SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Heat and Mass Transfer on Unsteady MHD Kuvshinski Fluid Flow Past an Inclined Porous Plate with Multiple Slip Effect

Anil Kumar Janga[1], Radha Gajjala[2,*]

[1] Department of Science & Humanities, MLR Institute of Technology, Hyderabad, 500043, Telangana, India
[2] Department of Humanities and Sciences, K.S.R.M College of Engineering, Kadapa-516003, Andhra Pradesh, India

ARTICLE INFO

Article history:
Received 15 January 2023
Received in revised form 10 May 2023
Accepted 17 May 2023
Available online 3 June 2023

Keywords:
Magnetohydrodynamic; radiation absorption; chemical reaction; porous media

ABSTRACT

This paper presents the study of convective heat and mass transfer characteristics of an incompressible MHD free convection Kuvshinski fluid flow immersed in a porous medium over inclined plates with radiation absorption and chemical reaction effects. The systems of non-dimensional governing linear partial differential equations are solved analytically by using the perturbation technique. The expressions for the fields of velocity, temperature and concentration are obtained. With the aid of these the expressions for skin friction, Nusselt number and Sherwood number are derived. The effects of various physical parameters on the flow quantities are studied through graphs and tables. For the validity, we have checked our results with previously published work and found in good agreement.

1. Introduction

The study towards the flow on boundary layer of non-Newtonian fluids has been the subject of great interest to investigators and researchers. Viscoelastic fluid is a common form of non-Newtonian fluid, which this fluid having the characteristic that shows both viscous and elastic properties under some circumstances. This viscoelastic reaction and the fluid flow past a stretching sheet are so significant in some real life applications especially in the engineering field, for instance, in the paper production, extrusion of plastic sheets, glass blowing, and metal spinning [1]. The flow of viscoelastic fluid past a stretching sheet has been studied by Rajagopal *et al.,* [2]. Later, Andersson [3] has added the magnetic effects towards the flow of a viscoelastic fluid past a stretching sheet and he obtained the exact analytical solution of the governing non-linear boundary layer equation. Consequently, Ariel [4] extended the problem by taking into account the flow with the existence of suction and found the exact solution. The investigation on the steady magnetohydrodynamic viscoelastic fluid flow over a semi-infinite, impermeable stretching sheet with the presence of thermal radiation and internal heat generation or absorption is investigated by Datti *et al.,* [5]. Moreover, Liu [6] presented the exact analytical solutions for the flow and heat transfer of second grade fluid over a stretching

* *Corresponding author.*
E-mail address: radhagajjala79@gmail.com

https://doi.org/10.37934/arfmts.106.2.103115

sheet with the presence of magnetic and viscous dissipation. Khan and Sanjayanand [7] have examined the viscoelastic boundary layer flow and heat transfer over an exponential stretching sheet. Viscous dissipation has been considered in the heat transfer and the obtained exact solution which then being compared with the numerical solution. Balamurugan *et al.,* [8] have analyze the effects of chemical reaction, thermal radiation and radiation absorption on unsteady double diffusive free convection flow of Kuvshinski fluid past a moving porous plate with heat generation under the influence of a uniform transverse magnetic field. Recently Prasad *et al.,* [9] have studied the aligned magnetic field and Kuvshinski fluid model on unsteady MHD free convective flow past a moving inclined plate in the occurrence of thermal radiation as well as radiation absorption with chemical reaction and mass blowing or suction. Recently Rajakumar *et al.,* [10] have reviewed Steady MHD Casson Ohmic heating and viscous dissipative fluid flow past an infinite vertical porous plate in the presence of Soret. Mohanaramana *et al.,* [11] have discussed Chemical reaction with aligned magnetic field effects on unsteady MHD Kuvshinski fluid flow past an inclined porous plate in the presence of radiation and Soret effects.

Magnetohydrodynamic free convective fluid flows with different geometries surrounded with porous media have plenty of engineering, industrial and geophysical applications. Some of them are utilized in geothermal reservoirs, drying process of porous solids, thermal filling, cooling of nuclear reactors, packed-bed catalytic reactors, superior oil recovery and underground energy transport. A renewed interest has been carried out in studying magnetohydrodynamic (MHD) flow with the occurrence of heat and mass transfer simultaneously in porous boundary by implementing several parameters in conducting fields. On the other hand this type of fluid flow under the influence of various physical parameters like thermal diffusion, heat source/sink, chemical reaction and thermal radiation has attracted the interest of many researchers. As a result plenty of research articles have been employed. Raghunath [12] has studied Study of Heat and Mass Transfer of an Unsteady Magnetohydrodynamic Nanofluid Flow Past a Vertical Porous Plate in the Presence of Chemical Reaction, Radiation and soret Effects. Raghunath *et al.,* [13] has analyzed Diffusion Thermo and Chemical Reaction Effects on Magnetohydrodynamic Jeffrey Nanofluid over an Inclined Vertical Plate in the Presence of Radiation Absorption and Constant Heat Source. Maatoug *et al.,* [14] have expressed Variable chemical species and thermo-diffusion Darcy–Forchheimer squeezed flow of Jeffrey nanofluid in horizontal channel with viscous dissipation effects. Omar *et al., [*15] have possessed Hall Current and Soret Effects on Unsteady MHD Rotating Flow of Second-Grade Fluid through Porous Media under the Influences of Thermal Radiation and Chemical Reactions. Deepthi *et al.,* [16] have discussed Recent Development of Heat and Mass Transport in the Presence of Hall, Ion Slip and Thermo Diffusion in Radiative Second Grade Material: Application of Micromachines.

Fluid flows through porous medium are seriously attracted by engineers and scientists. Now a days, due to their applications in the emerging trends in science and technology, namely in the field of agricultural engineering especially while studying water resources in the ground, to study the moment of natural gas, oil, and water through the reservoirs in the petroleum technology. Raghunath *et al.,* [17] have studied processing to pass unsteady MHD flow of a second-grade fluid through a porous medium in the presence of radiation absorption exhibits Diffusion thermo, hall and ion slip effects. Raghunath *et al.,* [18] have studied Influence of MHD mixed convection flow for maxwell nanofluid through a vertical cone with porous material in the existence of variable heat conductivity and diffusion. Raghunath *et al.,* [19] Radiation absorption on MHD Free Conduction flow through porous medium over an unbounded vertical plate with heat source. Li *et al.,* [20] have studied Effects of activation energy and chemical reaction on unsteady MHD dissipative Darcy–Forchheimer squeezed flow of Casson fluid over horizontal channel**.** Suresh Kumar [21] have expressed Numerical analysis of magneto hydrodynamics Casson nanofluid flow with activation energy, Hall current and thermal radiation. Reddy *et al.,* [22] have considered unsteady free convection MHD non-Newtonian flow through a porous medium bounded by an infinite inclined porous plate. Raju *et al.,* [23] have investigated the effect of radiation and mass transfer effects on a free convection flow past a porous medium bounded by a vertical surface. Seddek *et al.,* [24] have studied the effects of chemical reaction and variable viscosity on hydro magnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation. Ravikumar *et al.,* [25] have discussed the combined effect of heat absorption and MHD on convective Rivlin-Erichsen flow past a semi-infinite vertical porous plate with variable temperature and suction. Ibrahim *et al.,* [26] have analyzed the effect of the chemical reaction and radiation absorption on the unsteady MHD free convective flow past a semi-infinite vertical permeable moving plate with heat source and suction.

