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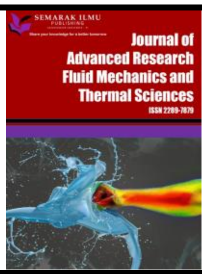

Heat and Mass Transfer in Unsteady Radiating MHD Flow of a Maxwell Fluid with a Porous Vertically Stretching Sheet in the Presence of Activation Energy and Thermal Diffusion Effects

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ABSTRACT

The aim of this study is to analyze the effects of activation energy and thermal diffusion an unsteady MHD reactive Maxwell fluid flow past a porous stretching sheet in the presence of Brownian motion, Thermophoresis and nonlinear thermal. The non-linear partial differential equations that govern the fluid flow have been transformed into a two-point boundary value problem using similarity variables and then solved numerically by fourth order Runge–Kutta method with shooting technique. Graphical results are discussed for non-dimensional velocity, temperature and concentration profiles while numerical values of the skin friction, Nusselt number and Sherwood number are presented in tabular form for various values of parameters controlling the flow system. The present study is compared with the previous literature and found to be in good agreement.

1. Introduction

Fluid mechanics is a scientific field that studies the properties and behavior of fluids, whether they are in a stationary or moving state. It has broad applications across many scientific disciplines. Various types of fluids, such as oil reservoirs, ions, liquids, and micropolar fluids, are used in diverse industries. Meteorologists use fundamentals of fluid mechanics to predict weather patterns by analyzing the movement of atmospheric fluids on Earth. In the field of heat transport technology, nanofluids have emerged as a groundbreaking concept Choi [1] introduced nanofluids, which are fluids that incorporate nanoparticles to enhance their thermal properties and transform fluid

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dynamics. This integration of nanoparticles into the base fluid offers an innovative approach to improving heat transport. Further advancements in nanofluids were explored by Liu *et al.,* [2] incorporated adaptable nanoparticles into heat-transporting materials, leading to significant enhancements in their thermal–physical characteristics. Nanofluids are commonly composed of nanoparticles that have a size similar to the particles in the base fluid. This similarity in size enables the nanoparticles to be uniformly dispersed throughout the fluid, preventing them from settling or clumping together. This uniform dispersion is crucial for maintaining the desired properties of the nanofluids. Hussain *et al.,* [3] emphasized the importance of nanometer-sized particles in advanced technology, particularly for enhancing the electrical properties of various types of fluids. Bhatti *et al.,* [4] conducted initial investigations into the use of nanofluids to enhance transport capabilities. Researchers have also investigated the influence of nanostructures present in plasma on the thermophysical properties of conventional liquids. Different convective flow models have been established to study the heat transfer mechanisms in nanofluids. For instance, Li *et al.,* [5] identified the seven-slip phenomenon and studied its effects. Li *et al.,* [6] proposed the common usage of mass transportation with activation power in critical domains such as hydroelectric engineering, chemistry, petroleum droplets, and food preparation. Nanofluids and nanoscale liquids have gained recognition in various industries due to their exceptional characteristics, including properties like ferromagnetic behavior, moisture control, electrical conductivity, spectroscopic response, and heat-related properties. These properties can be achieved by incorporating engineered nanostructures. Nanotechnology, which involves developing, observing, and controlling matter at a microscopic level, has found applications in diverse fields such as chemical engineering, materials research, biological sciences, and healthcare, as explored by Thejas *et al.,* [7]. Practical applications of nanofluids include engine cooling in automobiles, cooling systems for ventilation and electrical appliances, and cooling in power plants. They are also extensively employed in fields such as energy systems, bioengineering, pharmaceuticals, and technology. Ahmed *et al.,* [8] explored various nanomaterials, including carbon nanotubes, metal oxides, nanoscale polymers, and nanoscale clays, known for their excellent thermophysical characteristics. The advantages of nanofluids have been well-documented in various fields, which has prompted researchers to focus on computational and experimental analyses to further understand and apply nanofluids [9–11]. Nanotechnology is recognized as a crucial driver of the industrial revolution, leading to numerous studies aimed at optimizing industrial production examined by Ibrahim *et al.,* [12].

In magneto-hydrodynamic flows, other phenomena may also arise including Hall currents, ion slip and Ohmic (Joule) dissipation. In most simulations of magnetic heat transfer, the Joule dissipation term is conventionally neglected on the premise that under normal conditions the Eckert number is small based on an order of magnitude analysis. Reddy *et al.,* [13] have studied Effects of Hall Current, Activation Energy and Diffusion Thermo of MHD Darcy-Forchheimer Casson Nanofluid Flow in the Presence of Brownian motion and Thermophoresis. Raghunath *et al.,* [14] have discussed 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. Raghunath *et al.,* [15] have analyzed Unsteady MHD fluid flow past an inclined vertical porous plate in the presence of chemical reaction with aligned magnetic field, radiation, and Soret effects. Ramachandra Reddy *et al.,* [16] have possessed Characteristics of MHD Casson fluid flow past an inclined vertical porous plate. Raghunath *et al.,* [17] have expressed Effects of Radiation Absorption and Aligned Magnetic Field on MHD Cassion Fluid Past an Inclined Vertical Porous Plate in Porous Media.

The boundary layer flow of non-Newtonian fluid due to stretching surface finds vast applications in the field of biological systems, industrial manufacturing, metallurgy and chemical engineering. Its relevance can also be found in hot rolling, polymeric sheet manufacturing, wire drawing, drawing of plastic films, polymer extrusion processes, wire and fibre coating, etc. The flow and heat transfer characteristics of non-Newtonian fluids are quite different as compared to Newtonian fluids. There are many constitutive equations to describe all the properties of non-Newtonian fluids and are quite complex. Several models have been suggested; among those the Maxwell fluid model has gained popularity. The Maxwell fluid is a subclass of rate type fluid and it can predict the stress relaxation. Particularly, the Maxwell fluid model has been used for the viscoelastic fluid where the non-dimensional relaxation time is diminutive. Nevertheless, the Maxwell model is useful for a large relaxation time in concentrated polymeric fluids [18]. In view of this, Hayat *et al.,* [19] reported an analytic solution for the unsteady MHD flow of rotating Maxwell fluid through a porous medium. Further the same authors solved the problem of MHD flow of UCM fluid over a porous stretching plate and obtained the analytical solution by employing homotopy analysis method [20]. Noor [21] employed the spectral relaxation method for the numerical solution of the hydrodynamic flow of Maxwell fluid past a vertical stretching sheet with thermophoresis effect. Shatey [22] investigated the boundary layer flow of a Maxwell fluid past a vertical stretching sheet under the influence of thermophoresis and chemical reaction. Recently, Farhal Ali *et al.,* [23] have studied Analytical Study of MHD Mixed Convection Flow for Maxwell Nanofluid through a Vertical Cone with Porous Material in the Presence of Variable Thermal Conductivity and Soret, Dufour Effects.

