Contemporary Engineering Sciences, Vol. 5, 2012, no. 2, 67 - 74

CFD Simulation of Temperature Dependent Viscosity under Free Convection through Two-Layered Porous Media

Fatemeh Bahadori

Department of chemical engineering
Amirkabir University of Technology (Tehran polytechnic)
Tehran, Iran
Bahadori@aut.ac.ir

Fariboorz Rashidi

Department of chemical engineering
Amirkabir University of Technology (Tehran polytechnic)
Tehran, Iran
Rashidi@aut.ac.ir

Abstract

Influence of temperature dependent viscosity on natural convection in a vertical composite porous media, isothermally heated from one side and cooled from the opposing surface, is numerically analyzed using CFD commercial package. The composite cavity is formed by two regions with different permeability. The Darcy model is employed to predict the streamlines and heat transfer in two layered porous media. It is observed that viscosity reduction due to temperature increasing affect heat transfer rate and fluid movement from one layer to another layer.

Keywords: two layered porous media, viscosity, permeability ratio (Kr)

1. Introduction

Heat transfer in porous media has been extensively studied due to its numerous engineering and environmental applications. Oil recovery, underground spread of pollutants, grain storage, solar power collectors, optimal design of furnaces and packed-bed catalytic reactors are examples of applications of heat transfer mechanism in porous media.

Studies concerning natural convection in porous media can be found in the monographs of Ingham and Pop (1998) and Nield and Bejan (2006). The case of free convection in a rectangular porous media heated on one side and cooled at the opposing side is also an important problem in thermal convection in porous media. The work of Walker and Homsy (1978); Bejan (1979); Prasad and Kulacki (1984); Manole and Lage (1992); Saeid and Pop (2005) and others have further contributed with some classical results to this problem.

Multi layered cavity has been investigated: Poulikakos and Bejan (1983) studied horizontally and vertically layered cavity and approximated a correlation for N horizontal sub layers for calculation of overall Nusselt number. Lai and Kulacki (1988) discussed convection in a vertically divided rectangular cavity, which the right hand side wall was heated with constant heat flux.

Egorov and Polezhaev (1993) investigated theoretical model and showed that their numerical results are in the line with their experimental data for multilayer insulation. In addition, Merrikh and Mohamad (2002), Belghazi et al. (2010) and Ordo´n˜ez-Miranda and Alvarado-Gil (2010) and others have investigated multi layered porous media.

It can be seen that composite cavity under natural convection is evaluated extensively in literatures; however, the viscosity variation due to temperature rising is considered negligible. The main purpose of this paper is investigation of viscosity variation effect on the natural convection in a saturated enclosure, divided into two different porous layers, with different permeability subjected to a heat from one side and cool from another side.

2. Model equations

Incompressible, 2-D, natural convection in a two-layered cavity filled with saturated, isotropic porous medium with temperature dependent viscosity and density variation in the buoyancy term is studied numerically. It is assumed that the solid matrix and the fluid are in local thermal equilibrium. As suggested by Nield and Bejan (2006), the equations that govern the conservation of mass, momentum, and energy can be written as follows:

$$\nabla \boldsymbol{u} = \boldsymbol{0} \qquad \textbf{(1)}$$

$$\frac{\rho_f}{\varepsilon^2}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\frac{\partial P}{\partial x}-\frac{\mu}{K}u \tag{2}$$

$$\frac{\rho_f}{\varepsilon^2}\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=\frac{\partial P}{\partial x}-\frac{\mu}{K}\left[v+\rho g \beta (T_\infty - T)\right] \tag{3}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\nabla^2 T \tag{4}$$

