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Buoyancy Effect on MHD Slip Flow and Heat Transfer of a Nanofluid Flow Over a Vertical Porous Plate

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Abstract

This studyinvestigated the boundary layer flow and heat transfer aspects of a nanofluid over a porous plate with thermal radiation.Using suitable similarity transformations,partial differential equations were converted into ordinary differential equations and then solved numerically with the help of the Runge-Kutta scheme. The effects of various parameterswere analyzedsuch as Prandtl number P_r*, Lewis number* L_e*, Thermophoresis* N_t*, Mixed convection parameter* λ*,Brownianmotion* N_b*, Magnetic parameter M, and Suction/Blowing parameter S. The results were depicted with the help of graphs.*

Keywords: MHD, mixed convection, nanofluid, suction/blowing, thermal slip, velocity slip

Introduction

A fluid containing nanometer sized particles which are known as nanoparticles are called nanofluid and is typically prepared for metal, oxide, or carbon nanotubes. The common base fluid contains water and oil.

The study of the magnetic properties and behavior of electrically conducting fluid is called magneto-hydro-dynamics. There are many examples of magneto fluids including plasma, liquid metal, salt water, and electrolyte. Alawiet al. [1] focused on determining and modelling the dynamic thermal conductivity of nanofluids. Abbas et al. [2] discussedthe critical view of the influence of nanofluids on the improvement of the PV/T system. Ahmed et al. [3] considered transverse magnetic lea the transient free convective flow of nanofluids with generalized thermal transport between two vertical and parallel platters. Akbar et al. [4] discussed the peristaltic transport of fluid in human body.

Ahmadloo and Azizi [5] comparedthe neural network model for nanofluidswithbase fluids. Arulprakasajothi et al. [6] discussed the flux conditions forthe Nusselt number. Choi et al. [7] investigatedthe thermal conductivity of waterbased nanofluid. Daset al. [8] exploreda nanoparticle that has attracted much attention dueto the increase in heat. Devendiranet al. [9] investigated the heat transfer flow ofthe heat exchanging system. Esfe et al. [10] discussed the thermal conductivity of ferromagnetic nanofluids. Haque et al. [11]analyzed the effect of biting treatment with the help of the physical properties. Hayat et al. [12] analyzedthe flow of carreaunanofluid over a stretching sheet. Kundan and Mallick [13] explored experimentally by using volume fraction based nanofluids. Mansour et al. [14] investigated the proposition that MHD localizes heat sources. Mohammad et al. [15] discussedthe improvement resulting from the combination of nanoparticles. Mahmood et al. [16] analyzed the heat transfer of an incompressible fluid flow on a disc. Nicolas et al. [17] established the theory of thermal condition for obligatory temperatureat the wall. Prakash et al. [18] postulatedthat all fluidsarenanofluidsbecause they contain nanometersized particles known as nanoparticles. Ramzan et al. [19] analyzedthe boundary layer fluidflow of nanofluidson a moving surface.

Rao et al. [20] analyzedthe flow of Casson fluidson an inclined plate. Saleem et al.[21] studied the effect of gyrotactic microorganism on MHD flow of Jeffrey nanofluids.Thaku et al. [22] investigated the proposition that nanofluids can be used as heat transfer fluids due to their exceptional thermal properties. Uddin et al. [23] investigated the magneto-hydro-dynamic boundary layer flowover a permeable vertical surface. Uysall and Korkmaz [24] studiedthe numericallyhybrid nanofluid flux. Abdal et al. [25] studied numerically the effects of viscous dissipation on MHD. Abdal et al. [26] also discussed the multi-slip effects on MHD. Ali et al. [27] investigated the solutal boundary conditions on bio-convective micropolarnanofluid. Ali et al. [28] also investigated the multi-slip effects on unsteady Cassonnanofluid. Saba et al. [29] studied the viscous fluid buoyancy flow along with a porous plate.