Multi-specific applications, including Arrhenius energy activation and species response, have been of great interest to scientists and researchers in oil supplies, in particular oil and chemical engineering, cooling reactors, geothermal engineering, material degradation, mechanical chemistry, and oil and water emulsions. Generally, the relationship between mass transfer and chemical reactions is very complex and can often be studied at different rates for fluid flow and mass transfer together, through the manufacture and digestion of reagent species. Among the most important benchmarks is that the species does not usually respond to chemical reactions together with Arrhenius activation energy. Initially, Arrhenius [24] proposed an energy activation terminology. However, he stated that the smallest energy needed for molecules or atoms to function is a blinker of a chemical reaction. For the first time, Bestman [25] identified a primary model consisting of a boundary layer for fluid flow problems with Arrhenius activation energy under binary chemical reactions. He used the disturbance technique to describe the natural convection effect of the activation energy. Raghunath *et al.,* [26-28] have focused on various flow characteristics of Activation energy. Li *et al.,* [29] have possessed Effects of activation energy and chemical reaction on unsteady MHD dissipative Darcy–Forchheimer squeezed flow of Casson fluid over horizontal channel**.** Suresh Kumar *et al.,* [30] have discussed Numerical analysis of magnetohydrodynamics Casson nanofluid flow with activation energy, Hall current and thermal radiation. Raghunath [31] has reviewed 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. Omar *et al.,* [32] have expressed 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.,* [33] have analyzed 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. Aruna *et al.,* [34] have reviewed 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. Raghunath and Mohanaramana, [35] 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.

To the best of our knowledge, the present problem of presented the effects of Activation Energy and Thermal Diffusion on an unsteady magneto-hydrodynamic flow of Maxwell Nanofluid convective heat and mass transfer from vertical porous plate in the presence of Brownian motion, Thermophoresis and nonlinear thermal Radiation has been unexplored. A theoretical model is developed for this flow scenario. The governing equations can obtain similarity transformations that reduce a system of governing partial differential equations and associated boundary conditions to a system of ordinary differential equations. These equations are solved with the help of Runge Kutta's fourth order and shooting technique. The effects of different flow parameters on velocity, temperature, and concentration profiles are investigated and analysed with the help of a graphical representation.

2. Problem Formulation

We consider 2D viscous incompressible laminar flow with heat transmission of a non-Newtonian electrically conducting Maxwell Nanofluid through a porous medium and also the combined effects of mixed convection with convective boundary conditions. Flow is considered on a stretching sheet in the presence of Dufour and Soret effects and variable thermal conductivity. A uniform magnetic field $B = \frac{B_0}{\sqrt{1-\chi t}}$ is applied in opposite to the direction of the fluid flow. The stretched sheet of velocity is $U_w = \frac{cx}{\sqrt{1-\chi t}}$ and $v = v_w = \frac{v_0}{\sqrt{1-\chi t}}$ where c, χ are positive constants. In addition, all physical attributes related to the formula are measured to be constant. The geometry of this modelling can be displayed in Figure 1. Bossineq approximation is taken for both energy or temperature and concentration profiles. The continuity, momentum, energy and concentration equations governing such type of flow in the presence of chemical reaction are written as below

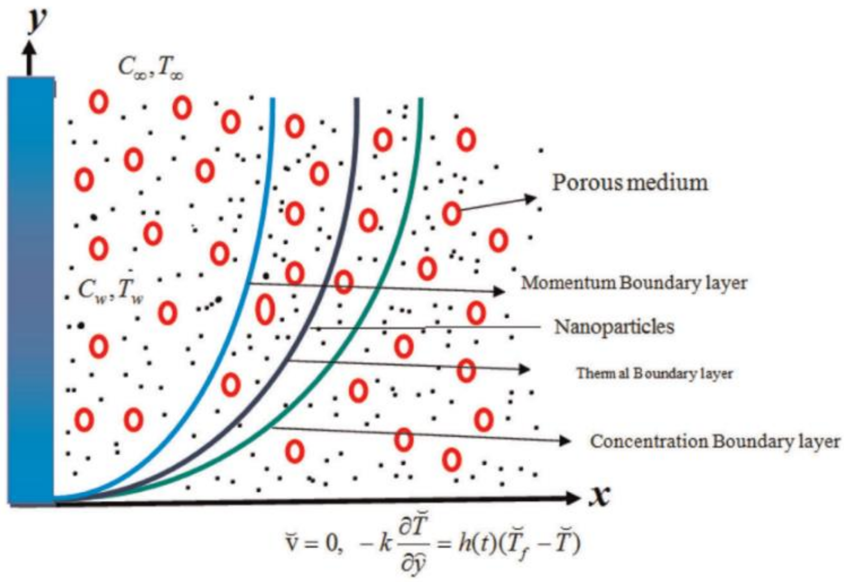

Fig. 1. Physical configuration of the problem

$$\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-\lambda_1\left(u^2\frac{\partial^2 u}{\partial x^2}+v^2\frac{\partial^2 u}{\partial y^2}+2uv\frac{\partial^2 u}{\partial x\partial y}\right)+ g\beta_T\left(T-T_\infty\right)+\ g\beta_C\left(C-C_\infty\right)-\sigma\frac{B_0(t)}{\alpha}-\ \frac{\vartheta}{k}u \tag{2}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_m\left(\frac{\partial^2 T}{\partial y^2}\right)+\tau\left(D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right)-\frac{1}{(\rho Cp)}\frac{\partial q_r}{\partial y}+\frac{Q_0}{\rho C_p}(T-T_\infty) \tag{3}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=\frac{D_m k_T}{T_m}\frac{\partial T^2}{\partial y^2}+D_B\left(\frac{\partial^2 C}{\partial y^2}\right)+\frac{D_T}{T_\infty}\left(\frac{\partial T^2}{\partial y^2}\right)--k_r^2\left(C-C_\infty\right)\left(\frac{T}{T_\infty}\right)^m\exp\left(\frac{-E_a}{K^*T}\right) \tag{4}$$

For this flow, corresponding boundary conditions are

$$\begin{aligned} &u=U_w(x,t),\quad v=0,-k\frac{\partial T}{\partial y}=h(t)\left(T_f-T_\infty\right),\quad C=C_w \quad \text{at } y=0\\ &u\to 0,\quad v\to 0,\quad T\to T_\infty \qquad C\to C_\infty \qquad\qquad \text{as } y\to\infty \end{aligned} \tag{5}$$

where (u,v) are the components of velocity in x and y directions, λ_1 is the relaxation time, υ is the kinematic viscosity, κ_0 is the chemical reaction parameter, g is the gravitational acceleration, β_T is the thermal expansion coefficient, (T,C) are fluid temperature and concentration, and DB and DT are Brownian and thermophoretic coefficient, the density of the fluid.

The radiative heat flux q_r (using Roseland approximation followed [24]) is defined as

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{6}$$

where k^* is the mean absorption coefficient, and σ^* is the Stefan-Boltzmann constant.

