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Simulation of two-phase air / water flows in bubbly flow in horizontal pipe

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Abstract

This study presents the two-phase CFD simulation of horizontal pipe flow experiments carried out on METERO-H facility in the frame of a Loss-Of-Coolant Accident (LOCA). The computational domain is based on conformal hexahedral mesh. A mesh sensitivity study was performed with a comparison with experimental data. A sensitivity study on number of field used in the modelling was performed. The three fields approach permits to well reproduce the experiments at high void fraction while the two fields approach underestimate the void fraction within the upper part of pipe. Results are in good agreement with experimental data.

Introduction

In Pressurized Water Reactors (PWRs), Loss of Coolant Accidents (LOCA) initiated by a breach in the primary circuit wall are the most studied accident situations for nuclear safety. The breach causes a leak of primary coolant and depressurization of the primary circuit with the steam produced by boiling, and thus the establishment of two-phase flow in horizontal pipe which is characterized by different regimes such as a Bubbly flow or stratified flow. This transition fundamentally changes the interactions between phases with notably the coefficient of interfacial friction, which decreases by several orders of magnitude, as well as the mass of water lost. The work presented here focuses on the simulation of two-phase flows of METERO-H experiment (Bottin 2010) under development in a horizontal pipe and more particularly the beginning of stratification with the buoyant bubbly flow and its transition to the intermittent flow which is the intermediate regime between bubbly flow and stratified bubbly flow.

Experimental Facility

The METERO-H experiment is dedicated to understand the responsible mechanisms of the transition between bubbly and stratified two-phase flows in a horizontal pipe. The METERO-H experiment allows measuring various two-phase air/water flow quantities, such as void fraction, interfacial area, bubble sizes, velocity of the gas phase, liquid height, turbulence level, mean and fluctuating velocity of the liquid phase in order to analyse two-phase flows in details. Each simulation is characterised by different couple of superficial velocities of water (JL) and of air (JG) at the pipe inlet. These different inlet conditions are summarised in Table 1. These conditions correspond to different flow regimes experimentally observed at 40D from the inlet which

are representative of buoyant bubbly flow, buoyant bubbly/stratified bubbly transition flow and stratified bubbly flow. In the following, the computed void fraction profiles are compared to experimental void fraction profiles measured at 40 D.

Table 1: Test conditions selected.

Flow regime	QL (m ³ /h)	JL (m/s)	QG (m ³ /h)	JG (m/s)
bubbly/stratified	125	4.42	30	0.068
Stratified	125	4.42	60	0.136
Bubbly	150	5.31	60	0.136

Numerical description

NEPTUNE_CFD is a generalised multiphase code with an Eulerian approach. The numerical algorithm is based on a non-linear fractional step method called alpha-pressure-energy cycle. The two-field modelling consists of a continuous liquid water field carrying a dispersed air field. The three-field modelling (Mimouni et al. 2017) uses an additional field which is a continuous air field that exchanges mass with the dispersed air field (Mimouni et al. 2014). Indeed, if the volume fraction of scattered air exceeds $\alpha_{crit} = 0.3$, then mass from the dispersed air field is transferred to the continuous air field. The bubble size variation can be taking into account with the interfacial area modelling with the interfacial area transport equation given by (Ruyer et al. 2007). Three mesh refinements are used which are Square 1 (3.10^5 cells), Square 2 (10^6 cells) and Square 3 (2.10^6 cells).

Results and Discussion

The two-field and three-field approaches were evaluated with the three grid levels. Figures 1 and 2 show the comparison of the air volume fraction profiles at 40 diameter

obtained with the 3 meshes and for the two approaches. In bubbly/stratified transition flow, the 3-field approach overestimates the void fraction with mesh level 2 while for the other mesh levels, the results are similar to the 2-field approach, which predicts a rather satisfactory void fraction.

