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A Study on the Flow Characteristics of a Smoke Reduction Device in a Diesel Engine

Hyowon Bang
Graduate Student, Graduate School of Automotive Engineering, Kookmin University, Seoul, Korea,
bhw9521@naver.com

Doo-Sung Baik*
Professor, Mechanical Engineering, Daejin University, Pocheon, Korea,
dsbaik@daejin.ac.kr

Abstract—

The DPF is a smoke reduction device that aims to reduce the soot emitted from diesel vehicles. In Korea, around 2000, it was supplied to large vehicles with a subsidy from the Ministry of Environment, and now it is applied to passenger cars as well. There are about 25 types of smoke reduction devices applied so far. Such a smoke reduction device can be installed only after passing exhaust regulations and a strict certification examination to determine whether it is suitable for the device vehicle before installation. In addition, after installation, follow-up management is thoroughly managed, and a periodic management system is applied to determine whether the DPF device is defective and to analyze the cause. Currently, DPF is being developed in various ways according to the amount of exhaust in a significantly more advanced stage compared to the DPF in the initial stage. According to the operation method of DPF, natural regeneration and forced regeneration are applied. Natural regeneration is a method of regenerating the exhaust gas temperature without regenerating the collected soot by burning it as an external heat source. However, if the driving link is short, the collected soot cannot be regenerated and the engine stops, resulting in a dangerous accident. Therefore, a lot of devices that use both forced regeneration and natural regeneration are being introduced depending on the driving mode. In the past, ceramic, SIC, or cordierite-based materials were applied to the DPF filter, but cracks that occur locally due to high heat due to the low thermal conductivity of the ceramic material in the regeneration process frequently occur. On the other hand, DPF cracks were easy to occur due to vibrations generated from the vehicle body even while driving. Recently, a wire-type metal DPF has been developed and applied to solve the problems caused by existing materials. On the other hand, looking at the DPF structure, it is composed of a small mesh to collect soot when exhaust gas passes through the DPF through the exhaust pipe. When the back pressure is filled after rising to a constant pressure, regeneration is required, and the timing of regeneration is very important. Currently, a mechanical system is applied, based on a certain temperature and pressure, and when such pressure and temperature are reached, regeneration is possible. This paper tries to understand the change in back pressure and temperature formed by changing the DPF length, porosity ratio, and the diameter of the substrate when exhaust gas passes through the DPF.

Keywords— **Aftertreatment Devices, CFD (Computational Fluid Dynamics), Porosity, Back Pressure, DPF (Diesel Particulate Filter)**

1. INTRODUCTION

Diesel engines have been used in various equipment due to their high thermal efficiency and output. However, in order to meet the emission regulations, various methodologies have been studied to reduce harmful emissions from the diesel engines. Hazardous substances from diesel engines consist of gaseous and particulate matters. The particulate material is mainly composed of iron, soot, tar, and carbonaceous materials.

Among harmful emissions, PM, which is the main cause of air pollution, is reduced through a diesel particulate filter (DPF). DPF is a device that collects and burns PM to reduce it, and the inside of the DPF has a layered structure called a cake-layer structure. For each layer, ceramic plugs alternately block both ends of the passage, so that the exhaust gas entering the open passage passes through the pores in the ceramic substrate and filters PM. In the process of filtering PM, ash and soot accumulate in the porous filter. Metal oxide deposits that make up the ash come from engine wear, fuel and oil additives, and corroded exhaust manifolds [1]. Soot is relatively rich and is formed near the central axis of unburned fuel spray, and reacts with oxygen to partially oxidize, but the remaining parts that cannot be oxidized are discharged to DPF. Some of the dust, such as ash and soot, is accumulated along the inner wall of the filter, and the rest is accumulated as the flow rotates at the end plugs of each layer. In particular, it has been studied that the ash layer accumulated in the end plug greatly reduces the effective filtration volume of the DPF inlet channel and increases the pressure drop of DPF up to 80% [2]. In addition, in the case of soot particles, as the diameter decreases, the degree of pressure drop increases and the combustion efficiency decreases during regeneration [3]. Therefore, when designing DPF, studies on the design of asymmetric substrates to optimize the accumulation period of dust such as Ash and Soot were conducted [4]. The asymmetric cell technology can minimize the pressure drop that occurs when the accumulation of dust is large by designing the intake channel width and the outlet channel width of the DPF differently based on the results of CFD research. Through this, it is possible to extend the life and regeneration cycle of the DPF.

If more than a certain amount of dust accumulates inside the DPF, a regeneration process is required for combustion. When the exhaust temperature is raised to about 600 °C, the particles accumulated inside can be regenerated by combustion, so a part of the diesel fuel flows through the exhaust pipe and reacts with oxygen and dust in the exhaust gas to raise the exhaust temperature by post-combustion. A method of regenerating DPF through a diesel burner that has relatively simple engine torque control and less dilution of oil by fuel is widely used.

