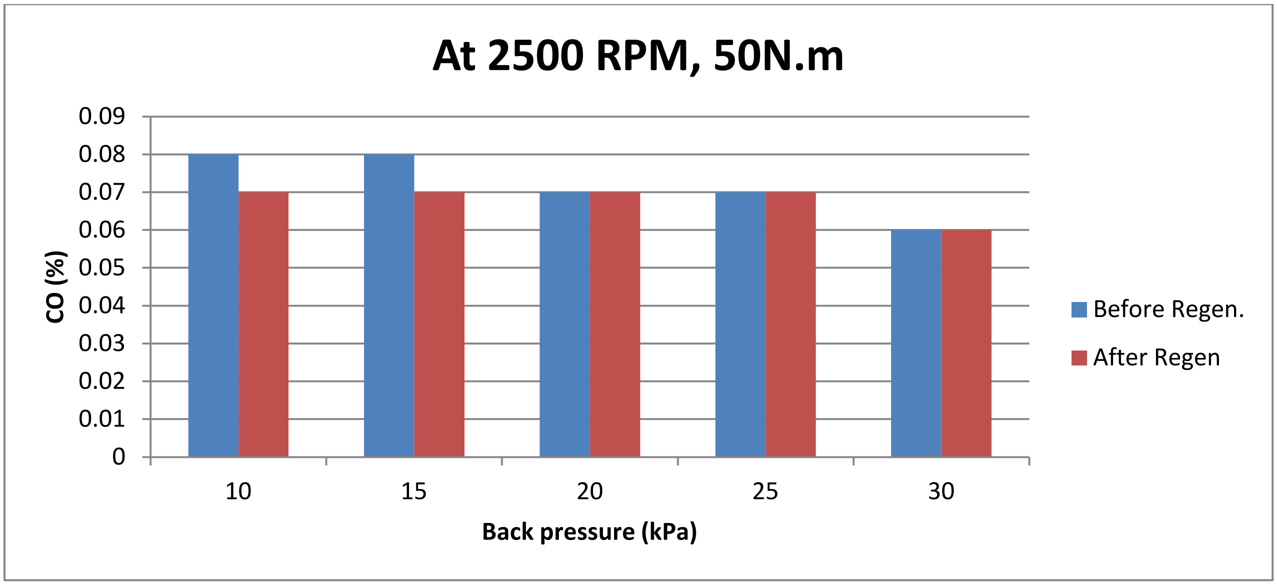


Fig.5.12 Emission of CO before and after the regeneration

5.4.1.2 Emission of CO_2

The concentration of CO_2 decreases after the regeneration as it was before the regeneration at lower back pressure. Bur there is no change in the CO_2 concentration at higher back pressure as depicted in the figure.

