Design of Sintered Metal Particulate Filter for Diesel and Biodiesel Engine

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Abstract

Diesel particulate filter (DPF) is after-treatment device that reduces particulate matter (PM) by trapping and oxidation. In trapping process, particulate is trapped on the surface pores of DPF. Therefore, pore size is key important parameter which directly affect to filtration behavior and efficiency. In the present research, DPF design is focused on porous structure and porosity that based on two main parameters. The first is physical and chemical properties of diesel and biodiesel particulate matter especially agglomerate particle. The second is metal powder size that would be shaped DPF and effects particulate matter filtration. When powder metal size reduces, particulate matter filtration should be increased. From all data can be designed pore size and thickness of DPF. Characteristic of DPF from this design should have appropriate particulate matter behaviors in trapping process. And this result would be used for future design and development of DPF configuration.

***Keywords**:* Diesel Particulate Filter (DPF), Particulate Matter (PM), Metal Powder, Pore Size

1. Introduction

Nowadays, emissions problem are the main problem for environment and human. Some parts of problems come from vehicles in transportation that emit pollution emission to surrounding especially the vicinity of roads in the city. Many toxicological and epidemiological studies established adverse health effects by particulate matter. There is increasing evidence that several health effects are associated with the ultrafine particles that have diameters less than 100 nm and nanoparticles that have diameters less than 50 nm. This particle type can come in cell membranes, blood and breathe system that was cause of many diseases. Many efforts are taken to reduce the emissions. Regulations were established and become stringent rules such as European emission standards. So many devices were made to reduce the pollution. One of technology is Diesel Particulate Filter (DPF)[1-2].

DPF is after-treatment device that reduce particulate by trap and oxidation. Particulate will be trapped at filter surface in trapping process and trapping particulate will be burnt at regeneration process. In regeneration process can add catalyst to increase reaction rate of particulate oxidation. DPF was used to made from many types of material that depends on oxidation temperature. For active system DPF, oxidation temperature is higher than 600°C, DPF usually makes from high temperature resistance material or ceramic such as silicon carbide or cordierite. Passive system catalyzed-DPF has to be added some devices to increase temperature of exhaust gas such as burner, post-injection and heater because carbon soot was burnt at 550-600 °C with O_2 [3]. In exhaust gas temperature of 300-400 °C, DPF can be made from metals.

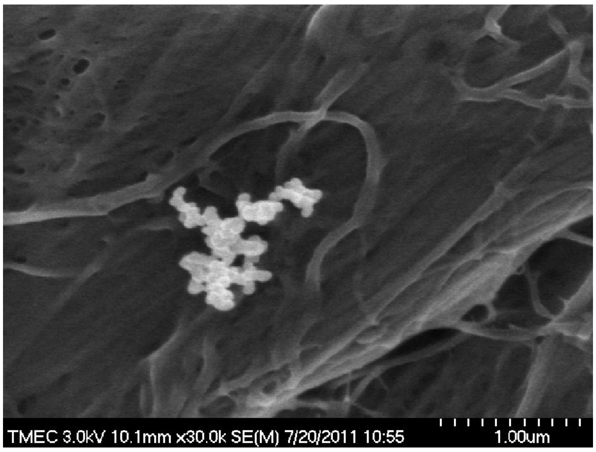
Engine exhaust consists primarily of nitrogen, oxygen, water vapor, and CO_2, with minor constituents of CO, hydrocarbons, NOx and Particulate matters. For particulate matters, consist of a Solid Fraction (SOL) and a Soluble Organic Fraction (SOF). SOL composed of carbon and traces of metallic ash. SOF composed condensed hydrocarbons and sulfate. The composition of particles from a diesel engine is widely depending on the operating conditions and fuel composition. [4-6]

Trapping and oxidation process of DPF occur on surface pore. Pore size and porosity strongly effect to both particulate matter trapping and oxidation process inside DPF. In the present research propose sintered metal DPF based on diesel and biodiesel particulate matter properties and metal powder size. The proposed DPF would be an advanced DPF for improvement reduction of diesel and biodiesel particle emission in Thailand.

