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REVIEW ON CONVECTION HEAT TRANSFER USING POROUS MEDIA

Rahimah Mahat[1, a], Wan Najat Wan Azman[1, b], Azzafeerah Mahyuddin[1, c], Rahimah Kassim[1,d]
[1]Universiti Kuala Lumpur, Malaysian Institute of Industrial Technology,
Masai, Johor Darul Takzim
[a] rahimahm@unikl.edu.my, [b]wannajat@unikl.edu.my, [c]azzafeerah@unikl.edu.my,
[d]rahimahk@unikl.edu.my

ABSTRACT: The present paper is intended to encompass a review of studies on natural convection heat transfer using porous media. By using porous media, there are two advantages. First, its dissipation area is greater than the conventional fin that can enhance the heat convection. Second is the irregular motion of the fluid flow around the individual beads which mixes the fluid more effectively. Thus, the purpose of this paper is to summarize the published articles in respect to the enhancement of convective heat transfer using porous media and identifies any opportunities for coming research.

Keywords: Porous media, convection heat transfer, thermal conductivity.

1. INTRODUCTION

By definition, a porous medium consists of pores between some particulate phase, contained within a vessel, or some control volume, as illustrated in Figure 1.

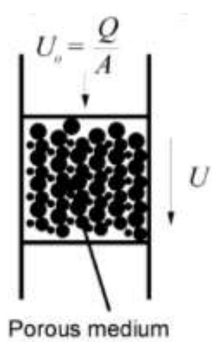

Figure 1: Illustration of fluid flow through a porous medium

The fluid flow rate through the bed is Q (m^3s^{-1}) and the bed cross sectional area is A (m^2). Thus the superficial (or empty tube) velocity U_0 is the total flow rate divided by the cross sectional area. The existence of the particles within the bed will reduce the area available for fluid flow; i.e. to preserve fluid continuity with the entering superficial flow the fluid will have to squeeze through a smaller area; hence the velocity within the bed (U– interstitial velocity) will be greater than the superficial.

The resistance to fluid flow through the porous medium is related to the amount of particles present, or volume concentration, but it is conventional to work in terms of bed porosity. At one extreme, when the bed is full of solids (porosity is zero – possible with cubic particles placed carefully within the bed) the resistance is infinite. At the other, when no solids are present and the porosity is unity, the interstitial velocity will be the same as the superficial velocity.

2. CONVECTION HEAT TRANSFER:

Before we go further, we have to know the definition of convection heat transfer. Convection is the transfer of heat from one place to another by the movement of fluids. If we mention about convection, it is usually the main form of heat transfer in liquids and gases as well.

If the motion of fluid is just due to the gradient of existing temperature between fluid and the solid, it is known as free (natural) convection. It is known as forced convection if the motion of fluid is due to external effects. Lastly, the convection heat transfer is known as mixed convection if the motion of fluid is just due to free (natural) and forced convection effects together [1].

3. FLUID FLOW IN POROUS MEDIA:

Fluid flow systems through porous media and the ideas of boundary layer will be discussed in this section. Over a decade ago, the researches of fluid flow in porous media are very famous. The earliest research regarding to this problems can be found in [2], [3], [4], [5] and [6]. There are some researches describes the fluid flow models by the Boussinesq equation [7], [8], [9], [10] and [11] which is very important equation especially in fluid dynamics. This equation describes a special case of porous media fluid flow with quadratic non-linearity. The Boussinesq equation can be written in the following form

$$\frac{\partial}{\partial t}\omega(x)(t)=\frac{\partial}{\partial x}\left(\omega(x)(t)\frac{\partial}{\partial x}\omega(x)(t)\right), \qquad (1)$$

A property like porosity and viscosity are important for porous media while for the flow of the fluids depends on fluid properties like density and viscosity.

Both density and viscosity depend not only on molecular composition of the fluid itself but also the pressure and temperature as well.

Porosity is defined as the ratio of the volume of voids to the total volume of the porous media. From the definition, the value of porosity may vary from 0 to 1. Meanwhile, permeability is defined as the ability of fluids to flow through porous media. Permeability may vary up to six orders of magnitude in a single reservoir. From the previous research, it is shown that an increase in permeability is expected to increase in porosity too. For example, if a material is permeable then it is also porous [12].