Combined heat and mass transfer problems with chemical reaction, are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. In the processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electric power is one in which, electrical energy is extracted directly from a moving conducting fluid. Very recently Raghunath and Mohanaramana [27] have studied Hall, Soret, and Rotational Effects on Unsteady MHD Rotating flow of A Second-Grade Fluid through a Porous Medium in the Presence of Chemical Reaction and aligned magnetic field. Raghunath *et al.,* [28] have discussed Hall and Ion Slip Radiative Flow of Chemically Reactive Second grade through Porous Saturated Space via Perturbation approach. Raghunath *et al.,* [29] studied Effects of Soret, Rotation, Hall, and Ion Slip on unsteady MHD flow of a Jeffrey Fluid through a Porous Medium in the Presence of Heat absorption and chemical reaction In the study of Alam *et al.,* [30] an analysis is carried out to investigate the effects of variable chemical reaction, thermophoresis, temperature-dependent viscosity and thermal radiation on an unsteady MHD free convective heat and mass transfer flow of a viscous, incompressible, electrically conducting fluid past an impulsively started infinite inclined porous plate. The results show that, higher order chemical reaction induces the concentration of the particles for a destructive reaction, and reduces for a generative reaction. Rashad *et al.,* [31] considered MHD free convective heat and mass transfer of a chemically reacting fluid, from radiate stretching surface embedded in a saturated porous medium. The Uri *et al.,* [32], studied unsteady double diffusive MHD boundary layer flow of chemically reacting fluid, over a flat permeable surface.

In spite of all the above studies, the aim of the present study is to analyze the effects of Radiation absorption and Chemical reaction an unsteady MHD free convection Kuvshinski fluid flow immersed in a porous medium over an inclined plate. The expressions are obtained for velocity, temperature and concentration and studied with the help of graphs in the presence of various physical parameters. The effects of various parameters on the skin-friction coefficient and the rate of heat and mass transfer at the surface are presented in the form of tables. Comparisons with previously published work performed and the results are found to be in the excellent agreement.

2. Mathematical Formulation

In this work, the combined effects of Radiation absorption and Chemical reaction on free convection flow of an incompressible and electrically conducting Kuvshinski fluid through porous medium with inclined plates. A homogenous first order chemical reaction between fluid and the species concentration is considered, in which the rate of chemical reaction is directly proportional to the species concentration. The magnetic Reynolds number is so small that the induced magnetic field can be neglected. Also no applied or polarized voltages exist so the effect of polarization of fluid is negligible. All the fluid properties except the density in the buoyancy force term are constants. The flow configuration of the problem is presented in Figure 1.

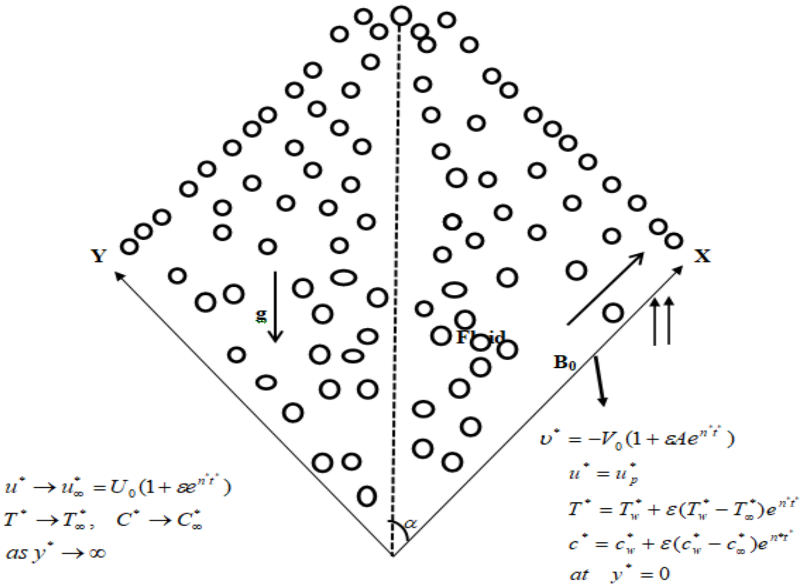

Fig. 1. The flow configuration of the problem

By considering the above assumptions, the governing equations are given by

$$\frac{\partial \mathbf{v}*}{\partial \mathbf{y}*} = \mathbf{0} \rightarrow \mathbf{v}^* = -\mathbf{v_0}(\mathbf{v_0} > \mathbf{0}) \tag{1}$$

$$\left[\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\frac{\partial u*}{\partial t*} + v*\frac{\partial u*}{\partial y*}\right] = -\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\frac{1}{\rho}\frac{\partial p*}{\partial x*} + \vartheta\frac{\partial^2 u*}{\partial y*^2} + g\beta_T(T*-T_\infty^*)Cos\alpha + g\beta_C(C*-C_\infty^*)Cos\alpha - \left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\left(\frac{\sigma B_0^2}{\rho}u* - \frac{\vartheta u*}{k^*}\right) \tag{2}$$

$$\left[\left(\mathbf{1}+\boldsymbol{\lambda}^*\frac{\partial}{\partial t^*}\right)\frac{\partial \boldsymbol{T}*}{\partial \boldsymbol{t}*} + \boldsymbol{v}*\frac{\partial \boldsymbol{T}*}{\partial \boldsymbol{y}*}\right] = \frac{\boldsymbol{K}}{\rho \boldsymbol{C_p}}\frac{\partial^2 \boldsymbol{T}*}{\partial \boldsymbol{y}*^2} - \frac{\mathbf{1}}{\rho \boldsymbol{C_p}}\frac{\partial \boldsymbol{q_r}*}{\partial \boldsymbol{y}*} - \frac{\boldsymbol{Q}*}{\rho \boldsymbol{C_p}}(\boldsymbol{T}*-\boldsymbol{T}_\infty^*) + \boldsymbol{Q}_1^*(\boldsymbol{C}*-\boldsymbol{C}_\infty^*) \tag{3}$$

$$\left[\left(\mathbf{1}+\boldsymbol{\lambda}^*\frac{\partial}{\partial t^*}\right)\frac{\partial \boldsymbol{C}*}{\partial \boldsymbol{t}*} + \boldsymbol{v}*\frac{\partial \boldsymbol{C}*}{\partial \boldsymbol{y}*}\right] = \boldsymbol{D}\frac{\partial^2 \boldsymbol{C}*}{\partial \boldsymbol{y}*^2} - \boldsymbol{K}^*\ (\boldsymbol{C}*-\boldsymbol{C}_\infty^*) \tag{4}$$

