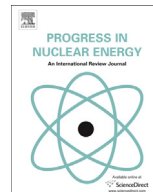




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Experimental study on Ledinegg flow instability of two-phase natural circulation in narrow rectangular channels at low pressure

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ABSTRACT

Ledinegg flow instability of two-phase natural circulation has been experimentally investigated based on a natural circulation device with narrow rectangular channels. When heating power reaches a certain range, the Ledinegg flow instability occurs in the system, accompanied by flow oscillation. The stability of the experimental system increases with the increasing of inlet sub-cooling, pressure and size of rectangular channels. Stability boundaries of the system are obtained by the sub-cooling number and the phase change number. It is discovered that there are 4 stages of Ledinegg flow instability in the narrow rectangular channels: condensation, ebullition, choking, and rebalance. Finally, the experience correlation is proposed for the initial power of Ledinegg flow instability in narrow rectangular channels.

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1. Introduction

As an important energy for the development of human beings, the security of nuclear energy has attracted much attention. Natural circulation (Jiang et al., 1995; Tao et al., 2016), does well in mitigating reactor accidents, which can improve the inherent safety of a nuclear reactor. However, the Ledinegg flow instability occurs at some certain conditions, limiting the range of some reactor parameters. Hence, it is essential to investigate the characteristics of Ledinegg flow instability in natural circulation.

The Ledinegg flow instability is an important part in the research of reactor thermal hydraulics. Ledinegg (1938) first investigated this static flow excursion which is called Ledinegg flow instability. It was presented that this instability deviates from its original equilibrium state and then reaches a new balanced state under new operating conditions. The Ledinegg flow instability in natural circulation is a new research direction in the study of two-

phase flow, and some researchers have investigated this phenomenon based on theory and experiments. Ick Soo Kyung (Soo Kyung and Yong Lee, 1996) investigated Ledinegg flow instability in an open two-phase natural circulation loop. At high inlet subcooling, periodic circulation appears at different heat flux conditions. M. Furuya (Furuya et al., 1996) conducted experiments to investigate flashing-induced density wave oscillations in natural circulation, and mechanism of instability and stability map were obtained. JIANG Shengyao (Shengyao and Youjie, 2000; Xingtuan and Shengyao, 2002a, 2002b) point out that the Ledinegg flow instability accompanied with flow oscillation phenomenon under certain conditions is observed in the heating reactor test loop of the 5 MW reactor. KUANG Bo (Jijun and Bo, 2000; Bo and Hong, 2005) predict the Ledinegg flow instability of two-phase natural circulation based on homogeneous model and nonlinear bifurcation theory. The above researchers are focused on circular channel in natural circulation system. The heat transfer capability of the narrow rectangular channel is 1.3–2.1 times of that in conventional channel (Liangming et al., 2002). Due to this characteristic, the advanced reactors and research reactors (Tiancai et al., 2006) adopt this channel.

For the rectangular channel, some preliminary research has

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been presented (Tao et al., 2013a, 2013b). However, natural circulation flow in narrow rectangular channel which can be influenced by bubbles and flow patterns is complex. Hence, it is necessary to further investigate the characteristics of the Ledinegg flow instability in narrow rectangular channel based on experiments.

2. Experiment system

2.1. Experimental facility

Fig. 1 shows the experiment facility which is used to investigate the Ledinegg flow instability. It consists of a preheater channel, a rectangular heater channel with a visible window, a condenser, and a descending channel. The deionized water is used as fluid medium, flowing through preheater channel, rectangular heater channel and condensed channel which is driven by the fluid density difference. Twelve heating elements are evenly arranged on the rear part of the experiment channel and the maximum power of each heating element is 2.5 kW. There is a uniform heat flux distribution along the experiment channel. The condenser is to cool water in natural circulation system which can maintain an appropriate temperature of inlet water in experiment channel. The flow rate of natural circulation system is measured by a turbine flowmeter with a tolerance of ± 0.001 L/min and the pressure is balanced by a pressure stabilizer. The temperature is measured by sheathed thermocouples, and the measurement accuracy is $\pm 0.25\%$. There are 20 uniformly distributed test points on the heating wall. Additionally, there are 2 temperature test points installed at the inlet and outlet of the experimental channel to measure fluid temperature.