Darcy's law is a phenomenological derived constitutive equation that describes the flow of a fluid through a porous medium. Darcy's law also explain that elevation is a simple proportional relationship between the instantaneous discharge rates through a porous medium, the viscosity of the fluid and the pressure drop over a given distance.

$$Q=\left(\frac{-KA}{\mu}\right)\times\left(\frac{p_b-p_a}{L}\right)$$

Where Q is volume per time, A is area, p is total pressure drop, μ is viscosity and L is the length over which pressure drop is taking place. The negative sign is needed because fluid flows from high pressure to low pressure.

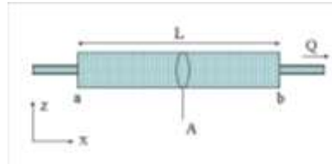

Figure 2: Diagram showing definitions and directions for Darcy's law [1]

4. CONVECTION IN HEAT TRANSFER AND FLUID FLOW IN POROUS MEDIA

4.1 Natural Convection

Natural convection is a mechanism, or type of heat transport, in which the movement of the fluid is not generated by any external source like a pump, fan or any other suction device. But the movement is only by the differences of density in the fluid occurring due to temperature gradients. In natural convection, fluid surrounding a heat source will receive heat, becomes less dense and rises. The mechanisms will repeat again until there is no difference in the temperature. Natural convection has attracted a great deal of attention from researchers because of its presence both in nature and engineering applications. Interest in natural convection fluid flow and heat transfer in porous media has been motivated by a broad range of applications, including geothermal systems, crude oil production, storage of nuclear waste materials, ground water pollution, fibre and granular insulations, solidification of castings, etc [13].

Comprehensive literature survey concerned with this subject will be discussed later. Most of the published papers are concerned with the analysis of natural convection heat transfer in such a system, rectangular enclosure filled with porous layer; see for example, [14], [15], [16], [17], [18], [19], [20], [21] and [22]. In reality, the shape of the enclosure can also be non-rectangular in practical engineering

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applications such as solar collectors or heat exchangers with different shaped duct constructions. The study of convective flow in this kind of geometries is more difficult than that of square or rectangular enclosures due to the presence of sloping walls. In general, the mesh nodes do not lie along the sloping walls and consequently, from a programming and computational point of view, the effort required for determining flow characteristic increases significantly.

4.2 Forced Convection

Forced convection is a mechanism and process in which the type of transport in fluid motion is generated by an external source. Some of the examples of external sources are pump, suction device and fan. The forced convection is considered as one of the main methods in the heat transfer. These mechanism and process are found very commonly in everyday life, including central heating, air conditioning, steam turbines and in many other machines.. The comprehensive literature survey concerned with this subject is given by:

Ho and Lin 2014 [23] who studied the influence of elevated inlet fluid temperature on the turbulent forced convective heat transfer effectiveness of using alumina–water nanofluid over pure water in an iso-flux heated horizontal circular tube at a fixed heating power. In the experiment, the authors used a circular pipe of inner with a diameter 3.4 mm in forced convection for the parameters with the following range of temperatures, T_{in} = 25 °C, 37 °C and 50 °C; the parameters of the Reynolds number, Re_{bf} = 3000–13,000; the mass fraction of the alumina nanoparticles in the water-based nanofluid formulated, ω_{np} = 0, 2, 5, and 10 wt.%; and the heating flux, q_o'' = 57.8–63.1 kW/m^2. From the experiment, it is clearly state that effectiveness of the alumina–water nanofluid in the turbulent forced convection heat transfer over that of the pure water can be further uplifted by increasing the inlet temperature that enters the circular tube above the ambient. In the conclusion, if we increase the average of the heat transfer more than 44% arises for the nanofluid of ω_{np} = 2 wt.% as the inlet fluid temperature is increased from 25 °C to 50 °C.