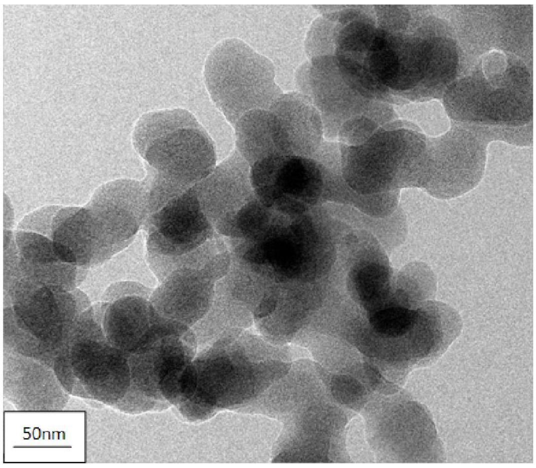
2. Design Concept

2.1 Particulate matter size

Figure 1 shows (a) SEM image and (b) TEM image of the soot particles emitted by the diesel engine. Primary particles can be observed that were homogenous size and agglomerate. Agglomerate particle size was approximately 100-500nm.The size of agglomerated particle might be also strongly depended on related energies such as, electrostatics, drag and Brownian forces. Figure 2 shows TEM images of (c) diesel and (d) biodiesel particulate matters for primary particle study. The primary particle size of diesel and biodiesel were approximately 50-60 nm and 30-40 nm. Diesel particulate size is larger than biodiesel particulate size because biodiesel has more amount of oxygen content than diesel that can oxidize with particulate matter in combustion [7].

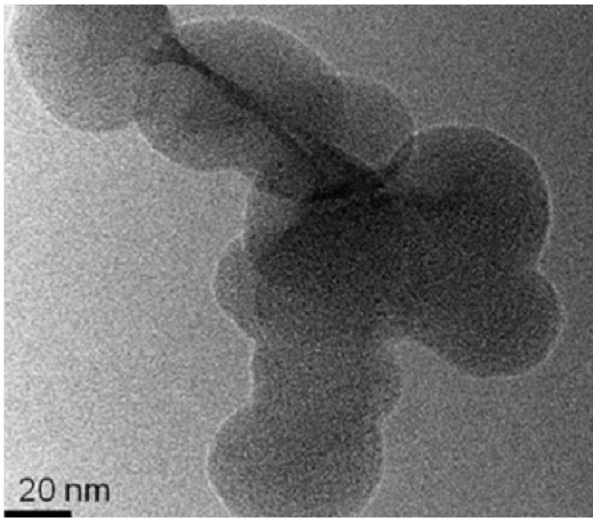


(a) SEM image of agglomerated particle

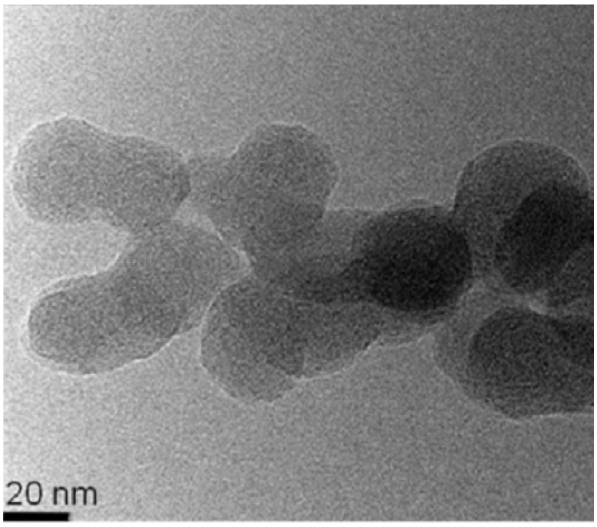


(b) TEM image of agglomerated particle

Fig. 1 (a) SEM image and (b) TEM images of the soot particles emitted by the diesel engine [7].



