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ENHANCED HEAT AND MASS TRANSFER IN AN OSCILLATORY FLOW SYSTEM: INVESTIGATING THE EFFECT OF THERMAL RADIATION

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ABSTRACT: *Within the context of a magnetic field and chemical reaction, this article investigates the impact of thermal radiation on the MHD Heat and Mass transfer of an oscillatory flow through a vertical plate that is embedded with porous material. Regular perturbation techniques are used to solve the nonlinear partial differential equations driving the heat and mass transfer processes. The momentum, energy, and concentration equations were derived from this linear transformation. The investigation and visual representation of the consequences of various pertinent flow-encased properties were undertaken. Researchers have found that increasing the thermal radiation parameters causes the fluid velocity to rise, but increasing the magnetic field parameter, Schmidt number, and Prandtl number causes the velocity profile to fall. Increasing the chemical reaction parameter also causes the concentration to climb. In addition, a thorough validation was carried out between the current work and the previous literature.*

KEYWORDS: Mass transfer, oscillatory flow, chemical reaction, porous medium and thermal radiation.

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INTRODUCTION

When a surface is heated to a certain point, it releases electromagnetic radiation in a spherical pattern; this radiation then travels to its destination at the speed of light, independent of any medium that could slow it down. This process is known as thermal radiation. Surfaces that emit electromagnetic waves carrying thermal energy are said to be releasing "thermal radiation" in this context. To achieve high temperatures, thermal radiation must be applied. At extremely high temperatures, thermal radiation plays a major role in a variety of technical activities, including the re-entry of missiles and spacecraft. A lot of researchers are curious about the convective flow of hydromagnetic nano-fluids and how various combinations and geometries of radiation affect them. An example of a transfer of energy based on radiation is the process by which the Sun warms the Earth. An additional illustration would be the practice of heating a room with an open-hearth fireplace. Things in the room retain most of the heat from sources like flames, coals, and hot bricks, while the air around them absorbs very little. The majority of the displaced air that is heated in a fireplace does not connect back into the room; instead, it ascends the chimney along with the smoke and other combustion by-products. Considering the findings of the study by Reddy and Sademaki (2022). Many activities in industry and the natural world include radiation flows. For instance, solar power technologies, re-entry of spacecraft, evaporation from huge open water reservoirs, astrophysical flows, heating and cooling chambers, and energy processes including the combustion of fossil fuels. Based on research conducted by Vijaya *et.al* (2013). Regular perturbation allowed them to derive analytical solutions for the stream function's velocities, pressure gradients, and pressure rises. The extraction of crude oil from petroleum products is one of several engineering and industrial applications of the study of non-Newtonian fluids. In contrast to most fluid models, which utilise convected derivatives, the simpler linear model of a Jeffrey fluid uses time derivatives. This makes it a non-Newtonian fluid.

The potential uses of free convective heat and mass transfer flow in various technological and scientific contexts have piqued the interest of numerous researchers in recent years. These include transportation cooling of re-entry vehicles and rocket boosters, cross-hatching on ablative surfaces, and film vaporization in combustion chambers Suresh*et et al*. (2019). Numerous researchers have taken an interest in magneto-hydrodynamics, mass and heat transfer with radiation and diffusion, because of the wide range of possible applications. Research into solar and star structures, radio waves as they travel through the ionosphere, and other related topics are some of its many uses in geophysics and astrophysics. A few examples of its engineering uses include multi-helical gearboxes (MHD) and bearings (MHD). Chemical reaction-related combined heat and mass transport issues have garnered a lot of research interest as of late due to their prevalence in various processes. Heat and mass transfer happen simultaneously in processes including drying, surface evaporation, energy transfer in wet cooling towers, and movement in desert coolers. There are a lot of sectors that may benefit from this type of movement. Electricity can be produced, for instance, in the power sector in part by the use of a conducting fluid in motion. The importance of understanding how radiation affects MHD flow and heat transfer problems in industry has grown. The radiation effect can become substantially more pronounced at elevated operating temperatures. Because of the prevalence of high-temperature processes in engineering, understanding radiation heat transfer is crucial for developing appropriate machinery. Such fields of engineering include nuclear power stations, gas turbines, and the numerous propulsion systems used by spacecraft, missiles, satellites, and aircraft Srihari. *et al*. (2017).

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Chemical reactions between masses and fluids in motion do occur in many chemical engineering processes. Polymer manufacture, ceramics and glassware making, and food processing are just a few of the many industrial applications of these technologies. Considering that, there has been a lot of focus in recent years on the integration of mass and heat transfer issues with chemical reactions, which are crucial in many processes. Heat and mass transfer happen simultaneously in processes including drying, surface evaporation of water, energy transfer in a wet cooling tower, and movement in a desert cooler. There are a lot of sectors that may benefit from this type of movement. A technique that is used in the power industry to generate electricity involves drawing electrical energy directly from a conducting fluid that is in motion Ramaiah *et al*. (2016). There has been a lot of focus and interest in recent years in studying first-order chemical reactions with simultaneous heat and mass transport. Evaporation on water surfaces, heat and mass transfer, energy transfer in a wet cooling tower, and desert cooler flow are just a few examples of the many processes that can happen at the same time. The power business is just one of several that makes use of this flow type; one way to generate electricity is to draw current directly from a moving conducting fluid.

