International Journal of Thermal Sciences 99 (2016) 170–179

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

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

Experimental investigation of convective heat transfer in a vertical channel with brass wire mesh blocks

Renju Kurian [1], C. Balaji*, S.P. Venkateshan

Heat Transfer and Thermal Power Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600036, India

ARTICLE INFO

Article history:
Received 7 May 2015
Received in revised form 13 July 2015
Accepted 5 August 2015
Available online xxx

Keywords:
Wire mesh
Vertical channel
Porous media
Porosity
Thermal dispersion
Mixed convection
Cost effectiveness

ABSTRACT

The present paper reports the hydrodynamic and thermal performance of brass wire mesh blocks in a vertical channel. Commercially available brass wire meshes are arranged side by side to act as a porous block. Convective heat transfer experiments in a vertical channel using an isothermal flat plate are conducted for a velocity range of 0–2 m/s. The plate is sandwiched with wire mesh block on either side so that the assembly completely fills the channel. The pressure drops across the filled region are measured for the velocity range discussed. The plate temperature is measured under steady state conditions. Empty channel experiments are also conducted under same conditions for purposes of comparison. The thermo-hydrodynamic experiments conducted showed a similar behavior to those seen in open-celled metal foams. The novelty of the present study is that a simple and cost effective method without any permanent bonding is developed for different porosities and the heat transfer enhancement studied. This situation represents the least performance of the porous structure. The effect of porosity in hydrodynamic and thermal performance is analysed. The performance of the porous blocks were also compared with other porous structures of similar porosity available in literature. Nusselt number correlations were developed to match with experimental data. Attempts to identify mixed convection regimes have been done. The paper also discusses the role of thermal dispersion in heat transfer enhancement using metallic wire meshes.

1. Introduction

Metallic fibrous media have been investigated by several researchers as possible candidates for increasing heat dissipation for various industrial applications. One of the major heat transfer applications is in the electronic industry. Due to their large surface area to volume ratio, they can be effectively used as good candidates for heat transfer enhancement applications, thereby replacing conventional heat sinks. Their porous structure reduces the boundary layer thickness, thus increasing the surface area of contact with the fluid.

As the structure of the fibrous media is random in nature, their physical properties differ significantly from one media to another. Hence obtaining a general conclusion for the thermal and hydrodynamic behavior is difficult. This has been discussed by various researchers during the last few decades. Megerlin et al. [1] used mesh and brush inserts to enhance heat transfer in electrically heated circular tube test sections. Even though the mesh inserts produced a nine times increase in heat transfer coefficient as compared to an empty tube case of same mass velocity, the associated pressure drop was very large. Hunt and Tien [2] investigated non-Darcian flow and heat transfer in high porosity fibrous media of different permeability, porosity and thermal conductivity. The authors concluded that one of the major reasons for heat transfer enhancement was due to dispersion, a non-Darcian phenomenon occurring by intra-pore mixing, as the fluid moves past the solid surfaces. The mechanism increases with flow rate and permeability, and at high Reynolds numbers, it even dominates the solid conduction within the fibrous medium. Özdemir and Özgüc [3] conducted experimental and theoretical investigations on hydrodynamic and heat transfer characteristics of wire screen meshes filled in a horizontal channel with water as working fluid. The authors developed correlations for Nusselt number from experimental data. Lu [4] analytically studied the efficiency of micro-cell aluminum honeycombs in augmenting heat transfer in compact heat exchangers and found that the performance is comparable with open-celled aluminum foams. Angirasa [5] used aluminum

* Corresponding author.
E-mail addresses: balaji@iitm.ac.in (C. Balaji), spv@iitm.ac.in (S.P. Venkateshan).
[1] Research scholar.

http://dx.doi.org/10.1016/j.ijthermalsci.2015.08.002

Nomenclature

A	surface area of the aluminum plate, m^2
a,b	coefficients of fit in Eq. (1)
C	form drag coefficient, m^{-1}
C_p	specific heat at constant pressure, J/kg K
f	Darcy friction factor defined in Eq. (4)
Gr_H	Grashof number based on mesh thickness defined in Eq. (10)
H	mesh thickness, m
h	heat transfer coefficient, W/m^2 K
j	Colburn j factor defined in Eq. (14)
K	permeability of mesh assembly, m^2
k_{eff}	effective thermal conductivity of porous medium defined in Eq. (8), W/m K
k_f	thermal conductivity of air, W/m K
k_s	thermal conductivity of solid medium, W/m K
L	length of mesh assembly in flow direction, m
Nu_H	Nusselt number based on mesh thickness, hH/k_{eff}
PPI	number of pores per inch of metal foam used in Table 2
Pr	Prandtl number
ΔP	pressure drop across test section, Pa
Q	heat input, W
Q_{loss}	heat loss to the insulation, W
Re_H	Reynolds number based on mesh thickness, UH/ν
Ri_H	Richardson number based on mesh thickness defined in Eq. (11)
St	Stanton number $= h/\rho UC_p$ used in Eq. (14)
T	surface temperature of aluminum plate, °C
ΔT	excess temperature of air over ambient defined in Eq. (7), °C
U	inlet velocity of air, m/s

