SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Radiation Absorption and Diffusion Thermo Effects on Unsteady MHD Casson Fluid Flow Past a Moving Inclined Plate Embedded in Porous Medium in the Presence of Chemical Reaction and Thermal Radiation

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ARTICLE INFO

Article history:
Received 15 May 2023
Received in revised form 10 September 2023
Accepted 18 September 2023
Available online 4 October 2023

Keywords:
Casson fluid; inclined plates; chemical reaction; radiation absorption; radiation; porous media

ABSTRACT

The aim of the present paper is to investigate the effects of Radiation absorption and diffusion thermo on unsteady magnetohydrodynamic Casson fluid flow past an inclined permeable moving plate in Presence of thermal radiation, heat absorption and homogenous chemical reaction. The plate is assumed to be embedded in a uniform porous medium and Moves with a constant velocity in the flow direction in the presence of a transverse magnetic Field. The equations governing the flow are transformed into a system of nonlinear ordinary differential equations by using perturbation technique. Graphical results for the velocity distribution, temperature distribution and concentration distribution based on the numerical solutions are presented and discussed. Also discuss the effects of various parameters on the skin-friction coefficient and the rate of heat transfer in the form of Nusselt number and rate of mass transfer in the form of Sherwood number at the surface. Velocity and temperature distribution is observed to increase with an increase in radiation absorption and Dufour parameter, whereas diminishes with enhances of Magnetic field, heat absorption coefficient, radiation parameter and chemical reaction parameter in respective velocity, temperature and concentration distributions.

1. Introduction

In geophysical science and technology, the current study is useful to calculate as well as learning the position as well as velocity by regard to the enduring structure of references onto the exterior of the earth it revolves with the inertial structures underneath the intensity of the magnetic fields. The regions of geo-physical mechanisms these days have become essential branches of fluid mechanics due to the attractive interests to studying atmospheric science. In astrophysical science it is utilized to find out the stellar in addition to solar constructions, inter planetary as well as inter stellar matter, solar storms in addition to flames etc. In the engineering, those determined their application into MHD powers generators, ions propulsions, MHD bearings, MHD pumping, MHD frontier stratum

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https://doi.org/10.37934/araset.32.3.92107

control of re-entry vehicle. The magnetic fields impact on trembling liberated and/or normal convection movements during an absorbent media had been imperative applications into the subjects of astrologic as well as terrestrial magnetosphere, movements on aeronautic plasmas, industrially and/or chemically engineering as well as those significance to nuclear exploitation disposals, absorbent temperature exchangers, thermally insulation as well as a quantity of reasonable applications. The temperature as well as accumulation transport was utilized in the food's dispensations, wet-rhizomes thermometers as well as polymers solutions in addition to these are preserved in the formations of agricultural engineering in addition to technologies.

The modern progress in technology required the significant revolutions into the domain of temperature transportations. Regardless of the complicatedness of non-Newtonian fluid, sensible mathematics in addition to engineering researchers are associated in the non-Newtonians liquids dynamics because of, the flows as well as temperature transportations features of those liquids is an imperative to plentiful as well as a range of systems in bio-tech, pharmaceutical as well as chemical engineering, etc. In expansively, non-Newtonian modelling has non-linearly relationships bordered by stresses in addition to pace of strains. The mechanical features on non-Newtonian fluids, together thinner as well as sheared thicknesses, regular stresses difference, along with visco-elastic reacting, might not be portrayed by the conservation hypothesis; hence, an innovative and effective prediction is requisites. Dissimilar constitutive model equalities have been recommended to portray the progressive and temperature transportation mechanism, through these, Casson modelling has increased an enormous dealt acceptance. Casson modelling is sustained on the structure modelling of the interaction nature of solid and fluids stages of the two-model suspension. The different well-known illustrations of Casson liquids comprised that, jelly, tomato sauce, honey, soup as well as concentrate fruits juices. Human blood might as well be deemed as Casson liquid owing to the representing of quite a few substances which are protein, fibrinogen, and globulin in aqueous based plasma in addition to human's reddish blood cell. The Casson fluids modelling become non-Newtonian fluids to explore because those of extensive range applications to the range of bio-medical as well as industrial engineering, the energy construction, geo-physical fluid mechanism in addition to dynamics. Between those plentiful non-Newtonian models, Casson fluids modelling is the important and significant rheological modelling as well as it was initially built up by Casson [1].

The fundamental investigations of Casson fluids using homogeneously and heterogeneously reactions have been discovered by Khan *et al.,* [2]. The time contingent MHD Casson fluids enlightened flow past a fluctuating straight up plate entrenched by a spongy media has been researched by Khalid *et al.,* [3] making utilize of Laplace transforms technique. Rauf *et al.,* [4] explored the frontier layered flow of Casson fluids on the sheets stretching in two varied ways depictions to cross wise magnetic field and thermal radiation. Zaib *et al.,* [5] explored on Casson fluids by the impacts of jellylike dissipation stirring on an exponential dwindling sheet. Vaddemani *et al.,* [6] explored the comparison to Casson fluid with the Newtonian fluids over an exponential dwindling sheet under the impacts of thermally radiation.

With its broad range of applications in physics and engineering, especially for equipment design, processes of high-temperature, and space technology, radiation on natural convection has become more prominent. Nuclear power plants, hypersonic aircraft, space vehicles, and other recent advancements in these fields include gas-cooled nuclear reactors. Chemical reactions in the context of collective heat and mass transfer flow issues have received tremendous attention in a variety of chemical engineering processes. Chemical reaction consequences are critical in the dispersion of temperature and moisture across agricultural regions, the manufacture and dispersion of fog, cooling tower designs, and configurations of chemical process apparatuses. Malapati and Polarapu [7] explored the impact of an unsteady MHD flow of viscous, incompressible fluid past a vertical permeable channel under the influence of thermal radiation and chemical reaction, and their outcomes demonstrated that raising the chemical reaction parameter resulted in a slower velocity. Ibrahim *et al.,* [8] investigated an unsteady MHD free convective flow through a semi-infinite vertical permeable plate with a heat generation and suction, according to their results a rise in absorption radiation parameter leads to a rise in the velocity and temperature profiles inside the boundary layer. Maatoug *et al.,* [9] have studied Variable chemical species and thermo-diffusion Darcy–Forchheimer squeezed flow of Jeffrey nanofluid in horizontal channel with viscous dissipation effects. Bafakeeh *et al.,* [10] have analyzed 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. Raghunath and Mohanaramana [11] have possessed 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. Deepthi *et al.,* [12] have discussed Recent Development of Heat and Mass Transport in the Presence of Hall, Ion Slip and Thermo Diffusion in Radiative Second grade material. Numerous researchers and analysts have examined and discussed many intriguing studies on MHD flow past a vertical plate with thermal radiation and chemical reaction [13-17].

