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Research Article

HEAT TRANSFER THROUGH POROUS MEDIA: AN OVERVIEW

[1,*]Purna Chandra Barman, [2]Ashoke Das and [1]Md. Rabiul Islam

[1]Department of Physics, Raiganj University, Raiganj-733 134, West Bengal, India
[2]Department of Mathematics, Raiganj University, Raiganj-733 134, West Bengal, India

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ABSTRACT

The phenomenon of heat transfer through a porous medium plays an important role in many problems which deals with transport of flow. It acquired advantage in the fact that the governing equations relating to diverse flow and transport phenomena in porous media are all generally based on the same form of mass as well as energy conservation laws. Various dimensionless parameters such as Nusselt number, Reynolds number etc. which predominant the flow of heat in porous media, are denoted. It is seen that with increases of thickness of the porous layer and Reynolds number, the rate of heat transfer increases along the flow direction. For non-Newtonian fluid the temperature and concentration of the wall are constant. Heat transfer through a porous medium is found to be potentially appropriate exhibiting novel properties that make them useful in many applications in nano technology.

INTRODUCTION

Heat transfer in porous media is the subject of interest due to its a lot of implications involving in many industrial devices such as chemical engineering, heat exchangers, nuclear reactor, as well as in geophysics. The heat transfer problems are often characterized by highly non-linear couplings involving with many different scales. Numerous heat convection studies in porous media are reported to consider the constant of physical properties of the ambient fluids. However, it is well known that the temperature is treated as prime factor which control the viscosity of liquid evidently and influences the variation of velocity through the flow. So, constant viscosity with considerable errors may be occurred when applied to practical heat transfer problems with the large temperature difference between the surface and the fluid. Lai *et al*. (1990) examined the problem of the variable viscosity effect for a mixed convection flow along a vertical plate embedded in a porous medium. The convective heat transfer studies from a vertical flat plate embedded in a thermally stratified porous medium has attracted many investigators due to its wide range of applications in geophysics and thermal Sciences. The problem of natural convection in an enclosed rectangular cell filled with fluid saturated porous medium with one wall heated and the other cooled illustrates important application engineering studies.

Corresponding author: Purna Chandra Barman,
Department of Physics, Raiganj University, Raiganj-733 134, West Bengal, India.

Heated fluid raising from the hot wall overlays the top of the cell and the cool fluid falling from the cold wall lies along the bottom thereby creating stratification inside the cell. Free convection heat and mass transfer studies in a porous medium for axisymmetric bodies are attracted by many investigators because of applications in geophysics and energy related problems such as thermal insulation, enhanced recovery of petroleum resource, geophysical flows, polymer processing in packed beds and sensible heat storage bed. In this point of view, to design a suitable canister for nuclear waste disposal into the earth's depth of the or into the sea bed demands a thorough understanding of the convective mechanism in a porous medium for taking care of the safety measure for all sea living beings. In this direction, all needs to study the convective heat and mass transfer from various geometries. A nanofluid is a stable, uniform suspension of nanometer sized solid particles (< 100 nm) in conventional liquids such as water and ethylene glycol. An innovative procedure for improving heat transfer by using ultra fine solid particles in fluids is used extensively. The thermal conductivity of a suspension containing solid particles may be expected to be significantly greater than that of the base fluid. A non-linear relationship between shear stress and shear rate is exhibited by Non-Newtonian fluids. Many inelastic non-Newtonian fluids encountered in chemical engineering processes, are known to follow the empirical Ostwaled-de-Waele model which is also called power-law model in which the shear stress varies according to a power function of the strain rate.

Radiative convective flows are frequently encountered in many scientific and environmental processes, such as astrophysical flows, water evaporation from open reservoirs, heating and cooling of chambers and solar power technology. Several researchers investigated radiative effects on heat transfer in non porous and porous medium utilizing the Rosseland or other radiative flux model. The study of convective heat and mass transfer accompanied by melting effect in porous media are received a much attention in the recent years because of its important applications in casting, welding and magma solidification, permafrost melting and thawing of frozen ground etc.

