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An experimental investigation on forced convection heat transfer of single-phase flow in a channel with different arrangements of porous media

Shahram Baragh[a], Hossein Shokouhmand[b,*], Seyed Soheil Mousavi Ajarostaghi[c], Mohammad Nikian[a]

[a] Faculty of Mechanical Engineering, Islamic Azad University, Takestan Branch, Takestan, Iran
[b] School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran
[c] Faculty of Mechanical Engineering, Babol Noshirvani University of Technology, Babol, Iran

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ABSTRACT

Nowadays, heat transfer in porous zone plays an important role in many industrial and modern applications. For this reason, issues related to porous media are important in the design and analysis of heat exchangers. In this study, a single-phase flow of air in channel having circle cross-section with different arrangements of porous media is experimentally studied. Changes in hydrodynamic parameters, improvement of heat transfer by porous media in the channel as well as pressure drop resulted from porous media are considered. Results from these experiments show that presence of porous media leads that the thermal flux applied to walls of channel be transferred into fluid due to creating a uniform space and high conductivity of porous media. Also, the mean temperature of the fluid increases and this leads to decrease temperature difference between channel wall and the mean temperature of the fluid. Because of the heat transfer coefficient has an inverse relationship with the temperature difference between the walls of the channel and the mean temperature of the fluid, the heat transfer coefficient increases. For investigation the heat transfers with pressure drop simultaneously, heat transfer performance ratio and heat transfer enhancement ratio are defined. The results of this study show that fully filled channel of porous media has the best heat transfer enhancement (in both laminar and turbulent flows). In turbulent flow, channel with annulus shape porous zones (the porous zone inserted adjacent to wall) has the best thermal performance that means has the large value of heat transfer with low pressure drop.

1. Introduction

Today, the issues related to porous media are important issues in the design and analysis of heat exchangers. Basically, reducing size of heat transfer devices by using porous media was led to be feasible of creating flow with smaller Reynolds numbers. Along with the progresses over the years, the registered relationship for converters has been changed and grown, large scale has been becoming small scale and smaller. ast forward to the smaller scales and larger thermal flux in cooling electronic devices is the greatest manifestation of this trend and it is pertinent to say that the formulation of new heat exchanger design and analysis is based on the principles of the porous media.

The fluid flow and heat transfer in composite systems containing simultaneously fluid and porous regions have received considerable attention due to their importance in many industrial applications, such as petroleum processing, solid matrix or micro-porous heat exchangers, direct contact heat exchangers, drying processes, solar collectors, and many others. Several authors have been studied channels partially filled with porous mediums and they showed that it may not be necessary to completely fill the channel with the porous medium to achieve the maximum heat transfer. Study convection heat transfer in porous media within a channel is a common and important problem. In several papers, fluid flow and heat transfer in the channels partially filled with porous plates were analyzed as analytical, experimental and numerical.

Nimvari et al. [1] numerically investigated the turbulent flow and heat transfer through a partially porous channel. Two common arrangements of a porous layer in the channel were considered; central arrangement and boundary arrangement. Different values of the porous layer thickness as well as Darcy number are studied for both arrangements. An effective Nusselt number has been employed and via its values, an optimum thickness of the porous layer was proposed.

Heat transfer performance assessment was made for forced

* Corresponding author.
E-mail addresses: sh.baragh@kalleh.com (S. Baragh), hshokoh@ut.ac.ir (H. Shokouhmand), s.s.mousavi@stu.nit.ac.ir (S.S.M. Ajarostaghi), m.nikiyan@tiau.ac.ir (M. Nikian).

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Nomenclature

A	Area, (m^2)
D	Outer diameter of porous zone, (m)
d	Inner diameter of porous zone, (m)
q''	Heat flux, (W/m^2)
Q	Heat, (W)
L	Distance between porous zones
$\dot{m}$	Mass flowrate, (kg/s)
V.I	Thermal power of heater, (W)
T	Temperature, (K)
X	Distance between sensor and entrance of test section
h_i	Local heat transfer coefficient, W/(m^2.K)
$\bar{h}_l$	Mean heat transfer coefficient, W/(m^2.K)
U	Velocity, (m/s)
k	Thermal conductivity, (W/(m.K))
Nu_i	Local Nusselt number
f	friction coefficient
Re	Reynolds number
Nu_{ER}	Heat transfer enhancement ratio, (PR)
Nu_{PR}	Heat transfer performance ratio, (ER)
Pr	Prandtl number
P	Pressure, (Pa)

