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Numerical and Experimental Studies to Evaluate the Conservative Factor of the Convective Heat Transfer Coefficient Applied to the Design of Components in Particle Accelerators

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Abstract

The fluid boundary condition applied to the design of components in particle accelerators is calculated as a global variable through experimental correlations coming from the literature. This variable, defined as the convective heat transfer coefficient, is calculated using the conventional correlations of Dittus and Boelter (1930), Sieder and Tate (1936), Petukhov (1970), Gnielinski (1976), among others. Although the designs based on these correlations work properly, the hypothesis of the present study proposes that the effectiveness of these approximations is due to the existence of a significant and unknown conservative factor between the real phenomenon and the global variable. To quantify this conservative factor, this work presents research based on Computational Fluid Dynamics (CFD) and experimental studies. In particular, recent investigations carried out at ALBA confirm in a preliminary way our hypotheses for circular pipes under fully and non-fully developed flow conditions. The conclusions of this work indicate that we could dissipate the required heat with a flowrate lower than that obtained by applying the conventional experimental correlations.

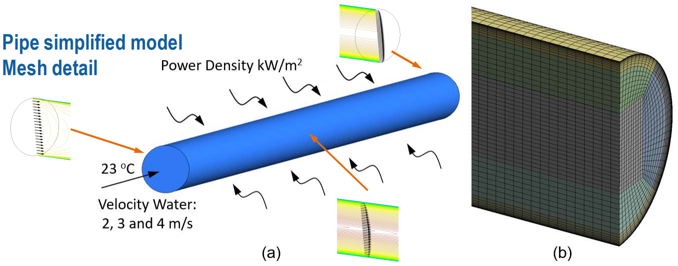
Objective and Strategy

(i) **Objective**: Study of the conventional convective heat transfer coefficient (*h*) for internal flow in cooling channels with the aim to estimate the conservative factors inherent in the "*h*" coefficient, currently obtained from experimental correlations.

(ii) **Strategy**: Investigations based on CFD (Computational Fluid Dynamics), Heat Transfer (HT) simulations, and preliminary experimental studies. The HT simulation approximates the heat transfer in the fluid using the conventional "*h*" coefficient.

Circular Channels: CFD Studies

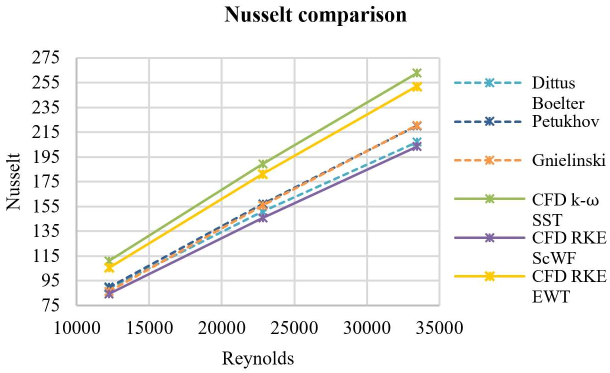
(a) Pipe simplified model
(b) Mesh detail



Model Description

- Two pipes with an internal diameter of **8 and 10 mm** have been studied, both 0.5 m lengths.
- The heat flux applied to the surface are assumed to be constant values of 80 and 12.55 kW/m^2, respectively. At the inlet, water at 23 ºC and a velocities < 4 m/s are fixed.
- The highest refinement has generated a mesh of around **2.5 million elements**. A group of viscous models have been tested such as the $k-\omega$ Shear-Stress Transport (SST), $k-\omega$ Standard, the Realizable k-ε with Scalable Wall Functions (RKE ScWF), the Realizable k-ε with Enhanced Wall Treatment (RKE EWT) and the Transition SST.
- Simulations have been carried out using ANSYS WORKBENCH.

Results

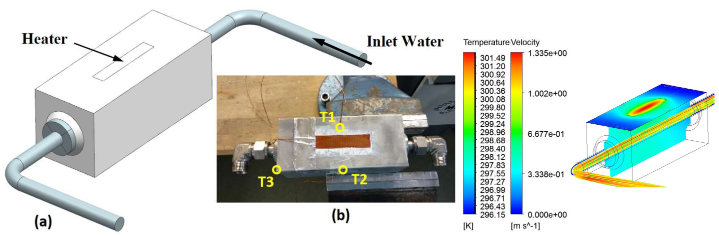


Comparison of Nusselt calculated by CFD to experimental correlations for channel 10 mm diameter.

Mirror: CFD, HT, and Experimental Studies

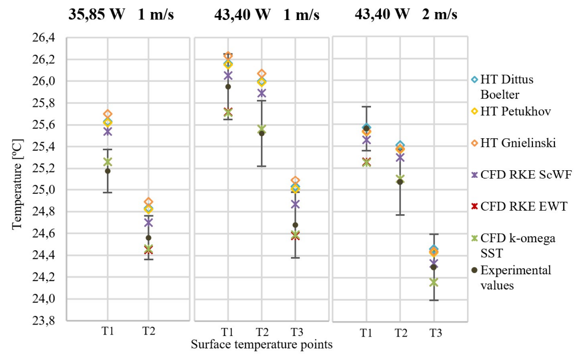
Model Description

- Numerical (CFD and HT) and experimental studies for non-fully developed flow conditions.
- Mirror model with internal cooling channel. The geometry consists in an Al 6082 T6 block of 60×60×150 mm with a 10 mm diameter hole where the water flows through.
- Heat flux on the top surface (35.85 and 43.4 W) and fluid velocities of 1 and 2 m/s are imposed.
- For the experiment, heat flux is applied using two 65×11 mm heater foils.
- Thermocouples type K are placed to measure surface temperature (T1, T2, and T3).



(a) Mirror simplified model, (b) Details of temperature sensors and heater for experiment. Right: Velocity and temperature distributions for the case CFD k-ω SST, 43.4 W, and 1 m/s inlet

Results



Results of numerical simulations and experimental studies for three study conditions

Conclusions

For the case of fully developed flow conditions in pipes with an internal diameter 8 mm, the CFD calculations (applying the **k-ω SST** viscous model) confirm the existence of an average conservative value of **14%** in the conventional convective heat transfer coefficient (taking as reference the Dittus and Boelter correlation). For the pipe of 10 mm diameter, average variations of **25.9 and 20.1%** are obtained when the "*h*" coefficient (based on the Dittus and Boelter correlation) is compared with CFD calculations (based on the models of turbulence k-ω SST and RKE EWT, respectively).
The experimental results for the proposed case also confirm the existence of the conservative value for non-fully developed flow conditions. However, to have a definitive conclusion, it is recommended to carry out similar experiments subject to **higher heat fluxes**.