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Review

Pool boiling critical heat flux (CHF) – Part 1: Review of mechanisms, models, and correlations

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ABSTRACT

Critical heat flux (CHF) is arguably the most important design and safety parameter for any heat-flux controlled boiling application. The present two-part study is focused on CHF for pool boiling from flat surfaces. The first part will review different CHF models and associated mechanisms and parametric trends, while the second part will be dedicated to assessment of CHF models and correlations. Aside from Kutateladze's 1948 pioneering CHF formulation, which is based on dimensional analysis, five different CHF mechanisms are prevalent in the literature: bubble interference, hydrodynamic instability, macrolayer dryout, hot/dry spot, and interfacial lift-off. Additionally, many modifications to these mechanisms have been proposed to improve predictive accuracy in tackling the parametric influences of pressure, surface size and roughness, surface orientation, and contact angle. Among the five mechanisms, Zuber's hydrodynamic instability theory has received the most attention because of both its mechanistic formulation and theoretical appeal. More recently, the interfacial lift-off mechanism, which is also theoretically based, has received significant experimental validation, and offers the advantage of tackling different surface orientations. Overall, it is shown that, despite the large body of published pool boiling CHF literature, there are major data gaps in the coverage of relevant parameters. This points to a need for more strategically planned future experiments that would also include microphotographic analysis of near-wall interfacial features, in order to validate or dispute proposed CHF mechanisms.

Contents

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Nomenclature

A	area
A_g	area occupied by vapor jets
A_w	total surface area
c_p	specific heat at constant pressure
d	bubble diameter
D_j	vapor column (jet) diameter
f	bubble departure frequency
f_i	interfacial friction factor
g	gravitational acceleration
H	wall thickness
h_{fg}	latent heat of vaporization
K	dimensionless critical heat flux
k	thermal conductivity; empirical parameter
L	heater length
P	pressure
P_c	critical pressure
Pr	Prandtl number
q''	heat flux
q''_{CHF}	critical heat flux
q''_l	localized heat flux; wetting front heat flux
R	vapor stem radius
r	radius of curvature of interface
R_a	surface roughness
R_i	individual gas constant
S	thermal activity parameter
S_m	mean spacing between surface roughness peaks
T	temperature
t	time
ΔT_{sat}	surface superheat, $T_w - T_{sat}$
ΔT_{sub}	liquid subcooling, $T_{sat} - T_f$
u	velocity

Greek symbols

α	contact angle
δ	macrolayer thickness; vapor layer thickness
δ_*	linear scale of capillary disturbance
θ	surface orientation angle measured from horizontal, upward-facing orientation
λ	wavelength
λ_c	critical wavelength of Taylor instability; critical wavelength of Helmholtz instability
λ_d	most dangerous wavelength of Taylor instability
λ_H	wavelength of Helmholtz instability
λ_T	wavelength of Taylor instability
μ	dynamic viscosity
υ	kinematic viscosity
ρ	density
σ	surface tension
τ	bubble hovering time

Subscripts

asy	asymptotic
c	critical
d	most dangerous
f	liquid
g	vapor; gas
H	Helmholtz
h	high
j	jet
l	low
max	maximum
sat	saturation
sub	subcooling
T	Taylor
w	surface

1. Introduction

1.1. Pool boiling applications

The past four decades have witnessed unprecedented increases in rate of heat dissipation in a number of technologies, coupled with a trend for smaller and more lightweight system architectures. Responding to these trends, a variety of two-phase thermal management techniques have been proposed [1,2]. These techniques have been the focus of extensive studies at the Purdue University Boiling and Two-Phase Flow Laboratory (PU-BTPFL) spanning over three decades. They include passive (pump-free) cooling schemes, including both capillary-driven devices (heat pipes, capillary pumped loops, and loop heat pipes) [3] and pool