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Experimental study on turbulent flow and heat transfer in an air to water heat exchanger using perforated circular-ring

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ABSTRACT

In this study, heat transfer and pressure loss in an air to water double pipe heat exchanger are experimentally investigated. Typical circular-ring (TCR) and perforated circular-ring (PCR) turbulators are placed in annular pipe. The working fluids are air, flowing in the annular pipe, and water through the inner circular tube. The experiments are conducted for different governing parameters namely; air flow Reynolds number (6000–12,000), pitch ratio (1.83, 2.92 and 5.83) and number of perforated hole (0, 2, 4 and 8). Correlations for friction factor, Nusselt number and thermal performance are presented according to experimental data. Results indicated that using PCRs leads to obtain lower heat transfer enhancement than the CRs because of reduction of intersection angle between the velocity and the temperature field. Thermal performance increases with increase of N but it decreases with increase of Reynolds number and pitch ratio.

1. Introduction

One of the significant types of heat exchanger is air to water heat exchanger. This kind of heat exchanger has various applications such as: apartment buildings and condominiums, residential heating, hybrid systems, air conditioning, dehumidification. Utilize of augmentation techniques lead to increase in heat transfer coefficient but at the cost of enhance in pressure drop. To reach high heat transfer rate while taking care of the augment pumping power, various techniques have been presented in recent decade. Currently, swirl flow devices have widely been used for increasing the convective heat transfer in various industries. This application is because of their low cost and easy setting up. Vermahmoudi et al. [1] studied the overall heat transfer coefficient of water based iron oxide nanofluid in a compact air cooled heat exchanger. They indicated that the overall heat transfer coefficient and the heat transfer rate of nanofluid have been improved with increase of air flow Reynolds number. Buchlin [2] investigated effect of perforated ribs in a channel flow. He tested five types of perforated ribs made in Plexiglas and found that the optimum design of ribs combines a rib pitch ratio of 5 with an open area ratio of 0.53. Promvonge and Eiamsa-ard [3] presented the effect of a free-spacing snail entry together with conical-nozzle turbulators on turbulent heat transfer and friction characteristics in a uniform heat-flux tube. Bayrak et al. [4] studied the performance assessment of porous baffles inserted in solar air heaters (SAHs). They showed that the highest collector efficiency and air temperature rise are achieved by SAHs with a thickness of 6 mm and an air mass flow rate of 0.025 kg/s. Sheikholeslami et al. [5] studied about swirl flow devices effect on fluid flow and heat transfer.

Helical-wire-coils fitted inside a round tube have been experimentally studied by Garcia et al. [6]. They found that wire coil inserts offer their best performance within the transition region. Response surface methodology (RSM) based on central composite design (CCD) was applied by Hatami et al. [7] to obtain an optimization design of finned type heat exchangers (HEX) to recover waste heat from the exhaust of a diesel engine. Parametric analysis and optimization of entropy generation in unsteady MHD flow over a stretching rotating disk was investigated by Rashidi et al. [8]. Durmus et al. [9] used snail entrance in order to increase heat transfer in concentric double-pipe heat exchangers. They concluded that the swirl flow effect of the snail caused some increase in pressure drop while this effect was unimportant compared with the improvement in heat transfer capacity. Bandos et al. [10] studied the effects of thermal storage and vertical temperature variations on energy pile heat exchangers. Promvonge and Eiamsa-ard [11] used combined conical-nozzle inserts and swirl generator in

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Nomenclature

A	heat transfer area
A_i	inner pipe inside surface area
A_o	inner pipe outer surface area
c_p	specific heat at constant pressure
d	diameter of inner pipe
D	diameter of outer pipe
f	friction factor (dimensionless)
h_o	average heat transfer coefficient of cold fluid
h_i	average heat transfer coefficient of hot fluid
k	thermal conductivity
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	Reynolds number
T	fluid temperature
U	overall heat transfer coefficient

