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Effects of porosity and thickness of porous sheets on heat transfer enhancement in a cross flow over heated cylinder ☆

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ABSTRACT

An experimental study is carried out to investigate the thermal impact of wrapping an aluminum porous sheet over a circular tube in a heat convection configuration. The experimental apparatus consists of a heated horizontal cylinder with a constant heat flux. The cylinder is then covered with porous sheets of different thicknesses. The tube is exposed to a cross flow of air at different speeds which corresponds to different Reynolds numbers. The effect of the added porous layer on the pressure loss over the cylinder was also investigated. It is observed that heat transfer is greatly enhanced with the addition of the porous layer. Also, the addition of the porous layer doesn't appear to increase the pressure loss.

1. Introduction

Studies to develop new methods for enhancing heat transfer in compact heat exchangers have been attracting much attention in engineering applications. The goal of those studies is to reduce weight and size of these kinds of equipment and also reduce the maintenance costs. They have many applications in engineering such as air conditioning and refrigeration systems, cooling of electrical devices, aircraft and automotive technology, ventilation and computer hardware.

Heat transfer enhancement techniques can be classified in two main groups, i.e. active and passive methods. Active methods enhance heat transfer greatly but with added cost to the process [1–6] such as adding mechanical energy or increasing thermal capacity of the medium of heat exchange. Passive methods, on the other hand, enhance heat transfer without adding cost to the process, and usually involve some alteration of the configuration of the heat exchanger. There are many examples of passive heat transfer enhancements such as twisted tape insert, different shapes of tube cross section, and the addition of fins to name a few. One of the passive techniques is the use of porous medium which is an area of interest for many researchers. The porous medium enhances heat transfer by reducing boundary layer thickness and slowing down the cross flow [7–10].

Kiwan [11] investigated the effect of radiative heat transfer on the natural convection from a porous fin attached to a vertical isothermal surface. He used the Rosseland approximation for the radiation heat exchange and the Darcy model for simulating the solid–fluid interactions in the porous medium. He observed that as the surface temperature increases the radiation effect becomes important. Also, he found that at high Rayleigh number the radiative effect becomes negligible. Kiwan and Al-Nimr [12] have used the concept of porous fins to enhance heat transfer from a given porous surface. The basic idea behind using porous fins is to increase the effective area to volume ratio while offering less resistance to the fluid flow around the fin. They observed that using porous fin with certain porosity may give the same performance as conventional fin and save 100th of the fin material. Stewart and Burns [13] investigated, numerically, convection from a horizontal cylinder with multiple, equally spaced and highly conductive permeable fins on its outer surface. They observed that heat convection characteristics in a concentric annulus with heat generating porous media were enhanced when using a permeable inner boundary. Zaho and Song [14] used similar idea to control heat transfer. Porous substrates were studied in double-pipe heat exchangers [15] and solar collectors [16].

The studies on heat transfer enhancement using porous layer are extremely limited. In this context, Yucel and Guven [17] made a numerical study to analyze steady laminar forced convection in a channel in which discrete heat sources covered with porous material are placed on the bottom wall. They reported hydrodynamic and heat transfer results by solving the governing equations via control volume method. They observed that the porous cover with high thermal conductivity enhances the heat transfer from the solid blocks

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Nomenclature

T_a	ambient temperature (°C)
T_s	surface temperature (°C)
V_H	heater voltage (volt)
R	electrical resistance (Ω)
ΔP	pressure drop (mm H_2O)
Pr	Prandtl number (−)
Re	Reynolds number (−)
Nu	Nusselt number (−)
D	diameter (m)
$\overline{V}$	average velocity (m/s)
ρ	air density (kg/m^3)

Fig. 2. A layer of porous material wrapped around the cylinder.

significantly and decreases the maximum temperature on the heated solid blocks. However, their work resembled porous fin study rather than porous layer.

The main aim of the present study is to present the effects of the addition of porous layer on heat transfer in a cross flow over a heated cylinder. The results of this study will pave the way toward the construction of more compact and efficient heat exchangers.

