§7. A New Concept of Liquid Metal Helical Divertor for FFHR-d1 and c1

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One of the critical issues that should be solved to realize a fusion reactor is the large divertor heat load. Even though the helical fusion reactor FFHR-d1 is free from the current disruption, which is also the unsolved problem for tokamak reactors, the steady-state peak heat load on the divertor is expected to be larger than 20 MW/m^2 and possibly exceeds 100 MW/m^2, depending on the design, and when the detachment condition is temporarily lost. This is much larger than the tolerable heat load even for the up-to-date divertor system being developed for ITER, which is composed of tungsten (W) mono-blocks cooled by water flowing in the copper (Cu) tube.

A divertor system using liquid metal, or molten salt, as plasma-facing material can be the solution for the divertor heat load problem. The liquid metal divertor concept has already been proposed in early 1970s and an experiment of liquid Ga jet-drop curtain limiter was carried out in the T-3M tokamak in 1992 [1]. Application of the liquid metal divertor (and 1st wall) was also considered in the design study of the ARIES-RS tokamak reactor [2].

It is also possible to apply the liquid metal divertor to the helical reactor. A vertical flow of liquid metal is necessary to cover all of the divertor area with three-dimensionally complicated structure, as shown in Fig. 1. The liquid metal helical divertor (LMHD) shown in the figure is composed of the “showerhead” and the “gutter” to form the vertical flow. Gravity is the important driving force in the LMHD system. The liquid metal supplied from the top of the device runs through the showerhead and falls to the gutter. The gutter leads the liquid metal to the exhaust hole at the bottom of the device. The liquid metal exhausted from the device is pumped up to the device top again, after cooling and purification.

Arrays of the liquid metal flow falling from the showerhead to the gutter form a curtain, or, blind, as shown in Fig. 2. As is seen in Fig. 2(a), the divertor plasma flowing along the magnetic field line slanted through the blind cannot penetrate the blind. Once the plasma becomes recombined on the liquid metal surface, the neutrals can be pumped out to the back of the blind (see Fig. 2(b)).

At this moment, pure tin (Sn) is considered to be the first candidate of the liquid metal for LMHD. The low vapor pressure (1 Pa at 1497 K), the low melting point of T_m = 505 K, and the high boiling point of T_b = 2676 K are the merits of Sn, compared with other candidates summarized in Table 1. To finally determine the material, nuclear properties and corrosion characteristics should be taken into account. Mixture of these materials or application of molten salt is also worth considering.

1) S.V. Mirnov, et al., J. Nucl. Mater. **196-198** (1992) 45.
2) M.A. Abdou, et al., Fusion Eng. Des. **54** (2001) 181.

(a)

(b)

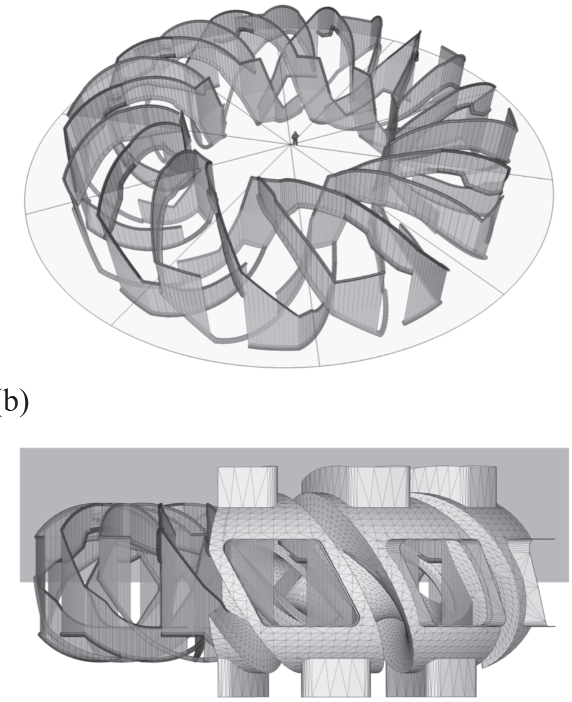

Fig. 1. (a) The bird’s eye view and (b) the side view of the liquid metal helical divertor, LMHD.

(a) (b)

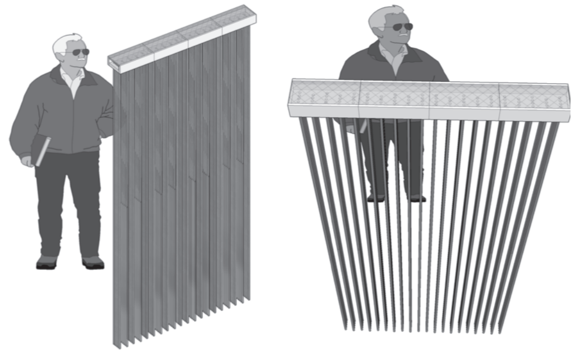

Fig. 2. The “blind” formed by arrays of the liquid metal vertical flow falling from the showerhead. The blind shut the slanting line-of-sight, which corresponds to the divertor magnetic field line, as shown in (a), *i.e.*, the plasma cannot go through the blind, while neutrals generated on the surface of the liquid metal flow can go through the blind as shown in (b).

Table 1. Comparison of the candidates of the liquid metal for LMHD. The atomic number, Z, the temperature resulting in the vapor pressure of 1 Pa, T_{1Pa} (K), the melting point, T_m (K), and the boiling point, T_m (K), are listed.

	Li	Na	Ga	**Sn**	Pb
Z	3	11	31	**50**	82
T_{1Pa}	797	554	1310	**1497**	978
T_m	454	371	303	**505**	601
T_b	1603	1156	2676	**2875**	2022