Sankar, M.; **Park, Youngyong**; **Lopez, J. M.**; **Do, Younghae**

Numerical study of natural convection in a vertical porous annulus with discrete heating.

(English) Zbl 1211.80026
Int. J. Heat Mass Transfer 54, No. 7-8, 1493-1505 (2011).

Summary: In this paper natural convection flows in a vertical annulus filled with a fluid-saturated porous medium has been investigated when the inner wall is subject to discrete heating. The outer wall is maintained isothermally at a lower temperature, while the top and bottom walls, and the unheated portions of the inner wall are kept adiabatic. Through the Brinkman-extended Darcy equation, the relative importance of discrete heating on natural convection in the porous annulus is examined. An implicit finite difference method has been used to solve the governing equations of the flow system. The analysis is carried out for a wide range of modified Rayleigh and Darcy numbers for different heat source lengths and locations. It is observed that placing of the heater in lower half of the inner wall rather than placing the heater near the top and bottom portions of the inner wall produces maximum heat transfer. The numerical results reveal that an increase in the radius ratio, modified Rayleigh number and Darcy number increases the heat transfer, while the heat transfer decreases with an increase in the length of the heater. The maximum temperature at the heater surface increases with an increase in the heater length, while it decreases when the modified Rayleigh number and Darcy number increases. Further, we find that the size and location of the heater effects the flow intensity and heat transfer rate in the annular cavity.

MSC:

80A20 Heat and mass transfer, heat flow (MSC2010)
76R10 Free convection
76S05 Flows in porous media; filtration; seepage
80M20 Finite difference methods applied to problems in thermodynamics and heat transfer
76M20 Finite difference methods applied to problems in fluid mechanics

Keywords:

natural convection; annulus; discrete heating; porous medium; radii ratio; Brinkman-extended Darcy model

Full Text: DOI

References:

[1] Vafai, K.; Hadim, H.: Overview of current computational studies of heat transfer in porous media and their applications – natural and mixed convection, Advances in numerical heat transfer (2000)

[2] , Transport phenomena in porous media (2005)

[3] , Handbook of porous media (2005)

[4] Nield, D. A.; Bejan, A.: Convection in porous media, (2006) · Zbl 1256.76004

[5] , Emerging topics in heat and mass transfer in porous media (2008)

[6] Lauriat, G.; Prasad, V.: Non-darcian effects on natural convection in a vertical porous enclosure, Int. J. Heat mass transfer 32, 2135-2148 (1989)

[7] Nithiarasu, P.; Seetharamu, K. N.; Sundararajan, T.: Natural convective heat transfer in a fluid saturated variable porosity medium, Int. J. Heat mass transfer 40, No. 16, 3955-3967 (1997) · Zbl 0925.76660 · doi:10.1016/S0017-9310(97)00008-2

[8] Chen, X. B.; Yu, P.; Winoto, S. H.; Low, H. T.: Free convection in a porous wavy cavity based on the Darcy – Brinkman – Forchheimer extended model, Numer. heat transfer part A: appl. 52, 377-397 (2007)

[9] Krishna, D. J.; Basak, T.; Das, S. K.: Natural convection in a heat generating hydrodynamically and thermally anisotropic non-Darcy porous medium, Int. J. Heat mass transfer 51, 4691-4703 (2008) · Zbl 1154.80327 · doi:10.1016/j.ijheatmasstransfer.2008.02.019

[10] Kumar, D. S.; Dass, A. K.; Dewan, A.: Analysis of non-Darcy models for mixed convection in a porous cavity using a multigrid approach, Numer. heat transfer part A: appl. 56, 685-708 (2009)

[11] Havstad, M. A.; Burns, P. J.: Convective heat transfer in vertical cylindrical annuli filled with a porous medium, Int. J. Heat

mass transfer 25, 1755-1766 (1982)

[12] Hickox, C. E.; Gartling, D. K.: A numerical study of natural convection in a vertical annular porous layer, Int. J. Heat mass transfer 28, 720-723 (1985) · Zbl 0575.76089

[13] Prasad, V.; Kulacki, F. A.: Natural convection in a vertical porous annulus, Int. J. Heat mass transfer 27, 207-219 (1984) · Zbl 0533.76089 · doi:10.1016/0017-9310(84)90212-6

[14] Prasad, V.: Numerical study of natural convection in a vertical, porous annulus with constant heat flux on the inner wall, Int. J. Heat mass transfer 29, 841-853 (1986)

[15] Hasnaoui, M.; Vasseur, P.; Bilgen, E.; Robillard, L.: Analytical and numerical study of natural convection heat transfer in a vertical porous annulus, Chem. eng. Commun. 131, 141-159 (1995)

[16] Reda, D. C.: Natural convection experiments in a liquid-saturated porous medium bounded by vertical coaxial cylinders, ASME J. Heat transfer 105, 795-802 (1983)

[17] Prasad, V.; Kulacki, F. A.; Keyhani, M.: Natural convection in porous media, J. fluid mech. 150, 89-119 (1985)

[18] Prasad, V.; Kulacki, F. A.; Kulkarni, A. V.: Free convection in a vertical porous annulus with constant heat flux on the inner wall-experimental results, Int. J. Heat mass transfer 29, 713-723 (1986)

[19] Marpu, D. R.: Forchheimer and Brinkman extended Darcy flow model on natural convection in a vertical cylindrical porous annulus, Acta mechanica 109, 41-48 (1995) · Zbl 0866.76087 · doi:10.1007/BF01176815

