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EFFECT OF CHEMICAL REACTION ON UNSTEADY MHD CONVECTIVE TRANSPORT PASSING A VERTICAL POROUS SHEET

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ABSTRACT

An analysis of the effect of chemical reactions on unsteady MHD convective transport passing a vertical porous sheet has been introduced in this research paper. The model formed of highly nonlinear governing equations are converted by inserting the similarity transformations. The numerical solutions of the fluid properties like concentration, temperature, and velocity are presented graphically. This paper also presented the heat transfer rate, mass transfer rate, and the local skin friction coefficient which are analyzed in tabular forms. The dimensionless parameters or numbers used in this problem are suction parameter, magnetic parameter, Prandtl number, Schmidt number, and chemical reaction parameter. Results give the improvement of concentration and motion of the fluid for growing values of the chemical reaction, but the reverse trends are found for the Schmidt number. The local skin-friction coefficient and the mass transfer rate are increased by about 23 % and 283%, respectively for growing amounts of the chemical reaction from 0.5 to 2.0.

Keywords: *MHD, Permeability, Chemical reaction, Heat, and mass transfer.*

1. INTRODUCTION

In industrial engineering processes, it is typical for non-Newtonian fluids to move over a vertical surface. Animal blood, pulps, fossil fuels, molten polymers, and fluids with specific additives, etc. are some examples of these non-Newtonian fluids. These fluids are sometimes utilized in industrial manufacturing. These non-Newtonian fluids' movements through the stretched surfaces at both vertical and horizontal directions have already been effectively clarified by fluid dynamics experts. Hydromagnetic (MHD) natural convective flow has grown interested by some investigators owing to its uses in numerous engineering fields in geothermal energy extraction nuclear reactors, plasma studies, boundary layer flow control, MHD generators and pumps, and boundary layer flow control. Many researchers such as (Gupta, 1962; Hossain, 1986; Kim, 2000; Ahmed et al., 2011; Hasanuzzaman et al., 2021) have studied these areas. Hossain et al. (2023) carried out the numerical investigation of unsteady convective thermal and mass transport passing a vertical porous plate with thermophoresis, chemical reaction and radiative thermal transfer with uniform magnetic field by a micropolar fluid with binary mixture. The importance of the magnetic field powered by the hydromagnetic fluid flow system causes the attention of investigators because of its significance in engineering science.

Heat and mass transfer frequently occur caused by buoyancy impacts produced by the diffusion of chemical and thermal species in both natural and industrial transport systems. The analysis of such a procedure helps enhance a variety of chemical technologies, including enhanced oil recovery, polymer production, manufacturing of ceramic, underground energy transport, and food processing. Heat and mass transfer are essential in many hydrometallurgical and chemical technology-related industries because of the influences of chemical reactions. Numerous chemical engineering procedures essentially involve a chemical reaction between an external mass and the fluid. Muthuchumaraswamy et al. (2009) have studied the impacts of mass transfer through a chemical reaction upon unstable flow over an enhanced isothermal vertical plate. The effects of radiation and chemical reactions on MHD flow passing an infinite vertical plate with varying temperatures have been addressed by Rajesh et al. (2009). Eckert and Drake (1972) researched the significance of thermal-diffusion and diffusion-thermo impacts for different fluid movements. Olajuwon (2011) analyzed convective heat and mass transfer in an MHD movement over a semi-infinite stretching sheet with thermal radiation and diffusion. Kumar et al. (2012) explored the impacts of radiation and thermal diffusion on unstable MHD flow considering the variation of mass diffusion and temperature with the heat source/sink. Taid and Ahmed (2022) studied the steady two-dimensional MHD free convection flow past an inclined porous plate embedded in the porous medium in the

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presence of heat source, Soret effect, and chemical reaction. Hossain et al. (2022) explored the thermal radiation effect of unsteady magneto-convective heat and mass transfer by micropolar binary mixture of fluid passing a continuous permeable surface. The effects of radiation and viscous dissipation on the transfer of unsteady magnetic-conductive heat-mass across a vertically porous sheet have been studied by Hasanuzzaman et al. (2022). Appidi et al. (2023) discussed the impact of chemical reaction and radiation on an unstable two-dimensional laminar flow around a viscous fluid over a semi-infinite, vertical absorbent surface that moves progressively.