According to the author's best knowledge, the study of the MHD buoyancy effect of a nanofluid flow over a vertical porous platehas not been undertaken yet.Moreover, the effects of thermal and velocity slipshavenot been analyzed. The physical interpretation for several parametersisinspectedwith the support of graphs in this study.Using similarity transformations, non-lineardifferential equationsare solved numerically employing Runge-Kuttashooting technique.

2. Formulation and Problem

We consideredthe buoyancy effect on MHD slip flow and heat transfer of a nanofluid flow over avertical porous plate. The governing equation's continuity, momentum, and heat transfer are written as follows,

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B^2}{\rho}(u-u_\infty)+g\beta^*(T-T_\infty) \quad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=k\frac{\partial^2 T}{\partial y^2}+\tau\left(D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) \quad (3)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial c}{\partial y}=D_B\frac{\partial^2 c}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} \quad (4)$$

where u and v are velocity components, $B=\frac{B_o}{\sqrt{x}}$ is the non-uniform magnetic field with B_o as a constant, μ is fluid viscositycoefficient, ρ is fluid density, σ is electric conductivity, k is thermal diffusivity, u_∞ is free stream velocity, $v=\mu/\rho$ is kinematic viscosity, β^* is volumetric coefficient of thermal expansion, T is the temperature, while T_∞ is the free stream temperature. D_B depictsBrownian diffusion, D_T depicts Thermophoresis diffusion, and τ is the ratio of heat capacities.

Boundary conditions for this problem are given by the following equation,

$$u=L_1\frac{\partial u}{\partial y}, v=-v_w, T=T_w+D_1\frac{\partial T}{\partial y} at y=0$$

$$u=u_{\infty,} T=T_\infty as y\to\infty. \quad (5)$$

Where T_w is variable with $T_w > T_\infty$,

$T_w = T_\infty + \frac{T_o}{x}, C_w = C_\infty + \frac{C_o}{x}$, *where* C_0 *and* T_0 are *constants.*

$L_1 = L(\mathrm{Re}_x)^{\frac{1}{2}}$ isthe velocity slip factor and $D_1 = D(\mathrm{Re}_x)^{\frac{1}{2}}$ isthethermal slip factor with L and D being the initial values of velocity and thermal slip factors, while $\mathrm{Re}_x = u_\infty \frac{x}{v}$ is the local Reynolds number.

3. Similarity Analysis

We also introduce the following dimensionless variable,

$$\theta = \frac{T - T_\infty}{T_w - T_\infty}, \phi = \frac{C - C_\infty}{C_W - C_\infty} \tag{7}$$

$$\psi = \sqrt{u_\infty v x} f(\eta), \eta = y\sqrt{\frac{u_\infty}{vx}}, \tag{8}$$

where ψ is the stream function such that

$$u = \frac{\partial \psi}{\partial y}, v = -\frac{\partial \psi}{\partial x},$$

$$u = u_\infty f'(\eta), \quad v = \frac{1}{2x} u_\infty . y f'(\eta) - \frac{1}{2\sqrt{x}} \sqrt{u_\infty v} f(\eta) \tag{9}$$

The boundary conditions are

$$\frac{\partial \Psi}{\partial y} = L_1 \frac{\partial^2 \Psi}{\partial y^2}, \frac{\partial \Psi}{\partial x} = v_W, \theta = 1 + D\frac{u_\infty}{v}\theta' \, at \; y = 0 \; \phi = 1 + D\frac{u_\infty}{v}\phi'$$

$$\frac{\partial \Psi}{\partial y} = u_\infty, \theta = 0 as y \to \infty$$

By using similarity transformation equation (7,8), the nonlinear partial differential Equations (2)–(4) transform into the system of nonlinear ODE's,