Recently, a plasma ignition diesel burner using a circular plasma, which has superior combustion efficiency compared to the conventional diesel burner, as an ignition source has been studied [5].

However, excessive regeneration may cause damage to the carrier due to thermal stress, and thus the performance of the DPF may be degraded. Therefore, recently, a study was conducted to analyze the cause of the uneven distribution of Soot inside the DPF by visualizing the flow through PIV (Particle Image Velocometry), an optical measurement technique, to understand the combustion characteristics of the soot particles accumulated inside the DPF regeneration. The distribution of the ash component can be analyzed by inductively coupled plasma mass spectrometry (LA-ICP-MS). This helps to understand the particle behavior characteristics inside the DPF during regeneration. Therefore, efficient DPF regeneration is possible if the fuel injection is precisely controlled while monitoring the reduction rate of the accumulated ash and soot in the DPF. For example, if the technology of injecting fuel in multiple pulses from the DOC installed in front of the DPF is applied, the regeneration process can be multistage and more precise and safe DPF regeneration is possible without significantly increasing the inner wall temperature [6].

As mentioned above, since the regeneration of DPF itself shows poor results in terms of durability and environment, a method of reducing the amount of Soot particles flowing to the DPF by installing a diesel oxidation catalyst (DOC) installed in front of the DPF is applied, or Alternatively, a method of lowering the intake exhaust temperature required for regeneration is used.

DOC supports the regeneration of DPF through two major regeneration methods. First, it is placed in front of the DPF and converts NO among the exhaust gas components to NO2 that can react with the Soot particles to oxidize some of the Soot particles to be accumulated in the DPF. Second, through post-injection, HC is discharged from the front of the DOC, and the heat generated during the oxidation reaction is used to increase the temperature for regeneration of DPF. Research on improving the catalytic performance of DDPF, which combines the functions of DOC and DPF into one, is also being conducted. In particular, it is important to optimize the two regeneration methods of DOC in a trade-off relationship [7].

Since the regeneration of DPF requires a complex system configuration for interaction with DOC, a DPF regeneration technology using hydrogen has also been studied to quickly reach the activation temperature without the help of DOC. The exhaust temperature of a diesel engine that has not been preheated is less than 100°C when it is idle, but it is known as a technology that can raise the exhaust temperature of the DPF front end to 700°C and the rear end temperature to 520°C when hydrogen is supplied. It has been studied that the entire DPF regeneration process can be completed in about 10 minutes by applying [8].

Recently, biodiesel fuel has been used that greatly reduces greenhouse gas emissions in accordance with the strengthening of engine emission regulations. Biodiesel fuel has a high oxygen content and a lower calorific value than regular diesel fuel, so it is necessary to take a new strategy for regeneration of DPF. It has been found that the total PM emission is low thanks to the high oxygen content, but the low low heating value (LHV) increases the amount of fuel required to oxidize the Soot inside the DPF. Therefore, it is necessary to optimize the regeneration cycle of DPF by adjusting the fuel injection strategy according to the fuel characteristics [9].

In order to minimize such DPF damage, it is necessary to reduce the temperature rise of the inner wall of the carrier layer as much as possible and to regenerate the DPF while minimizing fuel consumption. A research has been conducted to inject fuel into ‘Multiple pulses’ from DOC mounted in front of the DPF during the regeneration process Through this, it has been revealed that if the regeneration process is multi-layered, DPF can be regenerated more safely without significantly increasing the temperature. In addition, the shape of the intake pipe in DPF also has a significant impact on regeneration efficiency. Optimal design studies of DPFs using CFD analysis have shown that curved-shaped pipes reduce the uniform regeneration efficiency of filters more significantly [10]. Therefore, pipes for exhaust flow should be designed in a straight line to minimize local damage to the wall during regeneration.

DPF suffers from poor durability due to hot heat during regeneration, but when diesel high-sulfur fuels are used, the regeneration process produces white smoke containing odors and harmful contaminants. Recent studies have shown that sulfur compounds emitted from the engine are deposited in the catalyst of the DPF system, where SO_2 is oxidized to SO_3 in the catalyst at temperatures above 450 °C and absorbed by Al_2O_3. The absorbed SO_3 was converted to white smoke through the hydrolysis process [11]. The intensity of these white smoke depends on the amount of SO_3 and the rate of temperature increase, especially the larger the temperature increase, the greater the production of white smoke.

