Advances in Pure Mathematics, 2023, 13, 153-166
https://www.scirp.org/journal/apm
ISSN Online: 2160-0384
ISSN Print: 2160-0368

Slip Condition Effects on Unsteady MHD Fluid Flow with Radiative Heatflux over a Porous Medium

Abdullahi Ahmad[1], Muhammad Nasir Sarki[2]

[1]Department of Mathematics, Kebbi State Polytechnic, Dakingari, Kebbi, Nigeria
[2]Department of Mathematics Kebbi State University of Science and Technology, Aleiro, Kebbi, Nigeria
Email: abdahmej@gmail.com, nasirsarki26@yahoo.co

How to cite this paper: Ahmad, A. and Sarki, M.N. (2023) Slip Condition Effects on Unsteady MHD Fluid Flow with Radiative Heatflux over a Porous Medium. *Advances in Pure Mathematics*, **13**, 153-166.
https://doi.org/10.4236/apm.2023.133008

Received: September 13, 2022
Accepted: March 12, 2023
Published: March 15, 2023

Abstract

The objective of this paper is to study unsteady magneto hydrodynamic (MHD) free flow of viscoelastic fluid (Walter's B) past an infinite vertical plate through porous medium. The temperature is assumed to be oscillating with time. The solution obtained shows different profiles of effects of slip conditions on primary and secondary velocity. Also, the effects of various parameters on temperature, concentration, primary and secondary velocity profiles were presented graphically. The result indicated the secondary velocity is enhanced with increase in slip parameter. Primary velocity demonstrated opposite trend.

Keywords

Radiation, Slip Parameter, MHD, Heat Flux and Porous Medium

1. Introduction

The boundary layer problems are given more consideration nowadays, this may not be unconnected with roles it plays in the areas of technology, engineering and industrial applications. Radiation effects on heat and mass transfer are of greater importance in many processes and have, therefore, received a considerable amount of attention in recent time, for example nuclear reactor, solid matrix heat exchanger, thermal insulation, surface catalysis of chemical contaminants in various processes, storage of nuclear waste materials, grain storage and drying and many others [1]. It is applied in engineering fields and physiology such as transpiration, cooling gaseous diffusion and blood flow in arteries. The flow through the porous media occurs on the ground water hydrology. Irrigation and drainage problems are critical areas of greater concern, henceforth, scientific treatment of the problems of irrigation, soil erosion and tile drainage are some of the recent developments of porous media.

Several researches indicated significant effects of slip condition on many problems of physical interest, among which are boundary layer flow control, plasma studies, geothermal energy extraction, metallurgy, chemical, mineral and petroleum engineering to mention but few.

[2] investigated the effects of slip conditions on unsteady MHD oscillatory flow of a viscous fluid in a planar channel. MHD flow and heat transfer over permeable stretching sheet with slip conditions were studied by [3]. [4] discussed thermally stratified stagnation point flow of Casson fluid with slip conditions. [5] analysed the radiation and mass transfer effects on MHD free convectional flow past an exponentially accelerated vertical plate with variable temperature. Hall effects on heat and mass transfer in the flow of oscillating viscoelastic fluid through porous medium with slip condition, were examined by [6]. The investigation revealed that the slip parameter enhances the primary velocity and transverse component of the friction and reduces secondary velocity and the axial components of the skin friction of the plate. [7] studied effects of variable suction on transient free convective viscous incompressible flow past a vertical plate with periodic temperature variations in slip regime. [8] illustrated the effects of slip condition and hall current on unsteady MHD flow of a visco-elastic fluid past an infinite porous vertical plate through porous medium. This research indicates that primary velocity initially increases and thereafter decreases for no slip condition in comparison with flow in slip regime. Moreover, secondary velocity decreases for no slip condition in comparison with slip regime flow. [9] examined MHD slip flow on Newtonian fluid past a stretching sheet with thermal convective boundary condition, radiation and chemical reaction. Effects of slip condition and Newtonian heating on MHD flow Casson fluid over a non-linearly stretching sheet saturated in a porous medium, was analysed by [10]. [11] studied Effects of MHD and slip on heat transfer boundary layer flow over a moving plate based on specific entropy generation. [12] demonstrated the Influences of slip velocity and induced magnetic field on MHD stagnation point flow over a stretching sheet. Finite Element simulation of multiple slip effects on MHD unsteady Maxwell Nona fluid flow over a permeable stretching sheet with radiation and thermos diffusion in the presence of chemical reaction was detailed by [13]. [14] examined multiple slip effects on MHD unsteady flow heat and mass transfer impinging on permeable stretching sheet with radiation. [15] studied unsteady two-dimensional hydro magnetic flow and heat transfer of fluid. Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, was described by [16]. Effects of Nervier slip on a steady flow of an incompressible viscous fluid confined within spirally enhanced channel was analysed

by [17]. Mass transfer effects on MHD unsteady free convective Walter's memory flow with constant suction and heat sink, studied by [18]. [19] highlighted the effects of chemical reaction and radiation on heat and mass transfer past semi-infinite vertical porous plate with constant mass flux and dissipations. [20] studied MHD boundary layer flow in double stratification medium. [10] illustrated effects of slip conditions and Newtonian heating on MHD flow of casson fluid over a non-linearly stretching sheet saturated in a porous medium. Hall current effects on unsteady MHD fluid flow with radiative heat flux and heat source over a porous medium was demonstrated by [21]. Effects of slip condition on MHD flow and heat transfer through a permeable non-linearly stretching sheet in a porous medium using the Homotopy analysis method was highlighted by [22].

In the above-mentioned literature none of the researchers studied the slip condition effects on an electrically conducting incompressible fluid past a continuously moving plate in the presence of radiative heat flux heat source, mass flux and viscoelasticity through a porous medium.

