



Impacts of Thermal Conductivity and Variable Viscosity on the Dissipative Heat and Species Transport of MHD Flow in Porous Media

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

The investigation of dissipative heat and species diffusion of a conducting liquid under the combined influence of buoyancy forces in a moving plate is examined in the existence of magnetic field. The flowing liquid heat conductivity and viscosity are taken to be linearly varied as a temperature function. The governing derivative equations of the problem are changed to non-linear coupled ordinary derivative equations by applying similarity quantities. The dimensionless model is solved using shooting technique along with the Runge-Kutta method. The outcomes for the flow wall friction, heat gradient and species wall gradient are offered in table and qualitatively explained. The study revealed that the Newtonian fluid viscosity can be enhanced by increasing the fluid flow medium porosity and the magnetic field strength. Hence, the study will improve the industrial usage of Newtonian working fluid.

Keywords: Viscosity; dissipation; thermal conductivity; porous medium; buoyancy force.

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1 Introduction

Several transport procedures in an industry such as plastic and rubber manufacturing, metal extrusion, glass fibre and many more occurs simultaneously in the existence of propagation of heat and mass diffusion. The process that is stimulated by the joint effects of buoyancy species and heat distribution. Various investigations presented for a horizontal, inclined plate and vertical surface with a magnetic transverse field has shown to be essential in technologies and sciences. In view of the usages of thermal distributed fluids, Fenuga et al. [1] considered convective mixed laminar flow stimulated by linearly stretchable porous surface while Swati et al. [2] analyzed thermal diffusion of MHD flowing fluid through non-isothermal permeable stretchable media with temperature free variable stream. The impacts of fluid varying materials and convectively mixed hydromagnetic thermal diffusion in a heated vertical medium, entrenched in springly filled absorbent media was examined by Nalinakshi et al. [3].

The combination of heat and reacting species are very essential and currently receiving a substantial quantity of consideration. In the procedures, for instance, the desert cooler, water evaporation from surface body, drying, heat transfer in the cooling of wet tower, heat dispersion and reacting mass diffusion occur simultaneously. Therefore, Alireza et al. [4] carried out investigation on the stagnation MHD point flow solution and permeable heat transport past elongating plates with reacting species. Okedoye [5] examined the flow of thermal and mass convection of a MHD fluid analytically in a permeable channel. Reddy [6] studied steady heat transport and chemical species transfer of dissipative MHD fluid flowing in an inclined plate using scaling transformation while Fenuga et al. [7] studied chemical reaction and heat dissipation of convective MHD free flowing liquid through an inclined stretchable porous plate. From both studies, the impact thermal dissipation term i.e., Eckert number was reported to have created an increasing influence on the temperature field and velocity distribution. Eshetu and Shankar [8] investigated in permeable channel, the MHD heat and chemical reacting transport of a nanofluid with dissipation and radiation influences. Salawu et al. [9] analyzed species transport and radiating heat of a convective free flow of MHD fluid past a moving surface with reacting chemical species, dissipation and heat source. Also, Reddy et al. [10] reported on the similarity variables solution of a mass transport and heat propagation, steady convection MHD chemical reacting flow of a dissipative liquid in a porous inclined sheet. None of the above authors considered the impacts of varying thermal conductivity and viscosity flowing fields. The conducting incompressible boundary layer MHD flowing liquid is usually come across in technological and chemical processes, astrophysics, and geophysics. Therefore, the analysis of continuous flow over a boundary layer moving sheet with uniform ambient flow velocity was pioneered by Sakiadis [11]. In the investigation, the continuous flow of quiescent liquid momentum past a motioning surface was analyzed. The modelled equation was protracted by Erickson et al. [12] by including moving plate suction or blowing. Afterward, Tsou et al. [13] reported on the experimental and analytical study of the uninterrupted moving boundary layer flowing liquid and heat diffusion. Salawu and Kareem [14] examined pressure driven fluid stream of boundary nonlinear layer for a heat propagation and hydromagnetic liquid in the existence of heat conductivity and varying viscosity while Mureithi [15] carried out study on a flow in a stretchable boundary layer sheet with variable viscosity and heat transport. Kareem and Salawu [16] investigated in permeable media, the radiative and thermal conductivity impacts on a fluid flowing and heat transfer past a stretchable plate.

The study was extended by Gitima [17] to include magnetic field for a conducting flow. Subsequently, Krishnendu et al. [18] studied the heat distribution and slip flowing fluid in a moving boundary layer and heat dependent varying liquid viscidness. Dulal and Hiranmoy [19] reported on the heat dependent conductivity and viscosity influences on a mixed diffusion-convection of non-Darcy MHD flow through a distending surface. Hunegnaw and Naikoti [20] studied temperature distribution and heat dissipation of a MHD variable viscosity fluid flow with heat generation in a stretchable porous plate. Abel and Mahesha [21] investigated radiation, varying heat source and thermal conductivity of viscoelastic heat distribution MHD flow past a moving plate while Salawu [22] examined MHD non-Newtonian thermal conducting liquid with varying viscosity and heat transport over moving surface. Moreover, Hazarika and Utpal [23] analyzed the impacts of variable heat conduction and viscosity on a hydromagnetic liquid in a heated vertical device. Hunegnaw and Kishan [24] examined transient conducting heat fluid flow and reacting species transport in permeable channel and stretchable plate with reaction order, viscous heating and variable properties.

