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Effect of Electrification of Nanoparticles on Natural Convective Boundary Layer Flow and Heat Transfer of a Cu-WaterNanofluid past a Vertical Flat Plate

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Abstract

An investigation of the steady laminar natural convective boundary layer flow of a Cu-water nanofluid past a vertical flat plate has been carried out in the present study. A mathematical model based on Buongiorno's two component non-homogeneous nanofluidmodel is considered with the inclusion of the Brownian motion, Thermophoresis and Electrification of nanoparticles. The governing equations are solved using similarity transformation followed by sixth order Runge-Kutta method with shooting technique. The effects of Brownian motion, Thermophoresis, Buoyancy ratio and Electrification parameters on the non-dimensional velocity and normalized temperature as well as the rate of heat transfer of Cu-water nanofluid are illustrated through graphs and tabular forms. From this investigation it is observed that the higher electrification parameter is to reduce the normalized base fluid temperature and to enhance the non-dimensional velocity as well as rate of heat transfer of the nanofluid.

Keywords:

Natural convection;
Nanofluid;
Boundary layer flow;
Heat transfer;
Electrification of nanoparticles.

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1. Introduction

A wide variety of industrial processes involve thermal management, which deals with control of system temperature using thermodynamics and heat transfer. Active modes of improving heat transfer involve increasing coolant velocity and thermal conductivity of the coolants. Hence, improving the thermal conductivity of the coolants appears to be an appropriate choice for heat transfer applications. Boundary layer flow problems over a flat plate under the principles of transport phenomena are important as it occurs in several heat transfer process. The heat removal processes in many engineering applications such as cooling of

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electronic devices rely on natural convection heat transfer, due to its simplicity, minimum cost, low noise, smaller size and reliability. In most natural convection flow problems, the base fluid has a low thermal conductivity, which limits the heat transfer enhancement. Choi [1] has first introduced the technique ofadding the nanoparticles of higher thermal conductivity with base fluids in order to increase the thermal conductivity of fluids in heat transfer processes.

Several ideas have been proposed by different authors to enhance the heat transfer characteristics of nanofluids. Masuda et al. [2] have studied the alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles. Buongiorno and Hu [3] have studied the nanofluid coolants for advanced nuclear power plants. Pak and Cho [4] have introduced the hydrodynamic and heat transfer study of dispersed fluids with sub micro metallic oxide particles. Xuan and Li [5] have investigated the convective heat transfer and flow features of nanofluids. Ahuja [6] studied the augmentation of heat transfer in laminar flow of polystyrene suspensions. However, after a comprehensive survey of convective transport in nanofluids, Buongiorno [7] considered seven slip mechanisms: inertia, Brownian diffusion, thermophoresis, diffusiophoresis, fluid drainage, Magnus effect and gravity settling. He concluded that the Brownian diffusion and the themophoresis are two important mechanisms of slip velocity in laminar flows. Kuznetsov and Nield [8] have investigated the effect of nanoparticles on natural convection boundary layer flow past a vertical plate by considering Brownian motion and thermophoresis. Nield and Kuznetsov [9] have extended the Cheng and Minkowycz [10] problem for natural convective boundary layer flow in a porous medium by cosideringnanofluid along with Brownian motion and thermopforesis. Khan and Pop [11] have studied the boundary layer flow of a nanofluid past a stretching sheet. Pakravan and Yaghoubi [12] have investigated the combined thermophoresis, Brownian motion and Dufour effects on natural convection of nanofluids. Aminfar and Hoghoo [13] have investigated the effects of Brownian motion and thermophoresis on natural convection of alumina-water nanofluid. Pakravan and Yaghoubi [14] have studied the analysis of nanoparticles migration on natural convective heat transfer of nanofluids. Hadded et al. [15] have investigated effects of Brownian motion and thermophoresis on heat transfer enhancement and natural convections in nanofluids. Hu et al. [16] have studied the natural convection heat transfer of Alumina-water nanofluid in vertical square enclosures. Dastmalchi et al. [17] have studied the double-diffusive natural convective in a porous square enclosure filled with nanofluid. Khan and Aziz [18] have investigated the natural convection flow of a nanofluid over a vertical plate with uniform surface heat flux.

Effect of magnetic field on nanofluid with different geometries has been investigated by several researchers. For instance, Lavanya and LeelaRatnam [19] have investigated the dufour and Soret effects on steady MHD free convective flow past a vertical porous plate embedded in a porous medium with chemical reaction, radiation, heat generation, and viscous dissipation. Shariful and Rahman [20] have investigated the dufour and Soret effects on MHD convective heat and mass transfer flow past a vertical porous flat plate embedded in a porous medium. Hamad et al. [21] have investigated the effect of magnetic field on free convection flow of a nanofluid past a vertical semi-infinite flat plate.Noghrehabadi et al. [22] have investigated the effect of magnetic field on the boundary layer flow, heat, and mass transfer of nanofluids over a stretching cylinder.Das and Jana [23] have studied the hydromagnetic boundary layer flow past a moving vertical plate in nanofluids in the presence of a uniform transverse magnetic field and thermal radiation. Recently, Yadav et al. [24] have investigated the electrothermal instability in a porous medium layer saturated by a dielectric nanofluid. But in all cases the base fluid is taken to be electrically conducting and electrification of nanoparticles has not been taken into consideration.

