Middle-East Journal of Scientific Research 25 (5): 950-959, 2017
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2017.950.959

Mixed Convection Flow of a Jeffrey Nanofluid in a Vertical Channel

K. Sushma, S. Sreenadh and P. Dhanalakshmi

Department of Mathematics, S.V. University, Tirupati - 517 502, A.P., India

Abstract: The laminar fully developed mixed convection flow of a Jeffrey Nanofluid in a vertical channel bounded by parallel plates with asymmetrical thermal and nanoparticle concentration conditions at the walls is investigated. The nanofluid model used here includes the effects of Brownian diffusion and thermophoresis. The expressions for the velocity, temperature and nanoparticle concentration profiles are obtained. Nusselt and Sherwood numbers at the left wall of the channel are determined and discussed in detail. When the Jeffrey parameter and heat source parameter tend to zero, the results deduced agree with the corresponding ones of Grosan and Pop [27]. It is observed that the velocity increases at the hot wall and decreases at the cold wall due to increasing Jeffrey parameter. But opposite behaviour is noticed in the case of the buoyancy ratio, thermophoresis, Brownian motion and heat source parameters. Further a numerical solution is also obtained and is compared with the analytical solution.

Key words: Vertical Channel · Mixed Convection flow · Jeffrey nanofluid

INTRODUCTION

Combined forced convection and natural convection, or mixed convection, occurs when natural convection and forced convection mechanisms act together to transfer heat. This occurs where both pressure forces and buoyant forces interact. Heat transfer applications in a channel where both forced and free convection play a role in determining the velocity and temperature fields arise in many practical applications. A frequently encountered configuration in thermal engineering equipment is the vertical channel. This configuration is used to model, for example, collection of solar energy and cooling devices of electronic and microelectronic equipments. Literature review of the fully developed mixed convection flow in channels has been presented by Tao [1], Aung and Worku [2], Cheng *et al*. [3], Hamadah and Wirtz [4], Chen and Chung [5], Barletta [6], Barletta *et al*. [7, 8], Boulama and Galanis [9], etc. It is observed that conventional heat transfer fluids such as ethylene glycol mixture, etc.) are poor heat transfer fluids because of their low thermal conductivity. In order to increase the thermal conductivity of the base fluids, researchers have tried to suspend solid particles in fluids, since the thermal conductivity of solids is typically higher than that of liquids [10] Fluids with particles of the order of nanometers suspended in liquids are called nanofluids [11]. It is repeated that they have superior properties compared to usual heat transfer fluids. Successful application of nanofluids will support the current trend towards component miniaturization by enabling the design of smaller and lighter heat exchanger systems. The convective heat transfer characteristics of nanofluids depend on the thermophysical properties of the base fluid, the flow pattern and the volume fraction of the suspended particles and their dimensions. and the shape of these particles. Nanofluids have many important industrial applications also (for example nuclear reactors, nanodrug delivery, cancer therapeutics, sensing and imaging). Buongiorno [12] reported that the nanoparticle absolute velocity can be viewed as the sum of the base fluid velocity and a relative velocity. He calls it as the slip velocity. He has concluded tha in the absence of turbulent effects, it is the Brownian diffusion and the thermophoresis that are important and he has suggested conservation equations based on these two effects. This model has been used by Nield and Kuznetzov [13], Kuznetov and Nield [14], Khan and Pop [15] and several authors to study Convective flows of nanofluids. Numerical and experimental studies on nanofluids inside cavities are made by Kang *et al*., Khanafer *et al*., Tiwari *et al*. and Aminossadati *et al*. [16-19]. Important reviews on nanofluid flows are given by Daungthongsuk

Corresponding Author: S. Sreenadh, Department of Mathematics, S.V. University, Tirupati - 517 502, A.P., India.

and Wongwises [20], Wang and Mujumdar [21] and Kakac¸ and Pramuanjaroenkij [22]. Fully Developed Mixed Convection in a Vertical Channel Filled by a Nanofluid is studied by Grosan and Pop [23]. Natural convective boundary-layer flow of a nanofluid past a vertical plate is discussed by Kuznetsov and Nield [24]. Effects of Heat Generation or Absorption on Free Convection Flow of a Nanofluid past an Isothermal Inclined Plate are analysed by Akilu and Narahari [25]. MHD free Convection Flow of a Nanofluid past a vertical Plate in the Presence of heat generation/ absorption effects is studied by Chamkha and Aly [26]. Analytical solution for peristaltic flow of conducting nanofluids in an asymmetric channel with slip effect of velocity, temperature and concentration is studied by Sreenadh *et al*. [27].

In this paper mixed convection flow of a Jeffrey nanofluid in a vertical channel is studied.