In the above studies, the effect of chemical as well as the combined effect of buoyancy forces, variable heat conduction and viscosity on the temperature distribution and species diffusion has not been considered.

Meanwhile, it is known that temperature distribution and liquid viscosity changes considerably with the thermo-fluid properties. The flow characteristics changes significantly when variable heat conduction and viscosity are considered in related to a constant physical property. Therefore, the current investigation seek to study heat dependent variable thermal conduction and viscosity of flowing viscous dissipative fluid past a stretchable surface subjected to magnetic field influence and buoyancy forces in permeable flow channel. As such, a linear temperature function is assumed for the thermal conduction and viscosity of the reacting chemical species.

2 Flow Model Formulation

A heat and species diffusion of conducting free convection, incompressible and steady fluid flowing past a stretchable porous medium and heated surface is examined. The flowing liquid is influenced by buoyancy forces, viscous dissipation and perpendicularly applied magnetic field. Thermo-fluid temperature dependent quantities are considered for the thermal conductivity and viscosity. The flowing liquid is taken along the x -axis while y -direction is assumed to be in perpendicular direction to the flow. A uniform B_0 of magnetic strength field is examined to create electromagnetic force with continual flowing fluid. The stretchable surface and species concentration are motionless with an equivalent and resistance forces applied in the x -direction. The flow device medium wall is sustained with constant temperature and reacting chemical propagation T_w, C_w and far flowing heat diffusion and mass transfer T_∞, C_∞ individually. The flow dimensional equations are as follows:

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

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \frac{\mu}{\rho} \frac{\partial^2 u}{\partial y^2} + \frac{1}{\rho} \frac{\partial \mu}{\partial T} \frac{\partial T}{\partial y} \frac{\partial u}{\partial y} - \frac{\mu}{K^*} u - \frac{1}{\rho} \sigma B_0^2 u + g \beta_T (T - T_\infty) + g \beta_C (C - C_\infty) \quad (2)$$

$$\rho C_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k \frac{\partial^2 T}{\partial y^2} + \frac{\partial T}{\partial y} \frac{\partial k}{\partial y} + \mu \left(\frac{\partial u}{\partial y} \right)^2 + Q_0 (T - T_\infty) \quad (3)$$

$$u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D \frac{\partial^2 C}{\partial y^2} - \gamma (C - C_\infty) \quad (4)$$

With suitable boundary conditions:

$$\begin{aligned} u = u_w (= bx), v = 0, T = T_w (= T_\infty + Ax), C = C_w (= C_\infty + Bx) \text{ at } y = 0 \\ u = 0, T = T_\infty, C = C_\infty \text{ as } y \rightarrow \infty \end{aligned} \quad (5)$$

Here, u, v, T and C are the x and y module velocities, flow heat transfer and mass transport correspondingly, and u_w denotes wall velocity of the fluid. The variables $\nu = \frac{\mu}{\rho}, \mu, \rho, K, \sigma, C_p, k, Q_0, D$ and λ represent kinematics fluid viscosity, coefficient of fluid friction, density, flow medium porosity, electric conductivity of the fluid, constant pressure heat capacity, heat conductivity, heat source, mass diffusivity and reacting chemical coefficient separately. g denotes gravity, β_T and β_C represent coefficient heat and mass expansion, A, B, b are prescribed constants.

The fluid variable viscosity is taken as a temperature function described along Mukhopadhyay et al. [25] and Pantokratoras [26].

$$\mu = \mu_\infty [\alpha + r(T_w - T)] \quad (6)$$

where μ_∞ is the fluid free stream dynamic viscosity, α and r are constants and $r(> 0)$. The viscosity-temperature relation is $\mu = \alpha - rT$ which agrees quite well with the relations $\mu = \frac{1}{(r_1 + r_2 T)}$ where $\alpha = \frac{1}{r_1}, r = \frac{r_2}{r_1}$ and $\mu = e^{-\alpha T}$ with the second and order higher terms been ignored, Saikrishnan and Roy [27] as well as Bird et al. [28] respectively.

The heat conductivity of the fluid, k , is taken to vary as a temperature linear function according to Chiam [29].

$$k = k_{\infty}(1 + \beta\theta) \tag{7}$$

where $\beta = \frac{k_w - k_{\infty}}{k_{\infty}}$ depicts heat conductivity term.

