RADIATION AND CHEMICAL REACTION EFFECTS ON UNSTEADY VISCOELASTIC FLUID FLOW THROUGH POROUS MEDIUM

Bamdeb Deya\textsuperscript{a,}\textsuperscript{†}, Bhrigu Kumar Kalita\textsuperscript{b}, Rita Choudhury\textsuperscript{b}

\textsuperscript{a} Assam Don Bosco University, Guwahati, Assam, 781017, India
\textsuperscript{b} Gauhati University, Guwahati, Assam, 781014, India

ABSTRACT

In this paper, we attempt to analyze the effects of radiation and chemical reactions on laminar boundary layer flow of an electrically conducting unsteady viscoelastic incompressible fluid flow along a vertical semi-infinite plate passing through porous channel. The coupled nonlinear partial differential equations for energy, momentum, and mass diffusions are solved analytically with the use of perturbation technique. Moreover, the analytical expressions for fluid velocity, temperature, and concentration distributions are obtained and interpreted using the software MATLAB. The enhancement of velocity is prominent with the growth of $G_r$, $G_m$, $N_r$ and $K_r$ but a reverse pattern is observed with the rise of $P_r$. The physical values of skin friction coefficient, Nusselt number and Sherwood number are estimated remembering their importance in engineering and technology fields. The graphical augmentation are instituted in possible cases for various viscoelastic parameters in combination of other dimensionless flow parameters. The simulations presented here relate to metal extraction in chemical and polymer processes.

Keywords: Viscoelastic, chemical reaction, radiation, porous medium

1. INTRODUCTION

In the past few decades, the application of boundary layer flow for non-Newtonian fluids has been continuously increasing, as it plays an important role in different fields like engineering, processing, metal extraction, aerospace, polymer processing, and contemporary technology. Non-Newtonian fluid flow can also be practically applicable in bioengineering, for instance, there are various viscoelastic fluid models to describe the blood circulation process through animal arteries, then also to understand the mechanism of dialysis of blood through artificial kidneys one can study viscoelastic pulsatile flow.

There are many hydrometallurgical industries and transport affairs which are governed by the combined effect of buoyancy forces due to mass diffusion and thermal energy in presence of radiation and chemical reaction effects. Further, these processes occur in the combustion system, solar collectors, nuclear reactor safety and chemical engineering, etc.

MHD flow through an exponentially extending sheet with a heat sink: chemical reaction and radiation impact has been first studied by (Khalili et al., 2017). Many researchers have studied various problems related to Walters B fluid model. To mention a few, the simultaneous investigation of heat and mass transfer, as well as magnetohydrodynamic (MHD) flow through a vertically oscillating plate contained in a porous medium, was investigated using Walters Liquid Model-B given by (Abro and Khan, 2018). The constitutive equations of some non-Newtonian fluid flows, with short memories, have been studied by (Walters, 1964) and (Bread and Walters, 1964). On an unstable MHD heat and mass transfer flow across an accelerated inclined vertical plate, finite element Soret Dufour impacts have been investigated by

Bejawada et al. (2021).