The average Nusselt number is defined by:

$$\overline{Nu}=\int_0^{2L} Nu_x \, dx \tag{5}$$

It is considered that viscosity is varying with temperature in the following forms:

$$\mu=C \tag{6a}$$

$$\mu=T_0-\lambda(T-T_0) \tag{6b}$$

$$\mu=T_0\exp(\gamma T) \tag{6c}$$

3. Numerical procedure and grid independence

The model equations were solved using commercial flow simulation software FLUENT (version 6.3.26). Fig.1 shows the geometry of the simulated media. As it can be seen, two rectangular enclosures with different permeability are separated at X=L/2. In order to obtain grid independent results, different uniform grid numbers, 44 × 44, 66 × 66 and 90 × 90 are tested for Ra_m=100, Da= 1×10^{-2} and Kr = 100. It is noticed that the difference between the results predicted based on 66 × 66 and 90 × 90 grids is insignificant (<1%). The average Nusselt numbers for the tested grid points are 3.109, 3.711 and 3.721 for grids 44 × 44, 66 × 66 and 90 × 90 respectively. Thus, 66 × 66 grid was used for generating the results.

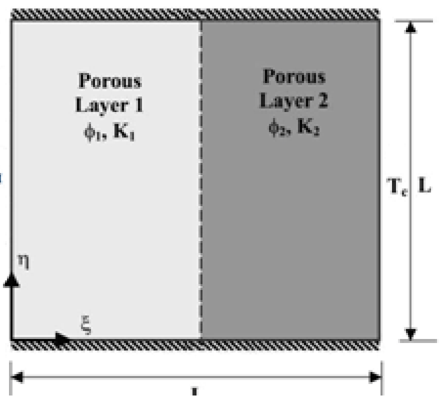


Fig.1- Schematic of the layered porous media and the coordinate system

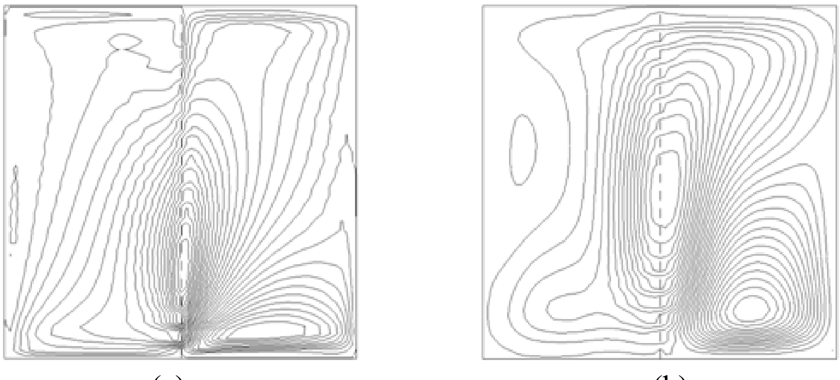
4. Results and discussion

4.1. *Effect of viscosity variation*

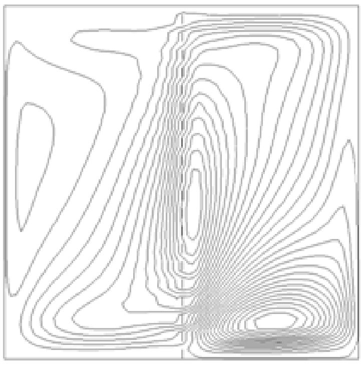
Fig.2 visualizes the streamlines for $Ra_l=10^4$ (Ra_l is Ra number for the heated region), Da=0.001, Kr=0.001 and Fig.3 illustrates streamlines for $Ra_l=10^4$, Da=0.001, Kr= 1000 for vertically divided porous media. As it can be seen, viscosity reduction due to temperature raising cause to increase flow penetration rate from one layer to another layer. In addition, flow penetration rate for the case, which has been modeled by considering exponential variation of viscosity is higher than the case with lineal variation of viscosity.