Finding solution to the stretching boundary problem, the following similarity transform are introduced

$$\psi = (bv)^{\frac{1}{2}}xf(\eta), \eta = \left(\frac{b}{v}\right)^{\frac{1}{2}}y \tag{8}$$

The flow rate, heat and chemical reaction modules are related in stream function $\psi(x, y)$ by

$$u = \frac{\partial\psi}{\partial y} = axf'(\eta), v = -\frac{\partial\psi}{\partial x} = -(av)^{\frac{1}{2}}f(\eta), \theta(\eta) = \frac{T-T_{\infty}}{T_w-T_{\infty}}, \phi(\eta) = \frac{C-C_{\infty}}{C_w-C_{\infty}} \tag{9}$$

Introducing equations (6)-(9), the continuity equation is automatically gratified equations (2)-(4) becomes.

$$[\alpha + A(1 - \theta)]f'' + (f - A\theta')f' - f'^2 - (D_a[\alpha + A(1 - \theta)] + M)f' + Gr\theta + Gc\phi = 0 \tag{10}$$

$$\frac{\partial}{\partial\eta} [(1 + \beta\theta)\theta] + PrEc[\alpha + A(1 - \theta)](f')^2 + Prf\theta' - Pr(f' - Q)\theta = 0 \tag{11}$$

$$\phi'' + Scf\phi' - Scf'\phi - Sc\lambda\phi = 0 \tag{12}$$

The corresponding boundary conditions becomes

$$\begin{aligned} f'(0) = 1, f(0) = 0, \theta(0) = 1, \phi(0) = 1 \\ f(\infty) = 0, \theta(\infty) = 0, \phi(\infty) = 0 \end{aligned} \tag{13}$$

where $A = r(T_w - T_{\infty})$ is the viscosity parameter, $Q = \frac{Q_0}{\rho c_p b}$ denotes heat source term, $\lambda = \frac{\gamma}{b}$ is the concentration term, $M = \frac{\sigma B_0^2}{\rho b}$ symbolizes magnetic term, $D_a = \frac{\nu}{k^* b}$ is the Darcy number, $Gr = \frac{g\beta_r(T_w - T_{\infty})}{b^2 x}$ is the thermal Grashof number, $Gc = \frac{g\beta_c(C_w - C_{\infty})}{b^2 x}$ is the solutal Grashof number, $Ec = \frac{u_w^2}{c_p(T_w - T_{\infty})}$ is the Eckert number, $Pr = \frac{\mu_{\infty} c_p}{k}$ is the Prandtl number and $Sc = \frac{\nu}{D}$ is

Schmidt number.

The variables of practical importance are the wall local friction C_f , Nusselt number Nu and wall mass gradient Sh described as:

$$C_f = \frac{\tau_w}{\rho u_w^2}, Nu = \frac{q_w x}{k(T_w - T_{\infty})}, Sh = \frac{q_m x}{D(C_w - C_{\infty})} \tag{14}$$

The terms τ_w , q_w and q_m are correspondingly defined by

$$\tau_w = \mu \left(\frac{\partial u}{\partial y}\right)_{y=0}, q_w = k \left(\frac{\partial T}{\partial y}\right)_{y=0}, q_m = D \left(\frac{\partial C}{\partial y}\right)_{y=0} \tag{15}$$

Hence, the engineering wall effects are as follows:

$$C_f Re_x^{\frac{1}{2}} = f''(0), Nu Re_x^{-\frac{1}{2}} = \theta'(0), Sh Re_x^{-\frac{1}{2}} = \phi'(0) \tag{16}$$

where $Re_x = \frac{u_w x}{\nu}$ depicts Reynolds local number.

Table 1. Effect of $M, \alpha, A, Sc, Ec, Pr, \beta$ and λ on the $f''(0), \theta'(0)$ and $\phi'(0)$

P	values	$f''(0)$	$-\theta'(0)$	$\phi'(0)$	P	values	$f''(0)$	$-\theta'(0)$	$\phi'(0)$
M	0.5	-0.49754	0.80459	0.88389	Ec	0.03	-0.49754	0.80439	0.88389
	2.0	-1.08423	0.70835	0.80802		0.50	-0.46962	0.73173	0.88864
	3.0	-1.39678	0.65657	0.76941		1.00	-0.44227	0.66271	0.89338
	5.0	-1.91489	0.57271	0.70987		1.50	-0.41704	0.60107	0.89785
	α	1.0	-0.49754	0.80439		0.88389	Pr	0.5	-0.43965
2.0		-0.46716	0.81392	0.89412	0.71	-0.49754		0.80439	0.88389
3.0		-0.44676	0.81982	0.90113	2.0	-0.68001		1.42489	0.85880
4.0		-0.43177	0.82368	0.90629	5.0	-0.83201		2.32510	0.84879
A		0.0	-0.36775	0.81223	0.89020	β		0.1	-0.49754
	1.0	-0.49754	0.80439	0.88389	0.5		-0.45336	0.65251	0.89031
	2.0	-0.62108	0.79690	0.87808	1.0		-0.41181	0.54081	0.89741
	3.0	-0.74021	0.78981	0.87273	2.0		-0.35450	0.41859	0.90895
	Sc	0.35	-0.43941	0.82363	0.64426		λ	0.1	-0.49754
0.45		-0.46456	0.81522	0.74026	0.7	-0.53243		0.79395	1.08498
0.62		-0.49754	0.80439	0.88389	1.0	-0.54527		0.79033	1.17113
1.00		-0.54690	0.78926	1.14963	2.0	-0.57699		0.78196	1.41818