Greek symbols

α	thermal diffusivity
ΔP	pressure drop (Pa)
μ	dynamic viscosity of nanofluid
θ	dimensionless temperature
ρ	density
η	thermal performance

Subscripts

i	inner
o	outer
a	air
w	water
s	smooth pipe

order to enhance in heat transfer. They showed that use of the conical nozzle in common with the snail leads to a maximum heat transfer rate that is up by 316%. Free convection heat transfer in a concentric annulus between a cold square and heated elliptic cylinders in presence of magnetic field was investigated by Sheikholeslami et al. [12]. They found that the enhancement in heat transfer increases as Hartmann number increases but it decreases with increase of Rayleigh number. Yakut and Sahin [13] used conical-ring turbulators placed inside the tube to produce reverse flows in each module of the conical rings. In their experimental study, the level of the reverse flow (re-circulation flow) was generated from the separation and reattachment of a boundary layer from different pitch lengths between the modules.

The main purpose of this paper is to investigate the effect of typical circular-ring (TCR) and perforated circular-ring (PCR) turbulators on flow and heat transfer in an air to water double pipe heat exchanger. Experimental set up and formulas for calculating heat transfer rate, friction factor and thermal performance are presented. The effects of Reynolds number, pitch ratio and number of perforated hole on heat transfer rate and pressure drop are studied.

2. Experimental set-up and procedure

The experimental set-up is shown in Fig. 1(a). The dimensions of the inner and outer pipes of the heat exchanger are: $D_i = 2.8$ 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 is passed through the inner pipe, while cold air is flowing through the annulus. Heating of the water was achieved with an electrical heater at the upper tank (three heaters are used in the upper tank with the capacity of 2 kW, 2 kW and 3 kW). In the experimental work, it is intended to search for the changes in the heat transfer coefficients of the air side turbulent flow by affecting the regions near the wall of the pipe flow. The inner tube is made from copper with thermal conductivity ($k = 300$ kcal/(m h °C)), while the outer tube is made from Plexiglas with an outer with thermal conductivity ($k = 5 \times 10^{-4}$ kcal/(m h °C)). The inlet and outlet temperatures of the fluids (air and water), the temperatures of the points on the inner pipe wall (six points), the temperatures of four points in different distant from inner wall and ambient temperature 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 inlet bulk air at 28 °C from a 0.75 kW blower was directed through an orifice meter and passed to the heat transfer test section. The volumetric air flow rates from the blower, situated before the inlet of the test tube, are adjusted by varying the motor speed through the SV008iG5A-2 inverter. The flow rates of the water are adjusted with valves and measured with rotameter. The experimental work is repeated for counter flow modes at various Reynolds numbers. The physical properties of air and water are variable with temperature as illustrated in Tables 1 and 2. In the test section, circular ring are used in order to heat transfer enhancement. Also perforated circular ring have been used in this study (Fig. 2).

Table 1
Temperature-dependent properties of air.

Coefficient	$A_1 + A_2 \times T + A_3 \times T^2 + A_4 \times T^3 + A_5 \times T^4$ Properties of air			
	ρ (kg/m^3)	C_p (J/(kg K))	μ (kg/(m s))	k (W/(m K))
A_1	4.5399557047065677	1.0540764984602797E+3	9.4680032779877928E−5	1.8028147194179223E−2
A_2	−2.3244292640615217E−2	−3.5067618164922393E−1	−1.0222587861878098E−6	−1.6851766935888901E−4
A_3	5.6404522707476041E−5	5.8416753365658986E−4	4.7054455296163551E−9	1.3838388187738584E−6
A_4	−6.2803748539876179E−8	3.0329858178609656E−7	−9.1119064881185846E−12	−3.2630462746304979E−9
A_5	2.3678170919661321E−11	−5.2479296621138882E−10	6.5461225665736524E−15	2.7514584927209003E−12