Modelling of Cooling Performance in Single and Multi-Channel High Heat Flux Structures

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Abstract

- A study conducted using commercial CFD code, Star-CCM+, using a conjugate heat transfer solver to explore the thermal efficiency in cooling streams for single-channel and multi-channel geometries for divertors applications.
- Type of cooling fluid investigated with water and liquid lithium used in simulations.
- Different inlet velocity profiles (swirled or unswirled) used to determine their impact on cooling performance.

Background

A critical area for the realisation of viable commercial fusion energy are the high heat flux components, principally the Divertor. As DEMO is likely to have increased requirements for thermal efficiency, peak heat loads and maintenance, current ITER type concepts may not be viable. Hence, alternative concepts have been proposed that take advantage of additive manufacturing (AM) techniques. These have benefits in high heat flux environments experienced in divertor applications [1].

One such concept uses multiple channels in a tungsten structure using water as the coolant. It is this concept that will be studied and compared to single channel configurations using computational fluid dynamics.

The main aims are:
- Simulate cooling performance of multichannel structures under high heat fluxes
- Determine the effectiveness of imparting swirl velocity to the fluid.
- Investigate using liquid lithium as a coolant

Methodology

Simulation Geometry

Two geometries for the tungsten structure were used in the conjugate heat transfer simulations:
- Single-channel, Diameter 10mm
- Multi-channel (3 channels), Diameter 3.3mm

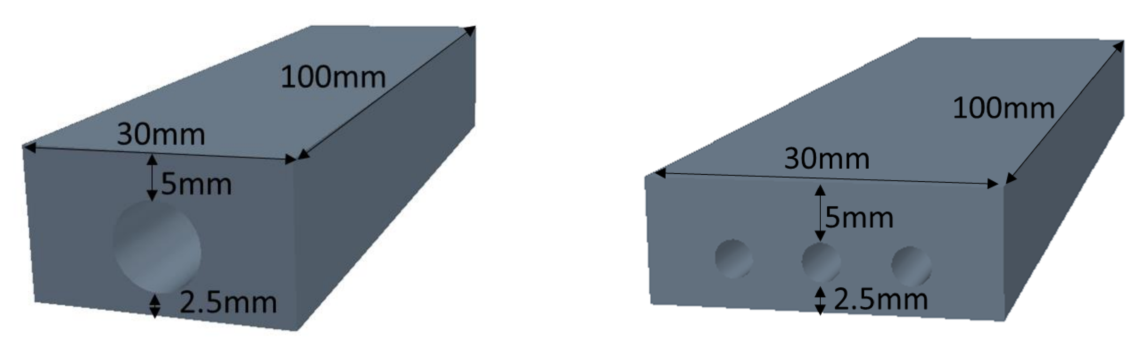

Figure 1: Single-channel and multi-channel geometry

Boundary Conditions

The structure had a constant heat flux applied to the heated surface. All outer walls were considered adiabatic.

The velocity profile, either with or without swirl, was specified at the fluid inlet 200mm upstream from the front on the structure. Swirl numbers of 0 (baseline case), 0.1 and 0.7 were applied.

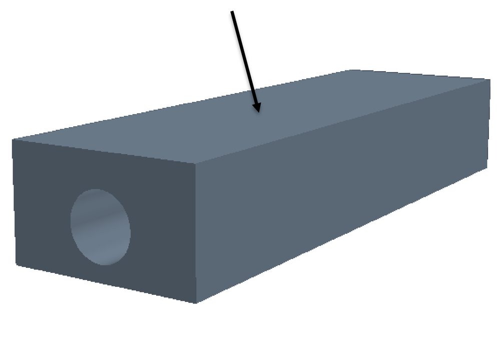

Figure 2: Single-channel structure boundary conditions

$$\text{Swirl Number} = \frac{\text{axial flux of the tangential momentum}}{\text{axial flux of the axial momentum}}$$

Outcome

Water Simulations

CHT simulations were performed on both single and multi channel configurations. The heat flux applied to the heated surface and the swirl number were both varied. Below results of the 5MW/m² heat flux is shown.