Yoon et all. [24] studied numerically about two-dimensional laminar force convection heat transfer that passes two rotating circular cylinders. In the experiments, the cylinders were arranged in a side-by-side at a various range of absolute rotational speeds ($|\alpha| \leqslant 2$) for four different gap spacings ($g*$) of 3, 1.5, 0.7 and 0.2 with the Reynolds number of 100, and a fixed Prandtl numbers of 0.7. As $|\alpha|$ increases, the thermal field became stabilized and steady. It depends on the gap spacing between the two cylinders. The experiment by Yoon was express in the Figure 1 as per below:

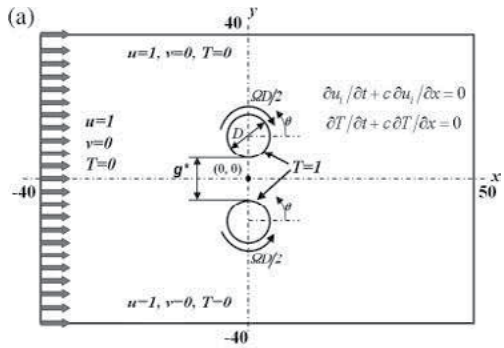

Figure 1: Schematic illustration of the problem under consideration Yoon

Chen et al. [25] studied Numerical simulations of forced convection heat transfer and flow characteristics of nanofluids in small tubes using two-phase models. Laminar and turbulent forced convection heat transfer and flow characteristics of nanofluids in small smooth tubes are numerically simulated using two kinds of multiphase-flow models. The simulated results are compared with the experimental results from the published papers and the traditional predicting correlations to investigate the applicability of these models for nanofluids. As a result, the present study indicates that the two-phase models, including mixture model and Eulerian model, can predict the forced convection heat transfer and flow characteristics of nanofluid well, and have important implications for the application of nanofluid.

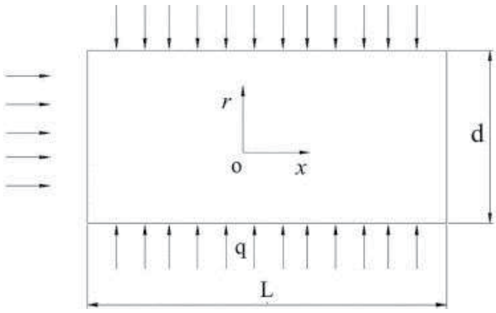

Figure 2: The flow and heat transfer in a horizontal tube as under consideration Chen.

4.3 Mixed Convection

Mixed or combined convection is a combination of forced and free convections. For a better understanding, the convection is occurring when a flow is determined simultaneously by both outer forcing system and inner volumetric forces. In a mathematical description of mixed convection in the equations of motion which is the Navier-Stokes equations, both the term characterizing the pressure head loss dp/dx and the term characterizing mass forces ρ_g are retained. Below are the comprehensive literature review that focus on mixed convection:

Dogan and Sivrioglu [26] studied experimental investigation of mixed convection heat transfer from longitudinal fins in a horizontal rectangular channel. Mixed convection heat transfer from longitudinal fins inside a horizontal channel has been investigated for a wide range of modified Rayleigh numbers and different fin heights and spacing. An experimental parametric study was made to investigate effects of fin spacing, fin height and magnitude of heat flux on mixed convection heat transfer from rectangular fin arrays heated from below in a horizontal channel. The optimum fin spacing to obtain maximum heat transfer has also been investigated. For mixed convection heat transfer, the results obtained from experimental study show that the optimum fin spacing which yields the maximum heat transfer is S = 8–9 mm and optimum fin spacing depends on the value of Ra^*.

Mixed convection heat transfer from confined tandem square cylinders in a horizontal channel was studied by Zhu Huang et al. [27]. This paper presents a numerical study on the two-dimensional laminar mixed convective flow and heat transfer around two identical isothermal square cylinders arranged in tandem and confined in a channel. The spacing between the cylinders is fixed with four widths of the cylinder and the blockage ratio and the Prandtl number are fixed at 0.1 and 0.7 respectively. Numerical results lead to the following conclusions:
(1) The flow is time-periodic unsteady and the patterns of instantaneous flow are similar due to the vortex shedding. (2) The lift coefficient is more sensitive to the thermal buoyancy effect than the drag coefficient and Nusselt number, and the heat flux transferred from the upstream cylinder is higher than that of downstream cylinder.

5. CONCLUSION

In this research, mass transfer and flow in porous media continue its steady expansion that has been seen over the past a decades with various situations, for example in declined channel, unsteady or steady flow, flow of fluid in enclosure filled and so on. There are various numbers of studies that focus on the development of the model of transport with reference to the temperature gradients. This research is very useful to the engineering field and in the execution of our daily application.

Another important research regarding this heat and mass transfer is the enclosure filled. This enclosure fill is very important nowadays as it is very useful in our daily life. The example of this

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