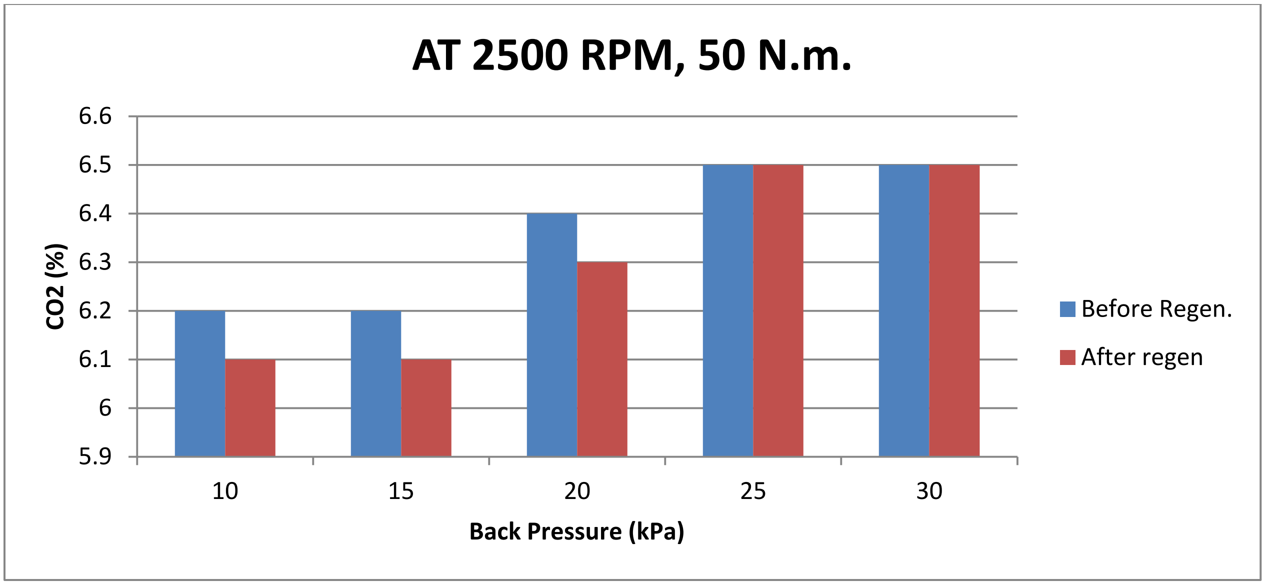


Fig.5.13 Emission of CO_2 before and after the regeneration

5.4.1.3 Emission of O_2

The concentration of oxygen in the exhaust increases after the regeneration when it was done at lower value of backpressure but it remains the same at higher value of backpressure. It is shown in the figure.

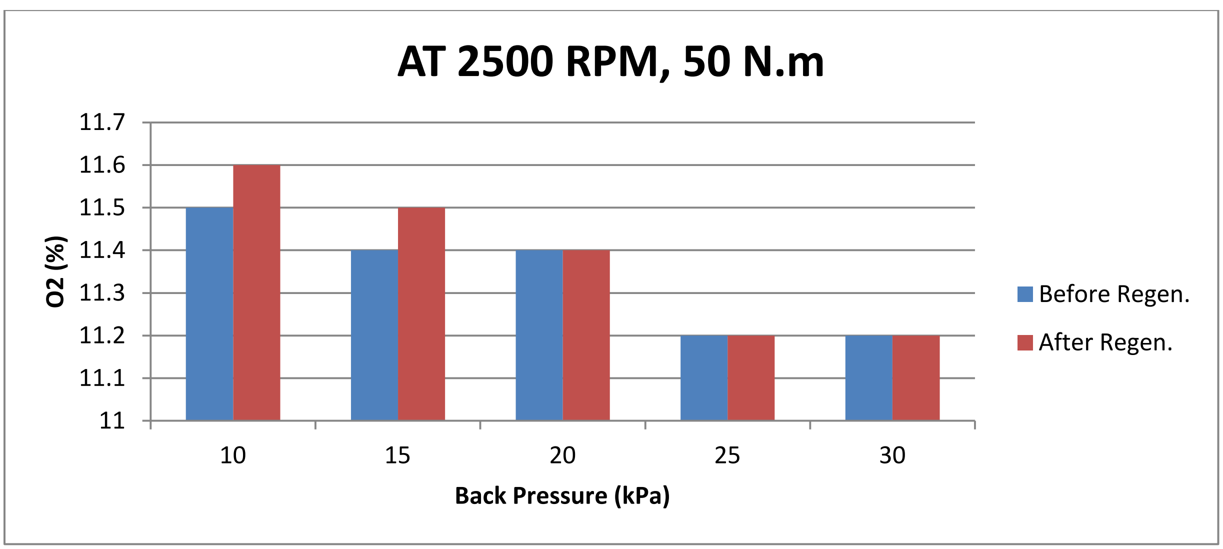


Fig.5.14 Emission of O_2 before and after the regeneration

5.4.1.4 Emission of NOx

It is clear from the figure that the emission of NOx decreases after the regeneration but the amount of reduction is less with increasing back pressure.

