## §2. Free Surface Flow Cooling on First Wall of FFHR

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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 $\nu$ 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.

According to the design concept of FFHR-2 [1], which is 2.5 times larger than LHD. The surface heat flux at the first wall is about 0.1MW/m$^2$, which is the sum of both Bremsstrhalung and synchrotron energy losses. If we need to include high energy-loss particles of $\alpha$, the averaged surface heat flux increases twice. The liquid wall concept holds a central position in the Advanced Power Extraction (APEX) study [2] prior to the upcoming FFHR free-surface concept. The APEX design idea includes both thin liquid films flowing with very high velocity over the first wall solid surface, and thick liquid layers acting as both the first wall and blanket flow. The working fluid is lithium-containing liquid metal or molten salt, such as Flibe.

As for the application of free surface concept to the FFHR design, it is necessary to consider the helical configuration, that is, at certain position the free surface would be at the ceiling as shown in Fig.1. In this case, the liquid might be falling down into the plasma. If we can make many micro grooves on the first wall as a flow passage, we will expect a capillary force to withstand the gravity force as follows [3]; $\rho gh=2\gamma\cos\theta/r+\Delta P$, where $\rho$, $h$, $\gamma$, $\theta$ are the density, height, surface tension and contact angle of a liquid in a groove, respectively, and $r$ is the half width of a groove in our model. $\Delta$P is a pressure drop due to a forced convection of Flibe coolant.

Figure 1 shows the grooved first wall, where the MARS (Multi-interface Advection and Reconstruction Solver) method [4] is used for numerical simulation in this work. As typical values for LiF-BeF$_2$(66-34 mole %) at about 500°C, we can use $\rho$ of 2,036kg/m$^3$, $\gamma$ of 0.196N/m, $\theta$ of about 135deg on tungsten, and thermal conductivity $\lambda$ of about 0.10W/mK. In this simulation, the free surface configuration can be calculated by a volume tracking procedure with Continuum Surface Force (CSF) model. For the wall material, tungsten is chosen as one of candidates because of high temperature resistance and low activation property, and, furthermore, good neutron multiplier to increase TBR. Under the surface heat flux of 0.1MW/m$^2$, it is observed in Fig. 2 that a pair of symmetrical spiral flows is formed in a groove due to buoyancy driven natural convection. The most attractive result is that this spiral flow enhances heat transfer efficiency as shown in Fig.3, where the local heat transfer coefficient h evaluated at the groove side wall (position 36) drastically increases about one order of magnitude.

Increase of the Flibe temperature, $T_{Flibe}$ , is one of critical issues from the point of view of vapor pressure, which is about 0.2Pa at 600°C and may influence at least the edge plasma. In the case of Fig.3, the bulk averaged $T_{Flibe}$ increases at the rate of about 25°C/s. Since the flow velocity in the groove is lower than 1m/s, the groove length longer than 5m may be feasible. Design of blanket units will be the next work with controlling the pressure loss distribution along the flow path.

References
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2) Abdou, M. et al., Fusion Eng. Des., 45 (1999) 145.
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4) Kunugi, T., Proc.ISAC97 (1997) 25

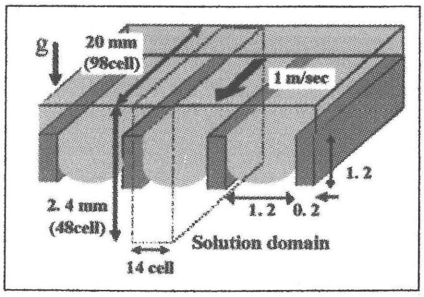

Fig.1 Schematic view of the concept and computational domain

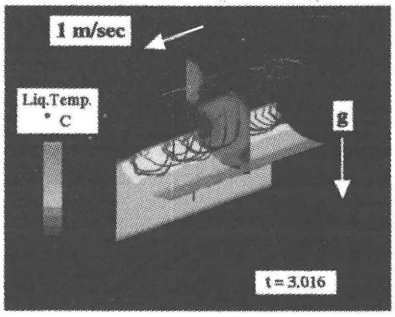

Fig.2 Spiral flow in parallel plates on the blanket structure

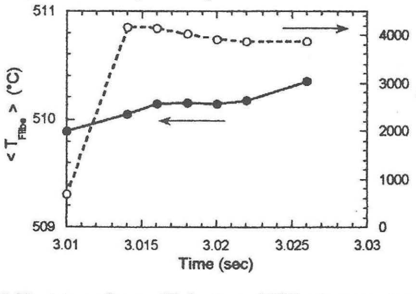

Fig.3 Heat transfer coefficients and Flibe temperature