International Communications in Heat and Mass Transfer 39 (2012) 161–166

Contents lists available at SciVerse ScienceDirect

International Communications in Heat and Mass Transfer

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

Improvement of heat transfer with perforated circular holes in finned tubes of air-cooled heat exchanger☆

Dong H. Lee [a], Jin M. Jung [b], Jong H. Ha [c], Young I. Cho [b,*]

[a] Department of Mechanical Design Engineering, Engineering College, Chonbuk National University, Jeonju, Jeonbuk, Republic of Korea
[b] Department of Mechanical Engineering and Mechanics, Drexel University, Philadelphia, Pennsylvania, USA
[c] Korea Heat Exchanger Co. Ltd, Gunsan, Jeonbuk, Republic of Korea

ARTICLE INFO

Available online 11 December 2011

Keywords:
Heat exchanger
Finned tube
Perforation
Circular fin

ABSTRACT

The present study investigated the effect of perforated circular finned-tube (PCFT) on the convective heat transfer performance of circular finned-tube heat exchangers. The air-side convective heat transfer coefficients increased by 3.55% and 3.31% for 2-hole and 4-hole PCFT cases, respectively. The increase in the convective heat transfer coefficient was related to the reduction of the recirculation region by introducing the perforations at the flow-separation locations on the finned tube. The pressure drop across the finned-tube bundles increased by 0.68% and 2.08% for the 2-hole PCFT and 4-hole PCFT cases, respectively. The greater pressure drop in the case of the 4-hole PCFT might be due to excessive flow disturbances produced by multiple perforations. The fin factor defined as the ratio of the % increase of the convective heat transfer coefficient and that of the pressure drop was 5.19 for the 2-hole PCFT case, whereas that was 1.59 for the 4-hole PCFT case.

1. Introduction

Heat exchangers are used in a number of applications such as refrigeration, air conditioning, space heating, thermo-electric power plants, etc. [1,2]. In an air-cooled heat exchanger, heat transfer takes place from a hot liquid flowing inside tube to air flowing in the outside of the tube. Since the dominant thermal resistance occurs on the air side, the various fins have been employed on the air side to increase the total surface area so that the air-side heat transfer performance of heat exchangers can be improved [3,4].

A circular finned tube has been widely utilized due to its low manufacturing cost. In addition, the circular finned-tube heat exchangers have been known with a high efficiency [5,6]. Heat transfer characteristics at the air side have been studied with various fin geometries with both experimental and analytical methods to improve the performance of the finned-tube heat exchanger [5].

Stasiulevicius et al. [7] developed correlations of the convective heat transfer coefficient and resistance of finned-tube bundles in a cross flow including the effects of geometric parameters of fins and tube arrangement within the bundle. Lee et al. [5] investigated a spiral-type circular finned-tube heat exchanger in terms of fin pitch, the number of rows, fin alignment, and heat exchanger geometry in comparison with a flat-plate finned-tube heat exchangers. Tang et al. [8] experimentally studied both heat transfer and frictional characteristics with five different fin configurations for multiple rows of tubes, including a genetic algorithm optimization. Nuntaphan et al. [9] examined the performance of ten cross-flow heat exchangers with a crimped spiral-fin type under dehumidification applications and showed the important role of transverse tube pitch and tube arrangement. Mon et al. [10] numerically investigated the effect of the ratio of fin-spacing to height on the unsteady flow and heat transfer performance in an annular finned-tube heat exchanger using a numerical renormalization group theory.

As seen from the aforementioned literatures, a number of techniques have been studied to enhance the convective heat transfer performance of circular finned-tube heat exchangers [5]. However, most of these studies focused on the effects of the finned-tube arrangement and fin geometry (i.e. fin size, fin spacing, fin pitch, etc.) on the convective heat transfer performance, and the results were compared with other fin configurations such as plate and wavy types. The objective of the present study was to investigate whether or not a perforated circular finned tube (PCFT) could reduce the air-side recirculation region behind the finned tube and thus enhance the convective heat transfer performance. The air-side heat transfer characteristics of the PCFT were experimentally studied by determining the changes in the convective heat transfer coefficient and the corresponding pressure drop for different numbers of the perforations on the finned tubes.

2. Methods

2.1. Experimental setup

Fig. 1 presents the schematic diagram of the present bench-scale heat exchanger test setup where cooling air flew over multiple rows of finned tubes. The airflow was generated by a centrifugal air blower,

☆ Communicated by: W.J. Minkowycz.
* Corresponding author. Tel.: +1 215 895 2425; fax: +1 215 895 1478.
E-mail address: choyi@drexel.edu (Y.I. Cho).

