INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: Development and Experimental Validation of Simple Methodologies for Modelling of Flow Boiling in Microchannels with Large Pressure Drop

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SHORT ABSTRACT

``Everything should be made as simple as possible but not simpler.'' Inspired by Albert Einstein's famous quote, this thesis proposes simple but accurate approaches to model the complex interplay between the various thermophysical phenomena occurring in flow boiling. The proposed methodologies incorporate the effect of flashing and local thermophysical properties on two-phase pressure drop evaluation, and hence on heat transfer prediction. The governing equations are derived in an elegant close form, consisting of a system of ODEs, and their simulation is computationally inexpensive. The new modelling approaches are validated by conducting experiments on a microchannel with a large pressure drop.

Dissipating high amount of heat flux is an important issue of modern thermal management with the ever-increasing demands for high performance and miniaturization. Flow boiling in microchannel heat sinks has emerged as one of the most effective solutions for cooling high and ultrahigh heat flux devices such as high-performance computer chips, laser diodes and nuclear fusion and fission reactors. Design of these miniature devices requires a proper estimation of the two-phase heat transfer, which, in turn, necessitates an accurate prediction of pressure drop in flow boiling. Two-phase pressure drop in microchannels is relatively high as compared to conventional channels, due to their very small sizes and moderate mass fluxes, the latter being so in order to achieve reasonable heat transfer coefficients. Due to the large pressure gradient, the saturation temperature drops, and hence the effects of flashing and axial variation of thermophysical properties become significant. An extensive review is done on flow and heat transfer in microchannels, and the existing predictive methods are assessed using experimental data. The existing approach for modelling flow boiling pressure drop evaluates thermophysical properties at the system pressure and neglects the effect of flashing. To develop the flow boiling heat transfer coefficient, the existing methods assume a linear pressure profile to estimate local saturation temperature. These methods give fairly accurate predictions for small pressure drop cases, but not in cases where a relatively large pressure drop occurs. It indicates the need for improvements in predictive approaches for flow boiling pressure drop and heat transfer, especially for large pressure drop. To fill this gap, a new modelling approach has been developed for comprehensive evaluation of pressure drop along a microchannel with flow boiling. It is based on the separated flow model, incorporating the evaluation of thermophysical properties at local pressure, the effect of flashing on thermodynamic quality, and the effect of heat flux on the two-phase multiplier. For the fluids with ideal gas behavior of the vapour phase, the Clausius-Clapeyron equation is used to relate local pressure and temperature. A modified form of the Clausius-Clapeyron equation is developed to characterize the saturation line on the P-T plane for fluids whose vapour phase has nearly constant compressibility factor in the range of operation. On the basis of existing literature, it can also be inferred that there is a need for different predictive tools for pressure drop calculation in flow boiling as opposed to those for condensing and adiabatic flows. Therefore, for the non-adiabatic case, the two-phase multiplier is modified incorporating the heating effect.

The existing method of evaluation of local flow boiling heat transfer coefficient using a linear pressure profile assumption gives good predictions if the pressure drop is low but shows significant errors for large pressure drop cases. Using the new modelling approach of pressure drop prediction, local saturation pressure is evaluated for both large and small pressure drop cases. Estimation of the local heat transfer coefficient is found to be accurate when compared to experimental data from the literature with local pressure measurements in microchannels. A new methodology is suggested to develop correlations for flow boiling heat transfer coefficient with correct calculation of experimental heat transfer coefficient and accurate estimation of the variables associated with the correlations.

To validate these new modelling approaches for flow boiling pressure drop and heat transfer in microchannel, experiments are conducted on a single microchannel with hydraulic diameter of 111 μm. The fabrication of the test sections is done using microfabrication facility available at CEN, IIT Bombay. Heat loss calibration and uncertainty analysis is carried out to ensure the correctness of the measurements. Development of correlations for two phase pressure drop and heat transfer requires corresponding correlations for single phase flow. Therefore, single phase pressure drop and heat transfer in a trapezoidal microchannel are investigated. A new sample correlation of friction factor for the trapezoidal microchannel with non-adiabatic condition is developed. Flow boiling experiments are performed using two working fluids (water and FC-72) with mass flux 205-690 kg/m^{2}s and heat flux 4.5-19.5 kw/m^{2}s. The pressure drops observed for both the working fluids are large, facilitating validation of the new modelling approaches. The new predictive approaches for flow boiling pressure drop are validated for both the fluids. Comparison with experimental data demonstrates the effectiveness of the new pressure drop predictive approach relative to the existing approach. The new modelling approach for flow boiling heat transfer is illustrated by developing a sample correlation using experimental data from the literature and validating with experimental data. Another sample correlation is formulated using linear pressure profile assumption, and it is found that the correlation formulated with the new methodology predicts the data more accurately for both the fluids.

Flow boiling heat transfer experiments are conducted in the same microchannel for both the fluids (water and FC-72) and the local heat transfer coefficient is evaluated at 16 mm from the inlet. To illustrate the new modelling approach for flow boiling heat transfer, a sample correlation was formulated by modifying a randomly chosen existing correlation using the experimental data from the literature. It was found that the correlation formulated with the new modelling approach improves the prediction over the original existing correlation chosen, for both the fluids. The new sample correlation was tested for experimental data from literature, and it was observed that the predictions were better for some data sets but poor for some other data sets, thus implying the need for further improvement in the correlation of h_{TP} considering extensive data sets for different ranges of fluid properties, shape, size, surface properties, and pressure drop.

The main contributions of the thesis are the new methodologies to predict pressure drop and heat transfer for flow boiling in microchannels. This is accomplished by relaxing some of the assumptions made in the existing predictive methods and validating the results by conducting experiments.