$$f''' + \frac{1}{2} f f'' - M(f' - 1) + \lambda\theta = 0 \tag{10}$$

$$\theta'' + P_r f'\theta + \frac{1}{2} P_r f \theta' + P_r N_b \theta' \phi' + P_r N_t \theta'^2 = 0 \tag{11}$$

$$\phi'' + L_e(f'\phi + f\phi') + \frac{N_t}{N_b}\theta'' = 0 \tag{12}$$

The new boundary conditions are

$$f' = \delta f'', f = S, \theta = 1 + \beta\theta' \; at \; \eta = 0 \tag{13}$$

and

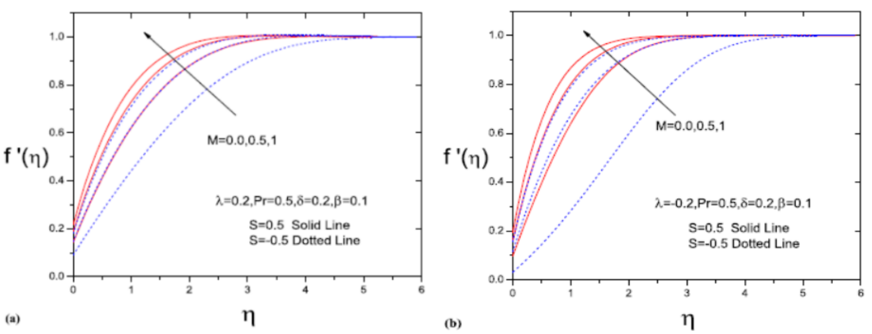
$$f' = 1, \theta = 0 \; at \; \eta \to \infty$$

Where $\lambda = g\beta^* \frac{T_0}{u_\infty^2}$ is the mixed convection parameter, $M = \frac{\sigma {B_o}^2}{\rho u_\infty}$ is the magnetic parameter, $P_r = \frac{v}{k}$ is the Prandtl number, $N_t = \frac{T_o D_T}{T_\infty v x}$ is the thermophoresis parameter, $N_b = T\left[\frac{D_B C_o}{v x}\right]$ is the Brownian motion parameter, and $L_e = \frac{v}{D_B}$ is the Lewis number parameter.

4. Results and Discussion

In order to get a clear insight intothe physical problem, numerical computations were carried out using Runge-Kutta method with shooting technique for various values of different parameters, such as the magnetic parameter M, mixed convection parameter λ, velocity slip parameter δ, thermal slip parameter β, suction/blowing parameter S, Prandtl number P_r, Lewis number L_e, Brownian motion N_b, and thermophoresis N_t.

Fig.1(a) shows that velocity profileincreases when the value of magnetic parameter M increases for buoyancy aided flow in the presence of S. A similar effect shows for buoyancy opposed flow in (b). Also, temperature profiledecreasesas the value of magnetic parameter M increases for buoyancy aided flow in the presence of S as shown in (c). A similar behavior shows for buoyancy opposed flow in (d).



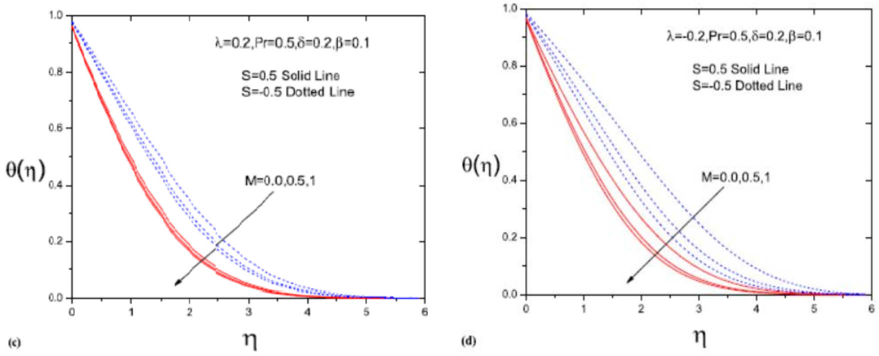


Figure 1. Velocity profile increases when the value of magnetic parameter M increases

