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Flow boiling and frictional pressure gradients in plate heat exchangers. Part 2: Comparison of literature methods to database and new prediction methods

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ABSTRACT

In the second part of this study a sensitivity analysis on the prediction methods is performed to consider the effect of plate geometry on thermal–hydraulic performance and an extensive comparison of all the two-phase pressure drop and flow boiling heat transfer prediction methods available in the open literature are also provided versus the large diversified database presented in Part 1. The experimental databank, from numerous independent research studies, is then utilized to develop the new prediction methods to evaluate local heat transfer coefficients and pressure drops. These new methods were developed from 1903 heat transfer and 1513 frictional pressure drop data points (3416 total), respectively, and were proved to work better over a very wide range of operating conditions, plate designs and fluids (including ammonia). The prediction for flow boiling heat transfer coefficients was broken down into separate macro- and micro-scale methods.

Ebullition en écoulement et gradients de pression dûes à la friction dans les échangeurs de chaleur à plaques. Partie 2: comparaison des méthodes de la littérature avec des méthodes nouvelles de prévision et par base de données

Mots clés : Analyse dimensionnelle ; Ebullition en écoulement ; Méthode générale de prévision du transfert de chaleur ; Méthode générale de prévision de la chute de pression ; Technique de régression multiple ; Echangeurs de chaleur à plaques

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Nomenclature

b	mean spacing between two plates (m)
Bo	boiling number
Bd	Bond number
C	leading coefficient for prediction methods
d	diameter (m)
f	Fanning friction factor
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 ($J\ kg^{-1}$)
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
L	length (m)
n	number of data
Nu	Nusselt number
p	pressure (Pa)
q	heat flux ($W\ m^{-2}$)
Re	Reynolds number
T	temperature (K)
u_s	superficial velocity ($m\ s^{-1}$)
W	width (m)
We	Weber number
x	vapor quality

Greek symbols

β	chevron angle (°)
β*	reduced chevron angle
|δ|	mean absolute error
δ	mean error
Δ	difference
λ	percentage predicted within ±50%
Λ	wavelength of surface corrugation (m)
μ	dynamic viscosity (Pa s)
ρ	density ($kg\ m^{-3}$)
ρ*	density ratio
σ	surface tension ($N\ m^{-1}$)
φ	enlargement factor
τ	shear stress ($N\ m^{-2}$)
Y	vector of data
ξ	percentage predicted within ±30%
Π	dimensionless number
Ψ	dimensionless number

Subscripts

eq	equivalent
exp	experimental
fri	frictional
h	hydraulic
l	liquid
lo	liquid only
m	mean or homogeneous
p	port
pre	predicted
r	reduced
sat	saturation
tp	two phase
v	vapor
vo	vapor only
wall	wall

1. Introduction

In the first part of the present work, an overview of the main research studies was given, the numerous prediction methods proposed in the literature to evaluate heat transfer coefficients and pressure drops were listed, and finally a comprehensive flow boiling databank was collected (see table 1, Part 1). Based on these results, in the current paper, the goal is to make a detailed comparison of the most quoted prediction methods against one another and perform a statistical comparison between the experimental databases (collected from the literature) and the prediction methods in order to analyze their accuracies. Finally, new prediction methods for the thermal–hydraulic performance of PHEs will be proposed here that provide better accuracies than the previous methods, in addition to covering a wider range of operating conditions, fluids and plate geometries.

2. Sensitivity analysis

The performance of the plate heat exchangers is strongly dependent on the geometry and dimensions of the corrugations of the plates. Therefore, it is instructive to perform a sensitivity analysis in order to highlight these influences. Accordingly, the heat transfer and frictional pressure drop prediction methods, described in Part 1, are used here to assess the effect of plate geometry and dimensions on thermal–hydraulic performance.

The influence of the chevron angle, β, and wavelength of surface corrugation, Λ, on the flow boiling heat transfer coefficient and the pressure drop are respectively illustrated in Figs. 1 and 2. For the following sensitivity analysis, thecorrelations are evaluated assuming saturated flow boiling of R410A, for the vapor quality range from 0.1 to 0.90 and the following typical conditions: a mass flux equal to 27 $kg\ m^{-2}s^{-1}$, a heat flux of 5.5 $kW\ m^{-2}$, a saturation temperature of 15 °C, a plate width of 200 mm and a port to port length of 600 mm. The Han et al. (2003b) correlation was chosen for this parametric study. It can be observed that the heat transfer coefficient, as well as the associated frictional pressure drop, increases with vapor quality along the plate in the convective flow boiling regime. In fact, during the evaporation process the refrigerant vapor quality grows and thus the specific volume grows and consequently the fluid velocity rises. The larger velocity promotes more shears between the liquid and vapor phases and provides higher turbulence; thus, the convective heat transfer coefficient is enhanced and the associated frictional pressure drop grows as well.

It can be seen that at the same value of vapor quality, the higher the plate chevron angle, the more effective the heat transfer but the higher the pressure drop (shown in Fig. 1a and b). Similar outcomes are achieved for the shorter corrugation pitches, i.e. the higher aspect ratios (see Fig. 2a and b).