Under the above assumptions, the appropriate boundary conditions for the distributions of velocity, temperature and concentration are given by

$$\boldsymbol{u}*=\boldsymbol{u}_p^*, \boldsymbol{T}*=\boldsymbol{T}_w^*+\boldsymbol{\varepsilon}(\boldsymbol{T}_w^*-\boldsymbol{T}_\infty^*)\boldsymbol{e}^{\boldsymbol{n}^*\boldsymbol{t}^*}, \boldsymbol{C}*=\boldsymbol{C}_w^*+\boldsymbol{\varepsilon}(\boldsymbol{C}_w^*-\boldsymbol{C}_\infty^*)\boldsymbol{e}^{\boldsymbol{n}^*\boldsymbol{t}^*} \text{at} \boldsymbol{y}^*=\mathbf{0} \ \boldsymbol{u}*\rightarrow \boldsymbol{u}_\infty^* = \boldsymbol{U_0}(\mathbf{1}+\boldsymbol{\varepsilon}\boldsymbol{e}^{\boldsymbol{n}^*\boldsymbol{t}^*}), \rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\ \boldsymbol{T}*\rightarrow \boldsymbol{T}_\infty^* \boldsymbol{C}*\rightarrow \boldsymbol{C}_\infty^* \text{as} \boldsymbol{y}^* \rightarrow \infty \tag{5}$$

where u* and v* are velocity components in x* and y* directions respectively, g is the acceleration due to gravity, β is the thermal expansion coefficient, T* is the temperature of the fluid, $T_\infty^*$the temperature away from the plate, T_W^* the temperature near the plate, β* is the mass expansion coefficient, C* is the concentration of the fluid, $C_\infty^*$is the concentration away from the Plate, $C_W^*$is the concentration near the plate, σ is the magnetic permeability of the fluid, B_o is the Coefficient of magnetic field, q_r* is the Radiation heat flux density, ρ is the density of the fluid, α is the inclined angle, ϑ is the kinematic viscosity, k* is the permeability of porous medium, C_p is the specific heat at constant pressure, D is the chemical molecular diffusivity, D_1thermal diffusion coefficient, K^* is the chemical reaction rate constant , ε is the scalar constant, n is the dimensionless exponential index.

The equation of continuity yields that $v^*$is either a constant or some function of time, hence assuming that

$$\mathbf{v}* = -v_0(1+ A\,\varepsilon\, e^{n^*t^*}) \tag{6}$$

where A is a real positive constant, ε and Aε are small less than unity, V_0 is the scale of the suction velocity which has a non-zero positive constant.
Outside the boundary layer, Eq. (2) gives

$$-\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\frac{1}{\rho}\frac{\partial p*}{\partial x*}=\frac{\partial U_\infty}{\partial t*}+\frac{v}{k^*}U_\infty^*+\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\left(\frac{\sigma B_0^2}{\rho}U_\infty^* Sin^2\gamma\right) \tag{7}$$

We consider a mathematical model, for an optically thin limit gray gas near equilibrium in the form given by Cramer and Pai [32]. Later Grief *et al.,* [33].

$$\frac{\partial q_r*}{\partial y*}=4(T^*-T_w^*)I \tag{8}$$

where $I=\int_0^\infty K_{\lambda\omega}\left(\frac{\partial_{eb\lambda}}{\partial T}\right)_\omega d\lambda, K_{\lambda\omega}$the absorption coefficient at the wall and ebλ is Planck's function.

To normalize the mathematical model of the physical problem, introduce the following non-dimensional quantities and parameters

$$U_\infty=\frac{U_\infty^*}{U_0},U_p=\frac{U_p^*}{U_0},u=\frac{u*}{U_0},y=\frac{U_0 y*}{\vartheta},n=\frac{n^*\vartheta}{U_0^2},v=\frac{v^*}{U_0},\theta=\frac{T*-T_\infty^*}{T_w^*-T_\infty^*},\varphi=\frac{C*-C_\infty^*}{C_w^*-C_\infty^*},$$
$$Pr=\frac{\mu C_p}{K_T},Sc=\frac{\vartheta}{D},Q_1=\frac{\vartheta Q_1^*}{U_0^2}\frac{C_w^*-C_\infty^*}{T_w^*-T_\infty^*},Gr=\frac{\vartheta g\beta_T(T_w^*-T_\infty^*)}{U_0^3},Gm=\frac{\vartheta g{\beta_c}^*(C_w^*-C_\infty^*)}{U_0^3},$$
$$M=\frac{\sigma B_0^2\vartheta}{\rho U_0^2},K=\frac{U_0^2K_0^*}{\vartheta^2},t=\frac{t*U_0^2}{4\vartheta},K=\frac{\vartheta K^*}{U_0^2},Q=\frac{Q_1 v}{U_0^2},\lambda_1=\frac{\lambda_1^* v_0^2}{\vartheta}F=\frac{4I_1 v}{\rho C_p v_0^2} \tag{9}$$

The non-dimensional form of the Eq. (2) to (4) are

$$\left[\left(1+\lambda_1\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t}-(1+A\varepsilon e^{nt})\frac{\partial u}{\partial y}\right]=\left(1+\lambda_1\frac{\partial}{\partial t}\right)\frac{dU_\infty}{dt}+\frac{\partial^2 u}{\partial y^2}+Gr\theta Cos\alpha+$$
$$Gm\rightleftarrows\varphi Cos\alpha+(M+1/k)\left(1+\lambda_1\frac{\partial}{\partial t}\right)(U_\infty-u) \tag{10}$$

$$\left[\left(1+\lambda_1\frac{\partial}{\partial t}\right)\frac{\partial\theta}{\partial t}-(1+A\varepsilon e^{nt})\frac{\partial\theta}{\partial y}\right]=\frac{1}{Pr}\frac{\partial^2\theta}{\partial y^2}-(F+Q)\theta+Q_1\varphi$$
(11)

$$\left[\left(\mathbf{1}+\boldsymbol{\lambda_1}\frac{\partial}{\partial t}\right)\frac{\partial\boldsymbol{\varphi}}{\partial t}-\left(\mathbf{1}+\boldsymbol{A\varepsilon e^{nt}}\right)\frac{\partial\boldsymbol{\varphi}}{\partial y}\right]=\frac{\mathbf{1}}{\boldsymbol{Sc}}\frac{\partial^2\boldsymbol{\varphi}}{\partial y^2}-\boldsymbol{K\varphi}$$
(12)

The corresponding boundary conditions are given by

$$u=U_p\theta=1+\varepsilon e^{nt}\varphi=1+\varepsilon e^{nt},\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\ at\ \rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\ y=0$$
$$U\to U_\infty=1+\varepsilon e^{nt},\theta\to 0,\varphi\to 0 as y\to\infty \tag{13}$$

3. Method of Solution

The set of Eq. (10) – (12) are partial differential equations which cannot be solved in closed form. However, these can be solved by reducing them into a set of ordinary differential equations using the following perturbation method. Now represent the velocity, temperature and concentration distributions in terms of harmonic and non-harmonic functions as

$$u(y,t)=u_0(y)+\varepsilon u_1(y)e^{nt}+O(\varepsilon^2)$$
$$\theta(y,t)=\theta_0(y)+\varepsilon\theta_1(y)e^{nt}+O(\varepsilon^2)$$
$$\varphi(y,t)=\varphi_0(y)+\varepsilon\varphi_1(y)e^{nt}+O(\varepsilon^2) \tag{14}$$

Substituting Eq. (14) into Eq. (10) – (12), and equating the harmonic and non-harmonic terms, and neglecting the higher order terms of ε, obtain the following pairs of equations of order zero and order one.