MHD is the science of motion of electrically conducting fluids in presence of magnetic field. It concerns with the interaction of magnetic field with the fluid velocity of electrically conducting fluid. MHD generators, MHD pumps and MHD flow meters are some of the numerous examples of MHD principles. Dynamo and motor are classical examples of MHD principle. Convection problems of electrically conducting fluid in presence of magnetic field have got much importance because of its wide applications in Geophysics, Astrophysics, Plasma Physics, Missile technology, etc. MHD principles also find its applications in Medicine and Biology. Magnetohydrodynamics has many industrial applications such as physics, chemistry and engineering, crystal growth, metal casting and liquid metal cooling blankets for fusion reactors. Rehman *et al.,* [18] have studied MHD flow of carbon in micropolar nanofluid with convective heat transfer in the rotating frame. Ahmed *et al.,* [19] have analysed Numerical Computation for Gyrotactic Microorganisms in MHD Radiative Eyring–Powell Nano material Flow by a Static/Moving Wedge with Darcy–Forchheimer Relation. Bafakeeh *et al.,* [20] have discussed 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. Nazeer *et al.,* [21] have possessed theoretical analysis of electrical double layer effects on the multiphase flow of Jeffrey fluid through a divergent channel with lubricated walls. Tharapatla *et al.,* [22] have discussed heat alongside mass transport in a nonlinear free convection magnetohydrodynamics (MHD) non-Newtonian fluid flow with thermal radiation and heat generation deep-rooted in a thermally stratified penetrable medium.

Radiative heat and mass transfer play an important role in manufacturing industries for the design of fins, steel rolling, nuclear power plants, and gas turbines and various propulsion devices for aircraft, missiles, satellites, and space vehicles are examples of such engineering applications. The effect of radiation on MHD flow, heat and mass transfer becomes more important industrially. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. The quality of the final product depends to a great extent on the heat controlling factors, and the knowledge of radiative heat transfer in the system can lead to a desired product with sought qualities. Different researches have been forwarded to analyze the effects of thermal radiation on different flows. Khan *et al.,* [23] have expressed Evaluating the characteristics of magnetic dipole for shear-thinning Williamson nanofluid with thermal radiation. Khan *et al.,* [24] have analyzed Mathematical analysis of thermally radiative time-dependent Sisko nanofluid flow for curved surface. Chu *et al.,* [25] have reviewed radiative thermal analysis for four types of hybrid nanoparticles subject to non-uniform heat source: Keller box numerical approach. Cramer and Pai [26] discussed the effect of thermal radiation on MHD boundary layer flow of nanofluid and heat transfer over a non-linearly stretching sheet with transpiration. Greif *et al.,* [27] explored the thermal radiation and Joule heating effects on a MHD Casson nanofluid flow in the presence of chemical reaction through a non-linear inclined porous stretching sheet. Vaddemani *et al.,* [28] discussed Effects of Hall Current, Activation Energy and Diffusion Thermo of MHD Darcy-Forchheimer Casson Nanofluid Flow in the Presence of Brownian motion and Thermophoresis.

Therefore, the present work can be considered as extension of Vaddemani *et al.,* [6]. So, novelty of this paper is the discussion of the equations govern the flow are transformed into a set of nonlinear differential equations and solved by using a perturbation method and numerical solution using Matlab software of the radiation absorption, Casson fluid and Dufour effect with inclined plates. Due to Unsteady Magnetohydrodynamic flow past a Vertical Permeable Moving Plate in Presence of Thermal Radiation and Homogenous Chemical Reaction. The plate is assumed to be in a uniform porous medium and moves with a uniform velocity direction of the flow in the presence of a transverse magnetic field. 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

The channel considered unsteady MHD two dimensional flows of a laminar, viscous, incompressible, electrically conducting, double diffusive and absorbing fluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal radiation and homogeneous chemical reaction. It is assumed that there is no applied voltage which implies the absence of an electrical field. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall Effect are negligible. x^*-axis is taken in the upward direction along with the flow and y*-axis is taken perpendicular to it. Initially the plate is assumed to be moving with a uniform velocity U_p^* in the direction of the fluid flow, and the free stream velocity follows the exponentially increasing small perturbation law. Besides that, it is assumed that the temperature and the concentration at the wall as well as the suction velocity are exponentially varying with time.

Journal of Advanced Research in Applied Sciences and Engineering Technology
Volume 32, Issue 3 (2023) 92-107

