International Communications in Heat and Mass Transfer 91 (2018) 201–209

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Effect of chevron angle and surface roughness on thermal performance of single-phase water flow inside a plate heat exchanger

Kitti Nilpueng[a,b], Thawatchai Keawkamrop[b], Ho Seon Ahn[c], Somchai Wongwises[b,*]

[a] Research Centre for Combustion Technology and Alternative Energy (CTAE), Department of Power Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand

[b] Fluid Mechanics, Thermal Engineering and Multiphase Flow Research Lab (FUTURE), Department of Mechanical Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi, Bangmod, Bangkok 10140, Thailand

[c] Department of Mechanical Engineering, Incheon National University, Incheon, Republic of Korea

ARTICLE INFO

Keywords:
Heat transfer coefficient
Pumping power
Nusselt number
Friction factor
Thermal performance factor

ABSTRACT

New experimental data on plate heat exchanger performance including the heat transfer coefficient, pressure drop, and thermal performance factor under different chevron angles, surface roughness, and working conditions are presented. Plate surface roughness ranging between 0.95 μm and 2.75 μm with chevron angles of 30° and 60° are used. The experiments are performed at Reynolds numbers ranging between 1200 and 3500, a hot water temperature of 40 °C, and a cold water temperature of 25 °C. The experimental results show that the heat transfer coefficient and pressure drop increase when the chevron angle is decreased and the surface roughness and Reynolds number are increased. Under the testing conditions, the average thermal performance factors are 1.09 and 1.02 for 30° and 60° chevron angles, respectively. The optimum thermal performance of a plate heat exchanger is obtained at a 30° chevron angle, the highest surface roughness, and the lowest Reynolds number. A correlation of Nusselt number and friction factor for different surface roughness and chevron angles are also proposed for practical applications.

1. Introduction

Due to the fact that plate heat exchangers are small in size and weight, flexible and easy to clean compared with other types of heat exchangers, they are widely used for both single-phase and two-phase flows in many applications, such as food processing, brewing, chemical processing, heat pump systems, and cooling systems. The chevron-type plate heat exchanger, which is mostly used in industrial applications, is designed for improving the fluid mixing inside the channel and enhancing the heat transfer rate by 20–30% [1]. However, it also leads to an increase of pumping power consumption. Therefore, to obtain the optimum design for a plate heat exchanger, i.e., a high heat transfer coefficient and low pressure drop, knowledge about the plate configuration and working conditions of a plate heat exchangers' performance is very important and still needed. Over the last decade, research studies on the thermal performance of single-phase water flow inside plate heat exchangers have been continuously carried out by several researchers.

Luan et al. [2] designed and investigated the flow characteristics in a plate heat exchanger with a compound corrugation surface. Based on the new design of corrugation, the flow resistance of the working fluid decreased > 50% and the heat transfer performance decreased by about 25% compared with the traditional chevron-type plate heat exchanger. They reported that the compound corrugation surface reduced the flow path blockage problem in unclean working fluids application. Miura et al. [3] investigated the pressure drop of water flow inside the plate heat exchangers with different flow arrangements. A laboratory scale PHE with flat plates was experimentally tested. Based on their experimental data, an empirical correlation for predicting the effect of the number of passes and number of flow channels per pass on the pressure drop was proposed. Moreover, the CFD model was developed to predict the value of the pressure drop. A comparison between the model and the experimental data showed good agreement.

Durmus et al. [4] studied the heat transfer and pressure drop in plate heat exchangers with different surface profiles. They reported the effects of surface geometries (i.e., flat plate heat exchanger, corrugated plate heat exchanger, and asterisk plate heat exchanger) on heat transfer, friction factor and exergy loss. The heat transfer rate obtained from the corrugated-type heat exchanger was higher than that from other types. They concluded that the pressure drop resulted in an increase of the capital costs, but heat exchanger efficiency caused smaller dimensions and lower production costs. Kim et al. [5] studied and

* Corresponding author.
E-mail address: somchai.won@kmutt.ac.th (S. Wongwises).

https://doi.org/10.1016/j.icheatmasstransfer.2017.12.009

Nomenclature

A	heat transfer area, m^2
b_c	mean spacing between plates, m
$c_{p,h}$	specific heat of hot stream, J/kg K
$c_{p,c}$	specific heat of cold stream, J/kg K
D_H	hydraulic diameter of tube, m
ΔP_F	frictional pressure drop, Pa
ΔP_G	gravitational pressure drop, Pa
ΔP_M	pressure loss at the inlet and outlet, Pa
ΔP_T	total pressure drop, Pa
f	friction factor
g	gravitational acceleration, m/s^2
h_c	heat transfer coefficient of cold stream, W/m^2 K
h_h	heat transfer coefficient of hot stream, W/m^2 K
k_s	thermal conductivity of plate, W/m K
L	vertical length from inlet port to outlet port, m
LMTD	logarithmic mean temperature difference, K
$\dot{m}_h$	mass flow rate of hot stream, kg/s
$\dot{m}_c$	mass flow rate of cold stream, kg/s
Nu	Nusselt number
Pr	Prandtl number
Q_{avg}	average heat transfer rate, W
Re	Reynolds number
T_{ci}	cold stream temperature at inlet section, K
T_{co}	cold stream temperature at outlet section, K
T_{hi}	hot stream temperature at inlet section, K
T_{ho}	hot stream temperature at outlet section, K
U	overall heat transfer coefficient, W/m^2 K
V	velocity, m/s
w	plate width inside gasket, m
Δx	plate thickness, m

Greek symbols

ε	surface roughness, m
μ	dynamic viscosity, kg/m s
ρ	density, kg/m^3
υ	specific volume, m^3/kg

compared the heat transfer performance of single-wave and double-wave plate heat exchangers. Air and water flow in a crosswise direction were used as the working fluid in this testing. It was found that the heat transfer and pressure drop of the double-wave plate heat exchanger enhanced by about 50% and 30% when compared with the single-wave plate heat exchanger.

