Available online at www.sciencedirect.com
ScienceDirect
International Journal of Refrigeration 30 (2007) 821–830
REVUE INTERNATIONALE DU FROID
INTERNATIONAL JOURNAL OF
refrigeration
www.elsevier.com/locate/ijrefrig

Refrigerant R134a vaporisation heat transfer and pressure drop inside a small brazed plate heat exchanger

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Received 9 November 2005; received in revised form 23 October 2006; accepted 22 November 2006
Available online 19 January 2007

Abstract

This paper presents the experimental heat transfer coefficients and pressure drop measured during refrigerant R134a vaporisation inside a small brazed plate heat exchanger (BPHE): the effects of heat flux, refrigerant mass flux, saturation temperature and outlet conditions are investigated. The BPHE tested consists of 10 plates, 72 mm in width and 310 mm in length, which present a macro-scale herringbone corrugation with an inclination angle of 65° and corrugation amplitude of 2 mm.

The experimental results are reported in terms of refrigerant side heat transfer coefficients and frictional pressure drop. The heat transfer coefficients show great sensitivity both to heat flux and outlet conditions and weak sensitivity to saturation temperature. The frictional pressure drop shows a linear dependence on the kinetic energy per unit volume of the refrigerant flow.

The experimental heat transfer coefficients are also compared with two well-known correlations for nucleate pool boiling and a correlation for frictional pressure drop is proposed.

Keywords: Heat exchanger; Plate exchanger; Experiment; Heat transfer; Pressure drop; Evaporation; R134a

R134a: transfert de chaleur lors de la vaporisation et chute de pression à l'intérieur d'un échangeur de chaleur à plaques brasées de petite taille

Mots clés : Échangeur de chaleur ; Échangeur à plaques ; Expérimentation ; Transfert de chaleur ; Chute de pression ; Évaporation ; R134a

1. Introduction

Traditional plate heat exchangers (PHE) consist of a stack of corrugated metal plates assembled by means of sealing gaskets, frame plates and compression bolts. They have been successfully used since the 1930s for single-phase heat transfer from liquid-to-liquid in chemical and food processing industries. In the late seventies they were also used for two-phase heat transfer, particularly as evaporators and condensers in chillers and heat pumps. The application to high-pressure refrigerant fluids required the development of a new type of PHE, the brazed plate heat exchangers (BPHE) in which stainless steel plates are vacuum brazed

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doi:10.1016/j.ijrefrig.2006.11.011

Nomenclature

A nominal area of a plate (m^2)
b height of the corrugation (m)
Bo boiling number, $q/G\ \Delta J_{LG}$
c_p specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
C_{Ra} correction term in Eq. (25)
d_h hydraulic diameter, $d_h = 2b$ (m)
F correction term in Eq. (25)
g gravity acceleration ($m\ s^{-2}$)
G mass flux, $G = m/(n_{ch} \times W \times b)$, ($kg\ m^{-2}\ s^{-1}$)
h heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
J specific enthalpy ($J\ kg^{-1}$)
KE/V kinetic energy per unit volume ($J\ m^{-3}$)
L flow length of the plate (m)
m mass flow rate, $kg\ s^{-1}$
M molecular weight ($kg\ kmol^{-1}$)
n_{ch} number of channels
N number of effective plates
p pressure (Pa)
Pr Prandtl number, $Pr = \mu \times c_p/\lambda$
q heat flux ($W\ m^{-2}$)
Q heat power (W)
R_a arithmetic mean roughness (ISO 4271/1) (μm)
R_p roughness (DIN 4762/1) (μm)
Re Reynolds number, $Re = G \times d_h/\mu$
S nominal heat transfer area (m^2)
s plate wall thickness (m)
T temperature (K)
u mean flow velocity ($m\ s^{-1}$)
U overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
v specific volume ($m^3\ kg^{-1}$)
W width of the plate (m)
x vapour quality, $x = (J - J_L)/\Delta J_{LG}$
X co-ordinate in Fig. 3 (Eq. (6))
X_{tt} Martinelli parameter
Y co-ordinate in Fig. 3 (Eq. (7))

Greek symbols
β inclination angle of the corrugation
Δ difference
ΔJ_{LG} specific enthalpy of vaporisation ($J\ kg^{-1}$)
λ thermal conductivity ($W\ m^{-1}\ K^{-1}$)
μ viscosity ($kg\ m^{-1}\ s^{-1}$)
ρ density ($kg\ m^{-3}$)

Subscripts
a momentum
boil boiling
c manifold and port
E external channels
f frictional
g gravity
G vapour phase
i inlet
I internal channels
L liquid phase
ln logarithmic
m vapour–liquid mixture
o outlet
p plate
pb pre-evaporator
r refrigerant
t total
sat saturation
sup super-heating
w water
wi water inlet
wo water outlet
0 reference conditions in Eq. (25)

together using copper as the brazing material. This solution ensures a great mechanical resistance, but eliminates the flexibility and ease cleaning typical of PHE with gaskets.

In open literature, it is possible to find several works on traditional PHE in single-phase liquid-to-liquid heat transfer, whereas limited data can be found on refrigerant vaporisation and condensation inside BPHE. Thonon et al. [1] and Palm and Thonon [2] presented good reviews on the thermal and hydraulic performances of BPHE in refrigerant condensation and vaporisation. More recently Yan and Lin [3] and Yan et al. [4] experimentally investigated the effects of mean vapour quality, mass flux, heat flux and saturation pressure on heat transfer and pressure drop during vaporisation and condensation of refrigerant R134a inside a BPHE. They also presented empirical correlations for heat transfer coefficient and friction factor based on their experimental data. Hsieh and Lin [5,6] reported experimental data on vaporisation heat transfer and pressure drop of refrigerant R410A in a BPHE. The effects of mean vapour quality, mass flux, heat flux and saturation pressure were evaluated and empirical correlations were proposed for heat transfer coefficient and friction factor. Matsushita and Uchida [7] presented experimental data on vaporisation of refrigerant R22 inside a BPHE with special plates embossed with pyramid-like structures. These new plates gave a vaporisation heat transfer coefficient 50–100% higher than traditional herringbone-type plates and a similar pressure drop on the refrigerant side. Han et al. [8] presented experimental heat transfer coefficients and pressure drop measured during refrigerant R-22 and R410A vaporisation inside a BPHE. The effects of mass flux, heat flux, saturation temperature and plate geometry (inclination angle of the corrugation) were evaluated and empirical correlations were proposed for