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Overview of TBM R&D activities in India

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ABSTRACT

In India, development of Lead–Lithium Ceramic Breeder (LLCB) blanket is being performed as the primary candidate of Test Blanket Module (TBM) towards DEMO reactor. The LLCB TBM will be tested from the first phase of ITER operation (H-H phase) in one-half of an ITER port no. 2. The Indian TBM R&D program is focused on the development of blanket materials and critical technologies: structural material (IN-RAFMS), breeding materials (Pb–Li, Li_2TiO_3), development of technologies for Lead–Lithium cooling system (LLCS), helium cooling system (HCS), tritium extraction system (TES) and TBM related fabrication technologies. This paper will provide an overview of LLCB TBM R&D activities under progress in India.

1. Introduction

India is developing LLCB blanket as a primary option for its DEMO reactor [1]. In the Indian fusion roadmap towards DEMO reactor, ITER-Test Blanket Module program [2] is one of the major milestones through which the performance of the LLCB blanket, candidate blanket materials and auxiliary system technologies can be tested and qualified in real fusion environment.

The LLCB TBM will be tested from the first phase of ITER operation (H-H phase) in one-half of an ITER port no. 2. The Indian TBM R&D program is focused on the development of blanket materials and critical technologies: structural material (IN-RAFMS), breeding materials (Pb–Li, Li2TiO3), development of technologies for Lead–Lithium Cooling System (LLCS), helium cooling system (HCS), tritium extraction system (TES) and TBM related fabrication technologies. Lead–Lithium technologies development activities are focused on Lead–Lithium loop developments for MHD experiments, corrosion experiments and operational experience with critical loop components. IN-RAFM steel is a structural material under development for fusion reactor applications. Several fabrication procedures for manufacturing TBM sub-components and their assembly sequence need to be investigated in the developmental program. For the fabrication of TBM sub-components mock-up, IN-RAFMS is being considered to investigate its fabrication feasibilities by Hot Isostatic Press (HIP), Electron Beam Welding (EBW), laser and narrow gap TIG welding processes.

The R&D activities focusing on ITER-TBM system development are in full swing in Institute for Plasma Research (IPR) Gandhinagar, in collaboration with Bhabha Atomic Research Centre (BARC), Mumbai, Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, and other research institutions and universities within India. This paper provides an overview of the LLCB TBM activities and related R&D progress in India.

2. LLCB TBM description

The LLCB-TBM has both the features of solid breeder and liquid breeder blankets [3]. Fig. 1 shows the schematic view of LLCB TBM. The overall dimensions of the LLCB TBM are 1.66 m (h) × 0.484 m (w) × 0.534 m (t). The ‘U’ shaped First Wall (FW) encloses the internal ceramic breeder compartments containing Li_2TiO_3 pebbles and rectangular flow channels for flowing lead–lithium. Table 1 shows the LLCB TBM parameters. First wall is cooled by high-pressure helium gas. The molten Pb–Li eutectic alloy flows separately around the ceramic pebble bed compartments to extract heat that is produced in the ceramic pebbles and in Pb–Li itself. Tritium produced in the ceramic breeder zones is extracted by low-pressure purge gas helium. Fig. 2 shows the radial build-up of LLCB TBM. The structural material for TBM FW is IN-RAFMS with cooling channels running in radial–toroidal–radial direction. The FW is designed to withstand the energetic particle fluxes and heat fluxes from the plasma, high thermal and mechanical stresses and magnetic forces during plasma disruptions.

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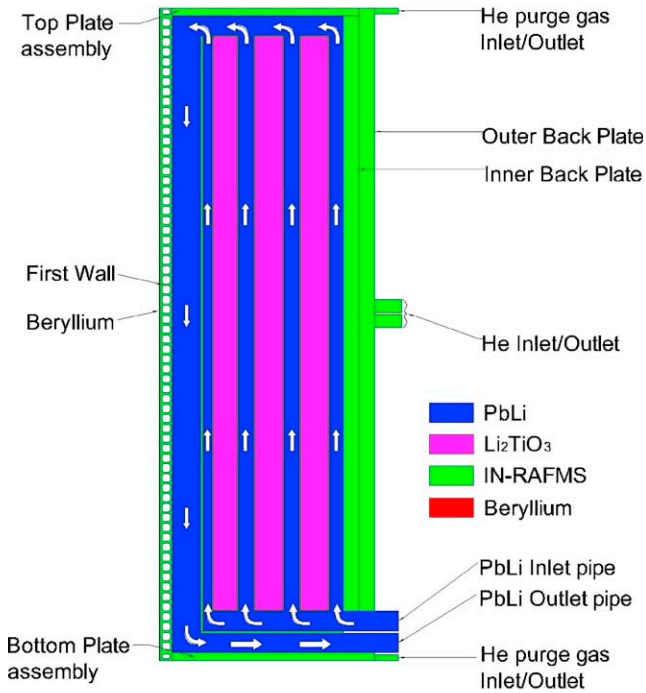

Fig. 1. Schematic view of LLCB-TBM.