Nomenclature:

A to G Constants
C Nanoparticles volume fraction
D_T Thermophoretic diffusion coefficient
L Distance between parallel walls
Gr Grashof number
Nb Brownian motion parameter
Nt Thermophoresis parameter
Sh Sherwood number
u, v, velocity components in the x- and y- directions
λ_1 Jeffrey parameter
c heat capacity at constant pressure
g Gravity acceleration vector
D_B Brownian diffusion coefficient
K Thermal conductivity
T Jeffrey parameter
Nr Buoyancy-ratio parameter
Nu Nusselt number
p Pressure
T Fluid temperature
x, y Cartesian coordinates
v velocity vector
γ heat source parameter

Greek Symbols:

α Pressure parameter
β Thermal expansion coefficient
ϕ Rescaled nanoparticle volume fraction
μ Dynamic viscosity
υ Kinematic viscosity
θ Dimensionless temperature
ρ Density

Subscripts:

f Base fluid
p Solid particle

Mathematical Formulation of the Problem: Consider a Jeffrey nanofluid that steadily flows between two vertical and parallel plane walls apportioned by a distance L. Let x-axis be aligned parallel to the gravitational acceleration vector $\overline{g}$, but with the positive direction and y-axis be taken orthogonal to the channel walls. Let y=0 and y=L act as two vertical walls respectively. It is assumed that the temperature and the nano particles concentration at the wall at y = 0 are T_1 and C_1 and at the wall at y = L are T_2 and C_2, respectively.

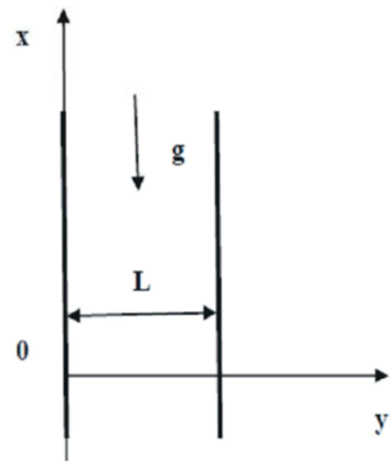

Fig. 1: Physical model

Assuming the Oberbeck-Boussinesq approximation, the governing equations reduce to [23].

$$v=0,\ \frac{\partial u}{\partial x}=0,\frac{\partial T}{\partial x}=0,\frac{\partial C}{\partial x}=0,\frac{\partial p}{\partial y}=0,\frac{\partial p}{\partial x}=\frac{dp}{dx}=\text{constant} \tag{1}$$

$$-\frac{dp}{dx}+\frac{\mu}{1+\lambda_1}\frac{d^2u}{dy^2}+\begin{bmatrix}(1-C_0)\rho_{f_0}\beta(T-T_0)\\ -(\rho_f-\rho_{f_0})(C-C_0)\end{bmatrix}g=0 \tag{2}$$

$$K\frac{d^2T}{dy^2}+(\rho c)_p\left[D_B\frac{dC}{dy}\frac{dT}{dy}+\left(\frac{D_T}{T_0}\right)\left(\frac{dT}{dy}\right)^2\right]+Q_0=0 \tag{3}$$

$$D_B\frac{d^2C}{dy^2}+\left(\frac{D_T}{T_0}\right)\frac{d^2T}{dy^2}=0 \tag{4}$$

The boundary conditions are given by;

$u = 0$, T - T_1, $C = C_1$ at y = 0
$u = 0$, $T = T_2$, C = C_2 at y = L (5)

In order to determine the pressure gradient from equation(2), the mass flux conservation Q is required.

$$\int_0^L u dy = Q \tag{6}$$

We introduce now the following dimensionless variables:

$$\begin{aligned} &Y = y/L, U(Y) = u(y)/u_0, \\ &P(Y) = p(y)/(\rho u_0^2), \\ &\theta(Y) = (T - T_0)/(T_2 - T_0), \\ &\phi(Y) = (C - C_0)/(C_2 - C_0) \end{aligned} \tag{7}$$

where, following Barleta and Zanchini [28], we assume that $T_0 = (T_1 + T_2)/2$ and $C_0 = (C_1 + C_2)/2$. Substituting these variables into Eqs. (2)-(4), we get the following ordinary differential equations:

$$\frac{d^2U}{dY^2} + \frac{Gr}{\mathrm{Re}}(1+\lambda_1)\theta(Y) - Nr(1+\lambda_1)\phi(Y) + \alpha(1+\lambda_1) = 0 \tag{8}$$

$$\frac{d^2\theta}{dY^2} + Nb\frac{d\theta}{dY}\frac{d\phi}{dY} + Nt\left(\frac{d\theta}{dY}\right)^2 + \gamma = 0 \tag{9}$$

$$\frac{d^2\phi}{dY^2} + \frac{Nt}{Nb}\frac{d^2\theta}{dY^2} = 0 \tag{10}$$

The boundary conditions (5) become

$$\begin{aligned} &U(0) = 0, \theta(0) = -1, \phi(0) = -1 \\ &U(1) = 0, \theta(1) = 1, \phi(1) = 1 \end{aligned} \tag{11}$$

The mass flux conservation relation (6), becomes

$$\int_0^1 U dy = 1 \tag{12}$$

where we have taken $Q = u_0L$.