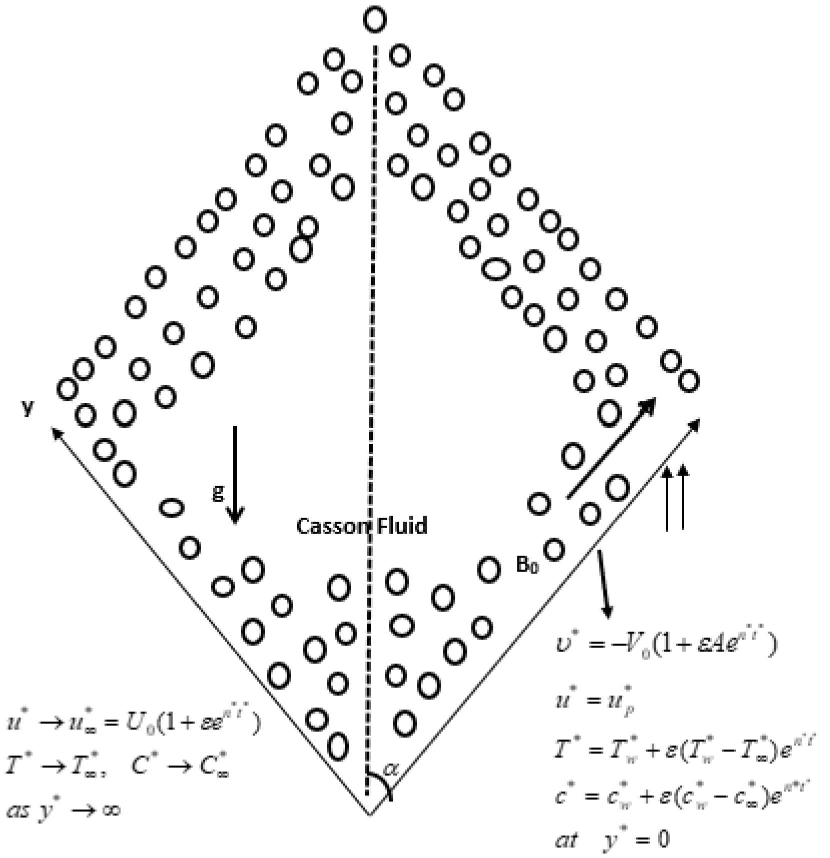

Fig. 1. Physical structure of the problem

By considering the above assumptions, the governing equations are given by [8]:

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

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

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{K}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial y^*} - \frac{Q^*}{\rho C_p}(T^* - T_\infty^*) + Q_1 (C^* - C_\infty^*) + \frac{D K_T}{C_S C_P}\frac{\partial^2 C^*}{\partial y^{*2}} \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - K^* (C^* - C_\infty^*) \tag{4}$$

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

$$u^* = u_p^*, \quad T^* = T_w^* + \varepsilon(T_w^* - T_\infty^*)e^{n^*t^*}, \; C^* = C_w^* + \varepsilon(C_w^* - C_\infty^*)e^{n^*t^*} \quad \text{at } y^* = 0$$
$$u^* \to u_\infty^* = U_0(1 + \varepsilon e^{n^*t^*}), \quad T^* \to T_\infty^* \quad C^* \to C_\infty^* \quad \text{as} \quad y^* \to \infty \tag{5}$$

where u* and v* are velocity components in x* and y* directions respectively, g is the acceleration due to gravity, β_T is the thermal expansion coefficient, T* is the temperature of the fluid, T_∞^* the temperature away from the plate, T_w^* the temperature near the plate, β_c is the mass expansion coefficient, C* is the concentration of the fluid, C_∞^* is the concentration away from the Plate, C_w^* is the concentration near the plate, Q_1 is the Radiation absorption, Du is the Dufour Parameter, 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, ϑ is the kinematic viscosity, k* is the permeability of porous medium, K is the thermal conductivity, C_p is the specific heat at constant pressure, D is the chemical molecular diffusivity, 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:

$$v^* = -V_0(1 + A\,\varepsilon\, e^{n^*t^*}) \tag{6}$$

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:

$$-\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} = \frac{\partial U_\infty}{\partial t^*} + \frac{\upsilon}{k^*}U_\infty^* + \frac{\sigma B_0^2}{\rho}U_\infty^* \tag{7}$$

We consider a mathematical model, for an optically thin limit gray gas near equilibrium in the form given by Cramer and Pai [26] and Later Greif *et al.,* [27].

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

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:

$$u=\frac{u^*}{U_0}, v=\frac{v^*}{v_0}\, y=\frac{U_0 y^*}{\vartheta}, U_\infty=\frac{U_\infty^*}{U_0}, U_p=\frac{U_p^*}{U_0}, \theta=\frac{T^*-T_\infty^*}{T_w^*-T_\infty^*}, \phi=\frac{C^*-C_\infty^*}{C_w^*-C_\infty^*}, K=\frac{\vartheta K^*}{v_0^2}, Q=\frac{Q^* v}{v_0^2}$$

$$\Pr=\frac{\mu C_p}{K_T}, Sc=\frac{\vartheta}{D}, M=\frac{\sigma B_0^2\vartheta}{\rho v_0^2}, t=\frac{t^* v_0^2}{\vartheta}, n=\frac{n^*\vartheta}{v_0^2}, Q_1=\frac{\vartheta Q_1^*(C_w^*-C_\infty^*)}{(T_w^*-T_\infty^*)v_0^2}, F=\frac{4I\upsilon}{\rho C_p v_0^2} \tag{9}$$

$$Gr=\frac{\vartheta g\beta_T(T_w^*-T_\infty^*)}{U_0 v_0^2}, Gm=\frac{\vartheta g\beta_c^*(C_w^*-C_\infty^*)}{U_0 v_0^2},\ \ k=\frac{v_0^2 k^*}{\vartheta^2},\ \ Du=\frac{DK_T}{\vartheta C_S C_P}\frac{(C_w^*-C_\infty^*)}{(T_w^*-T_\infty^*)}$$

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

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

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

$$\frac{\partial \phi}{\partial t}-(1+A\varepsilon e^{nt})\frac{\partial \phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}-K\phi \tag{12}$$

The corresponding boundary conditions are given by:

$$\begin{aligned}&u=U_p \quad \theta=1+\varepsilon e^{nt} \quad \phi=1+\varepsilon e^{nt}, \quad at \quad y=0\\ &U\to U_\infty=1+\varepsilon e^{nt}, \quad \theta\to 0, \quad \phi\to 0 \quad as \quad y\to\infty\end{aligned} \tag{13}$$

3. Method of Solution

The set of Eq. (10) Eq. (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:

$$\begin{aligned}u(y,t)&=u_0(y)+\varepsilon\, u_1(y)e^{nt}+O(\varepsilon^2)\\ \theta(y,t)&=\theta_0(y)+\varepsilon\,\theta_1(y)e^{nt}+O(\varepsilon^2)\\ \phi(y,t)&=\phi_0(y)+\varepsilon\,\phi_1(y)e^{nt}+O(\varepsilon^2)\end{aligned} \tag{14}$$