There are significant industrial and technological reasons why the impact of thermal radiation flow on mass and heat transfer hydromagnetic flow problems is important to consider. Foils, plastic sheets, missiles, planes, gas engines, spaceships, nuclear power stations, and satellites can all be made using thermal radiation. Many writers have taken heat radiation into account when solving their problems due to its practicality. Khan and Mustafa (2018) used a numerical solution to study the impact of non-linear radiation on MHD flow. Hosseinzadeh *et al*. (2019) used the Runde-Kutta method to show how radiation affects MHD flow. The effect of thermal radiation on magnetohydrodynamic flow in the presence of convective boundary conditions was studied by Yasin *et al*. (2019). In the presence of a convective surface boundary condition, Jha and Samaila (2020) have shown how radiative heat flux affects boundary layer flow. Unsteady magnetohydrodynamic free convective rotating flow over an exponentially accelerated inclined plate immersed in a saturated porous medium was investigated by Veera Krishna *et al*. (2020) in relation to the Hall and ion slip effects, taking into account the effects of concentration, variable temperature, and angle of inclination. Heat transfer in a stagnation-point hybrid nano-liquid flow via a permeable cylinder was investigated by Ramesh *et al*. (2020). As a result of dissipative flows of weakly conducting fluids passing over a sliding Riga plate, Wakif *et al*. (2020) studied thermo-magneto-hydrodynamic irreversibilities. Research by Bhowmik *et al*. (2019) examined the effects of natural convection heat transport on a horizontal cylinder during transients. Unsteady mixed convective heat and mass transfer flow across vertical porous media with chemical reactions, as studies were subjected to thermal diffusion, also known as the Soret effect. However, in the presence of thermal radiation, Reddy (2019) addressed the impact of chemical reactions on transient MHD flow involving mass transfer via an impulsively fixed infinite vertical plate. In the presence of thermal radiation and chemical reactions, the impact of force buoyancy and magnetohydrodynamics on convective mass and heat transfer flows via a contacting vertical porous plate. A system of self-similar equations is derived from the governing partial differential equations by the use of similarity transformations. The shooting technique and the 4th-order Runge-Kutta method are used numerically to solve the resulting equations. Suresh *et al*. (2019) discuss the results for the following variables: speed, temperature, concentration, Nusselt number, Sherwood number, and skin friction. The effects of several flow parameters, such as the Grashof number, Hartmann number, slip parameter, porosity parameter, radiation parameter, and oscillation frequency, are carried out. In the presence of a heat source or sink, and subjected to an applied

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transverse magnetic field, the effects of radiation and chemical reactions on unsteady maximum-pressure-hydraulic-dynamic (MHD) flow over a vertically-accelerated porous plate exhibit both temperature and mass diffusion variables. In this analysis, the dimensionless governing equations are solved by applying the closed analytical approach. Using graphs and other physical data, Srihari and Jaya (2017) study the velocities, temperatures, concentrations, skin friction, heat transfer rates, and mass transfer rates. Pattnaik *et al*. (2017) investigated the unsteady maximum heat-and-mass-transfer (MHDT) across a variable-concentration, exponentially-accelerated inclined plate. The impact of chemical reactions and radiation absorption on the unstable multi-layer hydrodynamic free convection flow past a semi-infinite vertical permeable moving plate with a heat source and suction was precisely solved by Ibrahim *et al.* (2017).

Chemical reaction effects on multi-phase heat transfer (MHFT) were investigated by Agarwalla et al. (2018) in the content of porous media, an inclined plate, thermal radiation, a heat source and a variable plate velocity embedded in a porous medium. Also, in a chemically reactive porous medium, Al-zubi (2018) studied the heat and mass transfer (MHD) of a periodic flow across a permeable vertical plate.

Mathematical Formulation of the Problem

Consider the unsteady one-dimensional free convection flow and viscous incompressible fluid past through a vertical porous channel placed at a distance h apart in the presence of thermo-diffusion and diffusion-thermo conditions. In a Cartesian coordinate system, the x-axis is taken along the plates and the y-axis is taken normal to it. Since the plates are considered infinite in y' –direction, then all flow quantities become self-similar. Therefore, all the physical variables become a function of t' and y' only. Initially, both the plates and fluid are at stationary conditions with the constant temperature T_0 and concentration C_0. At a time $t' > 0$ the temperature and concentration of the wall y' = 0 increase or decrease to T_w and C_w, respectively while the wall y' = h is maintained at T_0 and C_0. (fig 1)

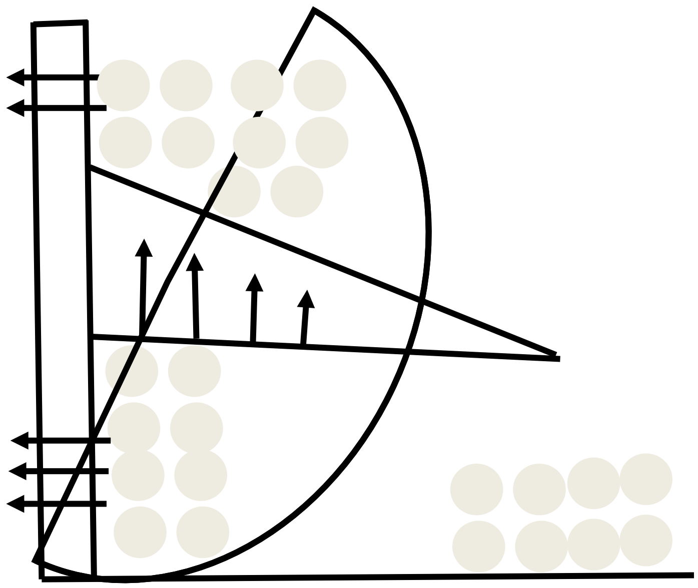

Figure 1: Sketch of the flow system

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The governing partial differential equation in dimensional form can be written as:

Momentum equation

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = v\frac{\partial^2 u'}{\partial y'^2} + v_r\frac{\partial^2 u'}{\partial y'^2} + g\beta_T(T - T_\infty)$$
$$+ g\beta_c(C - C_\infty) - \frac{\sigma B_0^2}{\rho}u' - \frac{v}{K'}u' - \frac{v_r}{K'}u' \qquad (1)$$

Energy equation

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \alpha\frac{\partial^2 T'}{\partial y'^2}\frac{1}{\rho c_p}\frac{dq_r}{dy'} \qquad (2)$$

