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The analysis of density wave oscillation in ocean motions with a density variant drift-flux model

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ABSTRACT

The two-phase flow instability in heated channels is an important phenomenon in industrial facilities. The effect of ocean motions upon the flow instability should be predicted accurately for the heat exchangers in floating platform. The reduced order model with drift-flux approach is developed to analyze the density wave oscillation in a uniformly heated channel in ocean motions. The density variation of coolant flow is considered. The stability maps can be predicted precisely on experimental data. The effect of ocean motions on the stability boundary is investigated quantitatively by the defining of the degree of instability. The subcritical Hopf bifurcation in ocean motions is also studied.

1. Introduction

The stability of two-phase flow in a uniformly heated channel is important in several industrial domains like refrigeration systems, turbo-machinery, boiling water reactors, solar steam generating systems and two-phase flow heat exchangers [1]. In the case of a reactor or a heated channel in a floating platform, the ocean motions could introduce an additional force to the system and induce the periodical fluctuation of primary coolant in the reactor core and destroy system stability. Therefore, it is important to clarify the effect of ocean motions upon the two-phase flow instability.

In nuclear reactors and thermal systems operated in high pressure, density wave oscillation (DWO) is observed most frequently. It is found that the marginal stability boundary (MSB) of regular complex flow oscillation is similar to that of the DWO in stationary state. The influence of rolling parameters on the MSB is not significant [2,3]. The models of two-phase flow instability between multi-channels (FIBM) in ocean motions were developed and used to obtain the instability oscillating trajectories of multi-channel systems. The instability zone of a nine-channel system in rolling motion was also analyzed and it was found that some of the trajectories showed chaotic characteristics [4]. Then these scholars analyzed the complex curve of mass flow with Fast Fourier Transformation (FFT) method and analyzed the onset of inherent parallel-channel instability [5]. A parallel nine- channel model in rolling motion was established based on homogeneous flow model [2]. The marginal stability boundary in rolling motion in that model was obtained numerically. It was observed that the unstable regions occurred in both low and high equilibrium-quality regions. In high equilibrium-quality region, the multiplied period phenomenon was observed and the chaotic phenomenon appeared on the right of marginal stability boundary. The flow instability of forced circulation in a mini-rectangular channel in rolling motion was also investigated experimentally [6].

Some researchers found that the flow oscillation in ocean motions was the superposition of thermal-induced oscillation and motion-induced oscillation [7]. It was found that the difference of boundary heat flux induced by ocean motions was not significant by comparing experimental results in stationary states and ocean motions. The instability was mainly affected by thermal parameters rather than ocean motions. An empirical formula which was capable of predicting the instability boundary under both static and motion conditions was also summarized. Shen et al developed a lumped model of flow instability in parallel-rectangular channels in heaving motion [8]. Their results indicated that heaving amplitude contributed slightly to the flow instability, which was in agreement with the results of [3,7]. It was also found that the threshold power was decreased as the heaving frequency which was next to the system characteristic frequency.

Until now, the numerical investigations for the two-phase flow instability in ocean motions were mainly carried out with time domain method and homogeneous equilibrium model (HEM) [9]. A one-dimensional HEM was used as the basis for the development

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Nomenclature

a	phase variable for single-phase enthalpy
C_0	void distribution parameter
D	channel diameter
g	gravitational acceleration
Fr	Froude number
h	coolant enthalpy
Δh_{fg}	latent heat
k	loss coefficient
L	channel length
N_f	Friction number
N_{pch}	phase change number
N_{sub}	Subcooling number
ΔP	pressure drop
q_w	heat flux
s	phase variable for two-phase quality
u	velocity
v_{gj}	drift velocity
x	vapor quality

Greek letters

ε	perimeter
μ	onset of boiling
ρ	density

Superscripts

–	dimensionless parameter

Subscripts

1ϕ	single-phase
2ϕ	two-phase
acc	acceleration
$exit$	channel exit
ext	external
f	liquid
g	vapor
m	mixture
r	reference

of a nodal model of a boiling channel. Then it was found that the simple model yielded a rich variety of nonlinear phenomenon [10]. This moving nodes model was also introduced by Bertodano et al in the analysis of the occurrence of sustained oscillations under operating conditions close to the linear stability margins [11]. However, it is known that HEM may not be useful to low flow rate conditions. Therefore, this approach was extended by Dokhane using drift flux model (DFM) [12]. Although these models predict the stability characteristics of the system having good agreement with experimental data sets [13], the analysis is difficult due to the large and tedious form of the set of coupled ordinary difference equations [14]. Besides that, the single-phase density of the coolant flow is considered to be constant (saturation density) in many aforementioned studies. Due to the fact that the density of a subcooled liquid is a function of temperature and enthalpy in these kinds of isobaric systems, it arises a discrepancy between the accounted density and actual density, which results in an unsatisfactory agreement between experimental data and numerical results. Therefore, the density variation should be included to improve the accuracy of prediction.

According to the Liapunov theorem [15], the stability of a linearized system corresponds to the stability of the nonlinear system operating under quasi-equilibrium conditions. Therefore, the analysis with reduced order model with linearization analysis in quasi-equilibrium conditions is satisfactory. In this work, the DWO in a uniformly heated channel in ocean motions is investigated by using reduced order model. This model does allow a deep insight into the complex processes determining two-phase flow instability, and provides a valuable tool for fast and detailed semi-analytical bifurcation analysis [12,14,16]. This is helpful for the analysis of two-phase flow instability in ocean motions in the future. The density variant drift flux equations were introduced to correlate the two-phase properties. The simulation results were validated with experimental data and some valuable results were obtained and analyzed.

2. Theoretical models

2.1. Flow channel and assumptions

The analyzed system is a uniformly heated channel, as shown in Fig. 1, which is identical to the test section designed by Saha [13], for the convenience of validation with experimental data. The

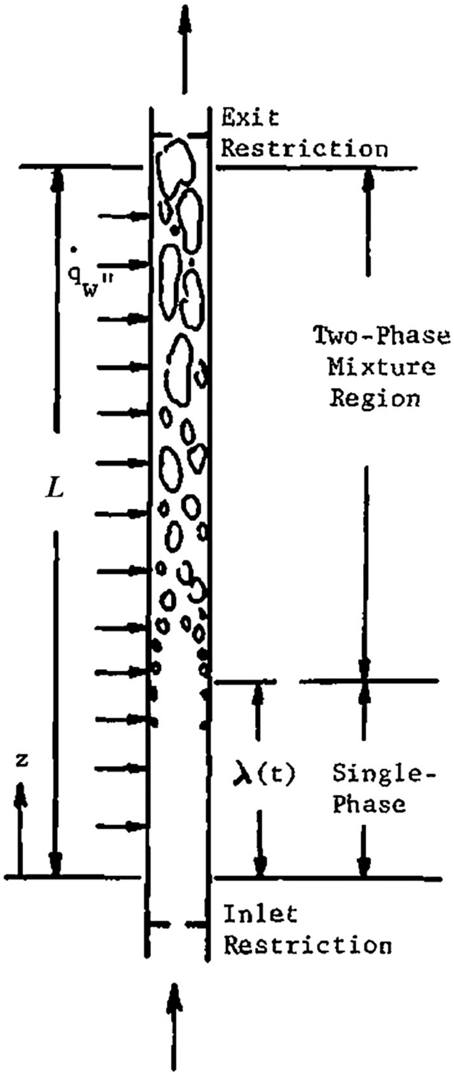

Fig. 1. Schematic of the uniformly heated channel [11].