The LLCB-Test Blanket System (TBS) includes several ancillary systems, namely primary HCS, LLCS, the secondary HCS (for Pb–Li), the tritium extraction system (from Pb–Li and helium purge gas), the coolant purification system and the control/instrumentation system. Some components of these systems are located in the port cell #02, the remaining components are located in level 4 and in level 2 of the tritium building [4].

2.1. LLCB TBM design activity

The LLCB TBM design activity is focused on the optimization of TBM design with respect to neutronic performance and high-grade heat extraction by keeping the temperature within allowable limits [5]. In this process, various internal configurations have been studied in detail such as series flow and parallel flow conditions. It is observed that the parallel flow configuration provides more advantages from MHD pressure drop limits and the corrosion levels with respect to the required flow velocities in lead–lithium flow in channels. The present design is focused on parallel flow configuration of liquid metal inside the TBM.

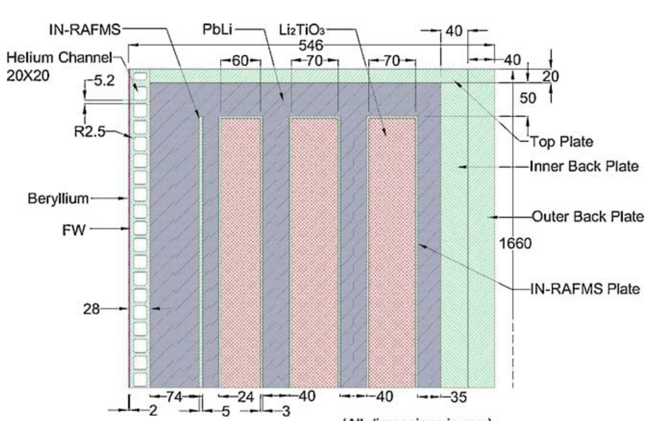

Fig. 2. Radial build-up of LLCB TBM.

Table 1
LLCB TBM parameters.

Structural material	IN-RAFMS	
Breeder material	Pb–Li, Li_2TiO_3	
Lithium enrichment	90% in Pb–Li	60% in Li_2TiO_3
Coolants	Helium, Pb–Li	
Helium temperature (inlet/outlet)	573–673 K	
Helium gas pressure	8 MPa	
Pb–Li temperature (inlet/outlet)	598–723 K	
Purge gas for tritium extraction	Helium with 0.1% hydrogen at 0.12 MPa	

Design of shield block module and pipe forest arrangement up to port cell is also one of the major design activities. Process system design such as helium cooling system, coolant purification system, lead–lithium cooling system, tritium extraction systems for both lead–lithium and helium gas are under progress. The preliminary safety analysis for the complete system has been completed and further detail work is in progress.

3. LLCB TBM R&D activities

R&D activities were identified for LLCB TBM system; the following sections will summarize the status of the R&D activities in major areas, such as liquid metal MHD, corrosion studies, ceramic breeder pebble development, and structural material development and fabrication technologies development.

3.1. Liquid metal technologies related R&D activities

3.1.1. Lead–lithium loop developments

Lead–lithium loop construction involves development of critical components like electromagnetic pump, heat exchanger, recuperator, cold trap, flow meter, and pressure transmitters. Electromagnetic induction pump development is based on permanent magnets; it is designed and constructed with the aim of attaining high-pressure heads and flow rates. Mass flow meters, cold traps are presently under fabrication. The lab scale lead–lithium has been prepared and its characterization is under progress. The loops are developed for both MHD experiments and corrosion experiments.

3.1.2. MHD studies

In LLCB TBM, the required Pb–Li circulation rate is rather moderate, which leads to average velocities in rectangular duct of typically 0.1–0.2 m/s. In such flow velocity conditions, it is found that the non-dimensional parameters [6], namely the Hartmann number (Ha) and interaction parameter (N) reach high values, Ha $\sim 2.0 \times 10^4$ and $N \sim 3.0 \times 10^3$, so that viscous and inertia forces are of minor importance compared to the electromagnetic forces in most of the flow domain. In order to address these MHD related issues, various R&D tasks have been initiated. A 3D MHD code is being developed using commercially available CFD code and extending it through user defined MHD subroutines. After validation of the code with subroutine the analysis is carried out for single rectangular duct of LLCB TBM. The heat transfer has been studied by keeping high temperature ceramic breeders at both sides of the lead–lithium flow channel. The simulation results suggest slight deformation in steady state velocity profile along flow path, which is attributed to the temperature dependent thermo-physical properties of Pb–Li. However, the temperatures in various zones remain well within the maximum allowable limit. The code is now being upgraded to predict the MHD velocity profile in more complex flow geometries, such as bends and expansion.

A mercury (Hg) loop experimental set-up is being developed at IPR, to study the MHD and heat transfer phenomena in a scale down version of LLCB TBM. The electromagnet is being designed for ∼1.3 T. Nuclear heating of the breeder region has been