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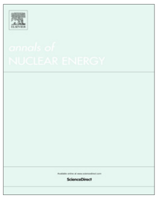

Numerical simulation of external inertia and compressibility effects on the dynamic instabilities of two-phase boiling flows in horizontal parallel channels

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Density wave oscillations and pressure drop oscillations are investigated numerically in two horizontal parallel channels using lumped parameter model assuming a homogeneous two-phase flow model. In this study the effects of external parameters, such as fluid inertia and compressible gases on the stability margins and transient behaviors of parallel channels system are analyzed. The results show, that the fluid inertia and compressible gases have high impact on the stability margins of two parallel channels; in fact, increasing the inlet inertia and outlet compressibility will increase the system stability while increasing the outlet inertia and inlet compressibility decrease its stability.

1. Introduction

It is well known that two-phase flow instabilities can introduce operational and safety problems to systems and components of great importance, such as nuclear reactors, liquid rocket engines, heat exchangers, steam generators, evaporators, and various chemical process units. To avoid the occurrence of these highly undesirable events, it is necessary to be able to predict accurately the onset of flow instabilities in such systems in terms of design parameters and operating conditions.

The thermo-hydrodynamic instabilities occurring in a boiling channel are divided in static and dynamic. The behavior of the static instabilities can be predicted from the steady-state conservation laws. On the other hand, in order to describe dynamic instabilities it should consider different dynamic effects, such as the propagation time, the inertia, compressibility, etc. In addition, the term compound instability is normally used when several of the basic mechanisms, interact with each other.

Different thermal–hydraulic system instabilities have been observed in two phase systems. Among the static instabilities, the most widely known is the Ledinegg type instability. Two main modes of dynamic instabilities, and widely studied are density wave oscillations (DWO) and pressure drop oscillations (PDO).

In the Ledinegg instability (1938) a sudden change in the flow rate to a lower value happens. It occurs when the slope of the channel demand pressure-drop versus flow rate curve (internal characteristic curve) is negative and steeper than the loop supply pressure-drop versus flow rate curve (external characteristic curve).

The density-wave oscillations are the most common type of instabilities encountered in practical systems, consequently, density-wave instability has been analyzed extensively. This instability is the result of multiple feedback effects of between the flow rate, the vapor generation rate and the pressure drop in the boiling channel system (Kakac and Bon, 2008)

Pressure-drop instability happens (like the Ledinegg instability) when the pressure drop across the channel decreases with increasing flow. This instability is actually compound instabilities, because it is a dynamic instability triggered by a static instability (flow excursion). This type of instability needs in order to happen a compressible volume upstream, or within, the heated section.

According to Fig. 1, the mechanism of pressure drop instability can be explained. When the slope of the channel demand pressure-drop versus flow rate curve (internal characteristic curve) curve (P2(Q1)) is more negative than loop supply pressure-drop versus flow rate curve (external characteristic curve) (P2(Q2)), the oscillatory behavior can happen. If the two curves (P2 vs. Q1 and P2 vs. Q2) are intercepted where the slope of internal characteristic curve is more negative than the slope of external characteristic curve, a

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Nomenclature

A	coefficients of equations
B	coefficients of equations
$b_1 - b_9$	coefficients of equations
C	coefficients of equations
De	hydraulic diameter (m)
G	mass flux (kg/(m^2 s))
G_0	reference mass flux
H	enthalpy (J/kg)
h_{fg}	latent heat of evaporation (J/kg)
K	local throttling coefficient
L	length of channel (m)
f	Darcy–Weisbach friction factor
P	pressure (Pa)
Q	power (W)
q	HEAT flux (W/m^2)
S	cross sectional area (m^2)
t	time (s)
U	velocity along the channel (m/s)
V	specific volume (m^3/kg)
W	mass flow rate (kg/s)
X	quality
x, y, z	Cartesian coordinate

Greek symbols

α	void fraction
γ	ratio of vg to vf
ζ	coefficient of equations
η	coefficient of equations
θ	angle
λ	boiling boundary
ΔP	pressure drop (Pa)
ΔT_{sub}	inlet subcooling (°C)
Π	coefficients of equations
ρ	density (kg/m^3)

Superscripts

+	dimensionless
–	average
–	average

Subscripts

0	reference
1φ	single phase
2φ	two phase
acc	acceleration
E	entrance
Ex	exit
f	saturated
f	frictional
h_{fg}	the difference between saturated vapor and liquid properties
g	saturated
H	heating section
in	inlet parameter
j	the jth channel
si	inlet surge tank
so	outlet surge tank

Dimensionless groups

$N_{pch} = Q.v_{fg}/(W.h_{fg}.v_f)$ Phase change number
$N_{sub} = (h_f - h_{in}).\ v_{fg}/(h_{fg}.v_f)$ Sub cooling number

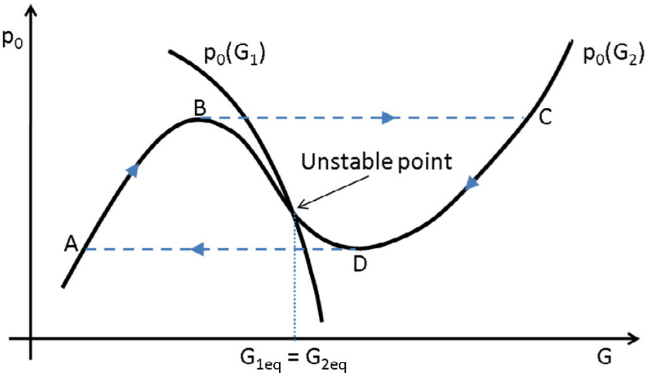

Fig. 1. Schematic of the system modeled.

small increase in P2 will cause Q2 to decrease more than Q1. This will make the level in the surge tank to rise and P2 will increase further. Because in this situation the system cannot be statically stable and there are no stable points in the interception of the two curves, the system will follow the limit cycle delimited by ABCD shown in Fig. 1.

Stability can be influenced by geometric and operating parameters. So, in order to study accurately the phenomena of two-phase flow instabilities, these effective parameters should be recognized. The effective parameters can be classified into two groups; internal and external parameters. Internal parameters are directly related to the heating section, such as operating pressure, heat flux and mass flow rate but external parameters are the parameters of auxiliary systems beside the heating section, like the inertia effects of external pipings, compressibility of surge tanks and pump characteristics.

Many experimental, theoretical and numerical studies have been performed in the area of two-phase flow instabilities in parallel channels but most of them only analyze the effect of internal parameters. For the case of internal parameters, recently, Libo et al. (2014) numerically analyzed density wave oscillations in parallel channels with a lumped mathematical model based on homogenous hypothesis. They examined the effects of the operating pressure P, inlet throttling coefficient, asymmetric heating and throttling, kin and exit throttling coefficient, kout on the stability margins of parallel channel system.

Very few studies consider the effect of external parameters on the two-phase flow instabilities. Maulbetsch and Griffith (1966, 1967), investigated PDOs in a single boiling channel. They found the frequency of the oscillations, after a linearization of the lumped parameters equations, is mainly proportional to the volume of the surge tank and the inertia of the flow.

In Schlichting et al. (2010), the pressure-drop oscillations (PDO) and density-wave oscillations (DWO) for a typical NASA type phase change system are investigated. The transient lumped parameter model, based on a homogenous equilibrium model (HEM), is considered. After a linearization, it is found that, the surge line inertia and the heated channel inertia have the same role in the system response. Indeed they have proved that external inertia can influence the system stability behavior. The other important result of this study, indicates that the dynamic models can predict the