Mass concentration/ Diffusion equation

$$\frac{\partial C'}{\partial t'} + v\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C}{\partial y'^2} + \gamma'(C - C_\infty) \qquad (3)$$

The relevant boundary conditions are:

$$\left.\begin{array}{ll} u' = u'_p, T = T_\infty + \varepsilon(T_w - T_\infty)e^{n't'}, C = C_\infty + \varepsilon(C_w - C_\infty)e^{n't'} & at\ y' = 0 \\ u' \to 0, \quad T \to T_\infty, \quad C \to C_\infty, & as\ y' \to \infty \end{array}\right\} \qquad (4)$$

It is convenient to introduce the following dimensionless quantities:

$$u = \frac{u'}{U_0},\ t = \frac{t'V_0^2}{v},\ \theta = \frac{T - T_\infty}{(T_w - T_\infty)},\ \phi = \frac{C - C_\infty}{(C_w - C_\infty)}, v = \frac{v'}{V_0},$$
$$G\mathrm{r} = \frac{vg\beta_T(T_w - T_\infty)}{U_0V_0^2}, Gm = \frac{vg\beta_T(C_w - C_\infty)}{U_0V_0^2}, y = \frac{V_0}{v'}y', Sc = \frac{v}{D},$$
$$M = \frac{\sigma\beta_0^2 v}{\rho V_0^2}, \beta = \frac{v_r}{v}, \lambda = \frac{KV_0^2}{v^2}, n' = \frac{V_0^2}{v}n, \mathrm{Pr} = \frac{v}{\alpha}\gamma_1 = \frac{v\gamma_1}{V_0^2},$$
$$u_p' = U_0U_p, R = \frac{4\sigma^* T_\infty^{*3}}{\mathrm{K}^* k} \qquad (5)$$

Inserting equation (5) into (1-3), we have the following dimensionless equations:

$$\frac{\partial u}{\partial t'} - \frac{\partial u}{\partial y} = (1 + \beta)\frac{\partial^2 u}{\partial y^2} + G_r\theta + G\phi_m - Mu - \frac{1+\beta}{\lambda}u \qquad (6)$$

$$\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial y} = \frac{1}{\mathrm{Pr}}\frac{\partial^2 \theta}{\partial y^2}(1 + R) \qquad (7)$$

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$$\frac{\partial \phi}{\partial t}-\frac{\partial \phi}{\partial y}=\frac{1}{S_c}\frac{\partial^2 \phi}{\partial y^2}+\gamma\phi \quad (8)$$

The relevant boundary conditions now become:

$$\left.\begin{array}{ll} u=U_p, \theta=\varepsilon e^{nt}, \phi=\varepsilon e^{nt} & as\ y=0 \\ u\to 0,\ \theta\to 0,\quad \phi\to 0, & as\ y\to\infty \end{array}\right\} \quad (9)$$

Method of Solution

To find the analytical solutions of the above system of partial differential equations (6), (7), and (8) subject to the boundary conditions (9) in the neighbourhood of the plate, we assume a regular perturbation method of the form.

$$U(y,t)=u_0(y)+\sum e^{nt}u_1(y)+o(\varepsilon^2) \quad (10)$$

$$\theta(y,t)=\theta_0(y)+\sum e^{nt}\theta_1(y)+o(\varepsilon^2) \quad (11)$$

$$\phi(y,t)=\phi_0(y)+\sum e^{nt}\phi_1(y)+o(\varepsilon^2) \quad (12)$$

Substituting (10-12) into equation (6-8) and neglecting the coefficient of higher order terms $o(\varepsilon^2)$, we obtain the following set of equations

$$u_0=C_1e^{h_3y}+C_2e^{-h_4y}+A_1+A_2e^{-Qy}+A_3e^{h_1y}+A_4e^{-h_2y} \quad (13)$$

$$u_1=C_3e^{h_5y}+C_4e^{-h_6y}+A_5e^{s_1y}+A_6e^{-s_2y}+A_7e^{s_3y}+A_8e^{-s_4y} \quad (14)$$

$$\theta_0=B_1+B_2e^{-Qy} \quad (15)$$

$$\theta_1=B_3e^{h_7y}+B4e^{-h_8y} \quad (16)$$

$$\phi_0=B_5e^{h_9y}+B_6e^{-h_{10}y} \quad (17)$$

$$\phi_1=B_7e^{h_{11}y}+B_8e^{-h_{12}y} \quad (18)$$

Substituting (13-18) into (10-12) we have

$$U(y,t)=C_1e^{h3y}+C_2e^{-h4y}+A_1+A_2e^{-Qy}+A_3e^{h1y}+A_4e^{-h2y}+ \\ \varepsilon e^{nt}(C_3e^{h5y}+C_4e^{-h6y}+A_5e^{S_1y}+A_6e^{-S_2y}+A_7e^{S_3y}+A_8e^{-S_4y}) \quad (19)$$

$$\phi(y,t)=B_5e^{h_9y}+B_6e^{-h_{10}y}+\varepsilon e^{nt}(B_7e^{h_{11}y}+B_8e^{-h_{12}y}) \quad (20)$$

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$$\theta(y,t) = B_1 + B_2 e^{-Qy} + \varepsilon e^{nt}(B_3 e^{h7y} + B_4 e^{-h8y}) \tag{21}$$

The physical quantities of engineering interest are also calculated such as Sharwood number, nusselt number and skin friction

$$sh = \left.\frac{d\phi}{dy}\right|_{y=0} = h_9 B_5 - h_{10} B_6 + \varepsilon e^{nt}(h_{11} B_7 - h_{12} B_8) \tag{22}$$

$$Nu = \left.\frac{d\theta}{dy}\right|_{y=0} = -QB_2 + \varepsilon e^{nt}(h_7 B_3 - h_8 B_4) \tag{23}$$

$$sk = \left.\frac{du}{dy}\right|_{y=0} = h_3 C_1 - h_4 C_2 - QA_2 + h_1 A_3 - h_2 A_4 + \varepsilon e^{nt}(h_5 C_3 - h_6 C_4 + S_1 A_5 - S_2 A_6 + S_3 A_7) \tag{24}$$

