§13. Design Study on Heat Engine for Fusion Reactor

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The conceptual design of heat engine in liquid breeder type fusion blanket was studied. In the previous study, the heat engine based on Rankine cycle was designed and its specification was compared with that of demonstration type fast reactor MONJYU[1)]. The feasibility of the heat engine by water/vapor Rankine cycle is sufficiently high because of the experience in the field of the fission reactors. However, the tritium permeation in the heat exchanger is one of the critical issues for the fusion reactors, since the tritium concentration in the water/vapor secondary system must be controlled from the safety point of view. Therefore, the secondary system by helium gas (He), in which tritium can be recovered easily rather than the water/vapor system, was proposed in the present study. The heat exchanger with the duplex coating, which has high performance as the tritium permeation barrier and the anti- corrosion barrier, was designed in the present study.

Figure 1 shows the schematic diagram of the liquid blanket system and secondary coolant system as an example. This blanket system equipped six primary and secondary loops with flowing Pb-17Li and flowing He. Tritium is produced and recovered before the heat exchange in the primary system. Here, the heat loss in the tritium recovery system was estimated as the 20% of the input power of the blanket system. Figure 2 shows the conditions of specific volume and pressure of the secondary loop. The thermal efficiency of the heat engine was evaluated as 32.7%.

The heat exchanger was designed as a shell and tube type heat exchanger for a counter current flow (Fig.1). It is assumed that the heat transfer tubes have the duplex coating on their surfaces by the MOD coating[2)] and the thermal spray coating by Atmospheric Plasma Spraying (APS) method. The coefficient of overall heat transfer of the heat transfer tube assuming the duplex coating thickness is evaluated with following equation;

$$Q1 = \Delta Tm \times A \times \frac{1}{\frac{1}{h1}+\frac{1}{h2}+\frac{t_{sus}}{\lambda_{sus}}+\frac{t_{cerami}}{\lambda_{ceramic}}} \quad (1).$$

It was found that the allowable thickness of the duplex coating is approximately 100μm. This thickness must be sufficiently large when the corrosion loss for 10 years in the flowing Pb-17Li is taken into consideration.

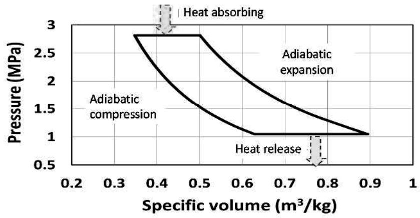

Figure 2 Conditions of specific volume and pressure of secondary loop

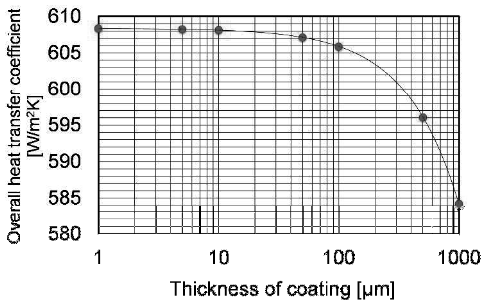

Figure 3 Influence of duplex layer thickness on overall heat transfer coefficient.

Nomenclature
ΔT_m: logarithmic mean temperature difference in heat exchanger,
A: total heat transfer area in heat exchanger ,
h_1: heat transfer coefficient by flowing Pb-17Li in heat exchanger,
h_2: heat transfer coefficient by flowing He,
t_{sus}: thickness of heat transfer tube,
$t_{ceramic}$: thickness of duplex coating in total,
λ_{sus}: heat conductivity of steel used for heat transfer tube,
λ_{sus}: heat conductivity of ceramics used for duplex coating

1) Kondo, M., et al., Design study on heat engine for fusion reactors, NIFS Annual report (2015).
2) D. Zhang, M. Kondo, T. Teruya, T. Muroga, T. Valentyn, Fusion Eng. Des. 86 (2011) 2508–2511.

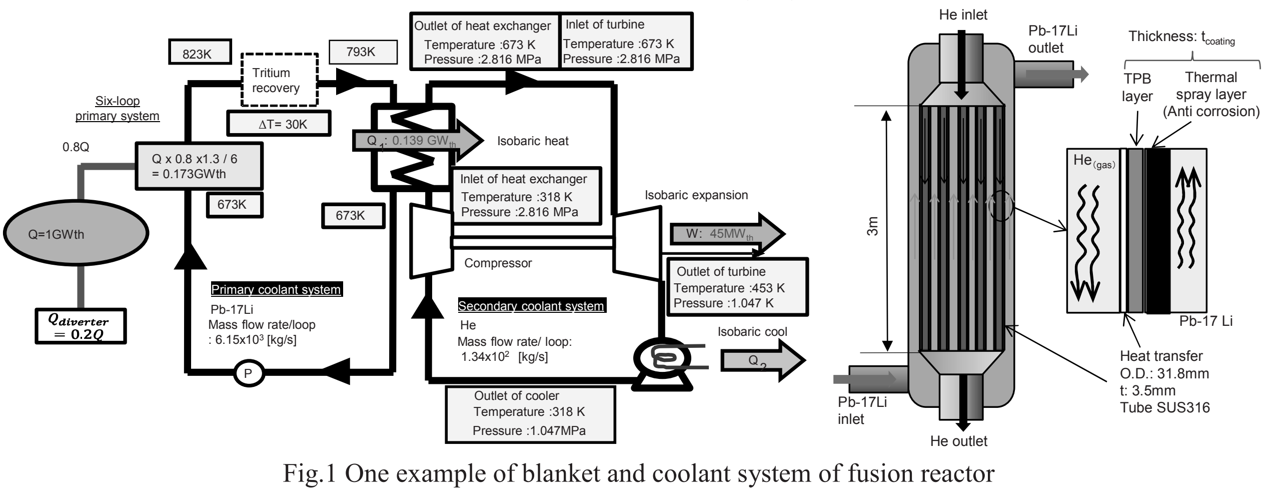

Fig.1 One example of blanket and coolant system of fusion reactor