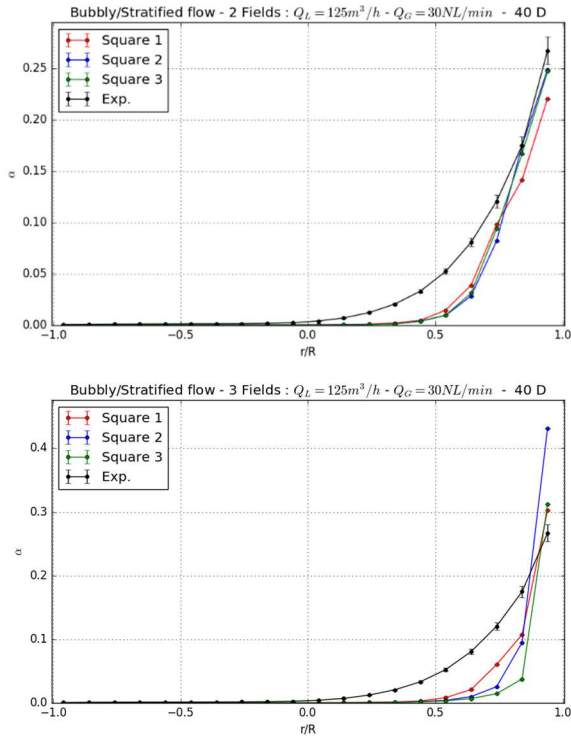


Figure 1: Air volume fraction for bubbly / stratified transition flow at 40 D: 2 fields (top), 3 fields (bottom).

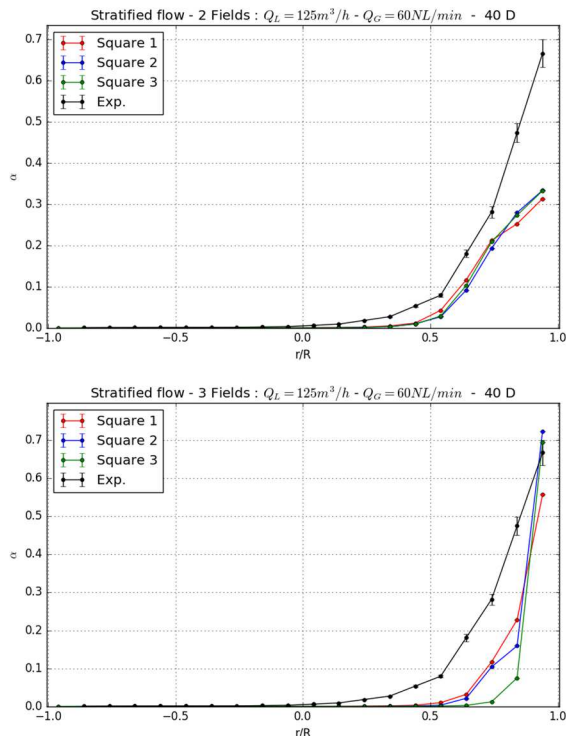


Figure 2: Air volume fraction for bubbly / stratified transition flow at 40 D: 2 fields (top), 3 fields (bottom).

For stratified flow, the 3-field approach calculates a void fraction of the same order of magnitude as the experimental

void fraction, whereas the 2-field approach underestimates the void fraction in the upper part of the pipe. For both approaches, there is no significant effect of the mesh on the results. For bubbly flow, the 2-field approach correctly predicts the void fraction distribution with the right order of magnitude in the pipe section. On the other hand, the 3-field approach overestimates the void fraction for all meshes. In cases of bubbly/stratified transition flow and bubbly flow, which are characterised by a moderate void fraction (< 0.3), the 2-field approach gives results that are in good agreement with experience. The 2-field approach does not allow to correctly calculating the void fraction in a stratified flow with a high void ratio.

Conclusion

The 2-field and 3-field approaches have been evaluated on bubbly flow, transition bubbly/stratified flow and stratified flow with a mesh sensitivity study. Concerning the bubbly configuration, the 2-field approach gives rather satisfactory results with all meshes. The 3-field approach gives results that are also satisfactory but still with a slight overestimation of the air volume fraction in the upper part of the test section. In case of stratified configuration, the 3-field are in better agreement with experimental data than the 2-field which strongly overestimates the air volume fraction in the upper part. This work is still in progress, a detailed analysis of the experimental data will be performed in order to determine which physical phenomena are taking place. The objective is to try to determine if fragmentation and coalescence phenomena occur and with what intensity respectively.

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