3.1 Zero Order Terms

$$\boldsymbol{u''_0}+\boldsymbol{u'_0}-(\boldsymbol{M}+\mathbf{1}/\boldsymbol{k})\ \mathrm{u_0}=\mathrm{-Grcos}\boldsymbol{\alpha}\ \boldsymbol{\theta_0}\ \mathrm{-\ Gmcos}\boldsymbol{\alpha\varphi_0}-(\boldsymbol{M}+\mathbf{1}/\boldsymbol{k})$$
(15)

$$\boldsymbol{\theta''_0}+\boldsymbol{Pr}\,\boldsymbol{\theta'_0}-(\boldsymbol{F}+\boldsymbol{Q})\mathrm{Pr}\boldsymbol{\theta_0}=-\boldsymbol{Q_1}\,\boldsymbol{Pr}\,\boldsymbol{\varphi_0} \tag{16}$$

$$\boldsymbol{\phi_0^{ll}}+\boldsymbol{Sc}\quad\boldsymbol{\phi_0^{l}}-\mathrm{Sc}\boldsymbol{K\phi_0}=0 \tag{17}$$

3.2 First Order Terms

$$\boldsymbol{u''_1}+\boldsymbol{u'_1}-((\boldsymbol{M}+\mathbf{1}/\boldsymbol{k})+\boldsymbol{n}+\boldsymbol{\lambda_1 n^2})\ \mathrm{u_1}=\mathrm{-Grcos}\boldsymbol{\alpha}\ \boldsymbol{\theta_1}\ \mathrm{-\ Gmcos}\boldsymbol{\alpha\varphi_1}-\boldsymbol{Au_0^l}-((\boldsymbol{M}+\mathbf{1}/\boldsymbol{k})+\boldsymbol{n}+\boldsymbol{\lambda_1 n^2}) \tag{18}$$

$$\boldsymbol{\theta''_1}+\boldsymbol{Pr}\,\boldsymbol{\theta'_1}-(\boldsymbol{n}+\boldsymbol{\lambda_1 n^2}+\boldsymbol{F}+\boldsymbol{Q})\mathrm{Pr}\ \boldsymbol{\theta_1}=-\mathrm{Pr}\boldsymbol{A\theta'_0}\mathrm{-Q_1}\,\boldsymbol{Pr}\,\boldsymbol{\varphi'_1}$$
(19)

$$\boldsymbol{\phi_1^{ll}}+\boldsymbol{Sc}\quad\boldsymbol{\phi_1^{l}}-\mathrm{Sc}(\boldsymbol{K}+\boldsymbol{n}+\boldsymbol{\lambda_1 n^2})\boldsymbol{\phi_1}=\mathrm{-ASc}\boldsymbol{\phi_0^{l}} \tag{20}$$

The corresponding boundary conditions are

$$\boldsymbol{u_0}=\boldsymbol{U_p},\boldsymbol{u_1}=\mathbf{0},\boldsymbol{\theta_0}=\mathbf{1},\boldsymbol{\theta_1}=\mathbf{1},\boldsymbol{C_0}=\mathbf{1},\boldsymbol{C_1}=\mathbf{1}\boldsymbol{at}\ \rightleftarrows\rightleftarrows\rightleftarrows\rightleftarrows\ \boldsymbol{y}=\mathbf{0}$$
$$\boldsymbol{u_0}=\mathbf{1},\boldsymbol{u_1}=\mathbf{1},\boldsymbol{\theta_0}\to\mathbf{0},\boldsymbol{\theta_1}\to\mathbf{0},\boldsymbol{C_0}\to\mathbf{0},\boldsymbol{C_1}\to\mathbf{0}\boldsymbol{asy}\to\infty \tag{21}$$

Solving Eq. (15) – (20) under the boundary conditions (21), the following solutions are obtained

$$\theta_0 = a_3\, exp(-m_1 y) + a_4\, exp(-m_3 y) \tag{22}$$

$$\phi_0 = exp(-m_1 y) \tag{23}$$

$$u_0 = 1 + a_9\, exp(-m_1 y) + a_{10}\, exp(-m_2 y) + a_{11}\, exp(-m_5 y) \tag{24}$$

$$\phi_1 = a_1\, exp(-m_1 y) + a_2\, exp(-m_2 y) \tag{25}$$

$$\theta_1 = a_5\, exp(-m_1 y) + a_6\, exp(-m_2 y) + a_7\, exp(-m_3 y) + a_8\, exp(-m_4 y) \tag{26}$$

$$\boldsymbol{u_1 = 1 + a_{12}\, exp(-m_1 y) + a_{13}\, exp(-m_2 y) + a_{14}\, exp(-m_3 y) + a_{15}\, exp(-m_4 y) + a_{16}\, exp(-m_5 y) + a_{17}\, exp(-m_6 y)} \tag{27}$$

Substituting Eq. (22)–(27) in Eq. (14), obtain the velocity, temperature and concentration distribution in the boundary layer as follows

$$u = (1 + a_9\, exp(-m_1 y) + a_{10}\, exp(-m_2 y) + a_{11}\, exp(-m_5 y)) + \varepsilon e^{nt} \begin{pmatrix} 1 + a_{12}\, exp(-m_1 y) + a_{13}\, exp(-m_2 y) + a_{14}\, exp(-m_3 y) + \\ a_{15}\, exp(-m_4 y) + a_{16}\, exp(-m_5 y) + a_{17}\, exp(-m_6 y) \end{pmatrix} \tag{28}$$

$$\theta = (a_3\, exp(-m_1 y) + a_4\, exp(-m_3 y)) + \varepsilon e^{nt} \begin{pmatrix} a_5\, exp(-m_1 y) + a_6\, exp(-m_2 y) + \\ a_7\, exp(-m_3 y) + a_8\, exp(-m_4 y) \end{pmatrix} \tag{29}$$

$$\boldsymbol{\varphi = exp(-m_1 y) + \varepsilon e^{nt}(a_1\, exp(-m_1 y) + a_2\, exp(-m_2 y))} \tag{30}$$

