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An experimental investigation on heat transfer enhancement of sprayed wire-mesh heat exchangers

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ABSTRACT

Three different porosities of aluminum wire meshes (10PPI, 14PPI, 20PPI) and three different diameters of aluminum wires were used to fabricate heat exchangers by connecting aluminum tubes to increase the heat transfer surface area. A twin wire-arc thermal spraying system can generate a dense, high strength aluminum coating to connect wires and aluminum tube. Tiled and clamped connections between the wire mesh and tube were applied to obtain an efficient heat exchanger. The heat transfer characteristics for plain tube, three sprayed tube-wire and six sprayed wire-meshes (SPW) heat exchangers were experimentally tested. Also, heat exchanger surface temperatures were measured using infrared camera. Ideal fin model was applied after validation using data of sprayed tube-wire heat exchangers. The tube inlet temperature ranged from 100 to 200 °C and the wind tunnel air velocity was from 2 to 20 m/s. The results indicate that all the SPW heat exchangers can enhance the heat transfer compared with plain tube heat exchanger. Tube outside Nusselt number was fitted with Reynolds number and wire mesh porosity. 20PPI clamped SPW was suggested to be used in the future design of compact heat exchangers due to the maximum 76.7% equivalent efficiency compared with ideal fin model.

1. Introduction

Compact heat exchangers are widely used in various applications, including air-conditioning evaporators and condensers, electronic cooling devices, waste heat recovery system and cryogenic exchangers [1]. To meet the needs of lightweight, space-saving and economical, extended surfaces with large surface area/volume ratios are normally applied in compact heat exchangers [2–4]. The large surface area is seized on the fin side since there exists lower heat transfer coefficient. Also, the fins attached with the wall can separate the two fluids and enhance the flow turbulences.

Metal foams, perforated sheets and wire meshes are equipped and researched in the compact heat exchangers these decades [5–8]. Open cell metal foam has high specific surfaces, relative high thermal conductivity and can also promote mixing when fluids flow through it. Mancin et al. [9] carried out heat transfer and pressure drop measurements during air forced convection through five different copper samples. The results demonstrate that heat transfer coefficient does not depend on the imposed heat flux and it increases with the increase of air mass flow rate. Besides, the pressure drop is higher with larger pore density. White et al. [10] presented a novel numerical modeling technique for perforated plate heat exchangers that the model allows each perforated plate to be modeled in detail. However, this method retains computational efficiency by using nodes exponentially concentrated near the edge of perforated plates. The numerical results are well matched with the experimental data applied in the silicon heat exchanger plates and glass spacers. Furthermore, pressure drops of four plain-square type woven metal screens with various porosities were experimented in Wu study [11]. It is estimated that the velocity developing section is relatively short for woven metal screens. The five new frictional factor empirical equations for various types of metal screens were presented in the study. Many other researchers have extensively studied on the fluid flow and heat transfer characteristics of porous media structures by experimental [12–21], numerical [22–27] and analytical methods [28,29]. Plenty of results can be used in the design and measurements of compact heat exchangers.

On the basis of previous research, one method to fabricate heat exchanger with porous media using thermal spray process has been effectively applied. Jazi et al. [30] sprayed to deposit Inconel 625 skins on the surface 10 and 20 pores per inch (PPI) nickel foams. A ceramic thermal barrier coating was deposited by plasma spraying to fabricate the heat exchanger. Flow and heat transfer characteristics were obtained when the air flows through heat exchangers. Tsolas and Chandra [31] used wire-arc thermal spray

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Nomenclature

A	tube section area (m^2)
Cp	isobaric specific heat capacity (kJ/kg °C)
D	wire diameter (m)
d	tube diameter (m)
h	heat transfer coefficient (W/m^2 °C)
l	wire length (m)
m	mass flow rate (kg/s)
Nu	Nusselt number
P	wire perimeter (m)
Pr	Prandtl number
q	heat transfer rate (W)
Re	Reynolds number
T	temperature (°C)
U	overall heat transfer coefficient (W/m^2 °C)
u	flow velocity (m/s)
x	distance (m)

Greek

μ	dynamic viscosity (Pa s)
ρ	density (kg/m^3)
ε	wire mesh porosity
λ	thermal conductivity (W/m °C)
η	correction factor
ξ	SPW heat exchanger efficiency

Subscripts

c	cross section
LMTD	logarithmic mean temperature difference
m	wire mesh
in	inlet
i	inner
out	outlet
o	outer
p	plain tube
w	wind tunnel side
s	base surface
t	tube side

