DESIGN STUDIES ON ADVANCED SELF-COOLED LIQUID TEST BLANKET MODULES FOR JA-DEMO

[1]T. TANAKA, [2]Y. SOMEYA, [3]M. KONDO, [4]S. EBARA, [4]S. ITO, [5]K. KATAYAMA, [4]R. KASADA, [6]N. OONO, [2]Y. SAKAMOTO

[1]National Institute for Fusion Science (NIFS), Toki/Gifu, Japan
[2]National Institute for Quantum Science and Technology (QST), Rokkasho/Aomori, Japan
[3]Insitute of Science Tokyo, Meguro-ku/Tokyo, Japan [4]Tohoku University, Sendai/Miyagi, Japan
[5]Kyushu University, Kasuga/Fukuoka, Japan [6]YOKOHAMA National University, Yokohama/Kanagawa, Japan
Email: tanaka.teruya@nifs.ac.jp

Comprehensive design studies on self-cooled liquid test blanket modules (TBMs) for the Japanese DEMO reactor (JA-DEMO) are being conducted to obtain the prospects of high-efficiency power generation for future reactors. A self-cooled LiPb concept has been selected as the first candidate and the feasibility was studied mainly from the viewpoint of MHD effects on the LiPb coolant flows. Numerical calculations indicated that angle misalignment between the first wall cooling channel and magnetic field induces high velocity layers in the coolant flow, and this MHD effect is essential to enhance the cooling performance and keep the first wall temperature acceptable. On the other hand, the magnitude of MHD pressure drop in the TBM system could be suppressed to acceptable levels by appropriate electrical insulation.

Present blanket design studies for ITER-TBMs and DEMO reactors in the world are focusing almost on water-cooled and He-cooled concepts (including double-coolant LiPb). By adopting a self-cooled concept in which a liquid tritium breeder is circulating also as a coolant, a simpler blanket structure and lower pressure system could be achieved.

1. TBM FOR JA-DEMO

In the strategy of JA-DEMO, electricity generation will be demonstrated with the water-cooled solid breeder blanket system [1]. However, in the later period of the operation, more advanced blanket concepts with higher efficiencies are planned to be tested by installing test blanket modules (DEMO-TBMs). Design studies of DEMO-TBMs with self-cooled liquid metal and molten salt blanket concepts are being conducted based on long-term material, technological and design research conducted by Japanese universities.

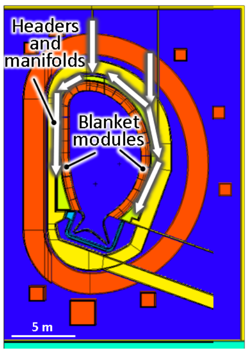
Although the number of test blanket modules installed in JA-DEMO would be one or few, the selected blanket concept must have prospects to achieve adequate performances in heat removal, tritium fuel breeding, coolant circulation control, etc. in a fusion reactor. Tritium breeding ratios (TBRs) obtained with candidate blanket concepts were evaluated assuming that all the original water-cooled blanket modules in JA-DEMO are replaced with them (Fig. 1). Blanket concepts which could achieve the TBRs higher than ~1.10 are shown in the table in Fig. 1.

2. SELF-COOLED LIPB TBM

Design studies of the DEMO-TBMs have been started with a self-cooled LiPb concept because of the chemical stability, low melting point (235 °C) and high heat removal performance of LiPb. Considering nuclear licensing of the module, RAFMs (Reduced activation ferritic/martensitic steel), i.e., F82H, was selected for the structural material. The structure of the proposed self-cooled LiPb DEMO-TBM is shown in Fig. 2 (a). In JA-DEMO, the maximum magnetic field strengths at blanket module positions and those angles to the horizontal plane of the torus were analyzed to be ~9.5 T and ~6° at the inboard side, and ~4.7 T and ~13° at the outboard side.

Thermal hydraulics analysis was performed by the STREAM code which can simulate MHD effects on a liquid metal flow, i.e., MHD pressure drop and velocity distribution. While the magnetic field lines and first wall cooling channels in the actual blanket modules will be curved along the toroidal direction of the torus, straight magnetic field lines and cooling channels are assumed in the present investigation on the coolant flow and temperature control in the module.

The LiPb breeder/coolant enters the module at 300 °C (Fig. 2(a)). The coolant reaches the first wall channels at ~320 °C and cools the first wall with the average velocity of 1.45 m/s. After that, the coolant flows slowly in the module and goes out at ~500 °C. At the first wall, the surface heat load of 0.5 MW/m^2 from the core plasma is the dominant heat source compared with nuclear heating. The cooling of the 6 mm thick first wall is the key issue. Fig. 3 shows the calculated temperature distribution of the first wall surface and velocity distribution in the cooling channel for the magnetic field of 9.5 T, i.e., the highest magnetic field in the blanket region.



Blanket	TBR
Li/V (V-alloy) (^{6}Li: 7.5%)	1.08
Li/V (^{6}Li: 35%)	1.18
LiPb/RAFMs (^{6}Li: 90%)	1.11
FLiBe+Be/RAFMs (^{6}Li: 90%)	1.31
FLiBe+Pb/RAFMs (^{6}Li: 90%)	1.17
FLiNaBe+Be/RAFMs (^{6}Li: 90%)	1.25
FLiNaBe+Pb/RAFMs (^{6}Li: 90%)	1.10

Fig. 1. Cross section of radiation transport calculation model and calculated tritium breeding ratios (TBRs).

