Nigerian Journal of Engineering Science Research (NIJESR).
Vol. 6, Issue 1, pp. 47-59, March, 2023

ISSN: 2636-7114
Journal Homepage: https://www.iuokada.edu.ng/journals/nijesr/

Reactivity Effect of on Unsteady Hydromagnetic Convective Flow of Reactive Viscous Fluid with Chemical Reaction and Suction/Injection

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Manuscript History
Received: 09/03/2022
Revised: 25/02/2023
Accepted: 29/03/2023
Published: 30/03/2023

Abstract: *In this paper, reactivity effect on unsteady hydromagnetic convective flow of reactive viscous fluid with chemical reaction and suction/injection on the boundary layer control played significant role in the field of aerodynamics and space sciences is examined. The flow is considered to be transient natural convection and mass transfer flow and electrically conducting fluid between vertical parallel porous plates under the influence of a transversely magnetic field of strength. We assuming that the magnetic Reynolds number is small so that the induced magnetic field and the hall effect of MHD are negligible. The assumption resulted into a system of two-dimensional coupled equations. The model obtained is transformed into dimensionless form and approximate analytical solution obtained which was used to justified the numerical solution of the two-dimensional model. Nondimensional physical parameters that govern the flow were investigated and analysed graphically for various physical parameters embedded in the problem. It is found that chemical reactivity, suction/injection, thermal diffusion, reaction consumption, and thermal and solutal buoyancy play an important role in controlling the transport phenomena.*

Keywords: *Unsteady, Hydromagnetic, Suction, Injection, Electrically Conducting, MHD Flow, Chemical Reactivity*

INTRODUCTION

When a viscous fluid flows along a fixed wall, or past the rigid surface or an immersed body in Nano-fluid, an essential condition is that the velocity at any point on the wall or other fixed surface is zero. The extent to which this condition modifies the general character of the flow depends upon the value of the viscosity and other flow governing parameters. If the body is of streamlined shape and if the viscosity is small without being negligible, the modifying effect appears to be confined within narrow regions adjacent to the solid surfaces; these are called *boundary layers*. Within such layers the fluid velocity changes rapidly from zero to its main-stream value, and this may imply a steep gradient of shearing stress; as a consequence, not all the viscous terms in the equation of motion will be negligible, even though the viscosity, which they contain as a factor, is itself very small. A more precise criterion for the existence of a well-defined laminar boundary layer is that the Reynolds number should be large, though not so large as to imply a breakdown of the laminar flow.

Suction or injection on the boundary layer control played significant role in the field of aerodynamics and space sciences. Shojaefard *et al.* (2005) utilized suction/injection to control liquid stream on the outer layer of subsonic airplane. By controlling the stream in that capacity, fuel utilization may be diminished by 30%, an impressive decrease in poison emanation is accomplished, and working expenses of business planes are diminished by no less than 8% (Braslow, 1999). In mass exchange cooling, pull or infusion of a liquid through the bouncing surface can essentially change the stream field and, subsequently, influence the intensity move rate from the plate (Ishak *et al.*, 2008). Many interests have been implicit the investigation of stream of intensity and mass exchange with attractions or infusion in light of its broad designing applications. In the space of consistent progression of gooey incompressible liquid over endless permeable plates subject to attractions or infusion, different parts of the issue have been explored by many creators. More specifically, Griffith and Meredith (1936) explored the consistent progression of an incompressible thick liquid over an endless permeable level plate subject to uniform pull.

Jena and Mathur (1982) concentrated on free convection in the laminar limit layer stream of a thermomicropolar liquid over an upward level plate subject to uniform pull or infusion. Limit layer controls by pull or infusion in the progression of incompressible liquid over an endless permeable wedge are to be found in the examinations by Devi and Kandasamy (2002), Kandasamy *et al.* (2005), and Kandasamy *et al.* (2006). Layek *et al.* (2007), Shateyi (2008), and Cortell (2005) have dissected the extending sheet issue with attractions or infusion. Attia (2002) revealed the temperamental stream because of a turning plate with uniform pull or infusion. Al-Sanea (2004) researched blended convection heat move along a ceaselessly moving warmed vertical plate with pull or infusion. Unstable free convection and mass exchange stream over a limitless vertical permeable plate considering attractions or infusion are to be found in the concentrate by Takhar *et al.* (2003). As of late, Cortell (2011) concentrated on the impacts of pull, thick scattering, and warm radiation on stream and intensity move of a power-regulation liquid beyond a boundless permeable plate. Impact of attractions and infusion on precarious free convection Couette stream and intensity move of receptive thick liquid in vertical permeable plate is to be found in the concentrate by Jha *et al.* (2012). The examination of the progression of an electrically directing liquid in a permeable divert within the sight of a cross over attractive field is significant as a result of its broad designing and modern applications like MHD marine drive, electronic bundles, microelectronic gadgets, warm protection, petrol supplies, MHD mixing of liquid metal, exothermic response in bundled reactors, and attractive levitation projecting. Then again, Soret or warm dispersion is significant where more than one substance animal types are available under exceptionally huge temperature angles, like compound responses and isotope partition, and in combinations of gases with extremely light atomic weight like hydrogen or helium and of medium sub-atomic weight like nitrogen or air. Due to the uses of MHD and Soret, many creators examined their impacts on normal convection intensity and mass exchange stream. Postelnicu (2004) revealed the impact of attractive field on intensity and mass exchange by normal convection from vertical surfaces in permeable media considering Soret and Dufour impacts. Osalusi *et al.* (2008) decided mathematically the impacts of Soret and Dufour on intensity and mass exchange of a consistent MHD convective and slip stream because of a pivoting plate with thick dissemination and ohmic warming. As of late, Turkyilmazoglu and Pop (2012) revealed the impacts of Soret and heat source on unstable radiative MHD free convection stream from a hastily endless vertical plate. In nutshell, there have been impressive distributed works managing consistent stream with Soret and Dufour impact; some of them are crafted by Alam *et al.* (2006), Chamkha and Ben-Nakhi (2008), Tsai and Huang (2009), Tak *et al.* (2010), and Magyari and Postelnicu (2011). Consistent streams with compound response considering Soret and Dufour impact are to be found in the examinations by Mansour *et al.* (2008), Beg *et al.* (2009), El-Kabeir *et al.* (2010), and Gangadhar (2013). Shaky liquid stream issues within the sight of Soret and Dufour impacts with compound response can be found in the examinations by Bhargava *et al.* (2009) and Pal and Mondal (2011). Nandkeolyar *et al.* (2013) researched mathematically and scientifically the impact of suction/injection on unstable hydromagnetic intensity and mass exchange stream of a transmitting and synthetically receptive liquid beyond a level permeable plate with inclined wall temperature.

