Contribution ID: **73** Type: **Poster**

Modelling of cooling performance in single and multi-channel high heat flux structures for fusion applications

Monday 4 November 2019 17:00 (15 minutes)

A numerical study is conducted to explore the thermal efficiency of cooling streams in geometries relevant for fusion reactor high heat flux components. A tile-type structure is considered employing one or more cooling channels within the heatsink, based on recent investigations showing the benefits of this approach and advances in additive manufacturing. Various flow configurations are explored and compared to each other in their potential to extract and distribute the strong heat flux from the plasma-facing surface, differing for i) type of fluid; ii) inlet turbulence level; iii) velocity profile (swirled or unswirled); and iv) configuration (single or multi-channel). The study is conducted using a fluid-structure interaction solver implemented in the commercial code StarCCM. A conjugate heat transfer model is used for the structural analysis and an unsteady-RANS model with k-omega turbulence closure is used for the flow. The configurations are varied keeping the same mass flow rate and fluid-structure interface area. It is worth noting that this analysis focuses prevalently on the flow behaviour, while the structural analysis is used with the only purpose to provide a meaningful temperature (or energy equivalently) boundary condition on the fluid-structure interface, which would need to be approximated otherwise.

The analysis indicates advantages of multi-channel configurations over single-channel, consistent with previous work. Furthermore, the potential benefits of using swirled configurations with certain levels of turbulence are shown, and how these can be achieved without penalties in pressure drops is discussed from both flow and manufacturing points of view. Further considerations on the flow and heat transfer behaviours within and near the boundary layer are given in the paper.

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Session Classification: Poster Session I

Track Classification: Plasma Facing Component Materials and Heat Exhaust for Steady State Operation