RESULTS AND DISCUSSION

The problem of mass and heat transfer of an oscillatory flow over a vertical permeable plate in a porous medium with chemical reactions was studied and an analytical solution was found for it. The analytical solutions are assessed numerically for the different issue parameters. Numerical computations using various values of physical parameters, such as the magnetic parameter, thermal Grashof number, permeability parameter, Solutal Grashof number, Prandtl number, Schmidt number, thermal radiation and chemical reaction parameter, for non-dimensional temperature, velocity, and concentration. Unless otherwise stated the following default values are taken below

$$\lambda = 2, Gr = 2.0, Gm = 1.0, \beta = 1.0, M = 4.0, \eta = 1.0, Sc = 2.0,$$
$$\gamma = 0.2, n = 0.1, \varepsilon = 0.01, t = 1.0, Rd = 0.1$$

Figure 2 and **Figure 3** depicted the validation between the present work and the work of Al Zubi (2018) for both temperature and velocity profiles, an excellent agreement was established.

Figure 4. Elucidates the effect of Prandtl number (Pr) for temperature profile. Prandtl number characterizes the ratio of thickness of viscous and thermal boundary layers. It is clearly seen from these figures that, an increase in Prandtl number causes the temperature profile to decrease. Plotting the temperature profiles against various thermal radiation (Rd) values is shown in **Figure 5**. It is evident that when thermal radiation (Rd) rises, the flow field's temperature surge consequently leads to an increase in fluid temperature. The unsteady temperature distribution is seen in **Figure 6**. It is evident that the temperature rises with increasing time.

The behaviour of concentration for various values of the chemical reaction parameter is portrayed in **Figure 7** Chemical reaction improves concentration transfer and thus speeds up the flow consequently leading to an increase in concentration profile. The concentration distribution for various Schmidt number Sc values is displayed in **Figure 8.** As the Schmidt number rises, the concentration falls. Resulting in a decrease in the concentration profile. The

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distribution of unsteady concentration is depicted in **Figure 9.** It is evident that as time passes, both fluid's concentrations rise. The concentration profile rises to its maximum near the surface and then falls until it reaches an asymptotic value. It is noticeable the identical effects with that of concentration in varying dimensional time (t) in the velocity domain. Velocity is seen in **Figure 10**.

The velocity distribution for various values of the magnetic field parameter M is shown in **Figure 11**. It is evident that when the magnetic field parameter falls, the velocity distribution increases. This is so because a flow-resistive force is created when a magnetic field is applied. The implication of thermal radiation is shown in **Figure 12**. It is evident that when thermal radiation (Rd) rises, the flow field's temperature surge consequently leads to an increase in fluid temperature, however, the fluid temperature indirectly enters the velocity profile through temperature therefore effect of thermal radiation in the velocity profile is identical with that of temperature.

Figure 13 elucidates the role of skin friction against time, clearly, it can be seen that as time radiation increases, the skin friction also increases at lower plate y=0 while no existence of skin friction at upper plate y approaches infinity. The role of frictional force is established in **Figure 14** it can be seen from this figure that as seen that as magnetic parameter increases there is a persistent spike in skin friction which tends to increase in frictional force within the wall of y=0. **Figure 15** portrayed the role of radiation on the rate of heat transfer, it was revealed that an increase in the ratio parameter tends to increase in Nusselt number at the lower plate. **Figure 16** demonstrates the consequences of thermal radiation against dimensional time (t), it was clearly seen that the rate of heat transfer increases with an increase in time (t.)

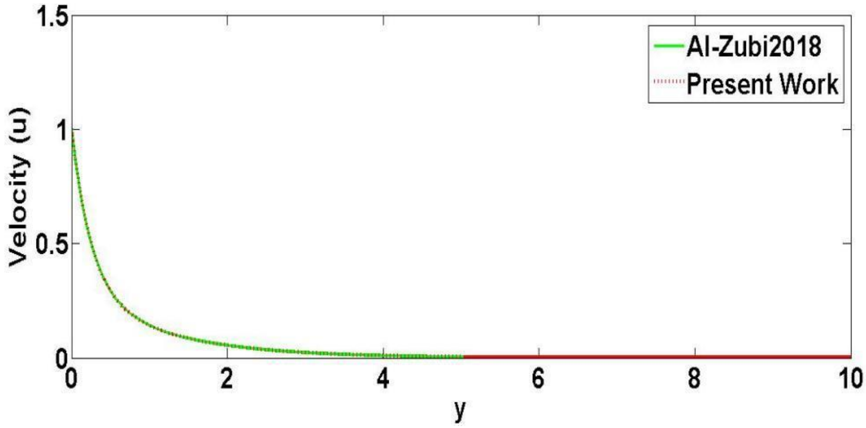

Figure 2: Comparison of Al Zubi (2018) with the present work for velocity gradient

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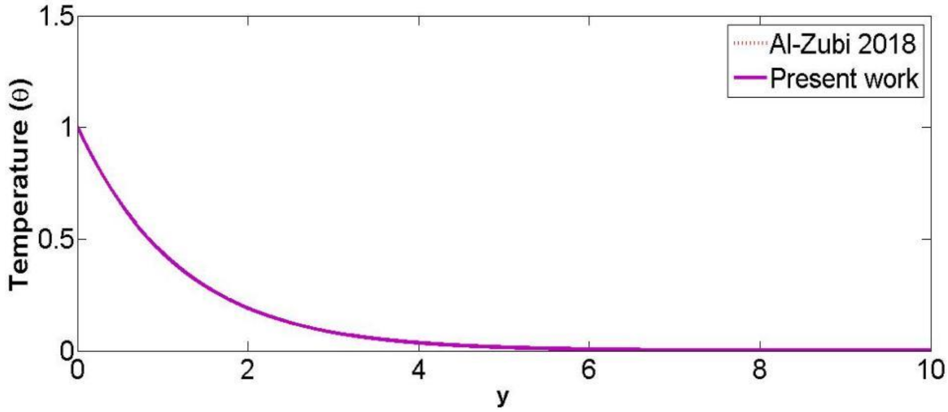

