Contribution ID: **25** Type: **Talk**

ST-E1 Dual-Cooled and Self-Cooled Blanket Concepts

Thursday 5 February 2026 11:05 (30 minutes)

In this work, we analyse and compare different liquid metal blanket designs that are based on alternative approaches to achieving heat balance, with a primary focus on understanding the MHD drag associated with these options. Specifically, we consider three concepts:
(i) Helium-cooled blanket: All heat is removed by helium flow, which is compressed and pumped at very high velocities through channels in the blanket module walls and cooling pipes embedded within the bulk of the blanket. In this design, lithium (the liquid metal breeder) is circulated through the blanket at a low velocity, as dictated by tritium extraction requirements. Consequently, the MHD drag associated with this flow is minimal, which is highly advantageous and accounts for the selection of this concept as the basis for the ST-E1 powerplant design. Nevertheless, the difficulties and costs associated with helium compression and pumping significantly reduce the overall efficiency of the concept and raise concerns regarding helium purity and availability. Therefore, we elected to investigate alternative approaches.
(ii) Dual-cooled blanket: Surface heat is removed by helium flowing through channels in the blanket walls, while volumetric heat is managed by lithium flow. Based on the heat removal requirements, we calculate the lithium mass flow rate and, using empirical relationships together with fully developed MHD flow calculations and ST-E1 design parameters, estimate the associated MHD pressure drop. These calculations account for flow through the inlet and outlet pipes (including sections influenced by the fringing magnetic field) as well as through the blanket itself. The blanket is subdivided into several channels by stiffening plates, and we propose an efficient flow arrangement that ensures a uniform outlet temperature. Our analysis indicates that the total MHD drag associated with this flow is approximately 0.5 MPa, which is well below the typical upper allowable pressure limit of 2 MPa.
(iii) Self-cooled blanket: Both surface and volumetric heat are removed by lithium flow. In this design, lithium is first pumped through a thin slot adjacent to the first wall at sufficiently high velocity, and then redirected to flow slowly through the main blanket volume. The flow through the breeder volume is therefore identical to that in the dual-cooled design. Using a 2D model for fully developed MHD analysis, we calculate the additional MHD drag associated with the fast flow near the first wall, which is shown to be negligibly small (~1 kPa) due to the slotted channel geometry.
In conclusion, the self-cooled blanket concept eliminates the inefficiencies associated with helium flow, substantially reduces the complexity and cost of the blanket module, and enhances the TBR value—all in exchange for the cost of MHD pumping, which we demonstrate to be acceptable for the ST-E1 design. The MHD drag remains low because, in a spherical tokamak, the breeder blanket is located exclusively in the outboard region, where the magnetic field is relatively weak (3T in the case of ST-E1). Nevertheless, more detailed 3D MHD analysis is required for the full validation of this concept.

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Session Classification: Session 3-10

Track Classification: LIBRTI Conference