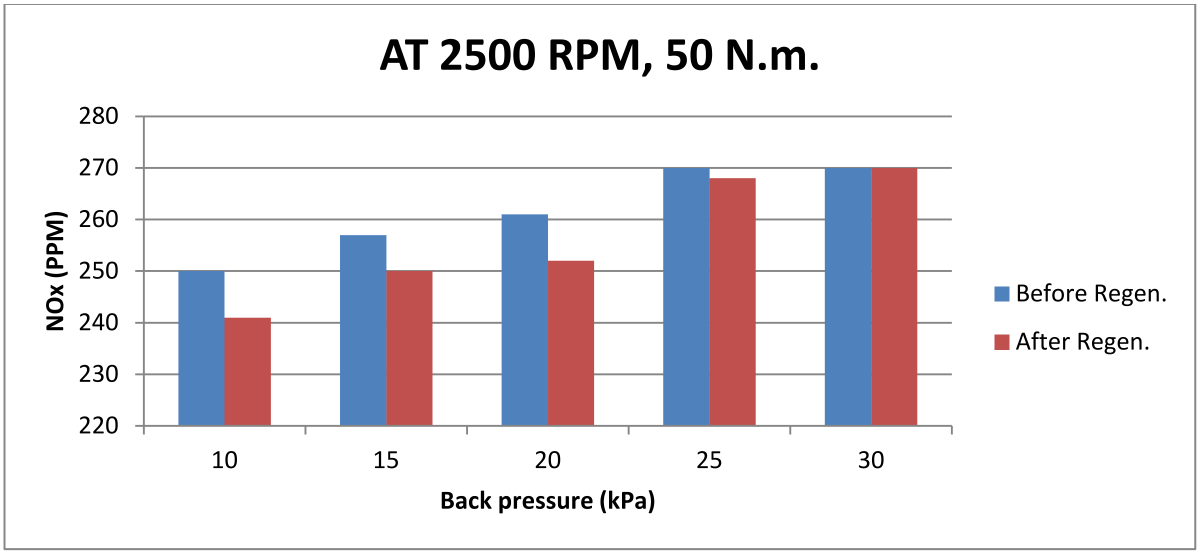


Fig.5.15 Emission of NOx before and after the regeneration

5.4.1.5 Smoke Opacity

The smoke opacity increases after the regeneration at lower value of back pressure and almost remains constant before and after the regeneration for higher back pressure as shown in the figure.

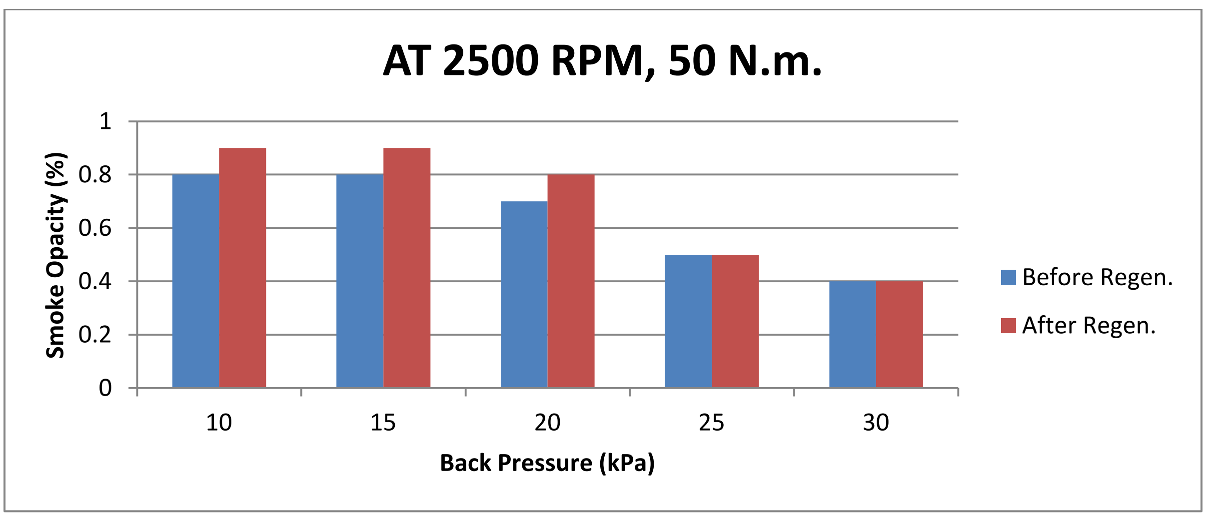


Fig.5.16 Smoke opacity before and after the regeneration

5.4.2 Emission during the regeneration

5.4.2.1 Emission of CO

The percentage of CO in the exhaust gases increased during the regeneration. Some of the accumulated carbon oxidized and came as CO in the exhaust. It is shown in the figure.