In the above equations, $\alpha = -\frac{dp}{dx}$ is the pressure parameter, Gr is the Grashof number, Re is the Reynolds number and Gr/Re is the mixed convection parameter, Nb is the Brownian motion parameter and Nt is the thermophoresis parameter . These parameters are given by;

$$Gr = \frac{(1-C_0)g\beta(T_2 - T_0)L^3}{\upsilon^2}, \mathrm{Re} = \frac{u_0 L}{\upsilon} \tag{13}$$

The physical quantities of interest are the Nusselt (Nu) and the Sherwood (Sh) numbers defined as;

$$\begin{aligned} &Nu = -\frac{L}{T_2 - T_0}\left(\frac{\partial T}{\partial y}\right)_{y=0}, \\ &Sh = -\frac{L}{C_2 - C_0}\left(\frac{\partial C}{\partial y}\right)_{y=0} \end{aligned} \tag{14}$$

Substituting Eq.(7) into Eq.(4), we get,

$$Nu = -\theta'(0), Sh = -\phi'(0) \tag{15}$$

Solution of the Problem: Equations (8)-(10) along with the boundary conditions (11) and the mass flux conservation equation (12) have been solved analytically. The expressions for velocity, temperature, concentration and the pressure gradient are given by;

$$U(Y) = (1+\lambda_1)\left[\begin{aligned} &\left(\frac{E}{B^2} - \frac{E}{B^2}e^{-BY} - \frac{F}{6}Y^3\right) \\ &+\left(\frac{-6}{1+\lambda_1} - \frac{6E}{B^3} + \frac{3E}{B^2} + \frac{F}{4} + \frac{6E}{B^3}e^{-B} + \frac{3E}{B^2}e^{-B}\right)Y^2 \\ &+\left(\frac{6}{1+\lambda_1} + \frac{6E}{B^3} - \frac{4E}{B^2} - \frac{F}{12} - \frac{6E}{B^3}e^{-B} - \frac{2E}{B^2}e^{-B}\right)Y \end{aligned}\right] \tag{16}$$

$$\theta(Y) = C + De^{-BY} - \frac{\gamma Y}{B} \tag{17}$$

$$\phi(Y) = -\frac{Nt}{Nb}\theta(Y) + AY - \frac{A}{2} \tag{18}$$

$$\alpha = \frac{12}{1+\lambda_1} + \frac{12E}{B^3}(1-e^{-B}) - \frac{6E}{B^2}(1+e^{-B}) - \frac{F}{2} - G \tag{19}$$

where,

$$A = 2\left(1 + \frac{Nt}{Nb}\right), B = ANb, C = \frac{1 + e^{-B} + \frac{\gamma}{B}}{1 - e^{-B}},$$

$$D = \frac{2 + \frac{\gamma}{B}}{e^{-B} - 1}, E = D\left(\frac{Gr}{\mathrm{Re}} + Nr\frac{Nt}{Nb}\right)$$

Table 1: Comparison between analytical and numerical results

$\frac{Gr}{Re}$	Nr	Nt	Nb	λ_1	γ	Pressure Gradient Analytic	Pressure Gradient Numeric	Nusselt Number θ' (0) Analytic	Nusselt Number θ' (0) Numeric	Sheerwood Number ϕ'(0) Analytic	Sheerwood Number ϕ'(0) Numeric
0	0	0	0.2	0.3	0.05	9.2308	9.23080	2.4533	2.45326	2	2.00000
	0	0.2	0.2	0.3	0.05	9.2308	9.23080	2.9338	2.93626	1.0662	1.08874
	5	0.2	0.2	0.3	0.05	8.4151	8.41510	2.9338	2.93626	1.0662	1.08874
1000	0	0	0.2	0.3	0.05	-75.5273	-75.52730	2.4533	2.45326	2	2.00000
	0	0.2	0.2	0.3	0.05	-153.9121	-153.91210	2.9338	2.93626	1.0662	1.08874
	5	0.2	0.2	0.3	0.05	-154.7278	-154.72780	2.9338	2.93626	1.0662	1.08874

$$F = -\left[\left(\frac{Gr}{\mathrm{Re}} + Nr\frac{Nt}{Nb}\right)\frac{\gamma}{B} + NrA\right],$$
$$G = C\left[\left(\frac{Gr}{\mathrm{Re}} + Nr\frac{Nt}{Nb}\right) + \frac{NrA}{2}\right] \tag{20}$$

Using Eqs.(17) and (18), the expressions for the Nusselt and Sherwood numbers defined by Eq. (15) become;

$$Nu = -\theta'(0) = BD + \frac{\gamma}{B},$$
$$Sh = -\phi'(0) = -\left[\frac{Nt}{Nb}\left(BD + \frac{\gamma}{B}\right) + A\right] \tag{21}$$

In order to check the analytical solution (16), (17) and (18) with numerical solution, we applied RK method of fourth order along with Shooting technique. The comparison is presented in Table 1. A very good agreement is seen between exact and numerical results.

RESULTS AND DISCUSSION

In this paper, steady flow of a mixed convection through vertical channel filled by a Jeffrey nanofluid is examined and the results are discussed for various physical parameters such as the buoyancy ratio parameter Nr, the Brownonian motion parameter Nb, the Thermophoresis parameter Nt, heat source parameter γ and Jeffrey parameter λ_1. In this analysis, for numerical calculation we used $Nt = Nb = 0.5$, $\lambda_1 = 0.3$, $\gamma = 0.5$ and $Nr = 100$, for a fixed value of the mixed convection parameter Gr/Re=1000. These assigned values are kept as common in the entire study except for discrete values as displayed in Figures 2-13.

