Instabilities in the two-fluid model relevant to fine-scale simulations of bubbly flows in nuclear reactors

INSTABILITIES IN THE TWO-FLUID MODEL RELEVANT TO FINE-SCALE SIMULATIONS OF BUBBLY FLOWS IN NUCLEAR REACTORS

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ABSTRACT

Bubbly gas-liquid flows are very important in the nuclear industry. The intricate details of the bubbly steam-water two-phase flow in a boiling water reactor significantly affects the coolant properties, which in turn influences the local heat transfer, the evaporation rates and the neutron transport. Due to the large size of a nuclear reactor, macroscopic models – such as the two-fluid model – are traditionally used to predict the features of the two-phase flow. Since high-frequency and small-scale phenomena are filtered out in the derivation of these models, the effect of such phenomena on the macroscopic fields must be artificially reintroduced, typically via experimentally-derived closure relationships. It could be speculated that more general two-fluid models could be developed if the macroscopic formulations were closed with information from highly resolved simulations with the same model. However, if one aspires to abandon the procedure to tune the macroscopic model directly to the available experimental data, it becomes very important to first scrutinize the behavior of the basic two-fluid model formulation at the finest scales. This observation is reinforced by the knowledge that both the formulation of the two-fluid model and the numerical algorithms employed to solve it will influence the stability of the solution.

In the present work, we investigate the performance of the two-fluid model on smaller scales than what is typically used in the nuclear industry today. We formulate a simplistic two-fluid model for bubbly steam-water flow and perform numerical simulations in periodic 2D domains, investigating the spontaneous emergence of non-uniform bubble volume fraction fields in the form of meso-scales. We examine how these instabilities are affected by the formulation of the case specifications, the model formulation and the methods used to obtain the numerical solution. The two-fluid model used in the present work is simple enough to enable direct observations of the effects of each feature added to the model.

The evolution of non-uniformities in the volume fraction fields is investigated for a number of computational cases where the domain is fully periodic, and at time zero, all fields (velocities, pressure and volume fractions) are uniform and the flow is stationary. The simulations reveal that under certain circumstances, very small initial disturbances have a tendency to grow and manifest in the form of mesoscopic flow structures.

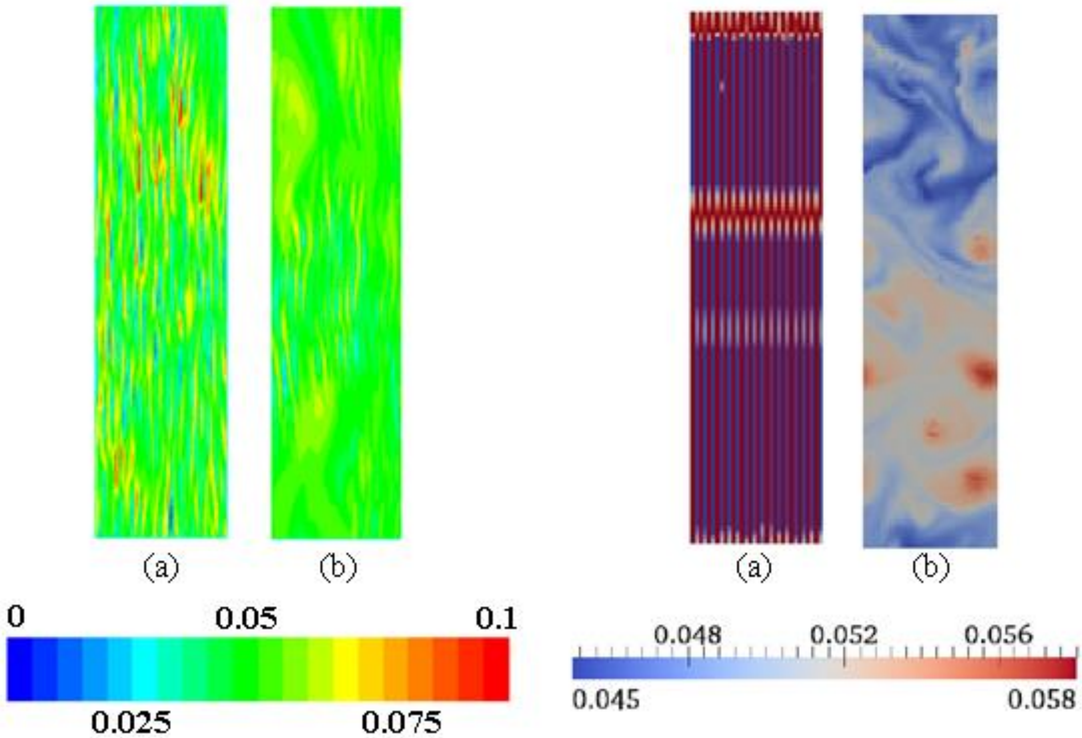

Figure 1. Examples of the bubble volume fraction field at (a) and a few seconds after (b) the attainment of the maximally unstable state in numerical simulations with two different numerical algorithms. The average bubble loading is 0.05.

Predictions obtained with different numerical algorithms yield qualitatively similar results. As an example, Figure 1 shows a comparison of two predictions of the bubble volume fraction field at a maximally unstable state obtained using different numerical algorithms. The exact magnitude and appearance of the fluctuations varies but the overall picture is the same. We take this to mean that the exact time-history obtained is unlikely to reflect a true physical behavior of the system, but should be interpreted rather as a display of the unstable character of a bubbly two-phase flow and the complex interplay between the design of the mathematical model and the choice of numerical algorithms employed in solving it. Implications of these findings for the possibilities to use fine-scale simulation results as a basis for deriving more general closure relations are discussed.

Key Words: **gas-liquid flow; bubbly flow; two-fluid model; thermal-hydraulics.**