Design and Simulation of Different Types of Cell Shapes of Diesel Particulate Filters

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***Abstract*:- Diesel Particulate Filters (DPF) are used to remove the solid particulate matter from the exhaust gas of the diesel engine. However, the exhaust of the engine produces a back pressure that reduces the efficiency of the engine and increases fuel combustion due to the DPFs. Therefore, it is necessary a device which gives less back pressure along with filtration efficiency that meets the requirements of the regulations. In this paper, three different designs of DPF namely square, hexagonal and octa-hexagonal Cell structure are investigated to check the pressure drop, velocity drop and the temperature of the diesel particulate filter. By considering the material and Cell structure, the simulations are done with star CMM+. It is found that the octa-hexagonal, a new design will give the least pressure drop giving less back pressure to the engine and hence the efficiency of the engine won't alter much because of this DPF.**

Keywords: Diesel particulate matter; Diesel Engine; Exhaust; Octa-hexagonal cell shape

I. INTRODUCTION

The problem of global warming is not new and is progressing day by day. To tackle this problem technologists continuously try to find out new ways to reduce carbon dioxide emissions. Same efforts are being made to reduce the carbon dioxide emission from automobiles. Even after the introduction of the electric cars, it is still considered that IC engines will be the appropriate selection for the automobiles at least for next two decades. And as the fuel efficiency for diesel engines is more when compared to petrol engines, former are considered more environment friendly than the latter. However, it is still important to implement environmental measures for diesel automobiles also. Recently more focused emissions that need to be controlled includes the particulate matter (PM) and Nitrogen oxides (NO_X) emission from the diesel engine. Our main focus here will be on the particulate matter. The Diesel Particulate Filters, also known as DPF, has enabled us to reduce the particulate matter emissions considerably. However, the rules and regulations for the emission of particulate matter are becoming more and more stringent and development of better performance DPFs is still undertaking [1]. The need for better DPFs further arises with recent introduction of Bharat stage- V (by 2020 in INDIA and 2018 in NCT) in India. DPF reduces the engine efficiency because of the back pressure created through the resistance of the flow. Reducing this back pressure is also very important.

Diesel particulate filters have contributed to decreasing particulate matter (PM) in the exhaust gas of diesel cars, and they have become standard diesel exhaust gas after-treatment devices. Unlike a catalytic converter which is a flow-through device, a DPF retains bigger exhaust gas particles by forcing the gas to flow through the filter. The particles with smaller size are not filtered by DPF. Sometimes a DPF breaks the bigger particles into smaller particles and removes from the exhaust [2].
Variety of DPFs has been manufactured from which few are available in the Indian market. Most common type of Diesel Particulate Filters are wall flow type filters. These filters remove close to 85% of soot and under certain conditions can attain soot removal efficiencies close to 100% [3]. A honeycomb structure is generally used in the DPFs. In this arrangement, the inlet pipes are blocked from outlet side and the outlet pipes are blocked from the inlet side. The gas enters from the inlet side passes through the material where the pores of the material filter the PM and then the gas gets out from the exhaust pipes. The exhaust gas that contains the Particulate matter enters from the inlet of the DPF and then travels through the wall made of materials like Silicon Carbide or Cordierite. Due to the small pore size of the material, the exhaust gas passes through the wall and gets out of DPF through the outlet. The particulate matter which is bigger than the pore size gets trapped and gets accumulated on the walls of DPF. Once the soot collected on the walls of DPF increases, the efficiency of the DPF decreases and hence this soot needs to be cleaned off. The inlet area is kept a little bigger than the outlet area which leads to less ash collection [4].Some diesel particulate filters are single use filters which are removed from the automobile once the soot is completely accumulated on the walls i.e. the DPF is completely loaded. Generally, a re-generation process is used where the walls

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of the temperature is either heated to remove the suit which has been accumulated on the walls or a catalyst is used to do the same.

