Energy Conversion and Management 118 (2016) 75–87

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Effect of discontinuous helical turbulators on heat transfer characteristics of double pipe water to air heat exchanger

M. Sheikholeslami *, M. Gorji-Bandpy, D.D. Ganji

Department of Mechanical Engineering, Babol University of Technology, Babol, Iran

ARTICLE INFO

Article history:
Received 5 January 2016
Received in revised form 13 March 2016
Accepted 26 March 2016

Keywords:
Discontinuous helical turbulators
Air to water heat exchanger
Double pipe
Friction
Heat transfer
NSGA II

ABSTRACT

Effect of typical and perforated discontinuous helical turbulators on flow and heat transfer in an air to water double pipe heat exchanger is experimentally studied. Experimental analysis is conducted for different values of open area ratio (0–0.0625), Reynolds number (6000–12,000) and pitch ratio (1.83–5.83). According to experimental data, correlations for Nusselt number, friction factor and thermal performance are presented as functions of variable parameters. Non-dominated Sorting Genetic Algorithm II (NSGA II) is applied to find the optimal designs of high efficiency heat exchanger. Pareto front is presented as set of multiple optimum solutions. Results show that friction factor and Nusselt number reduce with rise of open area ratio and pitch ratio. Thermal performance is an increasing function of open area ratio while it is a decreasing function of pitch ratio.

1. Introduction

Growth heat transfer improvement methods have been happened due to significance of improving the thermal performance of heat exchangers. These approaches improve convective heat transfer by decreasing the thermal resistance but at the cost of improve in pressure loss. A novel shell and tube heat exchanger with plate baffles was proposed by Yang and Liu [1]. They analyzed the temperature field, pressure field and path lines to demonstrate the advantage of their new heat exchanger. The heat transfer performance of porous-microchannels was studied by Dehghan et al. [2]. They found that porous inserts are more effective in the slip flow regime. Chen et al. [3] investigated performances of trisection helical baffled heat exchangers. They showed that both the shell side heat transfer coefficient and pressure drop increase. A new design of a finned double-pipe heat exchanger with longitudinal fins was presented by Syed et al. [4]. Their results indicated that the ratio of tip to base angles has proved to play significant role in the design of a double-pipe heat exchanger in reducing the cost, weight and frictional loss. Effect of porous baffles and flow pulsation on a double pipe heat exchanger performance was studied by Targui and Kahalerras [5]. They proved that the addition of oscillating components to the mean flow affects the flow structure, and enhances the heat transfer. Improvement of Nusselt number in a pipe with circular ring has been studied by Ozceyhan et al. [6]. They showed that the maximum overall improvement is 18% which is obtained at $Re = 15,600$. Effects of combined ribs and winglet type vortex generators (WVGs) on forced convection heat transfer and friction loss behaviors were investigated by Promvonge et al. [7]. They concluded that the values of Nusselt number and friction factor for utilizing both the rib and the WVGs are found to be considerably higher than those for using the rib or the WVGs alone.

Experimental investigation of thermal performance of solar water heater system fitted with helical and Left–Right twist has been performed by Jaisankar et al. [8]. They showed that the helical twisted tape induces swirl flow inside the riser tubes unidirectional over the length. Bayrak et al. [9] analyzed exergy and energy of solar air heaters with permeable baffles. They showed that maximum performance is obtained for thickness of 6 mm. Influence of rib height and inlet temperature of fluid on thermal performance was presented by Ma et al. [10]. They showed that the style of flow has no variation with changing of inlet temperature. Ibrahim [11] used helical screw-tape inserts in order to augmentation of laminar flow and heat transfer in flat tubes. They showed that averaged Nusselt number enhances with the rise in Reynolds number and with the decrease in twist ratio and spacer length. Sheikholeslami et al. [12] studied about swirl flow devices effect on fluid flow and heat transfer. To improve heat transfer, combined swirl generator and conical-nozzle inserts were used by Promvonge and

* Corresponding author.
E-mail addresses: mohsen.sheikholeslami@yahoo.com, m.sheikholeslami@stu.nit.ac.ir (M. Sheikholeslami), mirgang@nit.ac.ir (D.D. Ganji).

http://dx.doi.org/10.1016/j.enconman.2016.03.080
0196-8904/

Nomenclature

A	heat transfer area
d, D	inner and outer pipe diameter
f	Darcy friction factor (dimensionless)
ℓ	length of pipe
L	length of test section
Nu	Nusselt number
N	number of perforated hole
Pr	Prandtl number
P	pressure
PR	pitch ratio ($=P/D_o$)
Q	flow rate of water
Re_a	air flow reynolds number
T	fluid temperature
U	coefficient of overall heat transfer

Greek symbols

α	thermal diffusivity
λ	open area ratio $\left(=Nd_s^2/\left((D_o+2h)^2-D_o^2\right)\right)$
μ	dynamic viscosity of nanofluid
ρ	density
η	thermal performance

Subscripts

i	inner
o	outer
a	air
w	water
s	smooth pipe

Eiamsa-ard [13]. They showed that this method can improve rate of heat transfer up to 316%. Vibration behavior of conical ring was utilized by Yakut and Sahin [14] for increasing thermal performance. They concluded that maximum heat transfer occurs at the smallest pitch ratio.