Again, heat and mass transmission effects on unsteady MHD free convection flow past an infinite vertical plate, a numerical solution has been studied by (Kumari et al., 2021). Chemical reaction and hall effect in heat and mass transfer of MHD Casson fluid under radiation over an exponentially permeable stretching sheet was analyzed by (Ganesh et al., 2021). In the presence of thermal radiation and chemical reaction with suction, MHD boundary layer flow of nanofluid and heat transfer across a porous exponentially stretched sheet have been suitably illustrated by (Reddy et al., 2017) in presence of first-order chemical reaction and Joule heating. Also, the effects of thermal diffusion and chemical reaction on MHD flow on a vertical surface with a generation of heat has been discussed by (Bhavana et al., 2018). The hydromagnetic oscillatory slip flow effects on viscoelastic fluid have been studied by (Dey and Choudhury, 2019). The effects of Chemical Reaction and Suction/Blowing MHD Boundary Layer Flow of Nanofluid and Heat Transfer Over a Nonlinear Stretching sheet was illustrated by (Reddy et al., 2018) for nanofluids. Analysis of heat transfer and mass transfer results on MHD viscoelastic fluid flow on a stretching- sheet in presence of a chemical reaction was done by (Nayak et al., 2016). (Reddy et al., 2018) have discussed the effects of thermal diffusion and radiation on MHD dusty viscoelastic fluids between two parallel moving plates. (Jonnadula, 2015) have examined the influence of chemical reactions and thermal radiation on MHD viscous fluid flow. The unsteady viscous fluid flow in presence of chemical reaction and radiation has been analyzed by (Mishra et al., 2014). Chemical reaction over a curved surface with nonlinear thermal radiation and slip condition has been analyzed for nanofluids by (Ramzan et al., 2020). (Sivaraj and Kumar, 2013) have studied the viscosities of some non-Newtonian fluids as they are the building blocks of different engineering processes. The combined effects of Soret-Dufour on unsteady MHD flow of dusty fluid flow over inclined porous...
medium has been investigated by (Pandya et al., 2017). (Choudhury and Dey, 2019) have studied the unsteady thermal radiation effects on MHD convective ship flow of viscoelastic fluid. Furthermore, (Srinivasacharya and Reddy, 2016) have successfully illustrated mixed convection heat and mass transport over a vertical plate in a power-law fluid-saturated saturated porous medium: chemical reaction and radiation impacts. The survey of literature pacifies that, flow of viscoelastic fluid through porous medium for various outlook have been demonstrated by many researchers and the details engrossed readers are referred to the references.

In most of the above studies, chemical reaction and radiation effects on fluid flow are discussed for both Newtonian and non-Newtonian fluids. But in many practical situations, it has been seen that models based on natural non-Newtonian fluid flow are extensively applicable in many engineering and industrial applications. In presence of chemical reaction or thermal radiation, some models based on viscoelastic fluid flows through porous medium are found in the works of many researchers. The combined effects of chemical reaction and thermal radiation on unsteady viscoelastic fluid flow through porous media is considered here. In the present study, the inclusion of porous media is important since it greatly prevents heat loss in heat transport processes and also accelerates the process of heating/cooling. Also, the fluids may be chemically reactive so for the mass transport equation chemical reaction term is vital.

2. Formulation of the problem

We consider an incompressible, unsteady, laminar, electrically conducting, boundary layer flow of a viscoelastic fluid through a vertical semi-infinite plate via a porous medium in presence of radiation and chemical reactions. Further, the time-dependent suction is also considered. The physical configuration of the problem is shown in figure 1.

![Figure 1: Physical model](image-url)

Flow variables are functions of y’ and t’ only, as the plate is of infinite length along x’-direction. The governing equations of flow field are:

Equation of continuity: \( \frac{\partial u'}{\partial y'} = 0 \) (1)

Momentum equation:
\[
\frac{\partial u'}{\partial t'} + u' \frac{\partial u'}{\partial y'} = v' \frac{\partial u'}{\partial y'} - k' \frac{\partial^3 u'}{\partial y'^3} + g \beta (T - T_\infty) + g \beta^* (C - C_\infty) - \frac{\nu}{k'} u'' + \frac{\nu^2}{\rho} u''
\]

Equation of energy:
\[
\frac{\partial T'}{\partial t'} + u' \frac{\partial T'}{\partial y'} = \frac{k}{\rho c_p} \frac{\partial^2 T'}{\partial y'^2} + \frac{\partial q_r}{\partial y'}
\]

Energy of mass diffusion:
\[
\frac{\partial C'}{\partial t'} + u' \frac{\partial C'}{\partial y'} = D \frac{\partial^2 C'}{\partial y'^2} - K_r (C - C_\infty)
\]

For radiation, the Rosseland approximation can be taken as
\[
q_r = -\frac{4\sigma_r^4}{3k^4} \frac{\partial T'}{\partial y'}
\]

Using Taylor’s series T4 can be expanded linearly about the free-stream temperature T∞ and neglecting all higher order terms we get
\[
T' = \frac{\partial T}{\partial y'} = -\frac{4}{3} T_\infty \frac{\partial T}{\partial y'}
\]

Using equations (5) and (6), the energy equation reduces to
\[
\frac{\partial T}{\partial t'} + u' \frac{\partial T}{\partial y'} = \frac{k}{\rho c_p} \frac{\partial^2 T}{\partial y'^2} + \frac{16\sigma_r^4 T_\infty^4}{3\rho c_p} \frac{\partial T}{\partial y'^2}
\]