The past literature indicates that no consulted effort has been made to analyze the effect of electrification of nanoparticles on velocity profile, temperature profile and rate of heat transfer of a nanofluid flow where the base fluid is electrically non-conducting and nanoparticles are electrified. It was pointed out by Soo [25] that tribo-electrification of particles has a significant impact on the boundary layer characteristics of two phase flow. Homogeneity of the fluid have always assumed by most of the investigations (Kuznetsov and Nield [8,9], Pakravan and Yaghoubi [11]). Moreover, the assumption of homogeneity of the nanoparticles distribution may not hold when particle migration phenomena occur (Wen et al. [26]).Hemalatha et al. [27] have investigated the flow and heat transfer analysis of a nanofluid along a vertical flat plate in presence of thermal radiation using similarity transformation by considering three types of nanofluids, namely Cu-water, Al_2O_3-water and TiO_2-water and concluded that Cu-water has the highest heat transfer coefficient compered with Al_2O_3-water and TiO_2-water nanofluids. The above arguments just presented lead to the choice of employing a non-homogeneous model of Cu-waternanofluidfor the present investigation

In the present problem, the electrification of nanoparticles is introduced in Buongiorno's two component non-homogeneous model to study the combined effect of Brownian motion, thermophoresis and electrification of nanoparticles on the velocity and temperature profiles along with the rate of heat transfer of the Cu-water nanofluid to meet the inadequacy in the earlier studies.

2. Mathematical formulation

The steady laminar two-dimensional natural convective boundary layer flow of a nanofluidis considered over an isothermal vertical flat plate as illustrated in Fig. 1. The co-ordinate frame is selected in which the x-axis is aligned vertically upwards. At this boundary the temperature T and the concentration C take constant values T_w and C_w, respectively. The ambient values attained, as y tends to infinity, of T and C are denoted by T_∞ and C_∞ respectively.Therefore, the migration of heavy nano particles from the plate into the boundary layer induces a secondary buoyancy force in the vicinity of the plate. The migration of the nano particles would also change the local thermo-physical properties of the nanofluid in the boundary layer.

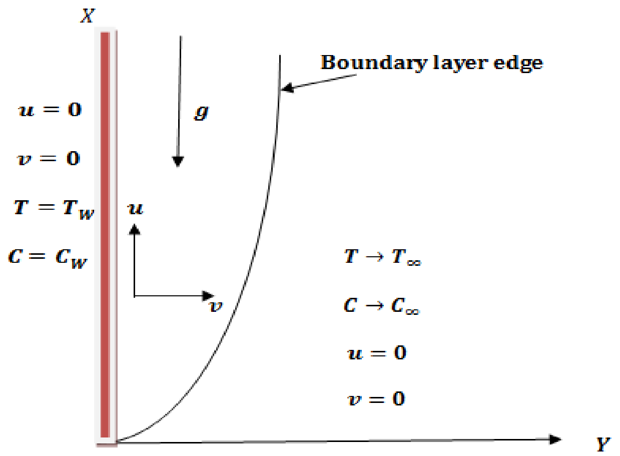

Figure1. Physical model and coordinate system

Fig. 1 depicts a schematic representation of the physical model and coordinate system of the flow problem. The fluid is water based nanofluid containing copper nanoparticles. In formulating the problem, the body force term of the momentum equation which is determined based on the Oberbeck-Boussinesq approximation. With the above assumptions, thegoverning boundary layerequations of nanofluid flow for conservation of mass, momentum, thermal energy and nanoparticles concentration are as following:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

$$\rho_{nf}\left[u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right] = \mu_{nf}\left[\frac{\partial^2 u}{\partial y^2}\right]+C\rho_s\left(\frac{q}{m}\right)\left(E_x-E_{x\infty}\right)+[\beta_{f\infty}\rho_{f\infty}(1-C_\infty)(T-T_\infty)g-$$
$$(\rho_s-\rho_{f\infty})(C-C_\infty)g] \quad (2)$$

$$(\rho c)_{nf}\left[u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right]=k_{nf}\left[\frac{\partial^2 T}{\partial y^2}\right]+(\rho c)_s D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{(\rho c)_s D_T}{T}\left(\frac{\partial T}{\partial y}\right)^2+\left(\frac{q}{m}\right)\frac{C(\rho c)_s}{F}\left(E_x\frac{\partial T}{\partial x}+E_y\frac{\partial T}{\partial y}\right) \quad (3)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T}\frac{\partial^2 T}{\partial y^2}+\left(\frac{q}{m}\right)\frac{1}{F}\left(\frac{\partial(CE_x)}{\partial x}+\frac{\partial(CE_y)}{\partial y}\right) \quad (4)$$

The boundary conditions for "(1)-(4)" are assumed in the form:

$$\left.\begin{array}{l} u=0,\ \ v=0,\ \ T=T_W,\ \ C=C_w\ at\ y=0 \\ u=0,\ \ v=0,\ \ T\to T_\infty,\ \ C\to C_\infty as\ y\to\infty \end{array}\right\} (5)$$

Where u and v are the velocity components of the nanofluid along $x$and y directions, respectively, p is the fluid pressure, ρ_{nf}, ρ_f, and ρ_s are the density of the nanofluid, base fluid, and nanoparticles respectively, μ_{nf} is the effective viscosity of the nanofluid, k_{nf} is the effective thermal conductivity of the nanofluid, $(\rho c)_{nf}$ is the nanofluid heat capacity,$(\rho c)_s$ is the nanoparticle heat capacity, β_f is volumetric thermal expansion coefficient of the base fluid, D_B is the Brownian diffusion coefficient, D_T is the thermophoretic diffusion coefficient, T is the local temperature,C is thelocalconcentration, g is the acceleration due to gravity, q is the charge of the nanoparticles, m is the mass of the nanoparticles, E_x and E_y are the electric intensity components along x and y directions, respectively, and F is the force acting on nanoparticles. The subscript ∞ denotes the values at large values of y where the fluid is quiescent.

