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Research paper

# Experimental study of the influence of perforated circular-ring on pressure loss and heat transfer enhancement using sensitivity analysis

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## HIGHLIGHTS

- Perforated circular rings are used in an air to water heat exchanger.
- Friction factor rises with increase of pitch ratio.
- Nusselt number is an increasing function of pitch ratio.
- Thermal performance rises with increase of open area ratio.

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## ABSTRACT

Experimental analysis on pressure loss and heat transfer improvement in an air to water double pipe heat exchanger is presented. Typical circular-ring (TCR) and perforated circular-ring (PCR) turbulators, assumed as turbulators. Water and air move through inner and outer pipes, respectively. Experimental analysis is conducted for various values of open area ratio (0, 0.0208, 0.0416 and 0.0833), Reynolds number (6000, 8000, 10,000 and 12,000) and pitch ratio (1.83, 2.92 and 5.83). According to experimental data, correlations for Nusselt number, friction factor and thermal performance are presented as functions of Reynolds number, pitch ratio and open area ratio. Sensitivity analysis is used to find the effect of each active parameter. Results indicated that using PCRs leads to obtain lower heat transfer enhancement than the CRs. Thermal performance increases with increase of open area ratio but it reduces with rise of pitch ratio and Reynolds number. The most effective parameter for thermal performance is open area ratio.

## 1. Introduction

Heat exchangers have several applications in different processes ranging from conversion, utilization and recovery of thermal energy in different industrial, commercial and domestic uses. Some public examples include condensation in power, steam generation, cooling in thermal processing of chemical, sensible heating, cogeneration plants, agricultural products, pharmaceutical, waste heat recovery and fluid heating in manufacturing. One of the important types of heat exchangers is air to water heat exchangers. These heat exchangers have different applications like dehumidification, residential heating, air conditioning and apartment buildings. The importance of increasing the thermal performance of heat exchangers has caused development for different ways of heat transfer improvement. These methods increase convective heat transfer by decreasing the thermal resistance in a heat exchanger. Utilize of augmentation techniques lead to enhance in heat transfer coefficient but at the cost of enhance in pressure loss. Recently, various techniques have been presented to obtain high heat transfer rate while taking care of the augment pressure loss. The reverse flow device or the turbulator is widely employed in heat transfer engineering applications. The effects of reverse flow and boundary layer disruption are to enhance the heat transfer coefficient and momentum transfers. The reverse flow with high turbulent flow can improve convection to the tube wall by increasing the effective axial Reynolds number, decreasing the cross-section flow area and increasing the mean velocity and temperature gradient.

Vermahmoudi et al. [1] investigated $Al_2O_3$–water nanofluid heat transfer improvement in a radiator. Their result indicated that rate of heat transfer improves with enhance of air flow Reynolds number and nanofluid volume fraction. Turbulent force convection

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**Nomenclature**

| | |
|---|---|
| $A$ | heat transfer area |
| $A_i$ | inner heat transfer area ($=\pi D_i L$) |
| $A_o$ | outer heat transfer area ($=\pi D_o L$) |
| $d$,$D$ | inner and outer pipe diameter |
| $f$ | Darcy friction factor (dimensionless) |
| $\ell$ | length of pipe |
| $L$ | length of test section |
| $Nu$ | Nusselt number |
| $N$ | number of perforated hole |
| $Pr$ | Prandtl number |
| $P$ | pressure |
| $PR$ | pitch ratio ($=P/D_o$) |
| $w$ | volume flow rate |
| $Re_a$ | air flow Reynolds number ($=\rho_a v_a D_H/\mu_a$) |
| $S_o$ | air side area ($= 0.25\pi(d_i^2 - D_o^2)$) |
| $T$ | fluid temperature |
| $U$ | coefficient of overall heat transfer |

*Greek symbols*

| | |
|---|---|
| $\alpha$ | thermal diffusivity |
| $\lambda$ | open area ratio ($= Nd_s^2/(d_i^2 - D_o^2)$) |
| $\mu$ | dynamic viscosity of nanofluid |
| $\theta$ | dimensionless temperature |
| $\rho$ | density |
| $\eta$ | thermal performance |

*Subscripts*

| | |
|---|---|
| $i$ | inner |
| $o$ | outer |
| $a$ | air |
| $w$ | water |
| $s$ | smooth pipe |

in an air cooled duct was investigated by Leung et al. [2]. They showed that thermal performance has no change with variation of rib size. Selleri et al. [3] proposed the mathematical model for a mini-channel heat exchanger. They used multi objective optimization using genetic algorithm in order to obtain a set of geometrical design parameters, leading to minimum pressure drops and maximum overall heat transfer coefficient. Zohir et al. [4] investigated the influence of pulsation on the heat transfer rates in a double-pipe heat exchanger. They indicated that pulsation of high frequency and amplitudes in a concentric tube equipped with coiled wires enhances heat transfer rates significantly.

Zhou and Ye [5] investigated the thermohydraulic performance of curved trapezoidal winglet as shown in Fig. 13. They observed that curved trapezoidal winglet delta winglet had the best thermohydraulic performance in fully turbulent flow region. Influence of rib height and inlet temperature of fluid on thermal performance was presented by Ma et al. [6]. They showed that the style of flow has no variation with changing of inlet temperature. Garcia et al. [7] analyzed hydrothermal behavior of three types of enhancement technique based on artificial roughness: corrugated tubes, dimpled tubes and wire coils. Their results showed that the shape of the artificial roughness exerts a greater influence on the pressure drop characteristics than on the heat transfer augmentation. Chokphoemphun et al. [8] presented an experimental investigation on enhanced heat transfer and pressure loss characteristics by using single, double, triple, and quadruple twisted-tape inserts in a round tube having a uniform heat-fluxed wall. Their results showed that the thermal enhancement factor of the inserted tube under similar pumping power is found to be above unity except for the single and the double co-twisted tapes. The quadruple counter-twisted tape insert provides the maximum thermal performance.

Durmus et al. [9] used snail entrance to improve Nusselt number in a double-pipe heat exchanger. They concluded that this device can improve the thermal performance. To improve heat transfer, combined swirl generator and conical-nozzle inserts were used by Promvonge and Eiamsa-ard [10]. They showed that this technique can improver rate of heat transfer up to 316%. Multi-objective optimal designs of high efficiency corrugated tube heat exchangers applied in nuclear plants were presented by Han et al. [11]. They revealed that augmenting the heat transfer performance caused by various design parameters in the optimum situation would lead to the increase of the resistance. Recently, several papers have been published about the application of different methods of heat transfer enhancement [12–18].

The aim of this article is to examine the influence of typical circular-ring (TCR) and perforated circular-ring (PCR) turbulators on pressure drop and improvement of heat transfer in an air to water double pipe heat exchanger. Experimental setup and formulas for measuring of $Nu$ 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 sensitivity analysis is used to find the effect of each active parameter.

## 2. Experimental technique

Fig. 1(a) depicts the experimental set-up. In this setup: $D_i = 2.8$ 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 of copper with thermal conductivity ($k = 348.66$ W/(m °C)), while the outer tube is made from Plexiglas with an outer with thermal conductivity ($k = 0.2092$ W/(m °C)). $T_1$, $T_2$, $T_{air1}$, $T_{air2}$, $T_{w1}$,...,$T_{w6}$ and $t_{a1}$,...,$t_{a4}$ were measured with Sheathed 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 repeated for counter flow state. 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).

Schultz and Cole method [19] 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 $\mathrm{U_R}$ is the total error, $U_{V_i}$ is the error of each independent parameter and $n$ is the number of total parameters. Uncertainties of