From equation (1), it can be assumed that suction is only dependent on time and can be assume as follows:
\[
u' = -V_0 (1 + e \Delta e^{nt})
\]

Making use of the above dimensionless parameters in equations (2), (7) and (4), the governing equations reduce to

\[
\frac{\partial u}{\partial \tau} - (1 + e \Delta e^{nt}) \frac{\partial u}{\partial \eta} = \frac{a^2 u}{\eta^2} - k \frac{\partial^3 u}{\partial \eta^3} + G_\theta \theta + G_m \phi + \frac{(M - 1) u}{3 R}
\]

The boundary conditions are:
\[
y = 0: u = 1, \quad \theta = 1 + e \Delta e^{nt}, \quad \phi = 1 + e \Delta e^{nt}
\]

3. Method of Solution

The nonlinear coupled differential equations (9) to (11) with the relevant boundary conditions (12) can be solved analytically. As the amplitude \( e \ll 1 \) is very small, so u, \( \theta \) and \( \phi \) can be taken as

\[
\theta(\tau, \eta) = \theta_0(\eta) + e \Delta e^{nt} \theta_1(\eta) + 0(e^2)
\]

\[
\phi(\tau, \eta) = \phi_0(\eta) + e e \Delta \phi_1(\eta) + 0(e^2)
\]

Substituting equations (13) to (15) into equations (9) to (11) respectively and equating harmonic, non-harmonic terms with the neglect of second and higher orders, we get zeroth and first order differential equations.

Zeroth-order equations:

\[
k_r u'''' - u''' - u' - (n - M + \frac{1}{R}) u = G_r \theta_0 + G_m \phi_0
\]

\[
\theta'' + \alpha \theta_0 = 0, \alpha = \frac{R}{1 + N_r}
\]

First-order equations:

\[
k_r u'''' - u''' - u' - (n - M + \frac{1}{R}) u = A u_0 + G_r \theta_0 + G_m \phi_0
\]

\[
\theta'' + n \alpha \theta_0 + A \theta_0 = 0
\]
\[ \phi'' + S \phi' - (n + K_r) \phi + A_S \phi = 0 \]  

The corresponding boundary conditions are
\[ y = 0: u_0 = 1, \phi_0 = 0; \theta = 1; y = \infty: u_0 = 1, \phi_0 = 1, \phi_1 = 1 \]

Solving equations (17), (18) and (20) and (21) subject to the boundary conditions (22) we get
\[ \theta_0 = e^{-a_y} \]
\[ \theta_1 = C_4 e^{-a_y} - \frac{A}{n} e^{-a_y} \]
\[ \phi_0 = e^{-a_y} \]
\[ \phi_1 = (1 - a_7) e^{-a_y} + a_7 e^{-a_y} \]

To solve equations (16) and (19), we are to use multiparameter perturbation scheme for small shear rate on \( k_1 \) as
\[ u_0 = u_{10} + k_1 u_{10} + O(k_1^2) \]
\[ u_1 = u_{10} + k_1 u_{11} + O(k_1^2) \]

Substituting equations (27) and (28) in equations (16) and (19) respectively, then comparing the like powers of \( k_1 \) and neglecting second and higher order terms we get

Zeroth-order equations:
\[ u''_{00} + u_{10} + \left( M - \frac{1}{K} \right) u_{00} = -(G_r \theta_0 + G_m \phi_0) \]
\[ u''_{10} + u_{10} - (n - M + \frac{1}{K}) u_{10} = -(G_r \theta_1 + G_m \phi_1 + A u''_{00}) \]

First-order equations:
\[ u''_{01} - u_{01} + \left( M - \frac{1}{K} \right) u_{01} = G_r \theta_0 + G_m \phi_0 \]
\[ u''_{11} - u_{11} + \left( n - M + \frac{1}{K} \right) u_{11} = A u'_{01} + G_r \theta_1 + G_m \phi_1 \]

corresponding boundary conditions are:
\[ y = 0: u_0 = 1, u_{01} = 0, u_{10} = 0, u_{11} = 0 \]
\[ y = \infty: u_0 \to 0, u_{01} \to 0, u_{10} \to 0, u_{11} \to 0 \]