Sulfuric acid also has a problem of corroding the wall when regenerating DPF. Therefore, DPF substrate materials should have robust heat resistance and chemical stability to sulfuric acid. This has led to the study of DPF applying Si-SIC materials with improved oxidation resistance and thermal stress resistance compared to SIC and Cordierite series materials, which were mainly used by conventional DPFs[12]

Since regeneration of the DPF exhibits durability degradation and poor environmental results, some methods are used to reduce the amount of soot particles flowing into the DPF by equipping Diesel Oxidation Catalysts (DOC) mounted in front of DPF, or to reduce the intake exhaust temperature required for regeneration. DOC supports the regeneration of DPF through two main regeneration methods. First, it is placed in the front of the DPF and converts NO among the exhaust gas components into NO_2 that can react with Soot particles, oxidizing and removing some of the Soot particles that are going to accumulate in the DPF. Second, by supplying HC from the front of the DOC through post-injection, the heat generated during the oxidation reaction of the HC is used to increase the temperature for regeneration of the DPF. These two regeneration methods of DPF are in a trade-off relationship.

CDPF technology, which incorporates the functions of DOC by coating precious metals on DPF walls, has also been actively studied. Since it is difficult to simultaneously perform the two regeneration techniques performed by DOC in CDPF, the CDPF catalyst coating technology must be optimized. To do this, a study has been conducted to create a CDPF sample graph defined as the relationship between the amount, ratio, and front and rear positions of Platinum Group Metals (PGM) to investigate the trade-off relationship between two regeneration methods. Manual regeneration, which eliminates Soot by oxidizing it, measured the rate of mass reduction of Soot due to oxidation reactions, and active regeneration, which generates heat oxide by HC injection, measured the decrease in DPF inlet regeneration temperature due to HC injection. These sample studies enable the basic design of CDPFs that can achieve optimal efficiency[13].

Most of the particle sizes emitted from diesel engines are known to be less than 1 μm, and these small particles have a relatively large specific surface area compared to large particles, making it known that carcinogenic and mutagenic materials are easily adsorbed. Micro diesel dust (PM 2.5) contains mutants, carcinogens, and other toxic substances, including heterocyclic compounds, polyaromatic hydrocarbon (PAH), and phenols, and is treated as a major particulate matter for environmental management. Fine dust and nitrogen oxides, which are emerging as the biggest issues among various emission pollutants, are in a trade-off relationship. These two materials cannot be removed without aftertreatment devices. Increasing the combustion temperature to reduce dust emission increases nitrogen oxide emission and lowering the combustion temperature to reduce nitrogen oxide increases the dust emission.

Diesel engines have used aftertreatment devices to cope with stringent environmental emission regulations. The diesel particulate filter (DPF) that reduces PM is composed of a porous filter, and as the mileage accumulates, soot and ash accumulates inside the filter and back pressure increases. In diesel particulate filter periodic regeneration is necessary to remove PM, and the porosity of DPF is a major variable that determines the regeneration cycle according to the filter efficiency as well as the back pressure characteristics.

Diesel particulate filter (DPF) is a device that collects and burns PM. Inside the DPF, there is a porous stacking structure called 'Cake-layer'[1]. On each floor, ceramic plugs alternately block both sides of the passage, and the exhaust gas entering open passage passes through a perforated hole in the ceramic wall and filters the PM. Since the accumulation of such dust impairs filter permeability and results in pressure drop, filters have been developed to minimize ash accumulation. For example, filter structure with asymmetrical channels have been studied to replace honeycomb-shaped channel structures. The results of the CFD study show that when the accumulation of dust is high, the pressure drop can be reduced by designing different inlet and exhaust channel width. This result can extend the regeneration cycle of DPF [14].

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If particulate matter continues to be collected in the filter, the filter must be regenerated periodically because the pressure increases significantly. Regeneration can be divided into a passive system and an active system according to the method. In the active system, the exhaust temperature can be increased by releasing a portion of the diesel fuel into the exhaust pipe. This fuel reacts with oxygen and dust This fuel reacts with oxygen and dust during the exhaust procedure, and exhaust temperature rises. As a result, dusts accumulated inside the DPF are burned, and the clogging surface of the channel covered with dust is restored, restoring the reduction performance. Since DPF is regenerated through high-temperature exhaust gas, thermal stress occurs as the DPF is repeatedly exposed to high temperatures during the regeneration process, resulting in poor durability of the substrate or damaging inside the substrate. When a DPF is damaged, DPF's filteration capability is significantly reduced so that PM will be released into the atmosphere in a large amount.

Because DPF regeneration leads to reduced durability and poor environmental results, a passive method is used to reduce the amount of soot particles entering the DPF by mounting a Diesel Oxidation Catalyst (DOC) on the front of the DPF, or to lower the intake and exhaust temperature required for regeneration. DOC assists the regeneration of DPF through two main regeneration methods. First, it is placed in the front of the DPF and converts NO among the exhaust gas components into NO_2 that can react with Soot particles, oxidizing and removing some of the Soot particles that are going to accumulate in the DPF. Second, by supplying HC from the front of the DOC through post-injection, the heat generated during the oxidation reaction of the HC is used to increase the temperature for regeneration of the DPF. These two regeneration methods of DPF are in a trade-off relationship.

