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Application of asymptotic model for the prediction of fouling rate of calcium sulfate under subcooled flow boiling

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In this work, a large number of experiments are performed to measure the heat transfer reduction and fouling resistance of $CaSO_4$ aqueous solutions in a vertical upward annulus under subcooled flow boiling condition. Experiments are designed so that the effects of different parameters such as solution concentration (1.5 g/l to 2.2 g/l), wall temperatures (102–115 °C), heat flux (up to 400 kW/m^2), and flow velocity (0.5–2 m/s) would be clarified. The experimental results were then used to develop a mathematical model to predict the fouling rate, based on an asymptotic model and Chen model. It was found that the advantage of the asymptotic model in comparison to the Chen model is not only its simplicity and more accurate prediction of flow boiling heat transfer coefficient, but also the physically sounder prediction of nucleate boiling fraction (NBF) which is a crucial concept in the fouling processes under boiling conditions. Furthermore, the frequency factors (k_o) used in the fouling kinetics proved to be the same in the boiling and non–boiling area of the heat transfer surface. This leads to a physically meaningful and mechanistic model for the prediction of the $CaSO_4$ fouling rate under subcooled flow boiling condition. The experimental data are in good agreement with the model predictions with an absolute average error of about 15%.

1. Introduction

The subcooled flow boiling region is characterized as boiling occurring close to the heated wall while the remaining bulk of the fluid is subcooled. Bubbles will be rapidly condensed as they move out of the developing saturation layer. As the bulk of fluid is gradually heated by conduction and convection, the saturation layer increases and eventually covers the entire flow channel. Subcooled flow boiling involves all the interactive, complicated, and dynamic processes such as hydrodynamics, heat and mass transfer, nucleation, departure, coalescence, and collapse of bubbles. Many industrial applications, for instance, boilers, boiling water reactors, and cooling of the newer generation of electronics and computer systems, are all interested in the understanding and modeling of subcooled flow boiling.

The contributions from nucleate boiling and convective boiling during flow boiling are well recognized. As Kandlikar [1] recently stated, the nucleate boiling contribution is dependent on the heat flux in a manner similar to the pool boiling with an exponent of around 0.7; the convective boiling component being independent of the heat flux and varies with the mass flux. For large diameter tubes, the mass flux dependence was identified with an exponent of 0.8, which is in agreement with the turbulent single–phase flow relationship. The nucleate boiling component is adversely affected with an increase in quality, while the convective boiling term increases with quality due to the higher specific volume of vapor being produced.

A common practical problem which occurs during flow boiling of aqueous solutions in boilers and evaporators is the accumulation and deposition of unwanted solid materials on the heat transfer surface. This process is called *fouling* and many investigations devoted to this field of study up to now. Although, heat exchanger and membrane fouling has been extensively researched many fouling problems are still unresolved. Scale deposits are classified according to the physical and chemical processes that occur. Fouling occurring on the heat transfer surfaces of boilers and evaporators is usually a crystalline deposit caused by precipitation from solutions of mineral salts which have inverse solubility behavior. Since the thermal conductivity of these crystalline deposits is very low (typically 0.5–2 W/m °C), deposits of these salts will reduce the overall heat transfer coefficient, significantly [2]. Calcium sulfate is a dominant foulant in most industrial water

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