The solutions of the equations (29) to (32), under the boundary conditions (33) are obtained as
\[ u_{00} = \left( 1 + a_7 + a_1 \right) e^{-a_y} \]
\[ u_{10} = a_1 \left( a_{13} e^{-a_y} - a_4 e^{-a_y} \right) + a_2 e^{-a_y} - a_7 e^{-a_y} - a_6 e^{-a_y} \]
\[ u_{01} = a_2 e^{-a_y} + a_4 e^{-a_y} + a_6 e^{-a_y} \]
\[ u_{11} = a_3 e^{-a_y} + a_5 e^{-a_y} + a_6 e^{-a_y} \]

With the help of the above solutions, we can find the expressions for velocity, temperature and concentration as follows:
\[ u = \left( A_3 e^{-a_y} + A_4 e^{-a_y} + A_5 e^{-a_y} + A_6 e^{-a_y} \right) + e^{nt} \left( A_7 e^{-a_y} - A_6 e^{-a_y} \right) \]
\[ \theta = e^{-a_y} + \epsilon e^{nt} \left( C_7 e^{-a_y} - \frac{A_8}{n} e^{-a_y} \right) \]
\[ \phi = e^{-a_y} + \epsilon \left( 1 - a_7 \right) e^{-a_y} - a_7 e^{-a_y} \]

The dimensionless form of the physical quantities, Skin-friction \( \tau \) along x-axis, Nusselt number \( N_u \) and Sherwood number \( S_h \) are:

\[ \tau = \frac{\partial u}{\partial y} \bigg|_{y=0} = -(a_{38}a_9 + a_{39}a_9 + a_{40}a_9) - \epsilon e^{nt} \left( (a_{41}a_{13} + a_{42}a_9) - a_{43}a_9 + a_{44}a_9 + a_{45}a_9 \right) \]
\[ N_u = \frac{\partial \theta}{\partial y} \bigg|_{y=0} = -\alpha + \epsilon e^{nt} \left( -a_2 C_4 + \frac{A_4^2}{n} \right) \]
\[ S_h = \frac{\partial \phi}{\partial y} \bigg|_{y=0} = -a_4 + \epsilon e^{nt} \left( -a_2 C_4 + \frac{A_4^2}{n} \right) \]

4. Results and Discussion

The goal of our present analysis is to highlight the effects of chemical reaction and radiation on unsteady viscoelastic fluid flow through a porous medium. The analytical outcomes are discussed in the previous section. In the present section, the simulation of divergent flow parameters has been analyzed using MATLAB code. The consequences of physical parameters, such as viscoelastic parameter \( k_1 \), Grashof number \( G_r \), modified/solutal Grashof number \( G_m \), N, \( N_t \), Schmidt number \( S_c \), porosity parameter \( K \) on fluid flow variables like velocity, skin friction, concentration, and temperature have been analyzed using simulation and explained graphically in Figures 2 to 10. Attention is directed towards the zero and non-zero values of the viscoelastic parameter, where the zero value of viscoelastic parameter \( k_1 \) acts for the Newtonian fluid motion and the non-zero value of \( k_1 \) results in enhanced the viscoelastic fluid motion. The numerical computations are executed by taking \( n=0.1, \epsilon=0.001, A=0.3, t=0.1, M=1.7, K=1/0.001, P_r=1.2, N_r=0.5, S_c=0.2, K_w=0.5, G_m=3, G_w=4 \) unless otherwise stated. Figures 2 to 5 illustrate the velocity distribution \( u(y, t) \) against \( y \) for different flow parameters involved in the fluid motion. From Figures 2 to 5, it has been observed that the velocity increases sharply up to \( y=1.25 \) near the plate, which gradually decreases and approaches zero as \( y \) increases. The variations of flow parameters in Figures 3 to 5 do not change the flow pattern of velocity both in Newtonian and viscoelastic fluids. Moreover, with the increase of viscoelastic parameter \( k_1 \), the speed of the fluid velocity enhances. In all the figures \( k_1 \) means \( k_1 \).
Throughout the study, Grashof number is considered to be non-zero and positive i.e., the fluid passes through a cooled plate (external). Figures 2 and 3 depict the effect of \( G_r \) on the velocity profile. It has also been found that with the enhancement of Grashof number, viscosity of a fluid diminishes which results a sharp hike in fluid velocity for both the fluids.