We assume that the temperature variances inside the flow are such that the term T^4 can be represented as linear function of temperature. This is accomplished by expanding T^4 in a Taylor series about a free stream temperature T_∞ as follows

$$T^4=T_\infty^4+4T_\infty^3\left(T-T_\infty\right)+6T_\infty^2\left(T-T_\infty\right)^2+........... \tag{7}$$

After neglecting higher-order terms in the above equation beyond the first-degree term in $\left(T-T_\infty\right)$, we get

$$T^4\cong 4T_\infty^3T-3T_\infty^4 \tag{8}$$

Using (8) in (6) and then the substitution of its value in Eq. (3), gives

$$\frac{\partial q_r}{\partial y} = -\frac{16\sigma^* T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial y^2} \tag{9}$$

Using (9), Eq. (3) can be written as

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha_m\left(\frac{\partial^2 T}{\partial y^2}\right) + \tau\left(D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) - \frac{1}{(\rho c)_f}\frac{16T_\infty^3\sigma^*}{\partial K^*}\left(\frac{\partial^2 T}{\partial y^2}\right) + \frac{Q_0}{\rho C_p}(T - T_\infty) \tag{10}$$

The following similarity variables are introduced for solving governing Eq. (2), (6) and (4) as

$$u = \frac{ax}{1-\chi t}f'(\eta),\ v = -\sqrt{\frac{a}{(1-\chi t)}}f(\eta),\ \eta = \sqrt{\frac{va}{1-\chi t}}y,\ \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty},$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, h(t) = \frac{d}{\sqrt{1-\chi t}}. \tag{11}$$

Substituting Eq. (11) into Eq. (2), (3) and (4), we get the following system of non-linear ordinary differential equations

$$f''' - f'^2 + ff'' + \Lambda\left(2ff f'' - f^2 f'''\right) - \delta\left(f' + \frac{1}{2}\eta f''\right) - (M + \beta)f' + \lambda(\theta + N\phi) = 0 \tag{12}$$

$$\left(1 + \frac{4}{3}R_d\right)\theta'' - \delta\Pr\frac{1}{2}\eta\theta' - \Pr f\theta' + \Pr N_b\left(\theta'\phi' + \frac{N_t}{N_b}\theta'^2\right) + \Pr Q\theta - E_c f'' = 0 \tag{13}$$

$$\phi'' - \delta\Pr\frac{1}{2}\eta\phi' - Sc(f\phi' - Sr\phi') + \frac{N_b}{N_t}\theta'' - K_E(1+\theta)^m\exp\left(\frac{-E}{1+\theta}\right)\phi = 0 \tag{14}$$

The corresponding boundary conditions (5) become

$$\begin{aligned} &f(\eta) = S,\quad f'(\eta) = 1,\quad \theta'(\eta) = -\gamma(1-\theta(\eta)),\quad \phi(\eta) = 1 \quad at \quad \eta = 0 \\ &f'(\eta) \to 0,\quad \theta(\eta) \to 0,\quad \phi(\eta) \to 0 \quad as \quad \eta \to \infty \end{aligned} \tag{15}$$

where prime denotes differentiation with respect to η, and the significant thermophysical parameters indicating the flow dynamics are defined by

$$\delta = \frac{c}{\chi},\ Q = \frac{Q_0}{\alpha\rho C_p},\ \Lambda = c\lambda_1,\ \lambda = \left(\frac{g\beta_T(T_w - T_\infty)x}{U_w^2}\right),\ N = \frac{\beta_c(C_w - C_\infty)}{\beta_T(T_w - T_\infty)},\ \beta = c\lambda_1,\ M = \frac{\sigma B_0^2}{\rho Cp},$$
$$N_b = \frac{\tau D_B(C_w - C_\infty)}{v},\ N_t = \frac{\tau D_T(T_w - T_\infty)}{\alpha T_\infty},\quad R_d = \frac{4\sigma^* T_\infty^3}{kk^*},\ \Pr = \frac{v}{\alpha} = \frac{v\rho C_p}{k},\ Sc = \frac{v}{D_B},\ \gamma = \left(\frac{h_f}{k}\sqrt{\frac{v}{\alpha}}\right),$$
$$E_c = \frac{U_w^2}{C_p(T_w - T_\infty)},\ S_r = \frac{D_m k_T(T_w - T_\infty)}{T_m\alpha_m(C_w - C_\infty)},\ \delta_1 = \frac{T - T_\infty}{T_\infty},\ K_E = \frac{k_r^2}{c},\ E = \frac{E_a}{K^* T_\infty}.$$

3. Physical Quantities

The local skin friction coefficient Cf, the local Nusselt number Nu_x, and the local Sherwood number Sh_x are the physical quantities of relevance that influence the flow. These numbers have the following definitions

$$C\,f = \frac{\tau_w}{\rho U_w^2},\quad Nu_x = \frac{xq_w}{k(T_w - T_\infty)},\quad Sh_x = \frac{x\,q_m}{D_B(C_w - C_\infty)} \tag{16}$$

The shear stress, heat, and mass flux are written as

$$\tau_w = \mu\left[\frac{\partial u}{\partial y}\right]_{y=0},\quad q_w = -k\left[\frac{\partial T}{\partial y}\right]_{y=0},\quad q_m = D_B\left[\frac{\partial C}{\partial y}\right]_{y=0} \tag{17}$$

The coefficient of skin friction, the Nusselt number, and the Sherwood number are all expressed in their non-dimensional versions in terms of the similarity variable as follows

$$\mathrm{Re}_x^{1/2}\,Cf = f''(0),\quad \mathrm{Re}_x^{-1/2}\,Nu_x = -\left(1 + \frac{4}{3}R_d\right)\theta'(0),\quad \mathrm{Re}_x^{-1/2}\,Sh_x = -\phi'(0) \tag{18}$$

4. Solution Methodology

As Eq. (12)–(14) with boundary conditions (15) are strongly non-linear, it is difficult or maybe impossible to find the closed form solutions. Accordingly, these boundary value problems are solved numerically by using the conventional fourth-order RK integration scheme along with the shooting technique. The first task to carry out the computation is to convert the boundary value problem to an initial value problem.