2. Problem Formulation

We consider the unsteady flow of a viscous incompressible and electrically conducting viscoelastic fluid with oscillating temperature. The flow occurs over an infinite vertical porous plate. The x^* axis is assumed to be oriented vertically upward along the plate and y^* axis taken normal to the plane of the plate. It is assumed that the plate is electrically none conducting and a uniform magnetic field of strength B_0 is applied normal to the plate. The induced magnetic field is assumed to be negligible so that $\boldsymbol{B}(0, B_0, 0)$. The plate is subjected to a constant suction velocity V_0.

Since the plate is infinite in extend all physical quantities are functions of y^* and t^* only. Thus the governing equations of the flow under the usual Boussinesq approximation are:

Continuity Equation;

$$\frac{\partial v}{\partial y} = 0 \tag{1}$$

The Momentum Equations:

$$\begin{aligned}\frac{\partial u'}{\partial t} - \upsilon_0 \frac{\partial u'}{\partial y'} &= \upsilon \frac{\partial^2 u'}{\partial y^2} - \upsilon \frac{u'}{K_l} - g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) \\ &\quad - \frac{\sigma\beta_0^2}{\rho\left(1+m^2\right)}\left(u + mw\right) - K_0\left\{\frac{\partial^3 w'}{\partial t \partial y'^2} - \upsilon_0 \frac{\partial^3 w'}{\partial y'^3}\right\}\end{aligned} \tag{2}$$

$$\begin{aligned}\frac{\partial w'}{\partial t'} - \upsilon_0 \frac{\partial w'}{\partial y'} &= \upsilon \frac{\partial^2 u'}{\partial y'^2} - \upsilon \frac{w'}{K_l} + \frac{\sigma\beta_0^2}{\rho\left(1+m^2\right)}\left(mu - w\right) \\ &\quad - K_0\left\{\frac{\partial^3 w'}{\partial t \partial y'^2} - \upsilon_0 \frac{\partial^3 w'}{\partial y'^3}\right\}\end{aligned} \tag{3}$$

Energy Equation;

$$\frac{\partial T'}{\partial t'}-\upsilon_0\frac{\partial T'}{\partial y'}=\frac{k}{\rho cp}\frac{\partial^2 T'}{\partial y'^2}-\frac{Q_0}{\rho cp}\left(T'-T'_\infty\right)-\frac{1}{\rho cp}\frac{\partial q_r}{\partial y} \tag{4}$$

Concentration Equation:

$$\frac{\partial C'}{\partial t'}-\upsilon_0\frac{\partial C'}{\partial y'}=D\frac{\partial^2 C'}{\partial y'^2}-K_c\left(C'-C'_\infty\right) \tag{5}$$

The initial boundary conditions are:

$$u'=L^*\left(\frac{\partial u'}{\partial y}\right),\quad w'=L^*\left(\frac{\partial w'}{\partial y}\right),\quad \theta=1+\varepsilon e^{i\Omega t},\quad C'=1+\varepsilon e^{\Omega ti},\quad y=0 \tag{6}$$

$$u'\to 0,\quad w'\to 0,\quad T'\to T'_\infty,\quad C'\to C'_\infty,\quad y\to\infty$$

Introducing the following dimensionless quantities and parameters

$$\eta=\frac{\upsilon_0 y'}{\upsilon},\quad u'=Uu_0,\quad u'_1=\frac{U}{e}u_1,\quad w'_0=Uw_0,\quad w'_1=\frac{U}{e}w_1,$$

$$h=\frac{\upsilon_0}{\upsilon}L',\quad \theta=\frac{T'-T'_\infty}{T'_\omega-T'_\infty}\ \Rightarrow\ C=\frac{C'-C'_\infty}{C'_\omega-C'_\infty},\quad M=\frac{\sigma\beta_0^2\upsilon}{\rho\upsilon_0^2},$$

$$Gr=\frac{\upsilon\beta\left(T'_\omega-T'_\infty\right)}{U\upsilon_0^2},\quad Gc=\frac{\upsilon\beta^*\upsilon\left(C'_\omega-C'_\infty\right)}{U\upsilon_0^2},\quad Km=\frac{K_0\upsilon_0^2}{\upsilon^2} \tag{7}$$

$$Sc=\frac{\upsilon}{D},\quad Pr=\frac{\mu Cp}{k},\quad K=\frac{K_l\upsilon}{\upsilon_0^2}$$

where, β volumetric coefficient of the thermal expansion, v the kinematic viscosity, ρ is density, μ the coefficient of viscosity, β^* is volumetric coefficient of expansion with concentration, u_0 the velocity of the plate, y the coordinate axis normal to the plate, g acceleration due to gravity, q_r the radiation heat flux in the y direction, Cp is specific heat at constant pressure, C' is specific concentration in the fluid, C'_∞ the concentration in the fluid far away from the plate, C'_W the concentration on the plate, D the mass diffusion coefficient, t' is time, h is the slip parameter T the temperature of the fluid near the plate, L^* is the characteristic length of the plate T_W the temperature of the plate, T_∞ the temperature of the fluid far away from the plate. M the Hartmann number, Km viscoelastic parameter, Ω, is the frequency of oscillation.