Mathematical examination of lightness consequences for hydromagnetic unstable course through a permeable channel considering pull and infusion is to be found in the concentrate by Makinde and Chinyoka (2013). transient magneto-hydrodynamic electroosmotic flow and heat transfer analysis in a rectangular horizontal micro channel by using perturbation technique as studied by Asibor and Asibor (2017).

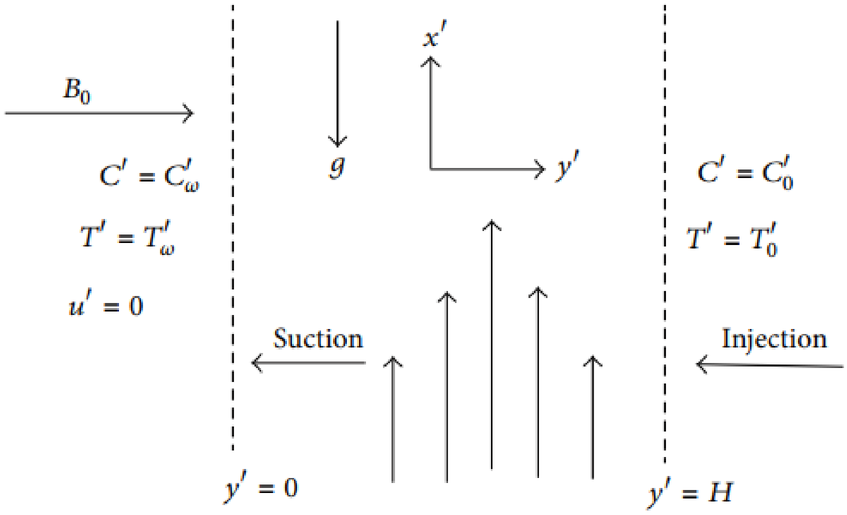

Fig. 1 Schematic diagram of the problem

Despite the contributions of the aforementioned authours, there is still a renewed interest in the understanding of reactivity effect of on unsteady hydromagnetic convective flow of reactive viscous fluid with chemical reaction and suction/injection. We therefore set out to investigate the impact of various emerging parameters on the velocity, thermal and chemical species boundary layers.

METHODOLOGY

2.1 Governing Equations

Consider the transient normal convection and mass exchange stream of thick responsive, incompressible, and electrically directing liquid between limitless vertical equal permeable plates affected by a dynamically attractive field of solidarity; see Fig. 1. The attractive Reynolds number is thought to be little with the goal that the prompted attractive field, furthermore, the corridor impact of MHD are irrelevant. At time $t_0 \leq 0$, both the liquid and the plates are at still and at a similar temperature and concentration T_0 and C_0, separately. At $t > 0$, the temperature and concentration of the plate $y = 0$ are raised to T_ω and C_ω from that point stay consistent and those of $y = H$ are brought down to T_0 and C_0, where $T_\omega > T_0$ and $C_\omega > C_0$. It is expected that the stream is exposed to pull of the liquid from one permeable plate and at a similar rate liquid is being infused through the other permeable plate. We picked a Cartesian direction framework with the x axis along the vertical bearing and the y normal to it. The actual properties are thought to be steady barring thickness in the lightness term. The liquid is thought to be Newtonian and complies with the Boussinesq's guess. Under the previous assumption, the momentum, energy and chemical species conditions in the layered structure are the following:

$$\frac{\partial u}{\partial t} - V_0 \frac{\partial u}{\partial y} = \nu \frac{\partial^2 u}{\partial y^2} + g\beta\,(T - T_0) + g\beta^*(T - T_0) + g\beta c(C - C_0) - \frac{\sigma B_0^2}{\rho} u \qquad (1)$$

(1)

$$\frac{\partial T}{\partial t} - V_0 \frac{\partial T}{\partial y} = \frac{k}{\rho Cp} \frac{\partial^2 T}{\partial y^2} + \frac{Q}{\rho Cp}(T - T_0) \qquad (2)$$

$$\frac{\partial C}{\partial t} - V_0 \frac{\partial C}{\partial y} = Dm \frac{\partial^2 C}{\partial y^2} + \frac{Dmk_T}{T_m} \frac{\partial^2 T}{\partial y^2} K(C - C_0) \qquad (3)$$

