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Review

Two-phase flow instabilities: A review

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ABSTRACT

An updated review of two-phase flow instabilities including experimental and analytical results regarding density-wave and pressure-drop oscillations, as well as Ledinegg excursions, is presented. The latest findings about the main mechanisms involved in the occurrence of these phenomena are introduced. This work complements previous reviews, putting all two-phase flow instabilities in the same context and updating the information including coherently the data accumulated in recent years. The review is concluded with a discussion of the current research state and recommendations for future works.

Contents

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Nomenclature

Abbreviations and acronyms

BWR	boiling water reactor
CHF	critical heat flux
DFM	drift-flux model
DSG	direct steam generator
DWO	density wave oscillations
DWO_I	DWO – due to gravity
DWO_{III}	DWO – due to momentum
DWO_{II}	DWO – due to friction
FDF	frequency domain formulation
FDI	flow distribution instability
FNS	fixed nodes scheme
FPT	flow pattern transition
FSH	flashing induced instability
GES	geysering
HEM	homogeneous equation model
LED	Ledinegg instability
MNS	moving nodes scheme
NBO	natural boiling oscillations
OFB	onset of nucleate boiling
OFI	onset of flow instability
OSB	onset of significant boiling
PDO	pressure drop oscillations
TAO	thermo-acoustic oscillations
TDF	time domain formulation
TFM	two-fluid model
ThO	thermal oscillations

Non-dimensional numbers

Fr	Froude number
Λ	friction number
N_{Pch}	phase change number
Re	Reynolds number
N_{Sub}	subcooling number
N_{Zu}	Zuber number, N_{Pch}

Variables and parameters

A	area
ρ	density
D	diameter
G	mass flow rate
K	valve constant
L	length
ΔP	pressure drop
P	pressure
q''	heat flux
T	temperature

Subscripts

ext	external
int	internal
in	inlet
out	outlet

1. Introduction

Historically, the study of two-phase flow instabilities started with the pioneering article of Ledinegg [1]. Several decades later, around 1960, the development of industrial high-power-density boilers and boiling water reactors (BWR) turned the attention of many researchers into this kind of phenomena occurring in two-phase flow systems. During those years, several experimental studies described different kinds of phenomena occurring in boiling channels. As described by Yadigaroglu [2, chap. 17], "a period of relative confusion followed, with many authors attempting to explain various widely different observations". Thus, it is not until late 1960s that the main instability mechanisms were understood, especially due to the development of analytical and computational tools, namely, Bouré and Mihaila [3]; Zuber [4]; Ishii and Zuber [5]; Ishii [6]. During the 70's and early 80's, several analytical works made a significant contribution on the understanding basis of thermo-hydraulic instabilities like that from Fukuda and Kobori [7]. With the development of computational tools, the study of transient phenomena related with accident analysis in nuclear reactors