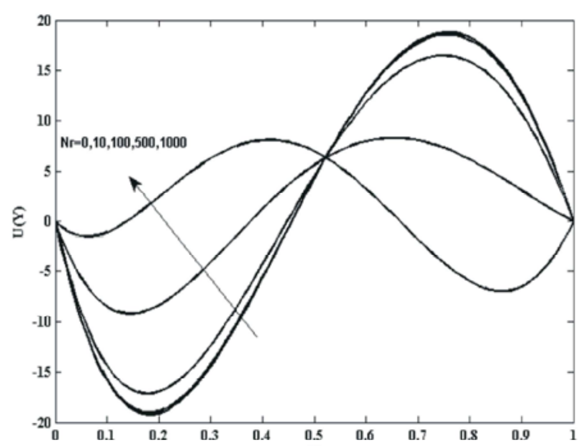

Fig. 2: Variation of dimensionless Velocity when Nr=0, 10, 100, 500, 1000 and Nt=Nb=0.5, $\lambda_1 = 0.3$, $\gamma = 0.5$

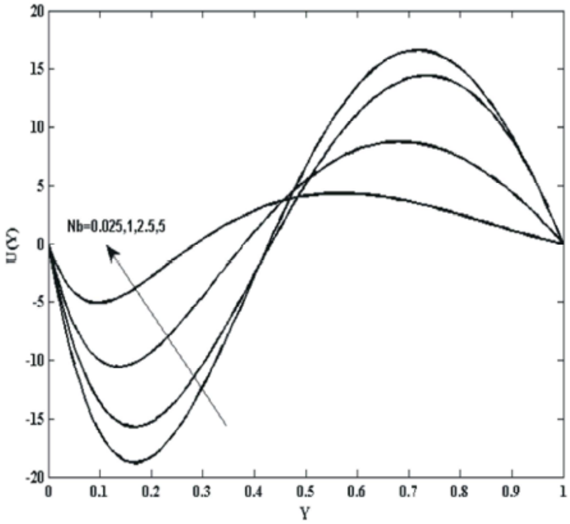

Fig. 3: Variation of dimensionless velocity When Nb=0.025, 1, 2.5, 5, Nt=0.5, Nr=100, and λ_1 = 0.3 γ = 0.5

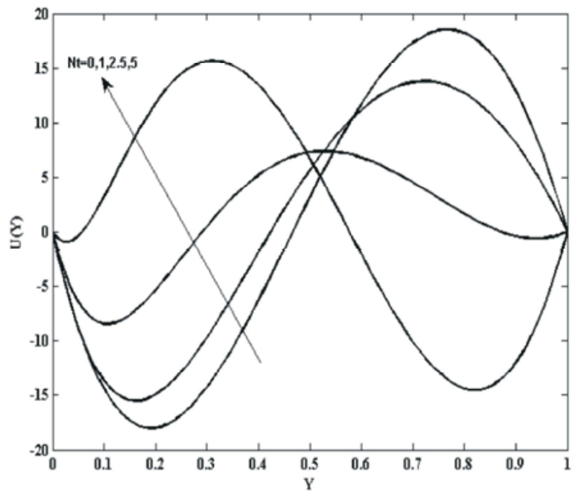

Fig. 4: Variation of dimensionless velocity when Nt=0.1, 2.5, 5, Nr=100, Nb=0.5 and λ_1 = 0.3, γ = 0.5

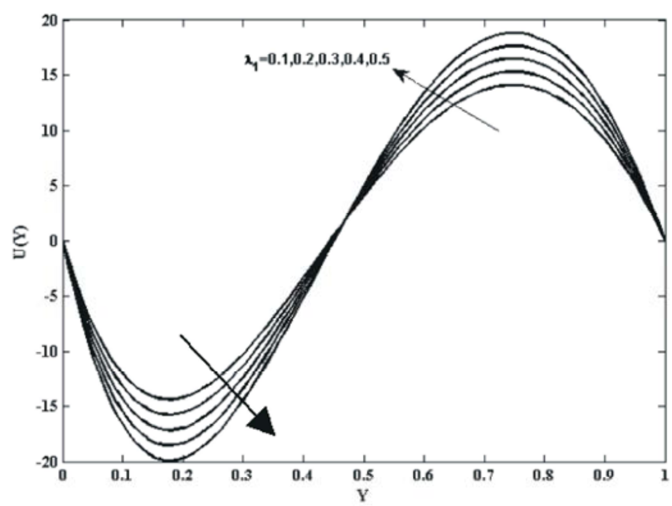

Fig. 5: Variation of dimensionless velocity when λ_1 = 0.5,0.6,0.7,0.8 and Nt=Nb=0.5, Nr=100, =0.5

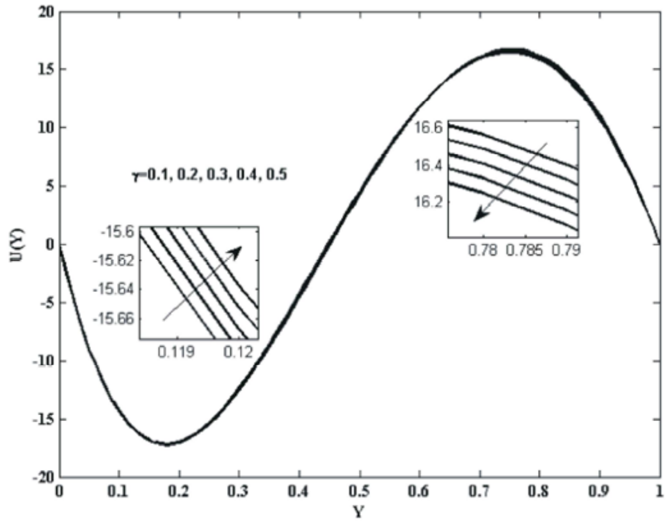

Fig. 6: Variation of dimensionless velocity when =0.1, 0.2, 0.3, 0.4, 0.5, Nt=0.5 Nr=100, Nb=0.5 and $\lambda_1 = 0.3$