The initial and boundary conditions for the present problem are the following:

$$t \leq 0: u = 0, T \to T_0, C \to C_0, 0 \leq y \leq H,$$
$$t > 0: u = 0, T = T_\omega, C = C_\omega \text{ at } y = 0, \qquad (4)$$
$$u = 0, T = T_0, C = C_0 \text{ as } y \to H,$$

where σ is the conductivity of the liquid, $B_0$is the electromagnetic enlistment, β is the coefficient of thermal development, β^* is the coefficient of concentration expansion, Q is the heat of reaction, ν is the kinematic viscosity, C_0 is the initial concentration of the reactant species, g is the gravitational force, C_p is the specific heat at constant pressure, k is the thermal conductivity of the fluid, ρ is the density of the fluid, Dm is the coefficient of mass diffusivity, Tm is the mean fluid temperature, and k_T is the thermal diffusion ratio. In order to solve (1) to (2), we employ the following dimensionless parameters:

$$y' = \frac{y}{H}, t' = \frac{tv}{H^2}, \ u' = \frac{u}{v_0}, \ \theta = \frac{T - T_0}{T_w - T_0}, \phi = \frac{C - C_0}{C_w - C_0} \qquad (5)$$

Using (5), (1) to (3) after dropping the prime, take the following form:

$$\frac{\partial u}{\partial t} - \gamma \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gc\phi - Mu, \qquad (6)$$

$$Pr \left(\frac{\partial \theta}{\partial t} - \gamma \frac{\partial \theta}{\partial y}\right) = \frac{\partial^2 \theta}{\partial y^2} + \lambda\theta, \qquad (7)$$

$$Sc \left(\frac{\partial \phi}{\partial t} - \gamma \frac{\partial \phi}{\partial y}\right) = \frac{\partial \phi^2}{\partial y^2} + Sr\frac{\partial \theta^2}{\partial y^2} + \beta\phi. \qquad (8)$$

The initial and boundary conditions in dimensionless form are the following:

$$u = 0, \theta = 0, 0 \leq y \leq 1, t \leq 0,$$
$$t > 0: u = 0, \theta = \theta_T, \phi = \phi_T \text{ at } y = 0, \qquad (9)$$
$$u = 0, \theta = 0, \phi = 0, \text{ as } y = 1.$$

2.2 Analytical Solutions

We first derived the analytical solutions of the flow problem in other to justify our claim. The analytical solution so obtained shall them be used to inspect the internal consistency of mathematical models and of the approximations adopted by Jha *et al.* (2012).

In other to do this, we set

$$\frac{\partial u}{\partial t} = 0, \frac{\partial \theta}{\partial t} = 0, \text{ and } \frac{\partial C}{\partial t} = 0$$

into (4) to (5) and by taking $\theta_T = 1$ and $\phi_T = 1$ at the boundary, we get

$$-\gamma \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gc\phi - Mu, \qquad (10)$$

$$Pr \left(-\gamma \frac{\partial \theta}{\partial y}\right) = \frac{\partial^2 \theta}{\partial y^2} + \lambda\theta, \qquad (11)$$

$$Sc \left(-\gamma \frac{\partial \phi}{\partial y}\right) = \frac{\partial \phi^2}{\partial y^2} + Sr\frac{\partial \theta^2}{\partial y^2} + \beta\phi. \qquad (12)$$

The boundary conditions are the following:

$$u = 0, \theta = 1, \phi = 1, at\ y = 0,$$
$$u = 0, \theta = 0, \phi = 0, at\ y = 1. \qquad (13)$$

The analytical solution to (10) – (12) subject to (13) is derived by using the regular method of undetermined coefficients. From (10)-(12) subject to (13), we obtained as

$$u(y) = b_2 \exp(-r_2 y) + a_2 \exp(-r_1 y) + c_6 \exp(m_1 y)$$
$$+c_7 \exp(m_2 y) + c_8 \exp(n_1 y) + c_9 \exp(n_2 y)$$
$$\theta(y) = a \exp m_1 y + b \exp(m_2 y) \qquad (14)$$
$$\phi(y) = a_1 \exp(n_1 y) + b_1 \exp(n_2 y) - c_1 \exp(m_1 y) - c_2 \exp(m_2 y)$$

where

$$m_1 = \frac{-Pr\gamma - \sqrt{(Pr\gamma)^2 - 4\lambda}}{2}, m_2 = \frac{-Pr\gamma + \sqrt{(Pr\gamma)^2 - 4\lambda}}{2}$$

$$n_1 = -\frac{Sc\gamma - \sqrt{(Sc\gamma)^2 - 4}}{2}, n_2 = -\frac{Sc\gamma + \sqrt{(Sc\gamma)^2 - 4}}{2}$$

$$r_1 = \frac{\gamma + \sqrt{\gamma^2 + 4M}}{2}, r_2 = \frac{\gamma - \sqrt{\gamma^2 + 4M}}{2}$$

$$c_1 = \frac{aSrm_1^2}{m_1^2 + Sc\gamma m_1 + \beta}, c_2 = \frac{bSrm_2^2}{m_2^2 + Sc\gamma m_2 + \beta},$$

$$c_3 = -\gamma n_1 - n_1^2 + M, c_4 = -\gamma n_2 - n_2^2 + M$$

$$c_5 = (m_1 + r_2)(m_2 + r_2)(n_1 + r_2)(n_1 + r_2)(m_1 + r_1)(m_2 + r_1)(n_1 + r_1)(n_2 + r_2)$$
$$c_6 = -\frac{c_4^2 c_3 (c_1 Gc - aGr)}{c_5}, c_7 = \frac{c_4 c_3^2 (c_2 Gc + bGr)}{c_5}, c_8 = \frac{c_3 a_1 c_4^2 Gc}{c_5}, c_9 = \frac{b_1 c_4 c_3^2 Gc}{c_5}$$
$$a = -\frac{\exp m_2}{\exp m_1 - \exp m_2}, b = \frac{\exp m_1}{\exp m_1 - \exp m_2}$$

$$a_1 = c_1 + \frac{c_2(\exp n_2 - \exp m_2)}{\exp m_1 - \exp m_2}, b_1 = \frac{c_1(\exp n_1 - \exp m_1)}{\exp m_1 - \exp m_2}$$

