Renewable and Sustainable Energy Reviews 42 (2015) 240–253

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Theoretical and experimental thermodynamic analyses of a chevron type heat exchanger

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ARTICLE INFO

Keywords:
Chevron
Plate heat exchanger
Energy
Exergy
Efficiency
Optimum

ABSTRACT

In this study, the theoretical results of energy and exergy analyses of the chevron type heat exchanger are compared with experimental ones. A test ring is set up and water is used as working fluid. While mass flow rate of hot water was kept constant as 0.083 kg s^{-1}, the mass flow rate of cold water varies from 0.027 kg s^{-1} to 0.083 kg s^{-1}, the hot water temperature from 35 to 60 °C, cold water temperature from 21 to 25.35 °C in the experiments. The energy efficiency increases linearly with respect to hot water inlet temperature at the cold water mass flow rate values, however, in exergy efficiency, the optimum conditions comes out. Energy efficiency of the chevron type heat exchanger has the theoretical and experimental values ranging from 45% to 78%. When it comes to the exergy efficiency of the chevron type, the heat exchanger has the theoretical values ranging from 16% to 39.5% and experimental values from 13% to 47.8%. It is found that the theoretical results have a good agreement with the experimental ones.

Contents

1. Introduction

Heat exchangers are important heat transfer means, and used frequently in the processing, heat and power, air-conditioning, refrigeration, heat recovery, transportation and manufacturing industries. Chevron type heat exchangers are extensively used for heating, cooling and heat-regeneration applications in the chemical, food and pharmaceutical industries due to their high thermal efficiency, flexibility and ease of sanitation [1,2]. Also, it is extensively applied in heat pumps, gas/oil-fired boilers and district heating substations, air conditioning and refrigeration applications as well as solar energy and geothermal energy applications.

The first law of thermodynamics deals with the quantity of energy and asserts that energy cannot be created and destroyed. The second law, however, deals with quality of energy. More specifically, it is concerned with the degradation of energy during a process, entropy generation, and the lost opportunities to do work [3].

There are many studies in the literature focusing on heat transfer characteristics of the chevron type heat exchanger experimentally. Focke et al. studied the effect of the corrugation inclination angle on the thermal hydraulic performance of the plate heat exchangers. They tested experimentally seven different inclination

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http://dx.doi.org/10.1016/j.rser.2014.10.019
1364-0321/

Nomenclature

A	total effective area (m^2)
b	mean channel flow gap (m)
C_p	specific heat ($kJ\,kg^{-1}\,K^{-1}$)
D	diameter (m)
$\dot{E}x$	exergy rate (W)
G	mass velocity ($kg\,m^{-2}\,s^{-1}$)
H	enthalpy ($J\,kg^{-1}$), heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
$\dot{I}$	irreversibility (W)
k	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
L_w	effective channel width (m)
$\dot{m}$	mass flow rate ($kg\,s^{-1}$)
N_{cp}	number of channels per pass (–)
Nu	Nusselt number (–)
Re	Reynolds number (–)
s	entropy ($kJ\,kg^{-1}\,K^{-1}$)
t	plate thickness (m)
T	temperature (°C)
U	overall heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
$\dot{Q}$	heat transfer rate (W)
β	chevron angle (degrees)
Δ	difference
ε	efficiency (–)
ρ	density ($kg\,m^{-3}$)
Ψ	flow exergy (availability) (W)
μ	dynamic viscosity ($kg\,m^{-1}\,s^{-1}$)

Subscripts

b	bulk
c	cold
ch	channel
$dest$	destroyed
e	equivalent
f	fluid (water)
gen	generation
h	hot
in	inlet
LMTD	logarithmic mean temperature difference
m	mean
$mass$	mass
max	maximum
min	minimum
o	restricted dead state
out	outlet
p	plate
w	wall
I	energy
II	second law

angles (0, 30°, 45°, 60°, 72°, 80°, and 90°) for the Reynolds numbers between 100 and 10,000. Based on detailed experimental observations, they determine that a change in inclination angle affects the flow structure, which is the primary factor influencing the heat transfer efficient and fanning coefficient [4]. Gut and Pinto, in their work, presented an optimization algorithm for the configuration design of plate heat exchangers (PHEs). They saw that this algorithm can successfully select a group of optimal configurations (rather than a local single solution) for a given application using a much reduced number of pressure drop calculations and thermal simulations [5]. Galeazzo et al. developed using computational fluid dynamics (CFD) a virtual prototype of a four-channel plate heat exchanger with flat plates. They used water as test fluid on hot and cold sides of the PHE. They tested parallel and series flow arrangements and compared experimental results with numerical predictions for heat load obtained from the 3D CFD model and also from a 1D plug-flow model. They found out that CFD results are in good agreement with experimental data, especially for the series arrangement [6]. Ko investigated the entropy generation in double-sine duct, which is frequently used in plate heat exchangers, by numerical methods. They selected air as working fluid. They found that their results provide important information for the heat exchanger design since the thermal system could have the least irreversibility and best exergy utilization if the optimal aspect ratio is used according to the practical design conditions [7]. Jassim et al. investigated adiabatic pressure drop in chevron and two styles of bumpy plate heat exchangers for vertical upward flow with R134a. They developed a two-phase pressure drop model, based on the kinetic energy of the flow, in order to relate the two-phase pressure drop data to the single-phase data. They propounded that the model predicts two-phase pressure drop within 15% of experimental measurements [8]. Longo and Gasparella investigated the effect of heat flux, mass flux, saturation temperature, outlet conditions and fluids properties on heat transfer and pressure drop during HFC-134a, HFC-410A and HFC-236fa vaporization inside a small brazed plate heat exchanger. They indicated that HFC-410A shows heat transfer coefficients 40–50% higher than HFC-134a and 50–60% higher than HFC-236fa and frictional pressure drops 40–50% lower than HFC-134a and 50–60% lower than HFC-236fa [9]. Fernandes et al. analyzed fully developed laminar flows in double-sine chevron type PHEs passages to a Newtonian fluid with constant physical properties, using the finite-element computational fluid dynamics program POLYFLOW. They proposed relations to predict the tortuosity coefficient and shape factor, and also they predicted the coefficient K (Kozeny's coefficient in granular beds) resorting to the tortuosity coefficient and shape factor [10]. Luan et al. designed and investigated new-type corrugation plate heat exchanger (PHE) using water as working fluids. Results from both numerical simulations and experiments showed that the flow resistance of the working fluid in this new corrugation PHE, compared with the traditional chevron-type one, was decreased by more than 50%, and corresponding heat transfer performance was decreased by about 25% [11]. Fernandes et al. numerically studied laminar flows of Newtonian and power-law fluids through cross-corrugated chevron type plate heat exchangers (PHEs) in terms of the geometry of the channels. They showed that the flow index behavior influences the velocity profiles and the magnitude of the average interstitial velocity and as a result of this effect, for each corrugation angle, the tortuosity coefficient decreases with the decrease of the referred index [12]. Longo presented the experimental tests on HFC-134a condensation inside a small brazed plate heat exchanger in which the effects of refrigerant mass flux, saturation temperature and vapor super-heating were investigated [13]. Tsai et al. investigated the hydrodynamic characteristics and distribution of flow in two cross-corrugated channels of plate heat exchangers using water as the test fluid. They conducted a three-dimensional model with the real-size geometry of the two cross-corrugated channels provided by chevron plates and taking into account the inlet and outlet ports for the numerical study. They showed that the numerical results have been validated with the measurements taken by laboratory