The effective densityρ_{nf}, thermal diffusivityα_{nf}, and the heat capacity$(\rho c)_{nf}$ of the nanofluid is given by

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s \quad (6)$$
$$\alpha_{nf} = \frac{k_{nf}}{(\rho c)_{nf}} \quad (7)$$
$$(\rho c)_{nf} = (1-\varphi)(\rho c)_f + \varphi(\rho c)_s \quad (8)$$

The thermal conductivity of the nanofluidk_{nf} for spherical nanoparticles is approximated by the Maxwell-Garnett model [28] as

$$k_{nf} = \frac{(k_s+2k_f)-2\varphi(k_f-k_s)}{(k_s+2k_f)+\varphi(k_f-k_s)}k_f \quad (9)$$

Also the effective dynamic viscosity μ_{nf} of thenanofluid given by Brinkman [29] as

$$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}} \quad (10)$$

In "(6)-(10)", the subscriptsnf, $f$and s denotes the thermophysical properties of the nanofluid, base fluid and nano particles respectively and φ denotes the solid volume fraction of nanoparticles.

3. Similarity transformations

The stream function $\psi(x,y)$is introduced to satisfy continuity equation (1) by

$$u = \frac{\partial\psi}{\partial y}, v = -\frac{\partial\psi}{\partial x} \quad (11)$$

The following variables are introduced to transform equations (2)-(4) into ordinary differential equations

$$\eta = \frac{y}{x}(Ra_x)^{\frac{1}{4}},\ \psi = \alpha_f(Ra_x)^{\frac{1}{4}}s(\eta),\ \theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty}, f(\eta) = \frac{C-C_\infty}{C_w-C_\infty} \quad (12)$$

Where η is the similarity variable, s, θ, and f are non-dimensional variables and

$$Ra_x = \frac{(1-C_\infty)\beta_f g(T_w-T_\infty)x^3}{\nu_f\alpha_f},$$ is the local Rayleigh number.

The similarity variable was chosen on the basis of scale analysis. Substituting (11) in equations (2)-(4) and then using non-dimensional transformations (12), we get the momentum, energy and concentration equations as follows:

$$s''' + \varphi_1\frac{1}{4Pr}(3ss'' - 2(s')^2) + \varphi_1\varphi_2\frac{MN_B}{ScN_F} + (1-\varphi)^{2.5}(\theta - Nrf) = 0 \quad (13)$$

$$\theta'' + \frac{k_f}{k_{nf}}\varphi_5\frac{3}{4}s\theta' + \frac{k_f}{k_{nf}}Nbf'\theta' + \frac{k_f}{k_{nf}}Nt(\theta')^2 + \frac{k_f}{k_{nf}}N_{Re}N_BN_FNb\,\gamma\,\eta\theta' = 0 \quad (14)$$

$$f'' + \frac{3}{4}Lesf' + \frac{Nt}{Nb}\theta'' + N_{Re}N_FN_B\,\gamma = 0 \quad (15)$$

Where the primes represent differentiation with respect to η and the non-dimensional parameters are defined as follows:

$$Le = \frac{\alpha_f}{D_B}, Pr = \frac{\nu_f}{\alpha_f}, Sc = \frac{\nu_f}{D_B}, Nb = \frac{(\rho c)_s D_B(C_w-C_\infty)}{(\rho c)_f\alpha_f}, Nt = \frac{(\rho c)_s D_T(T_w-T_\infty)}{(\rho c)_f\alpha_f T_\infty},$$
$$Nr = \frac{(\rho_s-\rho_{f\infty})(C_w-C_\infty)}{(1-C_\infty)\rho_f\beta_f(T_w-T_\infty)}, N_{Re} = \left(\frac{q}{m}\right)^2\frac{\rho_s}{U^2\epsilon_0}\frac{x^2}{(Ra_x)^{\frac{1}{2}}}, N_B = \frac{Ux}{D_B(Ra_x)^{\frac{1}{4}}}, N_F = \frac{U(Ra_x)^{\frac{1}{4}}}{Fx},$$

$M = \frac{q}{m}\frac{1}{FU}(E_x - E_{x_\infty}), \gamma = \frac{C_\infty}{(C_w - C_\infty)}, \varphi_1 = \frac{\nu_f}{\nu_{nf}}, \varphi_2 = \frac{C_\infty \rho_s}{\rho_{nf}}, \varphi_5 = \frac{(\rho c)_{nf}}{(\rho c)_f}$.

Here $Le, Pr, Sc, Nb, Nt, Nr, N_{Re}, N_B, N_F, M, \gamma$ φ_1, φ_2 and φ_5 denote a Lewis number, a Prandtl number, a Schmidt number, a Brownian motion parameter, a thermophoresis parameter, a buoyancy ratio,an electric Reynolds number, a Peclet number, a momentum transfer number, an electrification parameter, a concentration ratio, a ratio of base fluid kinematic viscosity and nanofluid kinematic viscosity, a ratio of nanoparticle density and nanofluid density and ratio of nanofluid heat capacity and base fluid heat capacity.