As such, since DPF requires periodic regeneration for differential pressure compensation, it is important to secure the optimal regeneration cycle and PM filtering performance by understanding the original back pressure and temperature gradient characteristics of DPF in advance. Therefore, numerical simulation modeling studies have been conducted on the pressure drop phenomenon caused by DPF filtration. In particular, CFD analytical studies are used in various aspects such as internal flow uniformity, temperature gradient, and pressure distribution because CFD enables to easily interpret internal flow fields that are difficult to visualize experimentally and significantly reduce cost and time for verification [15-16].

Kitagawa[17] assured the temperature distribution of forced regeneration DPF filters according to operating conditions such as exhaust flow rate. Later, Park's numerical study applied the actual vehicle operating conditions to the inlet conditions on CFD and analyzed the temperature distribution inside DPF[18] Another numerical study was also conducted to analyze the effect of the filter material, location, and internal structure shape on the back pressure or temperature distribution characteristics.

In this study, as a follow up study, the characteristics of back pressure and temperature distribution according to the correlation between the change in porosity and structural shape of a filter made of a porous material were studied. In general, the higher the porosity of DPF filter, the more advantageous the PM filtration capacity is, so the industry tends to prefer filters with higher porosity. However, since filtration capacity and back pressure and temperature distribution characteristics are in a trade-off relationship, this research was conducted to develop a DPF having excellent back pressure characteristics with optimal DPF filtration capacity.

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Therefore, in this study, we investigated how changes in the DPF porosity, geometric size, and changes in the particle diameter passing through the filter affect the back pressure and temperature of the DPF. Computational fluid dynamics (CFD) can significantly reduce the time and cost required for internal flow analysis, so CFD was used to analyze porosity and back pressure characteristics of DPF according to cross-sectional diameter, and particle diameter.

2. NUMERICAL ANALYSIS

2.1 ANALYTICAL CONDITIONS

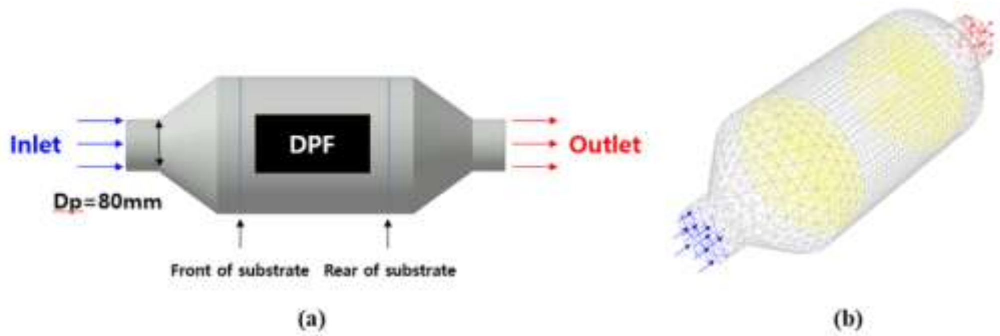

Fig. 1 Schematic of DPF system; (a) Side view of 3D model, (b) Mesh generation

This study applied a numerical analysis technique based on the finite volume method, and assumed a compressible turbulent flow in a normal state for exhaust flow. Accordingly, the compressible flow-based momentum equation, the continuous equation, and the turbulence motion equation were applied together. The RNG k-epsilon turbulence model, which calculates relatively robust results for turbulence flow was used [19] High-porosity DPF filter was set as a porous medium, and the internal flow was assumed to be a laminar. Fig. 1 shows the standard shape and mesh model of DPF used in this study. The diameter of the exhaust pipes (*Dp*) connected to the front and rear ends of the DPF was fixed to 80 mm, and the diameter or length of the DPF substrate was changed in accordance with the analysis conditions. Mesh elements are composed of a total of 150,000. The mesh element size of DPF substrate is 0.01mm.

2.2. POROUS MEDIA

When Porous media is set and analyzed, filters can be replaced with formulas related to inertial resistance and viscosity resistance, enabling accurate numerical analysis without complex modeling. Therefore, this research used a 'Porous model' to set and analyze the isotropic catalyst for emergency generators as areas with viscous resistance and inertial resistance, which are characteristic values of real porous media. If the loss due to viscous resistance and inertial resistance in a porous material is modified by the Ergun[20] equation, the pressure drop can be expressed as follows below:

$$\frac{\Delta p}{L}=\frac{150\mu\overline{V_0}}{{\Phi_s}^2 D_v^2}\frac{(1-\epsilon)^2}{\epsilon^3}+\frac{1.75\rho\overline{V_0}^2}{{\Phi_s}^2 D_v}\frac{(1-\epsilon)}{\epsilon^3} \qquad (1)$$