Figure 3: Comparison of Al Zubi (2018) with the present work for for temperature distribution

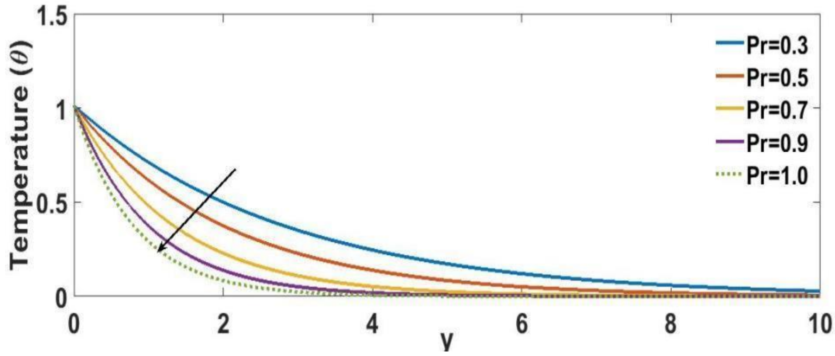

Figure 4: Temperature profile for different values of Pr

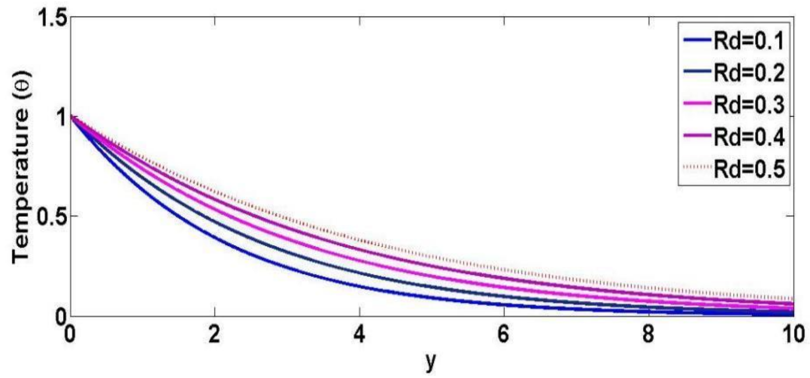

Figure 5: Temperature profile for different values of Rd

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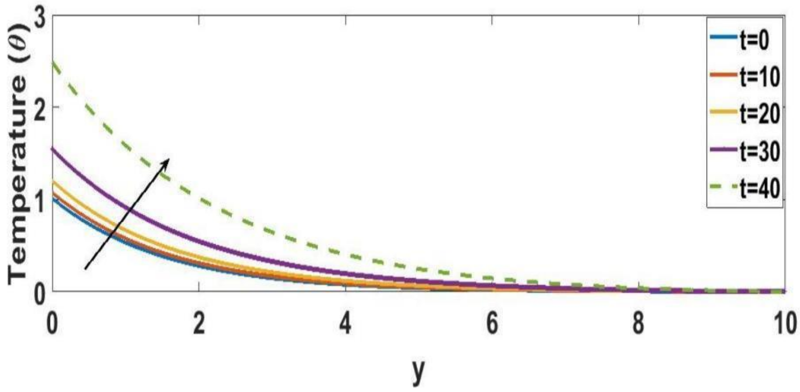