Let by using the following notations

$$f = y_1,\ f' = y_2,\ f'' = y_3,\ f''' = y_3',\quad \theta = y_4,\ \theta' = y_5,\ \theta'' = y_5',\ \phi = y_6,\ \phi' = y_7,\ \phi'' = y_7'. \tag{19}$$

By using the above variables, the system of first-order ODEs is

$$y_1' = y_2, \tag{20}$$

$$y_2' = y_3, \tag{21}$$

$$y_3' = \frac{1}{\left(1+\Lambda y_1^2\right)}\left(y_2^2 - y_1 y_3 - 2\Lambda y_2 y_3 + \delta\left(y_2 + \frac{1}{2} n y_3\right) + \left(M+\beta\right)y_2 - \lambda\left(y_4 + N y_6\right)\right), \tag{22}$$

$$y_4' = y_5, \tag{23}$$

$$y_5' = \frac{1}{1+R_d}\left(\frac{1}{2}\delta\eta \Pr y_5 + \Pr y_1 y_5 - \Pr N_b\left(y_5 y_7 + \frac{Nt}{Nb}\left(y_5\right)^2\right) - \Pr Q y_4 + E_c y_3\right) \tag{24}$$

$$y_6' = y_7, \tag{25}$$

$$y_7' = \frac{1}{2}\delta\eta \Pr y_7 + Sc\left(y_1 y_7 - Sr y_7\right) - \frac{N_b}{N_t} y_5' + y_6 K_E \left(1+y_4\right)^m \exp\left(\frac{-E}{1+y_4}\right) \tag{26}$$

The boundary conditions are given as

$$\begin{gathered} y_1(0) - S = 0,\ \ y_2(0) - 1 = 0,\ \ y_5(0) + \gamma\left(1 - y_4(0)\right) = 0,\ \ y_6(0) - 1 = 0 \\ y_2(\infty) = 0,\ \ y_4(\infty) = 0,\ \ y_6(\infty) = 0 \end{gathered} \tag{27}$$

The boundary conditions in Equation (27) are utilized via use a finite value of η_{max} as given

$$f'(\eta_{\max}) \to 0,\ \theta'(\eta_{\max}) \to 0,\ \phi'(\eta_{\max}) \to 0. \tag{28}$$

The step is taken $\Delta\eta = 0.001$ and convergent criteria is 10^{-6} for the desired accuracy

5. Code Validation

We checked the accuracy of current outcomes with previous literature in the limited case and obtained a fantastic agreement. Table 1 displays a comparison of numeric outcome for Sherwood number various values of the thermal diffusion parameter with the published result of Farhan Ali *et al.,* [23] with an outstanding agreement.

6. Result and Discussion

In the current work, the MHD flow of Maxwell nanoparticles with convective boundary conditions is examined. Also, heat transfer and viscous dissipation are considered. To show the effect of some pertinent physical aspects, the obtained result is computed. The outcome of these physical parameters is elaborated through graph 2–24 and in Table 2, we computed the value of $\mathrm{Re}_x^{1/2}\, Cf_x$, $\mathrm{Re}_x^{-1/2}\, Nu_x\, and\ \ \mathrm{Re}_x^{-1/2}\, Sh_x$ for entrenched flow variables.

For different values of the magnetic parameter M, the velocity and the temperature profiles are plotted in Figure 2 and 3 respectively. From Figure 2, it is clear that an increase in the magnetic parameter M leads to a fall in the velocity. The effects of the magnetic parameter to increase the temperature profiles are noticed from Figure 3. The presence of Lorentz force retards the force on the velocity field and therefore the velocity profiles decreases with the effect of magnetic parameter. This force has the tendency to slow down the fluid motion and the resistance offered to the flow. Therefore, it is possible for the increase in the temperature.

Figure 4–5 are displayed to study the velocity $f'(\eta)$, and temperature $\theta(\eta)$ profiles for the numeric value of porosity parameter β. It is observed that the velocity field is a declining function of porosity variable β. actually, a higher value of β causes a stronger restriction and growing thickness of porous medium due to which the fluid flow motion depreciates. So, the velocity of the fluid reduces with an increased value of β. But, the opposite behavior is noted in θ (η).The velocity $f'(\eta)$, temperature θ (η), and concentration ϕ (η), profiles for the diverse values of an unsteadiness parameter δ are evaluated in Figure 6–8. It is seen that from Figures 6 and 8, an increment in the value of δ obtains diminution in the velocity field and concentration distribution as the momentum and solute boundary layer. There is an increment in the temperature of nanoparticles via a larger value of δ as the thermal boundary layer.

The impact of fluid parameter $\wedge$ for velocity $f'(\eta)$, temperature field $\theta(\eta)$ and concentration of nanoparticles ϕ (η) is considered in Figure 9–11. It is clearly noticed from these figures the waning function of the fluid parameter. It can be observed that the influence of enhancing the estimations of fluid parameters ε is to depreciate the $f'(\eta)$, field and is associated with boundary layer thickness depreciating. The $\theta(\eta)$ and ϕ (η) both are showing as opposite behavior with increasing value of the fluid parameter.

Temperature is enhanced when the Brownian motion parameter Nb is increased. Larger the Brownian motion parameter, lower the viscous force and higher the Brownian diffusion coefficient which results an enhancement in the thermal boundary layer thickness and temperature and this phenomenon can be observed in Figure 12. From Figure 13, it is observed that the nanoparticle concentration decreases with an increment in Nb.

Figure 14 and 15 illustrate the effect of thermophoresis parameter Nt on the temperature and the nanoparticles concentration profile. One can observe that temperature fields' increase with an enhancement in Nt. Thermophoresis parameter plays an important role in the heat transfer flow. Thermophoresis force enhances when Nt is increased which tends to move the nanoparticles from the hot region to the cold and as a result the temperature and the boundary layer thickness increase. The opposite behavior has observed in figure 15, in the case of concentration field.

Figure 16-17 illustrates the influence of the radiation parameter (Rd) on the temperature and concentration profiles. It is apparent that an increase in the radiation parameter results in a corresponding temperature rise. The observed phenomenon can be attributed to the liberation of heat energy into the fluid, consequent to increased thermal radiation. The phenomenon of reversal behavior has been observed in the field of concentration. The temperature field's effects, as influenced by the Eckert number Ec are presented in Figure 18. The augmentation of the Eckert number results in an elevation of the temperature field.

Figure 19 and 20 illustrate that the Soret number Sr decreases temperature profile while there is an increase in concentration profile and boundary layer thickness. Higher temperature difference and a lower concentration difference are observed because of increasing values of the Soret number. This variation in the temperature and concentration differences is liable for the decrease in the temperature and an increase in the concentration. It is also noticed that the Dufour and Soret numbers have fairly contrary effects for temperature and nanoparticle concentration fields.

Figure 21 shows that the temperature $\theta(\eta)$ increases with an increase in the resistance of the heat source / sink, due to an increase in the resistance of the heat generation, the temperature rises.

The underlying cause is the transformation of mechanical energy into thermal energy. The observed phenomenon is solely attributed to the dissipation of thermal energy.

The influence of the activation energy (E) on the concentration field is seen in figure 22. The graph demonstrates that the concentration profile rises as the value of E increases. The Arrhenius function degrades due to the activation energy snowballing value, which ultimately leads to the encouragement of the generative chemical reaction, which in turn causes an improvement in the concentration field. When the temperature is low and the activation energy is high, a lower reaction rate constant is produced, which causes the chemical reaction to proceed more slowly. Increased focus is the direct result of this strategy. Figure 23 demonstrates that an increase in the rate of chemical reaction (δ_1) causes a significant decrease in the concentration profile. A high chemical reaction rate causes a fallout solute boundary layer to become denser.