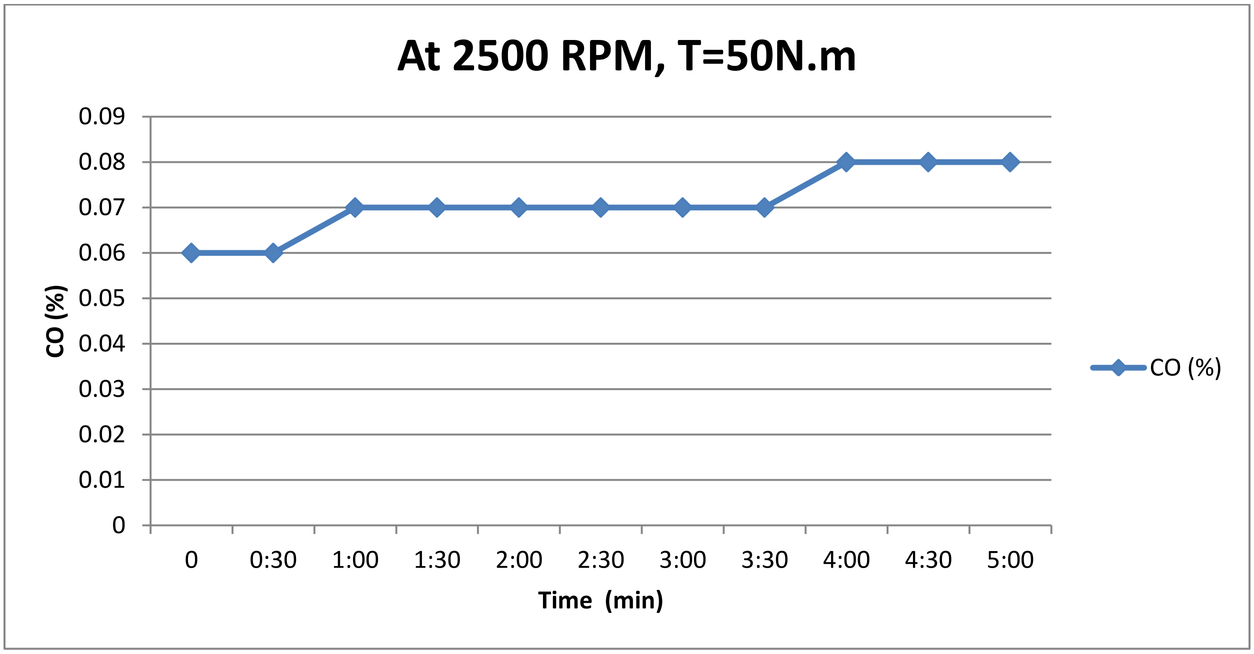


Fig.5.17 Emission of CO during regeneration

5.4.2.2 Emission of CO_2

The accumulated carbon at the DPF oxidized into CO_2 at high temperature and presence of oxygen so that concentration of CO_2 in the exhaust gas increased. This variation is shown in figure.