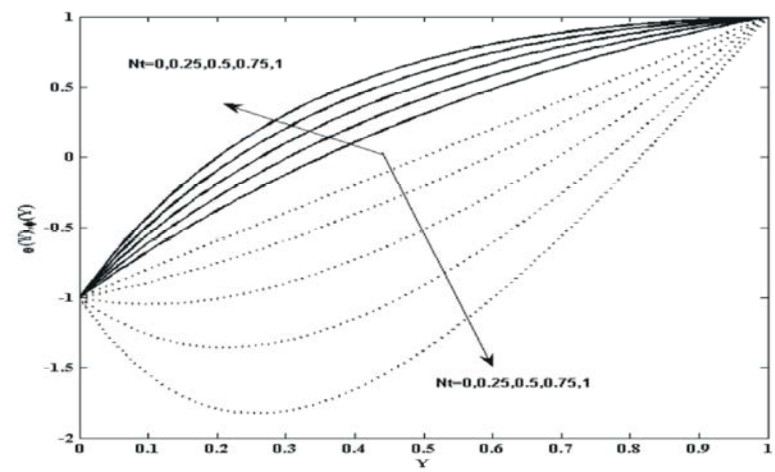

Fig. 7: Variation of dimensionless temparature (full line) and dimensionless concentration (dot line) when Nt=0, 0.25, 0.5, 0.75, 1 and Nb=0.5, $\lambda_1 = 0.3$, $\gamma = 0.5$

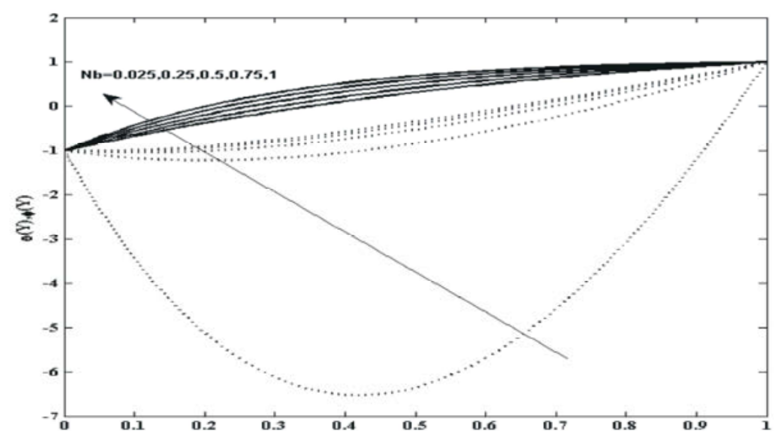

Fig. 8: Variation of dimensionless temparature (full line) and dimensionless concentration (dot line) when Nb=0.025, 0.25, 0.5, 0.75, 1 and Nt=0.5, $\lambda_1 = 0.3$, γ =0.5

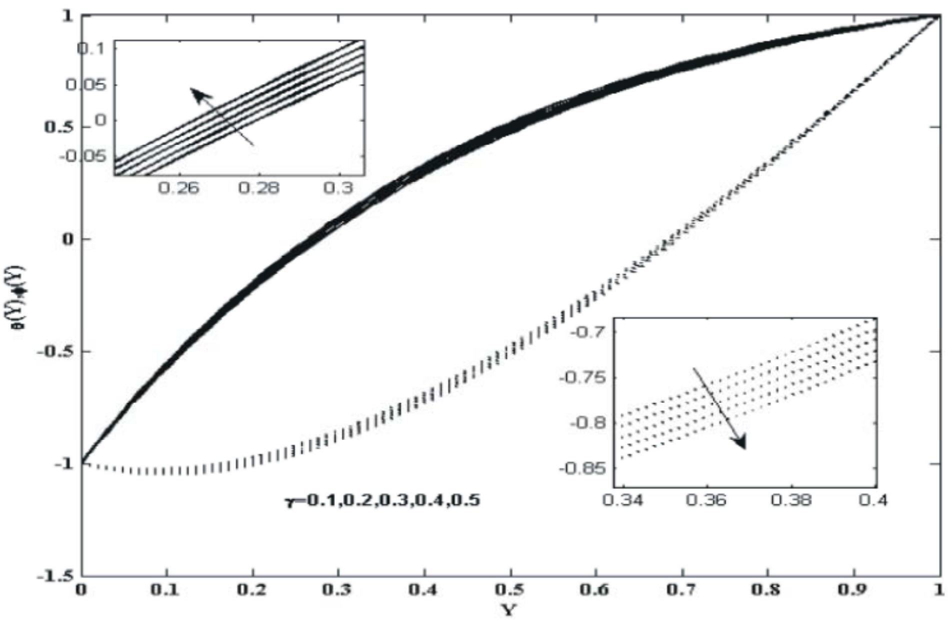

Fig. 9: Variation of dimensionless temparature (full line) and dimensionless concentration (dot line) when γ =0.1, 0.2, 0.3, 0.4, 0.5, Nb=0.5 and Nt=0.5, λ_1 = 0.3