The skin friction co-efficient, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow. These parameters can be defined and determined as follows

$$\boldsymbol{\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = -(m_1 a_9 + m_2 a_{10} + m_5 a_{11}) - \varepsilon e^{nt}(m_1 a_{12} + m_2 a_{13} + m_3 a_{14} + m_4 a_{15} + m_5 a_{16} + m_6 a_{17})} \tag{31}$$

$$\boldsymbol{Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = m_1 a_3 + m_3 a_4 + \varepsilon e^{nt}(m_1 a_5 + m_3 a_5 + m_1 a_7 + m_3 a_8)} \tag{32}$$

$$\boldsymbol{Sh = -\left(\frac{\partial \varphi}{\partial y}\right)_{y=0} = m_1 + \varepsilon e^{nt}(m_1 a_1 + m_2 a_2)} \tag{33}$$

4. Results and Discussion

In this paper, the unsteady magneto-hydrodynamic mixed convection flow over an inclined permeable moving plate in presence of aligned magnetic field, thermal radiation, heat absorption and homogenous chemical reaction, subjected to the variable suction are discussed in detail through graphs from Figure 1-13. The governing equations are having non- linear nature and have been solved by analytical method. The objective of this section is to analyze the behaviour of various involved parameters such as inclined angle (α), visco-elastic parameter (λ), Magnetic field parameter (M), Permeability of porous medium (k), Grashof number (Gr), modified Grashof number (Gm), Heat absorption coefficient (Q), prandtl number(Pr), radiation parameter (F), Schmidt number (Sc), chemical reaction parameter (K), on the velocity, temperature and concentration profiles. As well as the variation of skin friction, rate of heat and mass transfers in term of Nusselt and Sherwood numbers for various values of the involved parameters are shown in Table 1.

Figure 2 depicts the influence of the Hartmann number on velocity with a rise in the Hartmann number, the velocity falls. It's because the introduction of a transverse magnetic field produces a resistive type force (Lorentz force) that acts like a drag force, resisting fluid flow and lowering its velocity. In addition, when the Hartmann number raises, the thickness of the boundary layer decreases. The influence of the permeability of the porous media parameter on the velocity distribution is shown in Figure 3. As can be seen, the velocity rises as the dimensionless porous media parameter rises. Physically, this outcome may be obtained by ignoring the holes in the porous substance. Figures 4 and 5, effects of thermal and solute buoyancy on velocity is presented, in which it is noticed that velocity increases in both the cases as both the parameters namely Grashof number and modified Grashof number increase. It can be seen in Figure 6 that the angle of inclination (α) decreases the effect of the buoyancy force due to thermal diffusion. Consequently, the driving force to the fluid decreases as a result velocity of the fluid decreases. Figure 7 presents the velocity profiles for different values of visco-elastic parameter (λ). Velocity is observed to be increasing with the increase in visco-elastic parameter.

Figure 8 and 9 shows the effect of the radiation absorption parameter on velocity and temperature respectively. It is clear from these graphs that both velocity and temperature raises as the radiation absorption parameter rises. Because thermal radiation is linked with high temperature. Figure 10 illustrate the influence of the heat absorption coefficient Q on the temperature profile. Physically speaking, the presence of heat absorption (thermal sink) effects has the tendency to reduce the fluid temperature. Figure 11 depicts the effect of Prandtl number (Pr) on temperature profiles in presence of some selected fluids such as Hydrogen (Pr = 0.68), Air (Pr = 0.71), Carbon dioxide (Pr = 0.76) and Electrolytic solution (Pr = 1). From this figure, observed that, an increase in the Prandtl number decreases the temperature of the flow field at all points. Due to the ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity.

The influence of Schmidt number (Sc) on the velocity and concentration profiles is shown in Figure 12 .Graphical result of concentration profile for different values of Schmidt number Sc shows that with an increase in Sc, decreases the concentration profile. Physically this is true because of the fact that the water vapors can be used for maintaining normal concentration field whereas hydrogen can be used for maintaining effective concentration field. Figure 13, depicts the influence of chemical reaction effect on concentration. This figure witness that concentration decreases with an increase in the values of chemical reaction parameter.