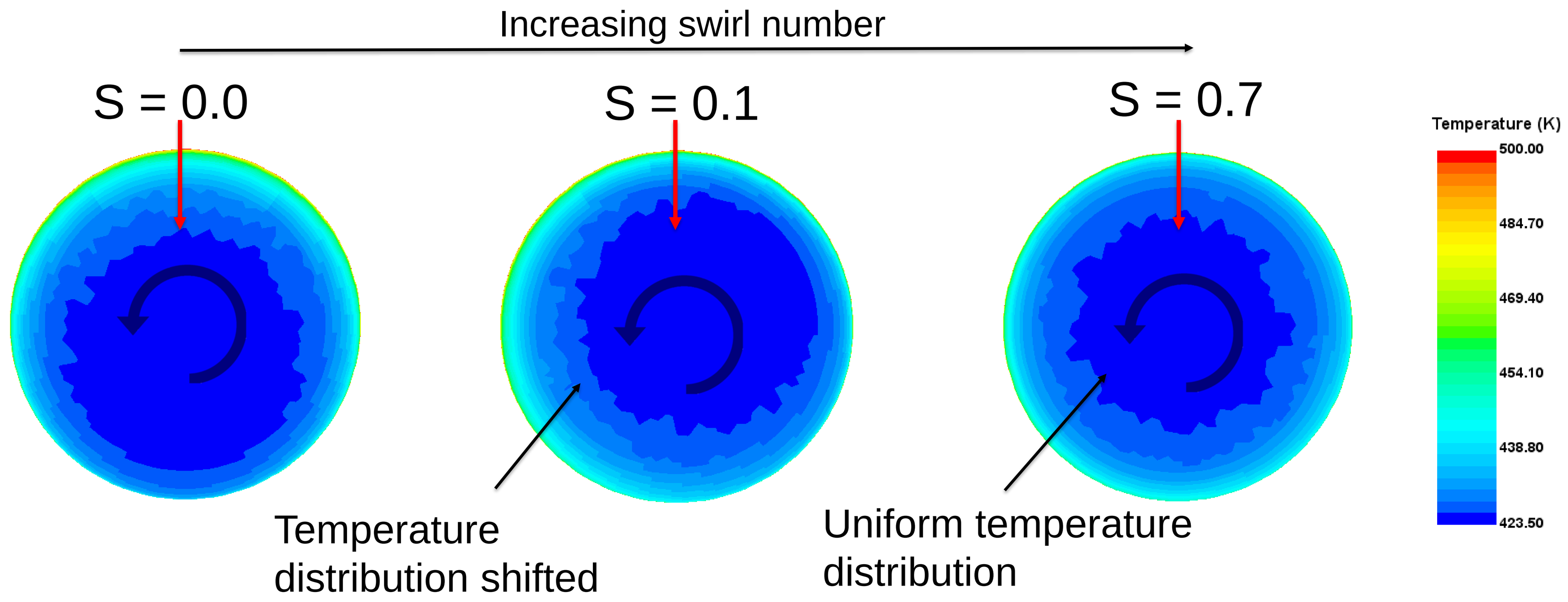

Figure 3: Comparison of swirl on single channel configuration

Comparison of single and multi-channel configurations with equal inlet velocity and surface area.