Here, ϵ is the porosity, Φ_s is particle sphericity, D_v is the diameter of particle, $\overline{V_0}$ is the average velocity, μ and ρ are viscous coefficients and fluid density, respectively. Equation (1) can be summarized for inertial resistance $\frac{1}{\alpha}$ and viscosity resistance C_2 as follows:

$$\frac{\Delta p}{L}=\frac{1}{\alpha}\mu\overline{V_0}+\frac{C_2}{2}\rho\overline{V_0}^2 \qquad (2)$$

Therefore, $\frac{1}{\alpha}$ and C_2 can be calculated using porosity, sphericity, and particle diameter as variables as shown in the equation (3) and (4).

$$\frac{1}{\alpha}=\frac{150(1-\epsilon)^2}{{\Phi_s}^2 D_v^2\epsilon^3} \qquad (3)$$

$$C_2=\frac{2\times1.75}{{\Phi_s}^2 D_v}\frac{(1-\epsilon)}{\epsilon^3} \qquad (4)$$

Here, the sphericity Φ_s was set to 0.75, which is an intermediate value of 0.6~0.9, which is a solid reference range, The particle diameter D_v was changed to 4,6,8 mm according to the analysis conditions based on 2 mm.

In the case of a filter, the porosity and cell density depend on the filtering ability [21], and the porosity of the DPF substrate changed from a minimum of 45% to a maximum of 90%. However, in this study, since the change in flow characteristics according to the change in porosity was the subject of interest, the analysis was conducted in consideration of the change in porosity and the change in viscosity and inertial resistance values according to the change in porosity. Table 1 shows boundary conditions for CFD analysis.

Table I. Boundary conditions for CFD analysis

Type	Parameter	Value
Exhaust System	Inlet mass flow rate [kg/s]	0.15861
	Outlet pressure [atm]	1
	Exhaust temperature [K]	576
DPF Model specification	Porosity [%]	45, 60, 75, 90
	Diameter of particles [mm]	2, 4, 6, 8
	Diameter of substrate [mm]	200, 250, 300
	Length of substrate [mm]	150, 200, 250

3. RESULTS

3.1 PRESURE DROP ACCORDING TO POROSITY AND DIAMETER

Since the cross-sectional area specification of the DPF may be varied by the exhaust flow conditions of the engine, the back pressure characteristics according to the change in the cross-sectional area and porosity were closely investigated and analyzed. If the area of the DPF is changed while the area of the exhaust pipe is constant, the angle of the inlet diffuser also changes, so the change in angle and cross-sectional area causes changes in the internal flow characteristics.

Table II shows the pressure changes when the cross-sectional diameter of the DPF is increased from 200mm to 250mm and 300mm under the same length and same porosity (45%). As a result, as the cross-sectional area increases, a back pressure between DPF inlet and outlet increases. This is because the flow rate decreases at the expanded cross-sectional area of DPF compared to the exhaust pipe, and the pressure at the front end is higher than the pressure at the rear end as shown in the path-line of [Fig.2]. In addition, in all three cases, most of pressure concentrated in the center of the DPF substrate.

Table II. Summary of pressure variations of DPF at cross-sectional diameters

Location	Pressure (mbar)

	Ø200mm	Ø250mm	Ø300mm
Front section	22.7	24.3	25.1
Rear section	5.8	5.9	6.1
Pressure drop	16.9	18.4	19.0

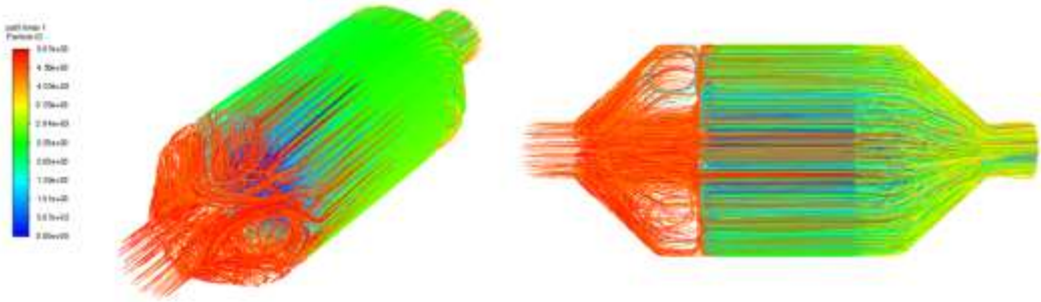

Fig. 2 Path-lines schematic of standard DPF system with vortex flow

Next, to understand the pressure gradient characteristics according to a change in porosity and cross-sectional area, the porosity was changed to 45%, 60%, 75%, and 90%, and the pressure drops before and after DPF for three types of cross-sectional area were analyzed. [Fig.3] showed the results in a graph.

