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Boundary Conditions for Combustion Field and LB Simulation of Diesel Particulate Filter

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Abstract. A diesel particulate filter (DPF) is a key technology to meet future emission standards of particulate matters (PM), mainly soot. It is generally consists of a wall-flow type filter positioned in the exhaust stream of a diesel vehicle. It is difficult to simulate the thermal flow in DPF, because we need to consider the soot deposition and combustion in the complex geometry of filter wall. In our previous study, we proposed an approach for the conjugate simulation of gas-solid flow. That is, the gas phase was simulated by the lattice Boltzmann method (LBM), coupled with the equation of heat conduction inside the solid filter substrate. However, its numerical procedure was slightly complex. In this study, to reduce numerical costs, we have tested a new boundary condition with chemical equilibrium in soot combustion at the surface of filter substrate. Based on the soot oxidation rate with catalysts evaluated in experiments, the lattice Boltzmann simulation of soot combustion in the catalyzed DPF is firstly presented to consider the process in the after-treatment of diesel exhaust gas. The heat and mass transfer is shown to discuss the effect of catalysts.

AMS subject classifications: 76S05, 80A20, 80A25, 80A32

Key words: Lattice Boltzmann method, DPF, heat conduction, X-ray CT, multiphase flow.

1 Introduction

Although combustion is widely used in our society such as engines and practical combustors, the phenomena inside these applications are very complex, which depend upon interrelated processes of flow, heat and mass transfer, and chemical reactions [6]. Due to the recent progress of computers, a numerical simulation is a powerful means to model and predict various combustion phenomena.

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One of the important targets is to design a better internal combustion engine. For example, since diesel engines have an advantage of lower fuel consumption, compared with gasoline engines, it is possible to reduce CO_2 emission from transport industries such as passenger cars and cargo trucks. However, the emission of particulate matters (PM) including soot from diesel engines causes a severe environment problem. Recently, much attention worldwide has been given to the influence of fine particles in the atmosphere on human health [5]. Then, stricter exhaust emission standards such as Euro V in 2008 are being set in many countries.

A diesel particulate filter (DPF) is a key technology to meet future PM emission standards. It generally consists of a wall-flow type filter positioned in the exhaust stream of a diesel vehicle. Fig. 1 shows a cordierite filter used in this study. In simple explanation of DPF, it traps PM when exhaust gas passes through its porous wall (Fig. 1(b)). It is the most efficient after-treatment device. Latest our researches have shown that DPF filtration efficiency can be as high as 99 % [9]. The filter would be plugged with particles to cause an increase of filter back-pressure, which must be kept at lower levels, because the higher back-pressure increases fuel consumption and reduces available torque [8]. To prevent pressure build-up, the accumulated soot is removed from the filter by combustion [7], which is called filter regeneration process. Usually, the exhaust gas temperature is insufficient to regenerate the filter. The soot combustion (oxidation) temperature can be lowered by impregnation of the filter substrate with an oxidation catalyst.

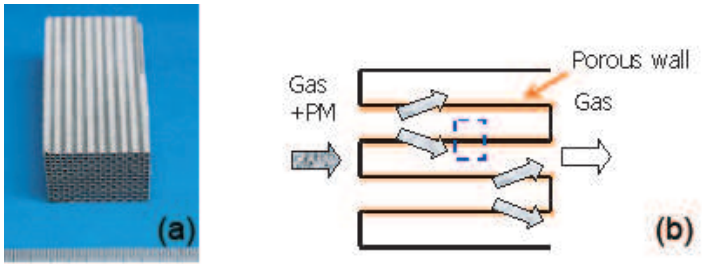

Figure 1: (a) Photograph of cordierite filter, and (b) PM trap inside porous filter wall. Calculation domain is shown by dotted line.

So far, there has not been enough data, and the phenomena occurring in the filter regeneration process are not well understood. This is because there are many difficulties in measurements. Typical inlet size of filter monolith is about 2 mm, and the thickness of the filter wall is only 0.2 mm where soot particles are removed. It is impossible to observe the small-scale phenomena inside the filter experimentally.

In this study, we firstly simulate the flow in a real catalyzed DPF by the lattice Boltzmann method (LBM). The structure of a cordierite filter is scanned by a 3D X-ray CT (Computed Tomography) technique. By conducting tomography-assisted simulation, it is possible to discuss the soot oxidation with catalyst, which is hardly obtained by measurements. Especially, to reduce numerical costs, we test a new boundary condition with chemical equilibrium. The lattice Boltzmann simulation of soot combustion in DPF is