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Incorporation of lithium lead eutectic as a working fluid in RELAP5 and preliminary safety assessment of LLCS

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HIGHLIGHTS

- The current work involves thermal hydraulic calculation of Lithium Lead Cooling System (LLCS) for the Indian test blanket module (TBM) for testing in ITER.
- It uses the RELAP portion of RELAP/SCDAPSIM/MOD4.0.
- RELAP steady state results closely match with the operating conditions of LLCS.
- Results from transient calculations show that a maximum temperature of 875 K is attained 300 s after the loss of LLE flow.

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ABSTRACT

The current work involves thermal hydraulic calculation of Lithium Lead Cooling System (LLCS) for the Indian test blanket module (TBM) for testing in International Thermonuclear Experimental reactor (ITER). It uses the RELAP portion of RELAP/SCDAPSIM/MOD4.0. Lithium-lead eutectic (LLE) has been used as multiplier, breeder and coolant in TBM. Thermodynamic and transport properties of the LLE have been incorporated into the code. The main focus of this study is to check the heat transfer capability of LLE as coolant for TBM system for steady state and the considered anticipated operational occurrences (AOO's), namely, loss of heat source, loss of primary flow and loss of secondary flow. The six heat transfer correlation (reported for liquid metals in the literature) has been tested for steady state analysis of LLCS loop and results are roughly same for all of them. A good agreement has been observed between the operating conditions of LLCS with those of RELAP5 calculations. Results from transient calculations show that a maximum temperature of 875 K is attained during a 300 s loss of primary flow (LLE).

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1. Introduction

India is currently involved in the design and development of its Lithium Lead Ceramic Breeder Test Blanket Module (LLCB TBM) for testing in ITER. This LLCB blanket concept [1,2] consists of lithium titanate as a ceramic breeder (CB) material in the form of packed pebble beds. Here, LLE acts as multiplier, breeder and coolant in LLCB TBM. There are two coolant circuits in this design. The first one is for the first wall (FW) and TBM structure box. The second one is for the CB packed beds. Molten LLE flows separately around the lithium titanate pebble bed compartments to extract heat from the CBs. Its flow velocity is moderate enough to extract effectively the self-generated heat and that transferred from the ceramic breeder bed. Helium is the coolant for the external box structure to extract the surface heat flux from the plasma and partially from the neutronic heat deposited in the RAFMS (reduced activation ferritic martensitic steel) box structure as well as the LLE interface locations. Tritium produced in ceramic breeder zones has to be extracted by low-pressure purge gas (helium). The tritium produced in LLE circuit has to be extracted separately by an external detritiation system. Design analysis indicates that the total heat generated [3] within TBM is 857 kW and the heat balance is as follows: (1) heat being transferred to FW helium is 300 kW, (2) the heat being transferred to LLE circuit is 557 kW and (3) the heat being transferred to helium purge gas system is considered to be

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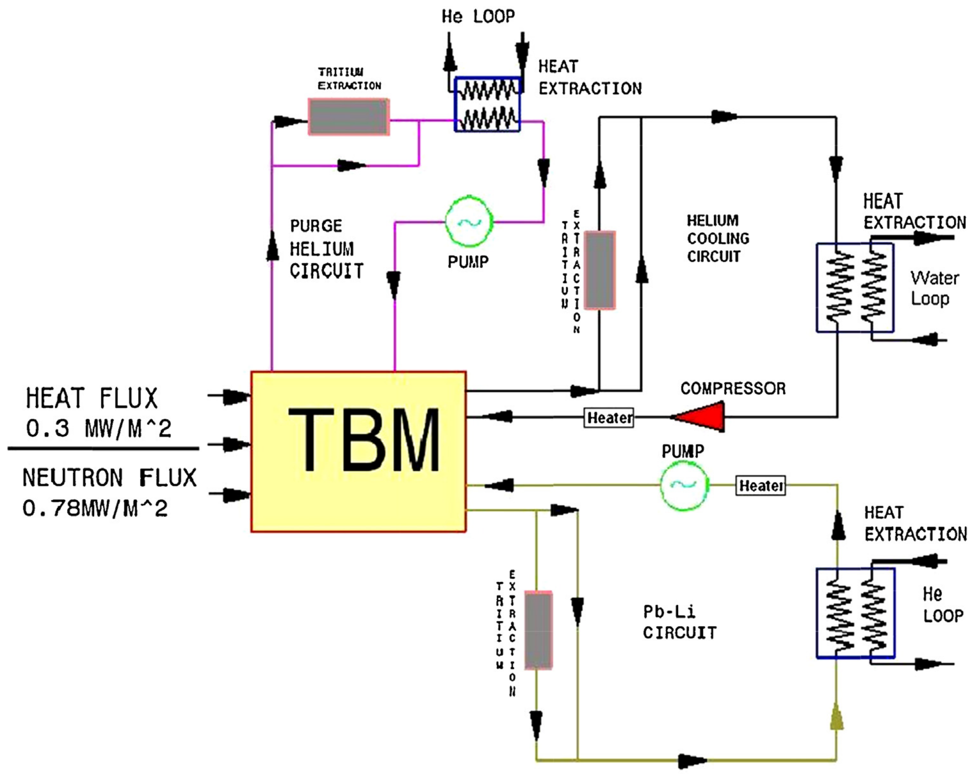