The impact of Schmidt number on the concentration profile is illustrated in Figure 24. There exists a correlation between the diffusivity of momentum and the diffusivity of mass. A decrease in the Schmidt number results in a decay of the concentration profile.

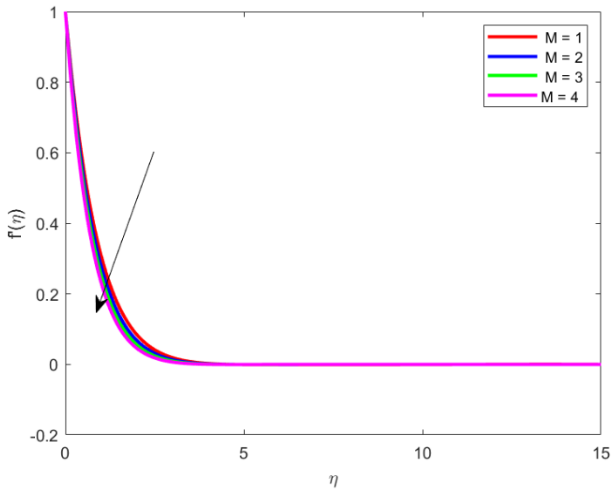

Fig. 2. Effect of magnetic parameter M on velocity profiles

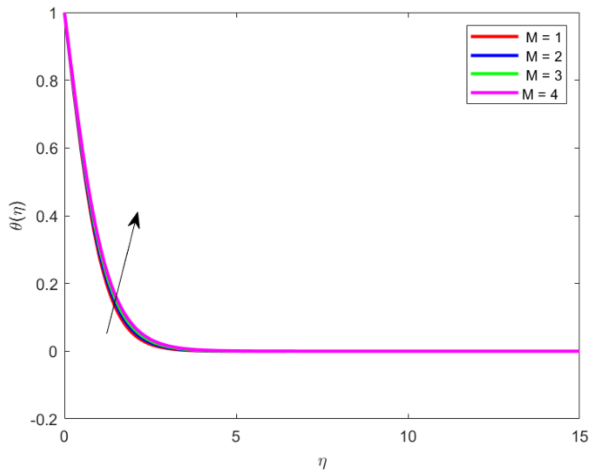

Fig. 3. Effect of M on temperature profiles

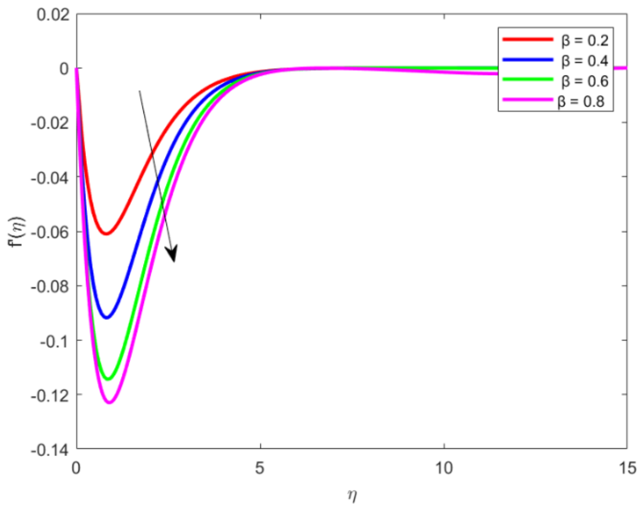

Fig. 4. Effect of porous parameter β on velocity profiles

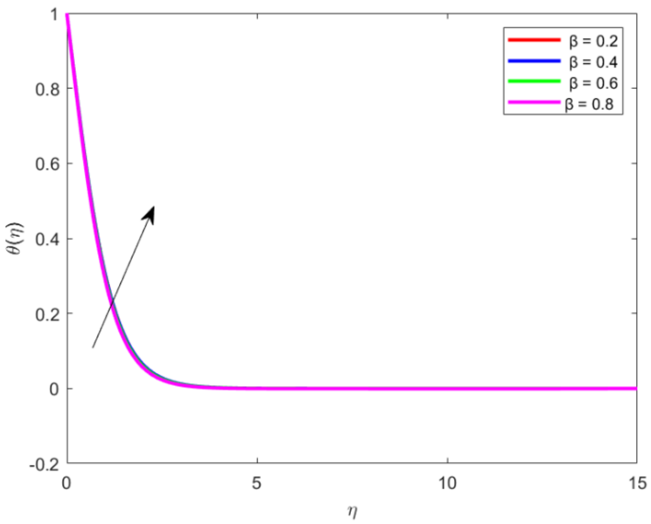

Fig. 5. Effect of porous parameter β on temperature profiles

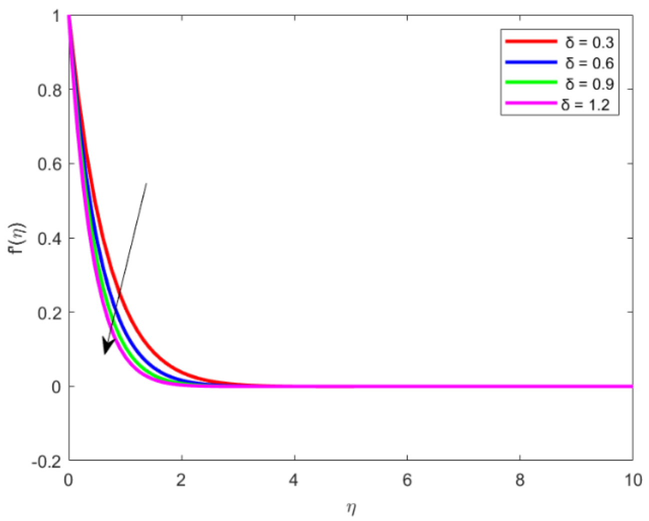

Fig. 6. Effect of unsteady parameter δ on velocity profiles

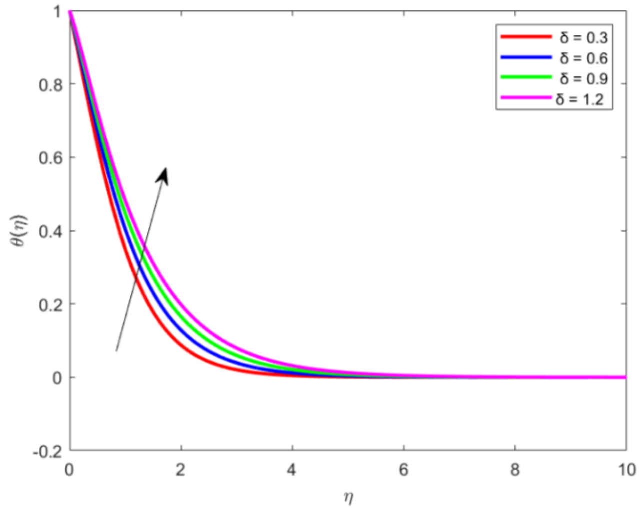

Fig. 7. Effect of unsteady parameter δ on temperature profiles

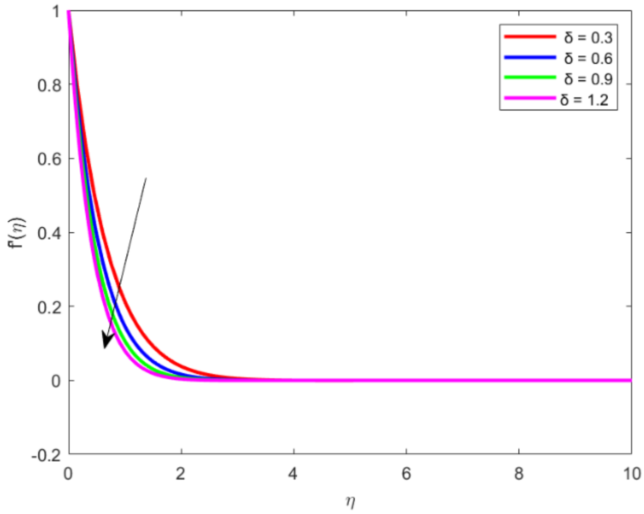

Fig. 8. Effect of unsteady parameter δ on concentration profiles

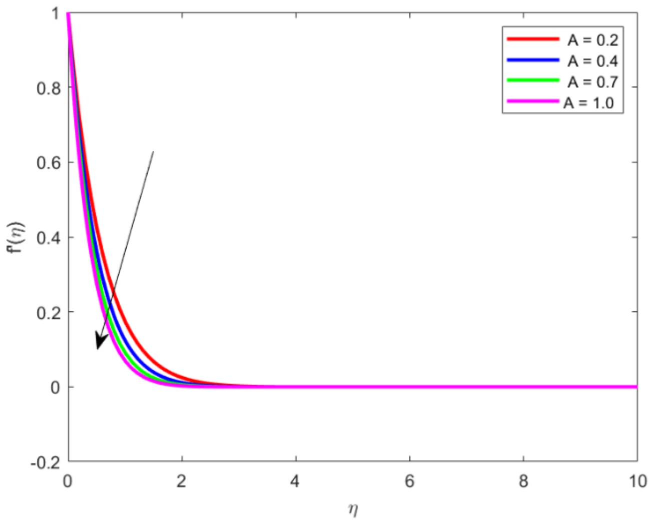

Fig. 9. Effect of Maxwell fluid parameter ∧ on velocity profiles

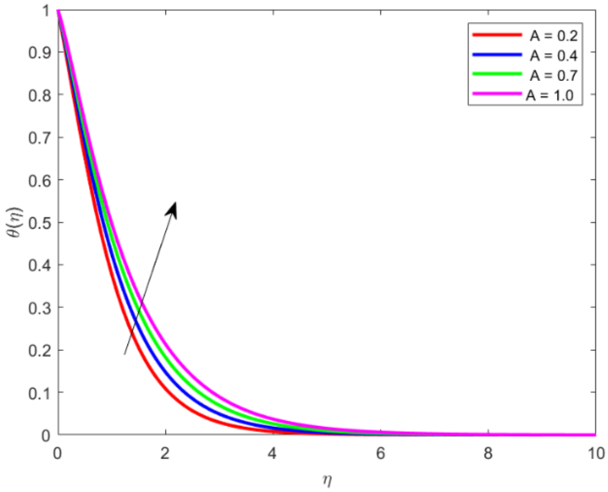

Fig. 10. Effect of Maxwell fluid parameter ∧ on temperature profiles

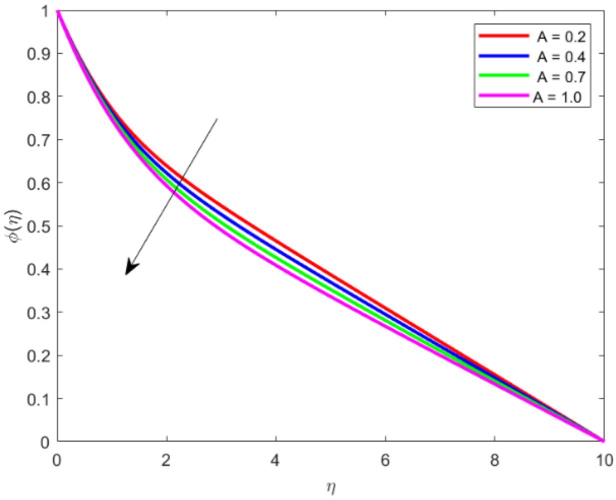

