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DESIGN OF EXPERIMENTAL DEVICE FOR TESTING OF SUBCOOLED FLOW BOILLING

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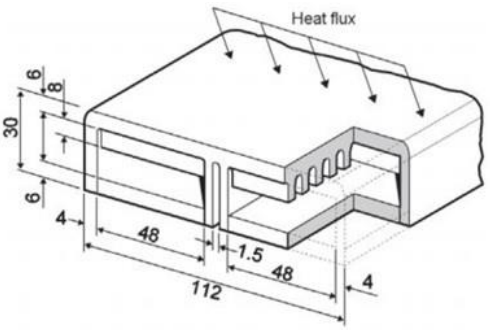
Abstract: *The article presents the principle and function of the Hypervapotron and the current work progress on the realisation of the experimental loop. Hypervapotron is a heat exchanger operating in a two-phase flow regime, in which the latent heat of the water/steam phase transformation is used, which enables the transfer of large heat fluxes (up to tens of MW/m^2). For this reason, it appears to be very promising for use in fusion reactors. The article describes the steps leading to the final design of the experimental loop - selection of suitable mesh parameters in the Star-CCM+ code, geometry and used materials of the single elements of the heating system using electromagnetic induction. The effort of the experimental loop and the flow study in the Hypervapotron in general, is dimensional and material optimization of the geometry is suitable for a wide range of applications for which the benefits of subcooled boiling and Hypervapotron geometry can be applied.*

Keywords: Hypervapotron, Star-CCM+, Fusion, Subcooled boiling, Induction heating.

1. Introduction

The term Hypervapotron was first used by Charles Beutheret (Milnes, 2010) in 1970 by deriving it from the terms Vapotron and Supervapotron. Vapotron indicates characteristic heat transfer by subcooled boiling, which is realized in a ribbed geometry with different temperatures along the height of the rib. This fact shifts the point of origin of the steam cushion and thus the boiling crisis to higher temperatures, which allows further growth of the critical heat flux.

The actual physical model of two-phase flow in Hypervapotron is due to the many degrees of freedom (geometry, transmitted heat power, material of the Hypervapotron, coolant and its pressure, temperature) is relatively complex and the CFD codes are able to successfully model it with some accuracy only in recent years. However, there is still a great dependence on the verification of the calculated data with the experiment, where the prediction of the behaviour of a new geometry type cannot be considered valid without verification with the experiment. Literature with sufficient data suitable for further validation is also relatively low, so the researchers are bound also to a narrow range of operating parameters and geometry of the test or eventually support the calculations by experiment.



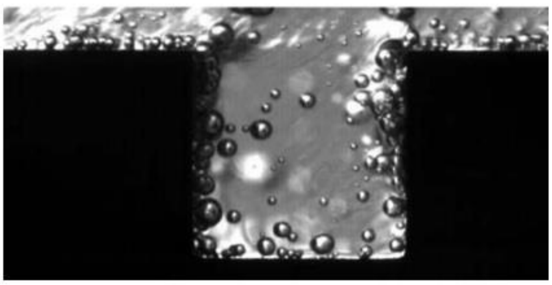


Fig. 1: Typical Hypervapotron geometry (left), inside view of the Hypervapotron (right) (Milnes, 2010).

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The most extensive and yet published work is a thesis of Joseph Milnes (Milnes, 2010). In his work he focused on modelling in CFX code, comparison the results with experimental data measured in Culham Centre for Fusion Energy (Milnes, 2010). His work was followed by next works at CTU in Prague, in the CFD codes ANSYS Fluent and CFX (Písek, 2016) and (Pitoňák, 2017). Similar simulations were also performed by Domalapally (Domalapally, 2015), who computed in Star-CCM+ code using the Rohsen's boiling model.