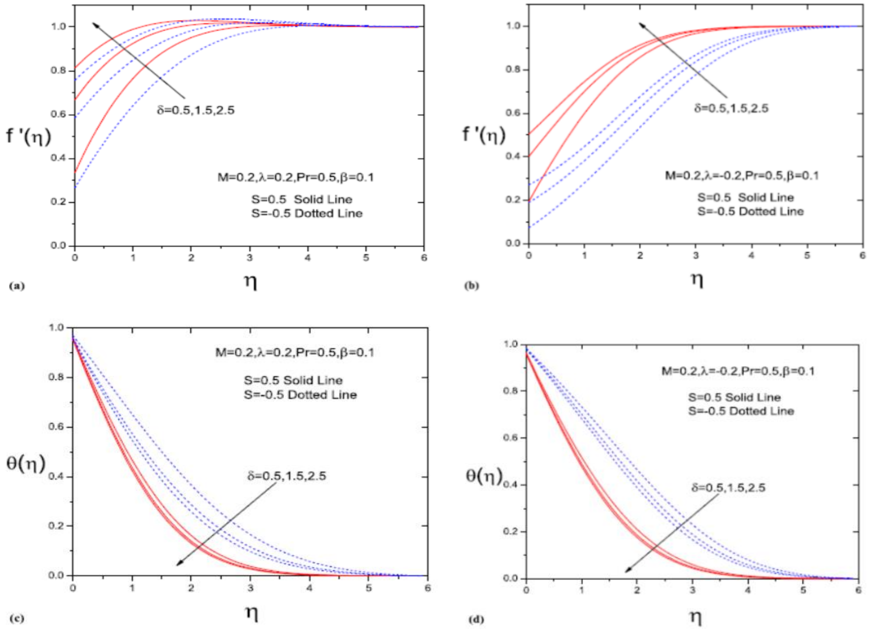


Figure 2. The effect of δ $(N_b = N_t = L_e = 0)$

Fig. 2(a) shows that velocity profile increases with the increasing value of δ for buoyancy aided flow in the presence of S. A similar effect shows for buoyancy opposed flow in (b). Also, temperature profiledecreases as the value of δincreases for buoyancy aided flow in the presence of S as shown in (c). A similar behavior shows for buoyancy opposed flow in (d).

Effects of mixed convection parameter λ on velocity and temperature are displayed in Figs. 3.

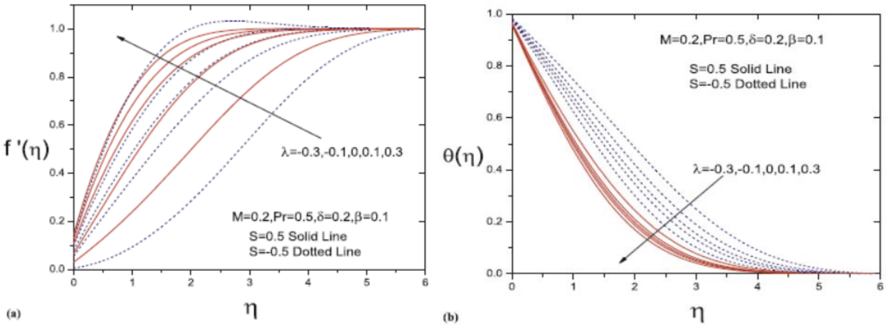


Figure 3. The effect of δ ($N_b = N_t = L_e = 0$)

Fig. 3(a) shows that velocity profileincreases with the increasing value of mixed convection parameter λ in the presence of S. Similarly, temperature profile increases as the value of mixed convection parameter λincreases in the presence of S. A similar behavior showsfor S, with and without λ, regarding velocity and temperature profiles as shown in Figs. 4.