Steady-state skin frictions, rate of heat transfer and rate of mass transfer on the boundary plates respectively are the following:

$$\left.\frac{\partial u}{\partial y}\right|_{y=0} = -(b_2 r_2 + a_2 r_1 + c_6 m_1 + c_7 m_2 + c_8 n_1 + c_9 n_2$$
$$\left.\frac{\partial \theta}{\partial y}\right|_{y=0} = a m_1 + b m_2. \tag{15}$$
$$\left.\frac{\partial \phi}{\partial y}\right|_{y=0} = a_1 n_1 + b_1 n_2 - c_1 m_1 - c_2 m_2$$

All the constant $a, a_1, a_2, b, b_1, b_2, c_i, i = 1..9$ are defined in the appendix section.

2.3 Numerical Solutions

The complete forms of the unsteady system of equations are solved numerically using inbuilt partial differential equation solver in Maple 2022. The pdsolve order returns a module that is utilized to process mathematical answers for time sensitive PDE frameworks over a decent limited 1-space span. It involves limited distinction techniques in getting the mathematical arrangements. We applied the method of activity that utilizes the default technique, which is a focused certain plan, we guarantee that the PDE frameworks is adequately near a standard structure. The time contention was utilized to indicates the name of the time variable for the issue, while the reach contention determines the spatial space of the issue. The upsides of the two choices are resolved consequently since the limit conditions are indicated at both end points of the space. The separating was picking little sufficient that an adequate number of focuses are in the spatial space for limit conditions, and spatial introduction. The logical arrangements got beforehand are utilized as a mind the precision and legitimacy of the mathematical arrangement. Once more, to reconfirm the precision of the plan, the mathematical outcomes for speed, concentration, and temperature are contrasted and the logical arrangements. It has been tracked down that the mathematical upsides of the speed, concentration, and temperature fields determined from the articulations (14) have coordinated very well with the mathematical got from the articulations (6)- (9) at the consistent state time. See Fig. 2-4 for the chart of the mathematical arrangements at consistent state and consistent state scientific answers for speed, focus, and temperature fields.

RESULTS AND DISCUSSION

The numerical results are obtained by solving (6)- (9) utilizing the strategy depicted in the past segment for different plusses of actual boundaries to portray the material science of the issue. The nondimensional boundaries that administer the stream are the Prandtl number (Pr), which is contrarily corresponding to the warm diffusivity of the functioning liquid, heat generation/absorption, the Soret number (Sr), the attractive boundary, the warm Grashof number (Gr), the solutal Grashof number (Gc), the nondimensional time, the Schmidt number (Sc), which is conversely relative to the mass diffusivity of the functioning liquid, and Fig. 2-3: Unstable and consistent state answers for speed, focus, and temperature profiles. suction/injection boundary, which were all the while applied each to inverse permeable plates of the channel at a similar rate. With the end goal of conversation, a few mathematical computations are completed for dimensionless speed, temperature, concentration, skin erosion, pace of intensity move as far as Nusselt number, and the pace of mass exchange as far as Sherwood number. Except if generally expressed, the qualities are utilized for the examination. Results got are shown graphically for speed, temperature, concentration, skin grating, Nusselt number, and Sherwood number for different stream boundaries.

Fig. 2-4 shows the fulfillment of consistent state front speed, temperature and substance species separately. From the Fig.s, we found that speed accomplish stream speed valueas temperature and centration achieved consistent state. Fig. (5)- (7) showed the portrayal of speed, temperature and synthetic species in 3-D structure. The structures relate to the appropriations of each field in the stream area. The impact of every boundary was shown in Fig.s (8)- (21). In Fig. 8, 9 and 10, we have introduced the reaction of the liquid speed to varieties in the Soret number (Sr) and attractive boundary within the sight of pull and infusion boundary.