Greek symbol

ε	Porosity in porous media
ρ	Density, (kg/m^3)
μ	Dynamic viscosity, (kg/(m. s))
υ	Kinematic viscosity, (m^2/s)

Subscript and superscript

tot	Total
w	Wall
rad	Radiation
cond	Conduction
conv	Convection
am	Ambient
loss	Lost
L	Local
in	Inlet
s	Surface
f	Fluid
h	Hydraulic
c	Cross-section
eff	Effective
b	Bulk

convection in a heated tube with a porous medium core and a tube with a wall covered with a porous medium layer by Yang et al. [2], so as to investigate effectiveness of porous material insertion within a tube. It has been found that the local thermal non-equilibrium analysis is essential for the case of forced convection in a tube with a heated wall surface covered with a porous medium layer. Nimvari and Jouybari [3] made a comparison between the results of turbulent and laminar flow simulations inside the porous region of composite porous/fluid domains in order to get more insight on the effects of turbulence inside the porous region on fluid flow and heat transfer in a pipe partially filled with a porous media. It was shown that the turbulence effects inside the porous layer are important even for pore base Reynolds numbers lower than the critical Reynolds number in porous media.

Kuznetsov [4] investigated analytically the effect of thermal dispersion on fully-developed forced convection in a parallel-plate channel partly called with a fluid-saturated porous media. The walls of the channel were subject to a constant heat flux. Peripheral parts of the channel were occupied by a fluid-saturated porous medium of uniform porosity.

Alkam et al. [5] numerically simulated the forced convection flow in the developing region of a parallel-plate channel partially filled with two porous substrates of equal thickness deposited at the inner walls of the channel, which remained isothermal. Superb and colleagues [6] numerically, in the case of laminar flow and heat transfer between two parallel plates using displacement Lattice- Boltzmann method, the study began. Also, Shokouhmand et al. [7] analyzed fluid flow and convection heat transfer in a channel that was air heater and filled by the porous media by minimum entropy law. The results of this study showed that by applying optimal value of the porosity of porous material, performance in air heating ducts can be optimized.

Shokouhmand et al. [8] examined the impact of position of porous materials in improving heat transfer in a channel partially -filled by porous media. In this paper, numerical study on laminar flow and convection heat transfer in a channel partially -filled by porous media was conducted by using LBM method. The obtained results showed that the pressure drop in the channel that porous media is placed in the center of channel is more than the state where the porous medium is attached to a side of wall.

Pavel and mohammad [9] conducted an experimental and theoretical study on improving heat transfer for gas heat exchangers that were covered with a porous media. From the results, it was concluded that high rates of heat transfer is achieved using the porous media.

2D numerical investigation and sensitivity analysis were performed on heat transfer rate and heat exchanger effectiveness of a double pipe heat exchanger filled with porous medium by Shirvan et al. [10]. The Darcy–Brinkman–Forchheimer model was applied to model the flow field in the porous zone. It was found that the heat exchanger effectiveness increases with the Re number and reduces with enhancement of the Da number.

Tu et al. [11] analyzed the heat transfer rate and the pressure drop of metal porous media inserts in the single phase. The friction factor increases with the decrease in the particle size. The heat transfer coefficient of the spherical particle is higher than that of dendritic particle. Laminar forced convection flow through a pipe partially and completely filled with a porous material was investigated numerically for three different cases by Teamah et al. [12]. The effect of the porous outer radius and Darcy number on the velocity profiles, the local Nusselt number, the average Nusselt number and the pressure drop were studied.

Cheng and Kuznetsov [13] presented the first attempt to investigate numerically heat transfer in a helical pipe filled with a fluid saturated porous medium. The analysis was based on the full momentum equation for porous media that accounts for the Brinkman and Forchheimer extensions of the Darcy law as well as for the flow inertia.

Nazari et al. [14] experimentally investigated the forced convective heat transfer due to flow of Al_2O_3/Water nanofluid through a circular tube filled with a metal foam. The experimental data indicated a significant improvement in the heat transfer rate at the cost of a pressure drop increase.

Astanina et al. [15] numerically investigated the laminar natural convection in a square cavity having two centered adherent porous blocks filled with an alumina/water nanofluid under the effect of horizontal temperature gradient. The obtained results revealed the heat transfer enhancement at the hot wall with the Darcy number, while a growth of the porous layer's size reduces the heat transfer rate at this hot wall.

Forced convection heat transfer and fluid flow characteristics were