(c) TEM image of diesel particle



(d) TEM image of biodiesel particle

Fig. 2 TEM images of (c) diesel and (d) biodiesel particulate matters for particle study [8].

2.2 Brownian motion of particle

When the particle comes in DPF, Many forces effect the particle movement into the surface pore. Mechanisms of trapping process were considered with the drag, Brownian diffusion and electrostatic forces (F_D, F_B and F_c). In this research, focuses on Brownian motion that influences particle near surface pore of filter. Figure 3 shows (a) Brownian motion and (b) r.m.s. displacement of particle, each particle has r.m.s. displacement and specific direction. particle change direction but r.m.s. displacement constant when particle moves in new pore. So particle has chance to move near surface pore. Opportunity of particle trapping comes from displacement of metal and r.m.s. displacement.

Result from this can calculate to thickness of filter by multiple with metal size.

For r.m.s. displacement is distance of the particle that can move within reference area. r.m.s. displacement can calculate from

$$r.m.s.displacement = \sqrt{2D_B t} \qquad (1)$$

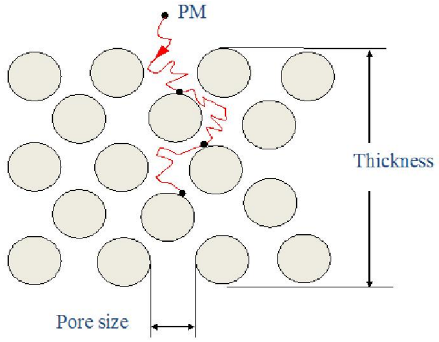
where D_B is the diffusivity of the particle and t is the diffusion time of particle pass through DPF. D_B can be calculated from

$$D_B = \frac{CkT_g}{6\pi\mu_g R_p} \qquad (2)$$

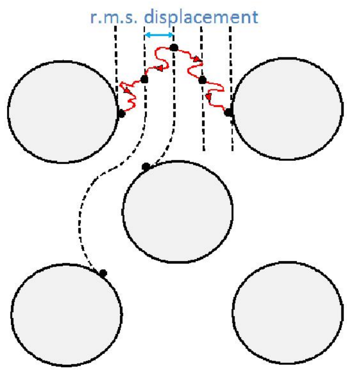
where C is Cunningham correction, k is the Boltzmann constant, T_g is the gas temperature, μ_g is the gas viscosity and R_p is the soot particle radius

$$C = 1 + \frac{2\lambda}{d}\left(A_1 + A_2 e^{\frac{-A_3 d}{\lambda}}\right) \qquad (3)$$

where λ is mean free path, d is particle diameter, A is constant. For air, $A_1 = 1.257$, $A_2 = 0.4$ and $A_3 = 0.55$ [9-10].



(a) Brownian motion of particle



(b) r.m.s. displacement of particle

Fig. 3 Concept of (a) Brownian motion and (b) r.m.s. displacement of particle

3. Result and discussion

3.1 Design result

Design filter for exhaust pipe is 5 cm, air volume is 3000 cc and filter structure is cylinder, porosity 50% and diameter filter is 10 cm. Assume exhaust gas from engine move into full exhaust pipe that install filter for trapping particle.

Figure 4 shows relation between revolution with thickness at 500, 600 and 700 K, PM size is 100 nm and metal size is 100 µm indicated temperatures give similar thickness. Filter has more thickness at low temperature. Therefore the lowest near exhaust gas temperature was approximately 500 K that was chosen to consider thickness result.

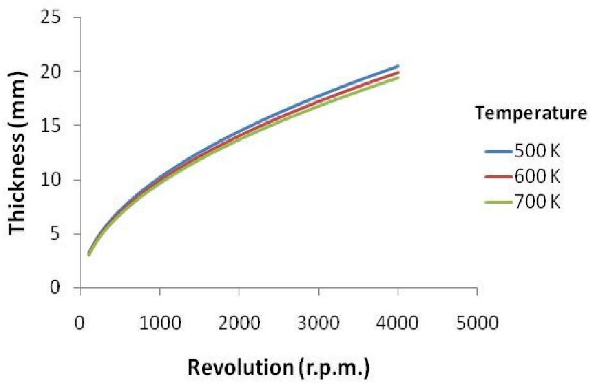


Fig.4 Relation between revolution with thickness at 500, 600 and 700 K, particle size is 100 nm and metal size is 100 µm.