The Grashof number has a favourable effect on velocity since it minimises frictional power. As a result, the Grashof number may be raised to lessen the effect of friction. Again, ejection of mass occurs due to the fluid motion relation with mass transfer. The free convective parameter for mass transfer is represented by \( G_m \). The positive non-zero value of \( G_m \) implies that the concentration at the boundary surface is more than the free stream concentration. Figures 2 and 4 indicates that with the increased value of \( G_m \), fluid viscosity enhances and which amplifies the velocity furthermore.

From figures 2 and 5, it is observed that with the grow of thermal radiation parameter (\( N_r \)) there is a rising trend in the fluid velocity in both Newtonian and viscoelastic fluid which is due to the internal heat generation.

Effect of chemical reaction parameter (\( K_r \)) is shown in figures 2 and 6. It has been noticed that with the enhancement value of \( K_r \), a considerable amount of growth in velocity is observed.

The Prandtl number signifies the effect of thermal diffusion and momentum in the heat transfer problems, so its effects can’t be ignored. From 2 and 7 it is clear that with the growing value of \( P_r \), the fluid velocity diminishes in the respective fluids.

Figures 8 to 10 characterize the behavior of the shearing stress against the flow parameters such as Grashof number (\( G_r \)), solutal Grashof number (\( G_m \)) and magnetic parameter (\( M \)) respectively. It has been noticed that shearing stress enhances with the increase of \( G_r \), but decreasing trend in shearing stress is observed with the growth of \( G_m \) and \( M \) in both Newtonian and viscoelastic fluids. Unlike fluid velocity, we observe a reverse trend in shearing stress. With the rise of viscoelastic parameter \( k_1 \) the shearing stress for viscoelastic fluids declines in comparison to Newtonian fluid.
Table 1: Values of Sherwood and Nusselt number for different parameters

| $k_1$ | $P_r$ | $N_r$ | $S_c$ | $K_r$ | $M$ | $G_m$ | $G_r$ | $S_h$ | $N_u$ |
|-------|-------|-------|-------|-------|-----|-------|-------|-------|-------|
| 0     | 1.2   | 0.5   | 0.2   | 0.5   | 1.7 | 3     | 6     | -0.5654 | -0.9245 |
| 0.05  | 1.2   | 0.5   | 0.2   | 0.5   | 1.7 | 3     | 6     | -0.5654 | -0.9245 |
| 0.1   | 1.2   | 0.3   | 0.2   | 0.5   | 1.7 | 3     | 6     | -0.5654 | -0.9245 |
| 0.15  | 1.2   | 0.7   | 0.5   | 1.7   | 3   | 6     | -0.5654 | -0.9245 |
| 0.05  | 1.2   | 0.5   | 0.7   | 0.5   | 1.7 | 3     | 6     | -0.5654 | -0.9245 |
| 0.1   | 1.2   | 0.5   | 0.9   | 0.5   | 1.7 | 3     | 6     | -0.5654 | -0.9245 |
| 0.15  | 1.2   | 0.5   | 0.5   | 0.5   | 1.7 | 3     | 6     | -0.5654 | -0.9245 |
| 0     | 1.2   | 0.5   | 0.2   | 0.4   | 1.7 | 3     | 6     | -0.6000 | -0.8013 |
| 0.05  | 1.2   | 0.5   | 0.2   | 0.6   | 1.7 | 3     | 6     | -0.6000 | -0.8013 |
| 0.1   | 1.2   | 0.5   | 0.2   | 0.8   | 1.7 | 3     | 6     | -0.6000 | -0.8013 |
| 0.15  | 1.2   | 0.5   | 0.2   | 0.5   | 1.7 | 3     | 3     | -0.4316 | -0.8013 |
| 0     | 1.2   | 0.5   | 0.2   | 0.5   | 1.7 | 3     | 5     | -0.4316 | -0.8013 |
| 0.05  | 1.2   | 0.5   | 0.2   | 0.5   | 1.7 | 3     | 7     | -0.4316 | -0.8013 |
| 0.1   | 1.2   | 0.5   | 0.2   | 0.5   | 1.7 | 3     | 7     | -0.4316 | -0.8013 |
| 0.15  | 1.2   | 0.5   | 0.2   | 0.5   | 1.7 | 3     | 7     | -0.4316 | -0.8013 |
3. CONCLUSIONS