2. Experimental setup

The experiments are carried out in a vertical wind tunnel where the suction side is located downstream of the cylindrical object and the airstream moves downward. Fig. 1 shows a diagram of the experimental apparatus. The heated cylinder is equipped with proper measuring probes to collect data needed to evaluate the thermal performance of the porous layer as shown in Fig. 2. Different types of porous sheets are shown in Fig. 3. An electrically heated element is inserted through the center to generate a constant heat flux to heat the cylinder. The constant power input to the heater is controlled using VARIAC power controller. A porous sheet of aluminum is carefully wrapped around the cylinder to keep the contact resistant to a minimum. The temperature is measured using copper–constantan thermocouples and fed to a data acquisition system along with the signal from a manometer located upstream.

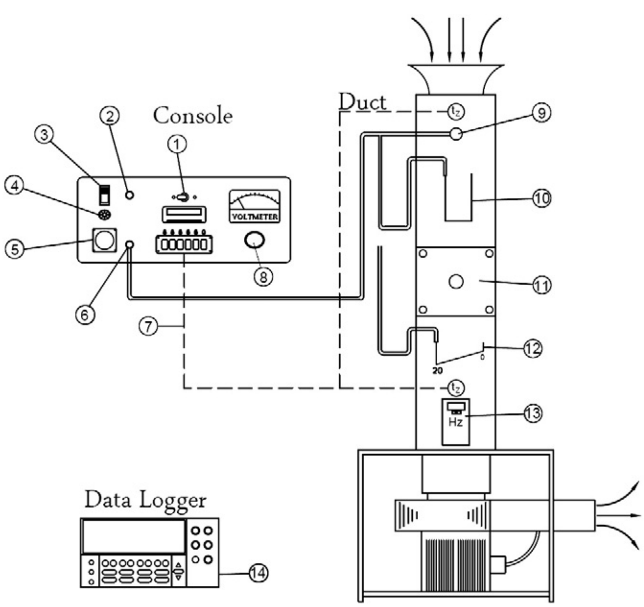

Fig. 1. Schematic configuration of experimental apparatus, 1) voltage selector, (35 V/70 V), 2) fuse, 3) main switch, 4) 4-35 V power and t1 (H351B), 5) 5-70 V power and t1 (H351A), (H351C), (H351D), 6) pressure connection, 7) duct air t2 socket, 8) heather voltage control, 9) intake depletion tapping, 10) manometer 0 to 100 mm H_2O, 11) heat exchanger carrier position, 12) manometer 0 to 20 mm H_2O, 13) fan speed control, 14) sensor and temperature input.

Three samples are investigated; sample 1 (Low porosity, 1 mm in thickness), sample 2 (High porosity, 1 mm in thickness) and sample 3 (Low porosity, 2 mm in thickness). The diameter of the heated cylinder is D = 15.8 mm, the length is 49.8 mm and the electric resistance is R = 72.1 Ω.

The Reynolds number is calculated as,

$$\mathrm{Re}_D = \frac{\rho \overline{V} D}{\mu} \tag{1}$$

where the average velocity $\overline{V}$ is calculated from Bernoulli's equation as the following,

$$\overline{V} = \sqrt{\frac{2.\Delta P}{\rho}} \tag{2}$$

and the pressure difference in the above equation was measured using a manometer placed at the entrance of the wind tunnel.

The Nusselt and Prandtl numbers are calculated as,

$$\mathrm{Nu_D} = \frac{\mathrm{hD}}{\mathrm{k_f}} \tag{3}$$

$$\mathrm{Pr} = \frac{\mathrm{C_p}\mu}{\mathrm{k_f}}. \tag{4}$$

All properties are obtained at the film temperature T_f which is the average between the free stream temperature and the surface temperature as

$$\mathrm{T_f} = \frac{\mathrm{T_s} + \mathrm{T_\infty}}{2}. \tag{5}$$

The heat flux that leaves the cylinder is calculated as the following,

$$Q = V_H . R \tag{6}$$

3. Results and discussion

This experimental study is carried out to investigate the heat transfer enhancement in a cross flow over a heated cylinder with different types of porous layers wrapped around the cylinder. Heat transfer characteristics are presented in terms of Nusselt number versus Reynolds number. The pressure loss for different porous layer