Variety of materials are used to manufacture the DPF. The most commonly used materials are: Cordierite, Silicon Carbide (SiC), Ceramic Fibre, Metal Fibre, Paper etc. The most commonly used material is cordierite. A DPF can be monolith or can have segments depending on the material used and the material's thermal stability. [5]

II. METHODOLOGY

The typical required properties of the DPF are summarized from the results of research papers and found to be pressure drop characteristics, PM collection characteristics, thermal shock resistance characteristics, and mechanical strength characteristics respectively [1]. Our main focus is on the pressure drop characteristics of the DPF. We will also try to include other parameters in the future
The methodology followed is as shown:

- The literature review was done and the information regarding DPF was collected
- Different cell shapes were finalized and the different shell sizes and **CPSI** was finalized.
- The engine on which the experimentation need to be done was arranged.
- The DPF size was finalized based on the size of the engine.
- SolidWorks model was made for all the three cell shapes selected and the different parameters were kept same for all the three designs,
- CFD Analysis was done on Star CCM+ and the different parameters were kept same for all the three designs. The porosity of the material for the simulation was calculated using Darcy equation where the inertial resistance and viscous resistance was calculated. The mesh was made using polyhedral mesh type. The porosity of the DPF can be kept between 55-60%. (pore diameter= 10-12 µm) [6].

III. DESIGN

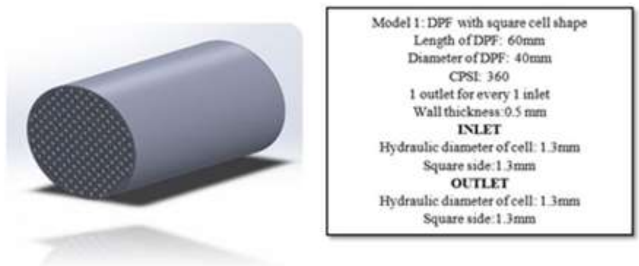

Fig. 1 Model 1: DPF with square cell shape

Fig. 2 Model 2: DPF with hexagonal cell shape

Fig. 3 Model 3: DPF with octa-hexagonal cell shape

DPF Designing in general consists of the following [1]

- Material Design: Design for a DPF material. This will affect the DPF thermal stability, thermal shock resistance, and mechanical strength and ash-resistance characteristics.
- Pore structure design: Design for the pore characteristics of the wall used as a filtration area. This will affect the filter's basic properties, namely the pressure drop characteristics and filtration efficiency.
- Cell structure design: Design for the honeycomb cell structure (configuration). This will affect the pressure drop, thermal shock resistance and ash resistance characteristics (physical accumulation).
- Macro design: Design for the DPF dimensions and configuration. The customer will specify this in consideration of canning and loading characteristics.

The mathematical models are also available for efficiency, pressure drop and soot oxidation [7].

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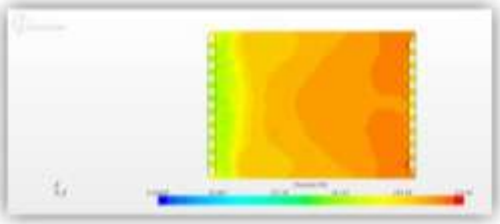
IV. RESULT AND DISCUSSION

Pressure Drop



(The flow is in the +z direction)

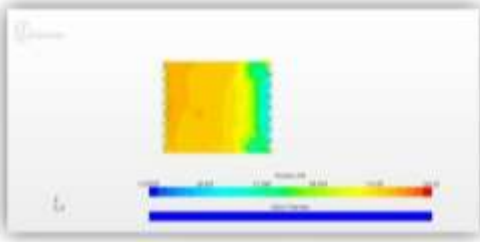
The Pressure drop for the DPF with square cell shape was found to be 84.846 Pa

Fig 4: Pressure drop in model 1

(the flow is in the -z direction)

The Pressure drop for the DPF with hexagonal cell shape was found to be 76.087 Pa

Fig 5: Pressure drop in model 2

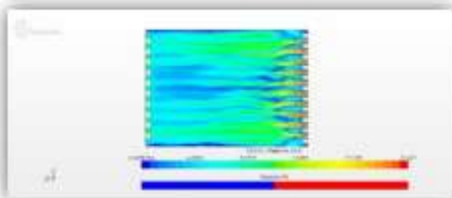


(the flow was in the -z direction)

The pressure drop for the DPF with octa-hexagonal cell shape was found to be 73.433 Pa