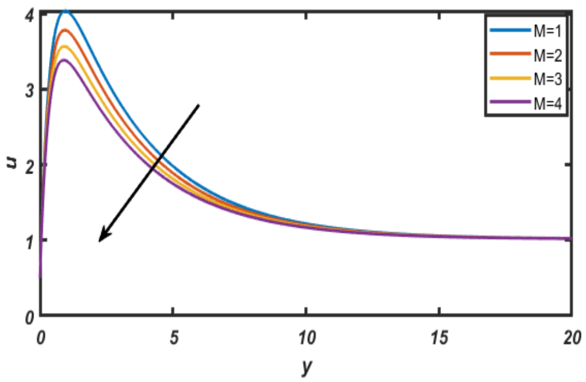

Fig. 2. The Influence of Magnetic field parameter (M) on velocity profiles

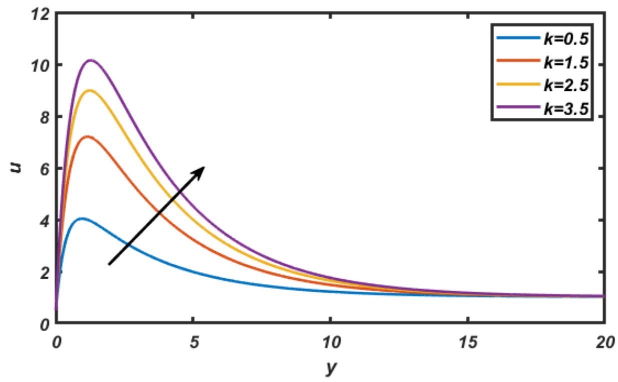

Fig. 3. The Influence of Permeability of porous media (k) on velocity profiles

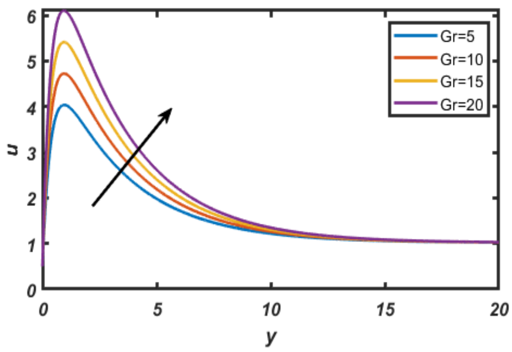

Fig. 4. The Influence of thermal Grashof number (Gr) on velocity profiles

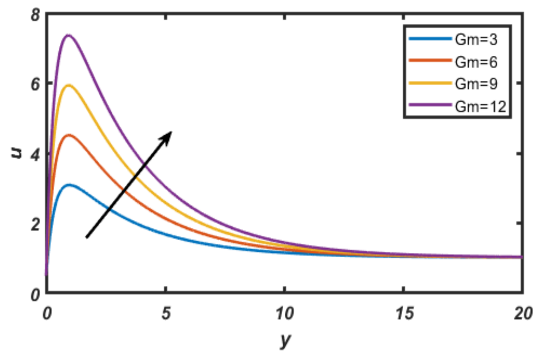

Fig. 5. The Influence of mass Grashof number (Gm) on velocity profiles

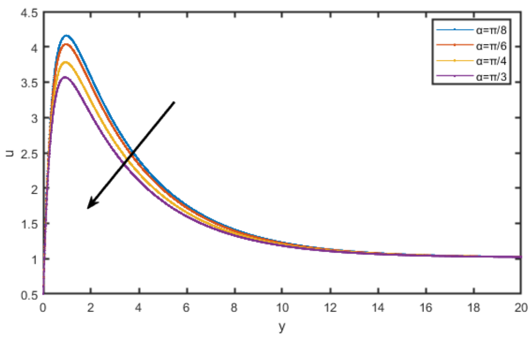

Fig. 6. The Influence of Inclined angle (α) parameter on velocity profiles

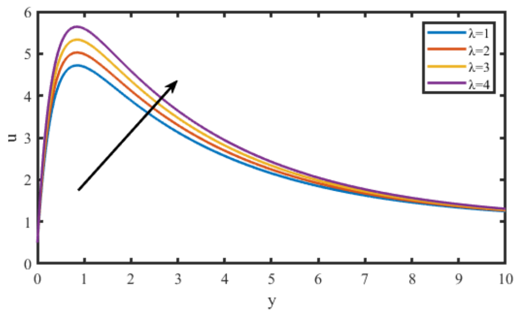

Fig. 7. The Influence of visco-elastic parameter (λ) on velocity profiles

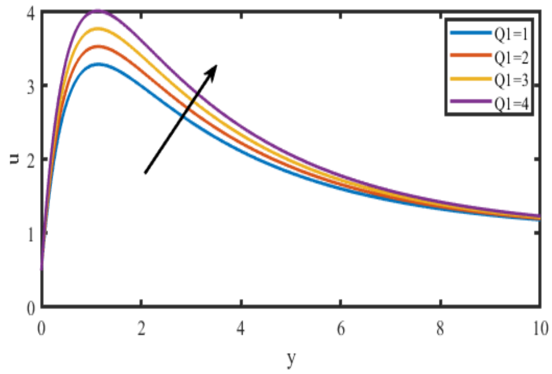

Fig. 8. The Influence of Radiation absorption (Q_1) parameter on velocity profiles

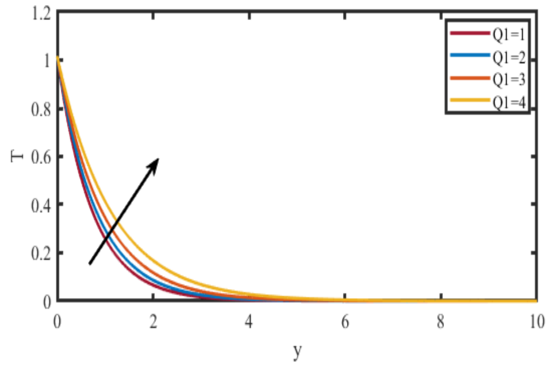

Fig. 9. The Influence of Radiation absorption (Q_1) parameter on Temperature profiles

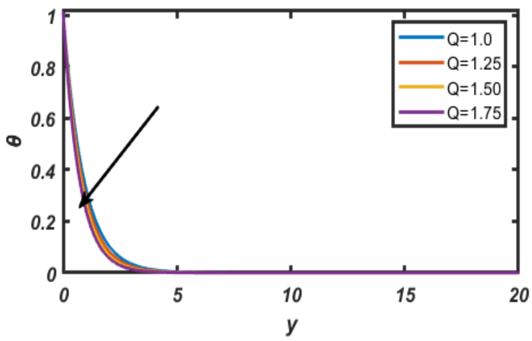

Fig. 10. The influence of Heat absorption coefficient (Q) on Temperature profiles

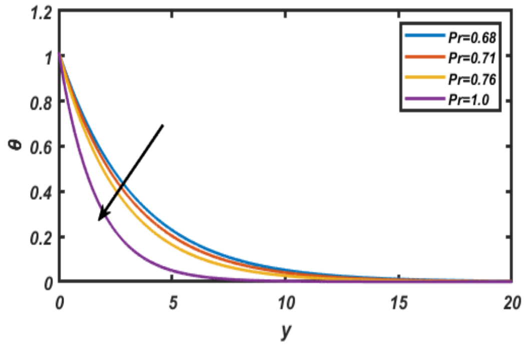

Fig. 11. The influence of Prandtl number (Pr) on Temperature profiles

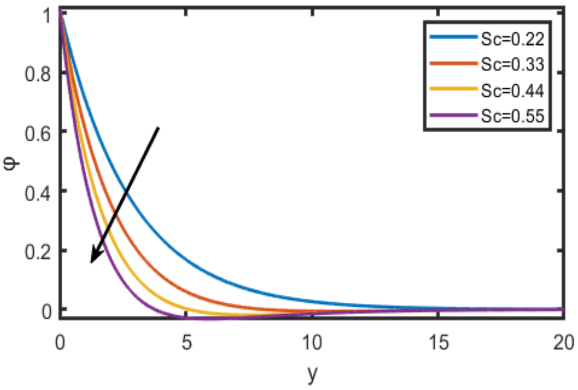

Fig. 12. The influence of Schmidt number (Sc) on Concentration profiles

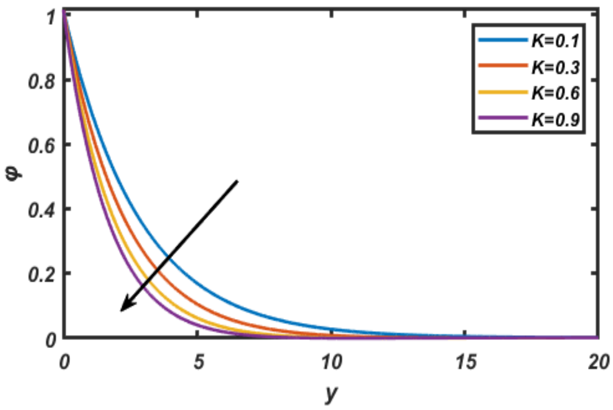

Fig. 13. The influence of Chemical reaction parameter (K) on Concentration profiles

The variation in skin-friction coefficient, the rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number for various parameters are studied through Table 1. For the validity of our work to compared our results with the existing results of Mohanaramana *et al.,* [11]. Our result appears to be in excellent agreement with the existing results.