The key aspects of this study are highlighted here. The final ordinary differential equations are facilitated with some flow parameters and almost every parameter plays an effective role in the fluid flow region. The conclusion of this study is as follows:

- The fluid velocity enhances sharply near the plate then decreases gradually and approaches to zero after attaining the peak.
- The speed of the fluid flow increases at each point with the growth of viscoelastic parameter in the flow region.
- Fluctuation of shearing stress is observed significantly for different flow parameters both in Newtonian and viscoelastic fluid.
- The Sherwood and the Nusselt number are not affected considerably with the change of viscoelastic parameter.
- No significant change is observed in the concentration and temperature profile by viscoelastic parameter due to constraining effects of elasticity.

ACKNOWLEDGEMENTS

The authors are grateful for the valuable suggestions from the reviewers.

NOMENCLATURE

- $x, y$: Cartesian coordinates
- $u, v$: Velocity along x and y directions
- $g$: Acceleration due to gravity
- $T$: Dimensional temperature
- $C$: Dimensional concentration
- $C_p$: Specific heat at constant pressure
- $t$: Time
- $B_o$: Magnetic field intensity
- $K$: Porous permeability
- $k$: Thermal conductivity
- $N_r$: Radiation parameter
- $A$: Suction parameter
- $n$: Exponential index, a constant
- $D$: Molar diffusivity

Greek symbols

- $\rho$: Fluid density
- $\sigma$: Electrical conductivity
- $\beta, \beta'$: Volumetric expansion due to temperature and concentration
- $\epsilon$: Reference parameter ($<<1$)

REFERENCES

Al-Mdallal, Q., Abro, K. A., & Khan, I. (2018). “Analytical solutions of fractional Walter’s B fluid with applications”. Complexity, 2018. https://doi.org/10.1155/2018/8131329

Aydn, O., & Kaya, A., 2008, “Radiation effect on MHD mixed convection flow about a permeable vertical plate”. Heat and Mass Transfer, 45(2), 239-246. http://dx.doi.org/10.1007/s00231-008-0428-y

Bataller, R. C., 2007, “Viscoelastic fluid flow and heat transfer over a stretching sheet under the effects of a non-uniform heat source, viscous dissipation and thermal radiation”. International Journal of Heat and Mass Transfer, 50(15-16), 3152-3162. http://dx.doi.org/10.1016/j.ijheatmasstransfer.2007.01.003

Beard, D. W., & Walters, K., 1964. “Elastico-viscous boundary-layer flows I. Two-dimensional flow near a stagnation point”. Mathematical Proceedings of the Cambridge Philosophical Society, 60(3), 667-674. http://dx.doi.org/10.1017/s0305004100038147

Bejawada, S. G., & Yanala, D. R. (2021). “Finite element Soret Dufour effects on an unsteady MHD heat and mass transfer flow past an accelerated inclined vertical plate”. Heat Transfer, 50(8), 8553-8578. https://doi.org/10.1002/htj.22990

Srinivasacharya, D., & Reddy, G. S. (2016). “Chemical reaction and radiation effects on mixed convection heat and mass transfer over a vertical plate in power-law fluid saturated porous medium”. Journal of the Egyptian Mathematical Society, 24(1), 108-115.
https://doi.org/10.1016/j.joems.2014.10.001

Bhavana, M., & Chenna Kesavaiah, D., 2018, “Perturbation solution for diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation”. International Journal of Future Revolution in Computer Science and Communication Engineering, 4(1), 215-220.

Choudhury, R., & Dey, B., 2018, “Unsteady thermal radiation effects on MHD convective slip flow of visco-elastic fluid past a porous plate embedded in porous medium”. International Journal of Applied Mathematics and Statistics, 57(2), 215-226.

Dey, B., & Choudhury, R., 2019, “Slip Effects on Heat and Mass Transfer in MHD Visco-Elastic Fluid Flow Through a Porous Channel”. Advances in Intelligent Systems and Computing Emerging Technologies in Data Mining and Information Security, 553-564. http://dx.doi.org/10.1007/978-981-13-1951-8_50

Fernandez, J., & Homsy, G. M., 2003, “Viscous fingering with chemical reaction: Effect of in-situ production of surfactants”. Journal of Fluid Mechanics, 480:267-281. http://dx.doi.org/10.1017/s0022112002003683.

