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Evaporation heat transfer and pressure drop of ammonia in a mixed configuration chevron plate heat exchanger

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A R T I C L E I N F O

Article history:
Received 4 September 2013
Received in revised form
23 December 2013
Accepted 28 December 2013
Available online 8 January 2014

Keywords:
Plate heat exchanger
Ammonia
Heat transfer
Evaporation
Pressure drop

A B S T R A C T

Ammonia is a naturally occurring environment friendly refrigerant with attractive thermophysical properties. Experimental investigation of heat transfer and pressure drop during steady state evaporation of ammonia in a commercial plate heat exchanger has been carried out for an un-symmetric 30°/60° chevron plate configuration. Experiments were conducted for saturation temperatures ranging from −25 °C to −2 °C. The heat flux was varied between 21 kW m^{-2} and 44 kW m^{-2}. Experimental results show significant effect of saturation temperature, heat flux and exit vapor quality on heat transfer coefficient and pressure drop. Current mixed plate configuration data are compared with previous studies on the same heat exchanger with symmetric plate configurations. This comparison highlighted importance of optimization in selection of the heat exchangers. Correlations for two phase Nusselt number and friction factor for each chevron plate configuration considered are developed. A Nusselt number correlation generalized for a range of chevron angles is also proposed.

Transfert de chaleur d'évaporation et chute de pression d'ammoniac dans un échangeur de chaleur à plaques

Mots clés : Echangeur de chaleur à plaques ; Ammoniac ; Transfert de chaleur ; Evaporation ; Chute de pression

1. Introduction

In today's highly industrialized world, energy is one of the major concerns. With rapid consumption of fossil fuels, saving energy has become an attractive topic for the researchers. Recently, a marked improvement in heat exchanger technology has been observed. With improved technology vivid energy savings are now possible with efficient natural refrigerants in compact heat exchangers, used in various applications.

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0140-7007/$ – see front matter © 2014 Elsevier Ltd and IIR. All rights reserved.
http://dx.doi.org/10.1016/j.ijrefrig.2013.12.015

Nomenclature

Bo	boiling number
D_h	hydraulic diameter (m)
f	fanning friction factor
G_r	refrigerant mass flux (kg m^{-2} s^{-1})
h	heat transfer coefficient (W m^{-2} K^{-1})
i	enthalpy (kJ kg^{-1})
k	thermal conductivity (W m^{-1} K^{-1})
Nu	Nusselt number
P	pressure (kPa) or Plate pitch (m)
P_{cr}	critical pressure (kPa)
P^*	reduced pressure (P/P_{cr})
Pr	Prandtl number
q''	heat flux (kW m^{-2})
Re	Reynolds number
t	plate thickness (m)
T	temperature (°C)
U	overall heat transfer coefficient (W m^{-2} K^{-1})
v	specific volume (m^3 kg^{-1})
x	exit vapor quality

Greek symbols

β	chevron or corrugation angle (deg)
Δ	change or difference
μ	dynamic viscosity (kg m^{-1} s^{-1})

Subscripts

acc	acceleration
core	core
ele	elevation
eq	equivalent
f	liquid
g	vapor
h	hot stream
m	measured
port	port
r	refrigerant
sp	single phase
tp	two phase

Plate heat exchangers (PHEs) are gaining popularity in recent years. However, data for two phase applications are still scarcely available in open literature, Khan et al. (2009). The gasketed plate heat exchangers are compact in nature, have high area to volume ratio, flexible in design and are easy to operate. Perhaps one of the major advantages of plate heat exchanger is its small size and relatively low energy usage. The flexible design of a plate heat exchanger allows overall reduced operational and maintenance costs. Because of their compact nature, these heat exchangers are not only energy efficient and cost effective but also adaptable for a variety of industrial applications.

Ammonia is a naturally available refrigerant and has long been used in the refrigeration industry. It is a relatively low cost refrigerant with attractive thermo-physical properties. Ammonia based systems require relatively low maintenance. On the other hand ammonia is toxic and when mixed in air is flammable under certain conditions. However, being self-alarming has low safety compromise. While chloro-fluoro-carbons are threat to ozone depletion and hydro-fluoro-carbons add to global warming, natural refrigerants like ammonia are not only environment friendly but have efficient thermo-hydraulic characteristics. Therefore, due to danger of ozone depletion and global warming, interest in the use of natural refrigerants in air-conditioning and refrigeration industry has increased Khan et al. (2012a,b).

The PHE used in the present study was configured in a single pass U-arrangement with counter flow setup. Such an arrangement is schematically shown in Fig. 1.

It is well known that two phase heat transfer in heat exchangers is a more efficient mode of heat transfer compared to single phase heat transfer. Although some two phase work on compact heat exchangers was reported in the last century, however, major two phase experimentation on plate heat exchangers has been reported in the last decade. It may be interesting to note that two phase flow investigations carried out on plate heat exchangers with natural refrigerants such as ammonia are comparatively less in number, Khan et al. (2009). Recently Khan et al. (2012a,b) carried out experimental investigations on evaporation of ammonia in a commercial plate heat exchanger with two different symmetric (60°/60° and 30°/30°) chevron plate configurations. The heat transfer coefficient and pressure drop are reported to increase with an increase in chevron angle and decrease in corrugation depth and mean channel spacing. Some other recent two phase studies using ammonia as refrigerant (Ayub, 2003; Sterner and Sunden, 2006; Djordjevic and Kabelac, 2008; Arima et al., 2010) are also discussed in Khan et al. (2012a,b).

The current study uses the same heat exchanger as was employed in Khan et al. (2012a,b) but with an un-symmetric (mixed) chevron plate configuration. The mixed configuration is achieved by combining 30° and 60° chevron angle plates. The present work focuses on experimental investigation of thermal hydraulic characteristics of a 30°/60° un-symmetric commercial chevron plate heat exchanger for two phase ammonia evaporation. The experimental results for the un-symmetric configuration highlights the importance

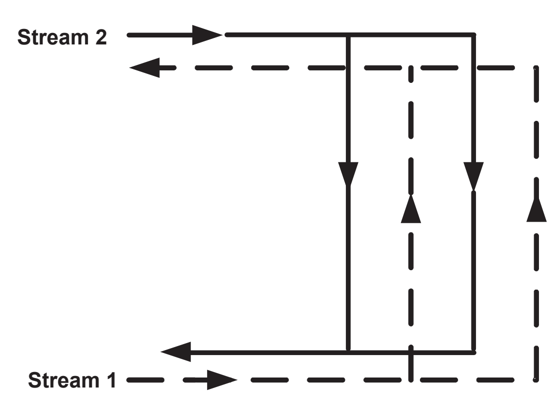

Fig. 1 – Schematic diagram of single pass U-arrangement for counter flow plate heat exchanger setup (Kakac and Liu, 2002).