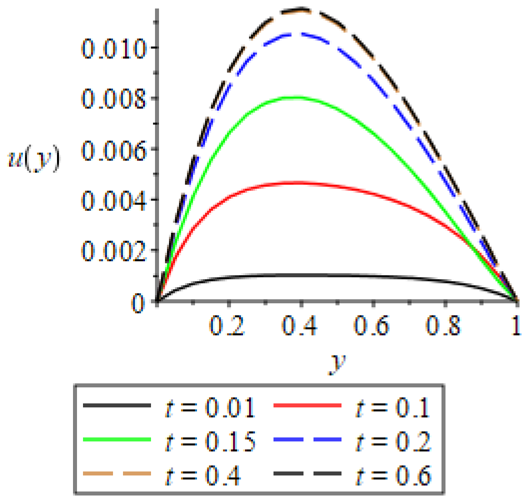

Fig. 2 Velocity distribution with respect to time

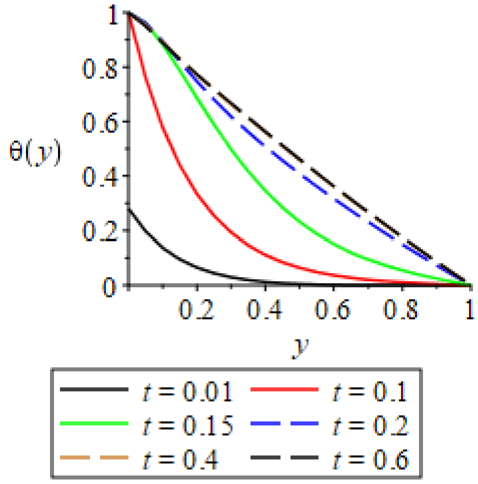

Fig. 3 Temperature distribution with respect to time

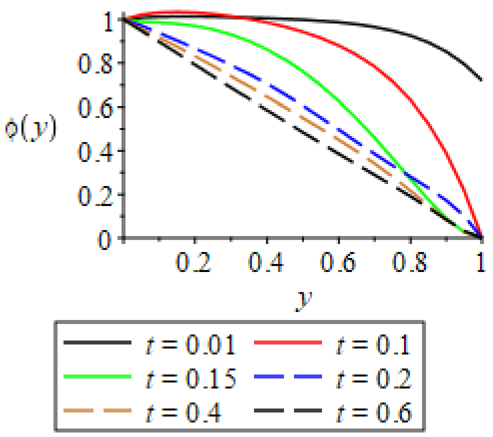

Fig. 4 Concnetration with respect to time

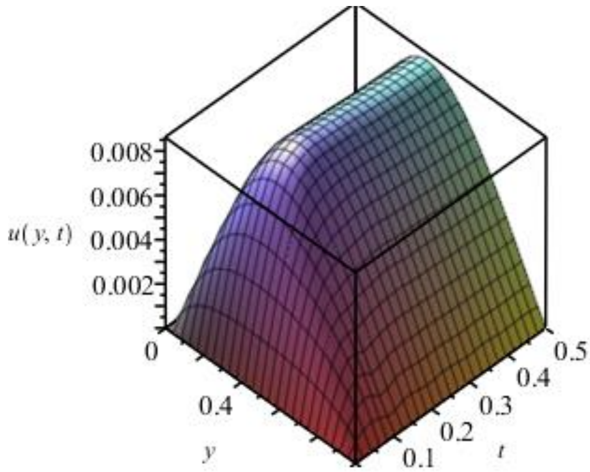

Fig. 5 Two-dimentional Velocity distribution

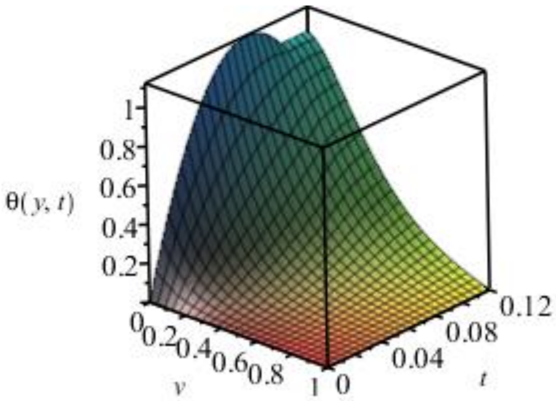

Fig. 6 Two-dimentional Temperature distribution

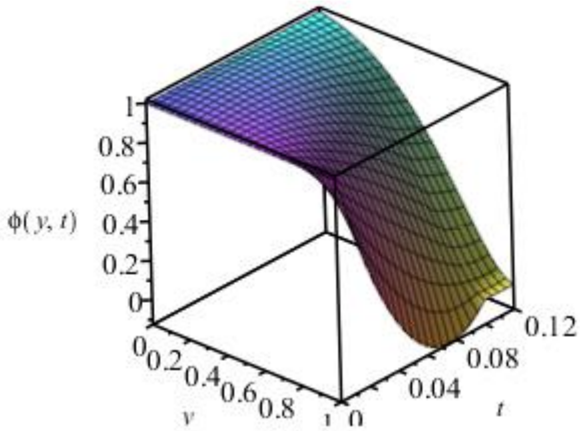

Fig. 7 Two-dimentional Concentration distribution

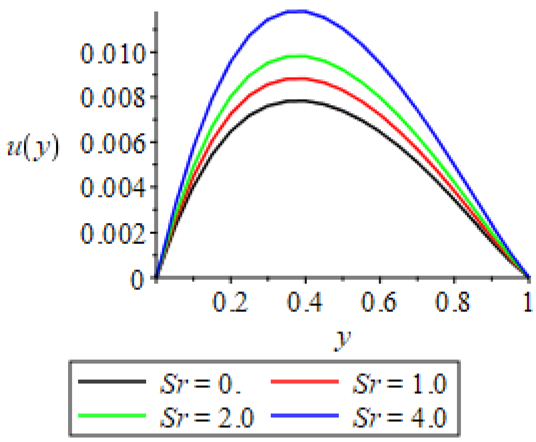

Fig. 8 Velocity Distribution with respect to Sr

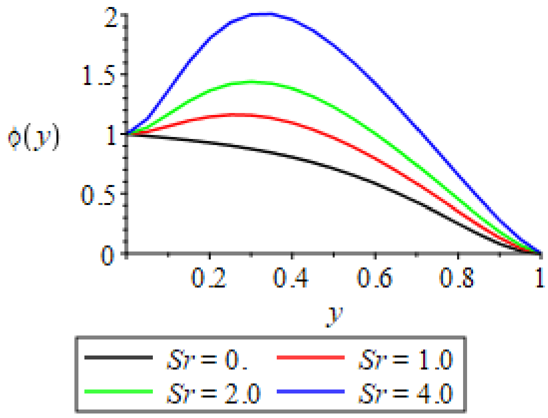

Fig. 9 Concentration field with respect to Sr

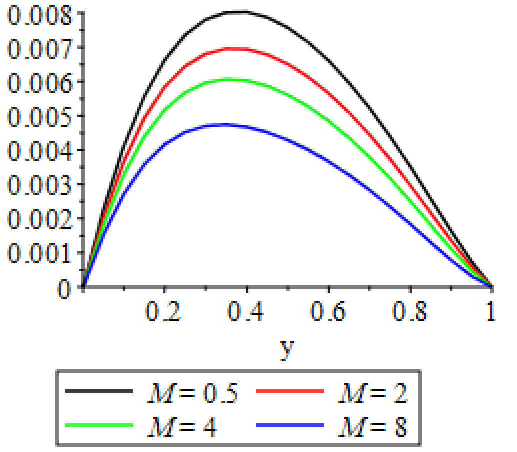

Fig. 10 Velocity Distribution with respect to M

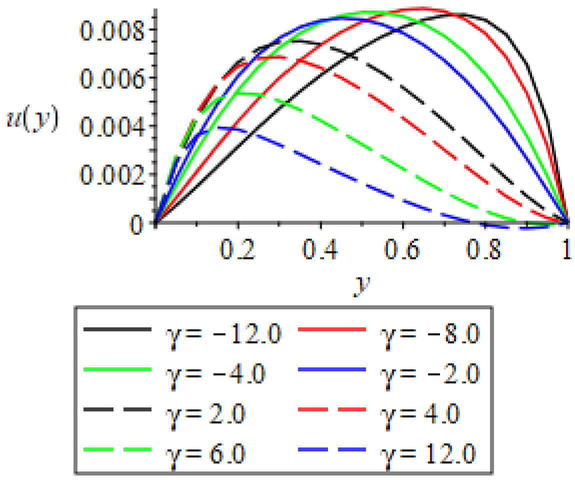

Fig. 11 Velocity Distribution with respect to γ

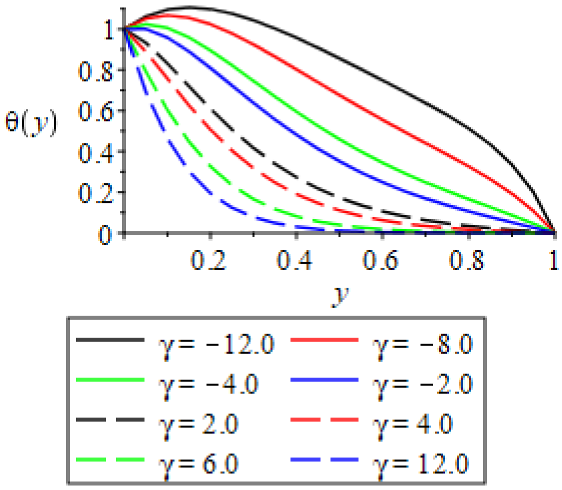

Fig. 12 Temperature distribution with respect to γ

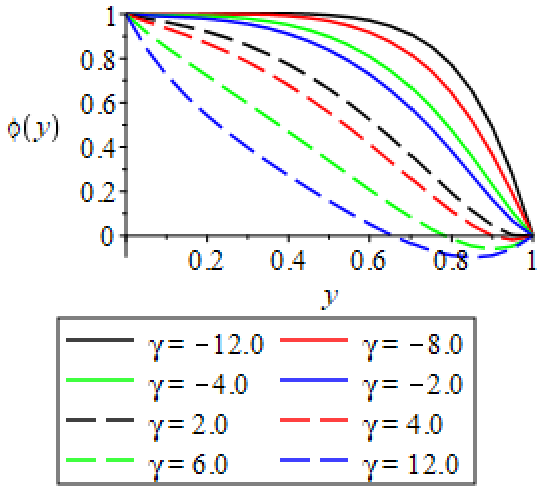

Fig. 13 Concentration field with respect to γ

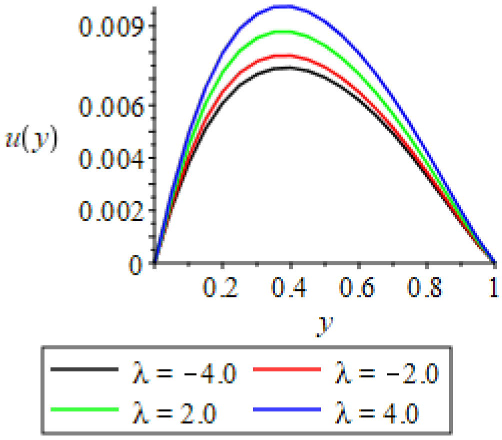

Fig. 14 Velocity Distribution with respect to λ

