Numerical simulation of unsteady film condensation in a vertical channel

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Abstract

Film condensation is a common vapor–liquid phase-change process which occurs in various energy systems such as nuclear and thermal power plants, refrigerators and air-conditioners. Extensive studies have been conducted to develop a predictive model for the film condensation during the last century. However, its general predictive model has not yet been developed due to the complexity of the associated two-phase flow coupled to phase-change heat transfer occurring in a very thin liquid film.

Numerical models for analysis of film condensation were developed in several studies using the volume-of-fluid method coupled to the Lee model for evaluation of the mass source due to phase change, Lagrangian methods for tracking the condensate film thickness as a function of time and the streamwise coordinate, and a level-set method coupled to the ghost fluid method for sharply enforcing the interface conditions in a very thin condensate film. However, the methods were not easily applicable to film condensation on a long surface.

In this work, a numerical method for film condensation is developed by combining an unsteady multi-dimensional CFD solver for gas flow with an unsteady 1D formulation for very thin condensate film. The present method can accurately simulate the condensation effect by explicitly implementing velocity, stress, and heat flux conditions at the interface, and implement the effect to the gas phase. In the unsteady 1D formulation for the very thin condensate film, the mass equation and the momentum equation including the wall and interface shear stresses and the surface tension are expressed in terms of the film thickness and the flow rate.

The present numerical method is applied to unsteady film condensation in a vertical channel. As the wall subcooling increases, the liquid film thickness increases and the associated wall heat flux increases. When the liquid film Reynolds number at the channel outlet is smaller than 30, the computed film thickness and wall heat flux show good agreement with the analytical steady predictions. In order to simulate the unsteady film condensation occurring at high Reynolds numbers, a small disturbance is included in the wall velocity near the channel inlet. The disturbance is observed to increase or decrease depending on the disturbance wavelength, the wall subcooling and the inlet vapor velocity. Their effects on the film thickness and wall heat flux in the film condensation are investigated.

Keywords: Film condensation, Liquid-gas interface, Unsteady flow.