There are two successive goals in the field of Hypervapotron research at CTU FME, department of Energy Engineering. The first is validation of the mathematical model from the CFD code Star-CCM+ in selected experimental data at the built experimental loop. The second goal is gradual optimization of the mathematical model, which will allow to design a Hypervapotron for a wider range of input parameters (geometry, operating pressure, mass flow, inlet temperature, etc.) without the need of performing additional experimental verifications for the changed input parameters.

2. Design and the model validation

The geometry of the Hypervapotron active channel model was taken from Milnes (Milnes, 2010). This decision was made mainly due to the sufficient amount of published data suitable for validation. Another reason for choosing this geometry are investigated operating parameters which have proven to be achievable using commercially available (heating) parts after a series of pre-analysis. This fact allows an accessible way to perform the prepared experiment. The main validation parameters were the temperature at the measured site (0) and the course of temperature propagation - isotherms in the volume (0) depending on the supplied heat flux.

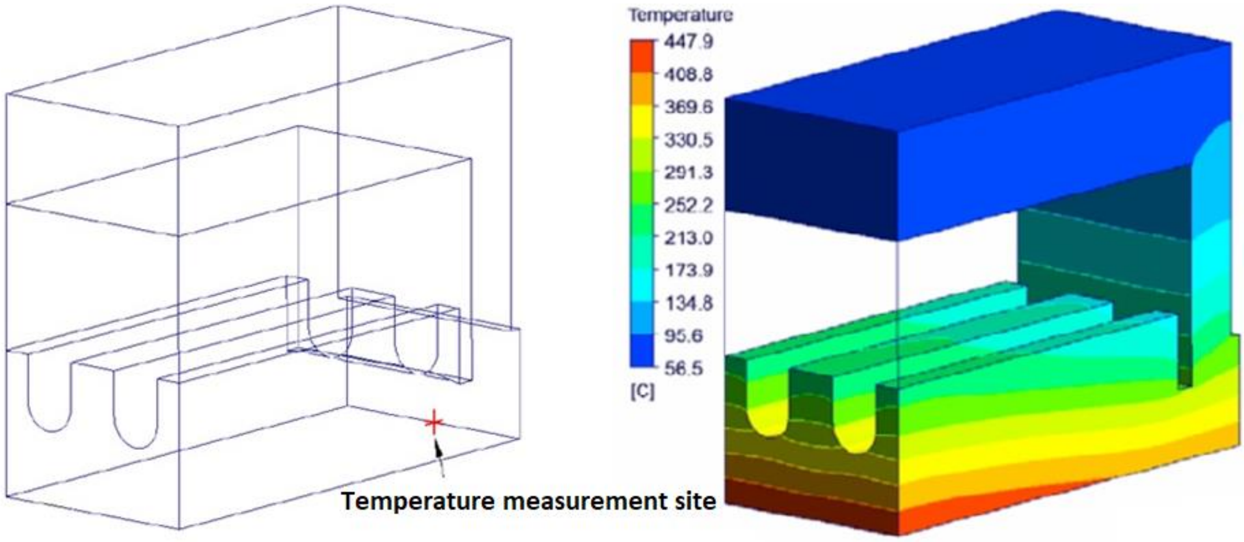

Fig. 2: Temperature measured site (Pitoňák, 2017) (left), Isotherm in the volume (Milnes, 2010) (right).

The heat flow calculation is performed using the CFD code Star-CCM +. The material of the active channel is a CuCrZr alloy, the coolant is water. Boundary conditions at the inlet are summarized in 0.

Tab. 1: Boundary condition at the inlet.

Parameter	Value
Pressure	6 bar
Inlet velocity	4 a 8.55 m/s
Inlet temperature	50 °C
Saturation temperature	158.85 °C
Heat flow	2; 4; 6; 8; 10; 12 MW/m^2

A summary of the main used numerical models is listed in 0.

Tab. 2: Summary of the main used numerical models.

