Wrocław, 01.06.2021

Abstract of doctoral thesis of

Stanisława Halon

titled „Characteristics of high temperature boiling of refrigerants in microchannels"

Advancing miniaturization of electronic systems causes that one of the key technical problems of this branch is finding the most effective way of dissipating heat that would allow minimizing heat transfer area along with maximizing heat transfer coefficients. Flow boiling in microchannels is considered to be one of the promising methods to achieve these goals.

The most important advantages of micro-scale flow boiling are high latent heat of evaporation, high values of heat transfer coefficient and large surface area to volume ratio. These features enable dissipating heat of high density using reduced amount of the working fluid. However, modeling micro-scale heat transfer is difficult as mechanisms responsible for heat exchange are not fully understood. Additionally, research available in the literature focuses mainly on saturation temperatures up to 40°C. This hinders development of models covering a wide range of working conditions that would allow optimizing the process for high temperature applications, e.g. electronics intended for harsh environments.

Presented thesis focuses mainly on experimental identification of the dominant heat transfer mechanism of micro-scale flow boiling for saturation temperatures ranging from 40 to 85°C. Investigated working fluid was R245fa as it allows reaching analyzed temperatures at lower pressures (e.g. for saturation temperature of 80°C the corresponding pressure of R245fa is 8 bar, whereas for R134a it is 26.4 bar).

First chapter of the dissertation covers literature review on small-scale flow boiling of two having similar properties refrigerants: R245fa and R236fa. It includes creating experimental database on the values of heat transfer coefficient as a function of vapor quality, mass flux, heat flux and saturation temperature. Gaps in investigated experimental conditions and channel geometries were identified. The review also covers models for prediction of heat transfer coefficient during flow boiling and verifying their accuracy against the gathered experimental data. Models with the highest accuracy were identified as well as conditions which correspond to the highest errors.

A common method for flow boiling modeling is based on an assumption that heat transfer is due to two interfering mechanisms – forced convection related to fluid flow, and nucleate boiling related to bubble nucleation in pool boiling. Second chapter covers experimental investigation of high temperature pool boiling of R245fa. Relation between heat transfer coefficient and heat flux or saturation temperature was identified. A model for nucleate pool boiling with the highest accuracy in predicting the gathered experimental data was found and used later in the last chapter of the thesis to increase the accuracy of one of the flow boiling heat transfer models.

Third chapter of the thesis concerns experiments on flow boiling of R245fa in microchannels with the hydraulic diameter of 1 mm. It focuses on determination of the relation between heat transfer coefficient and vapor quality, mass flux, heat flux and saturation temperature. Type of these relations is considered in the literature to be an indicator of the dominant heat transfer mechanism – forced convection or nucleate boiling. Based on the obtained results the dominant heat transfer mechanism was identified depending on whether the flow was subcooled or saturated. Additionally, two-phase flow patterns were recorded (bubbly, slug or annular flow) using a high-speed camera. Based on the photos taken flow pattern maps were developed. A connection between the flow patterns and the dominant heat transfer mechanism was investigated.

The last chapter of the thesis is about developing a modification of one of the heat transfer models during flow boiling from chapter one. It incorporates the model from chapter two to calculate heat transfer coefficient for nucleate boiling and a proposal of the form of correction factors which address the interaction between forced convection and nucleate boiling. Accuracy of the proposed modification was assessed employing commonly used quantitative criteria as well as not taken into account before qualitative criterium. First group included mean absolute percentage error and its standard deviation. For qualitative assessment a newly proposed criterium based on analytic geometry was employed. It allows assessing the accuracy of the model in predicting the type of relation between heat transfer coefficient and vapor quality (increasing, decreasing or constant).

Stanisława Hałon