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MHD mixed convection flow in the WCLL: heat transfer analysis and cooling system optimization

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In the Water-Cooled Lithium Lead (WCLL) blanket, a critical problem faced by the design is to ensure that the breeding zone (BZ) is properly cooled by the refrigeration system, thus to keep the structural materials under the maximum allowed temperature. For this purpose, CFD simulations are carried over using ANSYS CFX to investigate how the cooling system performances are affected by the tokamak magnetic field.
In the configuration studied, the blanket relies on a Single Module Segmentation approach. The LiPb flows inside long poloidal channels, developing along the whole module height; cooling is provided by double-walled tubes which are separated by a vertical pitch and inserted in the BZ from the back-supporting structure. The attention is focused on the sub-channel closest to the first wall (FW). The maximum of the neutronic power deposition is foreseen in this region; thus, intense buoyancy forces will arise due to the large temperature gradient in the radial direction ($Gr \approx 10^{10}$). These will interact with the forced convection flow ($Re \approx 10^{3}$), leading to the onset of a mixed convection regime. A constant magnetic field parallel to the toroidal direction is assumed with intensity in the Hartmann number range $0 \leq M \leq 10^{4}$. The walls bounding the channel and the water pipes are modeled as perfectly conducting.
The magnetic field is found to dampen the velocity fluctuations triggered by the buoyancy forces and, for $M=10^{4}$, the flow can be reduced to a pure forced convection regime. This effect causes the sharp reduction of the LiPb heat transfer coefficient to one-third of the ordinary hydrodynamic value. Consequently, hot-spots between the nested pipes and close to the FW are observed where the temperature exceeds the maximum allowed value. To address this issue, optimization strategies for the BZ cooling system layout are proposed and implemented in the CFD model, fulfilling the design criterion.

Co-author: TASSONE, Alessandro (Department of Astronautical Electrical and Energy Engineering Sapienza University of Rome)

Presenter: TASSONE, Alessandro (Department of Astronautical Electrical and Energy Engineering Sapienza University of Rome)

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