Convective heat transfer

Consider a vertical surface embedded in some fluid. The heat transferred through the surface from one side to other, can be written as in terms of the Newton's law of cooling. If q_x be the heat transfer rate along x-axis, the relationship between the heat transfer rate and the temperature difference between the surface and the ambient fluid is written as

$$q_x = h_x S(T_w - T_\infty) \tag{1}$$

Where, h_x is the average convective heat transfer coefficient, S is the total area of the surface T_w, T_∞ are the temperature of the wall and ambient temperature of the medium in which the surface is placed. The heat transfer coefficient depends on the flow configuration, fluid properties, dimensions of the heated surface, as well as on the temperature difference, in which q_x depend on i.e. On $T_w - T_\infty$, is not linear. From equation (1) the convective thermal resistance can be determined. According to Fourier's law we can write

$$q = kS\left(\frac{\partial T}{\partial y}\right) \tag{2}$$

Where, the temperature gradient is estimated at the surface when y = 0, in the fluid and k is the thermal conductivity of the fluid. From equation (2) it is assumed that the natural convection flow largely affects the temperature gradient at the surface unfaltering other remaining parameters. The analysis is directed at determining this gradient, which in turn depends on the nature and characteristics of the flow of fluids, temperature field as well as fluid properties. If external agents produce the motion of the fluid imparting the pressure which drives the flow, such process is termed forced convection. On the other hand, if no externally induced flow exists and the flow arises naturally from the effect of a density difference, resulting from a temperature or concentration difference in a body force field such as gravity, the process is termed natural convection.

Dimensionless Parameters

The most common Dimensionless Parameters that are used to characterized the heat transfer data, are Nusselt number (Nu), Prandlt number (Pr), Grashof numbers (Gr), Reynolds number (Re), etc. Here the only expression of Nusselt number (Nu) is given. It is the ratio of convective to conductive heat transfer normal to the boundary. It can be expressed as

$$Nu_L = \frac{\text{Total heat transfer}}{\text{Conductive heat transfer}} = \frac{hL}{k} \tag{3}$$

where h is the convective heat transfer coefficient of the flow, L is the characteristic length, k is the thermal conductivity of the fluid. Sometimes the thermal conductivity of the fluid is estimated at the film temperature. In engineering purposes this types of thermal conductivity may be calculated as the mean-average of the bulk fluid temperature and wall surface temperature. The average Nusselt number, local Nusselt number is defined by taking the length to be the distance from the surface boundary (Yunus, 2003) to the local point of interest is

$$Nu_x = \frac{h_x x}{k} \tag{4}$$

The *mean*, or *average*, number is calculated by integrating the expression over the range (Sanvicente, 2012) such as

$$Nu = \frac{1}{k}\int_0^H h_x(x)\,dx \tag{5}$$

Literature Review

Reddy *et al*. (2012) analyzed the effects of hall current, chemical reaction and radiation on a free convection flow considering an electrically conducting, radiating, viscous incompressible fluid passing through a porous medium taking up a semi-infinite region of the space bounded by a vertical infinite surface under the influence of uniform magnetic field which is applied normal to the surface. The governing partial differential equations are solved by using simple perturbation method to find the expressions for velocity, temperature, concentration, skin friction and rate of heat and mass transfer and the effects of various physical parameters such as Magnetic parameter , radiation parameter, Grashof number, modified Grashof number, Prandtl number, permeability parameter and the chemical reaction parameter are studied. The trouble of steady, laminar, coupled heat and mass transfer by mixed convective flow of a non- Newtonian power-law fluid over a permeable wedge embedded in a porous medium with variable surface temperature and concentration and heat generation or absorption and wall transpiration effects is studied by Chamkha (2010). Obtained a set of non-similar equations for the entire range of free-forced-mixed convection are solved numerically by employing an efficient implicit, iterative, finite-difference method to illustrate the effect of the various physical parameters which depends on temperature and concentration profiles as well as the local Nusselt and Sherwood numbers. Elgazery (2008) considering the unsteady, laminar boundary layer the problem of unsteady free convection with heat and mass transfer from an isothermal vertical flat plate in porous medium saturated with a non-Newtonian fluid is examined. Numerical calculations of the boundary layers problems are analyzed by finite difference method to obtain the values of friction factor, heat transfer and mass transfer coefficients approaching the steady state values.
Maintaining constant, but different, levels of temperature and concentration of the wall and the ambient medium, the influence of melting on mixed convection heat and mass transfer from the vertical flat plate in a non-Newtonian nanofluid saturated porous medium is studied by Kairi and RamReddy (2015) to discuss the variation of temperature, concentration, heat and mass transfer coefficients with the power-law index, mixed convection parameter, melting parameter, Brownian motion parameter, thermophoresis