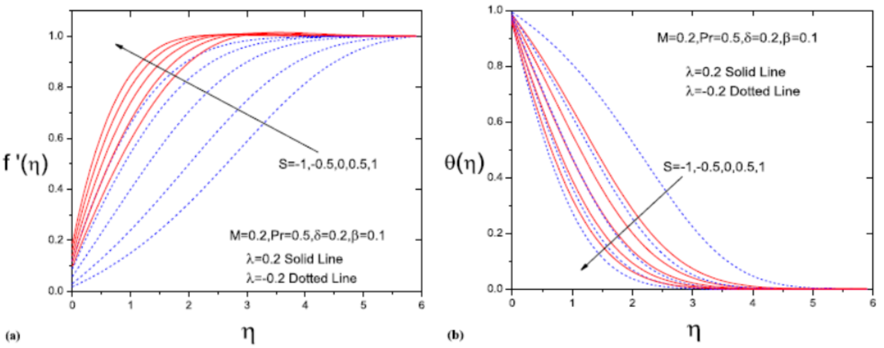


Figure 4. ($N_b = N_t = L_e = 0$)

Figs. 5(a)-5(d) show the effect of thermal slip parameter β on velocity and temperature profiles for buoyancy aidedandopposed flow ($N_b = N_t = L_e = 0$). Fig.5(a) shows that velocity profile decreases as the value of β increases for buoyancy aided flow in the presence of S. Velocity profile showsa similar behavior for β without S in buoyancy opposed flow. The opposite behavior shows for temperature profile as shown in 5(c) and 5(d).

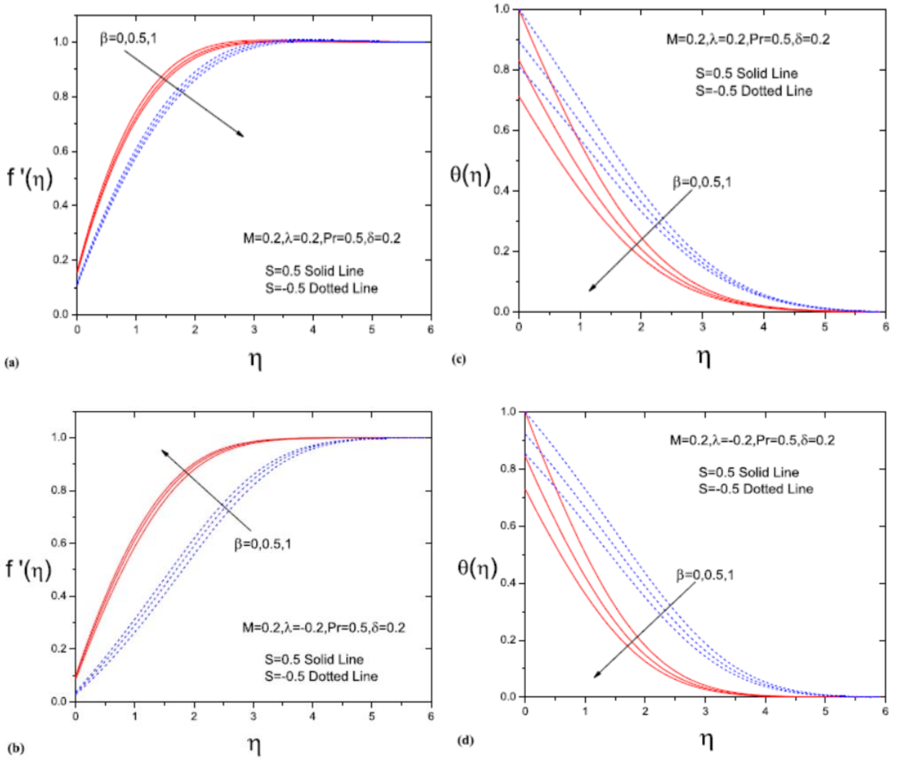
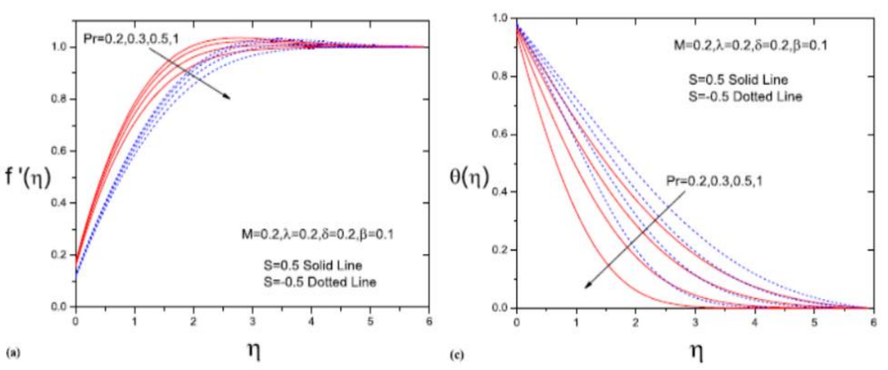