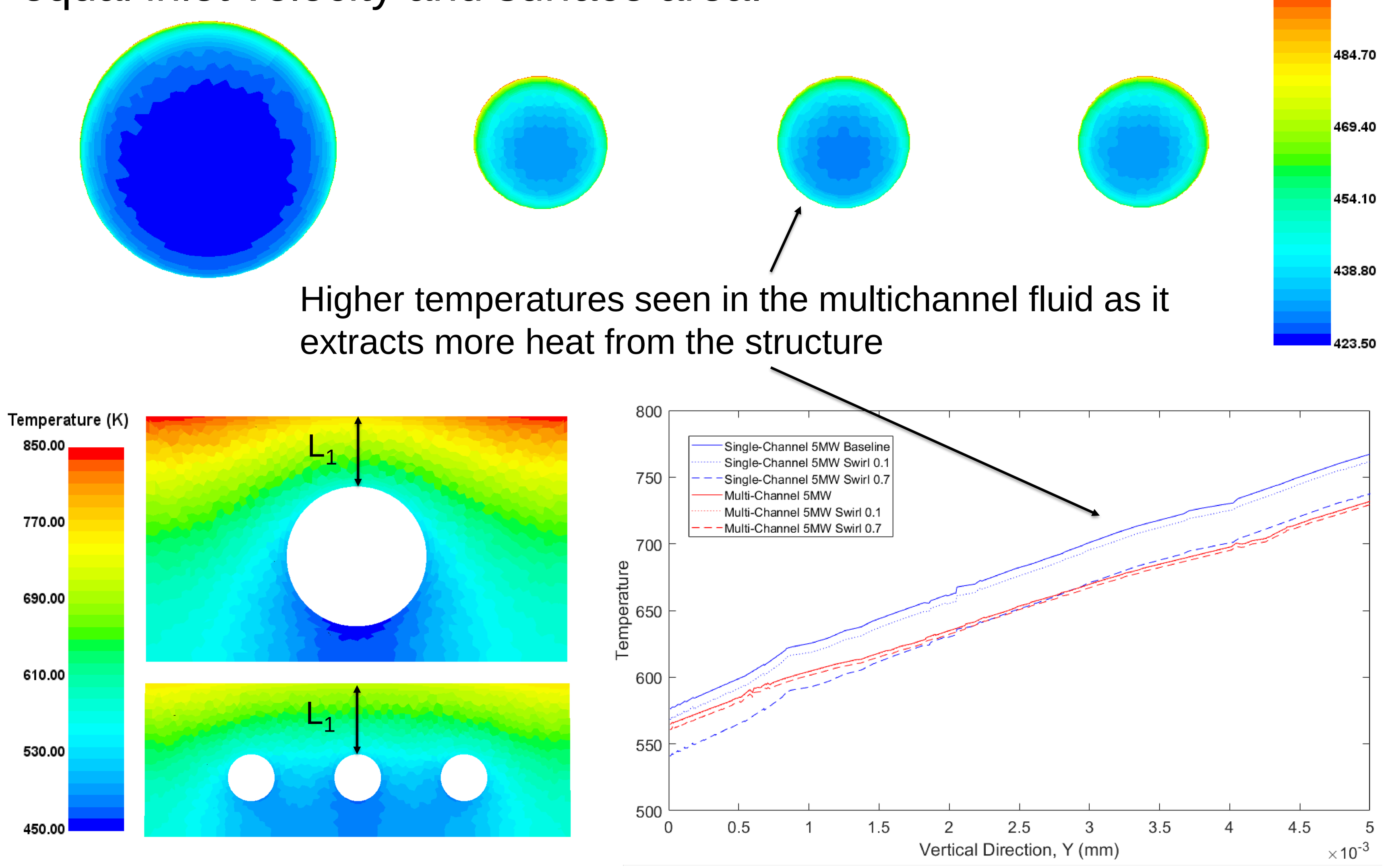

Figure 4:Comparison of single and multi channel configurations

Liquid Lithium Simulations

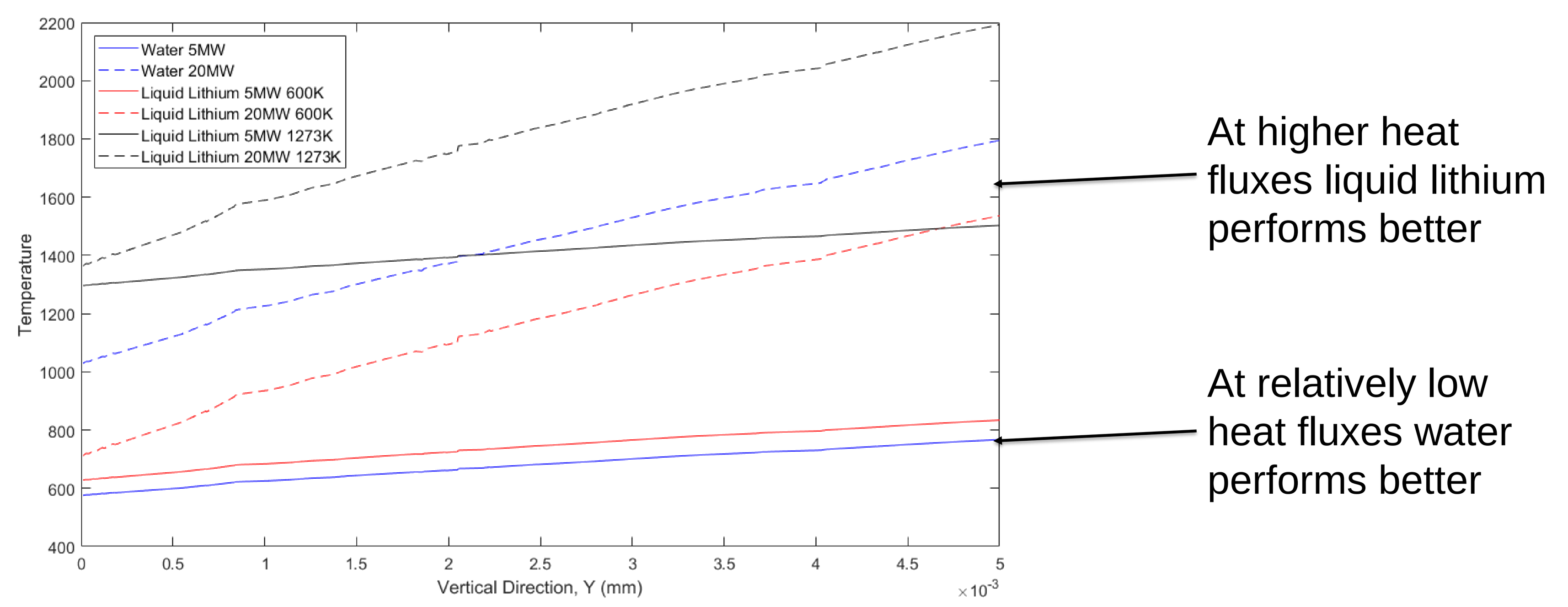

Figure 5:Comparison of water and liquid lithium as the coolant in single channel configurations

Conclusions & Further Work

- Multi-Channel has better cooling performance than single channel configurations under the investigated conditions.
- The addition of swirl to the fluid increases the cooling performance of the fluid but is less effective at smaller diameters.
- Liquid Lithium is more effective than water at higher heat fluxes.
- Turbulence and optimised geometries for its development can improve the heat transfer and will be investigated next.

REFERENCES

1. D.Hancock, D.Homfray, M.Porton, I.Todd, B.Wynne, Exploring Complex High Heat Flux Geometries for Fusion Applications Enabled by Additive Manufacturing, 2019

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