Greek symbols

λ	performance factor defined in Eq. (15)
μ	dynamic viscosity of air, kg/m-s
ν	kinematic viscosity of air, m^2/s
ρ	density of air, kg/m^3
ϕ	volumetric porosity of mesh assembly

Subscripts

eff	effective
f	air
loss	heat loss through the insulation
s	solid
∞	ambient conditions

fibrous heat blocks for forced convection heat transfer with air as coolant and found that porous blocks with lower porosity typically have lower thermal resistance and higher heat transfer rates. Wirtz et al. [6] investigated fluid flow and heat transfer characteristics of regularly stacked un-bonded three-dimensional metal textile sheets. It was found that the performance of these textile structures was comparable to plate-fins. Tian et al. [7] conducted fluid flow and heat transfer experiments using cellular metal lattice structures made from copper by transient liquid phase bonding and brazing of plane weave copper meshes under steady state forced air convection. The authors showed that the overall thermal efficiency of the metal structures is about three times larger than that of stochastic copper foams due to their periodic topology. Orientation effects were also studied and it was concluded that the overall heat transfer depends weakly on orientation. On the other hand, pressure drop was seen to depend on orientation. Bogdan and Abdulmajeed [8] conducted heat transfer studies in a pipe flow using high porosity metallic porous matrix made from aluminum screens. The authors concluded that porosity and fiber diameter have a positive influence on the heat transfer and a negative impact on the pressure drop. Tian et al. [9] made experimental and numerical studies of the thermal and hydraulic performance of sandwich panels with high or low thermal conductivity metallic textile cores, bonded using a brazing alloy. Experiments were conducted in air and water. The effects of cell topology, pore fraction and material properties on both coolants were studied and concluded that for a fixed surface area density, an optimal porosity exists for maximum heat dissipation, where a balance between solid conduction and thermal dispersion occurs. Similar experiments were conducted by Xu et al. [10] where the authors developed a direct simulation method to study laminar flow and heat transfer at the pore level. Both the pressure drop and heat transfer characteristics for various configurations of wire screen meshes were investigated, with water as coolant. Koichi et al. [11] described flow and heat transfer characteristics of a heat exchanger tube filled with a high porous material made from fine copper wires using air as working fluid and reported that the high porosity materials are effective at low Reynolds numbers. Venugopal et al. [12] experimentally investigated the use of a stack of metallic perforated plates filled inside a vertical duct for heat transfer augmentation under forced flow conditions. The effect of porosity variation was studied and obtained an optimum value of 0.85 where the average Nusselt number got a maximum increase of 4.52 times as that of a clear flow case. Dyga et al. [13] studied heat exchange and pressure drop with air and water flow through a channel with and without wire mesh packing. The authors obtained a 40% energetic gain by using wire mesh packing with air as working fluid. However, the higher energy consumption required for water pumping through the wire mesh packing, as compared to an empty channel case, is not compensated by an increase in the heat exchange in the packed channel. Joo et al. [14] experimentally investigated orientation effects on heat transfer with high porosity two-layered, brazed aluminum wire-woven bulk Kagome (WBK) sandwich panels for a wide range of Reynolds numbers. WBK orientation corresponding to two open area ratios were analyzed and found that the Nusselt number in the most closed orientation was consistently higher than that in the more open orientation. Nanan et al. [15] conducted experiments with wire-rod bundles as flow turbulators for heat transfer enhancement under turbulent flow in heat exchanger tubes. As compared to a plain tube, the heat transfer rate and friction factor are respectively increased in ranges of 3.5–68.8.

Metal foams are yet another type of metallic fibrous media that attracted the attention of many researchers in the last two decades due to their desirable flow and thermal characteristics. Most of the works in metal foams are forced convection dominant. A few examples are Calmidi and Mahajan [16], Bhattacharya and Mahajan [17] and Boomsma et al. [18]. Mixed convection studies in metal foams were also done by a few researchers, such as the one by Kamath et al. [19].

One of the main characteristics of transport phenomena in porous medium is dispersion. The dispersion effects are caused by flow disturbances that occur in a porous medium while the fluid moves along a tortuous path around the solid surfaces. These effects were analytically and experimentally investigated by many researchers in packed beds and similar low porosity media ([20–28]). Dispersion effects in high porosity media like metal