Water to air heat exchangers are one of the significant kinds of heat exchangers. Some of the uses of them are dehumidification, air conditioning, residential heating and apartment buildings. Sheikholeslami et al. [15] studied the turbulent flow and heat transfer in water to air double pipe heat exchanger. Sheikholeslami et al. [16] used agitator in water side to improve rate of heat transfer. They showed that effects of agitator are more pronounced for low Reynolds number. Recently, several authors studied about thermal enhancement methods [17–35].

The aim of this article is to study the effects of discontinuous helical turbulators on pressure drop and heat transfer improvement in an air to water double pipe heat exchanger. Experimental set up and formulas for measuring of η, Nu and f are presented. The impacts of open area ratio, pitch ratio and Reynolds number on pressure drop and heat transfer rate are studied. Also Non-dominated Sorting Genetic Algorithm II (NSGA II) is used to find the optimal designs of high efficiency heat exchanger.

2. Experimental technique

Experimental set up depicts in Fig. 1(a). In this set up: $D_i = 2.8$ cm, $D_o = 3$ cm, $d_i = 5$ cm, $d_o = 6$ cm. The length of the pipe is $\ell = 2$ m and the length of test section is $L = 1.2$ m. Hot water and cold air are passed through the inner and outer pipes, respectively. Three heaters are used in the upper tank with the capacity of 2 kW, 2 kW and 3 kW. The inner tube is made from copper ($k = 300$ kcal/(m h °C)), while the outer tube is made from Plexiglas ($k = 5 \times 10^{-4}$ kcal/(m h °C)). T_1, T_2, T_{air1}, T_{air2}, $T_{w1}, \ldots, T_{w6}$ and $T_{a1}, \ldots, T_{a4}$ were measured with Sheathe type thermocouples (element C.A; class 0.75) (Fig. 1(b)). An ST-8920 differential pressure is used to obtain the pressure drop in air side. It can measure the pressures in ±5000 Pa with 1 Pa resolution. In order to transfer the water from the lower tank to upper tank, a pump with the head of 5.5 m, is used. The 0.75 kW blower directed the air with $T_{air1} = 28$ °C to orifice meter. SV008iG5A-2 inverter is utilized to adjust air flow rate by changing the motor speed. Water flow rates are controlled with valves and measured with rotameter. The experimental work is done for counter flow state. The physical properties of air and water are variable with temperature as illustrated in Tables 1 and 2. In the test section, typical and perforated discontinuous helical turbulators are used in order to heat transfer enhancement (Fig. 2). Schultz and Cole method [36] is used for uncertainty analysis:

$$U_R = \left[\sum_{i=1}^{n}\left(\frac{\partial R}{\partial V_i}U_{V_i}\right)^2\right]^{1/2} \tag{1}$$

where U_R is the total error, U_{V_i} is the error of each independent parameter and n is the number of total parameters. Table 3 shows the uncertainties of the experimental parameters. The uncertainty analysis showed that the measuring errors were less than 10% for all the experiments presented in this study.

3. Measurement of coefficients of pressure loss and heat transfer rate

The method for determination friction factor and Nusselt number is summarized as follows:

$\dot{Q}_a$ is heat transferred to the cold fluid:

$$\dot{Q}_a = (T_{a,out} - T_{a,in})C_{p,a}\dot{m}_a \tag{2}$$

where $C_{p,a}, \dot{m}_a$ are specific heat and the rate of mass flow for air, respectively.

$\dot{Q}_w$ is heat transferred from the water:

$$\dot{Q}_w = (T_{w,in} - T_{w,out})C_{p,w}\dot{m}_w \tag{3}$$

where $C_{p,w}$, $\dot{m}_w$ are the specific heat and the rate of mass flow for water, respectively.

$\dot{Q}_{ave}$ is average heat transfer rate which is defined as follows:

$$\dot{Q}_{ave} = (\dot{Q}_a + \dot{Q}_w)/2 \tag{4}$$

h_i is the water side coefficient of heat transfer which is defined as follows:

$$\dot{Q}_{ave} = (T_{w,ave} - T_{s,ave})h_iA_i \tag{5}$$

where $A_i = \pi D_i L$.

U_i is coefficient of overall heat transfer can be defined as follows:

$$\dot{Q}_{ave} = U_iA_i\Delta T_{LMTD} \tag{6}$$

where ΔT_{LMTD} is $(= (\Delta T_1 - \Delta T_2)/Ln(\Delta T_1/\Delta T_2))$.

h_o is air side coefficient of heat transfer, obtained from:

$$\frac{1}{U_iA_i} = \frac{1}{h_oA_o} + \frac{\ln(D_o/D_i)}{2\pi k_{Cu}L} + \frac{1}{h_iA_i} \tag{7}$$

Average Nusselt number along the air side of inner pipe was calculated as follows: