Annals of Nuclear Energy 50 (2012) 103–110

Contents lists available at SciVerse ScienceDirect

Annals of Nuclear Energy

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

Experimental study of two phase flow instability in parallel narrow rectangular channels

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ARTICLE INFO

Article history:
Received 15 December 2011
Received in revised form 28 May 2012
Accepted 1 July 2012
Available online 21 September 2012

Keywords:
Density wave oscillation
Rectangular channel
Experimental study
Flow instability

ABSTRACT

Two phase flow instability in narrow rectangular channels has been studied experimentally. The test section consisted of one unheated by-pass and two heated rectangular channels, 1000 mm in length and having 25 mm × 2 mm cross sections. Various phenomena, in parallel channels, were studied in detail, from onset of flow instability (OFI) to density wave oscillation. The experimental results show that as the two heated rectangular channels operate past OFI, with a constant pressure drop, an increase in power can result in a sharp decrease in the mass flow rate. Following a continued increase of power, density wave oscillation occurs between the parallel channels. Concurrently, the effects of various conditions including operating system pressure, inlet subcooling number, and mass flow rate on the threshold of instability are presented. The stability boundary map of Density wave oscillation (DWO) is obtained through the use of the dimensionless subcooling number (N_{sub}) and phase change number (N_{pch}).

1. Introduction

Increasing numbers of high-tech heat exchangers are based on heat transfer of a boiling liquid flowing through narrow channels. Narrow channel heat transfer enhancement techniques exhibit great advantages such as small temperature difference, high heat transfer efficiency and compact configuration, without complex machining or additional surface processing. Some research reactors with narrow channel heat exchangers have exhibited susceptibility to thermal–hydrodynamic instabilities, which could induce boiling crisis, disrupt control systems, or cause mechanical damage. Flow instability characteristics play an important role in the security and reliability of these types of equipment.

Since the 1950s, with the beginning of the commercialization of nuclear reactors, the interest in two phase flow instability studies started to grow internationally. Boure et al. (1973) held that the flow instabilities in parallel channels could be classified into two types; namely static instabilities (e.g. Ledinegg type) and dynamic instability (e.g. density-wave). The latter type, particularly density-wave, has been adopted to describe flow oscillation as a result of multiple regenerative feedback loops between the flow rate, vapor generation rate, and pressure drop. Since then, this classification and the mechanism of density-wave have come to be widely used. Ishii (1976) studied instabilities with constant pressure drops. Fukuda and Kobori (1979) studied both low (type I) and high steam quality (type II) density wave instabilities for both natural and forced circulation.

Malankin (l996) studied flow instability during forced circulation in Plate Type fuel assemblies of pool research reactors. The Ledinegg type instability boundary was obtained in his study. Chang (1996) studied the onset of flow instability in vertical, uniformly heated thin rectangular channels. Kennedy et al. (2000) investigated OFI in uniformly heated micro channels using subcooled water flowing through 22 cm tubular test sections, which generated demand curves utilized for the specification of OFI points. Hamidouche et al. (2009) developed a simple model based on steady state equations, adjusted with drift-flux correlations, to determine OFI. Mochizuki (2001) investigated the threshold of DWO beyond the dryout conditions of boiling channels with constant flow rate. Two channels were tested in his study and the prediction capability of thermal hydraulic code was also partially validated by the experimental results. Noriyuki et al. (2003) investigated natural circulation flow instability in vertical parallel channels under low pressure. DWO heat flux threshold was presented in that study and It was indicated that the oscillation was related to the system pressure, inlet subcooling and channel length. Li (2005) studied the effects of pressure, mass flow, inlet subcooling, inlet and outlet throttling and volumetric compressibility on density wave oscillation in multi-channels.

When two phase flow instability occurs, similar phenomena might be found whatever the hydraulic diameter size.

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http://dx.doi.org/10.1016/j.anucene.2012.07.001

Nomenclature

Cp	fluid heat capacity (J/(kg °C))
ΔT_{sub}	subcooling (°C)
ρ	density of fluid (kg/m^3)
Q	heat input (kW)
q	heat flux (kW/m^2)
h	enthalpy (J/kg)
w	mass flow rate (kg/s)
G	mass flux (kg/m^2*s)
N_{sub}	subcooling number
N_{pch}	phase change number

Subscripts

g	vapor
in	inlet
l	liquid
OFI	onset of flow instability

Nevertheless, when decreasing the hydraulic diameter, some differences may exist. In a narrow channel the vapor growth phase is limited in the narrow direction. Only the large direction allows vapor growth when boiling occurs. As a result there can be some differences observed in the physical processes when compared to large hydraulic diameter systems. The study of flow instability in narrow channels is an important part of the safety operation for these equipments.

