

Module 6:Emission Control for CI Engines

Lecture 30:Diesel Particulate Filters

The Lecture Contains:

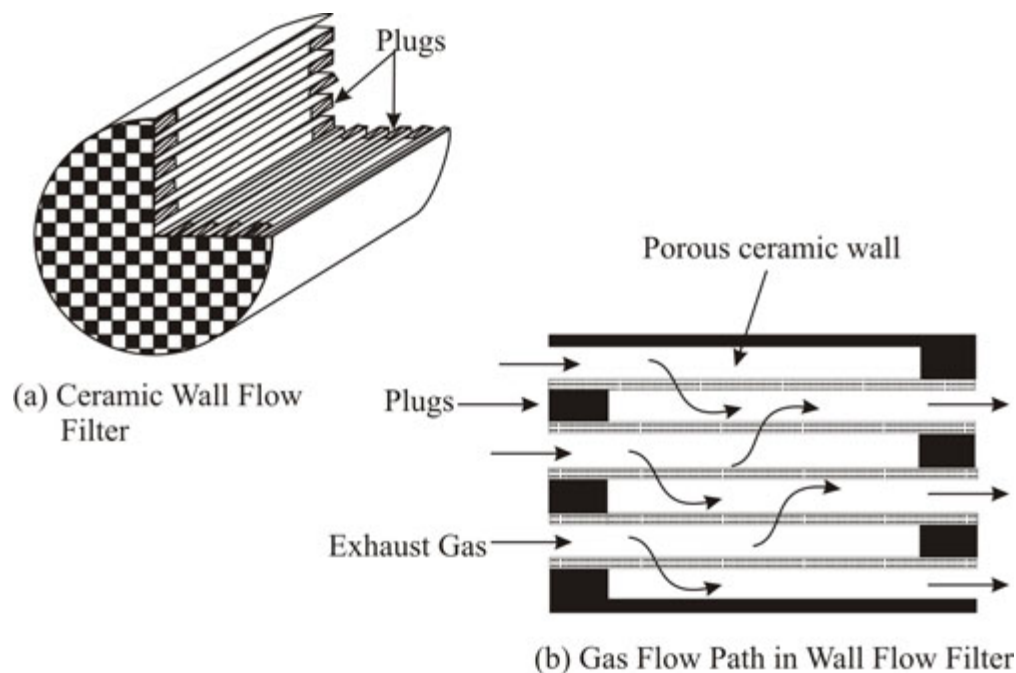
- ☰ Diesel Particulate Filters
- ☰ Regeneration of DPF
- ☰ Active DPF Regeneration

◀◀ Previous Next ▶▶

DIESEL PARTICULATE FILTERS

Diesel particulate filters (DPF) also called as 'particulate traps' have been developed to filter out PM from the diesel exhaust gases to meet very stringent emission limits. Alumina coated wire mesh, ceramic fiber, porous ceramic monoliths etc., have been studied as filtration media. Presently, ceramic monolith of honeycomb type structure is used to trap the particulate matter as the gas flows through its porous walls. These filters are also termed as 'ceramic wall flow filters'.

A ceramic honeycomb type particulate filter is shown in Fig. 6.14. In this cellular structure, alternate cells are plugged at one end and open at the opposite end. The exhaust gas enters the cells that are open at the upstream end and flows through the porous walls to the adjacent cells. The adjacent cells are open at the downstream end from where the filtered gas exits to the atmosphere. Flow path of gas through walls of the filter is also shown on Fig 6.14.