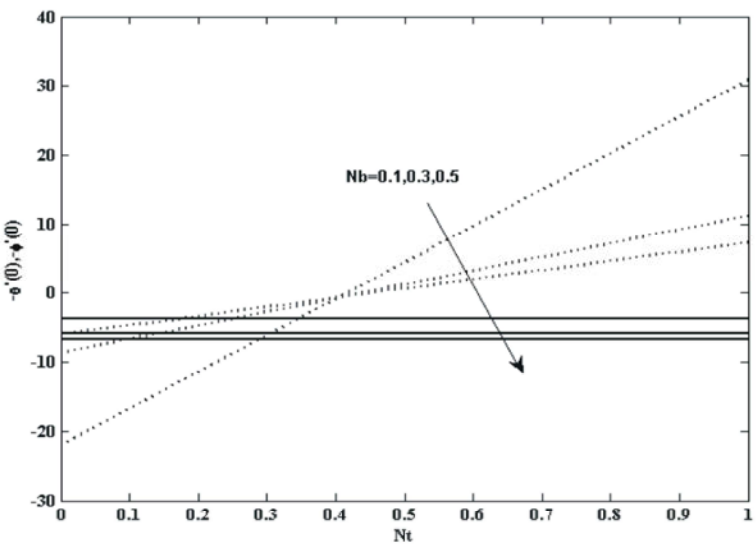

Fig. 10: Variation of reduced Nusselt number $-\theta'(0)$ (full line)and reduced Sherwood number $-\phi'(0)$ (dot line)with respect to Nt when Nb=0.1, 0.3, 0.5, $\gamma = 0.5$

The variation of velocity with y is computed from equation (16) and is shown in Figures 2 to 6 for different values of Nt, Nb, Nr, γ and λ_1. It depicts that the velocity increases at cold wall and decreases at hot wall with increasing Nr, Nt, Nb and γ, where as opposite phenomena is observed in Jeffrey parameter λ_1. The variation of temperature and nanoparticle volume fraction with y are computed from equations (17) and (18) for different values of Nt, Nb and γ. Figs. 7, 8 and 9 display the temperature and the nanoparticle volume fraction profiles for different values of Nb, Nt and γ. Thus, we notice from Figs. 7, 8 and 9 that both temperature and nanoparticle volume fraction profiles increase with the increasing of the parameter Nb, where as temperature profile increases and nanoparticle volume fraction decreases with the increasing of Nt and γ.

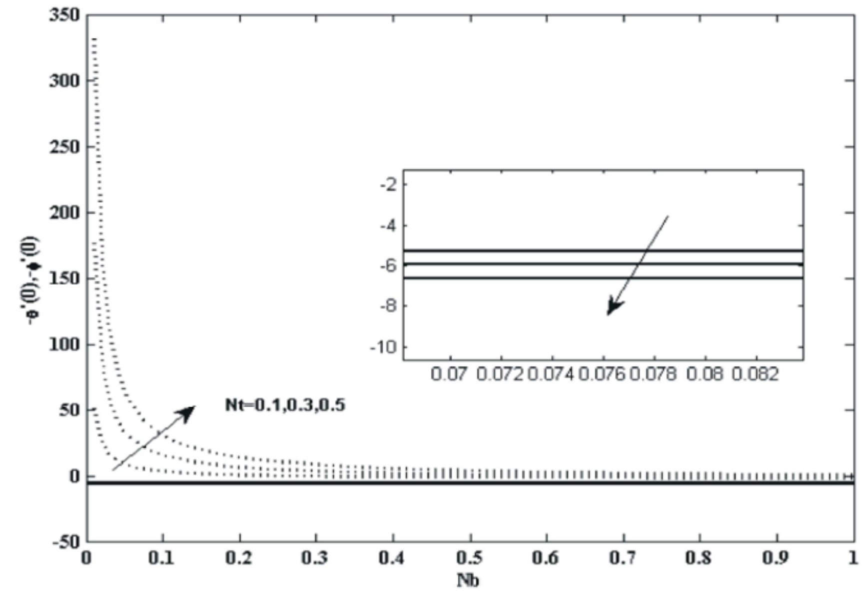

Fig. 11: Variation of reduced Nusselt number $-\theta'(0)$ (full line)and reduced Sherwood number $-\phi'(0)$ (dot line)with respect to Nb when Nt=0.1, 0.3, 0.5, $\gamma = 0.5$