The following are assumed solutions

$$U(\eta,t)=U_0(\eta)+U_1(\eta)\varepsilon e^{\Omega it} \tag{8}$$

$$w(\eta,t)=w_0(\eta)+w_1\varepsilon e^{\Omega it}$$

$$\theta(\eta,t)=\theta_0(\eta)+\theta_1(\eta)\varepsilon e^{\Omega it}$$

$$C(\eta,t)=C_0(\eta)+C_1(\eta)\varepsilon e^{\Omega it}$$

Substituting Equation (7) in (1) above

Equations (1) to (4) using (6) and (7) reduced to

$$Km\frac{\partial^3 U_0}{\partial\eta^3}+\frac{\partial^2 U_0}{\partial\eta^2}+\frac{\partial U_0}{\partial\eta}-LU_0-Jw_0=-Gr\theta-Gc \tag{9}$$

$$Km\frac{d^3w_0}{d\eta^3}+\frac{d^2w_0}{d\eta^2}+\frac{dw_0}{d\eta}-Lw_0-Jw_0=0 \tag{10}$$

$$Km\frac{\partial^3U_1}{\partial\eta^3}+\left(1-Kmi\Omega\right)\frac{\partial^2U_1}{\partial\eta^2}+\frac{\partial U_1}{\partial\eta}-LnU_1-Jw_1=-Gr\theta_1-GcC_1 \tag{11}$$

$$Km\frac{d^3w_1}{d\eta^3}+\left(1-i\Omega Km\right)\frac{d^2w_1}{d\eta^2}+\frac{dw_1}{d\eta}-Lnw_1-JU_1=0 \tag{12}$$

$$Z\frac{\partial^2\theta_0}{\partial\eta^2}+Pr\frac{\partial\theta_0}{\partial\eta}-S\theta_0=0 \tag{13}$$

$$Z\frac{\partial^2\theta_1}{\partial\eta^2}+Pr\frac{\partial\theta_1}{\partial\eta}-g\theta_1=0 \tag{14}$$

$$\frac{\partial^2C_0}{\partial\eta^2}+Sc\frac{\partial C_0}{\partial\eta}-ScKC_0=0 \tag{15}$$

$$\frac{\partial^2C_1}{\partial\eta^2}+Sc\frac{\partial C_1}{\partial\eta}-ScqC_1=0 \tag{16}$$

The transformed boundary conditions are.

$$U_0(0)=U_1(0)=h\left(\frac{\partial U}{\partial\eta}\right),\quad w_0(0)=w_1(0)=h\left(\frac{\partial w}{\partial\eta}\right),\quad \theta_0(0)=\theta_1(0)=1,$$
$$C_0(0)=C_1(0)=1 \quad \text{at} \quad \eta=1$$
$$U_0=U_1\to 0,\quad w_0=w_1\to 0,\quad \theta_0=\theta_1=0,\quad C_0=C_1=0 \quad \text{as} \quad \eta\to\infty \tag{17}$$

3. Method of Solution

Introducing $F=\left(u_0+iw_0\right)$, and $i=\sqrt{-1}$ also $H=\left(u_1+iw_1\right)$, Equations (9) to (12) transformed to,

$$Km\frac{d^3F}{d\eta^3}+\frac{d^2F}{d\eta^2}+\frac{dF}{d\eta}-FL-FJ=-Gr\theta_0-GcC_0 \tag{18}$$

$$Km\frac{d^3H}{d\eta^3}+E\frac{d^2H}{d\eta^2}+\frac{dH}{d\eta}-NnH=-Gr\theta_1-GcC_1 \tag{19}$$

But Equation (18) and Equation (19) are third order differential equation due to presence of viscoelasticity. Therefore F and H terms are expanded using [23] in terms of *Km*.

$$F_0=F_{00}+KmF_{01} \quad \text{and} \quad H_1=H_{11}+KmH_{12}$$

Zeroth-order

$$F_{00}{}^{111}+F_{01}{}^{11}+F_{01}{}^{1}-NF_{01}=0 \tag{20}$$

$$F_{01}{}^{11}+F_{01}{}^{1}-NF_{01}=-F_{00}{}^{111} \tag{21}$$

$$H_{11}{}^{111}+EH_{12}{}^{11}+H_{11}{}^{1}-NnH_{12}=0 \tag{22}$$

$$EH_{12}{}^{11}+H_{12}{}^{1}-NnH_{12}=-H_{11}{}^{111} \tag{23}$$

The corresponding boundary conditions transformed to

$$F_{00}(0) = F_{01}(0) = h\left(\frac{\mathrm{d}U}{\mathrm{d}\eta}\right) \quad \text{at } \eta = 0$$
$$F_{00} = F_{01} \to 0 \quad \text{as } \eta \to \infty$$
$$\text{similarly} \tag{24}$$
$$H_{12}(\eta) = h\left(\frac{\partial H_{12}}{\partial \eta}\right) \quad \text{at } \eta = 0$$
$$H_{00} = H_{11} \to 0 \quad \text{as } \eta \to \infty$$

Solving Equations (20) to (23) under the boundary Conditions (24) to obtain

$$U = (A_{10} + KmA_{15})\mathrm{e}^{-n_5\eta} - (A_{11} + KmA_{16})\mathrm{e}^{-n_1\eta} - (A_{12} + KmA_{17})\mathrm{e}^{-n_3\eta} + KmA_{14}\mathrm{e}^{-n_6\eta} + \varepsilon \mathrm{e}^{\Omega it}\left[(B_2 + KmB_7)\mathrm{e}^{-f_1\eta} - (B_3 + KmB_8)\mathrm{e}^{-n_2\eta} - (B_4 + KmB_9)\mathrm{e}^{-n_4\eta} + KmB_6\mathrm{e}^{-f_2\eta}\right]$$

$$W = (A_{11} + KmA_{16})\mathrm{e}^{-n_1\eta} + (A_{12} + KmA_{17})\mathrm{e}^{-n_3\eta} - (A_{10} - KmA_{15})\mathrm{e}^{-n_5\eta} - KmA_{14}\mathrm{e}^{-n_6\eta} + i\varepsilon \mathrm{e}^{\Omega it}\left[(B_3 + KmB_8)\mathrm{e}^{-n_2\eta} + (B_4 + KmB_9)\mathrm{e}^{-n_4\eta} - (B_2 + KmB_7)\mathrm{e}^{-f_1\eta} - KmB_6\mathrm{e}^{-f_2\eta}\right]$$

$$\theta(\eta) = \mathrm{e}^{-n_1\eta} + E\mathrm{e}^{(i\Omega t - n_2\eta)}$$
$$C(\eta) = \mathrm{e}^{-n_3\eta} + E\mathrm{e}^{(i\Omega t - n_4\eta)}$$

4. Results and Discussion

For easier illustrations on the influence of various parameters which include Grashof number Gr, mass Grashof number Gc, magnetic number M, chemical reaction parameter R, Schmits number Sc, Prandtl number Pr, radiation parameter R, heat source s, slip parameter m and viscoelastic parameter Km on velocity, temperature and concentration profiles. Computations were carried out using $Gr = 2$, $Gc = 2$, $Pr = 0.71$, $Sc = 0.6$, $R = 0.4$, $M = 10$, $K = 5$, $Ks = 0.5$, $h = 0.2$, $s = 0.2$, $m = 0.05$, and $Km = 0.0005$ various values based on physical quantities are computed and presented in **Figures 1-14**.