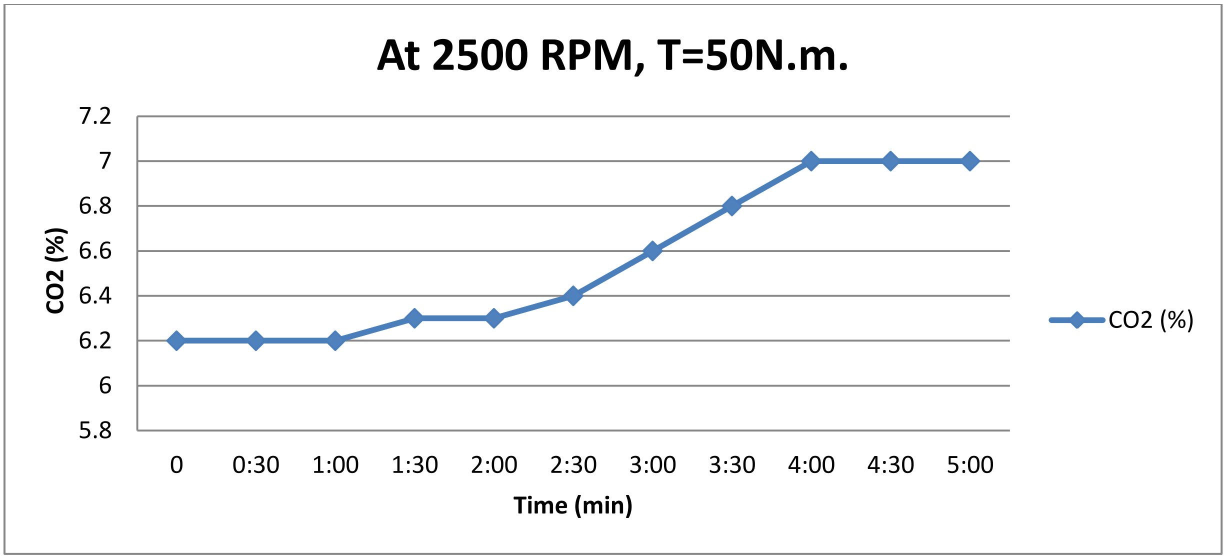


Fig.5.18 Emission of CO_2 during regeneration

5.4.2.3 Emission of NOx

Since fresh air is supplied in the exhaust line this means there is a good concentration of fresh oxygen and on the other hand the temperature of the exhaust is also high. So due to the presence of high temperature and availability of oxygen in the exhaust, the emission of NOx in the exhaust increases as depicted in figure.

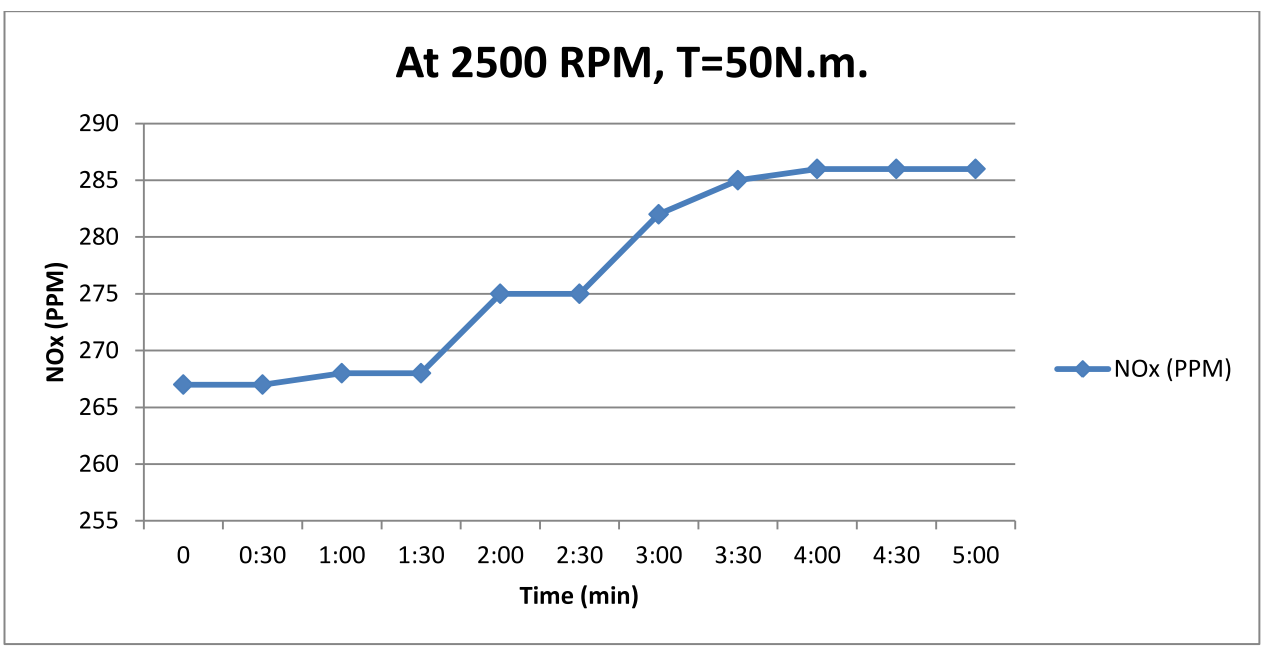


Fig.5.19 NOx emission during regeneration

5.4.2.4 Back Pressure

Since accumulated carbon was burned off so the backpressure reduced. It was 10kPa before the regeneration and came down to 6kPa after the regeneration. The variation in the backpressure is shown in the figure.