Figure 5 shows relation between revolution and thickness at different particle size and metal size is 100 µm, graph shows thickness increase when revolution increase. Particle size increase influences the filter thickness that was the result of r.m.s.displacement. The small particle has a large r.m.s.displacement so small particle was trapped easier than a big particle size. In the similar result of Fig.6 relation between revolution and thickness at different metal size, particle amount was caught by big metal is lower than small metal because blank between metal. A large amount of particle can pass though large blank in the other hand surface area for trap particle is less.

So metal size filter should have a small size because pore structure was small follow metal size.

Particle size effects trap in filter that shows in Fig. 7 relation between particle size and percent of trapping for difference metal layers and metal size is 100 µm. Percent trapping reduces rapidly in particle size in 1-100 nm and is very small in particle size from 100-500 nm. From this graph show particle size that has a limit design for each particle size. For small particle size, percent trapping can up to be 100 percents at low amount of metal layer. And big size particle, amount of metal layer has to increase. That was the result of r.m.s. displacement, a big particle has a low displacement so chance of particle trapping was difficult. But if metal size is change, percent trapping change too that show in Fig.8 relation between particle size and thickness at particle is 100 nm, Increase of 2 factors rather smooth. Percent trapping direct-changes with metal size, so filter from small metal size was thinner than filter from big size metal.

Fig. 9 shows relation between thickness and percent trapping at particle size is 100 nm, metal size is 100 μm and revolution is 2400 rpm, percent trapping increases when thickness increases. In the other hand, metal layer addition effects trapping efficiency. If filter has a limit for pore structure, thickness addition helps to increase percent trapping of filter.

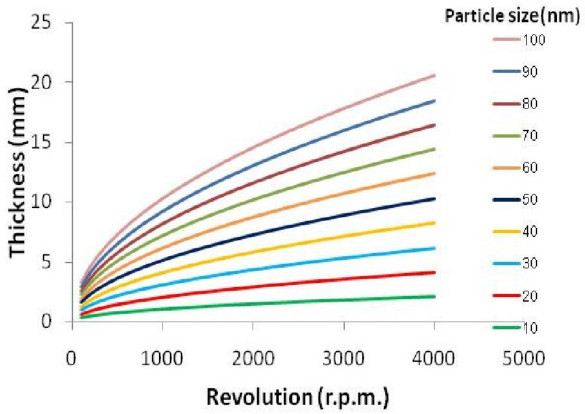


Fig. 5 Relation between revolution and thickness at different particle size and metal size is 100 μm

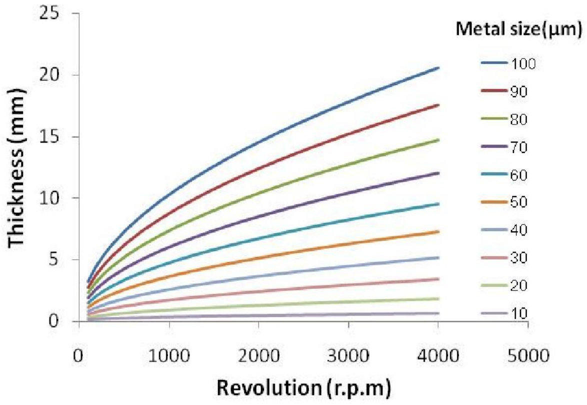


Fig. 6 Relation between revolution and thickness at different metal size and particle size is 100 nm