Figure 1 and **Figure 2** depict the effects of Prandlt number (Pr) and radiation parameter (R) respectively. Increase in thermal radiation usually discharges heat energy to the fluid flow and enhanced the temperature of the fluid. **Figure 3** and **Figure 4** demonstrate the effects of Schmidt number (Sc) and chemical reaction parameter (K) on concentration of the fluid. Both Sc and K have adverse effects on concentration of the flow, the concentration decreases with increase in Sc and K. **Figure 5** demonstrates the effects of Mass Grashof number (Gc) on primary velocity in slip regime. The velocity decreases with increase in the value of Gc and flow starts at different points on the plate. **Figure 6** shows the influence of Gc on secondary velocity in slip regime. The velocity increase with increase in the value of Gc. **Figure 7** illustrated the behaviour of Grashof number (Gr) on primary velocity. It indicates that velocity decrease with increase in Gr. **Figure 8** depicts the effect of Gc on secondary velocity, the result indicates that the velocity

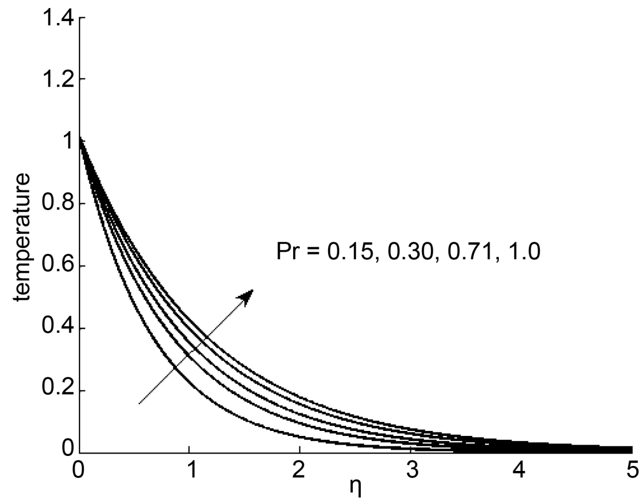

Figure 1. Effects of *Pr* on temperature profile.

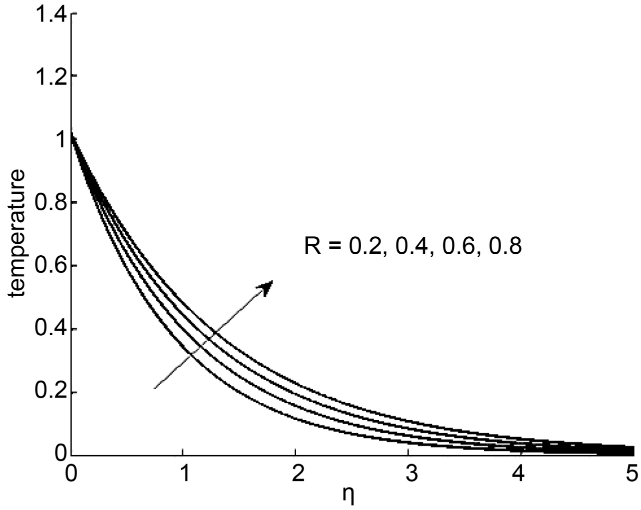

Figure 2. Effects of *R* radiation parameter on temperature.

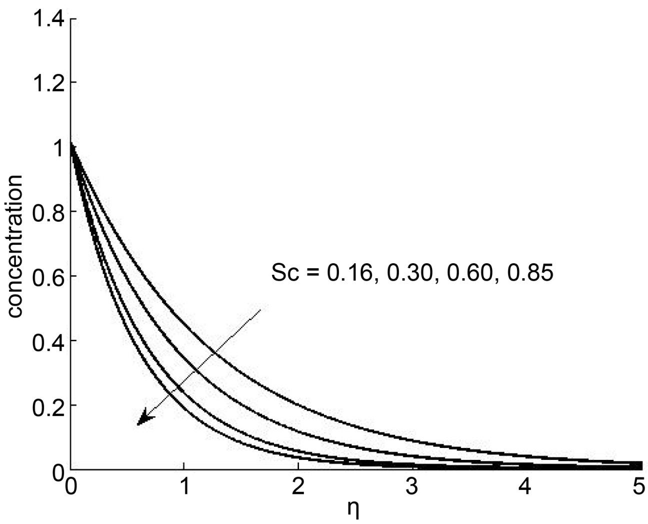

Figure 3. Effects of *Sc* on concentration profile.

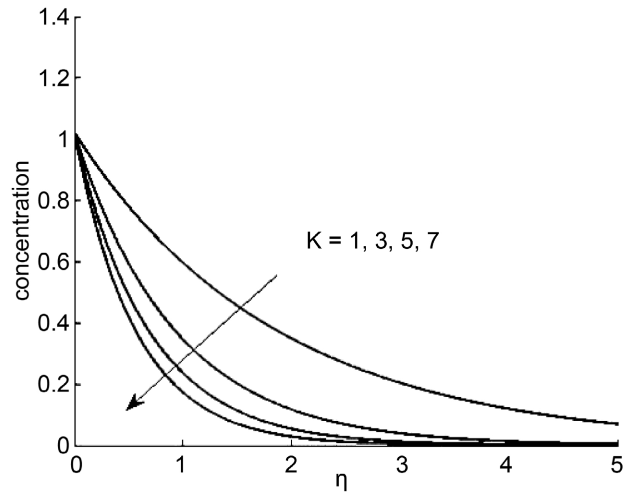

Figure 4. Effects of K on concentration profile.