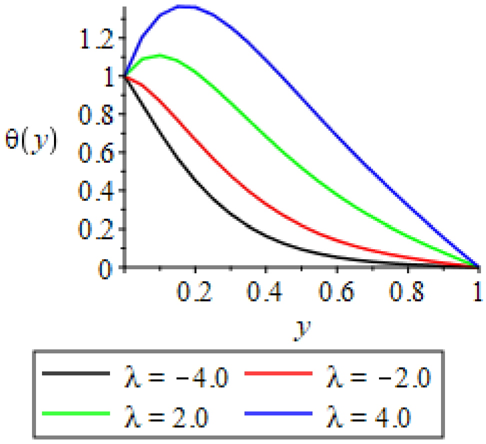

Fig. 15 Temperature distribution with respect to λ

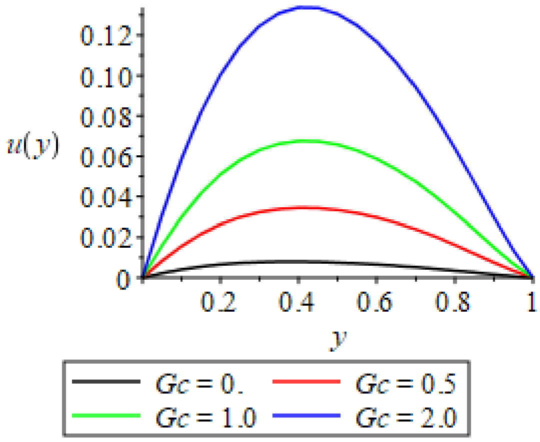

Fig. 16 Velocity Distribution with respect to Gc

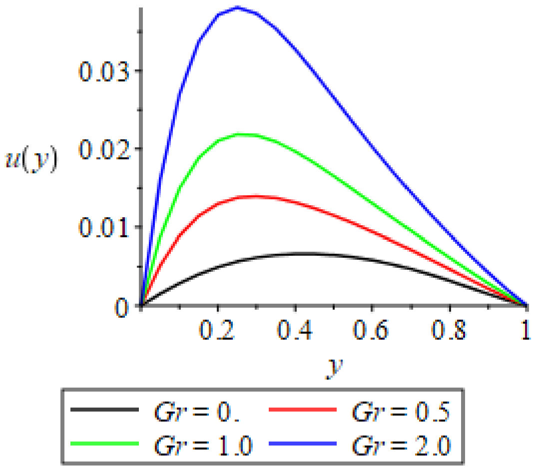

Fig. 17 Velocity Distribution with respect to Gr

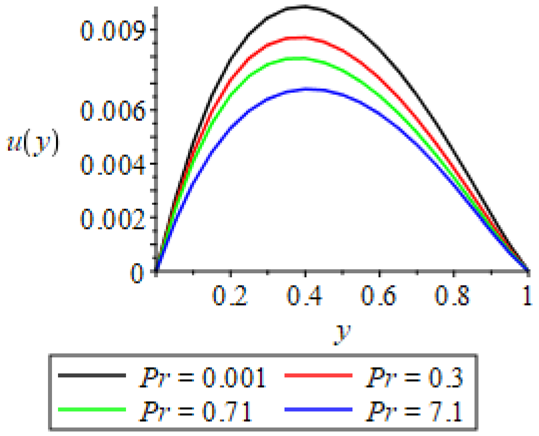

Fig. 18 Velocity Distribution with respect to Pr

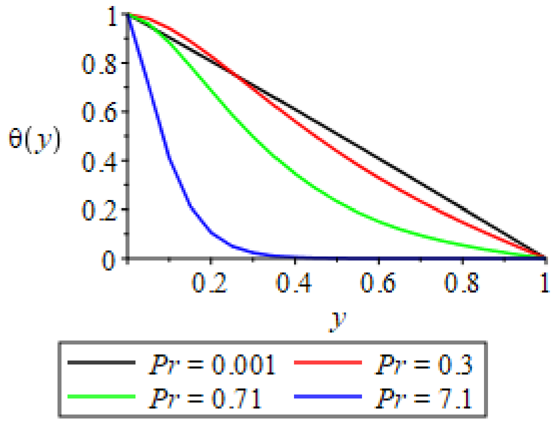

Fig. 19 Temperature distribution with respect to Pr

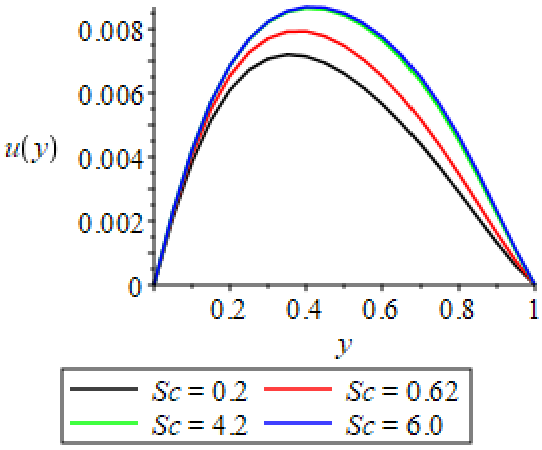

Fig. 20 Velocity Distribution with respect to Sc

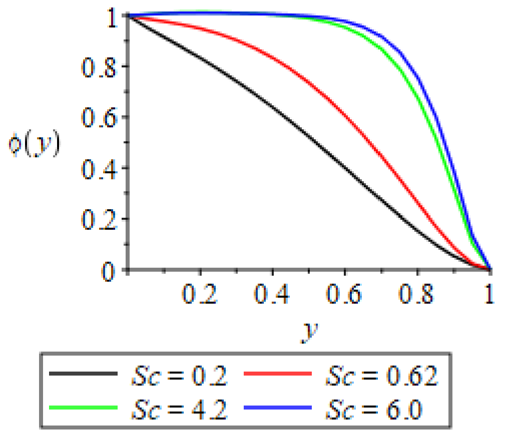

Fig. 21 Concentration field with respect to Sc

Fig. 8 and 9 shows the impact of the Soret number on the speed and focus with steady pull and infusion. From this Fig., it is noticed that Soret number speeds up the liquid speed within the sight of pull and infusion. In Fig. 8, it is seen that, within the sight of attractions, the speed of the liquid pushes toward the left permeable plate and in the event of infusion the greatest speeds move towards the right permeable plate. Fig. 10 uncovered that rising the strength of attractive boundary is to diminish speed profiles. This is because of the way that cross over attractive field delivers a resistivity force (Lorentz force) like the drag force which impedes the speed. It is seen that the speed of the liquid is more noteworthy in the event of infusion than attractions. Fig. 11-13 shows the impact of suction/injection on speed, temperature and focus fields individually. From these infusion builds speed, temperature and concentration dispersion while, attractions repress the advancement of speed temperature and focus fields. This is genuinely obvious since an expansion in prompts critical expansions in the response and thick source terms and thus essentially builds the liquid temperature. It is obvious from Fig.11 that temperature of the liquid is more noteworthy in the event of infusion than pull. Fig.12 addresses the impact of suction/injection boundary on the temperature field. From Fig.12, it is seen that temperature diminishes because of attractions yet builds because of infusion. In the event of pull, the liquid at encompassing circumstances is carried nearer to the surface and lessens the warm limit layer thickness. A similar guideline works yet in switch heading if there should be an occurrence of infusion.