3 Results and Discussion

The study computational analyze is done via shooting scheme along with integration algorithm for the Runge-Kutta of order four. The numerical outcomes are examined for the boundary layer edge smoothness conditions and found pleased. Computations is done for various default terms value as gotten from some theoretical studies, that is $Gr = Gc = A = \alpha = 1, Q = \beta = \lambda = Da = 0.1, Pr = 3, Sc = 0.62, Ec = 0.03$ and $M = 0.5$. Table 1 shows the computed outcomes represent the impact of entrenched terms on the dimension of the flow distributions. Its displays that a rise in the terms M, A, Sc, Pr and λ value decrease the flow wall friction, and leads to a boost in the heat wall transport except for Pr , that cause decrease in Nusselt number. Also, the parameters caused a rise in the mass wall transport gradient except for Sc and λ that cause decrease in Sherwood number. Whereas, an upsurge in the values of α, Ec and β cause a resultant boost of the wall coefficient drag force and the energy wall gradient except for α that causes decrease in the Nusselt number, meanwhile, the parameters reduced the concentration wall gradient.

Fig. 1 displays the effect of increasing magnetic field imposition on the flowing liquid. A rising value of M retarding the flow velocity dimension by inducing electromagnetic force that leads to a decreasing velocity field. This observation agrees with various studies (see Okedoye (2013), Salawu et al. (2019)), as a result of the exerted force creating by magnetic field that resist the free convective stream. The influences of thermal Grashof Gr and solutant Grashof Gc on the flow rate are presented in Figs. 2 and 3. It is noticed that a rise in the species or thermal buoyancy force relative to hydromagnetic viscous force significantly impacted the velocity magnitude. Therefore, energy or mass distribution has high effect on the flowing liquid field. Fig. 4 illustrates the effect of porosity parameter Da on the flow rate profile. The velocity distribution is seen to have decrease due to rising flow media porosity, as such, the surface wall creates an extra opposition to the dynamic of the flowing liquid that leads to a retarding temperature distribution.

Fig. 5 expressions the rate of flowing fluid field for a variation in the viscosity term A . The fluid velocity is noticed to have increase for a rising value of A due to an increasing velocity boundary film stickiness. The reason for this behavior is that, a rising in the value A decreases the viscosity of the liquid which causes rising viscous boundary film viscidness. Fig. 6 displays the impact of thermal conductivity parameter on the velocity dimension. When α is raised, the velocity profile increases, because the viscous boundary layer get thicker as the values of α increases. Figs. 7 and 8 show the effect of Prandtl number Pr on the flow rate and temperature distributions. Prandtl number describes the thermal diffusivity ratio to momentum diffusivity. An increase in the values of Pr resulted in a respectively decline in the flow rate and heat transport profiles. The reason for this behavior is a rise in Pr resulted in a reducing boundary viscosity film that thereby declines the quantity of heat transfer within flow dimension. Thus, Prandtl number may be utilized to raise the conductivity of the cooling streams. Figs. 9 and 10 depict the Schmidt number impact on the velocity field and mass transfer. The

Schmidt number Sc discourages the species transport field. Schmidt number is proportional to the mass propagation coefficient. Therefore, the velocity and mass transport decline with enhancing Sc .

The consequence of heat source on the heat transfer profile is represented in Fig. 11. From the figure, it is noticed that the temperature profiles increases when increasing the value of heat generation Q . The heat transfer reduces to increase the heat boundary film stickiness. The impact of heat dissipation term that is, Eckert number Ec on the heat diffusion is revealed in Fig. 12. The Eckert term Ec represents the enthalpy relation to the kinetic energy. It symbolizes the kinetic energy conversion to fluid stresses work done created by internal energy. The Eckert number corresponds to plate cooling i.e., plate to fluid heat loss. Therefore, high heat dissipation heat leads to rising temperature profile which is evident from Fig. 12. The influence of heat variable conductivity term β on the heat propagation field is displayed in Fig. 13. It is noticed in the figure that enhancing values of β resulted to rising temperature magnitude as a result of heat boundary stickiness film. Fig. 14 shows the influence of the reaction rate parameter on the mass distribution. It is observed from the concentration field that the boundary film viscosity reduces for rising in λ . The reacting species term is a reducing reactant which leads to thinner mass boundary film close to the plate become shrinks. This is because the reactant conversion due to reacting chemical reagent that thereby decrease the mass transfer boundary film.