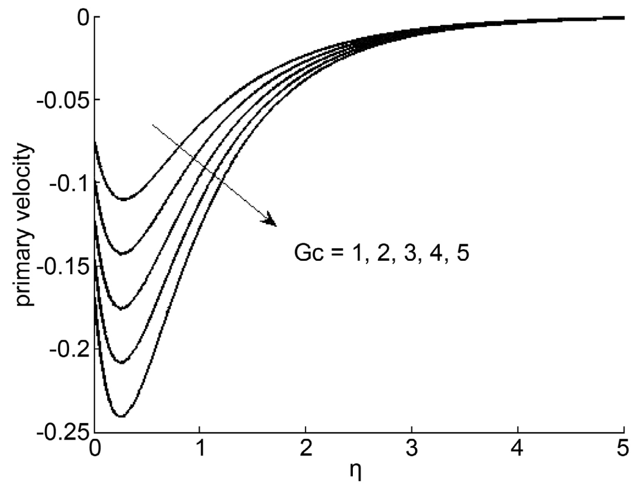

Figure 5. Effects of Mass Grashof number Gc on primary velocity in slip regime.

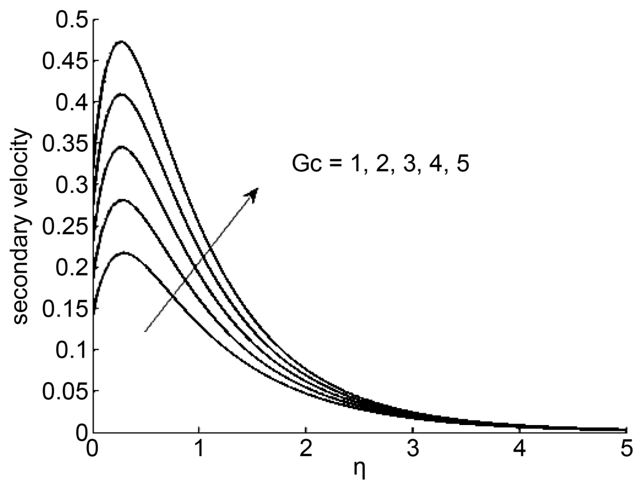

Figure 6. Effects of Mass Grashof number Gc on secondary velocity in slip regime.

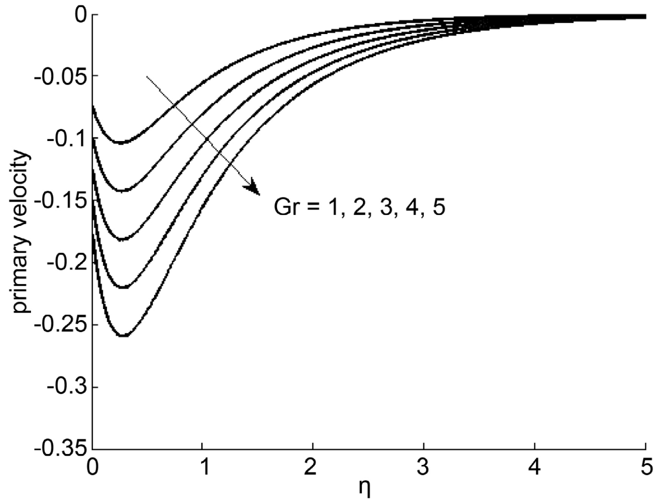

Figure 7. Effects of Grashof number *Gr* on primary velocity in slip regime.

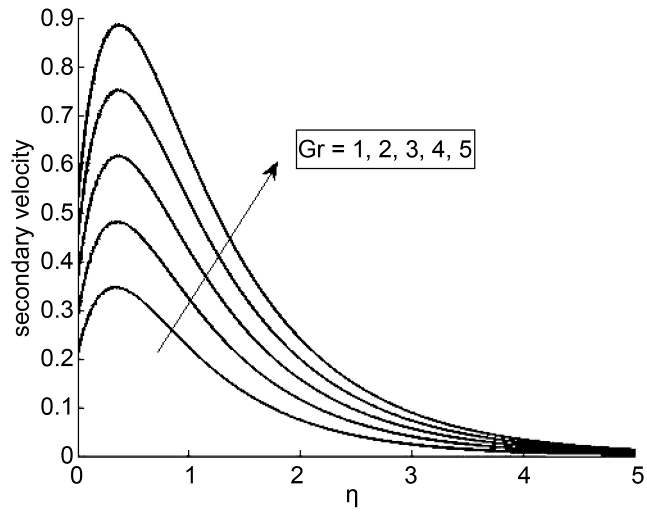

Figure 8. Effects of Grashof number *Gr* on secondary velocity in slip regime.

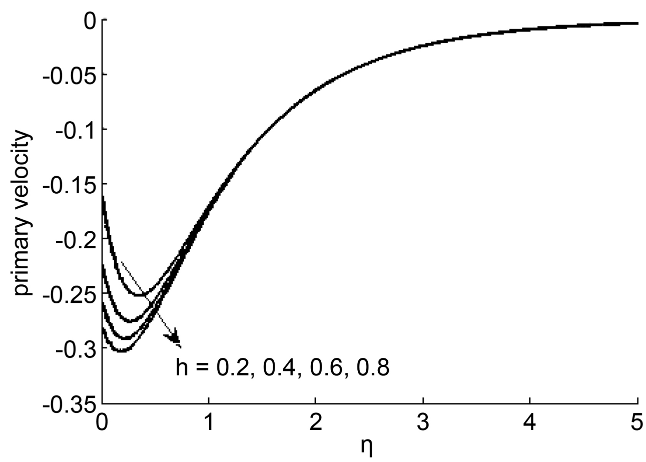

Figure 9. Effects of slip parameter (h) on primary velocity.