4.2. *Heat transfer*

Fig. 4 shows Nu numbers obtained by assuming (a) Exponential variation of viscosity with temperature, (b) Linear variation of viscosity with temperature and (c) Viscosity is constant and independent of temperature.
Fig. 4 depicts that the mean Nu number obtained with considering exponential variation with temperature (Nu_{exp}) is greater than the Nu number obtained with linear variation of viscosity with temperature (Nu_{lin}). In addition, Comparison of two temperature dependent curves with constant viscosity curve shows that at low Ra numbers, if temperature difference and T_h are low, Nu_{exp} and Nu_{lin} are lower than Nu_{con}. However, increasing Ra number cause to reduce the viscosity and increase mean Nu number. Furthermore, as it is expected, the average Nu number for Kr < 1 is substantially greater than this amount for Kr> 1 due to the fluid passing through the low permeable region to the high permeable zone

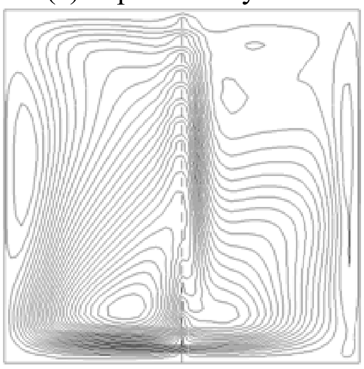


(a) (b)

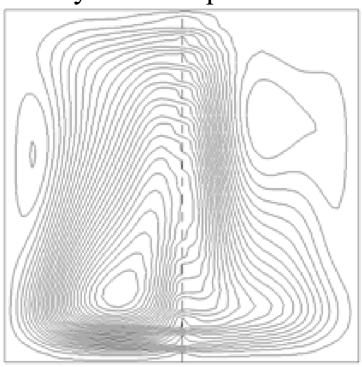


(c)

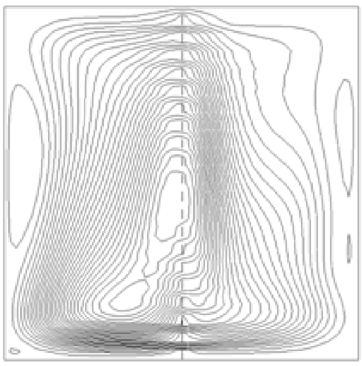
Fig. 2- Streamlines for vertically divided porous media, $Ra_1 = 10^4$, Da=0.001, Kr= 0.001 (a) constant viscosity, (b) linearly variation of viscosity with temperature and (c) exponentially variation of viscosity with temperature.



(a)



(b)



(c)

Fig. 3- Streamlines for vertically divided porous media, $Ra_1 = 10^4$, Da=0.001, Kr= 1000 (a) constant viscosity, (b) linearly variation of viscosity with temperature and (c) exponentially variation of viscosity with temperature.

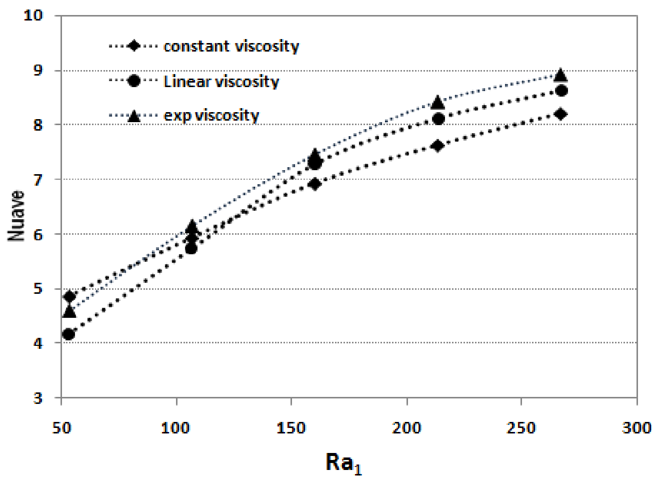


Fig. 4- Average Nusselt number for vertically divided enclosure Da=0.1, Kr= 10.

5. Conclusion

Viscosity variation effect on natural convection in a vertically layered porous media is investigated numerically using finite volume method. The results are presented for flow field and heat transfer of enclosures subjected to heat from one side and cool from the opposite wall, while the other walls were isolated.

