§5. Study on Advanced Thermo-Fluid System for a Helical Reactor

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The main feature of FFHR is force-free-like configuration of helical coils, which makes it possible to simplify the coil supporting structure and to use high magnetic field. The other feature is the selection of molten-salt Flibe as a self-cooling tritium breeder. In fusion application, Flibe was once put aside due to lack of databases, but still has attractive merits on safety aspects: low tritium inventory, low reactivity with air and water, low pressure operation, and low MHD resistance compatible with the high magnetic field design in FFHR. In general, a high Prandtl number ($Pr=\nu/a$, here ν is viscosity and a is thermal diffusivity) fluid like Flibe (Pr=~30) has less heat transport capability than liquid metal (Pr=~0.03 for Li), because of very low thermal diffusivity and low thermal mixing due to thinner thermal boundary layer at an interfacial region. Therefore, in particular, the design feasibility of the first wall for Flibe blanket is one of key issues.

In the present study, we investigated three subjects related to the heat transfer enhancement for the cooling system of the FFHR: (1) Ultrahigh heat transfer enhancement caused by nano-porous layer formed on the heat transfer surface, (2) Numerical study on fluid flow and heat transfer characteristics of a turbulent swirl flow in a pipe and (3) Numerical study on turbulent characteristics of sphere packed bed in a pipe.

(1) Ultrahigh heat transfer enhancement

An ultrahigh convective heat transfer performance compared to the well-known heat transfer correlations caused by a nano-particle porous layer formed on the heat transfer surface is discovered up to around 200%. The particle size used in this etching is less than around 100 nm, and the materials of particles are such as copper oxide, carbon including carbon nano-tube and aluminum oxide and so on. Moreover, we confirm the heat transfer enhancement for a parallel flowing heat exchanger consisted of hot and cold water-channels. On the other hand, in order to theoretically investigate effects of nano-particle structures on the surface on energy transfer, energy transfer from fluid to the surface is calculated in a model system by using a classical molecular dynamics method. Energy transfer to the surface from fluid is much dependent on the surface structures in nanometer scale that affect static structure and dynamic behaviors of fluid molecules in the vicinity of the surface [1].

We will apply this method to the fully developed coolant tube and investigate the applicability to the FFHR as a new three-year project of NIFS from 2004.

(2) Numerical study on turbulent swirl flow in a pipe

We carried out the numerical simulation of laminar swirl flow in a pipe last year [2]. In this year, we conducted the numerical simulation of turbulent swirl flow in a pipe. The pipe was divided by a thin metal twisted tape and transferred the heat through the tape, i.e., a conjugate heat transfer problem as shown in [2].

Figure 1 shows the variation of friction factor with Reynolds number ($Re=UD/\nu$, U; mean velocity, D; pipe diameter, ν; kinematic viscosity). In this Figure, there are the laminar swirl flow results [2] and the present results for turbulent swirl flow (the twisted ratio, $\tau=0$ marked as an open circle, $\tau=0.3$ as a solid triangle and $\tau=0.7$ as an open triangle) and Kumada's empirical correlation including swirl effect. According to these results, the friction factor increases with the increase of the twisted ratio despite of the flow conditions: laminar and turbulent. The friction factor of the turbulent swirl flow can be obtained a simple extrapolation of the laminar swirl flow correlation. The slope of the friction factor is similar to the Blasius's formula of a straight pipe if the twisted ratio is small. However, in case of the twisted ratio is large ($\tau=0.7$), it can be seen that the dependency of friction factor on the Reynolds number becomes weak.

(3) Numerical study on sphere packed bed in a pipe

We investigated the heat transfer enhancement caused by the wake of sphere pebbles packed in a pipe for high Pr fluid. As the first step of numerical investigation including a magneto-hydrodynamics effect, we performed a direct numerical simulation (DNS) for the homogeneous turbulence in the share packed bed in order to investigate the interaction between turbulent coherent structure and the spheres. According to the DNS results, it is found that the turbulent dissipation mechanisms for the different sphere sizes are very different.

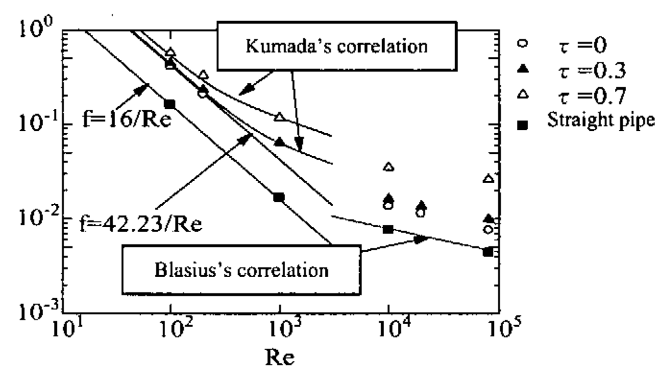

Fig. 1. Variation of friction factor with Re

References

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