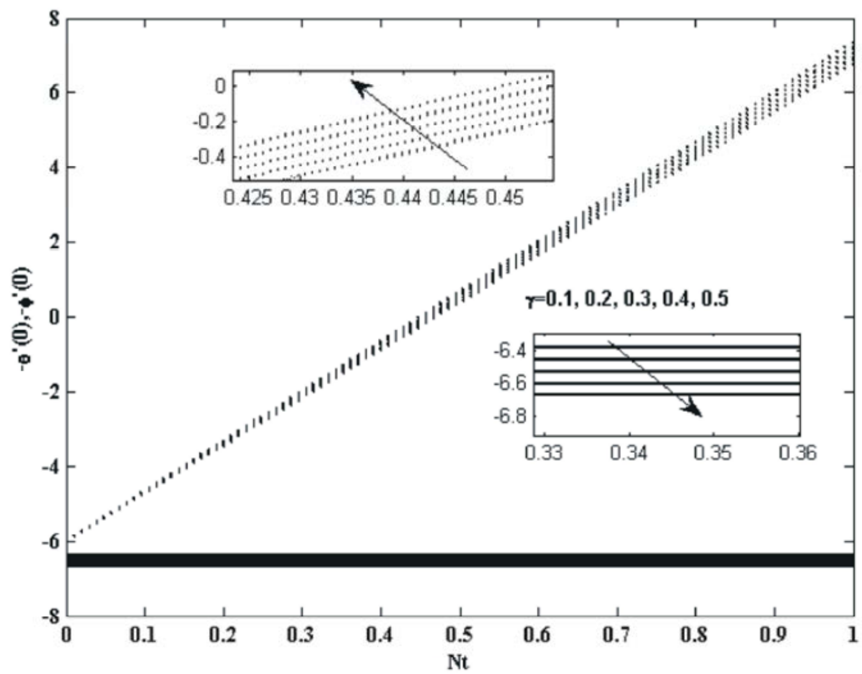

Fig. 12: Variation of reduced Nusselt number (full line) and reduced Sherwood number (dot line)with respect to Nt when $\gamma = 0.1, 0.2, 0.3, 0.4, 0.5$, Nb=0.5

The variation of Nusselt and Sherwood numbers with Nt, Nb and γ is computed from equation (21) and is shown in Figures 10 to 13 for different values of Nt, Nb and γ. It is seen that the Nusselt number and Sherwood number both decreases with increasing of Nb where as Nusselt number decreases and Sherwood number increases with increasing of Nt and Nusselt number increases where as Sherwood number decreases with increasing of γ at fixed values of Nt and Nb.

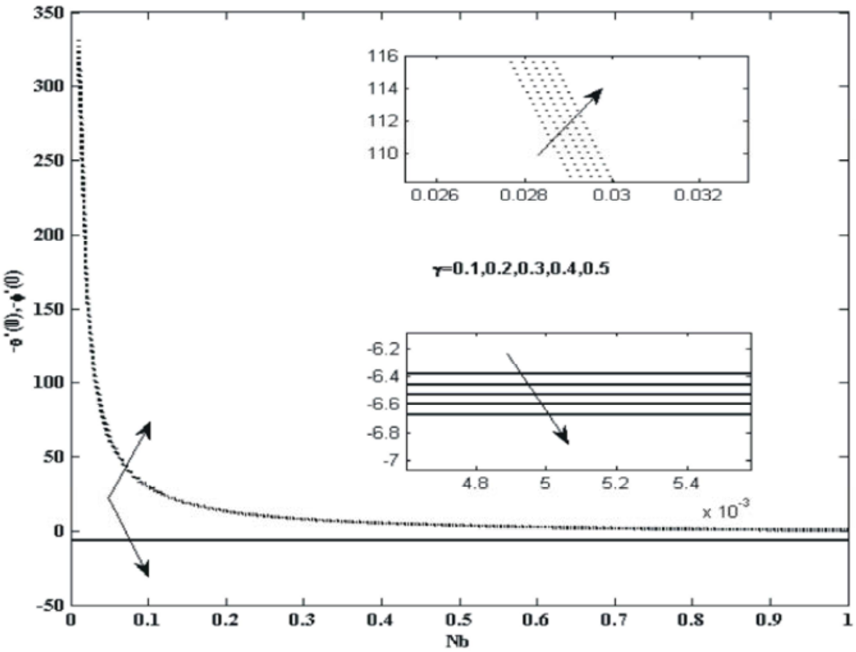

Fig. 13: Variation of reduced Nusselt number $-\theta'(0)$ (full line)and reduced Sherwood number $-\phi'(0)$ (dot line)with respect to Nb when γ =0.1, 0.2, 0.3, 0.4, 0.5, Nt=0.5

CONCLUSION

In this paper, we have studied the steady mixed convection flow in a vertical channel filled by a Jeffrey Nanofluid, using a model in which Brownian motion and thermophoresis effects are accounted for. This model authorizes a simple analytical solution which depends on six dimensionless parameters, namely the mixed convection parameter Gr/Re, the buoyancy ratio parameter Nr, the Brownian motion parameter Nb, the thermophoresis parameter Nt, the Jeffrey parameter λ_1 'and heat source parameter γ.

The obtained results show that the reduced Nusselt number is a decreasing function of Nb, Nt and γ. On the other hand, the reduced Sherwood number is a decreasing function of Nb and an increasing function of Nt and γ. Also, we observed that the velocity increases at the hot wall and decreases at the cold wall due to increasing Jeffrey parameter. But opposite behaviour is noticed in the case of the buoyancy ratio, thermophoresis, Brownian motion and heat source parameters.