Fig.s 14 and 15 delineated the impacts of the reactivity boundary on speed and temperature appropriations, individually. The two Fig.s uncovered that expanding speeds up the speed of the liquid in the event of pull and infusion. It is obvious from this Fig. that the speed is higher in the event of infusion than attractions.

From Fig.15, it is seen that temperature of the liquid decelerates because of attractions while it advances rapidly because of blowing. The actual clarification for such a way of behaving is that while more grounded blowing is given, the warmed liquid is pushed farther from the wall where the lightness powers can act to speed up the stream with less impact of the thickness. This impact acts to build the shear by expanding the greatest speed inside the limit layer. A similar standard works however in switch heading if there should be an occurrence of pull. It is likewise seen that, in the event of pull, speed of the liquid creates some distance from the channel centerline towards the plate and, if there should arise an occurrence of infusion, the greatest speeds are moved towards the right permeable plate. The impact of the warm Grashof number (Gr) and solutal Grashof number (Gc) is shown in Fig.s (16) and (17), separately. These plots of Fig.s show that the energy limit layer thickness increments with expanding upsides of Gr and Gc. It is additionally seen from these Fig.s that speed of the liquid is more prominent in the event of infusion than pull. The wall shear pressure reliance on response boundary is represented in Fig. 8 for changing upsides of the nondimensional time when pull and infusion happen. Fig.s 18 - 21 address the effect of Prandtl and Schmidt number on speed and focus individually. From the Fig.s, it is noticed speed and temperature limit layer diminishes as Prandtl number increments while the limit layers increment with expansion in Schmidt number. In Fig.s 22 and 23, we show the impact of intensity synthetic reactivity boundary on speed and focus. The Fig.s uncovered that speed and focus increment with expansion in for the instance of generative compound response while speed and concentration decline with expansion in for the instance of damaging synthetic response.

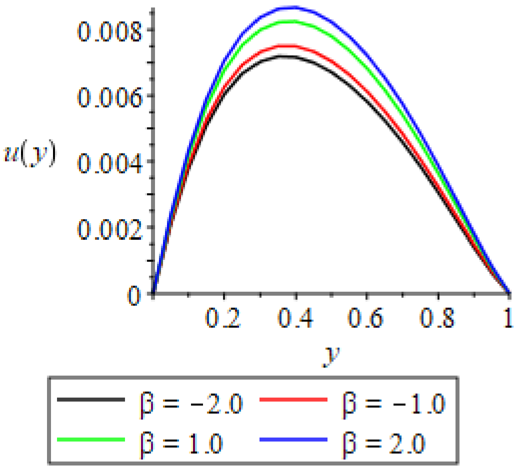

Fig. 22 Velocity Distribution with respect to β

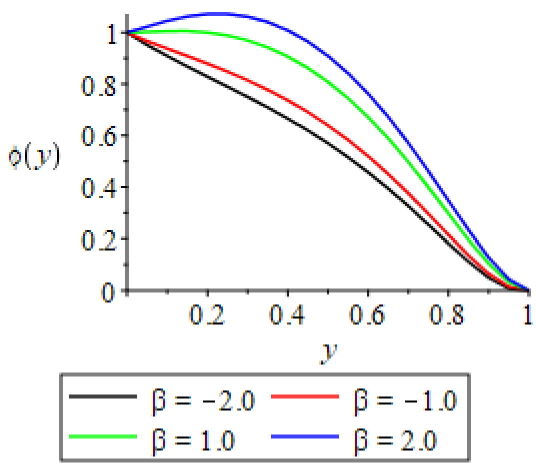

Fig. 23 Concentration field with respect to β

The presence of consistent state scientific arrangement ensures the presence of answer for non-consistent case and the achievement of consistent state with the stream area could be utilized to give farther data into the progression of suction/injection Impact of on flimsy hydromagnetic convective progression of receptive gooey liquid with synthetic response.

CONCLUSION

In the current work reactivity effect on unsteady hydromagnetic convective flow of reactive viscous fluid with chemical reaction and suction/injection on the boundary layer control played significant role in the field of aerodynamics and space sciences is examined. It is tracked down that synthetic reactivity, suction/injection, warm dissemination, response utilization, and warm and solutal lightness assume a significant part in controlling the vehicle peculiarities. Development of the base stream happens close to the wall where pull happens, while the greatest stream structures close to the wall where infusion happens besides in the focus circulation for differing upsides of warm dissemination.

It is found that chemical reactivity, suction/injection, thermal diffusion, reaction consumption, and thermal and solutal buoyancy play an important role in controlling the transport phenomena. It is hoped that this present work may be useful in engineering application where the formation of boundary layers will be enhanced.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGEMENT

The management of Igbinedion University, Okada is appreciated and thanked by the writers for providing conducive environment and research facilities. We also appreciate the unnamed referees' helpful comments, which helped to improve the final product.

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