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Heat transfers modeling for high-pressure boiling flows

Etienne CHAVASSE-FRÉTAZ^{*†}, Alan BURLLOT^{*}, Guillaume BOIS^{*}, Catherine COLIN[†]

Boiling flows are encountered in many industrial applications such as nuclear reactors or heat exchangers. We focus on the modeling of a high-pressure upward flow in a vertical pipe using two-fluid Euler-Euler RANS models. The cylinder is electrically heated on the wall on 3.5 meters. A recent benchmark¹ conducted by a dozen institutions showed that despite many years of research, current industrial calculation codes are unable to faithfully reproduce certain physical quantities in this configuration, in particular the spatial distribution of the two phases. The aim of our work is to improve the representation of this type of flow at the local scale. To this end, it is necessary to gain a better understanding of the interactions between the dynamic and thermal phenomena involved in order to know how to focus the modeling work.

The Debora experiment² consists in a high-pressure Freon (R12) flow and covers a wide range of inlet temperatures, pressures (14 to 26 bar), flow rates and parietal heat fluxes. It is designed to represent pressurized water reactor conditions (100 to 180 bar) via a scale similarity. The specificity of these experimental measurements is that they provide radial profiles rather than only an average over the section, unlike most other experiments. The approach adopted here is to constrain the calculation by imposing some of the experimental measurements from the Debora experiment in the NeptuneCFD simulation, in particular bubble diameters and the parietal heat flux partitioning (HFP). This eliminates some of the coupling between dynamic and thermal phenomena and makes it easier to compare the effects of the different models on the calculations. This comparison is based on an analysis of the void fraction distribution and the liquid enthalpy balance.

For an intermediate mass flux of $G = 2000 \text{ kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, a wall heat flux of $W = 16 \text{ kW}$ and an output thermodynamic quality of $-0.07 \leq x_{out} \leq 0.08$, the void fraction and liquid temperature profiles are almost insensitive to large changes of the HFP such as a decrease of the evaporation flux by a factor 10 (see Figure 1). However, the enthalpy balance is modified (see Figure 2) and shows that if the liquid is saturated close to the wall ($r^+ \geq 0.85$), a drop in vapour production is compensated by the superheating of the liquid. The discrepancies with the experimental data are partly explained by insufficient radial enthalpy transport. Our work suggests that the models that need to be improved to solve this problem are the lift and turbulent dispersion forces for the vapour phase, and turbulent heat transfer for the liquid phase. This analysis enables us to prioritize the influence of models on the prediction of physical quantities, and will be applied to a selection of models in the calculation codes.

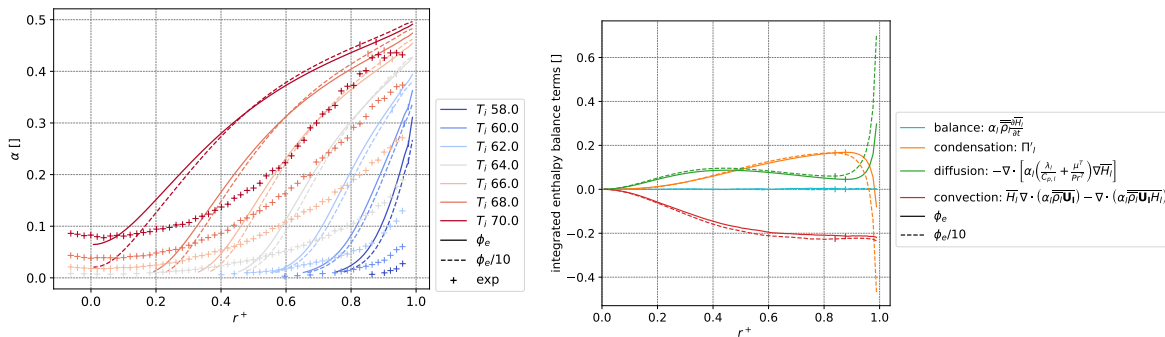


Figure 1: Radial profiles of void fraction for different inlet temperatures T_i [°C]. $r^+ = 0$: pipe axis. $r^+ = 1$: heated wall.

Figure 2: Radial profiles of enthalpy balance terms and integrated between 0 and r^+ for $T_i = 70.0^\circ\text{C}$, $x_{out} = 0.08$

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¹ Bois et al., *International Journal of Multiphase Flow* (submitted).

² Garnier et al., *Multiphase Science and Technology* **13** (2001).