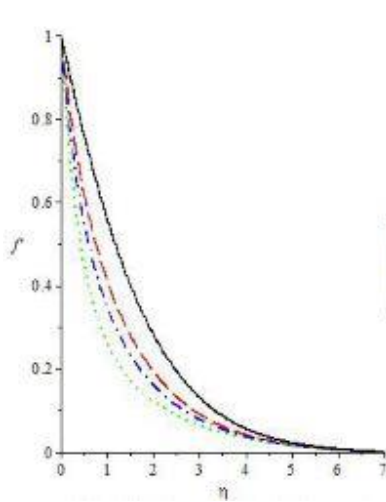


Fig. 1. Impact of (M) on flow velocity

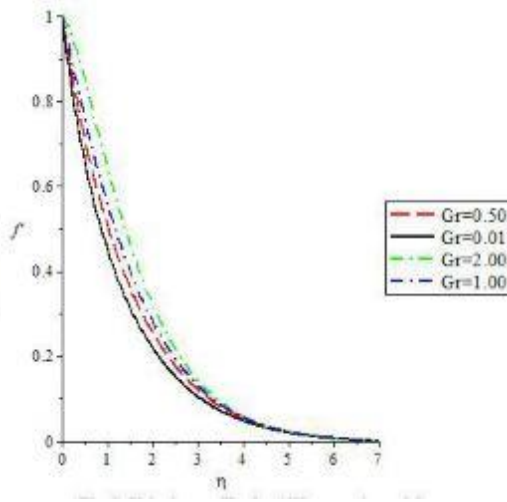


Fig. 2. Impact of (Gr) on velocity field

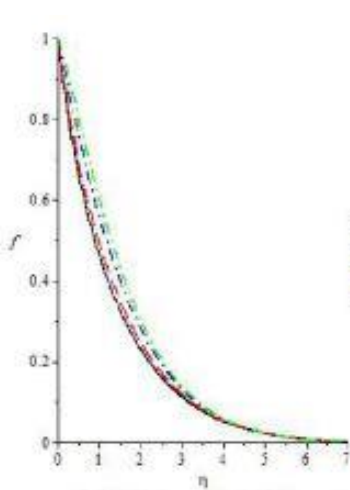


Fig. 3. Effect of (Gc) on velocity profile

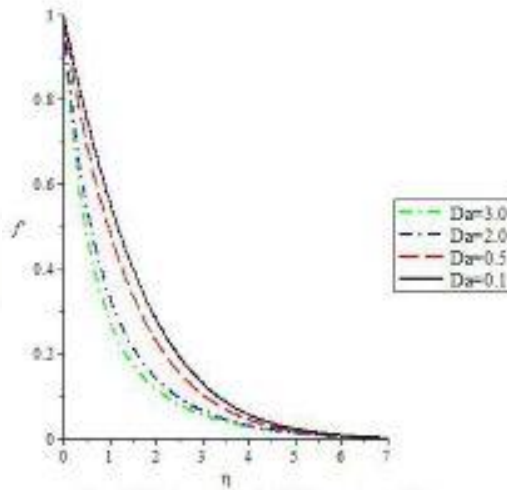


Fig. 4. Impact of (Da) on flow rate

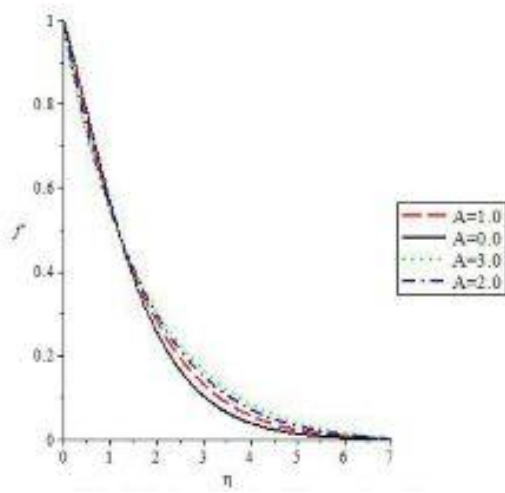


Fig. 5. Effect of (A) on flow distribution

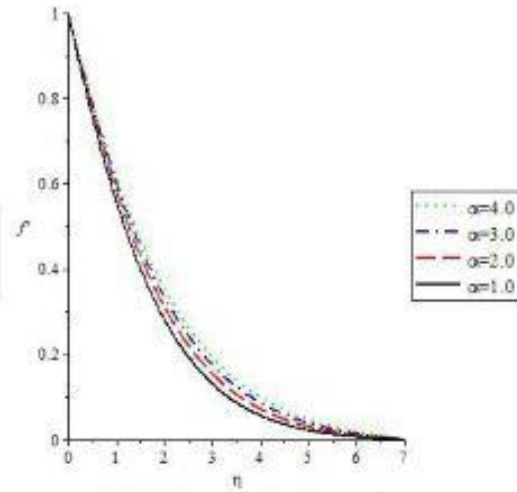


Fig. 6. Impact of (α) on flow profile