**Figure
6.14**

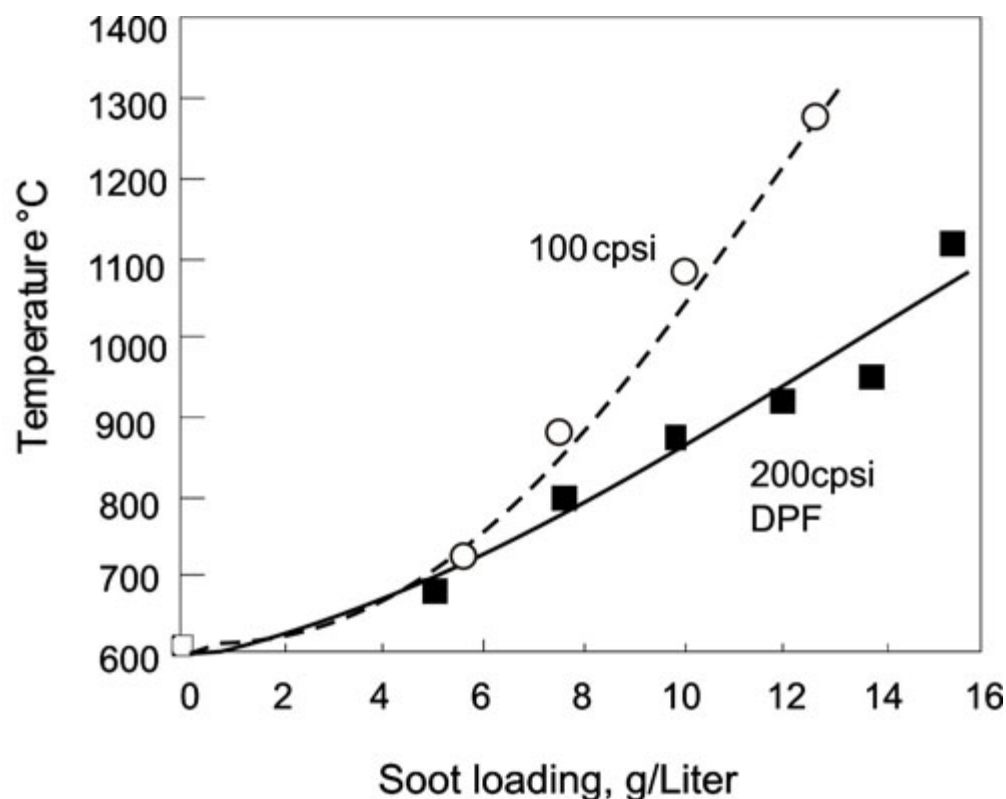
Ceramic wall flow filter for diesel particulate

Some advantages of wall flow filters over other filtration media are;

- The wall flow filters have a large filtration surface area per unit volume
- The pore size of walls can be controlled to provide gas flow without excessive pressure drop.
- Very high filtration efficiencies close to 98% are possible with acceptable pressure drop.

DPF Material, Cell Density

- DPF material should be chemically inert and have low thermal expansion and high melting temperature.
- Porous cordierite ceramic ($2MgO_2 \cdot Al_2O_3 \cdot 5SiO_2$) has been commonly used for diesel particulate filters. Its melting temperature is $\approx 1460^\circ C$
- The soot burns without catalyst at a temperature of $500 - 600^\circ C$. However, if the soot starts to burn uncontrollably the DPF may experience temperature of $1300^\circ C$ or higher resulting in melting of the ceramic filter. Typical temperatures achieved in the ceramic filter when soot gets burned are shown on Fig 6.15 for a 100 and a 200 cpsi DPF. Due to lower thermal capacity of the 100cpsi DPF, higher ceramic temperatures result when soot deposited on the DPF is burned. To overcome possible meltdown due to uncontrolled regeneration of DPF more advanced materials withstanding even higher temperature are required.

**Figure 6.15**

Maximum temperature attained during uncontrolled regeneration for two diesel particulate filters (144 mm dia X 150 mm length) having 100 and 200 cpsi cordierite substrates, 200 cpsi substrate has higher mass hence lower peak temperatures.

Module6:Emission Control for CI Engines

Lecture 30:Diesel Particulate Filters

Contd...

- High melting point materials of 'NZP' family like $\text{Na Zr}_2\text{P}_3\text{O}_{12}$, and silicon carbide 'SiC' have also been developed for diesel particulate filters. Melting point of NZP material is $\approx 1900^\circ\text{C}$ and of SiC of about 2400°C .
- Diesel particulate filters commonly have a cell density of 100-cpsi or 200 cpsi with 0.30 to 0.45 mm wall thickness. The 200-cpsi substrates provide 41 % higher filtration area but have a higher pressure drop.
- Filters with circular cross section are mostly used due to their superior mechanical strength and high thermal resistance as they experience less severe temperature gradients and have more uniform temperature distribution. Cylindrical filters are easy to pack and install on vehicle.
- Filter size is normally equal to the swept volume of the engine.