The boundary conditions (6) in terms of non-dimensional variables $s, \theta,$ and f become

$$\left.\begin{array}{c}\eta = 0, s' = 0, s = 0, \theta = 1, f = 1\\ \eta = \infty, s' = 0, \theta = 0, f = 0\end{array}\right\} \quad (16)$$

Accounts of practical interest, in this study, the dimensionless local Nusselt number Nu_x is defined as

$$Nu_x = \frac{q_w'' x}{k(T_W - T_\infty)} \quad (17)$$

Where q_w'' is the wall heatflux.

4. Numerical solutions

Equations (13)-(15) subject to the boundary conditions, Eq. (16), were solved numerically using FORTRAN 95. This software uses a sixth order Runge-Kutta method with shooting technique to solve the boundary value problems numerically. The value of integration length η_∞ varies with the non-dimensional parameter values and it has been suitably chosen each time such that the boundary conditions at the outer edge of the boundary layer are satisfied. It has been observed from the numerical result that the approximation to $-\theta'(0)$ is improved by increasing the infinite value of η which is finally determined as $\eta_\infty = 5.0$ with a step length of 0.125 beginning from $\eta_\infty = 0$. Depend upon initial guess and number of steps N. Theconsiderednanofluid is water based with $Pr = 6.2$ (considering pure water) containing copper (Cu) nanoparticle. The thermophysical properties of the fluid and nanoparticle (Oztop and Abu-nada [30]) are given in table-1.

Table 1:Thermophysical properties of water and copper nanoparticles

Property	**Fluid(Pure water)**	**Solid(Cu)**
$c(J/kgK)$	4179	385
$\rho(kg/m^3)$	997.1	8933
$k(W/mK)$	0.613	400
$\beta \times 10^{-5}(1/K)$	21	1.67

5. Results and Discussion

Numerical solutions are obtained for the effect of Brownian diffusion, thermophoresis and electrification of nanoparticles on heat transfer characteristics of boundary layer flow of a nanofluid over a vertical flat plate. The system of non-linear ordinary differential equations (13) – (15) along with the boundary conditions (16) are solved numerically using Runge – Kutta method of order six along with shooting scheme. In this problem the Brownian motion parameter Nb, the thermophoresis parameter Nt and the nanoparticle buoyancy ratio Nr are ranged from 0 to 1.0. The electrification parameter M is ranged from 0 to 6.0. The value of Lewis number Le is taken 10.In order to get the physical understanding of the flow characteristics, the effect of non-dimensional governing parameters such as Brownian motion parameter Nb, thermophoresis parameter Nt, buoyancy ratio Nr and electrification parameter Mon dimensionless velocity and dimensionless temperature were investigated numerically and the results for different values of governing parameters are presented in graphs. Also the effect of these parameters on dimensionless heat transfer coefficient reduced Nusselt number Nu_r is discussed. From the numerical computation the reduced Nusselt number is proportional to $-\theta'(0)$ is worked out and its numerical values are presented in tabular form. It is more relevant and significant to compare a special case result of the present study with the existing numerical solutions in the literature. Therefore, a comparison is made with the solution presented in Bejan [31], Kuznetsov and Nield [8]and it is found to be in good agreement, as seen from the Table 2.

Table 2: Comparison of present results with the results obtained by Bejan [31], Kuznetsov and Nield[8]. The values of reduced Nusselt number $Nu_r = Nu_x/{Ra_x}^{1/4}$presented for the limiting case of a regular fluid.

Pr	Nu_r [Bejan]	Nu_r [Kuznetsov and Nield]	Nu_r [present]
1	0.401	0.401	0.403
10	0.465	0.463	0.464
100	0.490	0.481	0.482
1000	0.499	0.484	0.485

5.1. Velocity profiles

The vertical component of the dimensionless velocity profiles are displayed in Figs. 2-5. The velocity in each case increases initially from a zero value at the plate to a maximum value within the boundary layer and then decreases asymptotically to zero at the edge of the momentum boundary layer. In case of nanofluid the velocity initially increases due to the presence of slip mechanisms between the nanoparticles and the base fluid.Figs. 2, 3, 4 and 5 have been plotted to demonstrate the effect of Brownian motion parameter Nb, thermophoresis parameter Nt, buoyancy ratio Nr and electrification parameter M on dimensionless velocity profile$s'(\eta)$ against the similarity variable η . As shown in Fig. 2, at the surface, the dimensionless velocity increases with the increase in the Brownian motion parameterNb. This is due to the increase in the collision of the fluid particles with nanoparticles. From Fig. 3, it is observed that the dimensionless velocity increases with the increase in the thermophoresis parameter Nt. This is because of an increase of the thermophoresis force increases the movement of nanoparticles and consequently increases the dimensionless velocity profiles. However, the dimensionless velocity decreases with increasing values of buoyancy ratio Nr as shown in Fig. 4. This is due to the increase in density. The Fig. 5 reveals that the dimensionless velocity increases with the increasing values of electrification parameter M. This is due to the increase in electrification parameter M causes the increase of drag force on the ions has an equal and opposite reaction force acting on the neutral fluid molecules. This phenomenon leads to increase the velocity of the fluid in the boundary layer region.