Substituting Eq. (14) into Eq. (10) to Eq. (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

$$\left(1+\frac{1}{\lambda}\right)u_0'' + u_0' - \left(M+\frac{1}{k}\right)u_0 = -\left(\mathrm{Gr}\,\theta_0 + \mathrm{Gm}\,\phi_0\right)Cos\alpha - \left(M+\frac{1}{k}\right) \tag{15}$$

$$\theta_0'' + \Pr\theta_0' - \left(F+Q_0\right)\Pr\theta_0 = -\mathrm{Q}_1\Pr\phi_0 - \Pr Du\,\phi_0'' \tag{16}$$

$$\varphi_0^{ll} + Sc\;\;\phi_0^{l} - \mathrm{Sc}\,\mathrm{K}\phi_0 = 0 \tag{17}$$

3.2 First Order Terms

$$\left(1+\frac{1}{\lambda}\right)u_1'' + u_1' - \left(M+\frac{1}{k}+n\right)u_1 = -\left(\mathrm{Gr}\;\theta_1 + \mathrm{Gm}\;\phi_1\right)Cos\alpha - Au_0' - \left(M+\frac{1}{k}+n\right) \tag{18}$$

$$\theta_1'' + \Pr\theta_1' - (n+F+Q_0)\Pr\theta_1 = -\left(\mathrm{A}\theta_0' + Q_1\phi_1 + Du\,\phi_1''\right)\Pr \tag{19}$$

$$\varphi_1^{ll} + Sc\;\;\phi_1^{l} - \mathrm{Sc}(\mathrm{K}+n)\phi_1 = -\mathrm{A}\,\mathrm{Sc}\,\phi_0^{1} \tag{20}$$

The corresponding boundary conditions are:

$$\begin{array}{ll} u_0 = U_p, u_1 = 0, \theta_0 = 1, \theta_1 = 1, \quad C_0 = 1, \quad C_1 = 1 & at \quad y = 0 \\ u_0 = 1, \quad u_1 = 1, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0 & as \quad y \to \infty \end{array} \tag{21}$$

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

$$\phi_0 = \exp(-m_1 y) \tag{22}$$

$$\phi_1 = B_1\exp(-m_1 y) + B_2\exp(-m_2 y) \tag{23}$$

$$\theta_0 = B_3\exp(-m_1 y) + B_4\exp(-m_3 y) \tag{24}$$

$$\theta_1 = B_5\exp(-m_1 y) + B_6\exp(-m_2 y) + B_7\exp(-m_3 y) + B_8\exp(-m_4 y) \tag{25}$$

$$u_0 = 1 + B_9\exp(-m_1 y) + B_{10}\exp(-m_3 y) + B_{11}\exp(-m_5 y) \tag{26}$$

$$\begin{aligned} u_1 = 1 &+ B_{12}\exp(-m_1 y) + B_{13}\exp(-m_2 y) + B_{14}\exp(-m_3 y) + B_{15}\exp(-m_4 y) \\ &+ B_{16}\exp(-m_5 y) + B_{17}\exp(-m_6 y) \end{aligned} \tag{27}$$

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

$$u = 1 + B_9 \exp(-m_1 y) + B_{10} \exp(-m_3 y) + B_{11} \exp(-m_5 y) + \varepsilon e^{nt} \begin{pmatrix} 1 + B_{12} \exp(-m_1 y) + \\ B_{13} \exp(-m_2 y) + \\ B_{14} \exp(-m_3 y) + \\ B_{15} \exp(-m_4 y) + \\ B_{16} \exp(-m_5 y) + \\ B_{17} \exp(-m_6 y) \end{pmatrix} \quad (28)$$

$$\theta = B_3 \exp(-m_1 y) + B_4 \exp(-m_3 y) + \varepsilon e^{nt} \begin{pmatrix} B_5 \exp(-m_1 y) + B_6 \exp(-m_2 y) + \\ B_7 \exp(-m_3 y) + B_8 \exp(-m_4 y) \end{pmatrix} \quad (29)$$

$$\phi = \exp(-m_1 y) + \varepsilon e^{nt} \left(B_1 \exp(-m_1 y) + B_2 \exp(-m_2 y) \right) \quad (30)$$

3.3 Skin Friction

Very important physical parameter at the boundary is the skin friction which is given in the non-dimensional form and derives as:

$$\tau = \left(\frac{\partial u}{\partial y} \right)_{y=0} = -\left(B_9 m_1 + B_{10} m_3 + B_{11} m_5 \right) - \varepsilon e^{nt} \begin{pmatrix} B_{12} m_1 + B_{13} m_2 + B_{14} m_3 + \\ B_{15} m_4 + B_{16} m_5 + B_{17} m_6 \end{pmatrix} \quad (31)$$

3.4 Nusselt Number

In Another physical parameter like rate of heat transfer in the form of Nusselt number expressed by:

$$Nu = -\left(\frac{\partial \theta}{\partial y} \right)_{y=0} = B_3 m_1 + B_4 m_3 + \varepsilon e^{nt} \left(B_5 m_1 + B_6 m_2 + B_7 m_3 + B_8 m_4 \right) \quad (32)$$

3.5 Sherwood Number

The rate of mass transfer in the form of Sherwood number are also derived by:

$$Sh = -\left(\frac{\partial C}{\partial y} \right)_{y=0} = m_1 + \varepsilon e^{nt} \left(B_1 m_1 + B_2 m_2 \right)$$
$$Sh = m_1 A_3 + m_3 A_4 + \varepsilon e^{nt} (m_1 A_5 + m_2 A_6 + m_4 A_7 + m_5 A_8) \quad (33)$$

4. Results and Discussion

In this paper, the effect of Radiation absorption of an unsteady magneto-hydrodynamic mixed convection flow past a permeable moving plate in presence of thermal radiation, heat absorption and homogenous chemical reaction, subjected to the variable suction are discussed in detail through graphs from Figure 1 until Figure 14. 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 Magnetic field parameter (M), Grashof number (Gr), modified Grashof number (Gm), Permeability of porous medium (k), Radiation absorption (Q1), Heat absorption coefficient (Q), radiation parameter (F), Prandtl number (Pr), chemical reaction (Kc), Schmidt number (Sc) 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 tables.