Table 1
The consequence of numerous quantities on the skin friction Nusselt number and Sherwood Number for Sc=0.22, Pr=0.71, Gr=5, k=0.5, K=0.1, M=1, Q=0.1, E=0.01, A=0.5, F=0.01, α=π/6, Gm=5, λ=0.5, t=0.5, n=1, Up=0.5, Q_1=0

Sc	k	Q	Sr	Pr	t	K_c	τ (previous) Mohanarama na *et al.,* [11]	τ (present)	Nu (previous) Mohanarama na *et al.,* [11]	Nu (present)	Sh (previous) Mohanarama na *et al.,* [11]	Sh (present)
0.22	0.5	1	0.3	0.71	0.5	1	3.3717	3.2325	-1.5796	-1.4587	-0.3995	-0.4001
0.3							3.2982	3.2478	-1.7797	-1.7521	-0.5409	-0.5452
0.6							3.2148	3.1254	-2.3370	-2.2477	-0.7564	-0.7522
0.6	0.1	1	0.3	0.71	0.5	0.1	3.3938	3.3657	-1.5796	-1.5788	-0.0864	-0.0120
	0.2			2		0.2	3.3604	3.4225	-3.4690	-3.5621	-0.1255	-0.1247
	0.3			7.0		0.3	3.3431	3.3141	-10.727	-10.865	-0.8443	-0.8121
0.6	0.5	0	0.3	0.71	0.1	1	3.7057	3.6558	-1.5823	-1.5877	-1.1686	-1.1452
		1			0.2		3.2148	3.1954	-1.5856	-1.4952	-1.2340	-1.2520
		2			0.3		3.1880	3.1985	-1.5880	-1.5895	-0.8995	-0.2845
0.6	0.5	1	1	0.71	0.5	1	3.2148	3.3001	-1.6512	-1.5412	-0.9487	-0.9052
			1.5				3.5740	3.5477	-1.7782	-1.8522	-0.8457	-0.8452
			2				3.6832	3.6874	-1.8457	-1.8922	-0.6487	-0.6452

5. Conclusion

In the present investigation have studied analytically Radiation absorption and Chemical Reaction effects on Unsteady MHD Kuvshinski fluid flow past an inclined porous plates. From the present investigation the following conclusions can be drawn.

The Fluid velocity rises when the Visco velocity parameter (λ), Grashof number(Gr) and modified Grashof number (Gm) rise, as does the porous medium's permeability parameter (k), but it decreases when the magnetic parameter (M) and inclination angle (α) are present. The fluid velocity and temperature enhances with increasing Radiation absorption (Q1). The fluid temperature decreases with the effect of the Prandtl number (Pr) and heat source parameter (Q). The concentration level of the fluid diminishes when an increasing chemical reaction parameter (K) and the Schmidt number (Sc).

References

[1] Mukhopadhyay, Swati. "Slip effects on MHD boundary layer flow over an exponentially stretching sheet with suction/blowing and thermal radiation." *Ain Shams Engineering Journal* 4, no. 3 (2013): 485-491. https://doi.org/10.1016/j.asej.2012.10.007

[2] Rajagopal, Kumbakonam R., T. Y. Na, and A. S. Gupta. "Flow of a viscoelastic fluid over a stretching sheet." *Rheologica Acta* 23 (1984): 213-215. https://doi.org/10.1007/BF01332078

[3] Andersson, H. I. "MHD flow of a viscoelastic fluid past a stretching surface." *Acta Mechanica* 95, no. 1-4 (1992): 227-230. https://doi.org/10.1007/BF01170814

[4] Ariel, P. D. "MHD flow of a viscoelastic fluid past a stretching sheet with suction." *Acta mechanica* 105, no. 1-4 (1994): 49-56. https://doi.org/10.1007/BF01183941

[5] Datti, P. S., K. V. Prasad, M. Subhas Abel, and Ambuja Joshi. "MHD visco-elastic fluid flow over a non-isothermal stretching sheet." *International Journal of Engineering Science* 42, no. 8-9 (2004): 935-946. https://doi.org/10.1016/j.ijengsci.2003.09.008

[6] Liu, I-Chung. "Flow and heat transfer of an electrically conducting fluid of second grade over a stretching sheet subject to a transverse magnetic field." *International Journal of Heat and Mass Transfer* 47, no. 19-20 (2004): 4427-4437. https://doi.org/10.1016/j.ijheatmasstransfer.2004.03.029

[7] Khan, Sujit Kumar, and Emmanuel Sanjayanand. "Viscoelastic boundary layer flow and heat transfer over an exponential stretching sheet." *International Journal of Heat and Mass Transfer* 48, no. 8 (2005): 1534-1542. https://doi.org/10.1016/j.ijheatmasstransfer.2004.10.032

[8] Balamurugan, K. S., P. Ramaiah, S. V. K. Varma, and J. L. Ramaprasad. "Thermal radiation and radiation absorption effects on unsteady MHD double diffusive free convection flow of Kuvshinski fluid past a moving porous plate embedded in a porous medium with chemical reaction and heat generation." *Far East Journal of Mathematical Sciences* 91, no. 2 (2014): 211.

[9] Rama Prasad, J. L., K. S. Balamurugan, and S. V. K. Varma. "Aligned magnetic field effect on unsteady MHD double diffusive free convection flow of Kuvshinski fluid past an inclined moving porous plate." In *Advances in Fluid Dynamics: Selected Proceedings of ICAFD 2018*, pp. 255-262. Springer Singapore, 2021. https://doi.org/10.1007/978-981-15-4308-1_20

[10] Rajakumar, K. V. B., M. Umasankara Reddy, K. S. Balamurugan, and K. V. B. S. Raja Ram. "Steady MHD Casson ohmic heating and viscous dissipative fluid flow past an infinite vertical porous plate in the presence of Soret, Hall, and ion-slip current." *Heat Transfer* 49, no. 3 (2020): 1583-1612. https://doi.org/10.1002/htj.21680

[11] Mohana Ramana, R., K. Venkateswara Raju, and K. Raghunath. "Chemical reaction with aligned magnetic field effects on unsteady MHD Kuvshinski fluid flow past an inclined porous plate in the presence of radiation and Soret effects." *Heat Transfer* 51, no. 7 (2022): 6431-6449. https://doi.org/10.1002/htj.22598

[12] Raghunath, Kodi. "Study of Heat and Mass Transfer of an Unsteady Magnetohydrodynamic (MHD) Nanofluid Flow Past a Vertical Porous Plate in the Presence of Chemical Reaction, Radiation and Soret Effects." *Journal of Nanofluids* 12, no. 3 (2023): 767-776. https://doi.org/10.1166/jon.2023.1965

[13] Raghunath, K., R. Mohana Ramana, V. Ramachandra Reddy, and M. Obulesu. "Diffusion Thermo and Chemical Reaction Effects on Magnetohydrodynamic Jeffrey Nanofluid Over an Inclined Vertical Plate in the Presence of Radiation Absorption and Constant Heat Source." *Journal of Nanofluids* 12, no. 1 (2023): 147-156. https://doi.org/10.1166/jon.2023.1923