Abbreviation

PPI	pore per inch
SPW	sprayed wire mesh

to deposit 2 mm thick metal skins on the surface of 10PPI and 40PPI nickel and copper foams. Pressure drop and temperature distribution were measured as the compressed air was blown through the foams. The results show that the heat transfer enhances nearly 7 times compared with the hollow tube and new friction factor correlation is updated with the permeability K and inertial coefficient C_F. Moreover, the wire mesh was tightly connected with the heat exchanger tube as the surface of the wire mesh and tubes were deposited coating using wire-arc thermal spraying in Rezaey et al. [32] research. This kind of heat exchanger is helpful to recover heat from hot combustion gases using cooling water and the maximum of 68% higher temperature rise is seized compared with plain tubes.

To recycle the waste heat of gas oven, aluminum U-tube heat exchangers were fabricated using wires and wire meshes. Wire mesh was tiled and clamped connected by coating sprayed using wire-arc thermal spraying system. Coating characteristics were analyzed in terms of scanning electron microscope and energy dispersive X-ray spectroscopy (SEM-EDS) technology and spraying parameters were controlled to obtain better bonding effect. Heat transfer characteristics were measured and calculated under various wind tunnel velocities. Pictures of heat exchanger tube surface temperature and heat transfer rate were analyzed to compare with fin model. Moreover, tube-outside heat transfer enhancement was significantly observed for different porosities of wire meshes.

2. Experimental description

2.1. Experimental apparatus

Fig. 1 presents the schematic diagram of experimental setup where the cooling air flowed over various heat exchangers.

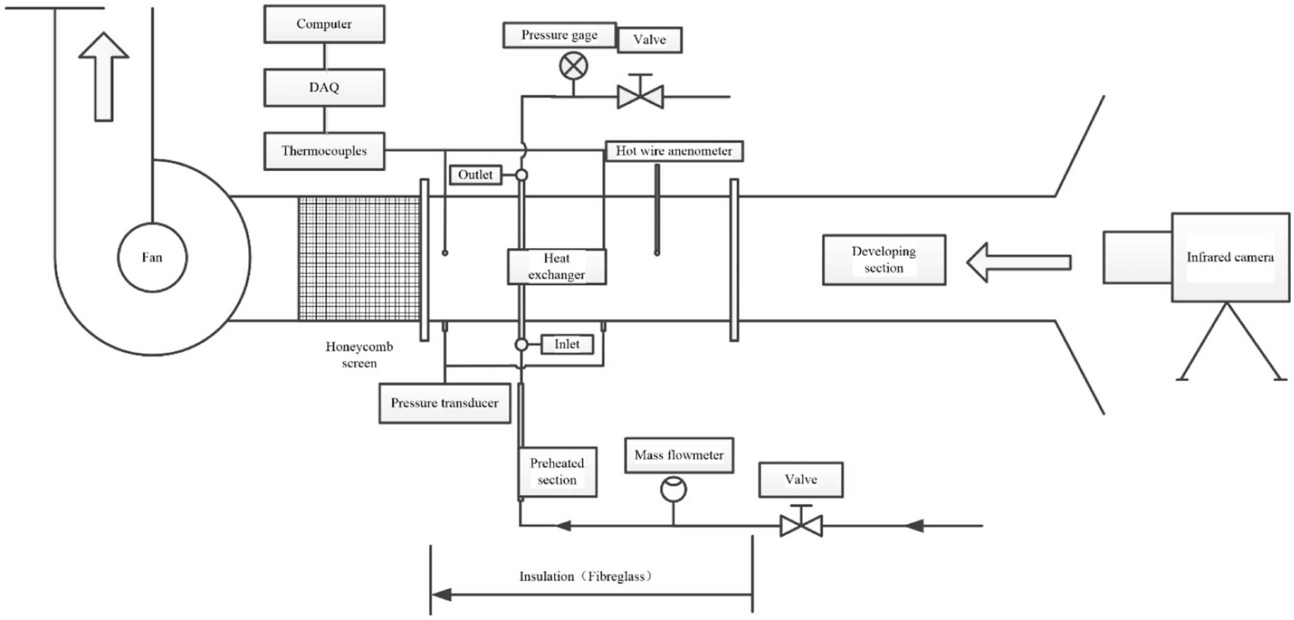

Fig. 1. Schematic diagram of heat exchanger experimental setup.