Figure 6: Temperature profile for different values of time

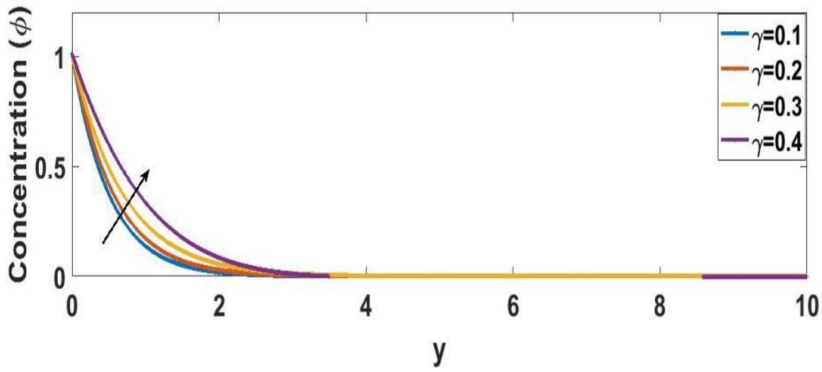

Figure 7: Concentration profile for different values of chemical reaction γ

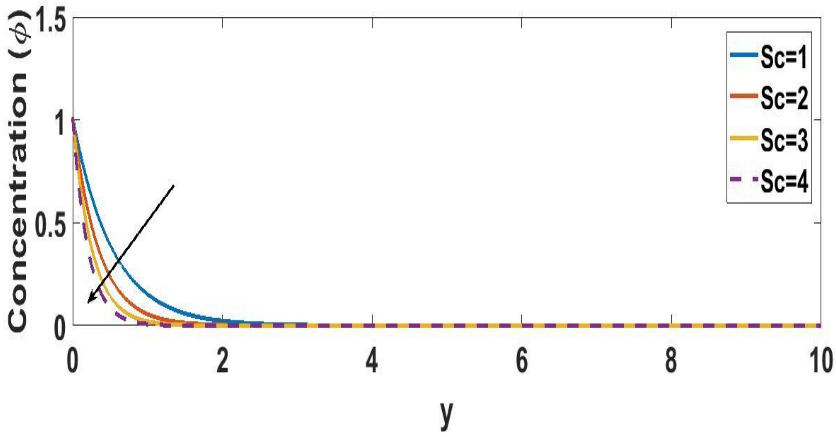

Figure 8: Concentration profile for different values of Sc

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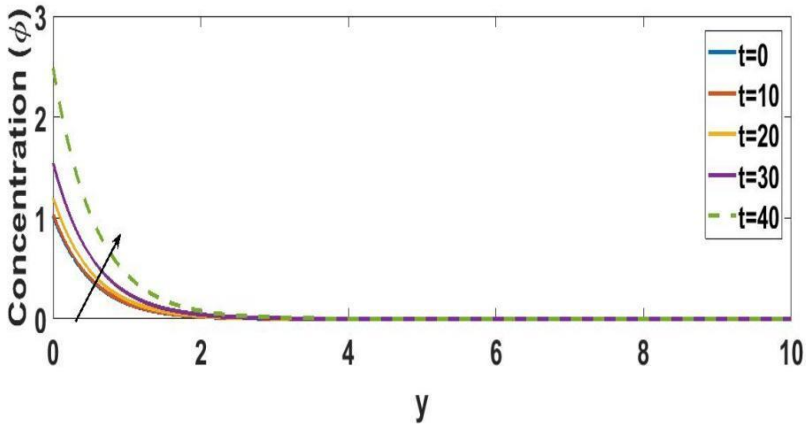

Figure 9: Concentration profile for different values of time

Figure 10: Velocity profile for different values of time

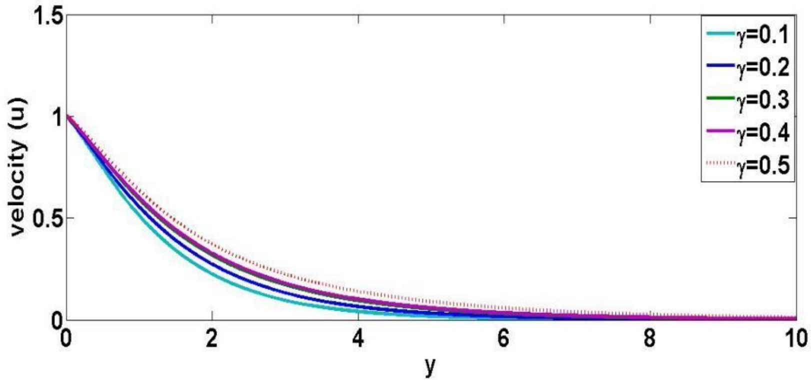

Figure 11: Velocity profile for different values of chemical reaction parameter γ

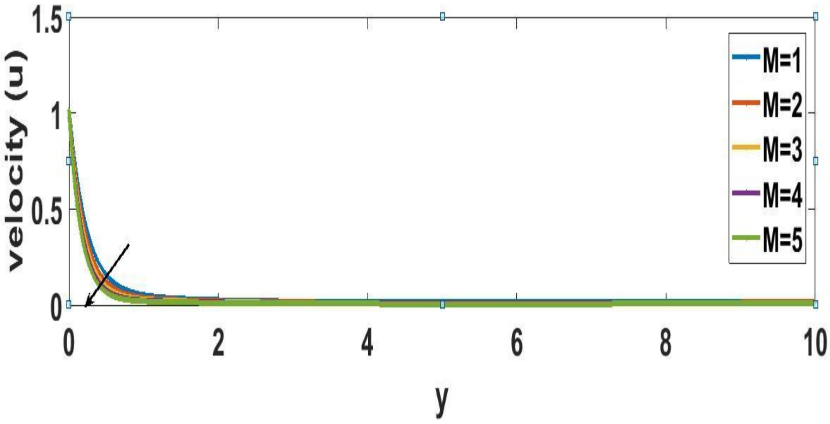

Figure 12: Velocity profile for different values of Magnetic

Figure 13: Velocity profile for different values of Radiation parameter Rd

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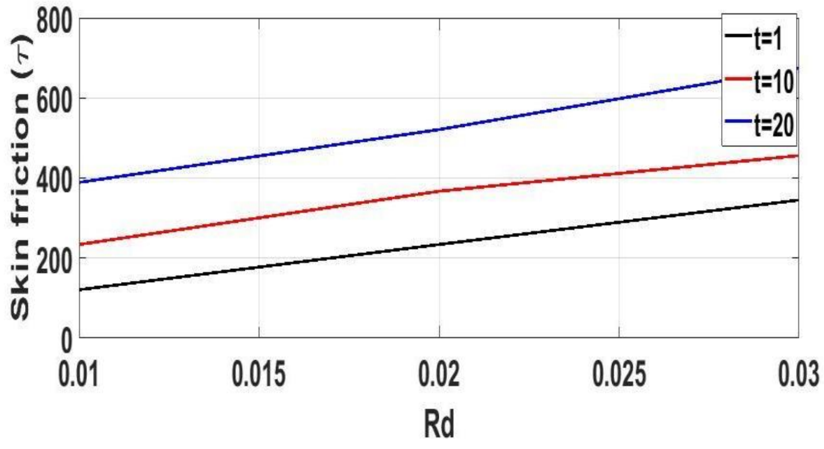

Figure 13: Skin friction profile for different values of Rd against time (t)