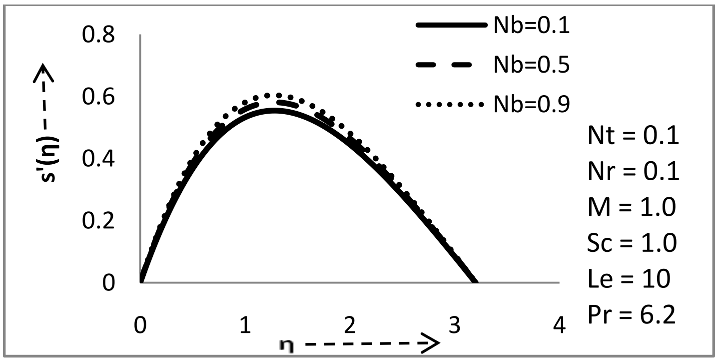

Figure 2.Velocity profiles for various values of Nb when $N_{Re} = N_B = N_F = \varphi = 0.01$

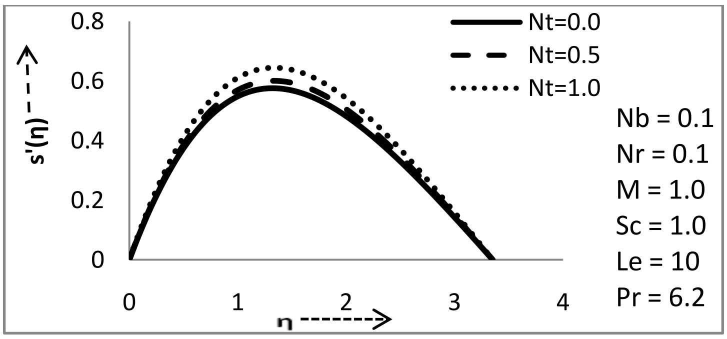

Figure 3.Velocity profiles for various values of Nt when $N_{Re} = N_B = N_F = \varphi = 0.01$

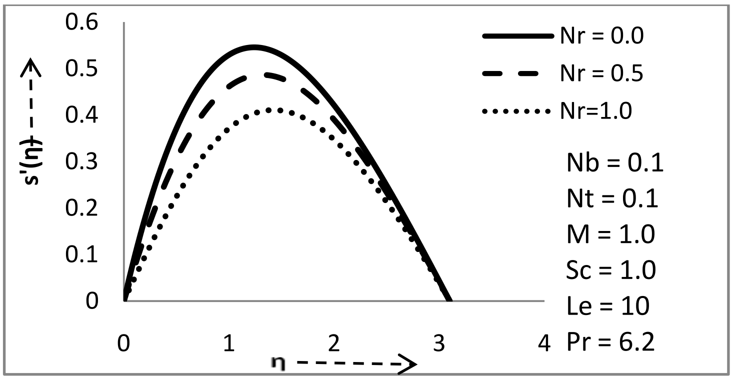

Figure 4.Velocity profiles for various values of Nr when $N_{Re} = N_B = N_F = \varphi = 0.01$

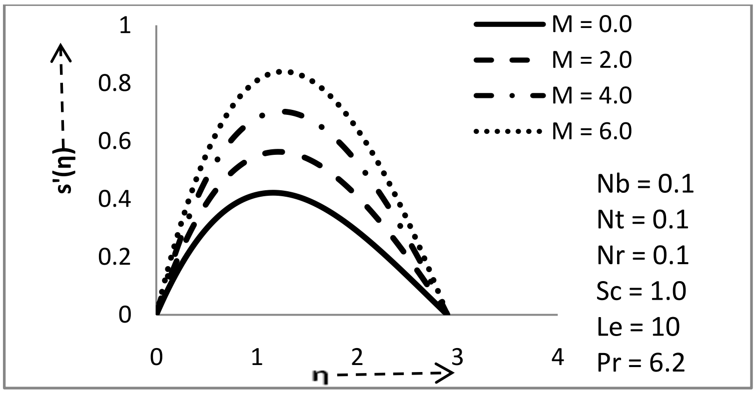

Figure 5.Velocity profiles for various values of M when $N_{Re} = N_B = N_F = \varphi = 0.01$

5.2. Temperature profiles

The dimensionless temperature profiles $\theta(\eta)$ corresponding to the dimensionless velocity profiles of Figs. 2-5 are plotted in Figs. 6-9. In each figure, the maximum temperature distribution is unity at the plate and decreases asymptotically to reach the free stream temperature ($\theta = 0$) at the edge of the thermal boundary layer.Figs. 6-9 illustrate the temperature distributions in the thermal boundary layer for different values of the Brownian motion parameter Nb, thermophoresis parameter Nt, buoyancy ratio Nr and electrification parameter$M$. Figs. 6 and 7 indicate that by increasing the values of Brownian motion parameter Nb and thermophoresis parameter Nt, the temperature increases. Increase of the Brownian motion parameter Nb increases the diffusion of nanoparticles, which results in the increase of the magnitude of the temperature profiles. In nanofluid, due to the presence of nanoparticles, the Brownian motion takes place and for the increase in values of Brownian motion parameter Nb, the Brownian motion is affected. The thermal conduction can be enhanced through one of the two mechanisms by the Brownian motion of nanoparticles. First, it can be enhanced by a direct effect owing to nanoparticles that transport heat or alternatively by an indirect contribution due to micro-convection of fluid surrounding individual nanoparticles. The high values of Nb indicates Brownian motion is strong for small particles and the converse case is for large particles. Thus, from Fig. 6, it is observed that Brownian motion parameter provides a significant enhancing influence on temperature profiles. Thermophoresis parameter is also an important parameter for analysing the temperature distribution. Increase in thermophoresis parameter Nt causes increment in the thermophoresis force which tends to move nanoparticles from hot regions to cold regions and consequently it increases the magnitude of temperature profiles. Fig. 8 elucidate that the temperature profiles increase with increasing buoyancy ratio Nr. This is because of increase in density. However, by increasing the electrification parameter M, the temperature profiles decreases as presented in Fig. 9.This is because ofincreasing electrification parameter M, the velocity of the fluid increase; thereby the hotter fluid particle moves away causes cooling of fluid and consequently the temperature of the fluid decreases.

