Applied Thermal Engineering 36 (2012) 21–31

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Theoretical study on the characteristics of critical heat flux in vertical narrow rectangular channels

D.X. Du [a], W.X. Tian [a], G.H. Su [a,*], S.Z. Qiu [a], Y.P. Huang [b], X. Yan [b]

[a] State Key Laboratory of Multiphase Flow in Power Engineering, Department of Nuclear Science and Technology, Xi'an Jiaotong University, Xi'an 710049, China
[b] Key Laboratory on Nuclear Reactor Thermal Hydraulic Technology, China National Nuclear Corporation, Chengdu 610041, China

ARTICLE INFO

Article history:
Received 5 April 2011
Accepted 19 November 2011
Available online 28 November 2011

Keywords:
Annular upward flow
Critical heat flux
Vertical narrow rectangular channel

ABSTRACT

A mathematical separated flow model of annular upward flow has been developed to predict the critical heat flux (CHF) in uniformly heated vertical narrow rectangular channels. The theoretical model is based on fundamental conservation principles: the mass, momentum, and energy conservation equation of the liquid film and the momentum conservation equation of the vapor core together with a set of closure relationships. The comparisons between the theoretically predicted results and the experimental data demonstrate that a good agreement between them has been achieved. With the applications of the present model, the influences of several parameters (such as system pressure, inlet mass flux and channel size) on the CHF in rectangular channels are analyzed, and the CHF is compared with that in annular channels.

1. Introduction

The study on the compact heat exchanger has become one of the major tasks and has been paid significant attention to due to its notable characteristics, such as high heat transfer efficiency, small size, lightweight and good flexibility, recently. One of the simplest compact heat exchangers is the narrow rectangular channel type, which has been applied in the nuclear reactor cores with plate fuel elements, new generation of steam generators, compact heat exchangers and the electronic component coolers. In the vertical upward channel, there are several changes from inlet to exit in the flow pattern of coolant [1]. It is easy to form vapor slug due to the accumulation of bubbles in the narrow channel, and annular flow is one of the primary flow patterns. The liquid film thickness of annular flow will decrease with the comprehensive effects of vaporization of the liquid film, deposition and entrainment of droplets. When the liquid film thickness decreases to a certain value, the surface temperature will rise suddenly due to the decrease of heat transfer coefficient, and then boiling crisis will occur. Boiling crisis occurring in an annular flow is called dry-out, and the heat flux just before dry-out is called critical heat flux (CHF) [2]. Critical heat flux is a crucial design limitation for the safe operation of heat dissipation applications. At the dry-out point, the rapid increase of wall temperature will lead to slow burnout of some equipment. In the narrow rectangular channels, the bubble shape in the flow regimes before annular flow will be restricted by the thin gap. The liquid film distribution along the channel circumference is non-uniform due to the liquid accumulation around the corners in annular flow. The two-phase flow and heat transfer mechanism and the characteristics of the critical heat flux in narrow rectangular channels may be different from those in circular tubes or general large ducts. Thus, it is important to study the characteristics of critical heat flux in vertical narrow rectangular channels for the engineering application and the safety of compact heat exchanger, which takes the narrow rectangular channel as its heat transfer tube.

Many experiments have been performed on the CHF in rectangular channels, and several empirical CHF correlations have been presented [3–7]. Empirical correlation is a convenient method to predict the CHF. However, the empirical correlation is available only for the specific flow configurations and operation conditions. When a correlation is applied to conditions beyond those for which it was originally developed, the prediction may be inaccurate. In view of this, several models, such as Utsuno et al. [8] and Celata et al. [9], have been developed to theoretically calculate the CHF in flow boiling tubes. Although good agreements of predicted CHF with experimental data were reported, it turns out that they over predict the CHF for short tubes and several factors in these models are need to be adjusted to achieve a better agreement. In addition, these models were built based on the geometrical characteristics of round tubes or annular channels. Only a few studies in the open literature have been reported on the CHF in rectangular gaps.

* Corresponding author. Tel./Fax: +86 29 82663401.
E-mail address: ghsu@mail.xjtu.edu.cn (G.H. Su).

1359-4311/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2011.11.039