Figure 2 demonstrates the effect of the magnetic field on the velocity profiles. It is observed that the velocity decreases with an increasing magnetic parameter (M). This is due to the Lorentz force acting on the fluid flow. This type of resisting force slows down the fluid velocity as shown in this figure. The effect of permeability parameter (k) on the velocity field is depicted in Figure 3. From this figure it is observed that velocity increases with an increase in permeability of porous media. Physically, an increase in the permeability of porous medium leads the rise in the flow of fluid through it. When the holes of the porous medium become large, the resistance of the medium may be neglected. So that velocity at the insulated bottom is observed to be zero and gradually it increases as it reaches the free surface and attains a maximum. Figure 4 and Figure 5 indicates that the increase of Grashof number (Gr) and modified Grashof number (Gm) increases the velocity of the fluid flow, this implies that the present study is a buoyancy assisting flow with thermal buoyancy and mass buoyancy. 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 inclined parameter (λ). Velocity is observed to be increasing with the increase in inclined parameter.

Figure 8 and Figure 9 depicts the effect of the radiating absorptions parameter in both velocity and temperature distributions. The statistics show that the velocity and temperature graphs increase in radiating absorptions due to the radiating absorptions across the whole liquid area. It was fascinating to see how an increase in the radiating absorption characteristics enhances the resulting velocity and temperature. Figure 10 and Figure 11 illustrates the velocity and temperature profiles for different values of the Dufour number Du. The analytical results show that the effect of increasing values of Dufour number results in a increases velocity and temperature. Causes influence of Dufour number controls the influence of chemical concentration on fluid temperature. The Dufour effect is the reciprocal phenomenon, i.e., the rate of a heat flux owing to a chemical potential gradient.

Figure 12 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 13 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 14. 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 15, 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.

