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Comparison of flow instabilities under static condition and marine motion conditions based on experiments

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An experimental investigation was performed on two-phase flow instability with twin parallel rectangular channels under static condition and marine motion conditions. Marine motion conditions include inclination, fluctuation and rolling. The maximum inclination angle is 45°, maximum amplitude and acceleration of fluctuation are 0.8 m and 1.9 m^2/s, respectively; maximum amplitude and angular acceleration of rolling are 30° and 0.5 rad/s^2, respectively. Test thermal parameters are 3–8 MPa for pressure, 300–700 kg/m^2s for mass velocity, and 15–90 °C for inlet subcooling in this experiment. Comparisons have been made on four aspects: (1) general observation of flow oscillation; (2) period of flow oscillation; (3) flow instability boundary heat flux; (4) flow instability zone under static condition and motion conditions. Contrary to what is observed under static condition, the flow oscillation under motion conditions is actually the superposition of thermal-induced oscillation and motion-induced oscillation. But further comparison indicates that the influence of marine motion conditions on flow stability is very limited. In general, the period of oscillation, flow instability boundary heat flux and distribution of instability zone are much more affected by thermal parameters than the motion conditions and the point to point comparison shows that the differences of boundary heat flux brought by motion is no more than ±5%. Finally, an empirical formula considering a pressure correction is correlated based on experimental data, which is applicable for the prediction of the instability boundary under both static and motion conditions.

1. Introduction

In recent years, ocean transportation, energy exploration and scientific investigation become popular, which makes it necessary for quick development of the shipbuilding technology. A number of new inventions were applied in modern ships, among which, marine nuclear reactor is one of the most successful facilities. The amazing power and long reload cycle of reactor guarantee the feasibility of long-distance navigation of ships. Different to land-based nuclear reactor, marine reactor normally works in an atrocious ever-changing ocean environment. During the voyage, ships constantly change the movement according to the conditions of wind and sea wave. Although the movement of ships is very complicated, the typical marine motions could be decomposed of inclination, fluctuation and rolling.

Two-phase flow oscillation is a common thermal hydraulic phenomenon in thermal equipments, which could cause mechanical vibration, reduce critical heat flux (CHF) and bring some control problems to the operation of nuclear reactor. It's very dangerous to have two-phase flow oscillation in the channels of reactor. For a marine nuclear reactor, motion conditions may affect the two-phase flow instability in the core or other thermal equipments based on the following reasons. First of all, part of pressure drop of flow changes under motion conditions and two-phase flow oscillation is generally believed to be dependent on the pressure drop of flow. For example, on inclination the gravitation pressure drop of flow is reduced. Under fluctuation and rolling, the total pressure drop experiences transient changes. Second, periodical marine motion could induce periodical flow oscillations, this kind of flow oscillation may couple with the thermal-induced flow oscillation and change the characteristics of two-phase flow oscillation in some way.

A number of researchers have experimentally investigated the influence of ocean condition on general hydraulic thermal phenomena. Isshiki et al. (1966) studied the effects of heaving and listing upon thermal–hydraulic performance and critical heat flux of water-cooled marine reactors. In the experiment, burn-out was observed in two simplified atmospheric models of marine water-cooled reactor core-loops on which cyclic heaving motions and constant listing were applied by a heaving apparatus. The critical heat flux decreases linearly with increasing heaving acceleration,

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Nomenclature

A_f	flow area, m^2	in	inlet
A	amplitude, m/°	fg	vaporization
h	enthalpy, kJ/kg	b	boundary parameters
N	nondimensionless number	pch	phase change number
G	mass velocity, kg/m^2s	sub	subcooling
P	pressure, MPa		
q	heat flux, kW/m^2	*Greek*	
t	time, s	β	angular acceleration
X	displacement	ψ	density, kg/m^3
		ρ	phase angle, rad
Subscript		τ	period, s
F	channel cross section	ω	angular frequency, rad/s
g	gas	Δ	difference of two parameters
H	heating		

and is accompanied by violent cyclic fluctuations of void and flow velocity when the inlet flow velocity is low.