Ganesh, G., & Sridhar, W. (2021), “Numerical approach of heat and mass transfer of MHD Casson fluid under radiation over an exponentially permeable stretching sheet with chemical reaction and hall effect”. Frontiers in Heat and Mass Transfer (FHMT), 16. http://dx.doi.org/10.10508/hmt.16.5

Gharami, P. P., Arifuzzaman, S. M., Reza-E-Rabbi, S., Khan, M. S., & Ahmmed, S. F., 2020, “Analytical and Numerical Solution of Viscous Fluid Flow with the Effects of Thermal Radiation and Chemical Reaction Past a Vertical Porous Surface”. International Journal of Heat and Technology, 38(3), 689-700. http://dx.doi.org/10.18280/ijht.380313

Haile, E., 2014, “Heat and Mass Transfer Through a Porous Media of MHD Flow of Nanofluids with Thermal Radiation, Viscous Dissipation and Chemical Reaction Effects”. American Chemical Science Journal, 4(6), 828-846. http://dx.doi.org/10.9734/acsj/2014/11082

Hayat, T., Nawaz, M., Asghar, S., & Mesloub, S., 2011, “Thermal-diffusion and diffusion-thermo effects on axisymmetric flow of a second grade fluid”. International Journal of Heat and Mass Transfer, 54(13-14), 3031-3041. http://dx.doi.org/10.1016/j.ijheatmasstransfer.2011.02.045

Jonnadula, M., Polarapu, P., M. G. R., & M. V., 2015, “Influence of Thermal Radiation and Chemical Reaction on MHD Flow, Heat and Mass Transfer Over a Stretching Surface”. Procedia Engineering, 127, 1315-1322. http://dx.doi.org/10.1016/j.proeng.2015.11.489

Kamalakar, P., Rao, R. R., & Rao, D. P., 2016, “Effect Of Chemical Reaction And Radiation On Unsteady Convective Heat And Mass Transfer Of A Viscous Fluid In A Vertical Wavy Channel With Oscillatory Flux And Heat Sources”. Frontiers in Heat and Mass Transfer, 7(1). http://dx.doi.org/10.5098/hmt.7.2

Kar, M., Sahoo, S. N., Rath, P. K., & Dash, G. C., 2014, “Heat and Mass Transfer Effects on a Dissipative and Radiative Visco-Elastic MHD Flow over a Stretching Porous Sheet”. Arabian Journal for Science and Engineering, 39(5), 3393-3401. http://dx.doi.org/10.1007/s13369-014-0991-0

Kumari, D., Sujja, V., & Kishore, P. M. (2021). “Numerical solution of the effects of heat and mass transfer on unsteady MHD free convection flow past an infinite vertical plate”. Frontiers in Heat and Mass Transfer (FHMT), 16. http://dx.doi.org/10.10508/hmt.16.24

Mallikarjuna, B., Chenna, K., & Ramana Reddy, G. V., 2018, “Effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates”. APRN Journal of Engineering and Applied Sciences, 13(22), 8863-8872.

Mishra, N. K., Sharma, V. K., & Rajput, D., 2014, “Unsteady viscous fluid flow with porous medium in the presence of radiation and chemical reaction”. Chinese Journal of Physics, 52(1), 185-191.

Mulinti, V. R., & Pallavarapu, L., 2021, Influence Of Thermal Radiation And Viscous Dissipation On Mhd Flow Of Ucm Fluid Over A Porous Stretching Sheet With Higher Order Chemical Reaction. Special Topics & Reviews In Porous Media: An International Journal, 12(4), 33-49. http://dx.doi.org/10.1016/s1615-specialtopicsrevporousmedia.2020033950

Nayak, A., Dash, G. C., & Panda, S., 2013, “Unsteady MHD Flow of a Visco-Elastic Fluid Along Vertical Porous Surface with Chemical Reaction”. Proceedings of the National Academy of Sciences, India Section A: Physical Sciences, 83(2), 153-161. http://dx.doi.org/10.1007/s40010-013-0066-8

Nayak, M. K., Dash, G. C., & Singh, L. P., 2016, “Heat and mass transfer effects on MHD viscoelastic fluid over a stretching sheet through porous medium in presence of chemical reaction”. Propulsion and Power Research, 5(1), 70-80. http://dx.doi.org/10.1016/j.jppr.2016.01.006

