INVESTIGATION ON BUBBLE DYNAMICS IN NATURAL CIRCULATION BOILING LOOP: VISUALIZATION TECHNIQUE

A Thesis

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by

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ABSTRACT

The present thesis on *Investigation on bubble dynamics in natural circulation boiling loop: visualization technique* has carried out extensive experimental and numerical investigations to meet the objectives - (i) to determine experimentally and numerically the bubble dynamics parameters (bubble departure diameter, bubble velocity, and bubble collapse rate) using a high-speed camera with the variation of heat flux, mass flux and degree of subcooling in natural circulation boiling loop (NCBL) (ii) to study the effect of bubble dynamics (bubble growth and collapse) on the onset of flow oscillation in the NCBL and to explain the experimental flow oscillations by the numerical simulations using the four-equation drift flux model (DFM4), and (iii) to study the experimental and numerical investigations on the motion and trajectory of a bubble in subcooled flow boiling.

Visualizing bubble dynamics using a high-speed camera requires studying the effect of vapor bubble size on the flow oscillation to find the critical bubble diameter which initiates the flow oscillation. The critical bubble diameter during bubble growth and bubble collapse in the subcooled liquid in the non-heating section of NCBL becomes important to initiate the flow instability. As the DFM4 computes two-phase boiling flow and bubble dynamics using the conservation equations and closure relations, it needs to be validated with the experiments to make a full use of DFM4. In the present thesis, the rise characteristics of vapor bubbles in the vertical boiling channel have been captured by the high-speed camera through the view glass when the bubble departs and rises through the subcooled liquid. The recording frequency was 500 fps with a resolution of 1696 × 1710 pixels. We observe that the growth and collapse of a vapor bubble with a critical diameter of 3.42 mm triggers the flow oscillation in the NCBL. The DFM4 based numerical simulation satisfactorily predicts the flow oscillations.

The present thesis contains seven chapters. *Chapter 1* (Introduction) contains the background, the origin of the work, and its applications in real life. This chapter discussed the classification of boiling, bubble dynamics (bubble growth and its force balance), and their theories and applications introduced in this chapter. The introduction of the working principle of the natural circulation boiling loop has also been discussed. *Chapter 2* (Literature review) contains state-of-the-art of related researches on bubble dynamics. Also, the role of bubble dynamics on the onset of flow

oscillations and the techniques for studying bubble dynamics in boiling channels have been discussed. From the survey of the literature, essential gaps and limitations have been identified. At the end of this chapter, the objectives of the present work to bridge the gaps have been presented. *Chapter 3* (Experimental setup and procedures) contains all the detailed explanations of various parts of the NCBL, including instruments, sensors, and their uncertainties have been discussed. The operation procedure of the NCBL and simultaneous image processing techniques have been presented elaborately. Experimental operating conditions and uncertainty of measurement have been discussed. *Chapter 4* (Numerical Models and Methods) presents the numerical model devolvement and solution of model equations used to describe the bubble dynamics in subcooled flow boiling. The models and correlations to predict bubble departure diameter, bubble velocity, and bubble trajectory in the natural circulation flow boiling are discussed. The model used for the prediction of steady-state behavior of the flow rate in the NCBL is presented. This chapter also presents the nonlinear model for stability boundary, and the numerical model and computational strategy of DFM4 for computing flow oscillations. *Chapter 5* (The dynamics of a vapor bubble in NCBL) describes the dynamics of a vapor bubble in the subcooled boiling experimentally investigated using a high-speed camera. The results obtained from visualization and experiment compared with existing models are discussed here. The effect of superheat (low to high), inlet subcooling, and mass fluxes on bubble size, velocity, trajectory, and collapse in subcooled boiling are presented. Determination of equivalent bubble diameter using various methods by the MATLAB programs for image analysis is shown. Various models used for the calculation of bubble parameters are described. The numerical results for predicting bubble departure diameter, velocity, and trajectory at different wall superheats are presented. *Chapter 6* (The effect of bubble dynamics on the flow instability in an NCBL) describes the role of vapor bubble dynamics in the flow oscillations for subcooled flow boiling in the NCBL. This chapter presents the experimental results of flow oscillations at different wall superheat and numerical results for predicting the flow oscillations in the NCBL. Steady-state analysis and stability behavior of the loop flow rate has been predicted by extending the existing models are discussed. The experimental results of loop flow rate, exit temperature, and dominant frequencies were predicted by the four-equation drift flux model (DFM4) are presented. The computed results of departure diameter D_d and bubble growth time t_g also explain the corresponding experimental results. Finally, *Chapter 7*

(Conclusions and Future Scopes) contains the conclusions of the experimental and numerical work and the recommendations from the reviewers for improvements to be made in the future.