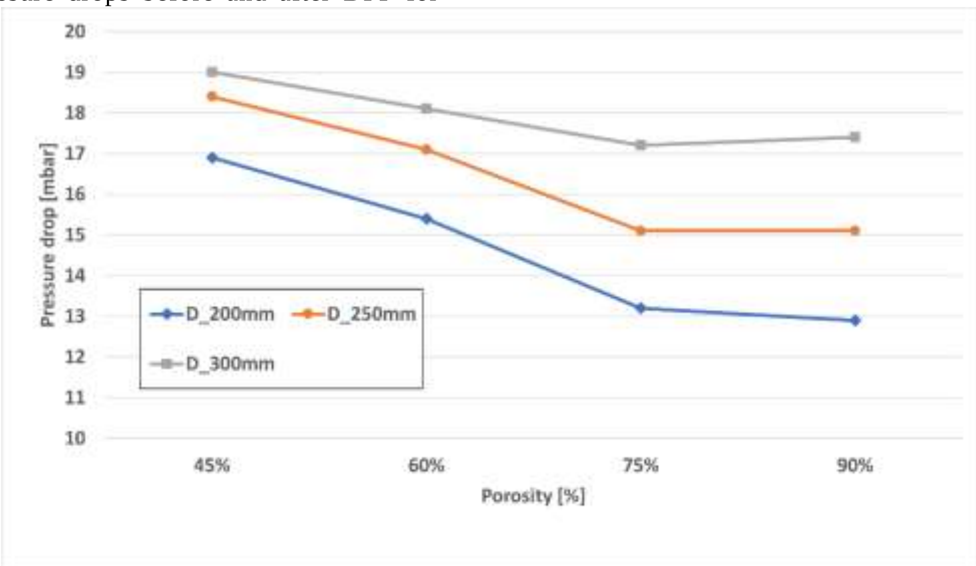

Fig. 3 Pressure drop according to the porosity, and DPF diameter

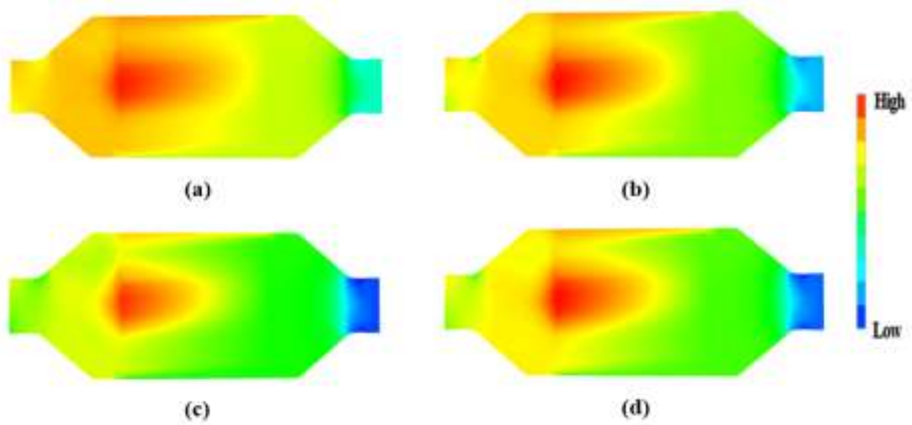

Fig. 4 Pressure contours for DPF with 300mm length;
(a) 45% porosity, (b) 60% porosity, (c) 75% porosity, (d) 90% porosity

As shown in Fig. 3, an increase in porosity reduced the resistance formed when the exhaust flow passes through the DPF and reduced the concentration of pressure on the front end of the DPF. Therefore, in all 200mm, 250mm, and 300mm diameter cases, pressure at the front of DPF decreased as the porosity increased, resulting in a decrease in the back pressure. However, when the porosity became greater than 75%, part of the pressure was concentrated on the wall of the substrate, resulting in an increase in pressure at the front, decreased back pressure, simultaneously. In particular, as shown in Fig.4, back pressure at the DPF with 300mm length decreased and then increased again when the porosity increased from 45% to 90%.

As such, the basis for the lower flow rate character due to the larger cross-sectional area can be found in the relationship between the superficial velocity passing through the porous medium and the porosity. Superficial velocity refers to the approximate average rate of fluid flowing through a porous medium such as a catalyst layer. It's mentioned in the Darcy-Weisbach equation [22] dealing with fluid flow inside the porous medium, and the average velocity v is defined as follows:

$$v = \frac{q}{\emptyset A} \qquad (5)$$

Here, q is the volume flow rate, A is the cross-sectional area of the catalyst layer, and ϕ is the porosity of the catalyst layer. That is, the velocity is proportional to the volume flow rate and inversely proportional to the catalyst cross-sectional area and porosity, so the velocity decreases as the porosity increases. This is because an increase in porosity increases the available area of the total cross-sectional area, resulting in an increase in the flow area.

