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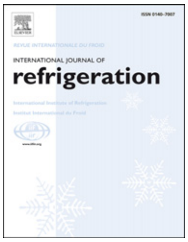

# Experimental investigation of evaporation heat transfer and pressure drop of ammonia in a 60° chevron plate heat exchanger

*Tariq S. Khan* [a], *Mohammad S. Khan* [a,*], *Ming-C. Chyu* [b], *Zahid H. Ayub* [c]

[a] *Faculty of Mechanical Engineering, GIK Institute of Engineering Sciences and Technology, Topi, Swabi, KPK 23640, Pakistan*
[b] *Department of Mechanical Engineering, Texas Tech University, USA*
[c] *ISOTHERM, Inc., Texas, USA*

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ABSTRACT

Ammonia is an environment friendly natural refrigerant with attractive thermo-physical properties. Experimental heat transfer and pressure drop data are obtained for evaporation of liquid ammonia in a commercial plate heat exchanger for symmetric 60°/60° (hard) chevron angle plates. Experiments were carried out for mass flux ranging from 8.5 to 27 kg $m^{-2}$ $s^{-1}$ at saturation temperatures ranging from −25 °C to −2 °C. The heat flux was varied between 21 kW $m^{-2}$ and 44 kW $m^{-2}$. The heat transfer coefficient increased with an increase in saturation temperature and mass flux. Furthermore, heat transfer coefficient was observed to increase with exit vapor quality. The friction factor decreased with exit vapor quality and equivalent Reynolds number, while it increased with the fluid temperature. The work reveals that ammonia has far better heat transfer and pressure drop characteristics compared to HFCs. Two phase Nusselt number and friction factor correlations are also proposed.

# Etude expérimentale sur le transfert de chaleur et la chute de pression lors de l'évaporation d'ammoniac dans un échangeur à plaque en chevron (60°)

*Mots clés :* échangeur de chaleur ; ammoniac ; flux thermique ; évaporation ; chute de pression

## 1. Introduction

Plate heat exchangers (PHEs) are widely used in a variety of industrial applications. Some of the major applications are in dairy, process, paper/pulp, refrigeration, heating, ventilating, and air-conditioning industries. Several features of PHEs make them more suitable than other types of heat exchangers. Generally, they are characterized by larger heat

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* *Corresponding author*. Tel.: +92 938 271 858; fax: +92 938 271 889.
E-mail addresses: khan@giki.edu.pk, khan101@hotmail.com (M.S. Khan).

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**Nomenclature**

| | |
|---|---|
| A | Effective heat transfer surface area ($m^2$) |
| b | Corrugation depth or mean channel spacing (m) |
| Bo | Boiling number |
| $c_p$ | Specific heat ($kJ\ kg^{-1}\ K^{-1}$) |
| $D_h$ | Hydraulic diameter (m) |
| f | Fanning friction factor |
| $G_r$ | Refrigerant mass flux ($kg\ m^{-2}\ s^{-1}$) |
| $G_h$ | Hot fluid mass flux ($kg\ m^{-2}\ s^{-1}$) |
| h | Heat transfer coefficient ($W\ m^{-2}\ K^{-1}$) |
| i | Enthalpy ($kJ\ kg^{-1}$) |
| k | Thermal conductivity ($W\ m^{-1}\ K^{-1}$) |
| L | Length(m) |
| $\dot{m}$ | Mass flow rate ($kg\ s^{-1}$) |
| Nu | Nusselt number |
| P | Pressure (kPa) |
| $P_{cr}$ | Critical pressure (kPa) |
| $P^*$ | Reduced pressure ($P/P_{cr}$) |
| Q | Heat load (kW) |
| $q''$ | Heat flux ($kW\ m^{-2}$) |
| Re | Reynolds number |
| t | Plate thickness (m) |
| T | Temperature (°C) |
| U | Overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$) |
| $\upsilon$ | Specific volume ($m^3\ kg^{-1}$) |
| x | Exit vapor quality |