6. Nomenclature

g: gravitational acceleration vector (m^2/s)
K: permeability of the porous matrix
K_r: permeability ratio (K_1/K_2)
Nu: Nusselt number
Ra: Rayleigh number ($g\beta\Delta TL^3/\nu\alpha$)
T: temperature
T_0: reference temperature
u: velocity in x-direction (m/s)
v: velocity in y-direction (m/s)
x : horizontal coordinate (m)s
y : vertical coordinate (m)
Greek symbols
α: thermal diffusivity (m2/s)
β: thermal expansion coefficient

λ: viscosity coefficient
γ: viscosity coefficient
ε: porosity
μ: viscosity ($kgm^{-1} s^{-1}$)
ν: kinematic viscosity
ρ: density (kg/m_{-3})
ζ: nondimensional coordinate in x-direction (x/H)

References

A.C. Baytas, I. Pop, Natural convection in a trapezoidal enclosure filled with a porous medium, Int. J. Eng. Sci. 39 (2001), 125–134.
A. Bejan, On the boundary layer regime in a vertical enclosure filled with a porous medium, Lett. Heat Mass Transfer 6 (1979), 93–102.
H. Belghazi, M. El Ganaoui, J.C. Labbe, Analytical solution of unsteady heat conduction in a two-layered material in imperfect contact subjected to a moving heat source, Int. J. of Thermal Sciences, 49 (2010), 311-318
R.J. Cross, M.R. Bear, C.E. Hickox, The application of flux-corrected transport (FCT) to high Rayleigh number natural convection in a porous medium, in:Proceedings of 8th Int. Heat Transfer Conference, San Francisco, 1986.
S. D. Egorov, V. I. Poleshaev, Thermal convection in anisotropic porous insulation, Heat Transfer Res. 25 (1993), 968–990.
B. Goyeau, J.P. Songbe, D. Gobin, Numerical study of double-diffusive natural convection in a porous cavity using the Darcy–Brinkman formulation, Int. J. Heat Mass Transfer 39 (1996), 1363–1378.
D.B. Ingham, I. Pop, Transport Phenomena in Porous Media, Elsevier, Amsterdam, 1998.
F. C. Lai, F. A. Kulacki, Natural convection across a vertical layered porous cavity. Int. J. Heat Mass Transfer 31 (1988), 1247–1260.
D.M. Manole, J.L. Lage, Numerical Benchmark Results for Natural Convection in a Porous Medium Cavity, Heat and Mass Transfer in Porous Media, ASME Conference, Htd, 216 (1992), 55–60.
A.A. Merrikh, A.A. Mohamad, Non-Darcy effects in buoyancy driven flows in a porous media filled with vertically layered porous media, Int. J. Heat Mass Transfer 45 (2002), 4305–4313.
D.A. Nield, A. Bejan, Convection in Porous Media, Springer, New York, 2006.
J. Ordo´n˜ez-Miranda, J.J. Alvarado-Gil, Frequency-modulated hyperbolic heat transport and effective thermal properties in layered systems, Int. J. Thermal Sci., 49 (2010), 209-217.
D. Poulikakos, A. Bejan, Natural convection in vertically and horizontally layered porous media heated from the side, Int. J. Heat Mass Transfer 26 (1983), 1805-1814.

V. Prasad, F.A. Kulacki, Convective heat transfer in a rectangular porous cavity effect of aspect ratio on flow structure and heat transfer, J. Heat Transfer 106 (1984), 158–165.
C. Revnic, T. Grosan, I. Pop, D.B. Ingham, Free convection in a square cavity filled with a bidisperse porous medium, Int. J. Thermal Sciences 48 (2009), 1876–1883
N. H. Saeid, I. Pop, Non-Darcy natural convection in a square cavity filled with a porous medium, Fluid Dynamics Research 36 (2005), 35–43.
Y. Varol, H.F. Oztop, I. Pop, Influence of inclination angle on buoyancy-driven convection in triangular enclosure filled with a fluid-saturated porous medium, Heat Mass Transfer 44 (2008), 617–624.
K.L. Walker, G.M. Homsy, Convection in porous cavity, J. Fluid Mech. 87 (1978), 449–474.

Received: September, 2011