Fig 6: Pressure drop in model 3

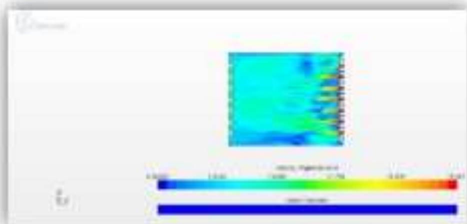
Velocity Drop



(The flow is in the +z direction)

The Velocity drop for the DPF with square cell shape was found to be 16.1542 m/s

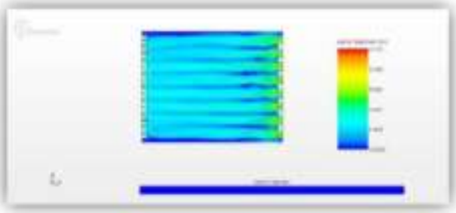
Fig 7: Velocity drop in model 1



(the flow is in the -z direction)

The Velocity drop for the DPF with hexagonal cell shape was found to be 13.0154 m/s

Fig 8: Velocity drop in model 2

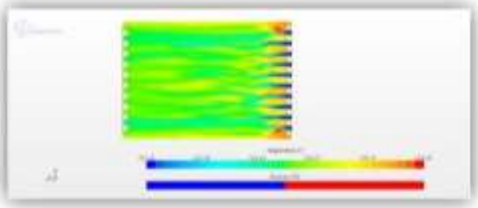


(the flow was in the -z direction)

The Velocity drop for the DPF with octa-hexagonal cell shape was found to be 12.9344 m/s

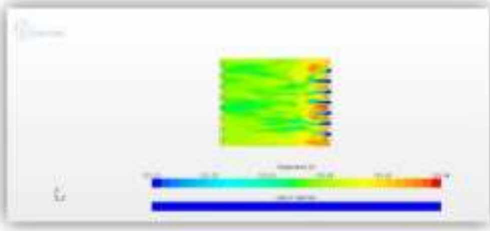
Fig 9: Velocity drop in model 3

Temperature Distribution



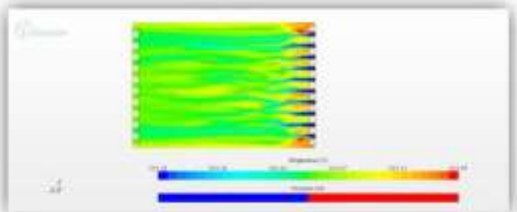
Due to small length of the DPF the temperature variation is not much, but the most affected areas can be seen.

Fig 10: Temperature distribution in model 1



Due to small length of the DPF the temperature variation is not much, but the most affected areas can be seen.

Fig 11: Temperature distribution in model 2



Due to small length of the DPF the temperature variation is not much, but the most affected areas can be seen.

Fig 12: Temperature distribution in model 2

V. CONCLUSION

The SolidWorks model of the three concepts were made as shown in the preceding sections and the analysis was successfully completed using Star CCM+ software. The porosity of the material was given using the Darcy equation. The results of the simulation are as shown:

(i) The pressure drop for the three models were ~ 84.846 Pa, ~ 76.087 Pa and ~ 73.433 Pa for model 1, model 2 and model 3 respectively. It was found that the pressure drop from model 3 was the least. Hence the back pressure of the DPF with cell shape of model 3 will be the least and therefore the reduction in the efficiency of the engine will be least if model 3 DPF is used. As the filtration area is more, it is expected that the filtration efficiency will be higher but the experimental validation is required for the same.

(ii) The velocity drop for the model 1, model 2 and model 3 were ~ 16.1542 m/s, ~ 13.0154 m/s and ~ 12.9344 m/s. It is evident that the decrease in pressure leads to an increase in velocity of the flow.

(iii) There was not much change in the temperature as the surface area of the DPF is small. However, the temperature distribution can give an idea for the re-generation process.

(iv) It is also recommended that the thermal shock resistance, ash characteristics, mechanical vibrations, mechanical strength (repeated loading), material properties needs to be considered for obtaining the detailed PM collection characteristics and planned to do in our future study. The mathematical model is also available for efficiency, pressure drop and soot oxidation.

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