Many authors considered the natural convection flows that happen in engineering and in nature practices to be very extensive because of their applications in geosciences, industry, and engineering like foam combustion, hydrology, gas-particle trajectories, petrology, and turbine blades. The conducting potential is more complicated in nature when mass and heat transfer happen together within the flux. Temperature gradients and mass gradients both contribute to the energy flux. Mass fluxes may also result from temperature gradients. Thermal diffusion or Soret influence is the term used to describe this. The concentration gradients may also produce heat fluxes. This is named the Dufour influence or mass diffusion. Postelnicu (2004) introduced the roles of Soret and Dufour on an unstable MHD natural convective transport upon a vertical plate in saturated permeable media. The impacts of the Soret and Dufour on combined convection flow over a vertically permeable sheet were analyzed numerically by Alam and Rahman (2006). Kumar et al. (2020) analyzed the significance of thermal diffusion on MHD natural convection transport passing over a vertically continuous porous plate. Hasanuzzaman et al. (2021) recently discussed the impacts of the Dufour and thermal diffusion time-dependent MHD free convective transport through a vertical permeable sheet. Further, Hasanuzzaman et al. (2022) extended Hasanuzzaman et. al. (2021) research by considering thermal radiation and chemical reactions, and internal heat generation, respectively.

The prime target of current research work is to observe the roles of chemical reactions upon time-dependent MHD convection transport over a vertically permeable sheet. The foremost innovation of the present study is further extended by considering the chemical reaction under the shooting technique which has not yet been investigated. The numerical solution for the non-dimensional equations such as concentration, velocity, and temperature equations is obtained graphically using MATLAB software and shooting technique. Additionally, the tabular representations include the mass transfer rate, coefficient of local skin friction, and heat transfer rate.

2. MATERIALS AND METHODS

An unstable 2D convective hydromagnetic incompressible viscous and electrically conducting boundary layer fluid flow passing over a vertically porous sheet embedded in a permeable media is considered. The plate has been taken along the x-direction. The free-stream velocity and vertical porous plate are considered parallel. The y-axis has been taken perpendicular to the vertical porous sheet. Transversely over the flow, a uniform magnetic field of strength B_0 is employed. The fluid concentration and temperature at the wall are denoted by C_w and T_w, respectively. The porous plate commences past emotively in its proper plate with the velocity U_0 for $t > 0$. Figure 1 represents the flow configuration and coordinate system. The fluid velocity is the function of t and y only.

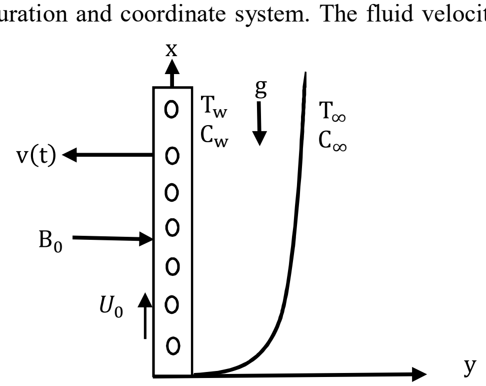

Figure 1: Coordinate systems and physical model.

The governing equations for the above problem using the Boussinesq approximation are as follows:

$$\frac{\partial v}{\partial y} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)+g\beta^*(C-C_\infty)-\frac{\sigma' B_0^2}{\rho}u \tag{2}$$

$$\frac{\partial T}{\partial t}+v\frac{\partial T}{\partial y}=\frac{D_m k_T}{C_s C_p}\frac{\partial^2 C}{\partial y^2}+\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2} \tag{3}$$

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

The boundary conditions associated with the given problem are-

$$u=U_0(t),\qquad T=T_w,\qquad C=C_w,\qquad v=v(t)\ \text{ at }\ y=0 \tag{5}$$

$$u=0,\qquad T\to T_\infty,\qquad C\to C_\infty,\qquad v=0\ \text{ at } y\to\infty \tag{6}$$

where the gravitational acceleration is g, fluid density is ρ, the fluid concentration at the free stream is C_∞, kinematic viscosity is υ, fluid concentration is C, wall temperature is T_w, wall concentration is C_w, fluid temperature is T, the fluid mean temperature is T_m, thermal conductivity is k, the chemical reaction rate of spices concentration is K^*, thermal diffusion ratio is k_T, the fluid temperature at the free stream is T_∞ , and mass diffusivity coefficient is D_m.
We used in this simulation the unsteady length scale (σ) which is the similarity parameter as

$$\sigma=\sigma(t) \tag{7}$$

The following is the given solution to the continuity equation (1):

$$v=-v_0\frac{\upsilon}{\sigma} \tag{8}$$

At the plate, the non-dimensional normal velocity is v_0. Here $v_0<0$ gives blowing and $v_0>0$ gives suction.
The similarity variables are considered as follows:

$$\eta=\frac{y}{\sigma},\qquad \phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty},\quad \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\quad f(\eta)=\frac{u}{U_0} \tag{9}$$