Pore Size and Soot Holding Capacity

- For good mechanical strength, wall porosity is kept about 48-50%.
- Pore size range from 12 to 35 μm .
 - Pore size of about 35 μm gives filtration efficiency of 60-75%
 - 20 to 25 μm pore size filters are used for 80-90 % efficiency and
 - 12 to 14 μm pore size for efficiency > 90%.

With higher pore size filtration efficiency as well as pressure drop is low. Hence, optimization of pore size, cell density and wall thickness is essential.

- Soot loading before regeneration ranges 5 to 10g/ l volume of substrate. When a 10-20 μm pore size DPF was loaded with soot in the range of 5 to 10 g/liter of substrate volume, pressure drop was 7 kPa and 11 kPa with 5 and 10-g/liter soot loading, respectively.

Regeneration of DPF

It is relatively easy to filter and collect the particulate matter in the trap but the soot is to be burned in-situ i.e., 'regenerate' the trap so that pressure drop across the filter is kept always at an acceptable level.

- Soot and other particulate get collected on the filter that although improves the filtration efficiency, but it results in an increased pressure drop across the filter. The pressure loss in the new and clean filter is about 70 mm H_2O for the 0.1 m/s gas velocity in filter channels. Design considerations limit soot loading to about 10 g/l of filter volume before filter should be cleaned or regenerated. As the soot is collected upto the limit of 10g/l, pressure drop increases to 300-350 mm of H_2O . An increase of engine backpressure by 350 mm H_2O results in 1 % loss in fuel economy at 65-km/h vehicle speed.
- For engine out PM emissions of about 0.25 to 0.33 g/kW-h and engine power output of about 17 kW/ liter swept volume, 10g/l soot would get collected on DPF in about 2 hours. Hence, the DPF regeneration should take place approximately every 2 hours. The soot in the filter is to be burned in-situ.
- Burning of soot particles begins at about 540° C. Such high exhaust gas temperatures do not occur during engine operation for sufficiently long periods of time. The diesel exhaust gas temperatures in the exhaust pipe typically reach to about 300°C only.
- For regeneration of the DPF, therefore additional measures are to be adopted.

Types of Regeneration Systems

Regeneration of the DPF to its original clean state has been a challenging task. Two types of regeneration systems have been investigated and a few developed for employment on production vehicles

- Active regeneration
- Passive regeneration

Active DPF Regeneration

A positive source of heat is employed to raise temperature of DPF to about 540° C. When oxidation of soot starts, the exothermic reactions sustain the combustion of soot particles and the DPF is regenerated. In the active regeneration systems, sensors are used to monitor pressure drop across the trap. On receiving the signal from the sensor, the exhaust gas temperature is increased above 500° C by any one of the following techniques:

- Engine throttling
- Use of electric heater upstream of filter
- Use of burner upstream of filter

Throttling of air reduces airflow that results in decrease of overall air-fuel ratio, which increases the combustion and exhaust temperatures. However, engine throttling increases the engine pumping losses which results in loss of fuel efficiency. Throttling also decreases oxygen concentration in the exhaust and for oxidation of soot 2-5% oxygen in the exhaust is necessary. Hence, the extent of throttling is to be controlled. Under normal cruising conditions, throttling is unable to increase the exhaust temperature to the levels needed for regeneration. Hence, throttling can work only at high loads, which is deliberately applied to raise the gas temperatures. It also increases HC, CO and smoke emissions. Engine throttling as a means of trap regeneration therefore, has had only a limited success.

For electric filter regeneration, power to the electric heater is supplied by the engine alternator. A typical truck DPF regeneration system may require a 3 kW heater. The electric regeneration hence, needs a high battery back-up or is to be done while the vehicle is in garage, which may not be accepted by the operators as regeneration is required quite frequently.

