INTERNATIONAL JOURNAL OF REFRIGERATION 61 (2016) 166–184

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

Review

Flow boiling and frictional pressure gradients in plate heat exchangers. Part 1: Review and experimental database

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ARTICLE INFO

Article history:
Available online 13 July 2015

Keywords:
Flow boiling heat transfer
Flow patterns
Literature review
Plate heat exchangers
Prediction methods
Two-phase pressure drop

ABSTRACT

This two-part paper presents an overview of evaporation heat transfer mechanisms, a review of the experimental and prediction methods and a creation of a consolidated multi-lab database of 3601 data points and provides a detailed comparison of all the prediction methods to this broad database and finally proposes new prediction methods for the local heat transfer coefficient and the frictional pressure gradient of flow boiling within plate heat exchangers. Specifically, in Part 1, a description of the complex geometry of plate heat exchangers and an introduction to their major applications are described, followed by an extensive literature survey of experimental studies and associated prediction methods. While many prediction methods are found to work in the literature, the results of this study show that these methods have only been compared to their original data, but have not been vetted against a large database covering many fluids, plate designs and test conditions.

Ecoulement en ébullition et gradients de pression dûes à la friction dans les échangeurs de chaleur à plaques. Partie 1 : Tour d'horizon et base de données expérimentale

Mots clés : Transfert de chaleur par écoulement en ébullition ; Modèles d'écoulement ; Revue littéraire ; Echangeurs de chaleur à plaques ; Méthodes de prévision ; Chute de pression diphasique

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http://dx.doi.org/10.1016/j.ijrefrig.2015.07.010

Nomenclature

a	amplitude of sinusoidal surface corrugation (m)
A	dimensionless corrugation parameter
b	pressing depth (m)
c_p	specific heat (J kg^{-1} K^{-1})
Bo	boiling number
Bd	Bond number
C	Chisholm parameter
Co	convective number
d	diameter (m)
f	Fanning friction factor
F	enhancement factor for convective boiling
Fr	Froude number
g	acceleration due to the gravity (m^2 s^{-1})
G	mass flux (kg m^{-2} s^{-1})
h	heat transfer coefficient (W m^{-2} K^{-1})
i_{lv}	latent heat of vaporization (J kg^{-1})
Ja	Jakob number
k	thermal conductivity (W m^{-1} K^{-1})
KE	kinetic energy (J)
L	length (m)
M	molar mass (g mol^{-1})
n	number of data
Nu	Nusselt number
N_{pass}	number of passages
p	pressure (Pa)
Pr	Prandtl number
q	heat flux (W m^{-2})
Re	Reynolds number
T	temperature (K)
S	suppression factor for nucleate boiling
u_s	superficial velocity (m s^{-1})
W	width (m)
x	vapor quality
X	Lockhart–Martinelli parameter
z	axial coordinate of the plate (m)

Greek symbols

α	thermal diffusivity (m^2 s^{-1})
β	chevron angle (°)
γ	corrugation aspect ratio
ζ	pressure loss coefficient
Δ	difference
θ	contact angle (°)
Λ	wavelength of surface corrugation (m)
μ	dynamic viscosity (Pa s)
ρ	density (kg m^{-3})
σ	surface tension (N m^{-1})
φ	enlargement factor
φ^2	two-phase multiplier

Subscripts

acc	acceleration
cb	convective boiling
ch	channel
cr	critical
eq	equivalent
fri	frictional
fl	fluid
g	gravitational
h	hydraulic
ht	heat transfer
in	inlet
l	liquid
lat	latent heat
lo	liquid only
m	mean or homogeneous
nb	nucleate boiling
o	departure
out	outlet
p	port
pool	pool boiling
r	reduced
s	saturation
sub	subcooling
sup	super-heated
tp	two phase
tt	turbulent–turbulent
v	vapor
vo	vapor only
wall	wall
w	water

1. Introduction

Plate heat exchangers (PHEs) are a type of compact heat exchanger widely used for industrial applications, such as refrigeration, heating, cooling, chemical processing, etc. They provide a large heat transfer surface area per volume, which makes them particularly suited for installation in confined spaces. Consequently they have a reduced refrigerant charge and require lighter structural supports. Generally, PHEs consist of thin, rectangular, pressed steel plates (most often stainless steel) that are stacked together, such that hot and cold fluid streams alternate through the inter-plate passages. The plates are stamped with corrugated patterns that not only provide a larger effective heat transfer surface area (but only on the order of 10–25% compared to the original flat plate) but also modify the flow field in order to promote enhanced thermal–hydraulic performance. Their most important feature is their larger heat transfer surface area per unit volume compared to a shell-and-tube unit and thus PHEs have increasingly become the heat exchanger of choice in many industrial and domestic applications in the small to medium size range. They are compact, flexible to alter the thermal size for accommodating varying heat load capacities by adding/removing the plates as well as changing their geometry, cleanable (e.g. the gasketed-PHE) and attractive to enhance heat transfer characteristics, as mentioned in the papers of Bergles et al. (1996) and Kakaç et al. (2002). The improved convective heat transfer encouraged by the corrugated plates and the consequent complex inter-plate channels is primarily linked to the effective heat transfer