Khalili, N. N. W., Samson, A. A., Aziz, A. S. A., & Ali, Z. M. (2017, September). “Chemical reaction and radiation effects on MHD flow past an exponentially stretching sheet with heat sink”. In Journal of Physics: Conference Series (Vol. 890, No. 1, p. 012025). IOP Publishing. https://doi.org/10.1088/1742-6596/890/1/012025

Ngiangia, A., & Harry, S., 2017, “Electroconductivity of Steady Viscous MHD Incompressible Fluid between Two Porous Parallel Plates Provoked by Chemical Reaction and Radiation”. Physical Science International Journal, 13(2), 1-13. http://dx.doi.org/10.9734/psij/2017/30177

Pal, D., & Biswas, S., 2016, “Influence of Chemical Reaction and Soret Effect on Mixed Convective MHD Oscillatory Flow of Casson Fluid with Thermal Radiation and Viscous Dissipation”. International Journal of Applied and Computational Mathematics, 3(3), 1897-1919. http://dx.doi.org/10.1007/s40819-016-0215-2

Pal, D., & Talukdar, B., 2011, “Combined effects of Joule heating and chemical reaction on unsteady magnetohydrodynamic mixed convection of a viscous dissipating fluid over a vertical plate in porous media with thermal radiation”. Mathematical and Computer Modelling, 54(11-12), 3016-3036. http://dx.doi.org/10.1016/j.mcm.2011.07.030

Pandya, N., Yadav, R. K., Shukla, A. K., 2017, “Combined effects of Soret-Dufour, radiation and chemical reaction on unsteady MHD flow of dusty fluid over inclined porous plate embedded in porous medium”. International Journal Advance Applied Mathematics and Mechanics, 5(1), 49-58.

Ramzan, M., Rafiq, A., “Chung, J. D., Kadry, S., & Chu, Y., 2020, Nanofluid flow with autocatalytic chemical reaction over a curved surface with nonlinear thermal radiation and slip condition”. Scientific Reports, 10(1). http://dx.doi.org/10.1038/s41598-020-73142-9
Raptis, A., 1998, “Radiation and free convection flow through a porous medium”. International Communications in Heat and Mass Transfer, 25(2), 289-295. [http://dx.doi.org/10.1016/s0735-1933(98)00016-5]

Reddy, Y. D., Rao, V. S., & Babu, L. A. (2017). “MHD boundary layer flow of nanofluid and heat transfer over a porous exponentially stretching sheet in presence of thermal radiation and chemical reaction with suction”. Int J Math Trends Technol, 27, 87-100. [https://doi.org/10.14445/22315373%2FIJMTT-V47P512]

Reddy, Y. D., Rao, V. S., Ramya, D., & Babu, L. A. (2018). “MHD boundary layer flow of nanofluid and heat transfer over a nonlinear stretching sheet with chemical reaction and suction/blowing”. Journal of Nanofluids, 7(2), 404-412. [https://doi.org/10.1166/jon.2018.1450]

Sakadias, B. C., 1961, “Boundary-layer behaviour on continuous solid surfaces: I. Boundary-layer equations for two-dimensional and axisymmetric flow”. AIChE Journal, 7(1), 26-28. [http://dx.doi.org/10.1002/aic.690070108]

Stokes, G. G., 1851, “Flow of viscous incompressible fluid past an impulsive started infinite horizontal plate”. Cambridge Phil. Trans, 9, 8-17.

Sivaraj, R., & Kumar, B. R., 2013, “Chemically reacting dusty viscoelastic fluid flow in an irregular channel with convective boundary”. Ain Shams Engineering Journal, 4(1), 93-101. [http://dx.doi.org/10.1016/j.asej.2012.06.005]

Walters, K., 1964, “Second-order effects in elasticity, plasticity and fluid dynamics”. Pergamon, New York, 507.

Zigta, B., 2019, “Thermal Radiation, Chemical Reaction and Viscous Dissipation Effects on Unsteady MHD Flow of Viscoelastic Fluid Embedded in a Porous Medium”: Budapest International Research in Exact Sciences (BirEx) Journal, 1(3), 35-57. [http://dx.doi.org/10.33258/birex.v1i3.346]