Module6:Emission Control for CI Engines

Lecture 30:Diesel Particulate Filters

Burner Regeneration

A diesel fuel burner is placed in the exhaust in front of the filter to regenerate the diesel particulate filter. This system can perform at all engine speeds and loads. Two types of system have been used;

1. burner full flow system and
2. burner bypass system

In the full flow system the total exhaust gas is to be heated to about 540°C . A large air pump for the burner and high burner fuel consumption are needed. Complex electronic controls to regulate burner fuel flow to maintain safe levels of gas temperature at inlet of filter are necessary. In the bypass system, only a small part of exhaust is allowed to flow through the filter when regeneration is carried out. A smaller air pump is required. A bypass burner regeneration system is shown on Fig 6.16. Regeneration process is independent of engine operating conditions, as the filter during regeneration is isolated from the engine exhaust. The fuel consumption by the burner to heat the inlet face of the filter to 540°C is an order of magnitude lower compared to the full flow system. The relative magnitudes of energy required to raise the exhaust temperature to 540°C in the full flow and bypass type burner regeneration system (10 % of total flow) are presented in Fig 6.17 for a 5.7 liter diesel engine.

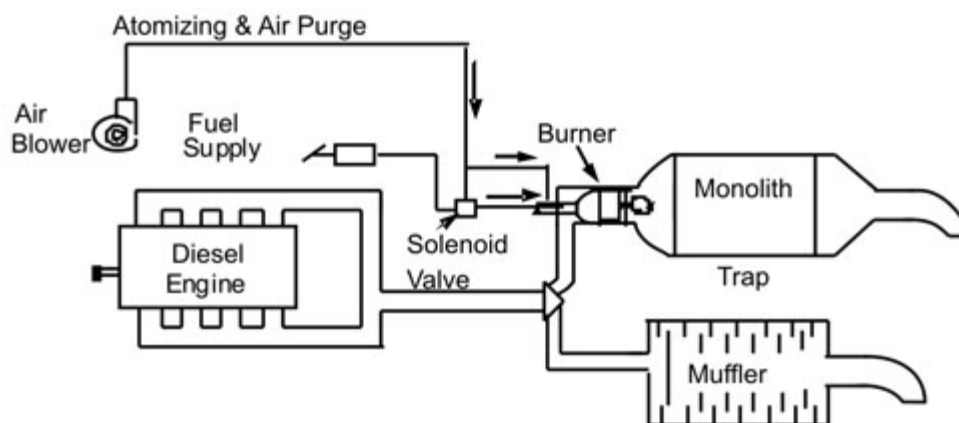


Figure 6.16 Schematic of diesel-fuelled Burner Bypass Regeneration system for Diesel Particulate Traps

The inlet face when heated to 540°C , soot oxidation begins. Increase in temperature of the gas accelerates combustion of soot further. The burning process progresses from the front and oxidizes soot in the remainder of the filter.

Control of Active Regeneration

The active regeneration is carried out once the filter is plugged and when the pressure drop across the filter increases to the threshold level. The entire filter is plugged with soot. The regeneration process starts at the front end and progresses towards downstream. Once the regeneration starts, heat released further heats-up the filter and soot burns at a progressively increasing rate. This may lead to uncontrolled rate of soot burning and high rates of heat release. Eventually, it may melt the filter substrate. Therefore, the filter temperatures are to be monitored continuously. To control temperatures during regeneration, the burner may be shut off midway through the regeneration cycle to prevent melting of the filter substrate. The DOF regeneration is thus, a carefully controlled process.

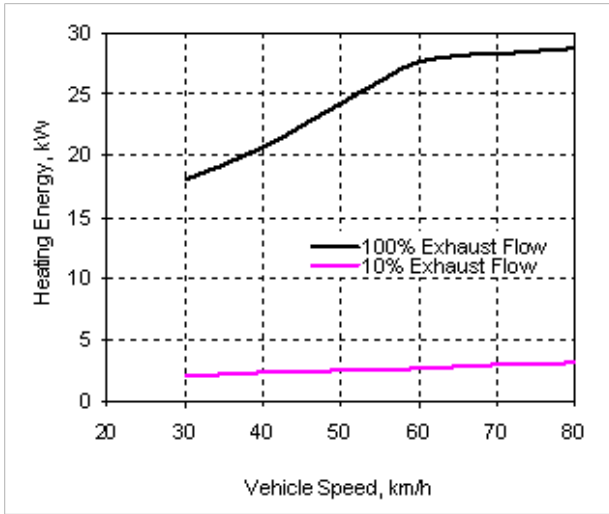


Figure 6.17 Energy required to heat exhaust gas to 540° C for full flow and by-pass diesel particulate filter regeneration systems, 5.7 liter diesel engine.