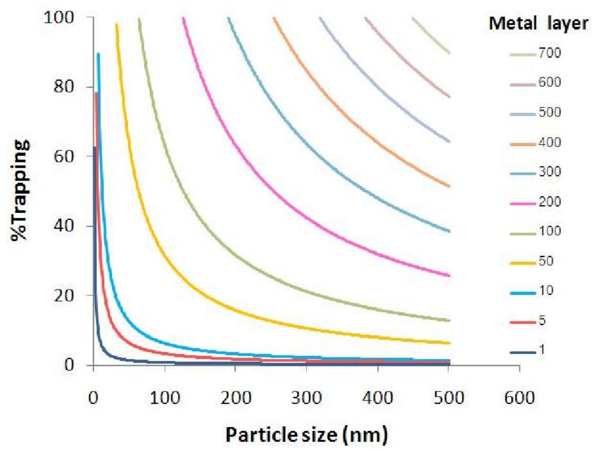


Fig. 7 Relation between particle size and percent trapping for difference metal layers and metal size is 100 μm

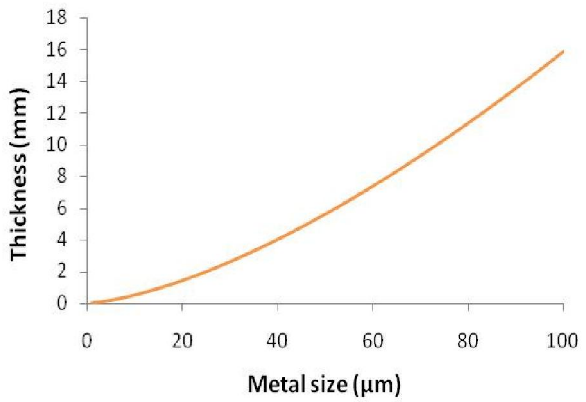


Fig. 8 Relation between particle size and thickness at particle is 100 nm

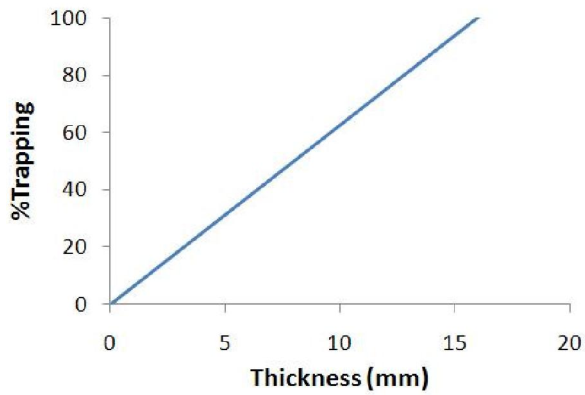


Fig. 9 Relation between thickness and percent trapping at particle size is 100 nm, metal size is 100 μm, revolution is 2400 rpm.

3.2 Experiment result

3.2.1 Powder size

In this research, Iron powder (ATOMET 195SP) is collected because iron metal is low cost when compares with other metal and iron oxide (Fe_2O_3) can oxidize with particulate. But filter catalyze (iron oxide) will be future studied.

Powder in Fig. 10 and 11 show iron powder size was made from atomization process so characterize should be sphere. Fig. 12 illustrates relation between percent distribution and metal size, range size was approximately 10-100 µm that was measured by mastersizer.