3.2 PRESURE DROP ACCORDING TO POROSITY AND DPF LENGTH

Next, the effect of changes in the length of DPF on pressure was analysed. [Table 3] shows the change in pressure that occurs when the porosity is fixed and the length of the DPF is increased to 150mm, 200mm, and 250mm under the same flow conditions. The cross-sectional diameter was fixed to 250 mm.

Table III. Pressure of DPF for various DPF length

	Pressure (mbar)		
	Length_150mm	Length 200mm	Length 250mm
Front section	24.3	23.8	23.6
Rear section	5.9	5.2	4.8
Pressure drop	18.4	18.6	18.8

As shown in the CFD results, as the length of the DPF increased, the pressure at the rear compared to the front dropped significantly, resulting in an increase in the overall back pressure. This is because the friction loss increased as the contact area with the wall increased when the length increased. However, compared to the case where the cross-sectional area changes, the increase in back pressure is low.
Next, to understand the pressure gradient characteristics according to changes in porosity and length of substrate, the porosity was changed to 45%, 60%, 75%, and 90%, and the pressure drops before and after DPF for three types of length were analyzed. Fig. 5 shows the results in a graph.

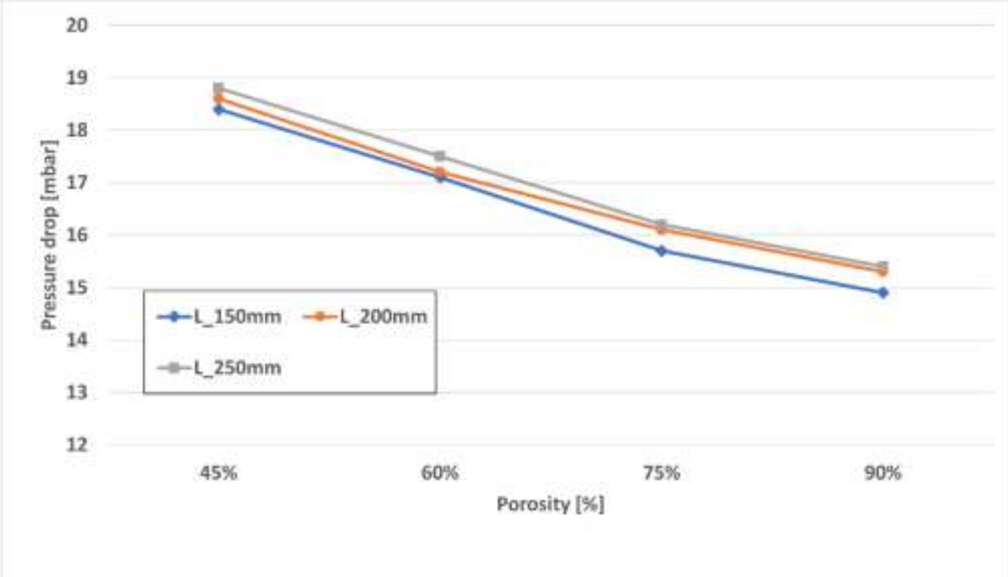

Fig. 5 Pressure drop according to the porosity, and DPF length

Like the previous results, an increase in the porosity increases the available area which the exhaust gas can flow, reducing the resistance at the front of DPF and then reducing the back pressure. However, since there was no secondary loss of flow velocity due to an increase in cross-sectional area, even if the porosity increased by more than 90%, it was not observed that the back pressure increased again as the flow velocity decreased.

3.1 PRESURE DROP ACCORDING TO POROSITYAND PARTICLE DIAMETER

In the aforementioned pressure drop equations (1) to (4), the unit particle diameter passing through the porous media is another variable that determines the magnitude of viscosity and inertial resistance. Therefore, the change in back pressure was analysed while changing the porosity for four different DPF cases with particle diameters of 2mm, 4mm, 6mm, and 8mm. Fig. 6 is a graph showing changes in DPF internal pressure characteristics according to particle diameter, and porosity.

As shown in the Fig. 6, pressure loss increases significantly as the particle diameter and porosity decrease, and as the porosity increases, pressure drop generally decreases regardless of the particle diameter. In particular, the smaller the particle diameter, the greater the amount of change in pressure drop according to the width of change in porosity.

At a porosity of 60% or less, the pressure loss increased very significantly at a particle diameter of 6 mm or less. At a relatively low porosity of 45%, it was shown that the difference in pressure loss according to the particle diameter was the largest because the smaller the particle diameter, the greater the resistance of exhaust flow acting at the front of DPF, and thus the larger the difference in pressure before and after the DPF. As the porosity increases, the back pressure decreases, and at a porosity of 75% or more, the back pressure converges to an average of 11.5 mbar under all particle size conditions. As such, a particle diameter affects the resistance at the front of DPF, and even in the temperature distribution characteristics, a temperature difference between the front and rear ends of the DPF increases as the particle diameter decreases. Fig.7 shows the temperature gradient visually according to the change in particle diameter at the same porosity of 45%.

