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Title(English)	A study of multi-layered membrane filters made of catalyst particles for a passive after-treatment system
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論文題目

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研究論文の概要

This study aimed to develop a comprehensive exhaust after-treatment system for gasoline engines by integrating a Three-Way Catalyst (TWC) converter and Gasoline Particulate Filter (GPF) into one device utilizing a multi-layer membrane filter. The membrane filter consisted of a top layer with nano-scale potassium catalyst particles for efficient soot filtration and lower soot oxidation temperature and a second layer with sub-micro TWC particles for simultaneous reduction of pollutant gases such as NOx, HC, and CO. To minimize pressure drop, the design of a granular substrate supporting the membrane was optimized through numerical simulations. Moreover, it is clarified that the use of porous TWC particles as a membrane layer could significantly reduce the pressure drop, as well as enhance a catalytic effect simultaneously. In Chapter 1, the current exhaust after-treatment system in gasoline engines and its limitations were discussed, emphasizing the importance and potential improvements of the membrane filter.

Chapter 2 focused on numerical simulations to investigate the bridge formation phenomenon on granular filters, which significantly affects the drastic increase in pressure drop at the beginning of trapping. The simulations revealed the formation of a bridge structure that shifted the flow velocity profile to the center hole and led to a fast-soot accumulation. The results aligned well with experimental data, confirming their accuracy. Additionally, the impact of gas flow rate on membrane fabrication was also examined, indicating that lower velocities result in less catalyst material.

In Chapter 3, the focus shifted to designing a new substrate exclusively for supporting the membrane, as the membrane's excellent filtration efficiency has made the granular substrate unnecessary for soot filtration. An optimized-granular substrate with a 12μm pore size coated with a 30μm membrane exhibited significant reductions in pressure drop and material consumption compared to a conventional GPF membrane. The investigation also explored the impact of PMMA particle size on the porous-particle membrane. It was found that 350 nm PMMA particles had the most significant influence on flow, resulting in a substantial decrease in pressure drop and enhanced catalytic activity attributable to their larger surface area.

In Chapter 4, various catalysts were evaluated for improving soot oxidation performance. The K-cat (K_2CO_3/Na-nepheline) catalyst exhibited high durability and significantly lowered the soot oxidation temperature in two modes of reaction. First, direct-contact oxidation enables rapid oxidation of soot adjacent to the catalyst. Second, the soot cake layer far from the catalyst

can be oxidized by the diffusive oxidation of oxygen species from the catalyst surface. This ensured a consistently clean filter with a low-pressure drop when operated at temperatures higher than the first oxidation peak at about 476 ºC.

Chapter 5 focused on the performance of the K-cat/TWC membrane, demonstrating a minimum of 80% conversion of CO and NO, along with efficient soot oxidation within a specific temperature range of 420 °C to 500 °C, under stoichiometric and slightly rich A/F. However, the exhaust gas lacks oxygen concentration during stoichiometric A/F. Thus, soot can be oxidized during the fuel cut period, where 20% oxygen is introduced into the filter or oxidized by the oxygen species that desorb from the oxygen storage material during stoichiometric A/F.