Fig. 1. Cooling loops associated with the TBM.

negligibly small, primarily due to low mass flow rate. Fig. 1 presents these three cooling loops associated with the TBM. Lithium lead ceramic breeder test blanket system (LLCB TBS) has the following ancillary systems: (1) First Wall Helium Cooling System (FWHCS), (2) Lithium Lead Cooling System (LLCS), (3) Lithium Lead Helium Cooling System (LLHCS), (4) Tritium Extraction System (TES) and (5) Coolant Purification System (CPS).

The current assessment includes the analysis of the LLCS and LLHCS to check the applicability of the RELAP5 system code for LLE thermodynamic/transport properties and heat transfer. The required flow of liquid LLE for cooling of TBM has been provided by LLCS. It consists of a dump tank, mechanical pump, heat exchanger (LLE-helium) and detritiation system (all located in the port cell). Trace heaters keep the complete loop at high temperature to avoid freezing of LLE. It flows through the internal channels surrounding ceramic breeder compartments in TBM. Table 1 summarizes the operational parameters of LLCS and LLHCS [1,2]. Heat has been extracted from circulating LLE to helium by LLHCS and it is then transferred to helium–water heat exchanger located in tokamak cooling water system (TCWS) vault. This system is independent from FWHCS. The process parameters for both FWHCS and LLHCS are similar. A total of 557 kW of heat has to be carried out by LLE [3] which goes to the helium gas in LLE-helium heat exchanger. The helium–water heat exchanger in LLHCS transfers this heat to water which then rejects it to atmosphere.

Table 1
Steady state calculated results of LLCS and LLHCS.

Description	Design data	RELAP5 value
Total thermal power to be removed by LLCS (kW)	557	
Temperature at inlet (K)	573	577
Temperature at outlet (K)[a]	692	695
Mass flow rate (kg/s)	25	25
Pressure (MPa)	1.2	1.15
Total thermal power to be removed by LLHCS (kW)	557	
Temperature at inlet (K)	508	508
Temperature at outlet (K)	626	627
Mass flow rate (kg/s)	0.9	0.9
Pressure (MPa)	8.0	8.0

[a] Design value of temperature for LLCS is 753 K.

2. Modification of RELAP5/MOD4.0 for LLCS TBM

The modified RELAP/SCDAPSIM/MOD4.0 [4] is selected as a simulation tool for studying normal and off-normal events in LLCB TBS. This code is meant for analysis of normal operating conditions and simulation of steady state parameters such as temperature, pressure and flow under design loads. It has also been selected to study the loss of coolant accidents (LOCA's) (like a liquid metal pipe break into TBM vault, port cell and vacuum vessel) and AOO's [5] (such as baking, warm up, shutdown, pump/circulator trip). An experimental loop has been planned [5] to validate the code against the AOO's as well as the accident cases at Institute of Plasma Research (IPR), India. It is currently under design phase as an appropriately scaled LLE and helium loop.

2.1. Thermodynamic and transport properties incorporated in the code

The numerical schemes in RELAP5 [4] require the thermodynamic and transport properties of the fluid/coolant over a range of temperature and pressure to solve the thermal hydraulic model. Thermodynamic/transport properties of LLE (incorporated in to RELAP/SCDAPSIM/MOD4.0) have been reported in Table 2. Thermodynamic methods have been used to estimate certain properties of LLE as per the given references.

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