parameter, buoyancy ratio and Lewis number having a wide range of values. The Ostwald–de Waele power-law model is used to characterize the non-Newtonian nanofluid behavior. A similarity solution for the transformed governing equations is considered. By using Matlab BVP solver bvp4c, which is a finite difference code that implements the 3-stage Lobatto IIIa formula the resulting ordinary differential equations along with the boundary conditions are solved. Poulikakos and Spatz (1988) analyzed the melting phenomena in a non-Newtonian fluid-saturated porous matrix due to free convection from a vertical front when the melt is a non-Newtonian fluid. To find out the results of the dependence of the local heat transfer at the melting front, as well as the dependence of the temperature and flow fields in the melt, the similarity equations are integrated numerically with the help of the fourth order Runge-Kutta method. Nakayama and Koyama (1991) examined the free convection in case of a non-isothermal body of arbitrary shape embedded in a porous medium. Shenoy (1994) presented numerous plenty applications of non- Newtonian power law fluids with yield stress on convective heat transport in fluid-saturated porous media considering geothermal and oil reservoir engineering applications. In the previous year Shenoy (1993) investigated the non-Darcy natural, forced and mixed convection heat transfer in non-Newtonian power-law fluid-saturated porous media. Mixed convection from a vertical plate in a porous medium with surface injection or suction studied by Hooper *et al*. (1993). Chamkha and Al-Humoud (2007) examined the problem of mixed convection heat and mass transfer of non-Newtonian fluids from permeable surface embedded in a porous medium in the presence of suction or injection with heat generation or absorption effects.

Deka and Das (1197) analyzed the effect of radiation on the unsteady natural convection flow in a viscous compressible fluid past an infinite vertical flat plate, wherein the plate temperature is a ramped one. The fluid is considered a gray, absorbing or emitting but a non-scattering medium. The velocity field, temperature field, skin friction and Nusselt number are studied depending on the influence of a choice of parameters. Mohammadein and E1-Amin (2000) investigated the influences of thermal radiation on buoyancy induced flow over horizontal flat plate embedded in a non-Newtonian fluid saturated porous medium. Rosseland approximation is used to describe the radiative heat flux in the energy equation. Similarity solution for the transformed governing equations is obtained with prescribed variable surface temperature. The basic equations for the steady two dimensional laminar free convection boundary layer flow of a viscous incompressible and electrically conducting fluid depending with viscosity as well as thermal conductivity on temperature in a past a semi-infinite vertical impermeable flat plate in the presence of a uniform transverse magnetic field to analyze the effects of Grashof number, Hartmann number and Prandtl number, Darcy parameter on velocity profiles and temperature profiles of that medium is studied by Rao *et al*. (2015).

Conclusion

The simultaneous developments of the problem of heat transfer through a porous medium are found to be quite useful in different applications due to the fact that the pressure difference reduces with increasing porous parameter which implies a reduction in mass of the fluid that reduces the velocities of the fluid. The finite difference method are used to compute unsteady natural convection as well as mixed convection with heat and mass transfer from an isothermal vertical flat plate to a non-Newtonian fluid saturated porous medium, which are modeled as a power-law fluid.

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