On the basis of previously obtained experimental results and despite extensive studies have been undertaken during the last several decades on the subject of density wave oscillation, only limited data can be found on this phenomenon in parallel narrow rectangular channels. Therefore, an experimental study of flow instability in narrow rectangular channels boiling flow system has been undertaken in order to obtain well-controlled experimental data which could be used for verification of analytical methods devised to predict the stability boundary. The experimental section consists of two heated rectangular channels and a bypass, with water as operating fluid.

In this work, we will describe the following experimental apparatus and present the experimental results: the phenomenon on onset of flow instability in parallel channels, the density wave oscillatory behavior, and the effects brought upon the stability boundary by changing the operating variables.

2. Experimental apparatus

2.1. Test loop

The schematic diagram (Fig. 1) describes a two phase flow loop, with a maximum pressure capability of 15 MPa. Water is used as the test fluid. The test loop consists of a pump, a preheater, a pressurizer, flowmeters, test sections, a condenser, a subcooler, and some valves. A steam-water pressurizer is used to control the system pressure. There is a flowmeter at the inlet of each channel to obtain the inlet flow rate. Appropriate instrumentation is installed to provide control and measurements of the test parameters, namely, flow rate, pressure, and temperature at various locations and the electrical heat input.

2.2. Test section

The geometry and dimensions of the test section are presented in Fig. 2, which gives details of the narrow rectangular channel's cross section. Each test tube is 1000 mm long and has 25 mm × 2 mm cross section. A Direct Current heating element is applied, along the wall of constant thickness, to provide an essentially uniform heat flux. The bypass tube is made of stainless steel with outer and inner diameters of 32 mm and 25 mm respectively.

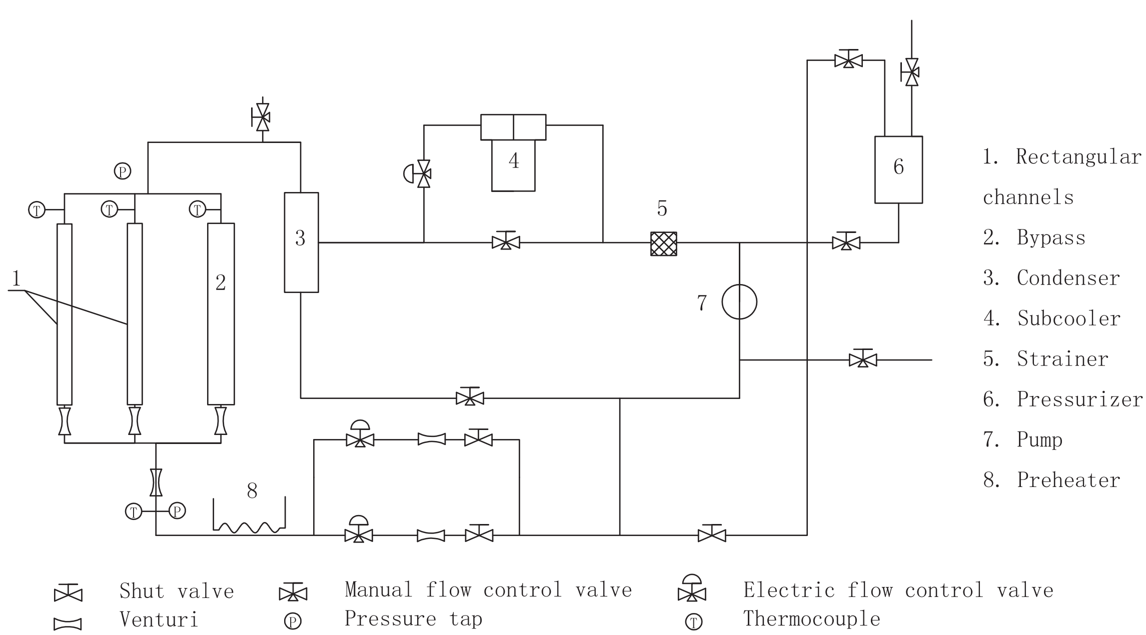

Fig. 1. Scheme for experiment loop.