Numerical models for liquid	Numerical models for phase interactions
Space: Three Dimensional	Phase Interaction: VOF-VOF
Time dependence: Steady	Boiling: VOF Boiling
Multifluid model: Eulerian Multiphase	Rohsenow Boiling
Multifluid model: Volume of Fluid (VOF)	(Cqw = 0.008; Np = 1.73)
Turbulent model: Standard k-Epsilon Low-Re	
Wall treatment: All y+ Wall Treatment	

The adjustable parameters of the Rohsenow boiling model were taken from Domalapally (Domalapally, 2015), the Rohsenow boiling model equation is given in (1)

$$q_{bw} = \mu_l h_{lat} \sqrt{\frac{g(\rho_l - \rho_v)}{\sigma}} \left(\frac{C_{Pl}(T_w - T_{sat})}{C_{qw} h_{lat} Pr_l^{n_p}} \right) \quad (1)$$

Based on the results of the calculation using a hexagonal mesh taken from Pitoňák (Pitoňák, 2017), a new computational mesh using polyhedral cells was created. Almost absolute agreement of the results was achieved with this polyhedral mesh, but with much better convergence and thus shorter computational time. For comparison, the number of cells in a hexagonal mesh is 89 390 and for the polyhedral mesh 54 815.

With the polyhedral mesh, the dependences of the temperature at the monitored site on the heat output were obtained by calculation. Comparison of the results with the results of Milnes (Milnes, 2010) and the measurement from Culham (Milnes, 2010) show a sufficient agreement, compared to the Culham measurement (Milnes, 2010), the average relative deviation is equal to 2.27 %. Comparison is depicted in 0.

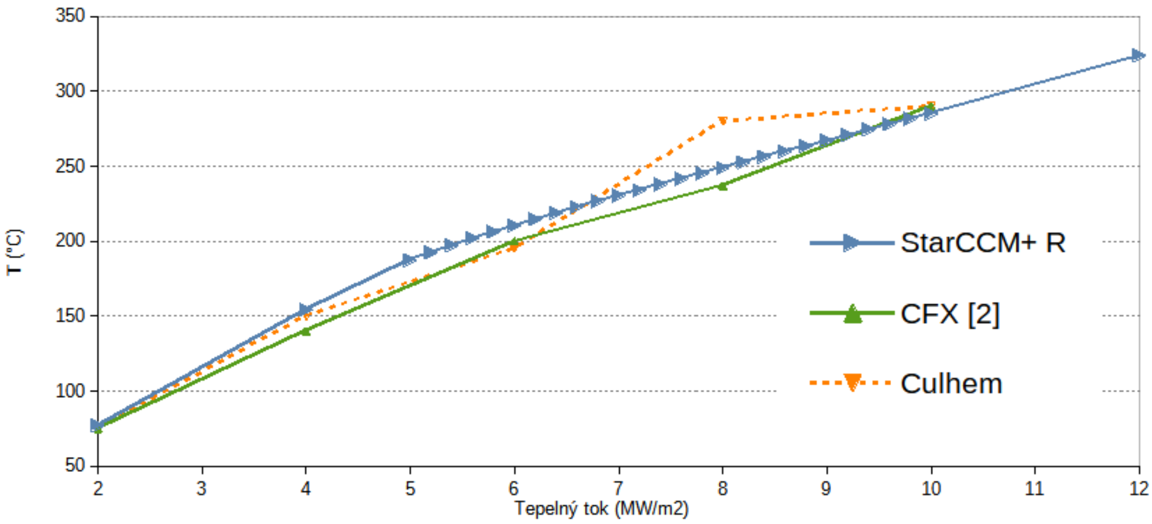

Fig. 3: Comparison of the results with Culham measurement and Milnes simulation (Milnes, 2010).

2.1. Heating system design

The active channel heating system is solved by electromagnetic induction. To create an induction field, a US Solid device with a power of 15 kW operating at a frequency of 30 - 80 kHz will be used. The heating coil will be formed from a copper tube with a diameter of 6 mm into an oval cross-section with internal dimensions of 65 x 30 mm and three threads. It will be cooled internally by flowing water.