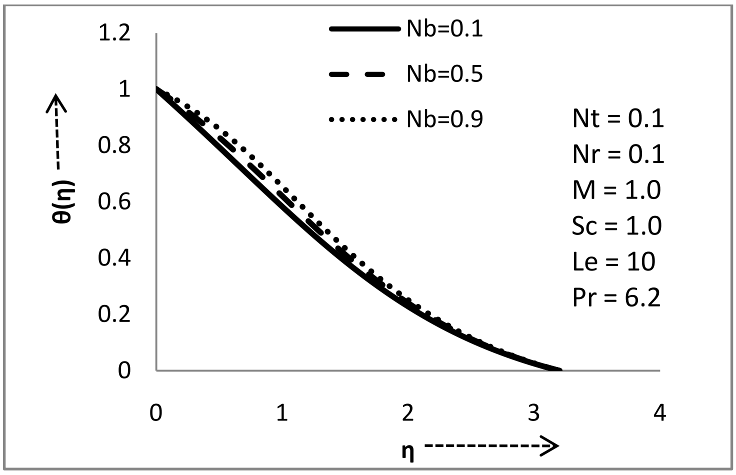

Figure 6.Temperature profiles for various values of Nb when $N_{Re} = N_B = N_F = \varphi = 0.01$

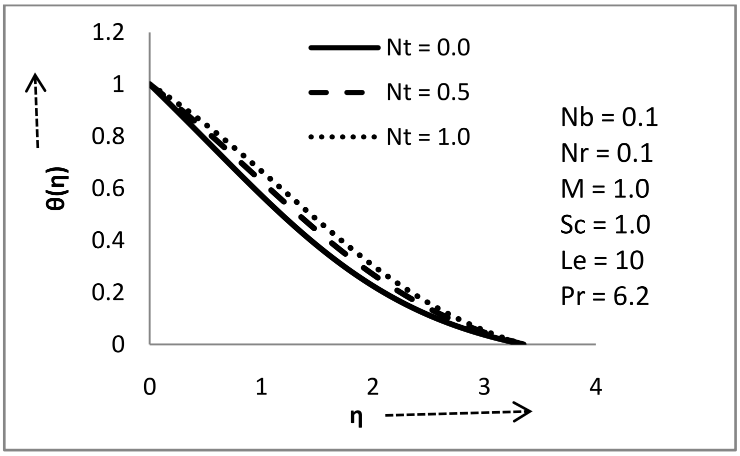

Figure 7.Temperature profiles for various values of Nt when$N_{Re} = N_B = N_F = \varphi = 0.01$

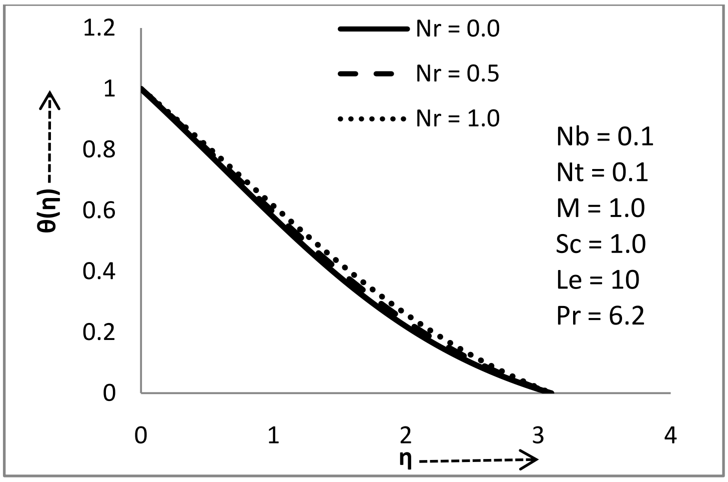

Figure 8.Temperature profiles for various values of Nr when $N_{Re} = N_B = N_F = \varphi = 0.01$

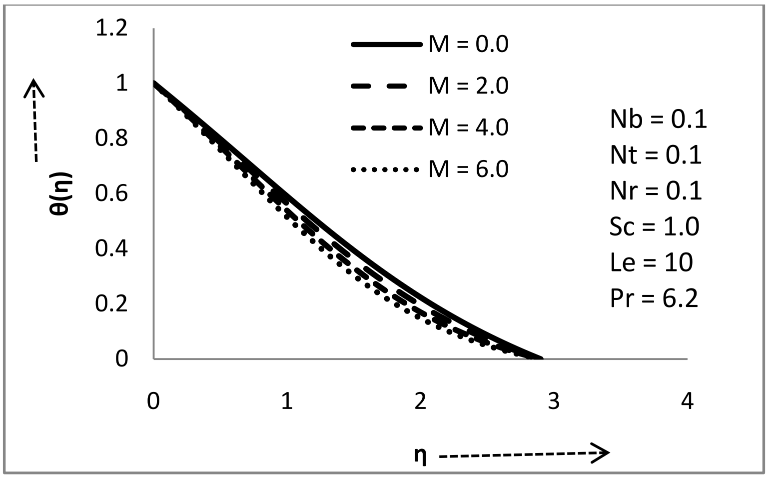

Figure 9.Temperature profiles for various values of M when $N_{Re} = N_B = N_F = \varphi = 0.01$