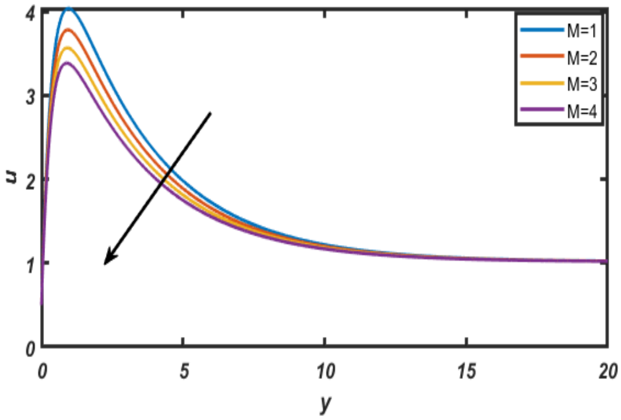

Fig. 2. The effect of magnetic field (M) parameter on velocity profiles

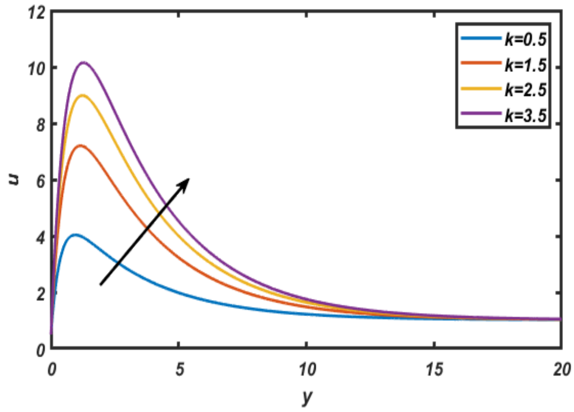

Fig. 3. The influence of permeability of porous media (k) on velocity profiles

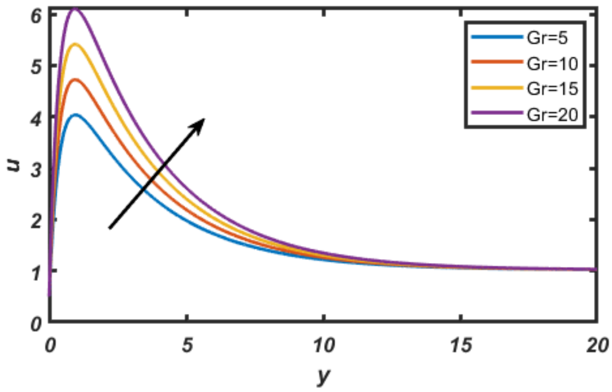

Fig. 4. The consequence of thermal Grashof number (Gr) on velocity profiles

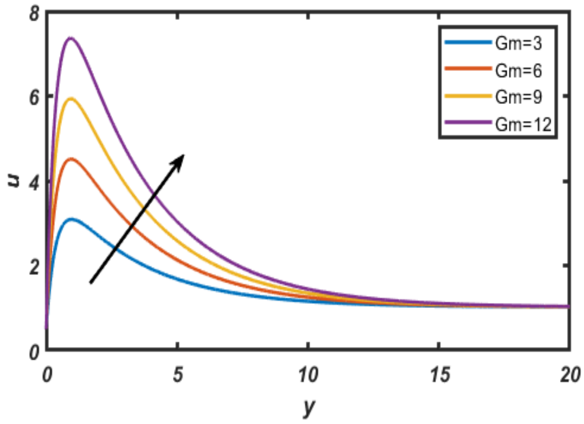

Fig. 5. The effect of mass Grashof number (Gm) on velocity profiles

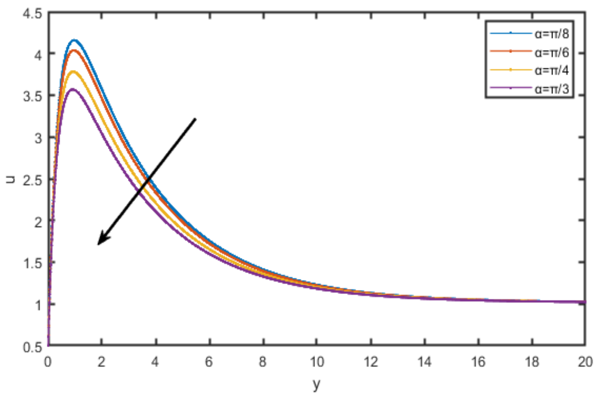

Fig. 6. The influence of inclined angle (α) parameter on velocity profiles

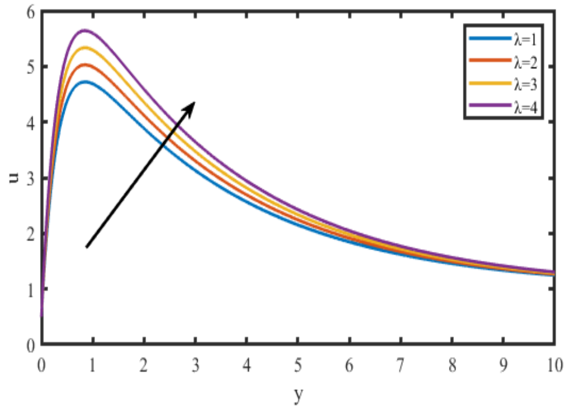

Fig. 7. The consequence of inclined parameter (λ) on velocity profiles

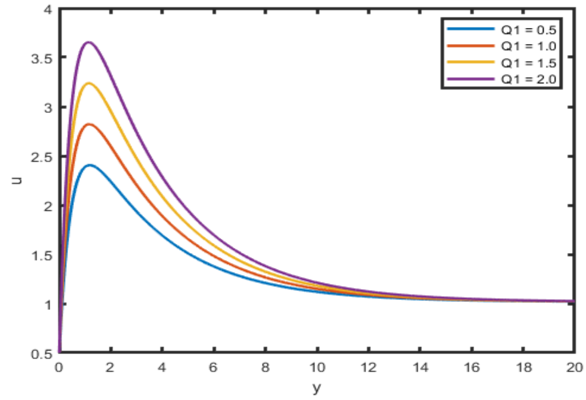

Fig. 8. The effect of radiation absorption specification (Q_1) on velocity profiles

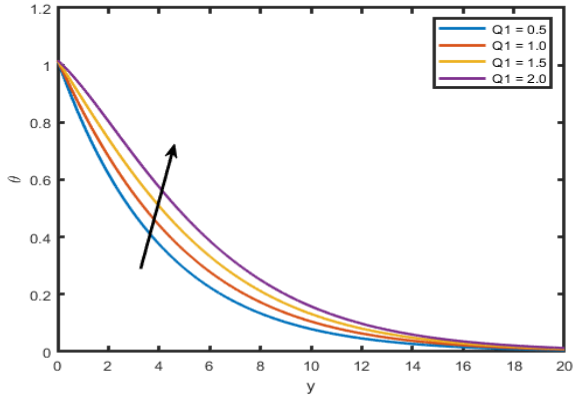

Fig. 9. The influence radiation absorption (Q_1) coefficient on temperature profiles

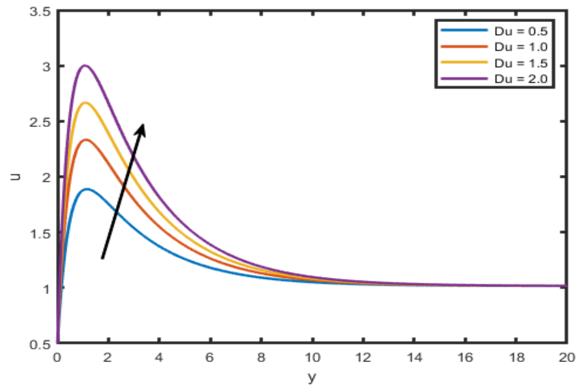

Fig. 10. The consequence of Dufour specification (D_u) on velocity profiles

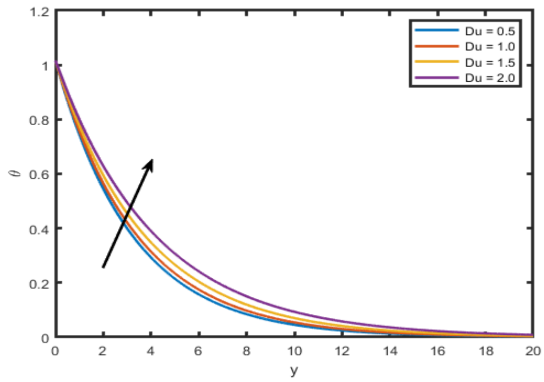

Fig. 11. The effect Dufour specification (D_u) on Temperature profiles

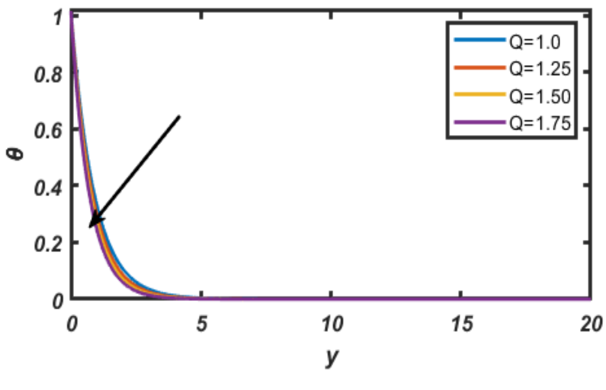

Fig. 12. The influence of heat absorption (Q) coefficient on temperature profiles

