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Numerical Analysis and Optimization of Granular Substrate for Three-Way Catalyzed Membrane Filter to Achieve Zero-Soot Emission

Teerapat Suteerapongpun [1)] **Katsunori Hanamura** [1)]

1) Tokyo Institute of Technology, Graduate school of Engineering, Department of Mechanical Engineering
2-12-1 Ookayama, Meguro City, Tokyo 152-8550, Japan (E-mail: suteerapongpun.t.aa@titech.ac.jp)

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A membrane filter has been proposed for better filtration efficiency of Particulate Matters (PMs). Moreover, the membrane filter can minimize the devices required for the exhaust gas system in the current gasoline engine vehicles. By fabricating the membrane composed of microscale Three-Way Catalyzed (TWC) particles on a honeycomb-structured Gasoline Particulate Filter (GPF) can combine those into only one device. Furthermore, the early study has demonstrated that membrane filters can achieve 100% soot filtration efficiency from the initial state. However, they indicated that the membrane filter caused a slightly high-pressure drop, especially in the surface pore deposition regime. Therefore, the current morphology must be re-designed to support the membrane particularly.

A morphology of the granular substrate, used as a supporter for the three-way catalyzed membrane filter, has been optimized using the computer numerical simulation to reduce the pressure drop caused by the surface pore deposition of TWC particles inside the granular structure of the particulate filter. The original GPF model was used as a reference to optimize the granular supporter for the membrane. The morphology and porosity of the artificial supporter were carried from the original GPF model. The pore size was varied from 6µm to 14µm, and thickness was varied from 50µm to 150µm to observe the total pressure after membrane fabrication. Results showed that the pressure drop monotonically decreased with respect to the decrease in the granular supporter thickness. Therefore, it may conclude that the thinner the supporter, the lower the pressure drop. However, the actual product's durability must be another concern due to the thin supporter. In the case of supporter pore size optimization, there was a local-minimum pressure after the completion of membrane fabrication between the range of 8µm to 12µm, as shown in figure 2 (right). This is because the narrow pore size led to the high-pressure drop by the supporter itself, while the large pore size led to the deeper pore filtration of the membrane inside the supporter. The pore size was limited to the maximum of 14µm for 75µm supporter thickness. Because the large supporter pore size could lead to a non-homogeneous membrane surface (i.e. the island structure of the supporter appeared), which negatively affects the membrane durability. In comparison to the conventional membrane fabricating on GPF, the proposed granular supporter could achieve about a 65% lower pressure drop and a 66% material reduction. Considering the uniform membrane surface.

Soot filtration efficiency enhanced by TWC membrane has been investigated to find the minimum membrane thickness for perfect soot trapping performance. The membrane consisted of spherical particles with a mean diameter of 1.6µm and a porosity of 65 percent. Figure 1 (right) shows the filtration efficiency at the initial state (clean filter) of soot trapping on the membrane layer. The total thickness of the membrane was ranged from 15µm to 55µm. The filtration efficiency increased drastically as the thickness increased from 15µm to 20µm, reaching 90% at 25µm. After the 30µm regime, the soot filtration performance was only slightly improved. On the other hand, the thicker the membrane, the higher the pressure drop and the higher the material consumption. So, it was recommended that the membrane must be fabricated at about 30µm to achieve 95% initial filtration efficiency while not generating too high-pressure drop.

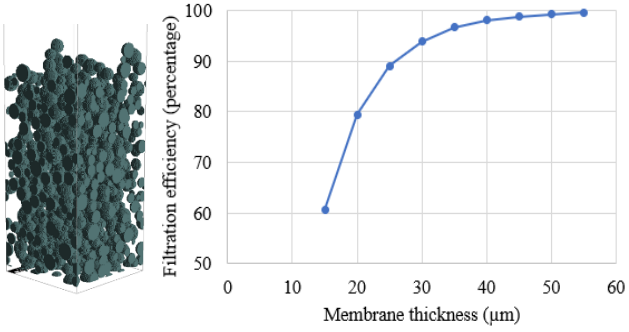

Fig. 1 The artificial membrane layer thickness of 35µm (left) and the initial soot filtration efficiency in each membrane thickness (right).

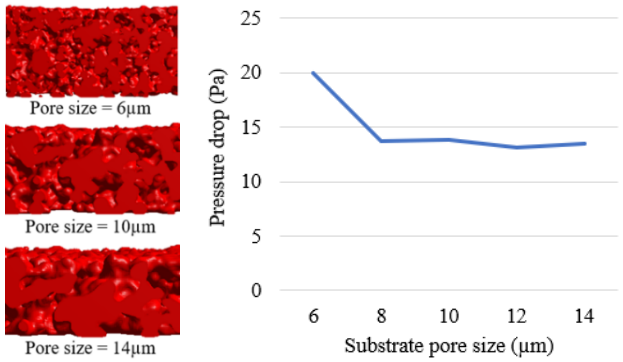

Fig. 2 The artificial supporters in each pore size at the same 75µm thickness (left), the total pressure drop after fabricating a 30µm thickness membrane on each artificial supporter (right).