5.3. Dimensionless heattransfercoefficient

The effects of the Brownian motion parameter Nb, thermophoresis parameter Nt, buoyancy ratio Nr and electrification parameter Mon dimensionless heat transfer coefficient is presented in Table 3. The numerical results of Table 3 depicts that dimensionless heat transfer coefficient reduced Nusselt number $(-\theta'(0))$ increases with increasing electrification parameter M but decreases with increasing Brownian motion parameter Nb, thermophoresis parameter Nt and buoyancy ratio Nr. This is due to the temperature distribution in the boundary layer increases with increase in Nb, Nt and Nr but decreases with increase in electrification parameter M.

Table 3**:** The effects of the Brownian motion parameter, thermophoresis parameter, buoyancy ratio and electrification parameter on the reduced Nusselt number $(-\theta'(0))$ when $Pr = 6.2, Le = 10, Sc = 1.0,\ N_{Re} = N_B = N_F = \varphi = 0.01$

$-\theta'(0)$										
Nb	Nt	M = 1.0			M = 2.0			M = 3.0		
		Nr =0.0	Nr= 0.1	Nr = 0.2	Nr = 0.0	Nr = 0.1	Nr= 0.2	Nr= 0.0	Nr= 0.1	Nr= 0.2
0.1	0.1	0.40447	0.40128	0.39999	0.42018	0.41722	0.41436	0.43414	0.43345	0.43238
	0.2	0.38844	0.38408	0.37986	0.40322	0.39992	0.39578	0.41695	0.41470	0.41316
	0.3	0.37089	0.36778	0.36367	0.38610	0.38275	0.37867	0.39954	0.39482	0.39273
0.2	0.1	0.37543	0.37283	0.37015	0.38973	0.38709	0.38497	0.40349	0.40251	0.40169
	0.2	0.35982	0.35710	0.35438	0.37335	0.37077	0.36840	0.38617	0.38424	0.38294
	0.3	0.34597	0.34343	0.33950	0.35828	0.35627	0.35346	0.36973	0.36747	0.36526
0.3	0.1	0.34833	0.34600	0.34422	0.36280	0.36223	0.35954	0.37476	0.37390	0.37136
	0.2	0.33370	0.33147	0.32927	0.34661	0.34519	0.34275	0.35805	0.35660	0.35435
	0.3	0.32144	0.31930	0.31708	0.33300	0.33039	0.32963	0.34376	0.34162	0.34009

6. Conclusions

In the modelling of the nanofluid flow, the effects of some governing parameters namely Brownian motion parameter Nb, thermophoresis parameter Nt, buoyancy ratio Nr and electrification parameter M on velocity and temperature profiles are graphically presented and discussed. Numerical results for the reduced Nusselt number is presented in tabular form. The following conclusions can be summarized from the numerical investigation:

1. An increase in Nb, Nt and M increase the velocity in the boundary layer region but velocity decreases with increasing Nr. A rise in Nb, Nt and Nr enhance the temperature in the boundary layer whereas increasing M decreases temperature.
2. As already been pointed out, the force on the fluid particles, i.e.,$\vec{f} = q\vec{E}$, due to electrification of nanoparticles, facilitates to increase in the velocity, thereby the hotter fluid particles moves away causes cooling of fluid which leads to enhance the heat transfer rate from plate to fluid and cooling effect on the plate. Perhaps a possible important mechanism for enhancement of thermal conductivity of base fluid is the electrification of nanoparticles.
3. The dimensionless heat transfer coefficient reduced Nusselt number is a decreasing function of Brownian motion parameter Nb, thermophoresis parameter Nt and buoyancy ratio Nr whereas the interesting fact is that the dimensionless heat transfer coefficient reduced Nusselt number is an increasing function of electrification parameter M.

References

[1] Choi,S.,"Enhancing thermal conductivity of fluids with nanoparticle",*in: D.A. Siginer, H.P.Wang (Eds.), Developments and Applications of Non-Newtonian Flows, ASME MD* vol. 231 and FED vol.66, 1995, pp. 99-105.

[2] Masuda, H., Ebata, A.,Teramae, K. andHishinuma,H.,"Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles", *NetsuBussei* 7 (1993) 227-233.

[3] Buongiorno, J., Hu, W.,"Nanofluid coolants for advanced nuclear power plants", Paper *no. 5705, Proceedings of ICAPP 05, Seoul*, (May 2005) 15-19.

[4] Pak, B. C. and Cho,Y.,"Hydrodynamic and heat transfer study of dispersed fluids with sub micro metallic oxide particles", *Exp. Heat transfer*, 11(1998), 151-170.

[5] Xuan, Y. And Li,Q.,"investigation on convective heat transfer and flow features of nanofluids", *J. Heat transfer*, 125(2003),151-155.

[6] Ahuja,A.,"Augmentation of heat transfer in laminar flow of polystyrene suspensions", *J. Appl. Physics*, 46(8) (1975), 3408-3425.

[7] Buongiorno,J.,"Convective transport in nanofluids", *ASME J. Heat Transfer*, 128 (2006) 240–250.