By considering the earlier equations (7) - (9), the equations (1) - (4) are changed into the dimensionless couple ODEs as follows:

$$f''(\eta)+2\xi f'(\eta)+G_r\theta(\eta)+G_m\phi(\eta)-Mf(\eta)-\frac{1}{Da}f(\eta)-\frac{ReFs}{Da}f^2(\eta)=0 \tag{10}$$

$$\theta''(\eta)+\Pr\left\{Df\phi''^{(\eta)}-Ec\left(f'(\eta)\right)^2+2\xi\,\theta'(\eta)+Q\,\theta(\eta)\right\}=0 \tag{11}$$

$$\phi''(\eta)+2\xi Sc\phi'(\eta)+Sc\,Sr\theta''(\eta)-Kr\phi(\eta)=0 \tag{12}$$

The transformed boundary conditions are provided by:

$$f(\eta)=1,\ \ \phi(\eta)=1,\qquad \theta(\eta)=1\ \ \text{ at }\ \eta=0 \tag{13}$$

$$f(\eta)=0,\qquad \phi(\eta)=0,\qquad \theta(\eta)=0\ \ \text{ at }\ \eta\to\infty \tag{14}$$

where the Schmidt number is $S_c=\frac{\upsilon}{D_m}$, Prandtl number is $\Pr=\frac{\rho\upsilon C_p}{k}$, local Grashof number is $G_r=\frac{g\beta(T_w-T_\infty)\sigma^2}{U_0\upsilon}$, magnetic parameter is $M=\frac{\sigma' B_0^2\sigma^2}{\rho\upsilon}$, Soret number is $Sr=\frac{D_m k_T(T_w-T_\infty)}{\upsilon T_m(C_w-C_\infty)}$, the Dufour number is $D_f=\frac{D_m k_T(C_w-C_\infty)}{C_s C_p\upsilon(T_w-T_\infty)}$, the modified local Grashof number is $G_m=\frac{g\beta^*(C_w-C_\infty)\sigma^2}{U_0\upsilon}$, chemical reaction parameter is $Kr=\frac{K^*\sigma^2}{\upsilon}$ and $\xi=\eta+\frac{v_0}{2}$.
The flow parameters such as the Nusselt number (Nu), shear stress (τ), and Sherwood number (Sh) are stated by:

$$Nu\propto-\theta'(0),\ \ \tau\propto f'(0),\ \ Sh\propto-\phi'(0) \tag{17}$$

3. RESULTS AND DISCUSSIONS

The impacts of chemical reactions on the unsteady free hydromagnetic convective transport over a vertically porous sheet have been explored in this research work. The shooting technique is used to numerically solve the ODEs (10) through (12). The non-dimensional fluid and concentration, temperature, and velocity distributions for various amounts of non-dimensional numbers/parameters are provided in Figures 2 to 11. The numerical values like the mass transfer rate $\left(-\phi'(0)\right)$, the heat transfer rate $(-\theta'(0))$, and the local skin friction coefficient $\left(f'(0)\right)$ are given in Tables 1 to 3. We have considered, $M = 0.5, Gr = 10.0, Df = 0.5, \; Pr = 0.71, \; Gm = 10.0, \; Sc = 0.22,$ and $Sr = 2.0$ unless it is mentioned in all of the figures.

3.1 Effect of Suction

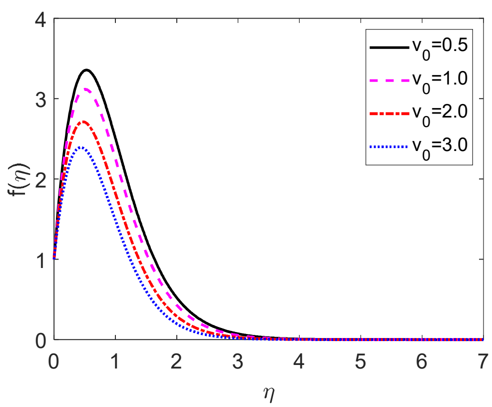

Figure 2: Velocity profile for suction parameter (v_0).

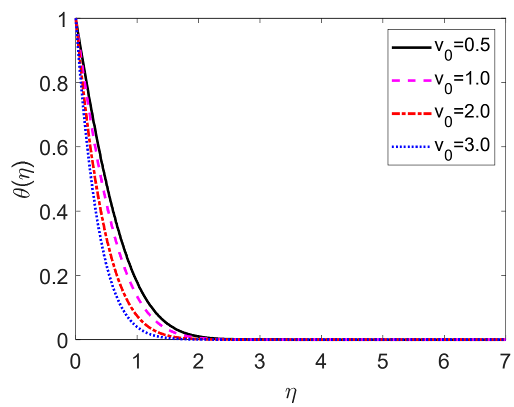

Figure 3: Temperature profile for suction parameter (v_0).