Murata et al. (1990) studied the natural circulation of ship reactor under rolling condition in stormy weather. The results indicated the flow rate of each loop oscillated with the change of rolling angle in natural circulation.

Ishida et al. (1995) investigated the influence of ocean condition on the natural circulation of marine reactor DRX. Two-phase flow oscillation appeared in reactor when the power rise to 210% of rated value. And flow oscillation could occur under lower power level if the void fraction of coolant in reactor core is very large. Further more, a superposition of density-wave oscillation and fluctuation induced oscillation has been found in experiments, which made the flow oscillation more violent.

Some researchers investigated the two-phase flow oscillation in parallel channels and the influence of ocean condition on thermal hydraulic phenomena theoretically. Ishida and Tomiai (1992) developed Retran-02/GRV to simulate the transient thermal-hydro-dynamics behavior of the single phase and two-phase natural circulations.

Guo et al. (2008) studied the influence of ocean condition on flow instabilities in a multi-channels system. The mathematical model in this study was proposed based on Lee and Pan's method (1999). This study indicated the typical ship motion under ocean condition indeed has some effect on flow instability zone. Besides, nonlinear dynamics analysis was made on flow oscillation and the chaos was found in multichannel system under rolling condition.

Lu et al. (2014) theoretically investigated two-phase flow instability in parallel channels heated by axial non-uniform heat flux.

Although the study on two-phase flow oscillation is abundant, experimental study on the influence of ocean condition on two-phase flow instability is scant. This paper is aimed to find the influence of ocean condition on two-phase flow oscillation by comparative experiments of two-phase flow instabilities separately under static and marine motion conditions in twin parallel rectangular channels.

2. Experimental apparatus and method

Experimental apparatus including test loop, test section and motion platform is simply introduced here and the experimental procedure is described.

2.1. Test loop

A schematic of the boiling loop used in this study is shown in Fig. 1. It is a closed cycle loop with maximum pressure capability as 16 MPa. The pressure of the loop was stabilized by a pressurizer with nitrogen charged in its upper space.

Demineralized and degasified water was chosen as the operating fluid. It was fed into the boiling loop by a plunger pump. Two gas regulate valves, installed separately on the bypass (GV1) and the test branch (GV2), controlled the flow rate through the test section. A direct electrical-heating preheater was used to regulate the liquid temperature at the inlet of the heated test section. Two-phase mixture flowing out of the test section was chilled by a heat exchanger, where the temperature of fluid could be condensed to below 40 °C.

2.2. Test section

The test section was composed of two 1000 mm long, parallel rectangular channels made of 0Cr18Ni10Ti stainless steel plate with a cross section of 50 mm × 2 mm (Fig. 2). Each side of the heating plate had the same thickness of 3 mm.

The roughness of the heating plate was less than 3.2 μm. The test section was heated by a direct DC power supply and a chamfered edge was designed to avoid an excess of heating in the edge of channels. Because of the constant wall thickness of the channels, the heat flux is essentially uniform.

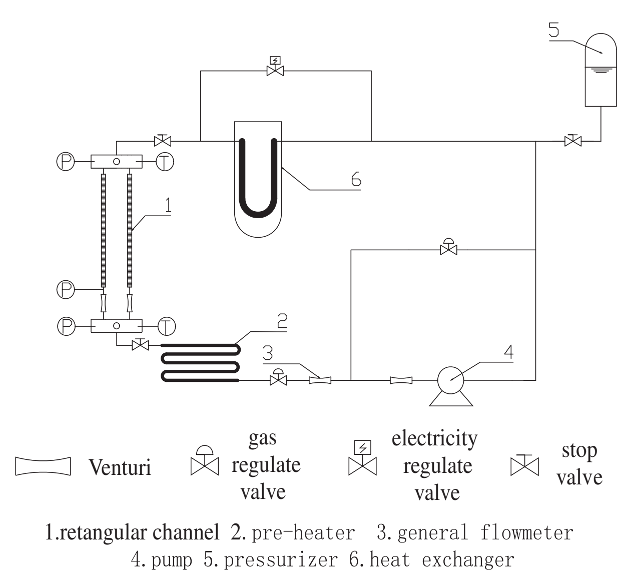

Fig. 1. Schematic diagram of test loop.