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## Evaluation of condensation models on TOPFLOW experiment

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### Abstract

Some condensation models were evaluated in this work using TOPFLOW experiment, in which saturated steam bubbles are injected in sub-cooled water inside a vertical pipe. At different heights, the void fraction, velocity and bubble size distribution were measured as radial profiles. A monodispersed approach was used for CFD simulations with Neptune\_CFD code. The results obtained with this code slightly overpredicts the void fraction at the first 1.5 meters of the pipe and underestimates it above 1.5m. The void fraction depends of heat and mass transfers between phases, which is linked to the interfacial area and so, to the fragmentation and coalescence phenomena. As a consequence, an analysis of the experimental results will be done to investigate the role of each phenomena. Then, the most appropriate condensation model will be used.

### Introduction

The condensation play a significant role in nuclear field in case of sub-cooled boiling or bubbles entrainment caused by emergency core cooling (ECC) injection. For this reason, some models have been developed in order to predict as well as possible the condensation rate. The most frequently used is the Ranz-Marshall model (Ranz and Marshall 1952) and some others are presented in (Kim and Park 2011). The main advantage of working on this TOPFLOW experiment is that the walls are adiabatic so there is no boiling, which means that all heat and mass change are generated by the condensation phenomena.

### Experimental Facility

The experiment is described in detail in (Lucas et al. 2013). It consists of an injection of steam bubble in subcooled water at high pressure (65bar) inside a large vertical pipe with an inner diameter of 195.3mm and a length of about 8m. There are tests with injection orifices of 1mm and 4mm, which allows variation of initial bubble size distribution. The test case selected in the current work is the test 096 of K16 test series. The detail of this test case is provided in table 1.  $J_l$  and  $J_v$  are respectively the liquid and vapor superficial velocity,  $\Delta T_{in}$  the inlet subcooling and  $D_{orifice}$  the orifice diameter.

P [bar]	$J_l$ [m/s]	$J_v$ [m/s]	$\Delta T_{in}$ [K]	$D_{orifice}$ [mm]
65	1.017	0.0898	5.0	1.0

**Table 1: Description of the selected test case**

### Model setup

Neptune\_CFD is a 3D multifield CFD code using Eulerian approach (Guelfi et al. 2007). The solver is based on a pressure correction method simulating multi-component multi-phase flows by solving the three balance equations for each phase as follows. In those equations, the overline represents the statistical average, and a weighted average is introduced:

$$\overline{\xi_k} = \frac{\overline{\rho_k \xi_k}}{\overline{\rho_k}} \quad (1)$$

The equations are given in their primary form with  $k = v, l$  denoting vapor and liquid phases:

$$\frac{\partial}{\partial t}(\alpha_k \bar{\rho}_k) + \nabla \cdot (\alpha_k \bar{\rho}_k \cdot \bar{\underline{v}}_k) = \Gamma_k \quad (2)$$

$$\frac{\partial}{\partial t}(\alpha_k \bar{\rho}_k \bar{\underline{v}}_k) + \nabla \cdot (\alpha_k \bar{\rho}_k \bar{\underline{v}}_k \cdot \bar{\underline{v}}_k) = \nabla \cdot (\alpha_k \bar{\underline{\tau}}_k^m + \bar{\underline{\tau}}_k^T) - \alpha_k \nabla P + \alpha_k \bar{\rho}_k \underline{g} + \Gamma_k \bar{\underline{v}}_k^I + \underline{I}'_k \quad (3)$$

$$\frac{\partial}{\partial t}(\alpha_k \bar{\rho}_k \bar{H}_k) + \nabla \cdot (\alpha_k \bar{\rho}_k \bar{H}_k \bar{\underline{v}}_k) = -\nabla \cdot (\alpha_k \bar{\underline{Q}}_k) + \alpha_k \frac{\partial P}{\partial t} + \Pi_k + q_{wk} \quad (4)$$

$\Gamma_k$  represents the volumetric mass transfer rate across the interface. The interphase mass transfer due to condensation will intervene in this term as:

$$\Gamma_l = \frac{\dot{q}_l}{h_{fg}} = \frac{h_{l,k}(T_{sat} - T_l)A_i}{h_{fg}} \quad (5)$$

$h_{fg}$  is the latent heat,  $A_i$  the interfacial area density. By assuming a spherical morphology of interfacial structure,

which is a common assumption for small bubbles, the interfacial area density is given by:

$$A_i = \frac{6\alpha_g}{d_b} \quad (6)$$

$\alpha$  is the void fraction and  $d_b$  the bubble diameter. The heat transfer coefficient  $h_l$  is provided by the Ranz-Marshall correlation:

$$h_l = \frac{\lambda_l}{d_b} (2 + 0.6Re_b^{0.5} Pr_l^{0.3}) \quad (7)$$

Then, a monodispersed approach is used with the interfacial area transport equation given by (Ruyer et al. 2007).