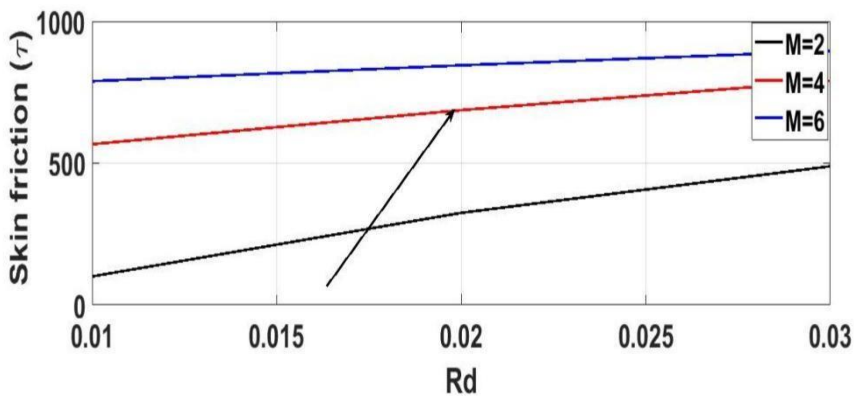

Figure 14: Skin friction profile for different values of M against time (t)

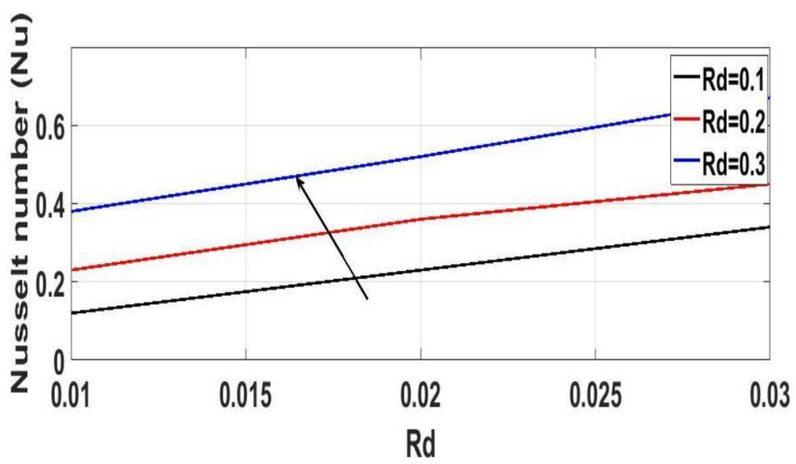

Figure 15: Nusselt number for different values of time (t) against Rd

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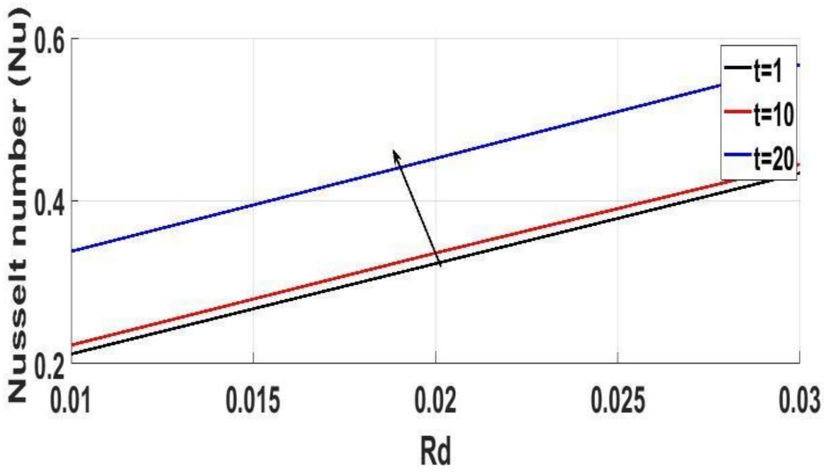

Figure 16: Nusselt number for different values of Rd against time (t)

CONCLUSIONS

Thermal radiation and a transverse magnetic field were used to study the mass and heat transfer of a one-dimensional oscillatory viscous electrically conducting fluid over an infinitely moving permeable plate in a saturated porous media. The study's conclusions are as follows:

i. An increase in thermal radiation parameters was associated with an improvement in the temperature and velocity profiles.

ii. The concentration and velocity of the fluid were found to rise as the chemical reaction parameter increased.

iii. As time goes on, the fluid's velocity, temperature, and concentration all rise with time

iv. Prior to reaching a wall end, the velocity profile increases to its peak close to the surface, after which it decreases. The temperature distribution at the wall and the heat transfer rate are both enhanced when the thickness of the thermal boundary layer decreases with decreasing time.

v. As the Prandtl number increases, the temperature and velocity of the flow field both decrease. The temperature profile is highest close to the surface and rapidly decreases to an asymptotic value as it moves away from the wall. As the Schmidt number increases, the fluid velocity and concentration decrease; at the same time, the boundary layer thickness decreases, and the profiles of both decrease.

vi. An excellent agreement was established between the present work and Al-Zubi (2018).

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Appendix

$$Q=\frac{\Pr}{1+R}, S_1=-\frac{1}{2}Q+\frac{1}{2}\sqrt{Q^2-4m_2}, S_2=-\frac{1}{2}Q+\frac{1}{2}\sqrt{Q^2-4m_2},\ k_3=\sqrt{Q^2-4nQ,}$$

$$h_7=-\frac{Q}{2}+\frac{k_3}{2},\ k_3=\sqrt{Q^2-4nQ,}\, h_8=\frac{Q}{2}+\frac{k_3}{2}, k_4=\sqrt{Sc^2-4Sc\gamma}$$

$$h_9=-\frac{Sc}{2}+\frac{k_4}{2}, h_{10}=\frac{Sc}{2}+\frac{k_4}{2}, k_4=\sqrt{Sc^2-4Sc\gamma}$$

$$k_5=\sqrt{Sc^2-4Sc(n+\gamma)},\ h_{11}=-\frac{Sc}{2}+\frac{k_5}{2}, h_{12}=\frac{Sc}{2}+\frac{k_5}{2},$$

$$h_7=-\frac{1}{2a_1}+\frac{k_2}{2}, h_7=-\frac{1}{2a_1}-\frac{k_2}{2}, k_2=\sqrt{\frac{1}{a_1^{\ 2}}-4a_3}, a_1=1+\beta$$

$$k_1=\sqrt{\frac{1}{a_1^{\ 2}}-4a_2}, a_{2=}\frac{1}{\lambda}+\frac{M}{a_1}, B_1=B_3=B_5=B_7=0, C_2=\frac{1}{1-e^{Q\infty}}$$

$$B_2=B_4=B_6=B_8=1, C_1=1-C_2, C_3=1-C_4, C_4=\frac{e^{s_1}-e^{s_2}}{e^{s_1}}$$

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REFERENCES

Agarwalla, S. & Ahmed N. (2018). MHD mass transfer flows past an inclined plate with variable temperature and plate velocity embedded in a porous medium, Heat Transfer. *Asian Research*. 47(1), 27-41.