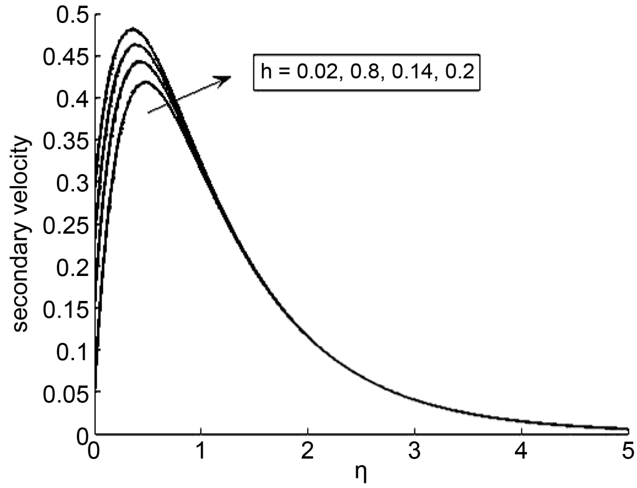

Figure 10. Effects of slip parameter (h) on secondary velocity.

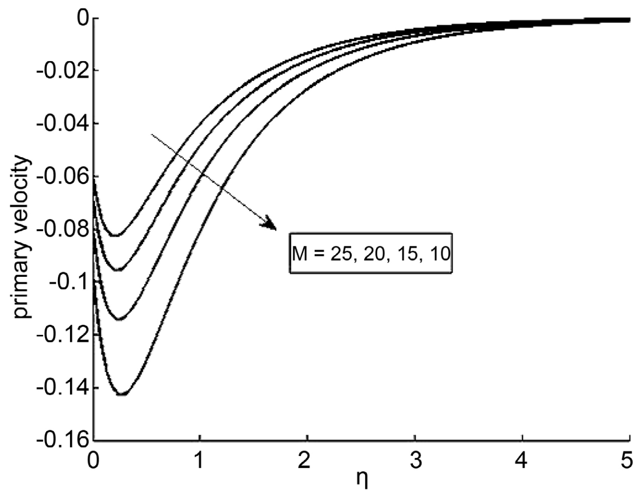

Figure 11. Effects of Hartmann number (M) on primary velocityin slip regime.

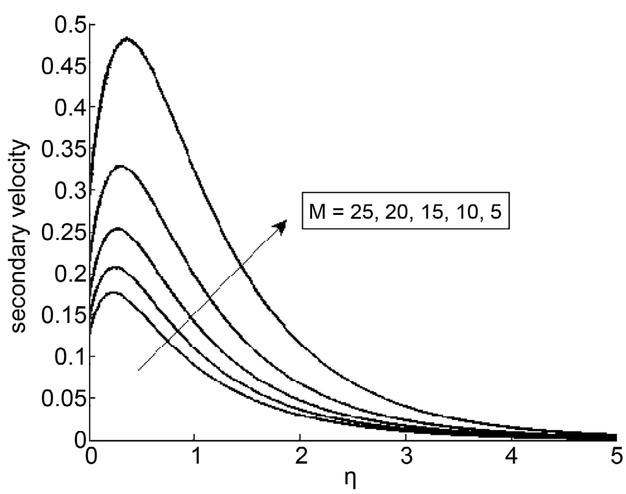

Figure 12. Effects of Hartmann number (M) on secondary velocity in slip regime.

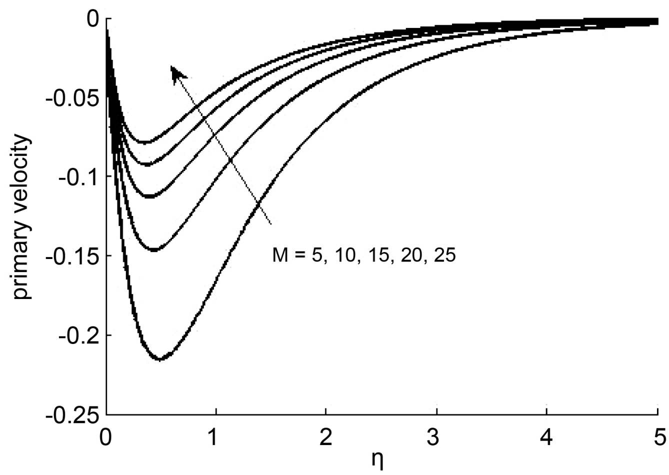

Figure 13. Effects of Hartmann number (M) on primary velocity in no slip regime.

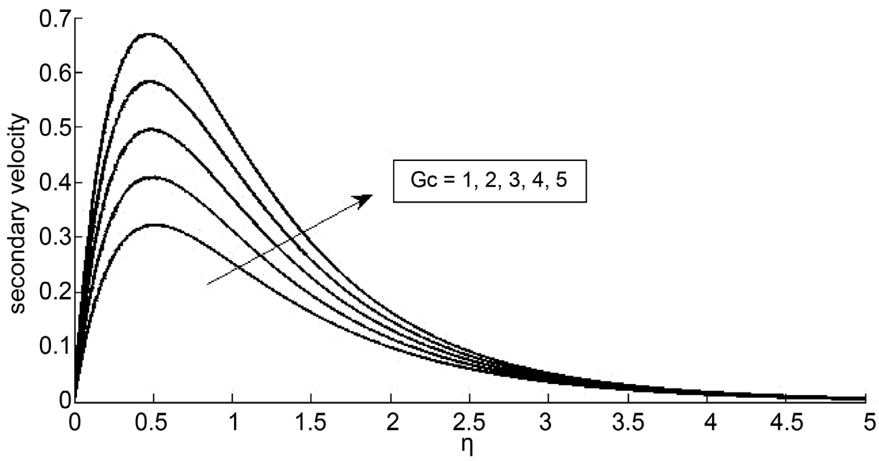

Figure 14. Effects of Mass Grashof number (Gc) on Secondary velocity in no slip regime.

