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Review

A survey of correlations for heat transfer and pressure drop for evaporation and condensation in plate heat exchangers ☆

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ABSTRACT

Plate Heat Exchangers (PHEs) are used in a wide variety of applications including heating, ventilation, air-conditioning, and refrigeration. PHEs are characterized by compactness, flexible thermal sizing, close approach temperature, and enhanced heat transfer performance. Due to their desirable characteristics, they are increasingly utilized in two-phase flow applications. Detailed research on heat transfer and fluid flow characteristics in these types of exchangers is required to design and use plate heat exchangers in an optimal manner. This paper reviews the available literature on the correlations for heat transfer and pressure drop calculations for two-phase flow in PHEs as an initial process step in order to understand the current research status. Comparative evaluations for some of the existing correlations are presented in the light of their applicability to different refrigerants. Overall, there is a significant gap in the literature regarding two-phase heat transfer and fluid flow characteristics of these types of exchangers.

Une étude des corrélations pour le transfert de chaleur et la chute de pression pour l'évaporation et la condensation dans les échangeurs de chaleur à plaques

Mots clés : Échangeurs de chaleur à plaques ; Condensation ; Évaporation ; Simulation ; Corrélations ; Synthèse de la littérature

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Nomenclature

Symbols

A	heat transfer area [m^2]
b	corrugation pitch [m]
Bo	boiling number [dimensionless]
C_p	specific heat [J kg^{-1} K^{-1}]
Co	convection number [dimensionless]
D_h	hydraulic diameter [m]
f	Darcy friction factor [dimensionless]
Fr	Froude number [dimensionless]
Ga	Galileo number [dimensionless]
g	gravitational acceleration [m s^{-2}]
G	mass flux [kg m^{-2} s^{-1}]
h	convective heat transfer coefficient [W m^{-2} K^{-1}]
Ja	Jacob number [dimensionless]
k	thermal conductivity [W m^{-1} K^{-1}]
L	length [m]
M	molecular number
Nu	Nusselt number [dimensionless]
p	pressure [MPa]
Pr	Prandtl number [dimensionless]
q''	heat flux [W m^{-2}]
Re	Reynolds number [dimensionless]
T	temperature [K]
X_{tt}	Lockhart–Martinelli parameter
x	vapor quality

Greek letters

α	thermal diffusivity [m^2 s]
β	chevron angle [$\circ$]
ε	arithmetic mean roughness [μm]
ϕ	two-phase multiplier [dimensionless]
φ	surface enlargement factor [dimensionless]
γ	latent heat of vaporization [J kg^{-1}]
μ	dynamic viscosity [Pa·s]
ρ	density [kg m^{-3}]
ω	accentric factor

Subscripts

c	critical
cb	convective boiling
cr	critical
eq	equivalent
emp	empirical
g	vapor
l	liquid
m	mean
nb	nucleate boiling
red	reduced
sat	saturation
tt	turbulent–turbulent
w	wall

1. Introduction

Plate Heat Exchangers (PHEs) were introduced to the dairy industry in the late 1800s. Later improvements to the plate designs, sealing aspects, and other mechanical issues allowed them to gain success in many industries including, but not limited to, heating, refrigeration, and air-conditioning (HVAC), food processing, chemical industry, marine, and energy generation systems. PHEs are highly compact because turbulence is readily achieved due to flow separation which takes place as a result of the corrugated pattern and thus the required surface area for heat transfer is smaller than the surface area needed by other types of heat exchangers as well as the refrigerant charge. Low charge is favored by the HVAC industry because it decreases the environmental impact of refrigerants and lowers inventory costs. PHEs are characterized by high effectiveness of heat transfer which is highly required in the competitive heat exchanger industry.

Brazed plate heat exchangers (BPHE) consist of a pack of thin metal or metal alloy (usually stainless steel) plates and two end plates, which are brazed together using a brazing material, such as copper or nickel for ammonia applications, where two or more fluids flow in between the plates and exchange thermal energy. BPHEs are favored by the HVAC industry due to concerns over refrigerant leakage and high compactness. They can be used for high temperature and high pressure applications, including water-cooled evaporators and condensers refrigeration applications, as well as process water heating and heat recovery in various applications (Shah and Sekulic, 2003).

Due to the high cost of building and testing PHE prototypes, it is desired to predict the performance of different PHE designs using numerical models. However, in order to be able to accurately predict the performance of PHEs, reliable heat transfer and pressure drop correlations are required to be used in such models. Several studies on single-phase heat transfer correlations, however specific in nature, are present in literature, while studies on two-phase heat transfer correlations are more limited. A summary of important single-phase correlations can be found in Ayub (2003) and in Khan and Chyu (2010). Unlike single-phase heat transfer, two-phase heat transfer in PHEs is a function of various parameters such as the plate surface structure, heat flux, mass flux, vapor quality, film thickness, flow regime, dry out, and effects of lubricant oils. Thus, it is more challenging to obtain a general correlation that would take into account the effects of all these parameters.

Due to the negative impacts and serious destruction caused by CFC refrigerants to the ozone layer, and due to the global warming potential caused by other HFC refrigerants, lower GWP and natural refrigerants are becoming more favorable in air-conditioning and refrigeration applications. Ammonia is widely used in industrial processes in PHEs (Ayub, 2003) as the ODP and the GWP of ammonia are zero. However, limited research has been conducted for two-phase flow on natural refrigerants in PHEs and correlations on natural refrigerant mixtures are scarce.