[14] Maatoug, Samah, K. Hari Babu, V. V. L. Deepthi, Kaouther Ghachem, Kodi Raghunath, Charankumar Ganteda, and Sami Ullah Khan. "Variable chemical species and thermo-diffusion Darcy–Forchheimer squeezed flow of Jeffrey nanofluid in horizontal channel with viscous dissipation effects." *Journal of the Indian Chemical Society* 100, no. 1 (2023): 100831. https://doi.org/10.1016/j.jics.2022.100831

[15] Bafakeeh, Omar T., Kodi Raghunath, Farhan Ali, Muhammad Khalid, El Sayed Mohamed Tag-ElDin, Mowffaq Oreijah, Kamel Guedri, Nidhal Ben Khedher, and Muhammad Ijaz Khan. "Hall current and Soret effects on unsteady MHD rotating flow of second-grade fluid through porous media under the influences of thermal radiation and chemical reactions." *Catalysts* 12, no. 10 (2022): 1233. https://doi.org/10.3390/catal12101233

[16] Deepthi, V. V. L., Maha MA Lashin, N. Ravi Kumar, Kodi Raghunath, Farhan Ali, Mowffaq Oreijah, Kamel Guedri, El Sayed Mohamed Tag-ElDin, M. Ijaz Khan, and Ahmed M. Galal. "Recent development of heat and mass transport in the presence of Hall, ion slip and thermo diffusion in radiative second grade material: application of micromachines." *Micromachines* 13, no. 10 (2022): 1566. https://doi.org/10.3390/mi13101566

[17] Raghunath, Kodi, Ravuri Mohana Ramana, Charankumar Ganteda, Prem Kumar Chaurasiya, Damodar Tiwari, Rajan Kumar, Dharam Buddhi, and Kuldeep Kumar Saxena. "Processing to pass unsteady MHD flow of a second-grade fluid through a porous medium in the presence of radiation absorption exhibits Diffusion thermo, hall and ion slip effects." *Advances in Materials and Processing Technologies* (2023): 1-18. https://doi.org/10.1080/2374068X.2023.2191450

[18] Kodi, Raghunath, Charankumar Ganteda, Abhishek Dasore, M. Logesh Kumar, G. Laxmaiah, Mohd Abul Hasan, Saiful Islam, and Abdul Razak. "Influence of MHD mixed convection flow for maxwell nanofluid through a vertical cone with porous material in the existence of variable heat conductivity and diffusion." *Case Studies in Thermal Engineering* 44 (2023): 102875. https://doi.org/10.1016/j.csite.2023.102875

[19] Raghunath, Kodi, Mopuri Obulesu, and Konduru Venkateswara Raju. "Radiation absorption on MHD free conduction flow through porous medium over an unbounded vertical plate with heat source." *International Journal of Ambient Energy* (2023): 1-9. https://doi.org/10.1080/01430750.2023.2181869

[20] Li, Shuguang, Kodi Raghunath, Ayman Alfaleh, Farhan Ali, A. Zaib, M. Ijaz Khan, Sayed M. ElDin, and V. Puneeth. "Effects of activation energy and chemical reaction on unsteady MHD dissipative Darcy–Forchheimer squeezed

flow of Casson fluid over horizontal channel." *Scientific Reports* 13, no. 1 (2023): 2666. https://doi.org/10.1038/s41598-023-29702-w

[21] Suresh Kumar, Y., Shaik Hussain, K. Raghunath, Farhan Ali, Kamel Guedri, Sayed M. Eldin, and M. Ijaz Khan. "Numerical analysis of magnetohydrodynamics Casson nanofluid flow with activation energy, Hall current and thermal radiation." *Scientific Reports* 13, no. 1 (2023): 4021. https://doi.org/10.1038/s41598-023-28379-5

[22] Raju, M. C., S. Vijaya Kumar Varma, and N. Anandareddy. "Radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface." *i-Manager's Journal on Future Engineering and Technology* 7, no. 2 (2011): 7. https://doi.org/10.26634/jfet.7.2.1757

[23] Seddeek, M. A., A. A. Darwish, and M. S. Abdelmeguid. "Effects of chemical reaction and variable viscosity on hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation." *Communications in Nonlinear Science and Numerical Simulation* 12, no. 2 (2007): 195-213. https://doi.org/10.1016/j.cnsns.2006.02.008

[24] Ravikumar, V., M. C. Raju, and G. S. S. Raju. "Combined effects of heat absorption and MHD on convective Rivlin-Ericksen flow past a semi-infinite vertical porous plate with variable temperature and suction." *Ain Shams Engineering Journal* 5, no. 3 (2014): 867-875. https://doi.org/10.1016/j.asej.2013.12.014

[25] Ibrahim, F. S., A. M. Elaiw, and A. A. Bakr. "Effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction." *communications in Nonlinear science and Numerical simulation* 13, no. 6 (2008): 1056-1066. https://doi.org/10.1016/j.cnsns.2006.09.007

[26] Chamkha, Ali J., Harmindar S. Takhar, and V. M. Soundalgekar. "Radiation effects on free convection flow past a semi-infinite vertical plate with mass transfer." *Chemical Engineering Journal* 84, no. 3 (2001): 335-342. https://doi.org/10.1016/S1385-8947(00)00378-8

[27] Raghunath, Kodi, and Ravuri Mohanaramana. "Hall, Soret, and rotational effects on unsteady MHD rotating flow of a second-grade fluid through a porous medium in the presence of chemical reaction and aligned magnetic field." *International Communications in Heat and Mass Transfer* 137 (2022): 106287. https://doi.org/10.1016/j.icheatmasstransfer.2022.106287

[28] Kodi, Raghunath, Mohanaramana Ravuri, Nagesh Gulle, Charankumar Ganteda, Sami Ullah Khan, and M. Ijaz Khan. "Hall and ion slip radiative flow of chemically reactive second grade through porous saturated space via perturbation approach." *Waves in Random and Complex Media* (2022): 1-17. https://doi.org/10.1080/17455030.2022.2108555

[29] Raghunath, Kodi, G. Charankumar, and L. Giulio. "Effects of Soret, rotation, Hall, and ion slip on unsteady MHD flow of a Jeffrey fluid through a porous medium in the presence of heat absorption and chemical reaction." *J. Mech. Eng. Res. Dev* 45, no. 3 (2022): 80-97.

[30] Theuri, David, Makinde Oluwole Daniel, and Kabuki Nancy Wangare. "Unsteady double diffusive magneto hydrodynamic boundary layer flow of a chemically reacting fluid over a flat permeable surface." *Austr J Basic Appl Sci* 7, no. 4 (2013): 78-89.

[31] Cramer, Kenneth R., and Shih-I. Pai. "Magnetofluid dynamics for engineers and applied physicists." (1973). https://doi.org/10.1002/eej.4390930120

[32] Greif, R., I. S. Habib, and J. C. Lin. "Laminar convection of a radiating gas in a vertical channel." *Journal of fluid Mechanics* 46, no. 3 (1971): 513-520. https://doi.org/10.1017/S0022112071000673