The active channel in FIG. is connected in the lower part to the heating element, which will be heated by induction. The dimensions and shape of the designed heating element are based on the requirement for maximum reduction of the thermal load of the whole element and the ability to uniformly transfer the induced power to the active part of the channel. The heating element consists of a copper block in which are embedded 4 steel plates.

The sample simulation in the Star-CCM+ program (0) shows that for the selected coolant input parameters (inlet velocity, temperature, pressure) the maximum temperature in the heating element reaches 743.6 °C. from 0. it is further apparent that the heat transfer to the active channel is uniform throughout the cross section.

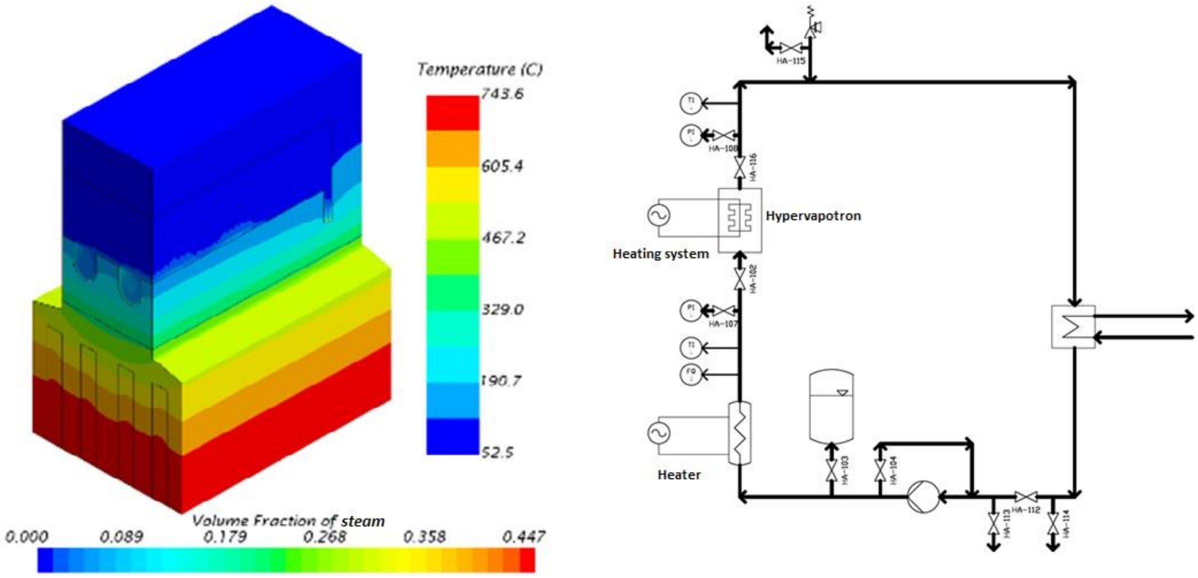

Fig. 4: Heating element from the Star-CCM+ (left), scheme of the experimental loop (right).

2.2. Experimental loop

The proposed active channel with the heating system will be incorporated into the experimental loop of the experimental device, the wiring diagram of which is in 0 above on the right. The loop is dimensioned for the operating parameters listed in 0.

Tab. 3: Operating parameters of the experimental loop.

Parameter	Value	Parameter	Value
Maximum pressure	<10 bar	Maximum working temperature	<110 °C
Maximum coolant flow	416 l/min	Maximum heating power	15 kW
Maximum velocity	19 m/s	Maximum heat flux	12 MW/m^2

3. Conclusion

The presented work is a partial study within the research of the Hypervapotron at CTU in Prague, FME. Interim results of the work are presented, which include a computational model with a polyhedral mesh from the STAR-CCM+ code. The model was validated using data achieved in Milnes and Culham measurement (Milnes, 2010). The second part of the output includes a shape and a heating element geometrical analysis for the induction heating, which subsequently initiates production of the first sample of the Hypervpapotron’s active channel.

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