



Heat transfer mechanisms in pool boiling

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ARTICLE INFO

Article history:

Received 1 May 2013

Received in revised form 16 September 2013

Accepted 16 September 2013

Available online 13 October 2013

Keywords:

Pool boiling
Heat transfer
Natural convection
Nucleate boiling
Transition boiling
Film boiling

ABSTRACT

Pool boiling is a heat transfer mechanism carrying a phase transition from liquid to vapor. However, the exact characteristics of pool boiling are obscure because of the lack of the theoretical approach method. We have proposed a statistical thermodynamic heat transfer theory which is applicable to the heat transfer mechanisms of both conduction and internal convection. We here apply the heat transfer theory to pool boiling as an explicit illustration to understand the kinetics of phase transition mechanisms at the interface of two different phase materials. Three variable separation constants stand for particle number constants and play the key roles in exploiting the distinct boiling mechanisms. The theory accounts for the four boiling mechanisms of natural convection, nucleate boiling, transition boiling, and film boiling in pool boiling. It is able to match heat fluxes in wide ranges of temperature, time, and space. Particularly, the heat flux curve is sketched as a function of excess temperature between wall temperature and saturation temperature in the four regimes. Three limiting heat fluxes and four activation temperatures are employed as input parameters. Theoretical heat flux–temperature curves agree with experimental heat flux profiles in a significantly broader range of temperature than those from any existing theories.

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1. Introduction

A phase transition is a vital subject in science and engineering since it is central to matter in the universe. Heat transfer is a driving force for a phase transition which is the transformation of a thermodynamic system from one phase of matter to another.

Pool boiling heat transfer has recently had various applications in reactors, rockets, distillation, air separation, refrigeration, and power cycles. Boiling is a phase transition process of heat transfer whose area is undergoing accelerating expansion. However, the complicated characteristics of pool boiling remain incompletely understood. In this context, a systematically unified theory for heat transfer in non-equilibrium, quasi-equilibrium, and equilibrium has been proposed [1].

We here apply the heat transfer theory [1] to pool boiling to prove the validity of the theory and to understand the detailed characteristics of pool boiling. The theory has a close analogy to the statistical thermodynamic theory for electrochemical reactions [2,3]. It can exactly account for heat flux profiles for the four mechanisms of natural convection, nucleate boiling, transition boiling, and film boiling. In other words, the heat transfer theory produces heat fluxes in pool boiling as a function of temperature, time, and space in the whole range of boiling regimes.

Since the pioneering investigation by Nukiyama's experiment [4], heat transfer in pool boiling has attracted great attention, from an empirical approach to theoretical understanding of boiling phenomena. The four mechanisms in pool boiling have been observed. Several physical mechanisms have been proposed for heat transfer occurring during the saturated boiling process [5]: microlayer evaporation [6], reflooding transient conduction [7,8], natural convection [9,10], microconvection [11–13], and combined mechanism models [14,15]. Nevertheless, the heat flux as a function of temperature has not been theoretically evaluated with complete satisfaction. The heat flux in a wide range of temperature has been only determined experimentally since theoretical correlations are valid only in the narrow regimes they were developed for. Existing theories such as the Rohsenow equation in nucleate boiling [11] reflect the heat fluxes in a narrow temperature regime of boiling. They do not predict both the limiting heat flux and the activation temperature of different boiling regimes. They cannot demonstrate the S-shape behavior of heat flux versus excess wall temperature.

There is also a heat flux or temperature excursion at the initiation of nucleate boiling. The mismatch at the end of a natural convection regime and the inception of the nucleate boiling regime has been reported in Refs. [15–21] and an interpolation formula for the boiling curve has also been suggested by Bergles and Rohsenow [22]. Therefore, the reason for the mismatch deserves to be an important issue in understanding boiling, and a rigorous approach is required to clarify this phenomenon.

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