Fig. 11. Effect of Maxwell fluid parameter ∧ on concentration profiles

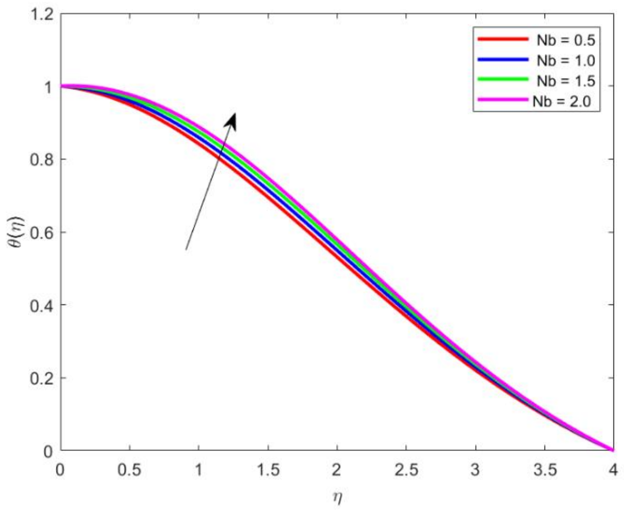

Fig. 12. Effect of Brownian motion parameter Nb on temperature profiles

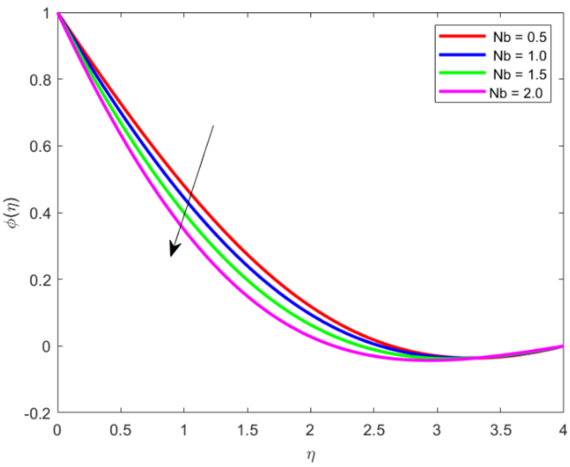

Fig. 13. Effect of Brownian motion parameter Nb on concentration profiles

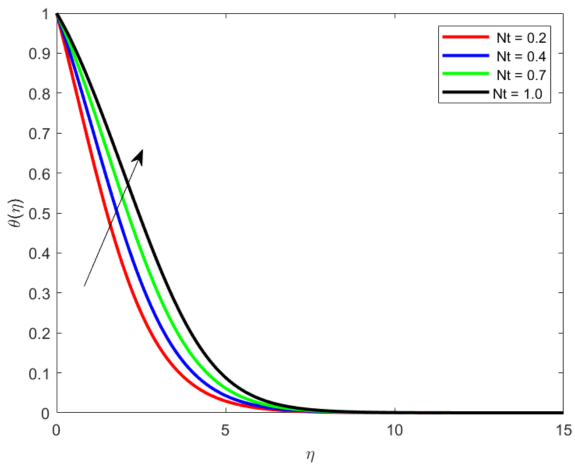

Fig. 14. Effect of thermophoresis parameter Nt on temperature profiles

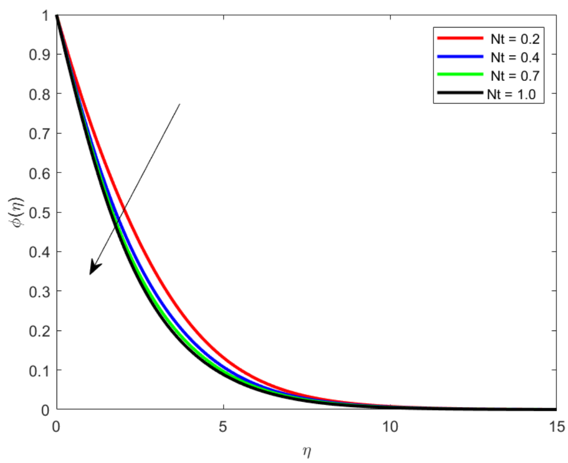

Fig. 15. Effect of thermophoresis motion parameter Nt on concentration profiles

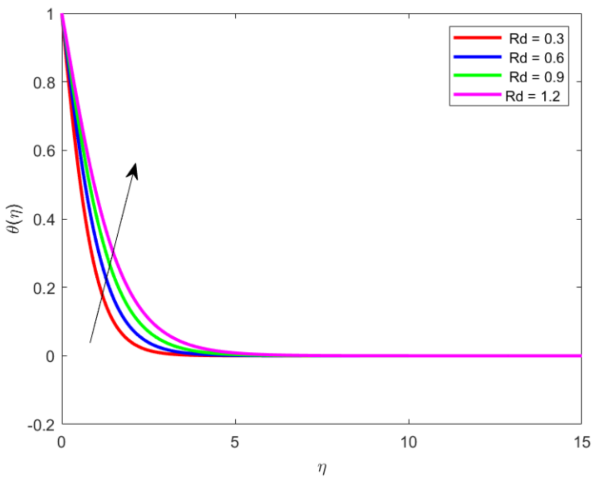

Fig. 16. Effect of Radiation parameter Rd on temperature profiles

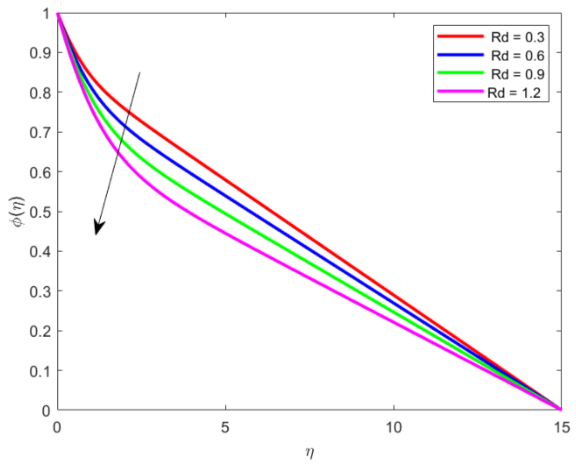

Fig. 17. Effect of Radiation parameter Rd on concentration profiles

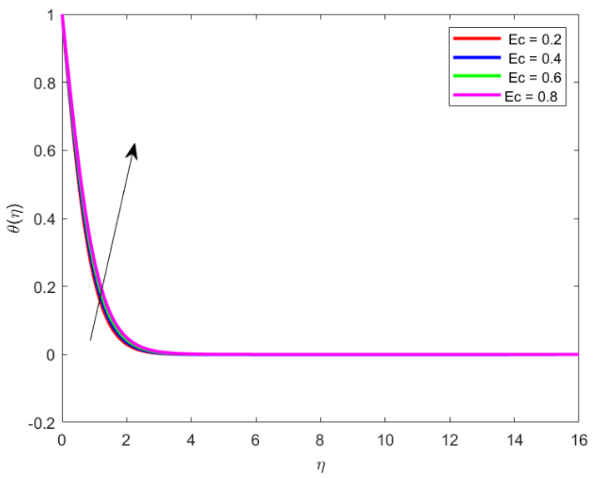

Fig. 18. Effect of Ekert number Rd on temperature profiles

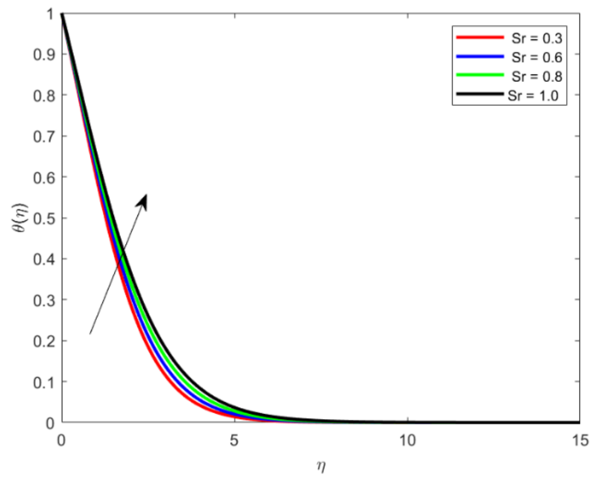

Fig. 19. Effect of thermal diffusion parameter Sr on temperature profiles

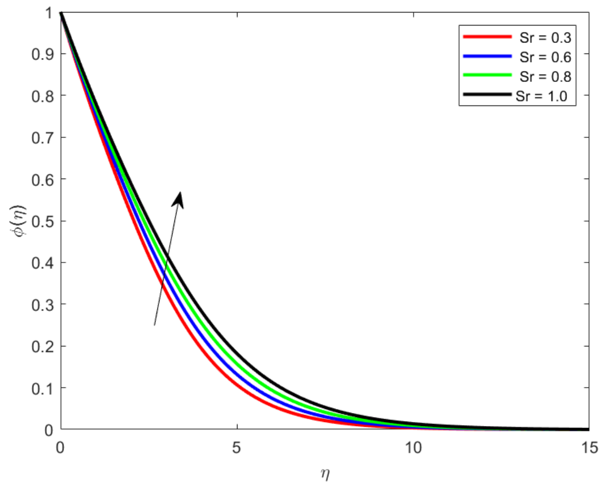

Fig. 20. Effect of thermal diffusion parameter Sr on concentration profiles

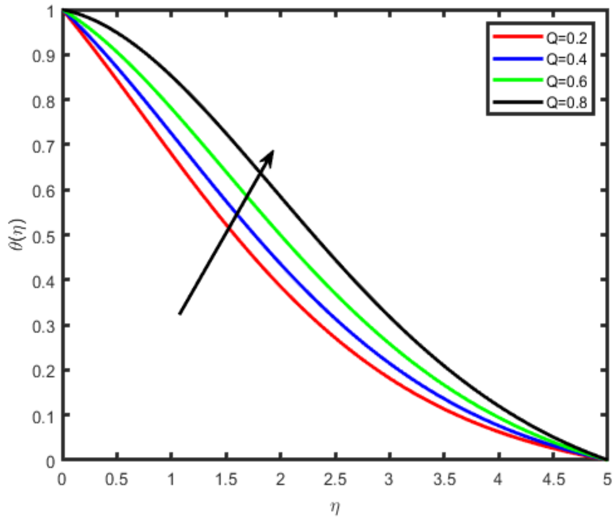

Fig. 21. Effect of heat source Parameter Q on temperature profiles

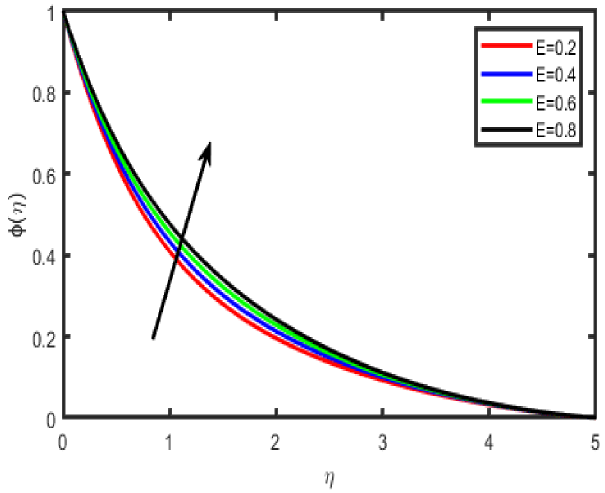