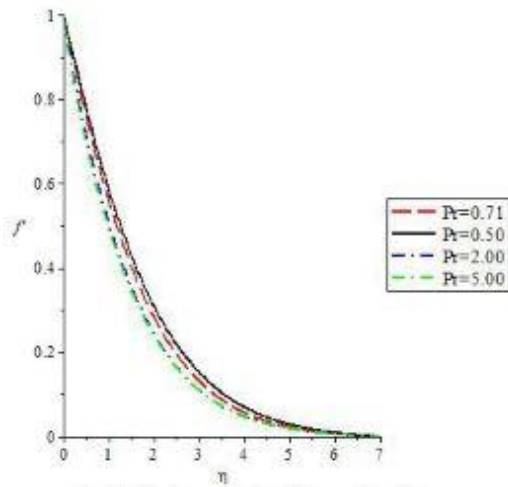


Fig. 7. Velocity field for different (Pr) values

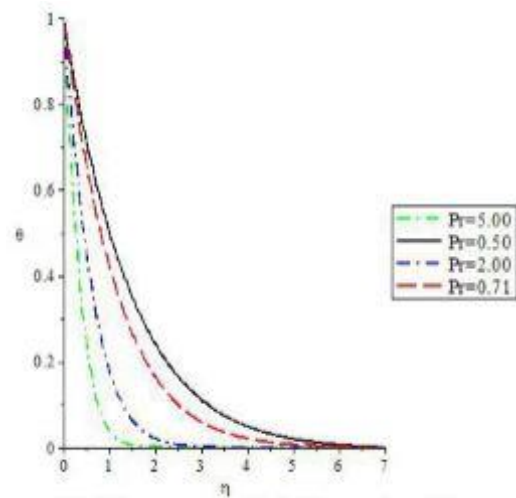


Fig. 8. Temperature field for various (Pr)

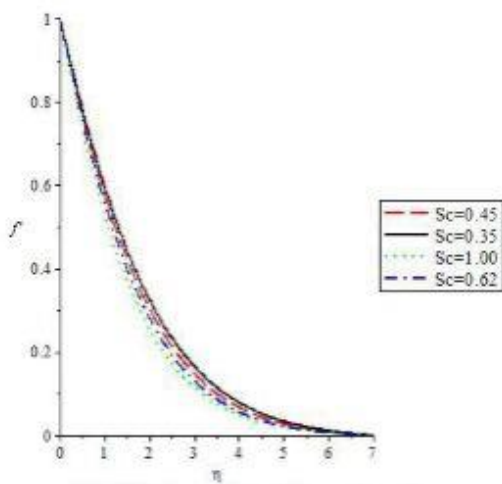


Fig. 9. Velocity profile for (Sc) effect

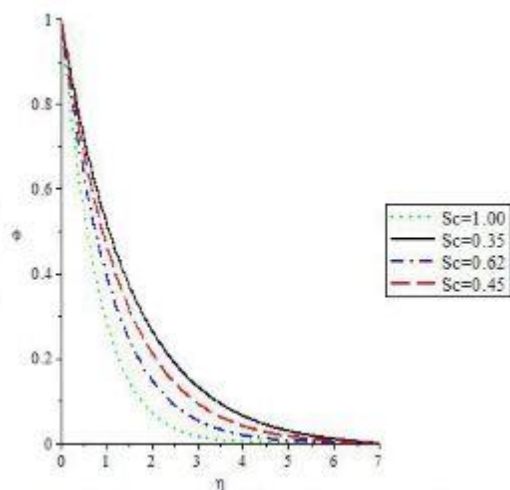


Fig. 10. Concentration field for various (Sc)

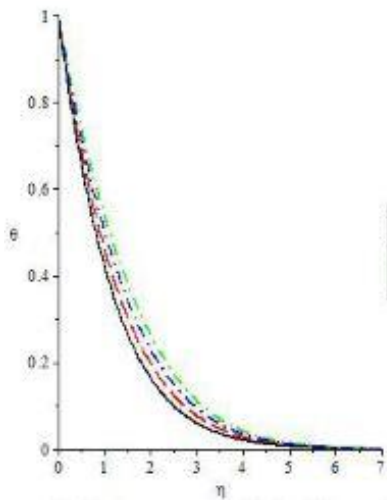


Fig. 11. Temperature field for (Ec) effect

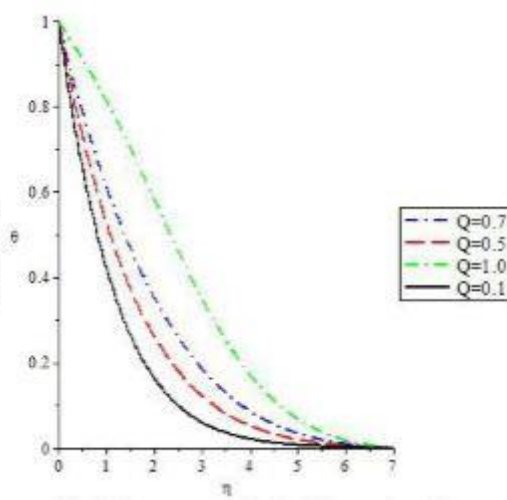


Fig. 12. Heat transfer for various (Q)

