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Review

A Review of two-phase flow dynamic instabilities in tube boiling systems

S. Kakac [a,*], B. Bon [b]

[a] *Department of Mechanical Engineering, TOBB University of Economics and Technology, Sogutozu, Ankara, Turkey*
[b] *Department of Mechanical and Aerospace Engineering, University of Miami, Coral Gables, FL 33124, USA*

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Abstract

The earliest research in the field of two-phase flow was conducted by Lorentz (1909). The studies on the analysis of two-phase flow instabilities by Ledinegg (1938) created considerable interest concerning the phenomenon of thermally induced flow instability in two-phase flow systems. The objective of this review is to sum up the experimental and theoretical work carried out by various investigators over a period of several years, demonstrating and explaining three main instability modes of two-phase flow dynamic instabilities, namely, density-wave type, pressure-drop type and thermal oscillations, encountered in various boiling flow channel systems. The typical experimental investigations of these instabilities in tube boiling systems are indicated and the most popular models to predict the two-phase flow dynamic instabilities, namely the homogenous flow model and the drift-flux models are clarified with the solution examples and the validation of the model results with experimental findings are also provided.
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Keywords: Two-phase flow instabilities; Pressure-drop; Density-wave; Thermal oscillations

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Contents

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[*] Corresponding author. Tel.: +90 312 292 4087; fax: +90 312 292 4091.
E-mail addresses: Sadikakac@yahoo.com (S. Kakac), Miami0007@aol.com (B. Bon).

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Nomenclature

A	heater inner surface area, m^2
A	speed of sound, m/s
c_h	specific heat of heater wall material, kJ/(kg K)
C	wetted perimeter of the heater tube, m
c_p	specific heat capacity at constant pressure, kJ/(kg K)
D	inner diameter of the heater tube, m
D_e	equivalent diameter, m
f	friction factor, dimensionless
F_m	two-phase flow friction multiplier, dimensionless
g	gravitational acceleration, 9.806 m/s^2
G	fluid mass velocity $= \rho u$, kg/(m^2 s)
G_1	inlet fluid mass velocity into surge tank, kg/(m^2 s)
G_2	outlet fluid mass velocity from surge tank, kg/(m^2 s)
h	specific enthalpy of the fluid, J/kg
h_s	saturation enthalpy, J/kg
h_e	equivalent enthalpy of the fluid (drift-flux model), J/kg
h_{lv}	latent heat of evaporation, J/kg
k	thermal conductivity of the fluid, W/(m K)
L	tube length, m
L_h	heated length of the tube, m
$\dot{m}$	mass flow rate, kg/s
Nu	Nusselt number $= \alpha d/k$, dimensionless
P	pressure, Pa
P_e	exit pressure, Pa
P_s	surge tank pressure, Pa
P_{sao}	steady-state pressure of air in the surge tank pressure, Pa
P_{sa}	unsteady state pressure of air in the surge tank pressure, Pa
P_o	main tank pressure, Pa
Pr	Prandtl number $= c_p \mu/k$, dimensionless
Q_I	heat input into the fluid, W
Q_o	electrical heat generation rate in the heater wall, W
R	resistance coefficient for inlet restriction, dimensionless
Re	Reynold's number $= \rho ud/\mu$, dimensionless
T	temperature, K
t	time, s
Δt	time increment in the numerical scheme, s
T_i	fluid inlet temperature, °C
u	fluid velocity, m/s
V	volume, m^3
V_{go}	steady-state volume of the gas in the surge tank, m^3
x	quality of the liquid–vapor mixture, dimensionless
z	axial distance along the flow path, m

Greek symbols

α	heat transfer coefficient, W/(m^2 K)
μ	dynamic viscosity of the fluid, Pa s
ρ	density, kg/m^3
Φ	heat input to fluid per unit inner volume of heater, W/m^3
ψ	void fraction, dimensionless
τ_w	shear stress at the wall, N/m^2

Subscripts

e	exit condition
f	fluid parameter
g	gas
h	heater
i	axial label of a node
i	inlet condition
l	liquid
o	steady-state condition
e	exit condition
f	fluid parameter
g	gas
s	surge tank
v	vapor
w	wall condition

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