increase with increase in the value of Gr. **Figure 9** and **Figure 10** demonstrate the results of slip parameter on both primary and secondary velocities. It exhibits the same trend as Gr and Gc on velocity. **Figure 11** and **Figure 12** show the effects of Hartmann number (M) on primary and secondary velocity in slip regime. It can be observed that as the value of M decreases the primary velocity increases and as the value of M increases, the fluid flow in secondary velocity depreciates. **Figure 13** and **Figure 14** indicate the effects of M and Gc on primary and secondary velocity respectively in no slip regime. The two results presented generalised that both primary and secondary velocity obey the boundary condition in no slip regime that is when $h = 0$ the fluid flows start from the initial.

5. Conclusion

The Slip Condition effects on unsteady MHD fluid flow with radiative heat flux and heat source over a porous medium are investigated by transforming the governing partial differential equations into ordinary differential equations which are then solved using perturbation techniques. The result of the flow variables indicates that the fluid temperature is relatively reduced by increasing radiation parameter (*R*) and Prandtl number (*Pr*). Concentration is reduced with slight increase in chemical reaction parameter (*K*) and Schmidt number (*Sc*). The primary velocity retards with increase in mass Grashoof number (*Gr*) and thermal Grasshoof number (*Gc*), also the reverse is the case in secondary velocity. The primary velocity appreciates with increase in *M* and depreciates in secondary velocity. These results indicate that flow of fluids with higher magnetic flux can be enhanced in slip regimes. This research could further be extended to cover the effects of slip condition in a mixed convection fluid flow.

Competing Interest

Authors declared that no competing interest in this research.

References

[1] Jha, B.K., Samaila, A.K. and Ajibade, A.O. (2012) Unsteady/Steady Free Convective Couette Flow of Reactive Viscous Fluid in a Vertical Channel Formed by Two Vertical Porous Plates. *International Scholarly Research Notices*, **2012**, Article ID: 794741. https://doi.org/10.5402/2012/794741

[2] Mehmood, A. and Ali, A. (2007) The Effects of Slip Conditions on Unsteady MHD Oscillatory Flow of a Viscous Fluid in a Planar Channel. *Romanian Journal of Physics*, **52**, 85-91.

[3] Hayat, T., Qasim, M. and Mesloub, S. (2011) MHD Flow and Heat Transfer over Permeable Stretching Sheet with Slip Conditions. *International Journal for Numerical Methods in Fluids*, **66**, 963-975. https://doi.org/10.1002/fld.2294

[4] Hayat, T., Farooq, M. and Alsaedi, A. (2015) Thermally Stratified Stagnation Point Flow of Casson Fluid with Slip Conditions. *International Journal of Numerical Methods for Heat & Fluid Flow*, **25**, 724-748. https://doi.org/10.1108/HFF-05-2014-0145

[5] Rajesh, V. and Varma, S.V.K. (2009) Radiation Effects on MHD Free Convective Flow Past an Exponentially Accelerated Vertical Plate with Variable Temperature. *ARPN Journal of Engineering and Applied Sciences*, **4**, 20-26.

[6] Chand, K. and Kumar, R. (2012) Hall Effects on Heat and Mass Transfer in the Flow of Oscillating Viscoelastic Fluid through Porous Medium with Slip Condition. *Indian Journal of Pure and Applied Physics*, **50**, 149-155.

[7] Sharma, P.K. and Chaudhary, R.C. (2003) Effects of Variable Suction on Transient Free Convective Viscous Incompressible Flow Past a Vertical Plate with Periodic Temperature Variations in Slip Regime. *Emirate Journal of Engineering Research*, **8**, 33-38.

[8] Kumar, R. and Chand, K. (2011) Effect of Slip Conditions and Hall Current on Unsteady MHD Flow of a Viscoelastic Fluid Past an Infinite Vertical Porous Plate through Porous Medium. *International Journal of Engineering Science and Technology*, **3**, 3124-3133.

[9] Abdel-Rahman, R.G. (2013) MHD Slip Flow of Newtonian Fluid past a Stretching Sheet with Thermal Convective Boundary Condition, Radiation, and Chemical Reaction. *Mathematical Problems in Engineering*, **2013**, Article ID: 359817.

https://doi.org/10.1155/2013/359817

[10] Ullah, I., Shafie, S. and Khan, I. (2016) Effects of Slip Condition and Newtonian Heating on MHD Flow Casson Fluid over a Non-Linearly Stretching Sheet Saturated in a Porous Medium. *Journal of King Saud University—Science*, **29**, 250-259. https://doi.org/10.1016/j.jksus.2016.05.003

[11] Ellahi, R., Alamri, S.Z., Basit, A. and Majeed, A. (2018) Effects of MHD and Slip on Heat Transfer Boundary Layer Flow over A Moving Plate Based on Specific Entropy Generation. *Journal of Taibah University for Science*, **12**, 476-482. https://doi.org/10.1080/16583655.2018.1483795

[12] El-Aziz, M.A. and Afify, A.A. (2018) Influences of Slip Velocity and Induced Magnetic Field on MHD Stagnation-Point Flow and Heat Transfer of Casson Fluid over a Stretching Sheet. *Mathematical Problems in Engineering*, **2018**, Article ID: 9402836. https://doi.org/10.1155/2018/9402836