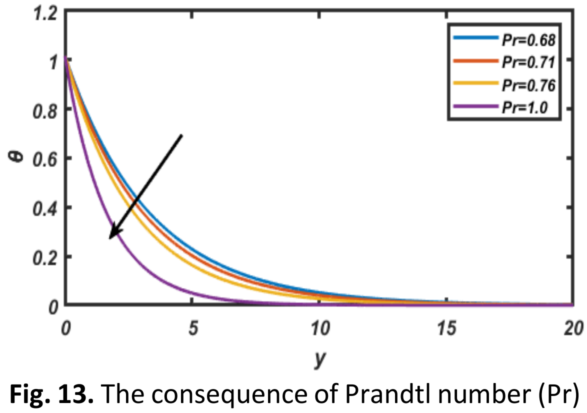

Fig. 13. The consequence of Prandtl number (Pr) on temperature profiles

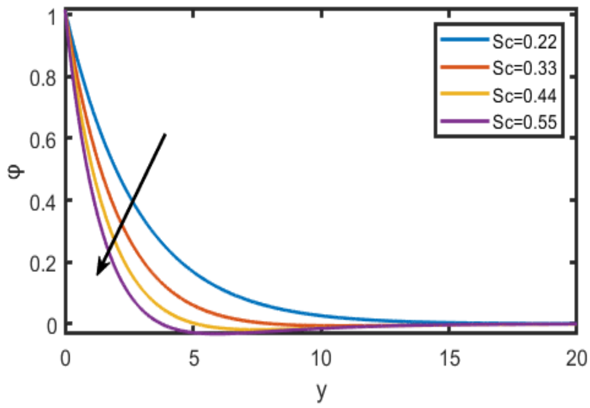

Fig. 14. The effect of Schmidt number (Sc) on concentration profiles

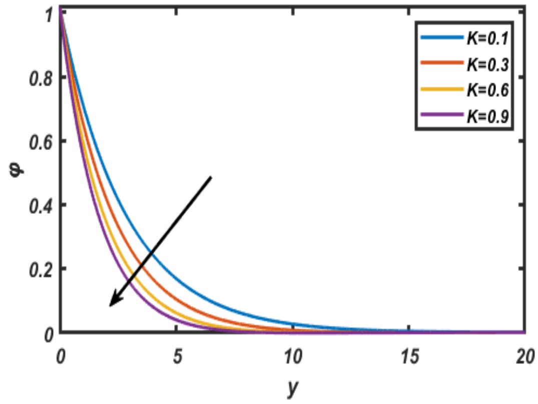

Fig. 15. The influence of chemical reaction (K) parameter on concentration profiles

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 to Table 3. For the validity of our work to compared our results with the existing results of Vaddemani *et al.,* [6]. Our result appears to be in excellent agreement with the existing results

Table 1 show numerical values of skin-friction for several of Grashof number (Gr), modified Grashof number (Gm), Magnetic parameter (M), and Porosity parameter (k). From Table 1, we observe that the skin-friction increases with an increase in Grashof number (Gr), modified Grashof number (Gm), Porosity parameter (K) where as it decreases under the influence of magnetic parameter (M). Table 2 demonstrates the numerical values of Nusselt number (Nu) for different values of Prandtl number (Pr), Radiation parameter (R), Heat source parameter (Q). From Table 2, we notice that the Nusselt number increases with an increase in Prandtl number, Radiation parameter and Heat source parameter. Table 3 shows numerical values of Sherwood number (Sh) for the distinction values of Schmidt number (Sc), Chemical reaction parameter (K) and Dufour parameter (Du). It can be noticed from Table 3 that the Sherwood number enhances with rising values of Schmidt number, chemical reaction parameter where as it decreases under the influence of Dufour parameter.

Table 1 the consequence of numerous quantities on the skin friction for Sc=0.22, Pr=0.71, Gr=5, k=0.5, Kc=0.1, M=1, Q=0.1, E=0.01, A=0.5, F=0.01, Gm=5, t=0.5, n=1, Up=0.5, Q_1= Du=α=λ=0.

Table 1
Numerical values of skin-friction for several of Grashof number (Gr), modified Grashof number (Gm), Magnetic parameter (M), and Porosity parameter (k)

Gr	Gm	M	k	τ, Present Values	τ, Vaddemani *et al.,* [6]
5	5	1	0.5	0.797852	0.7924
6	5	1	0.5	0.894552	0.8966
12	5	1	0.5	1.209457	1.2093
5	5	1	0.5	0.845785	0.8445
5	10	1	0.5	1.415478	1.4285
5	15	1	0.5	2.014785	2.0126
5	5	0.5	0.5	1.047852	1.0429
5	5	1	0.5	0.845785	0.8445
5	5	1.5	0.5	0.714578	0.7194
5	5	1	1	0.678522	0.6770
5	5	1	2	0.790124	0.7936

Table 2
The consequence of numerous quantities on the Nusselt number for Pr=0.71, λ=0.5, Q=0.1, E=0.01, A=0.5, F=0.01, t=0.5, Du=0, F=0

Pr	R	Q_1	Nu, Present Values
0.4			1.1371145
0.7			1.6218651
0.9			1.9151785
	2		1.8937124
	3		2.1128658
	4		2.3072745
		1.5	1.7712012
		2.5	2.0069450
		3	2.1128012

Table 3
The consequence of numerous quantities on the Sherwood Number for Sc=0.22, Pr=0.71, K=0.1, Q=0.1, E=0.01, A=0.5, F=0.01, t=0.5, n=1, Up=0.5

Sc	K	D_u	Sh
0.16			0.2896451
0.22			0.3256785
1			0.4633214
	0.5		0.1637021
	2		0.4687452
	4		0.7204012
		2	0.0829145
		3	-0.123475
		4	-0.3306321

4. Conclusion

In this paper investigated Radiation absorption and Dufour effects on radiative MHD flow of a chemically reacting fluid over an exponentially accelerated inclined porous plate with heat absorption. From the present investigation the following conclusions can be drawn:

i. The fluid velocity increases when the Grashof number (Gr), modified Grashof number (Gm), the porous media (k) increase. Whereas it has reverse effect on fluid velocity with enhances magnetic field parameter (M).
ii. The fluid velocity diminishes with increase of Casson fluid parameter and angle of inclination.
iii. The fluid temperature decreases with the effect of the Prandtl number, radiation parameter, and heat source parameter.
iv. Both velocity and temperature enhance with increasing Radiation absorption and Dufour Parameters.
v. The fluid temperature decreases with the effect of the Prandtl number (Pr), radiation parameter (F) and heat source parameter (Q).
vi. The concentration level of the fluid diminishes increasing chemical reaction parameter (K) and the Schmidt number (Sc).

Acknowledgement
This research was not funded by any grant.

References

[1] Casson, N. "Flow equation for pigment-oil suspensions of the printing ink-type." *Rheology of disperse systems* (1959): 84-104.