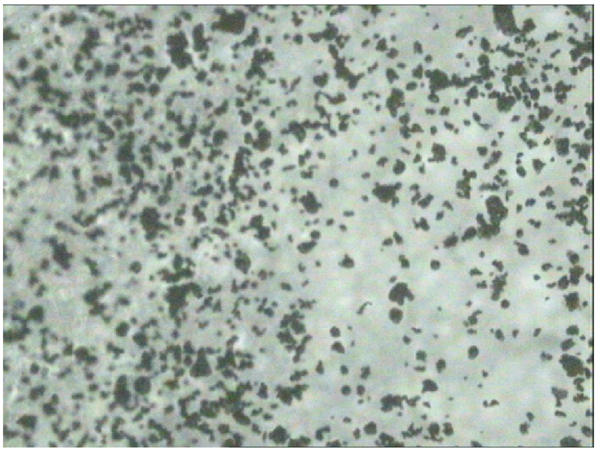


Fig. 10 Iron powder from optical microscope at 50x

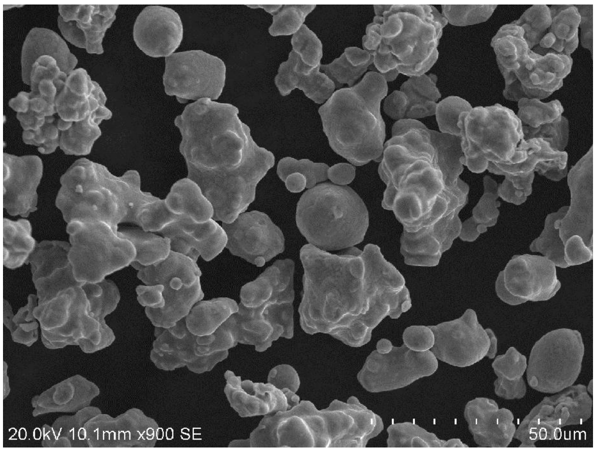


Fig. 11 SEM image of Iron powder

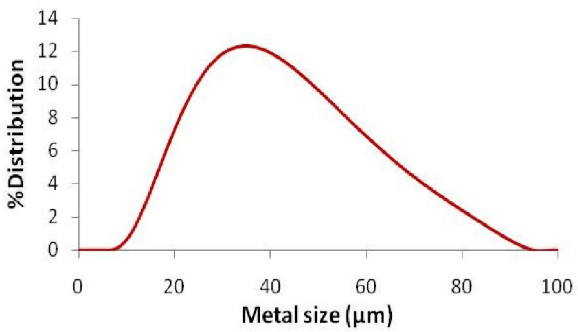


Fig. 12 Relation between %distribution and metal size

3.2.2 Sample DPF

Fig. 13 shows process for this experiment, Iron powder size at 5-90 µm was used to made sample. Powder was compacted in mold without binder and sintered at 1150 °C for 2 hrs. Sample DPF thickness for this work is 1 cm that comes from primary PM size and engine operates at 2400 rpm base on 1 cylinder. For the first trial, this sample is not appropriate for trapping PM because compact process is not suitable for porous structure. Solution for this problem has to be studied later.

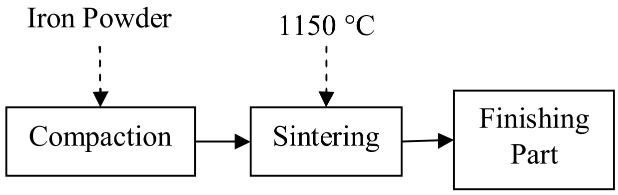


Fig. 13 Schematic diagram for filter forming

Fig. 14 The 1st trial sample

4. Conclusion

1. Exhaust gas temperature has a less effect to filter thickness. The thickness for each temperature has a similar result. So filter design can choose only one temperature condition for design.

2. Revolution influences to gas space velocity that effect particle velocity. So when revolution increases, thickness increase to follows that.

3. Particle movement was changed by size that was effect from r.m.s. displacement. Small particle size gives large r.m.s. displacement. So thickness of filter is thin because particle was trapped easily. For big particle size gives the opposite result.

4. Small metal size can be made thin filter because pore structure is minor. Small pore can trap particle easier than big pore from big metal.

5. Filter diameter can be based on exhaust gas diameter and thickness can be based on exhaust gas velocity. Because exhaust diameter effects to exhaust gas velocity, so filter diameter and thickness change. If filter diameter will be increased, filter thickness will be reduced.

From all result shows result from Brownian motion that was interested in small particle, optimization of filter should be suitable with engine, particle and filter material. But for particle was effected by many forces. In part of other effect will be studied later.

5. Acknowledgment

The author is grateful to TAIST-Tokyo Tech and NUI-RC of NSTDA for providing scholarship.

6. References

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