REFERENCES

1. Tao, L.N., 1960. On Combined Free and Forced Convection in Channels, ASME Trans. J. Heat Transfer, 82: 233-238.
2. Aung, W. and G. Worku, 1986. Theory of Fully Developed, Combined Convection including Flow Reversal, ASME Trans. J. Heat Transfer, 108: 485-488.
3. Cheng, C.H., H.S. Kou and W.H. Huang, 1990. Flow Reversal and Heat Transfer of Fully Developed Mixed Convection in Vertical Channels, J. Thermophys. Heat Transfer, 4: 375-383.
4. Hamadah, T.T. and R.A. Wirtz, 1991. Analysis of Laminar Fully Developed Mixed Convection in a Vertical Channel with Opposing Buoyancy, ASME Trans. J. Heat Transfer, 113: 507-510.
5. Chen, Y.C. and J.N. Chung, 1996. The Linear Stability of Mixed Convection in a Vertical Channel Flow, J. Fluid Mech., 325: 29-51.
6. Barletta, A., 1999. Analysis of Combined Forced and Free Flow in a Vertical Channel with Viscous Dissipation and Isothermal-Isoflux Boundary Conditions, ASME Trans. J. Heat Transfer, 121: 349-356.
7. Barletta, A., E. Magyari and B. Keller, 2005. Dual Mixed Convection Flows in a Vertical Channel, Int. J. Heat Mass Transfer, 48: 4835-4845.
8. Barletta, A., M. Celli, E. Magyari and E. Zanchini, 2007, Buoyant MHD Flows in a Vertical Channel: The Levitation Regime, Heat Mass Transfer, 44: 1005-1013.

9. Boulama, K. and N. Galanis, 2004. Analytical Solution for Fully Developed Mixed Convection Between Parallel Vertical Plates with Heat and Mass Transfer, ASME Trans. J. Heat Transfer, 126: 381-388.
10. Oztop, H.F. and E. Abu-Nada, 2008. Numerical Study of Natural Convection in Partially Heated Rectangular Enclosures Filled with Nanofluids, Int. J. Heat Fluid Flow, 29: 1326-1336.
11. Choi, S.U.S., 1995. Enhancing Thermal Conductivity of Fluids with Nanoparticles, Development and Applications of Non-Newtonian Flows, D. A. Siginer and H. P. Wang, eds., ASME, New York, MD-Vol. 231 and FED, 66: 99-105.
12. Buongiorno, J., 2006. Convective Transport in Nanofluids, ASME Trans. J. Heat Transfer, 128: 240-250.
13. Nield, D.A. and A.V. Kuznetsov, 2009. The Cheng-Minkowycz Problem for Natural Convective Boundary-Layer Flow in a Porous Medium Saturated by a Nanofluid, Int. J. Heat Mass Transfer, 52: 5792-5795.
14. Kuznetsov, A.V. and D.A. Nield, 2010. Natural Convective Boundary-Layer Flow of a Nanofluid Past a Vertical Plate, Int. J. Therm. Sci., 49: 243-247.
15. Khan, W.A. and I. Pop, 2010. Boundary-Layer Flow of a Nanofluid Past a Stretching Sheet, Int. J. Heat Mass Transfer, 53: 2477-2483.
16. Kang, H.U., S.H. Kim and J.M. Oh, 2006. Estimation of Thermal Conductivity of Nanofluid Using Experimental Effective Particle Volume, Exp. Heat Transfer, 19: 181-191.
17. Khanafer, K., K. Vafai and M. Lightstone, 2003. Buoyancy-Driven Heat Transfer Enhancement in a Two-Dimensional Enclosure Utilizing Nanofluids, Int. J. Heat Mass Transfer, 46: 3639-3653.
18. Tiwari, R.K. and M.K. Das, 2007. Heat Transfer Augmentation in a Two-Sided Lid-Driven Differentially Heated Square Cavity Utilizing Nanofluids, Int. J. Heat Mass Transfer, 50: 2002-2018.
19. Aminossadati, S.M. and B. Ghasemi, 2009. Natural Convection Cooling of a Localised Heat Source at the Bottom of a Nanofluid-Filled Enclosure, Eur. J. Mech. B/Fluids, 28: 630-640.
20. Daungthongsuk, W. and S. Wongwises, 2007. A Critical Review of Convective Heat Transfer Nanofluids, Renewable Sustainable Energy Rev., 11: 797-817.
21. Wang, X.Q. and A.S. Mujumdar, 2008. A Review on Nanofluids. Part I: Theoretical and Numerical Investigations, Braz. J. Chem. Eng., 25: 613-630.
22. Kakac¸, S. and A.Pramuanjaroenkij, 2009. Review of Convective Heat Transfer Enhancement with Nanofluids, Int. J. Heat Mass Transfer, 52: 3187-3196.
23. Grosan, T. and I. Pop, 2012. Fully Developed Mixed Convection in a Vertical Channel Filled by a Nanofluid, Journal of Heat Transfer, 134: 1-5.
24. Kuznetsov, K.V. and D.A. Nield, 2014. Natural convective boundary-layer flow of a nanofluid past a vertical plate: A revised model, International Journal of Thermal Sciences, 77: 126-129.
25. Akilu, S. and M. Narahari, 2014. Effects of Heat Generation or Absorption on Free Convection Flow of a Nanofluid past an Isothermal Inclined Plate, Advanced Materials Research, 970: 267-271.
26. Chamkha, A.J. and A.M. Aly, 2011. MHD Free Convection Flow of a Nanofluid past a Vertical Plate in the Presence of Heat Generation or Absorption Effects, Chem. Eng. Comm., 198: 425-441.
27. Sreenadh, S., A.N.S. Srinivas and C.K. Selvi, 2016. Analytical solution for peristaltic flow of conducting nanofluids in an asymmetric channel with slip effect of velocity, temperature and concentration, Alexandria Engineering Journal, 55: 1085-1098.
28. Barletta, A. and E. Zanchini, 1999. On the Choice of the Reference Temparature for Fully-Developed Mixed Convection in a Vertical Channel, Int.J.Heat Mass Transfer, 42: 3169-3181.