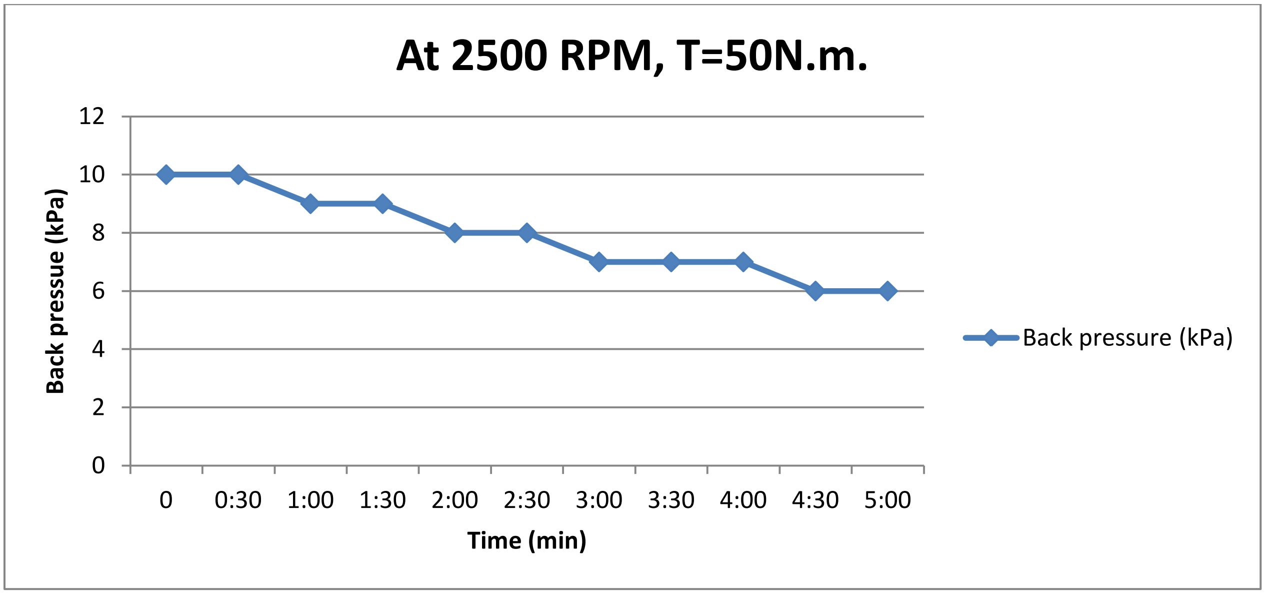


Fig.5.20 Backpressure during regeneration

CHAPTER 6

CONCLUSION

The Diesel Particulate Filter and its regeneration kit was successfully installed on the existing engine in the lab. An experimental study has been done on a Euro 1 diesel engine equipped with Diesel Particulate Filter. The effect of DPF on emissions and performance of the engine has been analyzed which are as follows:

1. The smoke opacity of the engine reduces drastically with Diesel particulate filter with a filtration efficiency of 94%.

2. The emission of NOx increases a little with the diesel particulate filter.

3. There is slight decrease in oxygen concentration with diesel particulate filter.

4. Emission of CO decreases whereas emission of CO_2 increases with Diesel Particulate Filter.

5. Brake thermal efficiency reduces a little with diesel particulate filter.

With the continued use of DPF, it starts to get choked and affect the performance of engine, which is undesirable. The first method of regeneration was time consuming activity whereas the active regeneration is fast and quick process. The following results were found from the regeneration of DPF.

1. The filtration efficiency of the DPF increases as the engine run more and more with the DPF.

2. The quantity of fuel injected and the injection time period should be optimized.

3. The fresh air or oxygen helps in better combustion of injected fuel.

4. Emission of CO_2 increases during the regeneration which is an indication of oxidation of carbon particles.

5. Emission of NOx increases during the regeneration period.

6.1 Scope for future work

The present work was done on a uncoated DPF. The regeneration is mainly a function of the temperature at which the accumulated carbon particles burn. This temperature can be brought down by using a catalytic coating on the DPF or by using some fuel borne catalyst or fuel additives. So that the DPF can be regenerated at lower exhaust temperature. The temperature of the exhaust gases can also be raised by electrical assistance. This will helps in avoiding the additional fuel penalty.

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