[8] Kuznetsov, A. V. and Nield, D. A.,"Natural convective boundary-layer flow of a nanofluid past a vertical plate", *Int. J. Thermal Sci.*, 49(2010)243-247.

[9] Nield, D. A. and Kuznetsov, A. V., "The Cheng-Minkowycz problem for natural convective boundary-layer flow in a porous medium saturated by a nanofluid", *Int. J. Heat Mass Transfer*, 52(2009)5792-5795.

[10] Cheng, P. and Minkowycz W.J., "Free convection about a vertical flat plate embedded in a porous medium with application to heat transfer from a dike", *J. Geophysics. Res*. 82 (1977) 2040-2044.

[11] Khan, W. A. and Pop,I.,"Boundary-layer flow of a nanofluid past a stretching sheet", *Int. J. Heat Mass Transfer*, 53 (2010) 2477-2483.

[12] Pakravan, H. A. and Yaghoubi, M., "Combined thermophoresis, Brownian motion and Dufour effects on natural convection of nanofluids", *Int. J. Therm. Sci.*, 50(2011) 394-402.

[13] Aminfar, H., and Haghgoo, M. R.,"Brownian motion and thermophoresis effects on natural convection of alumina-water nanofluid", *J. Mech. Eng. Sci.,* 6(2012) 1-11.

[14] Pakravan, H. A. and Yaghoubi, M., "Analysis of nanoparticles migration on natural convective heat transfer of nanofluids", *Int. J. Therm. Sci.*,68 (June 2013) 79-93.

[15] Hadded, Z., Abu-Nada, E.,Oztop, H. F. andMataoui,A.,"Natural convection in nanofluids: are the thermophoresis and Brownian motion effects significant in nanofluid heat transfer enhancement?",*Int. J. Therm. Sci.* 57 (2012) 1-11.

[16] Ho, C. J., Liu, W. K., Chang, Y. S. and Lin, C. C.,"Natural convection heat transfer of Alumina-water nanofluid in vertical square enclosures: an experimental study", *Int. J. Therm. Sci.*, 49 (2010) 1345-1353.

[17] Dastmalchi, M., Sheikhzadeh, G. A. and AbbasianArani, A. A., "Double-diffusive natural convective in a porous square enclosure filled with nanofluid", *Int. J. Therm. Sci.*, 95 (2015) 88-98.

[18] Khan, W.A. and Aziz,A.,"Natural convection flow of a nanofluid over a vertical plate with uniform surface heat flux", *Int. J. Therm. Sci.*, 50 (2011) 1207-1214.

[19] Lavanya, B. and LeelaRatnam, A.,"Dufour and Soret effects on steady MHD free convective flow past a vertical porous plate embedded in a porous medium with chemical reaction, radiation, heat generation, and viscous dissipation", *Advances in Appl. Sci. Research*, 2014, 5(1):127-142.

[20] Md. Shariful, A. and Rahman, M. M.,"Dufour and Soret effects on MHD convective heat and mass transfer flow past a vertical porous flat plate embedded in a porous medium", *Journal of Naval Architecture and Marine engineering*, 1(2015)pp:55-65.

[21] Hamad, M.A.A.,Pop,I. and Md.Ismail,A.I.,"Magnetic field effects on free convection flow of a nanofluid past a vertical semi-infinite flat plate", *Nonlinear Analysis: Real World Applications* 12 (2011) 1338–1346.

[22] Noghrehabadi,A.,Ghalambaz,M.,Izadpanahi,E. andPourrajab,R.,"Effect of magnetic field on the boundary layer flow, heat, and mass transfer of nanofluids over a stretching cylinder", *Journal of Heat and Mass Transfer Research*, 1 (2014) 9-16.

[23] Das,S. andJana,R. N.,"Natural convective magneto-nanofluid flow and radiative heat transfer past a moving vertical plate", *Alexandria Engineering Journal* (2015) 54, 55–64.

[24] Yadav,D., Lee, J. and Cho,H. H.,"Electrothermal Instability in a Porous Medium Layer Saturated by a Dielectric Nanofluid", ***J**ournal of **A**pplied **F**luid **M**echanics*, Vol. 9, No. 5,(2016) pp. 2123-2132.

[25] Soo, S.L., "Effect of electrification on the dynamics of a particulate system", *I and EC Fund,* (1964) 3:75-80.

[26] Wen,D.,Zhangi,L. andHe,Y.,"Flow and migration of nanoparticle in a single channel",*Heat and Mass Transfer*, 45(2009), 1061–1067.

[27] Hemalatha, K., Krishna keerthi, A. and Sambasiva Rao, G., "Flow and heat transfer analysis of a nanofluid along a vertical flat plate in presence of thermal radiation using similarity transformation method", *IOSR Journal of Mathematics*, Volume 10, Issue 2 (2014) pp 41-48.

[28] Maxwell, J., "A treatise on electricity and magnetism", *2nd ed. Cambridge (UK): Oxford University press*; 1904.

[29] Brinkman,H. C., "The viscosity of concentrated suspensions and solution", *J. Chem. Phys.*,vol. 20, 571-81, 1952.

[30] Oztop, H. F. and Abunada,E., "Numerical study of natural convection in partially heated rectangular enclosures filled with nanofluids",*Int. J Heat Fluid Flow*,vol.29 (2008); pp: 1326-36.

[31] Bejan,A.,"Convection Heat Transfer", *Wiley, New York, NY*, 1984.