Al Zubi, M. (2018). MHD Heat and Mass Transfer of an Oscillatory Flow over a Vertical Permeable Plate in a Porous Medium with Chemical Reaction. *Modern Mechanical Engineering,* 8, Pp:179-191. https://doi.org/10.4236/mme.2018.83012

Bhowmik, H., Gharibia, A., Yaarubia, A. & Alawia, N. (2019) Transient natural convection heat transfer analyses from a horizontal cylinder. *Case Studies in Thermal Engineering*, Pp: 14-31https://doi.org/10.1016/j.csite.2019.100422.

Hosseinzadeha, K., Asadia, A., Mogharrebia, A.R., Khalesib, J., Mousavisanib, S. & Ganjia, D.D.(2019). Entropy generation analysis of $(CH_2\,OH)_2$ containing CNTs nanofluid flow under effect of MHD and thermal radiation, Case Stud *Thermal Eng 4(*3) Pp: 100-112.

Ibrahim, D.Y., Haliru, A.A., Ibrahim, M. & Hamza M.M. (2017). Unsteady heat transfer to MHD oscillatory flow of Jeffrey fluid in a channel filled with porous material. International *Journal of Scientific and Research Publications*. 9(7), ISSN 2250-3153.

Jha, B.K.& Samaila, G. (2020). Thermal radiation effect on boundary layer over a flat plate having convective surface boundary condition, *SN Appl Sci* 2 Pp: 381-396.

Khan, J.A. & Mustafa, M. (2018). A numerical analysis for non-linear radiation in MHD flow Around a cylindrical surface with chemically reactive species, *Results Phys* 8(5) Pp: 963-970.

Kurma, B. (2021*)*.Radiation effect on magnetohydrodynamics flow with induced magnetic field and Newtonian heating/cooling *Propulsion and Power Research* 1-11.

Pattnaik, J.R., Dash, G.C., & Singh, S. (2017). Radiation and mass transfer effects on MHD free convective flow through porous medium past an exponentially accelerated vertical plate with variable temperature. *Ain Shams Engineering Journal*., 8, 67-75.

Ramesh, G.K., Shehzad, S.A., Rauf, A. & Chamkha, A.J. (2020) Heat transport analysis of Aluminium alloy and magnetite graphene oxide through permeable cylinder with heat source/sink. *Physica Scripta, 95,https://doi.org/10.1088/1402-4896/aba5af.*

Ramaiah, P., vijaya, S.K.V., Krishna, K.K.P. & Balamurugan K.S (2016). Chemical reaction and radiation absorption effects on MHD convective heat and mass transfer flow of a viscoelastic fluid past an oscillating porous plate with heat generation/absorption. *Int. J. Chem. Sci.: 14(2), 570-584. ISSN 0972-768X.*

Reddy, B.P.(2019). Effects of chemical reaction on transient MHD flow with mass transfer past an impulsively fixed infinite vertical plate in the presence of thermal radiation. *International Journal of Applied Mechanics and Engineering*, 24(4) 169-182.

Srihari, V.B.K. & Jaya Rami, J.R., (2017). Radiation and Chemical Reaction Effects on Unsteady MHD Free Convection Flow Past a Linearly Accelerated Vertical Porous Plate with Variable Temperature and Mass Diffusion. *Global Journal of Pure and Applied Mathematics*. 13(9),5341-5358. ISSN 0973-1768.

Suresh, P., Hari, Y.K., Sreedhar, R.R. & Janardhana, P. V. R. (2019). Effect of Chemical Reaction and Radiation on MHD Flow along a Moving Vertical Plate with Heat Source and Suction. *International Journal of Applied Engineering Research*. 14(4), 869-876. ISSN 0973-4562

Veera Krishna, M., Ahamad, N.A. & Chamkha, A.J. (2020). Hall and ion slip effects on unsteady MHD free convective rotating flow through a saturated porous medium over an

Article DOI: 10.52589/AJMSS-IQQTYYQH
DOI URL: https://doi.org/10.52589/AJMSS-IQQTYYQH

exponentially accelerated plate. *Alexandria Engineering Journal, 59, Pp:565-577, https://doi.org/10.1016/j.aej.2020.01.043*.

Wakif, A., Chamkha, A.J., Animasaun, I.L., Zaydan, M., Waqas, H. & Sehaqui, R. (2020). Novel Physical insights into the thermodynamic irreversibilities within dissipative MHD fluid flows past over a moving horizontal riga plate in the coexistence of wall suction and joule heating effects: A comprehensive numerical investigation. *Arabian Journal of Engineering and Science 45, Pp: 9423-9438,https://doi.org/10.1007/s13369-020-04757-3*.

Yasin, S.H., Mohamed, M.K., Ismail, Z., Widodo, B. & Salleh, M.Z. (2019). MHD flow and heat transfer of ferrofluid on stagnation point along the flat plate with convective boundary condition and thermal radiation effect, *J. Phys. Conf.* 1366012008

Article DOI: 10.52589/AJMSS-IQQTYYQH
DOI URL: https://doi.org/10.52589/AJMSS-IQQTYYQH