[20] Char, M. -I.; Lee, G-C.: Maximum density effects on natural convection in a vertical annulus filled with a non-Darcy porous medium, Acta mechanica 128, 217-231 (1998) · Zbl 0926.76109 · doi:10.1007/BF01251892

[21] Shivakumara, I. S.; Prasanna, B. M. R.; Rudraiah, N.; Venkatachalappa, M.: Numerical study of natural convection in a vertical cylindrical annulus using a non-Darcy equation, J. porous media 5, No. 2, 87-102 (2003) · Zbl 1151.76588

[22] Kiwan, S.; Al-Zahrani, M. S.: Effect of porous inserts on natural convection heat transfer between two concentric vertical cylinders, Numer. heat transfer part A: appl. 53, 870-889 (2008)

[23] Al-Zahrani, M. S.; Kiwan, S.: Mixed convection heat transfer in the annulus between two concentric vertical cylinders using porous layers, Transport porous media 76, 391-405 (2009)

[24] Reddy, B. V. K.; Narasimhan, A.: Heat generation effects in natural convection inside a porous annulus, Int. commun. Heat mass transfer 37, 607-610 (2010)

[25] Khan, J. A.; Kumar, R.: Natural convection in vertical annuli: a numerical study for constant heat flux on the inner wall, ASME J. Heat transfer 111, 909-915 (1989)

[26] Sankar, M.; Do, Y.: Numerical simulation of free convection heat transfer in a vertical annular cavity with discrete heating, Int. commun. Heat mass transfer 37, 600-606 (2010)

[27] Reeve, H. M.; Mescher, A. M.; Emery, A. F.: Unsteady natural convection of air in a tall axisymmetric non-isothermal annulus, Numer. heat transfer part A: appl. 45, 625-648 (2004)

[28] Abu-Sitta, N. H.; Khanafer, K.; Vafai, K.; Al-Amiri, A. M.: Combined forced- and natural-convection heat transfer in horizontally counter rotating eccentric and concentric cylinders, Numer. heat transfer part A: appl. 51, 1167-1186 (2007)

[29] Chang, W-J.; Hsiao, C-F.: Natural convection in a vertical cylinder filled with anisotropic porous media, Int. J. Heat mass transfer 36, No. 13, 3361-3367 (1993) · Zbl 0800.76427 · doi:10.1016/0017-9310(93)90017-Z

[30] Barletta, A.; Magyari, E.; Pop, I.; Storesletten, L.: Buoyant flow with viscous heating in a vertical circular duct filled with a porous medium, Transport porous media 74, 133-151 (2008)

[31] Amara, T.; Slimi, K.; Nasrallah, S. B.: Free convection in a vertical cylindrical enclosure, Int. J. Therm. sci. 39, 616-634 (2000)

[32] Banerjee, S.; Mukhopadhyay, A.; Sen, S.; Ganguly, R.: Thermomagnetic convection in square and shallow enclosures for electronic cooling, Numer. heat transfer part A: appl. 55, 931-951 (2009)

[33] Sharif, M. A. R.; Mohammad, T. R.: Natural convection in cavities with constant heat flux heating at the bottom wall and isothermal cooling from the sidewalls, Int. J. Heat mass transfer 44, 865-878 (2005)

[34] Deng, Q. -H.: Fluid flow and heat transfer characteristics of natural convection in square cavities due to discrete source-sink pairs, Int. J. Heat mass transfer 51, 5949-5957 (2008) · Zbl 1153.80313 · doi:10.1016/j.ijheatmasstransfer.2008.04.062

[35] Corcione, M.; Habib, E.: Buoyant heat transport in fluids across tilted square cavities discretely heated at one side, Int. J. Therm. sci. 49, 797-808 (2010)

[36] Saeid, N. H.; Pop, I.: Natural convection from discrete heater in a square cavity filled with a porous medium, J. porous media 8, No. 1, 55-63 (2005) · Zbl 1159.76382 · doi:10.1615/JPorMedia.v8.i1.50

[37] Saeid, N. H.: Natural convection from two thermal sources in a vertical porous layer, ASME J. Heat transfer 128, 104-109 (2006)

[38] Basak, T.; Roy, S.; Takhar, H. S.: Effects of non-uniformly heated \(wall(s)\) on a natural-convection flow in a square cavity filed with porous medium, Numer. heat transfer part A: appl. 51, 959-978 (2007)

[39] Sathiyamoorthy, M.; Basak, T.; Roy, S.; Pop, I.: Steady natural convection flow in a square cavity filled with a porous medium for linearly heated side \(wall(s)\), Int. J. Heat mass transfer 50, 1892-1901 (2007) · Zbl 1124.80363 · doi:10.1016/j.ijheatmasstransfer.2006.10.010

[40] Kaluri, R. S.; Basak, T.; Roy, S.: Bejan's heatlines and numerical visualization of heat flow and thermal mixing in various differentially heated porous square cavities, Numer. heat transfer part A: appl. 55, No. 5, 487-516 (2009)

[41] Marafie, A.; Khanafer, K.; Al-Azmi, B.; Vafai, K.: Non-darcian effects on the mixed convection heat transfer in a metallic porous block with a confined slot jet, Numer. heat transfer part A: appl. 54, 665-685 (2008)

[42] Waheed, M. A.: Heatfunction formulation of thermal convection in rectangular enclosures filled with porous media, Numer. heat transfer part A: appl. 55, 185-204 (2009)