<u>(i) First wall cooling:</u> The results indicate the importance of heat removal utilizing the characteristics of a liquid metal coolant under an intense magnetic field. When the directions of the cooling channel and magnetic field are completely aligned, ~1/3 of the first wall exceeds 600 °C (Fig. 3 (a)). Fig. 3(b) shows the results simulating the angle misalignment of 6° at the inboard blanket region. Under this condition, high velocity flow layers are induced in parallel with the first wall. This MHD effect enhances the cooling performance, and the maximum temperature of the first wall surface is suppressed to ~600 °C. Regarding the negative aspect of the MHD effect, i.e., MHD pressure drop, the magnitude depends on the magnetic field strength perpendicular to the cooling channel. The angle misalignment of 6° induces the pressure drop of ~ 0.5 MPa at the first wall cooling channel. The total pressure drop in the module under the inboard blanket environment was calculated to be ~1.0 MPa by installing electrical insulating walls except for the first wall cooling channels (Fig.2 (a)) and could be acceptable for the circulation of the LiPb coolant. In case of the outboard blanket condition, i.e., 4.7 T with the angle misalignment of 13°, the total pressure drop was calculated to be ~0.63 MPa because of the lower magnetic field strength and the first wall was also cooled to ~600 °C.

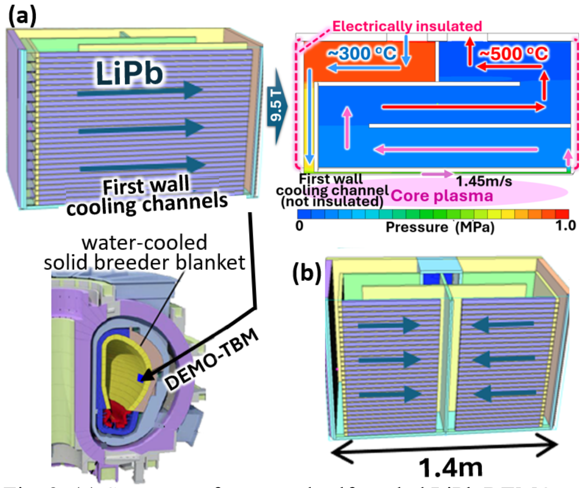


Fig. 2. (a) Structure of proposed self-cooled LiPb DEMO-TBM and pressure drop inside TBM. (b) Structure modified for suppression of coolant velocity and material corrosion.

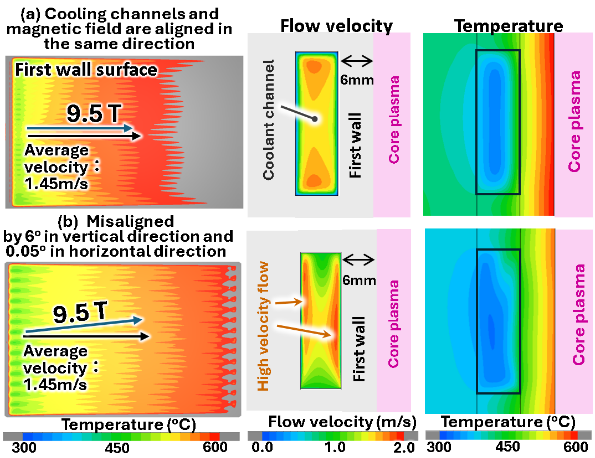


Fig. 3. Enhancement of heat removal performance utilizing MHD effects on liquid LiPb flow.

<u>(ii) Material and corrosion issues:</u> It is commonly recognized that the maximum acceptable temperature is 550 °C for F82H. The calculated results show that the temperature within 2.5 mm from the plasma facing surface exceeds 550 °C, and the temperature at 2.5-6 mm from the surface can be kept under 550 °C. Mechanical stress analysis is planned to examine whether this temperature distribution is acceptable, or modification of the cooling channel shape is required. Corrosion of the F82H channel wall could be the most critical issue for the concept due to the high velocity coolant flow. To suppress the corrosion by reducing the flow velocity, modification of the structure is also investigated as shown in Fig. 2 (b). Attachment of FeCrAr alloy liners inside the cooling channels might reduce the corrosion rate, since the alloy produces an Al_2O_3 layer on the surface and could be used as an anti-corrosion layer [2].

<u>(iii) MHD pressure drop at manifolds:</u> The calculation indicated that the maximum magnitude of MHD pressure drop in the LiPb blanket system will appear at metal headers and manifolds backside the blanket modules (Fig. 1) and it will be ~400 MPa, since the length is ~15 m and the magnetic field is 7.5-10 T. However, by electrically insulating the inner walls of the header and manifold with a ceramic material, the pressure drop will be suppressed to ~1.5 MPa and this would be acceptable. More suppression could be possible by modifying the configuration of the headers and manifolds.

3. SELF-COOLED FLINABE TBM

The self-cooled FLiNaBe (melting point: 305 °C) concepts could be the second candidate for DEMO-TBM using the similar structure. Since the electrical conductivities of the molten salts are significantly low, issues on the MHD pressure drop would be eliminated. Although the cooling of the first wall is a major issue due to the low thermal conductivity and high viscosity, calculations showed that the first wall temperature could be kept at ~600 °C by enhancement of heat removal performance with fins in the coolant channels.

4. FEEDBACK FROM EXPERIMENTAL STUDIES

Experimental studies on corrosion behaviors of materials [2], tritium recovery techniques [3], ceramic coating development [4], etc. are actively conducted in Japanese universities. The present designs of the DEMO-TBMs can be updated by reflecting the latest experimental results.

REFERENCES

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