§23. Heat Removal Enhancement of Plasma-Facing Components by Using Nano-Particle Porous Layer Method (II)

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I. Molecular Dynamics Approach

The classical molecular dynamics simulation was conducted in order to clarify the effects of the surface structural clearances in nanometer scale on thermal resistance at a liquid-solid interface as well as static and dynamic behaviours of fluid molecules in the vicinity of the surface. A liquid molecular region confined between the solid walls, of which the interparticle potential was Lennard-Jones type or SPC/E type, was employed as a calculation system. The thermal resistance between the liquid molecular region and the solid walls with nanostructures was calculated by the heat flux and the temperature jump obtained in the molecular dynamics simulations. Figure 1 shows the effects of nanostructural clearances and the potential energy functions between water molecules on the thermal resistances between the water molecular region and the surface wall. In the case of SPC/E potential the thermal resistances were calculated from the average temperature of translational and rotational temperature of water molecules. Regardless of the potential energy functions between water molecules and the nanostructural clearances the order of the thermal resistances calculated were in the range from 1.5×10^{-9} to 4.5×10^{-9} m^2K/W.

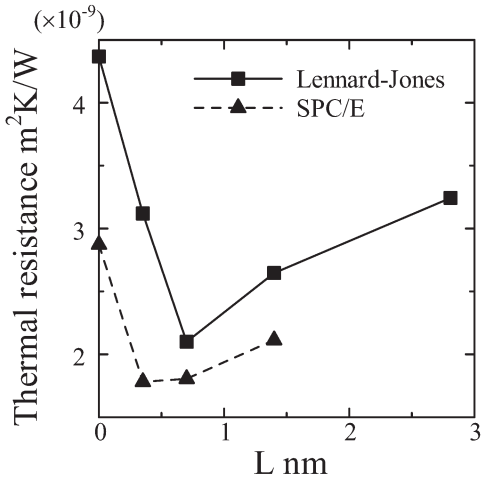

Fig. 1 Effects of nanostructural clearances and potential energy functions between water molecules (SPC/E potential and 12-6 Lennard-Jones potential) on thermal resistances between the water molecular region and the surface wall.

The thermal resistances calculated once decreased and became the minimum value and increased again in both cases of the potential energy functions. The thermal resistances with nanostructures were lower than those of flat surface in both cases of the potential functions. Surface area in molecular scale and fluid density at the interface were dependent on the surface structural clearances and the thermal resistance index calculated by the relative surface area in molecular scale and the relative fluid density at the interface could predict the thermal resistance change depending on the nanostructural clearances. Surface nanostructural clearances affected the fluid molecular motions along the heat transfer direction only when the molecular velocity was averaged over a specific characteristic time. Moreover, surface nanostructural clearances affected the diffusion behaviours of fluid molecules in the vicinity of the surface.

II. Computational Fluid Dynamics Approach

Two-dimensional Navier-Stokes equation with immersed boundary technique as additional terms was considered for flow fields with nano-porous wall condition. The additional terms were similar to immersed boundary technique, the terms accounted as the non-slip wall when the limit value was exceeded. Thus, the artificial nano-porous wall boundary conditions could be obtained when the parameter in the terms were controlled. The terms were adopted for wall-normal momentum equation and temperature equation.

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial x}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\beta\cdot\theta\cdot D(y) \quad (1)$$

$$\frac{\partial \theta}{\partial t}+u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}=\frac{1}{Pe}\left(\frac{\partial^2 \theta}{\partial x^2}+\frac{\partial^2 \theta}{\partial y^2}\right)+\alpha\cdot v\cdot D(y) \quad (2)$$

where, p is pressure, u and v are velocities in x- and y-direction respectively. θ is tempertature and $D(y)$ is source term. Re is Rynolds number and Pe is Pechet number. The additional terms in Eq. (1) is the intensity β multiplied temperate θ and the Eq. (2) is similar expression.

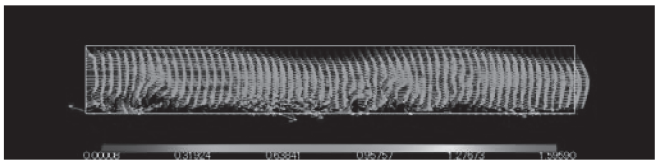

Fig. 2 Velocity vectors: α =0.8, β =0.6.

The two parameters in both equations were changed. Moreover, the flow condition with suction and blowing at the wall were performed to enlarge the effect of the artificial nano-wall. Figure 2 shows velocity vectors with suction and blowing on the artificial nano-wall. The velocity fluctuation with periodic blowing and suction are clearly observed. The similar phenomena in temperature fields are shown in Fig. 3. Therefore, when the artificial nano-wall model is improved, it seems that the mechanism of periodical temperature fluctuation in the actual laboratory experiment can be elucidated.

Fig. 3 Temperature distributions; Upper: α=0.0, β=0.0, Middle: α =0.6, β =0.8, Lower: α =0.8, β =0.6.