*Greek symbols*

| | |
|---|---|
| $\beta$ | Chevron or corrugation angle (deg) |
| $\Delta$ | Change or difference |
| $\lambda$ | Corrugation pitch (m) |
| $\mu$ | Dynamic viscosity ($kg\ m^{-1}\ s^{-1}$) |

*Subscripts*

| | |
|---|---|
| acc | Acceleration |
| ele | Elevation |
| eq | Equivalent |
| f | Liquid |
| g | Vapor |
| h | Hot stream |
| LMTD | Log mean temperature difference |
| m | Measured |
| p | Plate |
| port | Port |
| r | Refrigerant |
| sp | Single phase |
| tp | Two phase |

transfer area to volume ratio, lighter weight, design flexibility, high thermal effectiveness, hence are suitable for energy and space saving. Their design flexibility provides an advantage in varying heat transfer area by easily adding or removing plates without disturbing the piping connections. Fig. 1 shows a schematic of a PHE in a single pass U-arrangement and counter flow setup (Kakac and Liu, 2002).

Plate heat exchangers have clear advantage over shell and tube type due to their compact size and high thermal effectiveness. Being compact in nature, the PHEs have better heat transfer characteristics, however, may have higher pressure drop. Therefore, for wider engineering applications, experimental data are required for both heat transfer and pressure drop characteristics of the plate heat exchangers.

Numerous single phase studies on plate heat exchangers have been conducted in the past and heat transfer and pressure drop correlations have been developed (Ayub, 2003). However, two phase flow investigations carried out on plate heat exchangers are very limited and hence there is lack of basic two phase heat transfer and pressure drop information related to such types of exchangers (Khan et al., 2009). The corrugated channels in the plate heat exchangers make a very complex geometry having several parameters to be considered such as chevron angle, corrugation depth, overall size of the plate, surface area enhancement factors etc.

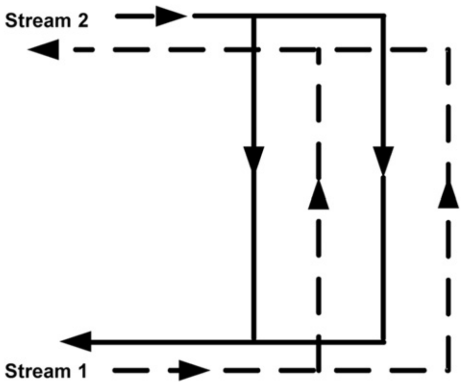

**Fig. 1 – Schematic diagram of single pass U-arrangement for counter flow heat exchanger setup (Kakac and Liu, 2002).**

Danilova et al. (1981) reported data on the heat transfer characteristics of some refrigerants, including ammonia, for plate heat exchangers. However, major two phase works on the compact heat exchangers have been reported in the last decade only. Yan and Lin (1999), Hsieh and Lin (2002) and Ouazia (2001) investigated heat transfer and pressure drop of R-134a in various plate heat exchangers. They also proposed correlations for the heat transfer coefficient and friction factors. Hsieh and Lin (2003) extended their previous work by investigating heat transfer and pressure drop characteristics of R-410A in the same experimental facility as used by Yan and Lin (1999). Heat transfer coefficient and frictional pressure drop were reported to increase with refrigerant mass flux and vapor quality. The heat transfer was also reported to increase with imposed heat flux, however, effect of heat flux and system pressure on frictional pressure drop was reported to be insignificant.

Han et al. (2003) in a similar study of R-410A and R-22 in a plate heat exchanger reported both heat transfer coefficient and pressure drop to increase with an increase in mass flux, chevron angle and vapor quality and with a decrease in evaporation temperature. Longo and Gasparella (2007a, b, c) investigated heat transfer and pressure drop characteristics of some Hydro-floro-carbons (HFCs) in a brazed plate heat exchanger. They reported heat transfer and pressure drop to be significantly affected by heat flux, exit vapor quality and