The velocity, concentration, and temperature distributions are displayed in Figures 2 to 4 for several amounts of suction parameter (v_0). Figure 2 states that the fluid mass in the computational domain declines in the case of suction $(v_0 > 0)$. The frictional force is thereby diminished. Therefore, with higher suction values, the fluid velocity falls. This occurs as a result of boundary layer stabilization for suction impact. The velocity field is overlooked and touches the extreme value in an area near the plate $(0.0 \leq \eta \leq 1.0)$, then gradually approaches zero. Figure 3 depicts how suction (v_0) affects the temperature distributions. It is demonstrated that the fluid temperature drops as the suction parameter rises. This is due to the suction parameter's ability to lower the number of fluid particles that pass through a permeable sheet, which in turn reduces the rise in the fluid's thermal boundary level. It is further noticed from Figure 4 that with rising suction levels, the concentration diminishes. This is because suction slows down fluid particles passing the porous plate and declines the uprise of concentration boundary layers.

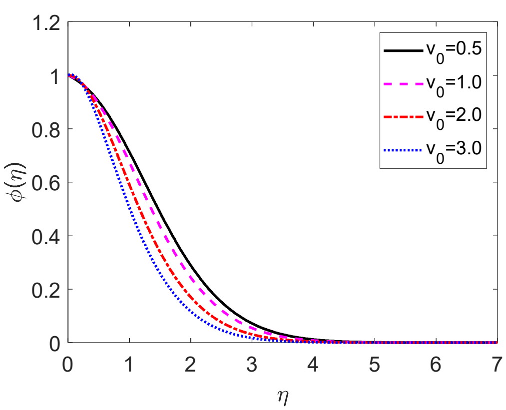

Figure 4: Concentration profile for suction parameter (v_0).

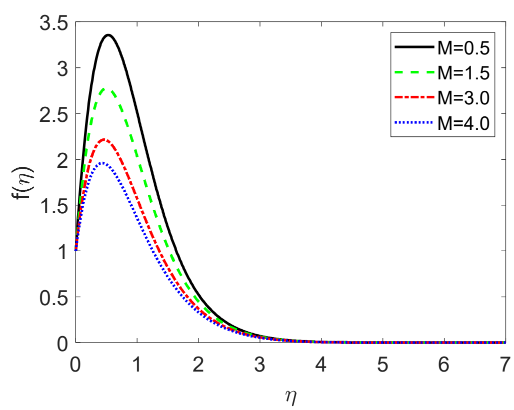

Figure 5: Velocity profile for magnetic parameter (M).

3.2 Effect of a Magnetic Field

The velocity fields for several amounts of the magnetic parameter (M) are illustrated in Figure 5. It is observed from Figure 5 that the fluid speed diminishes with growing levels of M. An upsurge in the quantities of the magnetic force parameter creates Lorentz force which acts like resistive force. This Lorentz force reduces the fluid's motion by obstructing its velocity. As a result, a physical phenomenon occurs where the velocity distribution lessens with increasing amounts of M.

3.3 Effect of Prandtl Number

The impacts of the Prandtl number (Pr) on velocity and temperature fields are revealed in Figures 6 and 7. Figure 6 describes that by the growing value of Pr, the velocity diminishes. We know that Pr is expressed as the ratio of kinematic viscosity to thermal diffusivity. Physically, the kinematic viscosity of the fluid increases due to growing amounts of Prandtl number (Pr). As a result, the fluid becomes significantly thicker and its velocity is reduced. Figure 7 displays that for mounting amounts of Prandtl number, the temperature lessens. Physically, thermal conductivity is comparatively low with higher Prandtl numbers. As a result, heat conduction is reduced, which lowers the temperature. Consequently, when Pr grows in magnitude, the heat transmission rate also improves. Finally, the temperature of the fluid drops.

3.4 Effect of Schmidt Number

The concentration and velocity outlines for various Schmidt number (Sc) values are presented in Figures 8 and 9. It is detected from Figure 8 that velocity diminishes with an upsurge of Sc. As Sc is expressed as the ratio of kinematic viscosity to the mass diffusivity, so growing amounts of Sc correspond to a lessening of mass diffusivity. Also, the medium viscosity improves and hence, the fluid motion is diminished. We realize from figure 9 that for growing amounts of Sc, the concentration border layer converts to thinner. This causes the concentration outlines to lessen. Physically, molecular diffusivity declines for upturning amounts of Sc. So, the species concentration becomes lesser for greater amounts of Sc and developed for minor amounts of Sc. We also observe that the concentration field firstly enhances very close to the wall $0.0 \leq \eta \leq 0.5$ and thereafter an opposite behavior is perceived as mentioned above and finally tends to zero asymptotically as $\eta \rightarrow 7$.