### Computational grid and boundary conditions

Since the geometry and the flow field inside the pipe is axially symmetrical, the simulations can be done in quasi 2D, for a slice of  $4^\circ$  as it is shown in Fig. 1. The inlet conditions of volume fraction, gas velocity and bubble size distribution as well as liquid temperature and mass flow rate were defined according to experimental data. The outlet pressure is also defined according to experimental data. The wall has no-slip conditions for liquid and is assumed adiabatic.

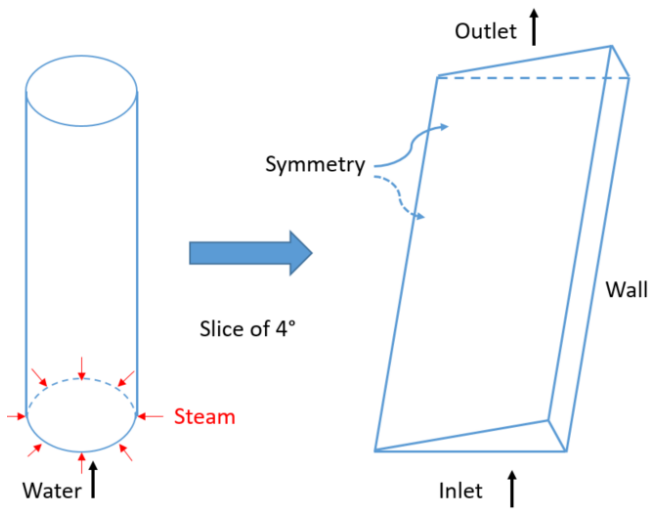


Figure 1: Calculation domain

### Results and Discussion

Overall, using Ranz-Marshall correlation, Neptune\_CFD code predicted well the condensation rate in the test case treated as shown in Fig. 2. However, in first quarter of the tube, where condensation plays a dominant role (from 6% of void fraction to 1%), the code slightly underpredicts the condensation and therefore, overpredicts the void fraction. This is in accordance with the results obtained with a poly-dispersed approach and Ranz-Marshall correlation on different test cases for this experiment (Liao et al. 2019). Then, the code overestimates the condensation from 1.5 m, since all the vapor is condensed at 3.5m, contrary to the experiment.

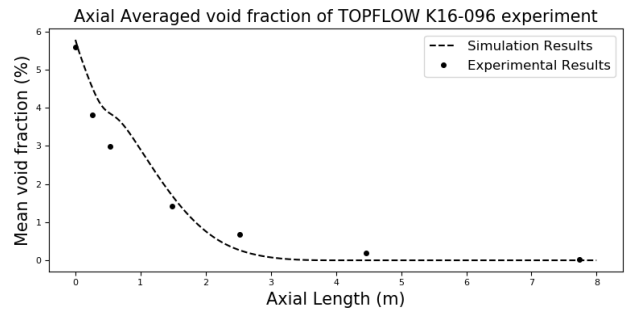


Figure 2: Evolution of cross-section averaged volume fraction in the axial direction between experimental measurements and simulation results

### Conclusion and future work

The Ranz-Marshall correlation has been evaluated in this work on the TOPFLOW experiment where saturated steam bubbles were injected in subcooled water. For the test case K16-096, the correlation seems to be adequate and gives rather satisfactory results with a monodispersed approach. This work is still in progress, this correlation as well as other correlations presented in (Kim and Park 2011) will be used for the other test cases of this experiment and will be compared. In addition of the axial evolution of cross-section averaged volume fraction, some local parameters will be compared between the code and the experiment. Indeed, radial profiles of void fraction, velocity and bubble size will be compared at each measurement point.

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