[13] Ali, B., Nie, Y., Khan, S.A., Sadiq, M.T. and Tariq, M. (2019) Finite Element Simulation of Multiple Slip Effects on MHD Unsteady Maxwell Nanofluid Flow over a Permeable Stretching Sheet with Radiation and Thermo-Diffusion in the Presence of Chemical Reaction. *Processes*, **7**, Article No. 628. https://doi.org/10.3390/pr7090628

[14] Mabood, F. and Shateyi, S. (2019) Multiple Slip Effects on MHD Unsteady Flow Heat and Mass Transfer Impinging on Permeable Stretching Sheet with Radiation. *Modelling and Simulation in Engineering*, **2019**, Article ID: 3052790. https://doi.org/10.1155/2019/3052790

[15] Adhikary, S.D. and Misra, J.C. (2011) Unsteady Two-Dimensional Hydro Magnetic Flow and Heat Transfer of Fluid. I*nternational Journal of Applied Mathematics and Mechanics*, **7**, 1-20.

[16] Kesavaiah, D.C., Satyanarayana, P.V. and Venkataramana, S. (2011) Effects of the Chemical Reaction and Radiation Absorption on an Unsteady MHD Convective Heat and Mass Transfer Flow Past a Semi-Infinite Vertical Permeable Moving Plate Embedded in a Porous Medium with Heat Source and Suction. *International Journal of Applied Mathematics and Mechanics*, **7**, 52-69.

[17] Gbadeyan, J.A., Abubakar, J.U. and Oyekunle, T.L. (2020) Effects of Navier Slip on a Steady Flow of an Incompressible Viscous Fluid Confined within Spirally Enhanced Channel. *Journal of the Egyptian Mathematical Society*, **28**, Article No. 32. https://doi.org/10.1186/s42787-020-00081-9

[18] Kumar, J.G. and Satyanarayana, P.V. (2011) Mass Transfer Effects on MHD Unsteady Free Convective Walter's Memory Flow with Constant Suction and Heat Sink. *International Journal of Applied Mathematics and Mechanics*, **7**, 97-109.

[19] Uwanta, I.J. (2012) Effects of Chemical Reaction and Radiation on Heat and Mass Transfer Past Semi-Infinite Vertical Porous Plate with Constant Mass Flux and Dissipations. *European Journal of Science Research*, **87**, 190-200.

[20] Ismail, N.S.A., Aziz, A.S.A., Ilias, M.R.I. and Soid, S.K. (2021) MHD Boundary Layer Flow in Double Stratification Medium. *Journal of Physics: Conference Series*, **17709**, Article ID: 012045. https://doi.org/10.1088/1742-6596/1770/1/012045

[21] Ahmed, A., Uwanta, I.J. and Sarki, M.N. (2015) Hall Current Effects on Unsteady Mhd Fluid Flow with Radiative Heatflux and Heat Source over a Porous Medium. *Journal of Advances in Mathematics and Computer Science*, **6**, 233-246. https://doi.org/10.9734/BJMCS/2015/13849

[22] Agrawal, R. and Kaswan, P. (2021) Effects of Slip Condition on MHD Flow and Heat Transfer through a Permeable Non-Linearly Stretching Sheet in a Porous Me-

dium Using the Homotopy Analysis Method. *Computational Thermal Sciences: An International Journal*, **13**, 1-15.
https://doi.org/10.1615/ComputThermalScien.2020033258

[23] Beard, D.W. and Walters, K. (1964) Elastico-Viscous Boundary Layer Flows I. Two-Dimensional Flow near a Stagnation Point. *Mathematical Proceedings of the Cambridge Philosophical Society*, **60**, 667-674.
https://doi.org/10.1017/S0305004100038147

Appendix

$$n_1=\frac{-\frac{Pr}{Z}\pm\sqrt{\left(\frac{Pr}{Z}\right)^2+4\frac{S}{Z}}}{2},\quad n_3=\frac{-SC\pm\sqrt{(SC)^2+4SCK}}{2},\quad n_5=\frac{-1\pm\sqrt{1+4N}}{2},\quad A_{11}=\frac{-Gr}{n_1^2-n_1-N},$$

$$A_{10}=\frac{(1+hn_1)A_{11}+(1+hn_3)A_{12}}{1+hn_5},\quad n_6=\frac{-1\pm\sqrt{1+4N}}{2},\quad \therefore A_{15}=\frac{n_5^3A_{10}}{n_5^2-n_5-N},\quad \therefore A_{16}=\frac{n_1^3A_{11}}{n_1^2-n_1-N},\quad \therefore A_{17}=\frac{-n_3^3A_{12}}{n_3^2-n_3-N},$$

$$A_{14}=\frac{-A_{15}(1+hn_5)+A_{16}(1+hn_1)+A_{17}(1+hn_3)}{1+hn_6},\quad n_2=\frac{-\frac{1}{2}\pm\sqrt{\left(\frac{1}{2}\right)^2+\frac{4g}{Z}}}{2},\quad n_4=\frac{-SC\pm\sqrt{(SC)^2+4SCq}}{2},$$

$$B_2=\frac{B_3(1+hn_2)+B_4(1+hn_4)}{1+hf_1},\quad f_1=\frac{-1\pm\sqrt{1+4ENn}}{2E},\quad B_3=-\frac{Gr}{En_2^2-n-Nn},\quad B_4=-\frac{Gc}{En_4^2-n_4-Nn},$$

$$f_2=\frac{-1\pm\sqrt{1+4ENn}}{2E},\quad B_7=\frac{f_1^3B_2}{Ef_1^2-f_1-Nn},\quad B_8=\frac{-n_2^3B_3}{En_2^2-n-Nn},\quad B_9=\frac{-n_4^3B_4}{En_4^2-n_4-Nn},$$

$$B_6=\frac{-B_7(1+hf_1)+B_8(1+hn_2)+B_9(1+hn_4)}{1+hf_2}$$