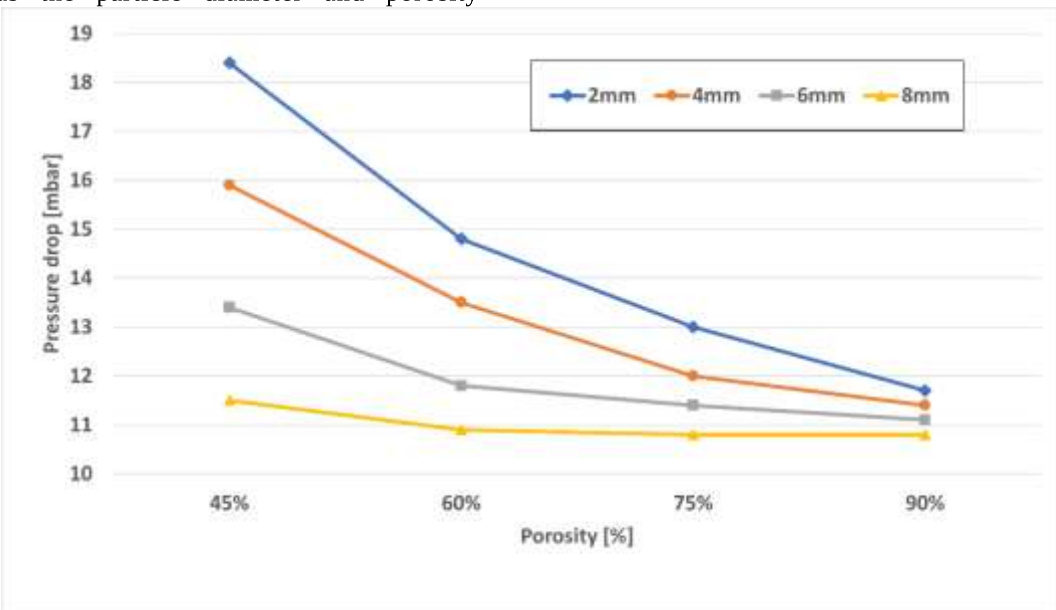

Fig. 6 Pressure drop according to the porosity, and particle diameter

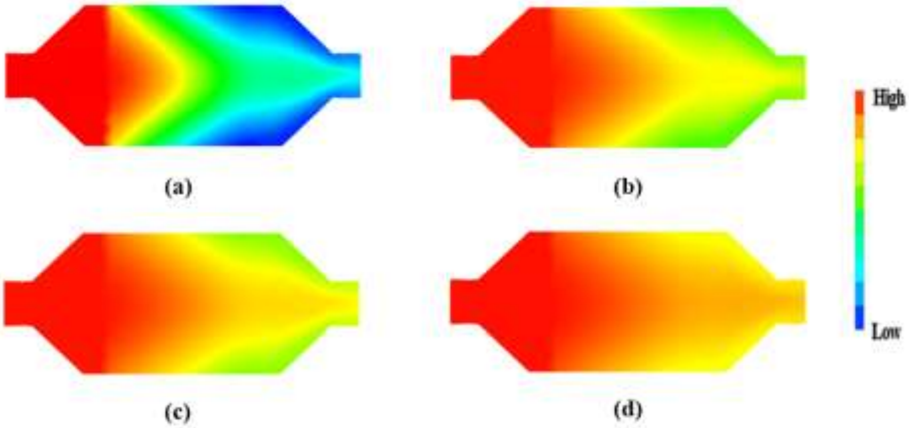

Fig. 7 Temperature contours for DPF with various particle diameter;
(a) 8mm, (b) 6mm, (c) 4mm, (d) 2mm

4. CONCLUSIONS

In this study, CFD analysis was performed to investigate the back pressure characteristics according to the change in the porosity, geometric size, and particle diameter of DPF, and the results are as follows:

1) As the cross-sectional area of DPF increases, the back pressure increases. In addition, if the porosity is increased in DPF with the same cross-sectional area, the back pressure is decreased, but if the porosity is increased by 75% or more, the average flow speed decreased, and back pressure is increased again.
2) Increasing the length of the DPF induces friction pressure on the wall surface, thereby increasing the back pressure. However, rather than an increase in back pressure with length, the decrease in back pressure with an increase in porosity is greater.
3) The lower the porosity and the smaller the particle diameter, the larger the back pressure and temperature gradient occurs. As the porosity increases, the back pressure decreases, but under a porosity condition of 75% or more, the back pressure converges to one uniform value under all particle diameter conditions.

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