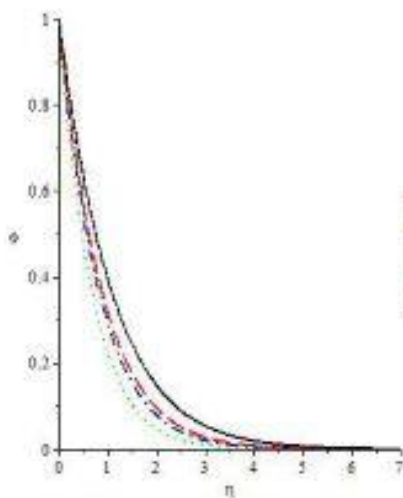


Fig. 13. Concentration profile for (λ) effect

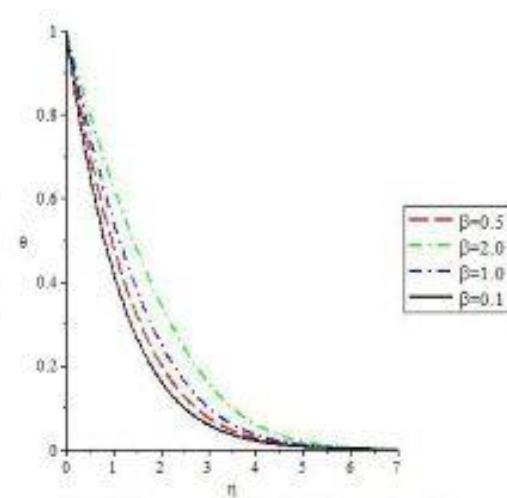


Fig. 14. Heat distribution for various (β)

4 Conclusion

From the computed outcomes, it is noticed that rising computational value of the terms M, Da, Pr and Sc slowdown fluid flowing rate that thereby creates a decreasing flowing fluid velocity distribution, while enhancing in the values of Gr, Gc, A and α cause a corresponding increase in the viscous boundary layer, as a result, the flow rate distribution upsurges. Also, it is observed from the plots that enhancing the value of the terms Q, Ec and β raises the temperature boundary viscosity film by creating an enhancing temperature distribution, while rising Pr declines the heat boundary film viscidness and influences the heat to propagate to the surroundings. This therefore decreasing the heat transport fields, meanwhile, variation in the values of Sc and λ retarded the concentration profiles due to thinner in solute boundary layer.

Competing Interests

Authors have declared that no competing interests exist.

References

- [1] Fenuga OJ, Salawu SO, Osilagun JA, Abiala IO. Effects of internal heat generation and suction/injection on a chemically reacting MHD heat and mass transfer fluid flow over a permeable surface with convective boundary conditions. *FUW Trends in Science & Technology Journal*. 2021;6(1):243-249.
- [2] Swati M, Iswar CM, Rama SRG. MHD flow and heat transfer past a porous stretching non-isothermal surface in porous medium with variable free stream temperature. *Thermal Energy and Power Engineering*. 2013;2(1):29-37.
- [3] Nalinakshi N, Dinesh PA, Chandrashekar DV. Effects of variable fluid properties and MHD on mixed convection heat transfer from a vertical heated plate embedded in a sparsely packed porous medium. *IOSR Journal of Mathematics (IOSR-JM)*. 2013;7(1):20-31.
- [4] Alireza R, Mahmood F, Seyed RV. Analytical solution for MHD stagnation point flow and heat transfer over a permeable stretching sheet with chemical reaction. *Journal of Theoretical and Applied Mechanics*. 2013;51(3):675-686.
- [5] Okedoye AM. Analytical solution of MHD free convective heat and mass transfer flow in a porous medium. *The Pacific Journal of Science and Technology*. 2013;14(2):119-128.
- [6] Reddy MG. Scaling transformation for heat and mass transfer effects on steady MHD free convection dissipative flow past an inclined porous surface. *Int. J. of Appl. Math and Mech*. 2013;9(10):1-18.
- [7] Fenuga OJ, Aroloye SJ, Salawu SO. Mathematical model and solution for an unsteady MHD fourth grade fluid flow over a vertical plate in a porous medium with magnetic field and suction/injection effects. *Journal Scientific Research*. 2020;12(4):485-498.
- [8] Eshetu H, Shankar B. Heat and mass transfer through a porous media of MHD flow of nanofluid with thermal radiation, viscous dissipation and chemical reaction effects. *American Chemical Science Journal*. 2014;4(6):828-846.
- [9] Salawu SO, Dada MS, Adebimpe O. Analysis of pressure driven heat and mass transfer of hydromagnetic flow past Darcy-Forchheimer porous media using Lie group. *Journal of Engineering and Applied Science*. 2019;14(13):4405-4413.
- [10] Reddy GVR, Ibrahim SM, Bhagavan VS. Similarity transformations of heat and mass transfer effects on steady MHD free convection dissipation fluid flow past an inclined porous surface with chemical reaction. *Journal of Naval Architecture and Marine Engineering*. 2014;11:157-166.
- [11] Sakkiadis BC. Boundary layer behaviors on continuous surface. *AIChE*. 1961;7(2):221-225.
- [12] Erikson LE, Fan LT, Fox VG. Heat and mass transfer on a moving continuous plate with suction and injection. *Ind. Eng. Chem. Fundamental*. 1966;5:19-25.
- [13] Tsou FK, Sparrow FM, Goldstien RJ. Flow and heat transfer in the boundary layer in continuous moving surface. *Int. J. Heat Mass transfer*. 1967;10:219-235.
- [14] Salawu SO, Kareem RA. Analysis of heat absorption viscoelastic exothermic chemical reactive fluid with temperature dependent viscosity under bimolecular kinetic. *Applications and Applied Mathematics: An International Journal*. 2019;14(2):1232-1242.
- [15] Mureithi EW, Mwaonangi JJ, Makinde OD. On the boundary layer flow over a moving surface in a fluid with temperature-dependent viscosity. *Open Journal of Fluid Dynamics*. 2013;3:135-140.