2.2. Visual experiment channel with narrow rectangular slit

Fig. 2(a) shows the cross-section of visual experimental channel with narrow rectangular slit. Fig. 2(b) shows the three-dimensional view of the experimental channel. The size is $2\text{--}5\text{ mm} \times 40\text{ mm}$, and the length is 1 m. One side is heating surface made of stainless steel, and the other side is a visual window with quartz glass. The flow medium is observed through the quartz glass. The maximum effective heating power can be adjusted continuously between 0 and 30 kW.

2.3. Measurement device

Fig. 3 shows the measurement device of experiment channel with a narrow rectangular slit. From the entrance to the exit of the

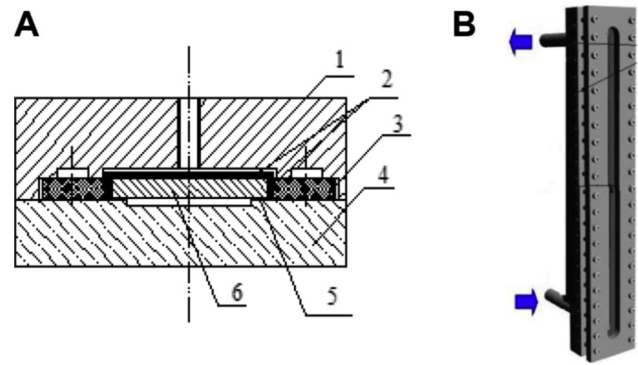


Fig. 2. a Cross-section of experimental channel. b Three-dimension channel.

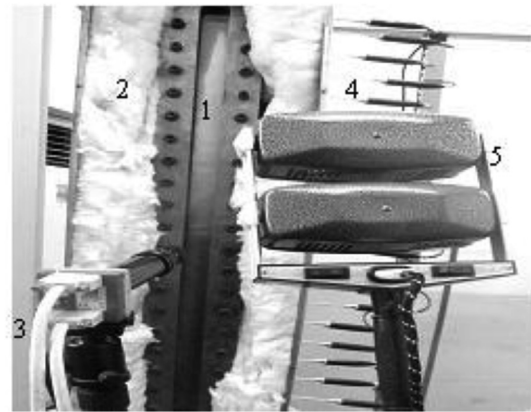


Fig. 3. Measure device of experiment channel.

experiment channel, 20 temperature thermocouples which are used to transfer the collected temperature signals to the data acquisition unit, are installed on the side of the metal heat surface. The behavior of flow medium in experiment channel is recorded by high speed camera whose maximum frame frequency is 1000. The behavior of bubbles and change of flow patterns can be quickly captured in the experiment channel. The instruments used in this experiment along with their errors are shown in Table 1. Based on this table, the relative errors of calculation have been shown below.

(1) Temperature t , obtained by thermocouples and data acquisition instrument, has a relative error as shown below:

$$\frac{\delta t}{t} = \sqrt{0.25^2 + 0.12^2} = 0.27\%$$

(2) Flow rate G , obtained by a turbine flowmeter and data acquisition instrument, has a relative error as shown below:

Table 1
Instruments and errors.

Parameter	Name	Model	Range	Errors
Pressure	Pressure transmitter	HSLT-P	0–6.0 MPa	0.25%
temperature	Thermocouple	WRNK101	0–600 °C	0.25%
Volume flow	Turbine flowmeter	LW-10	0–600 L/H	0.2%
Voltage	Voltmeter	HC-300/C	0–380 V	0.2%
Current	Ammeter	T23-A	0–5 A	0.2%
Data	Data acquisition instrument	KPCI-1813		0.1%

Fig. 1. Experimental facility of natural circulation system.

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