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Refrigerant pressure drop in chevron and bumpy style flat plate heat exchangers

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Abstract

Adiabatic pressure drop in chevron and two styles of bumpy plate heat exchangers were investigated for vertical upward flow with R134a. Qualities ranging from sub-cooled liquid to superheated vapor were investigated. Mass fluxes ranged from 16 kg/m^2 s (for superheated vapor) to approximately 300 kg/m^2 s (for sub-cooled liquid). The pressure drop experiments were conducted for 10 °C and 20 °C inlet temperatures. A two-phase pressure drop model, based on the kinetic energy of the flow, was developed in order to relate the two-phase pressure drop data to the single-phase data. The model predicts two-phase pressure drop within 15% of experimental measurements.

Keywords: Two-phase; Plate heat exchangers; Pressure drop

1. Introduction

Flat plate heat exchangers have been in commercial use since 1923 according to Raju and Chand [1]. They are widely used in the liquid-to-liquid configuration for food processing, dairy, and other industrial applications. Their compact size presents a clear advantage over shell and tube style heat exchangers in some applications. Since the single-phase flow configuration in flat plate heat exchangers has been used for a long period of time, there is a lot of single-phase flat plate literature available. Currently, flat plate heat exchangers are being used in two-phase configurations for applications such as automotive evaporators, and industrial applications. Chevron style flat plate heat exchangers are used for industrial refrigeration while bumpy style flat plate heat exchangers are commonly used for automotive air conditioners. There is limited information in the literature about two-phase flow in flat plate heat exchangers, especially with new refrigerants such as R134a. Furthermore, the relationship between "chevron" and "bumpy" style flat plate heat exchangers have yet to be identified in literature.

This report will focus on the pressure drop of R134a in chevron style and two types of bumpy style flat plate evaporators: a 1:1 aspect ratio bumpy plate and a 2:1 aspect ratio bumpy plate. Flat plate heat exchangers generally consist of complex passageways for the two-phase refrigerant flow. Chevron flat plate heat exchangers consist of passageways that have limited groove-to-groove access while bumpy plate heat exchangers have a more direct connection across groove (bump) rows. The 2:1 aspect ratio bumpy plate has less of a direct connection across groove (bump) rows than the 1:1 aspect ratio plate geometry. Consequently, the 2:1 aspect ratio bumpy plate represents an intermediate step between the chevron and 1:1 aspect ratio geometries. The rationale behind the plate designs was to provide a means of

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Nomenclature

a	curve fit constant (dimensionless)
A_m	mean cross sectional area (m^2)
A_w	wetted area of test section, excluding the headers (m^2)
b	curve fit constant (dimensionless)
D_h	hydraulic diameter (m)
f	friction factor
G	mass flux (kg/m^2 s)
g	gravitational acceleration (9.81 m/s^2)
h	vertical distance between test section pressure taps (m)
KE	kinetic energy (J)
L	test section length, excluding the headers (m)
m	slope of curve × 1000 (dimensionless)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
Pc	chevron pitch (mm)
Re	Reynolds number
V_{ts}	volume of test section excluding the headers (m^3)
x	quality
X_{tt}	Lockhart–Martinelli parameter

Greek symbols

α	void fraction
β	effective void fraction/homogeneous void fraction
βc	chevron angle from flow direction (°)
ΔP	pressure drop (kPa)
ρ	density (kg/m^3)
μ	viscosity (kPa s)

Subscripts

D	Darcy
e	effective
l	liquid
sp	single-phase
tp	two-phase
hom	homogeneous
v	vapor

comparing chevron plates to dimpled plates. Analysis of fundamental parameters, such as kinetic energy of the flow fields, can help identify similarities and differences among the plate designs, and provide a method to predict pressure drop in flat plates.

2. Single- and two-phase pressure drop literature

2.1. Relevant single-phase pressure drop literature

Luo and Yu [2] and Luo and Zhang [3] performed single-phase liquid pressure drop experiments with chevron geometry heat exchangers similar to the chevron geometry tested in this paper. They both used a 60 °C chevron angle, which is the angle between the corrugated channel and the flow direction. The geometry of Luo and Zhang [3] is closer to the geometry presented in this paper than that of Luo and Yu [2]. Luo and Yu [2] rounded the tops of the grooves where the plates come in contact, and found that this resulted in a significant pressure drop reduction. The friction factor, f, curve fits for Luo and Yu [2] and Luo and Zhang [3] are given in Eqs. (1) and (2), respectively

$$f = 5.94Re^{-0.062} \tag{1}$$

$$f = 7.70Re^{-0.067} \tag{2}$$

Both authors defined the Darcy Friction factor, f_D, and Reynolds number, Re, as in Eqs. (4) and (3), respectively

$$f_D = 2D_h\rho\frac{(\Delta P - \rho gh)}{LG^2} \tag{3}$$

$$Re = \frac{GD_h}{\mu} \tag{4}$$

where D_h is the hydraulic diameter, ρ is the density, ΔP is the pressure drop, g is the gravitational acceleration, h is the vertical distance between test section pressure taps, L is the test section length excluding the headers, G is the mass flux, and μ is the viscosity.

2.2. Two-phase pressure drop literature review

Flat plate heat exchangers have just recently been used for two-phase flow applications. Consequently, there is not a significant amount of two-phase literature available. Wang et al. [4], Yan and Lin [5], Yan et al. [6], Thonon et al. [7], and Mandrusiak and Carey [8] all present two-phase pressure drop data for flat plate heat exchangers. All of the geometries investigated are chevron style heat exchangers except for Mandrusiak and Carey [8] who investigated two-phase R113 pressure drop in a channel with offset strip fins. Wang et al. [4] investigated steam condensation in chevron heat exchangers. Yan and Lin [5] and Yan et al. [6] investigated R134a evaporation and condensation, respectively, in chevron style heat exchangers. Thonon et al. [7] investigated two-phase pressure drop of R22 in condensation and evaporation in chevron style heat exchangers.