- [16] Kareem RA, Salawu SO. Variable viscosity and thermal conductivity effect of sores and dufour on inclined magnetic field in non-Darcy permeable medium with dissipation. *British Journal of Mathematics & Computer Science*. 2017;22(3):1-12.
- [17] Gitima P. Effect of variable viscosity and thermal conductivity of micropolar fluid in a porous channel in presence of magnetic field. *International Journal for Basic Sciences and Social Sciences*. 2012;1(3): 69-77.
- [18] Krishnendu B, Layek GC, Rama SRG. Boundary layer slip flow and heat transfer past a stretching sheet with temperature dependent viscosity. *Thermal Energy and Power Engineering*. 2013;2(1):38-43.
- [19] Dulal P, Hiranmoy M. Effects of temperature-dependent viscosity and variable thermal conductivity on MHD non-Darcy mixed convective diffusion of species over a stretching sheet. *Journal of the Egyptian Mathematical Society*. 2014;22:123-133.
- [20] Hunegnaw D, Naikoti K. MHD effects on heat transfer over stretching sheet embedded in porous medium with variable viscosity, viscous dissipation and heat source/sink. *Ain Shams Engineering Journal*. 2014;5:967-977.
- [21] Abel MS, Mahesha N. Heat transfer in MHD viscoelastic fluid flow over a stretching sheet with variable thermal conductivity, non-uniform heat source and radiation. *Applied Mathematical Modeling*. 2008;32:1965-1983.
- [22] Salawu SO. On ignition slice-chain and heat distribution of MHD reactive Oldroyd 8-constant flow in a plane Couette. *Int. Journal of Comput. Engin. and Comput. Sci*. 2020;20:1-6.
- [23] Hazarika GC, Utpal SGC. Effects of variable viscosity and thermal conductivity on MHD flow past a vertical plate. *Matematicas Ensenanza Universitaria*. 2012;XX(2):45-54.
- [24] Hunegnaw D, Kishan N. Unsteady MHD heat and mass transfer flow over stretching sheet in porous medium with variable properties considering viscous dissipation and chemical reaction. *American Chemical Science Journal*. 2014;4(6):901-917.
- [25] Mukhopadhyay S, Layek GC, Samad SA. Study of MHD boundary layer flow over a heated stretching sheet with variable viscosity. *Int. J. Heat Mass Transfer*. 2005;48:4460-4466.
- [26] Pantokratoras A. Study of MHD boundary layer flow over a heated stretching sheet with variable viscosity: A numerical reinvestigation. *Int. J. Heat Mass Transfer*. 2008;51:104-110.
- [27] Saikrishnan P, Roy S. Non-uniform slot injection (suction) into steady laminar water boundary layers over (i) a cylinder and (ii) as sphere. *Int. J Eng. Sci*. 2003;41:1351-65.
- [28] Bird RB, Stewart WE, Lightfoot EN. (). *Transport phenomena*. New York: Wiley; 1960.
- [29] Chiam TC. Heat transfer with variable conductivity in a stagnation-point flow towards a stretching sheet. *International Communications in Heat and Mass Transfer*. 1996;23(2):239-248.

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