Fig. 22. Effect of activation energy E on concentration profiles

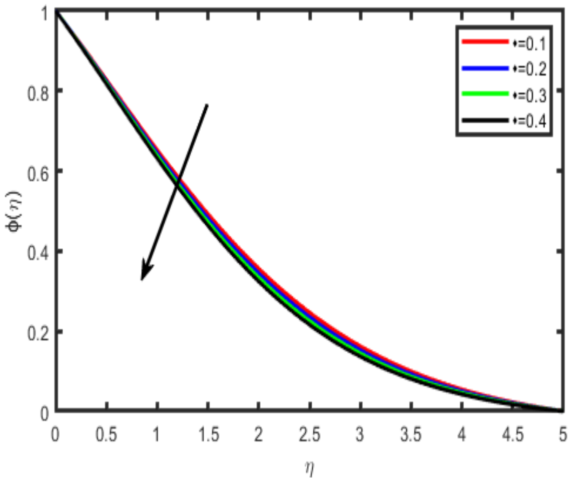

Fig. 23. Effect of chemical reaction Rate δ on concentration profiles

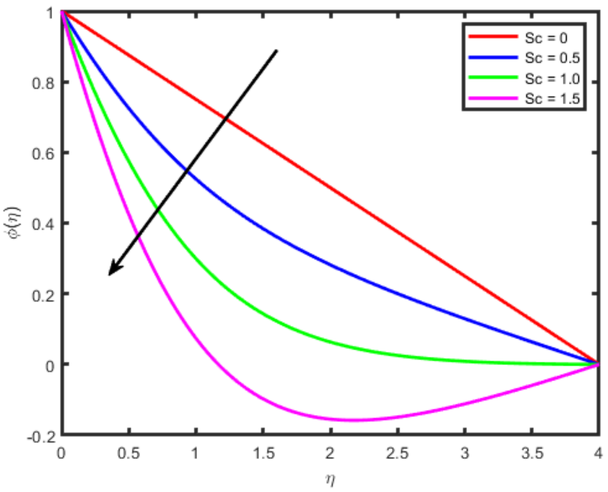

Fig. 24. Effect of Schmidt number Sc on concentration profiles

Table 1
Comparison of present Sherwood number with the published Sherwood number results of when E=Q=δ_1=0

Sr	Farhan Ali *et al.,* [23]	Present Study
0.2	0.4758676	0.47546
0.4	0.44578541	0.44856
0.6	0.48451235	0.485755

Table 2
Computation of $\mathrm{Re}_x^{1/2}\, Cf_x$, $\mathrm{Re}_x^{-1/2}\, Nu_x$ *and* $\mathrm{Re}_x^{-1/2}\, Sh_x$ for different parameters

Nb	Nt	Sc	E	Sr	M	^	$\mathrm{Re}_x^{1/2}\, Cf_x$	$\mathrm{Re}_x^{-1/2}\, Nu_x$	$\mathrm{Re}_x^{-1/2}\, Sh_x$
					1		1.1145	0.8947	0.2575
					2		1.4486	0.7607	0.6253
					3		1.8764	0.5437	0.9785
0.5							1.6576	0.8257	0.7378
1.0							1.1864	0.7267	0.9856
1.5							0.9985	0.5645	1.3528
	0.2						1.2375	0.9805	0.3606
	0.4						1.4275	0.7645	0.1045
	0.7						1.6275	0.5867	0.0987
		0.5					1.1074	0.1565	0.1467
		1.0					1.3565	0.1098	0.11587
		1.5					1.7126	0.0464	0.2189
			0.2				1.2507	0.1188	0.2467
			0.4				1.4947	0.1565	0.2236
			0.6				1.8286	0.0830	0.3096
				0.3			0.9486	0.8864	0.2766
				0.6			0.7257	0.81007	0.4585
				0.8			0.4764	0.7856	0.6575
						0.2	1.5137	0.1078	0.3476
						0.4	1.5958	0.0965	0.1079
						0.7	1.9126	0.0435	0.2487

7. Conclusion

In this work, investigated the effects of Activation energy and Thermal Diffusion an unsteady MHD mixed convective flow of Maxwell fluid past a porous vertical Stretching sheet in presence of Brownian motion, Thermophoresis and thermal radiation has been studied. The findings of the numerical results can be summarized as follows

i. A stronger magnetic parameter M results in an increase in the temperature, concentration and transvers velocity.
ii. The resulting concentration has enhances with increasing values of Soret and activation energy parameters.
iii. Thermal and concentration boundary layer thickness increase with the increase in thermophoresis parameter.
iv. Brownian motion parameter has opposite effect on temperature and concentration fields.
v. The temperature distribution is a reducing function of thermal radiation Rd, similar behavior has observed resultant concentration field with enhances of rate of chemical reaction rate.
vi. The fluid temperature and concentration are enhances with increasing the Thermal diffusion parameter.

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