Figure 5. The effect of thermal slip parameter β on velocity and temperature profiles

Fig. 6(a) shows that velocity profile decreases with the increasing value of Prandtl number P_r for buoyancy aided flow in the presence of S. The opposite behavior shows for buoyancy opposed flow as shown in 6(b). A similar behavior shows for P_r in 6(c) and 6(d).



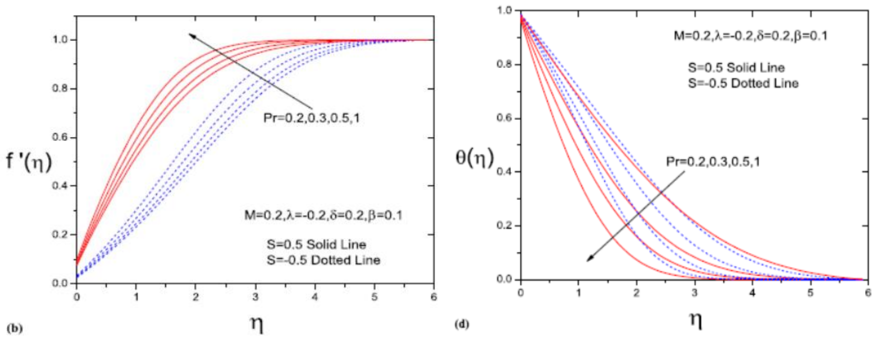


Figure 6. The effect of Prandtl number P_r with and without buoyancy flow

Figs. 6(a)-6(d) show the effect of Prandtl number P_r with and without buoyancy flow in the presence of S.

Fig. 7(a) shows the behavior of the skin friction coefficient. It was observed that f′′t0) increases with the increasing value of M. On the other hand, $\theta'(0)$ decreases with the increasing value of M$(N_b = N_t = L_e = 0)$. An opposite behavior shows for δ in 7(c) and 7(d).