[2] Khan, Muhammad Ijaz, Muhammad Waqas, Tasawar Hayat, and Ahmed Alsaedi. "A comparative study of Casson fluid with homogeneous-heterogeneous reactions." *Journal of colloid and interface science* 498 (2017): 85-90. https://doi.org/10.1016/j.jcis.2017.03.024

[3] Khalid, Asma, Ilyas Khan, Arshad Khan, and Sharidan Shafie. "Unsteady MHD free convection flow of Casson fluid past over an oscillating vertical plate embedded in a porous medium." *Engineering Science and Technology, an International Journal* 18, no. 3 (2015): 309-317. https://doi.org/10.1016/j.jestch.2014.12.006

[4] Rauf, A., M. K. Siddiq, F. M. Abbasi, M. A. Meraj, M. Ashraf, and S. A. Shehzad. "Influence of convective conditions on three dimensional mixed convective hydromagnetic boundary layer flow of Casson nanofluid." *Journal of Magnetism and Magnetic Materials* 416 (2016): 200-207. https://doi.org/10.1016/j.jmmm.2016.04.092

[5] Zaib, Aurang, Krishnendu Bhattacharyya, Md Sharif Uddin, and Sharidan Shafie. "Dual solutions of non-Newtonian Casson fluid flow and heat transfer over an exponentially permeable shrinking sheet with viscous dissipation." *Modelling and simulation in engineering* 2016 (2016). https://doi.org/10.1155/2016/6968371

[6] Vaddemani, Ramachandra Reddy, Raghunath Kodi, and Obulesu Mopuri. "Characteristics of MHD Casson fluid past an inclined vertical porous plate." *Materials Today: Proceedings* 49 (2022): 2136-2142. https://doi.org/10.1016/j.matpr.2021.08.328

[7] Malapati, Venkateswarlu, and Padma Polarapu. "Unsteady MHD free convective heat and mass transfer in a boundary layer flow past a vertical permeable plate with thermal radiation and chemical reaction." *Procedia Engineering* 127 (2015): 791-799. https://doi.org/10.1016/j.proeng.2015.11.414

[8] 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

[9] 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

[10] 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

[11] 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

[12] 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

[13] Ganjikunta, Aruna, Hari Babu Kommaddi, Venkateswarlu Bhajanthri, and Raghunath Kodi. "An unsteady MHD flow of a second-grade fluid passing through a porous medium in the presence of radiation absorption exhibits Hall and ion slip effects." *Heat Transfer* 52, no. 1 (2023): 780-806. https://doi.org/10.1002/htj.22716

[14] 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

[15] Raghunath, Kodi, Charankumar Ganteda, and Giulio Lorenzini. "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.

[16] Kodi, Raghunath, and Obulesu Mopuri. "Unsteady MHD oscillatory Casson fluid flow past an inclined vertical porous plate in the presence of chemical reaction with heat absorption and Soret effects." *Heat Transfer* 51, no. 1 (2022): 733-752. https://doi.org/10.1002/htj.22327

[17] Kodi, Raghunath, Obulesu Mopuri, Sujatha Sree, and Venkateswaraju Konduru. "Investigation of MHD Casson fluid flow past a vertical porous plate under the influence of thermal diffusion and chemical reaction." *Heat Transfer* 51, no. 1 (2022): 377-394. https://doi.org/10.1002/htj.22311

[18] Rehman, Fouzia, Muhammad Imran Khan, Muhammad Sadiq, and Asad Malook. "MHD flow of carbon in micropolar nanofluid with convective heat transfer in the rotating frame." *Journal of Molecular Liquids* 231 (2017): 353-363. https://doi.org/10.1016/j.molliq.2017.02.022

[19] Ahmed, Muhammad Faizan, A. Zaib, Farhan Ali, Omar T. Bafakeeh, El Sayed Mohamed Tag-ElDin, Kamel Guedri, Samia Elattar, and Muhammad Ijaz Khan. "Numerical computation for gyrotactic microorganisms in MHD radiative Eyring–Powell nanomaterial flow by a static/moving wedge with Darcy–Forchheimer relation." *Micromachines* 13, no. 10 (2022): 1768. https://doi.org/10.3390/mi13101768

[20] 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

[21] Nazeer, Mubbashar, Farooq Hussain, M. Ijaz Khan, and Khadija Khalid. "Theoretical analysis of electrical double layer effects on the multiphase flow of Jeffrey fluid through a divergent channel with lubricated walls." *Waves in Random and Complex Media* (2022): 1-15. https://doi.org/10.1080/17455030.2022.2126025

[22] Tharapatla, Gladys, Pamula RajKumari, and Gurrampati V. Ramana Reddy. "Effects of heat and mass transfer on MHD nonlinear free convection non-Newtonian fluids flow embedded in a thermally stratified porous medium." *Heat Transfer* 50, no. 4 (2021): 3480-3500. https://doi.org/10.1002/htj.22037

[23] Khan, Waqar Azeem, Muhammad Waqas, Wathek Chammam, Zeeshan Asghar, Ubaid Ahmed Nisar, and Syed Zaheer Abbas. "Evaluating the characteristics of magnetic dipole for shear-thinning Williamson nanofluid with thermal radiation." *Computer Methods and Programs in Biomedicine* 191 (2020): 105396. https://doi.org/10.1016/j.cmpb.2020.105396

[24] Khan, Waqar Azeem, Muhammad Waqas, Mehboob Ali, F. Sultan, M. Shahzad, and M. Irfan. "Mathematical analysis of thermally radiative time-dependent Sisko nanofluid flow for curved surface." *International Journal of Numerical Methods for Heat & Fluid Flow* 29, no. 9 (2019): 3498-3514. https://doi.org/10.1108/HFF-12-2018-0746

[25] Chu, Yu-Ming, M. Ijaz Khan, Tasawar Abbas, Maawiya Ould Sidi, Khalid Abdulkhaliq M. Alharbi, Umar F. Alqsair, Sami Ullah Khan, M. Riaz Khan, and M. Y. Malik. "Radiative thermal analysis for four types of hybrid nanoparticles subject to non-uniform heat source: Keller box numerical approach." *Case Studies in Thermal Engineering* 40 (2022): 102474. https://doi.org/10.1016/j.csite.2022.102474

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

[27] 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

[28] Vaddemani, Ramachandra Reddy, Sreedhar Ganta, and Raghunath Kodi. "Effects of Hall Current, Activation Energy and Diffusion Thermo of MHD Darcy-Forchheimer Casson Nanofluid Flow in the Presence of Brownian Motion and Thermophoresis." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 105, no. 2 (2023): 129-145. https://doi.org/10.37934/arfmts.105.2.129145