Khan et al. [6] investigated the effect of chevron angles on the heat transfer coefficient inside plate heat exchangers. Three different chevron angles of 30°/30°, 60°/60°, and 30°/60° were used. They stated that the chevron angle and Reynolds number had a significant effect on the heat transfer characteristics, and chevron angles of 30°/30° resulted in the highest heat transfer coefficient. Faizal and Ahmed [7] studied the heat transfer and pressure drop of water in plate heat exchangers under different low-temperature conditions. Three values of spacing between the plates were adjusted to investigate the plate heat exchanger performance. It was found that the pressure drop was increased when spacing between the plates was narrow, and optimum heat transfer occurred at a spacing of 6 mm.

Gherasim et al. [8] numerically studied the heat transfer coefficient and friction factor inside the gasket plate heat exchanger under laminar or turbulent flow conditions. Temperature variation and mass flow rate per unit area at any position were also presented. Water/water and water/engine oil were used as working fluids. The thermal field and the mass flow distribution of water/engine oil were more uniform compared with the water/water. The channel with longitudinal passages yielded a lower heat transfer rate and friction factor compared with the original geometry. Thermal and hydraulic characteristics of chevron-type gasketed plate heat exchangers with three different plate geometries were investigated by Gulenoglu et al. [9]. The experiment was performed at a 30° chevron angle and Reynolds numbers between 300 and 5000. Corrugation patterns, port diameter, enlargement factor, and channel flow area strongly affected the thermal and hydraulic performance of a heat exchanger. They concluded that thermal and hydraulic characteristics were enhanced by decreasing the plate size.

Lee and Lee [10] numerically investigated the fluid flow in chevron-type plate heat exchangers by using large-eddy simulation (LES). The friction factor (f) and Colburn factor (j) were reported for chevron angles ranging between 30° and 60° and the ratio of chevron pitch to chevron height ranging between 2.0 and 4.4. The increase of the chevron angle and decrease of the ratio of the chevron pitch to the chevron height resulted in an enhanced friction factor and Colburn factor. They reported that the chevron angle should be 30° for laminar flow and 60° for turbulent flow to achieve optimum performance. Nilpueng and Wongwises [11] presented the influence of a rough surface on the thermal performance of water flow inside a plate heat exchanger. The roughness of the plate surface was generated by using a sand blasting machine. Corrugated plates with surface roughness ranging between 0.936 µm and 3.312 µm were investigated. The experimental results showed that the increase of surface roughness resulted in the enhancement of the exergetic efficiency.

The 3D-flow analysis of single-phase flow in brazed plate heat exchangers was numerically investigated and compared with results from the experiment conducted by Sarraf et al. [12]. The effects of the chevron angle on the flow behavior and pressure drops were presented. They stated that the flow behavior depended on the chevron angle and mass flow rate. The simulation showed that the friction coefficient increased when the chevron angle was increased. Lee and Lee [13] numerically and experimentally investigated the friction factor and Colburn factor of single-phase water flow along chevron-type plate heat exchangers. The effect of the chevron angle, chevron pitch, and chevron height on thermal performance was reported. It was found that the numerical result agreed well with the experimental data, with a maximum error of 10%. They reported that the optimal points appeared at a chevron angle of 66.5° and a ratio of chevron pitch to height p/h of 2.73.

Dvorak and Vit [14] simulated the flow and heat transfer of air-to-air counter flow inside plate heat exchangers. The effect of thickness on pressure loss and effectiveness was presented. The effect of plate thickness on the effectiveness depended on the thermal conductivity of the plate material used. They concluded that a thin material led to high effectiveness and low pressure loss. Kumar et al. [1] presented the effect of chevron angles on the comparative energetic and exergetic performance of nanofluid-water flow in a plate heat exchanger. The symmetric chevron angles of 30°/30° and 60°/60° and the mixed chevron angle of 30°/60° were tested in the experiment. They reported that optimum enhancement in the heat transfer rate ratio and heat transfer coefficient ratio was obtained at 60°/60° for 1.0% particle volume concentration. Giurgiu et al. [15] numerically studied the heat transfer of mini channels with angles of 30° and 60° inside plate heat exchangers. The distribution of velocity, temperature fields, and distribution of convection coefficient along the active mini channel were presented. They reported that the larger inclination angle value led to higher heat transfer. The results showed the best heat transfer for plate heat exchangers using mini channels with an inclination angle of 60°. Satitchaicharoen and Wongwises [16] investigated the effects of gap size, channel width, and liquid viscosity on the flow patterns of vertical