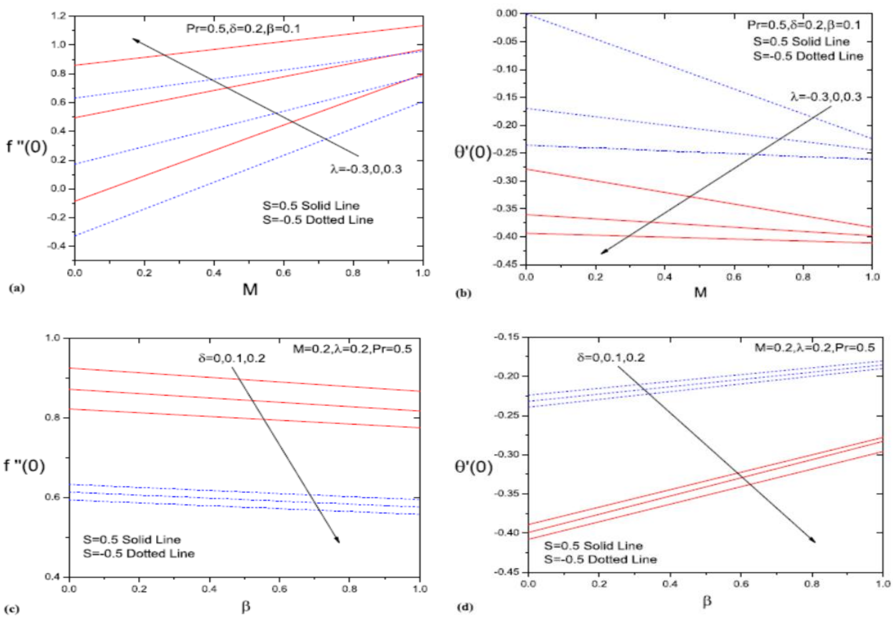


Figure 7. The behavior of the skin friction coefficient

Figs. 8(a)-8(b) show the effectof Brownian motion on velocity and temperature profiles, respectively.

(N_t = 0.1, 0.2, L_e = 0.1, 0.5)for Fig. 8(a), M =0.2, P_r = 0.5, $\delta = 0.2, \beta = 0.1, \lambda$=0.2 solid lines,$\lambda$= -0.2 dotted lines, and for Fig 8(b) M =0.2, P_r = 0.5, $\delta = 0.2, \beta = 0.1, \lambda$= 0.2 solid lines, λ= -0.2 dotted lines. It was observed that velocity profile increases with the increasing value of N_b.An opposite behavior shows for temperature profile. A similar effect shows for thermophoresis as shown in Figs. 9(a)-9(d).