0735-1933/$ – see front matter
doi:10.1016/j.icheatmasstransfer.2011.11.009

Nomenclature

A_f	Surface area of fin (m^2)
A_0	Total air-side surface area of finned tube (m^2)
A_w	Internal surface area of water side (m^2)
C_p	Specific heat (J kg^{-1} K^{-1})
d_i	Inner diameter of tube (mm)
d_o	Outer diameter of tube (mm)
f_i	Friction factor of water flow
h_0	Convective heat transfer coefficient of air side (W m^{-2} K^{-1})
h_w	Convective heat transfer coefficient of water side (W m^{-2} K^{-1})
k_{st}	Thermal conductivity of stainless steel tube (W m^{-1} K^{-1})
k_w	Thermal conductivity of tube wall (W m^{-1} K^{-1})
$\dot{m}$	Mass flow rate (kg s^{-1})
P_t	Transverse tube pitch (mm)
P_l	Longitudinal tube pitch (mm)
Pr	Prandtl number at the water side
q_a	Air-side heat transfer rate (W)
q_w	Water-side heat transfer rate (W)
q_m	Mean heat transfer rate (W)
r_c	Outer diameter of tube (mm)
Re_{Di}	Reynolds number at water side
R_{eq}	Equivalent radius of circular tube (mm)
R_t	Conductive thermal resistance of tube wall (m^2 K W^{-1})
Y_f	Fouling resistance (m^2 K W^{-1})
U	Overall heat transfer coefficient (W m^{-2} K^{-1})

Greek symbols

ΔT_{LMTD}	Log mean temperature difference (°C)
η_0	Surface effectiveness
η_f	Fin efficiency
μ	Dynamic viscosity (kg m^{-1} s^{-1})
ρ	Density (kg m^{-3})

Subscripts

c	Cold side
h	Hot side
i	Inlet
o	Outlet

SMB-9 Utility Blower (9 3/16″ Wheel diameter, American Fan Company, USA) with a fixed flow rate of about 1,700 CFM. Rectangular air duct with a cross-sectional area of 300 mm × 300 mm was used for air passage. The heat exchanger test section with perforated circular finned tubes (PCFT) was located in the middle of the duct.

Parameters measured in the study included temperatures of air at both the inlet and outlet, the mass flow rate of air at the inlet, and the pressure drop of air across the heat exchanger, temperatures of hot water at both the inlet and outlet of water, and the mass flow rate of water. In order to enhance the mixture of air stream and obtain accurate mean temperature data of air at both the inlet and outlet of the duct, honey comb meshes made of 1-mm-thick perforated aluminum were installed.

Fig. 2 shows the arrangement of four T-type thermocouples used for temperature measurements of air stream, which were calibrated to ±0.1 °C accuracy. Anemometer (Hot-wire type, Model. 407123, Extech, MA) was located upstream of the tube bundle to measure the flow velocity of air. The range of the flow velocity varied in 0.2–20.0 m/s with a measurement resolution of ±3% accuracy. The mass flow rate of air was calculated from the measured flow velocity and the frontal area of the heat exchanger. The pressure drop of air across the heat exchanger section was measured by a 45-degree inclined U-tube manometer, which was connected to four pressure taps at the upstream area and another four pressure taps at the downstream area of the heat exchanger test section.

For water side, the mass flow rate at the inlet and four temperatures at both inlet and outlet were measured. A constant-temperature water bath was used to provide hot water and regulate the temperature of water at around 45 °C. The hot water was circulated by a centrifugal pump (COMBB 33, Close-Couplued, 3/4 HP, 60 Hz, AC, Shertech, MN), where the maximum flow rate was 0.27 m^3/min. The temperature of hot water at both the inlet and outlet were measured using T-type thermocouples which were calibrated to ±0.1 °C accuracy. The mass flow rate of water was measured and recorded by a mass flow meter (Model 1700 transmitter, R-Series sensor, Micro Motion) with ±0.03% accuracy.

The sensors such as the thermocouples and flow meters were connected to a LabVIEW DAQ system for continuous monitoring, calculating and recording of the collected data. The test section, thermocouples, and flow meters were wrapped with fiberglass insulation blanket to minimize heat loss to the surroundings. Both air and water leakages were checked to ensure that the experimental system operated with minimal heat loss.

2.2. Perforated finned tube

In the present study, three different types of circular finned tubes having different numbers of perforations per fin (plain circular finned tube with no perforation, 2-hole PCFT, 4-hole PCFT) were tested as shown in Fig. 3. Detailed geometric parameters of the circular fin are listed in Table 1.

Fins were prepared with multiple perforations, each with 5 mm in diameter. As shown in Fig. 4, for 2-hole PCFT, two perforations were located at an angle of 120° from the leading edge on both top and bottom sides of the fin. Similarly, 4-hole PCFT was prepared at two angular locations of 90° and 120° from the leading edge also on both top and bottom sides of the fin.

Figs. 4 and 5 show the schematic details of the heat exchanger used in the study. The cross section of the main heat exchanger with PCFTs was 200 mm × 250 mm, where circular stainless-steel finned tubes were arranged in a staggered manner, consisted of 4 rows with each row composed of 3 finned tubes.

2.3. Test conditions

The experiment was performed with an inlet air velocity of 4 m/s, an inlet air temperature of 25 °C, a mass flow rate of water of 21 kg/min, and an inlet water temperature of 45 °C. The air blower was pre-warmed for approximately an hour prior to heat transfer tests to ensure a steady air flow inside the air duct during experiment. Once the heat transfer test was started, the temperature, pressure, and flow rate data were saved 30 min after all the test conditions such as air and water temperatures, pressure drop, and flow rates of both air and water were confirmed to reach stable states.

2.4. Data acquisition and related calculations

Using the present experimental setup, the air-side convective heat transfer coefficient was calculated from the collected data. In order to perform experimental analysis, the following assumptions were made to describe the characteristics of air-side heat transfer behavior.

1. The heat exchanger was fully insulated from the surroundings so that the heat was transferred from the hot-water side to the cold-air side only.