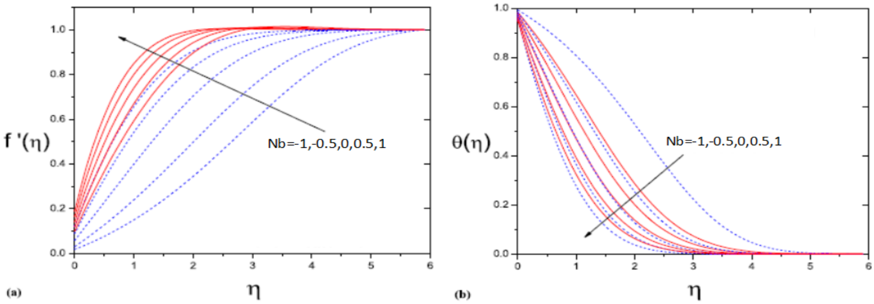


Figure 8. The effect of Brownian motion on velocity and temperature profiles

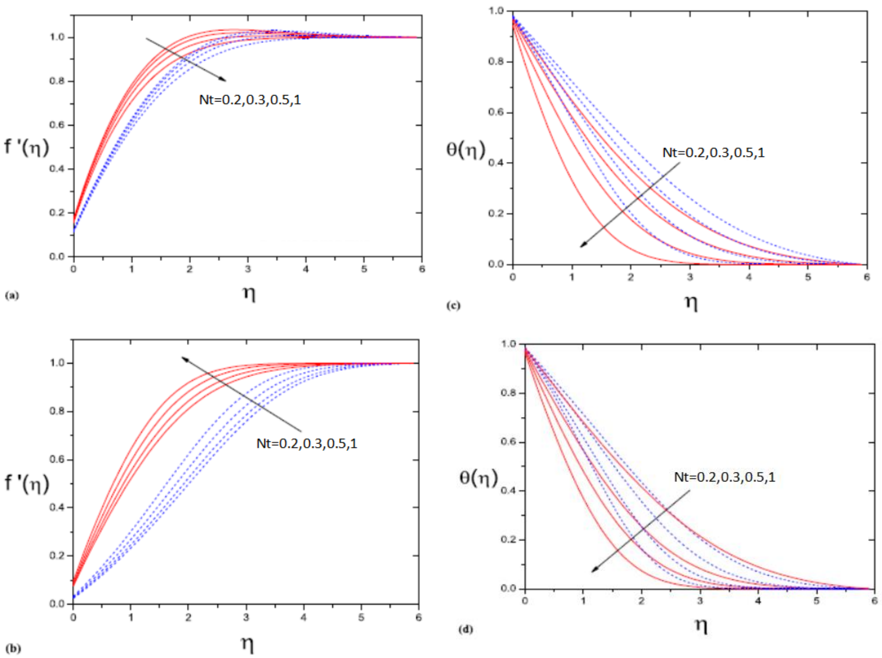


Figure 9. The effect of Brownian motion on thermophoresis

Figs. 10(a)-10(d) show the effect of Lewis number L_e, on velocity and temperature profiles for buoyancy aided and opposed flows. It was observed that velocity profile increases as the value of L_e increases, with and without buoyancy flow. An opposite behavior shows for temperature profile.

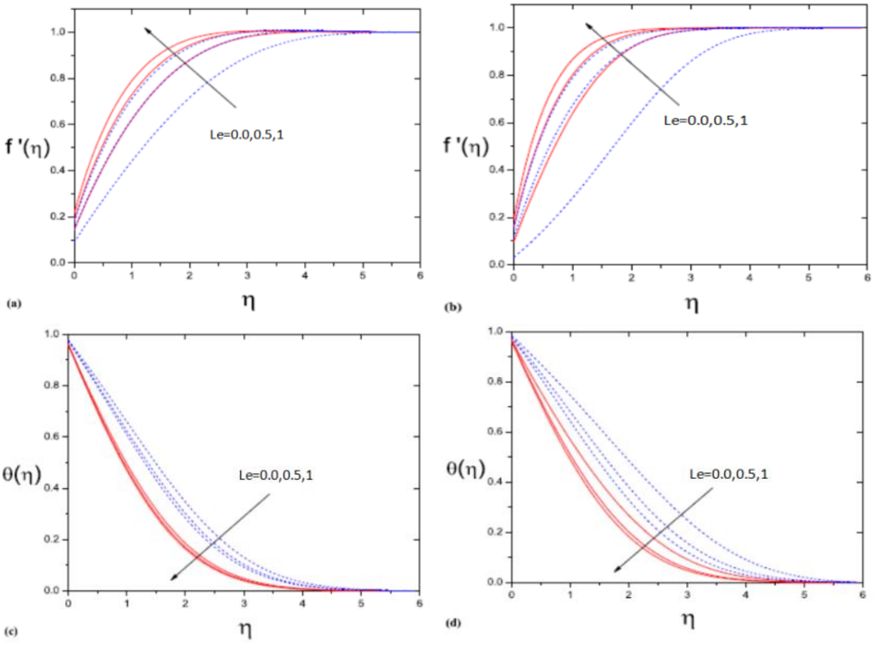


Figure 10. The effect of Lewis number L_e, on velocity and temperature profiles

5. Findings

The buoyancy effect on MHD slip flow and heat transfer of a nanofluid flow over a vertical porous plate were studied numerically.The impact of different physical parameters on velocity profile, temperature profile,Nusselt number,and skin friction coefficient were detected. The main outcomes are given below.

1. Velocity profile and mixed convection parameter both stretched within and opposite direction of flow.
2. Temperature profile decreased when magnetic parameter increased. Also, an opposite behavior showed for λ and S, for both assisting and opposing flows.

3. Skin friction coefficient increasedfor Hartmann number and mixed convection parameter.
4. The consequence of λon heat transfer was appreciable. Due to the increase in Hartmann number, Nusselt number also increased. However, it decreased according to the heat generation/absorption coefficient.

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