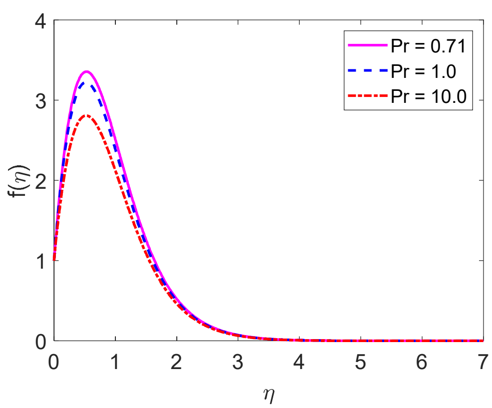

Figure 6: Velocity profile for Prandtl number (Pr).

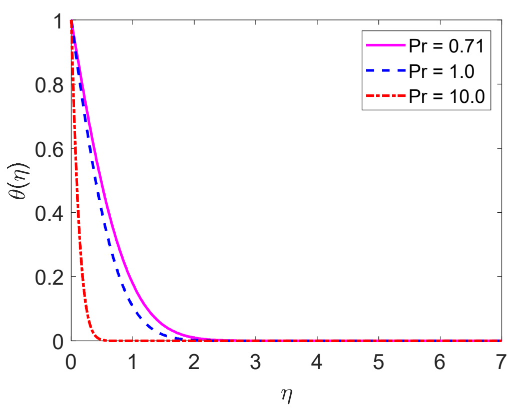

Figure 7: Temperature profile for Prandtl number (Pr).

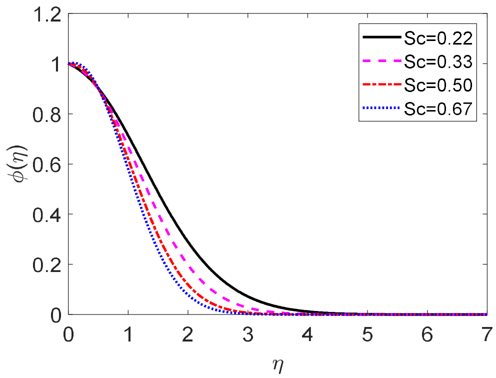

Figure 8: Velocity profile for Schmidt number (Sc).

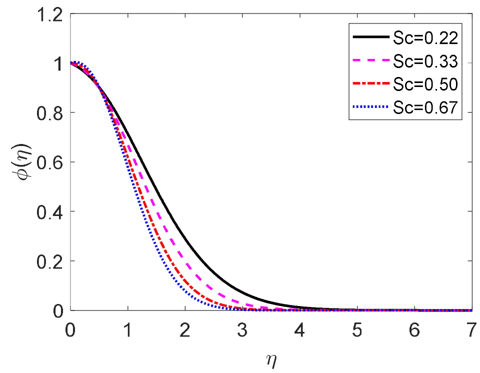

Figure 9: Concentration profile for Schmidt number (Sc).

3.5 Effect of Chemical Reaction Parameter

The influences of the chemical reaction parameter (Kr) on the concentration and velocity fields are described in figures 10 and 11. From figure 10, it is obvious that for growing values of Kr, the fluid motion enhances significantly. The influence of Kr is extremely noteworthy in the concentration field which is presented in Figure 11. Physically, chemical reaction plays a significant role to decline the interfacial mass transfer rate which upgrades the local concentration. So the fluid concentration develops with higher values of Kr.

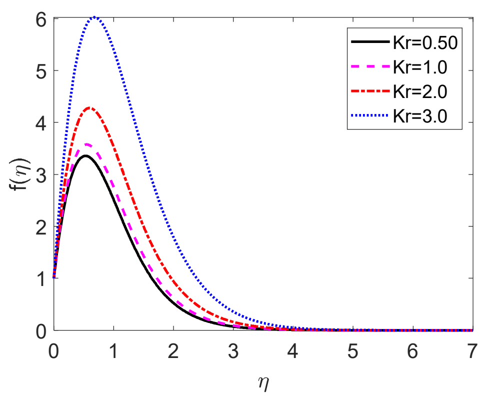

Figure 10: Velocity profile for chemical reaction parameter (Kr).

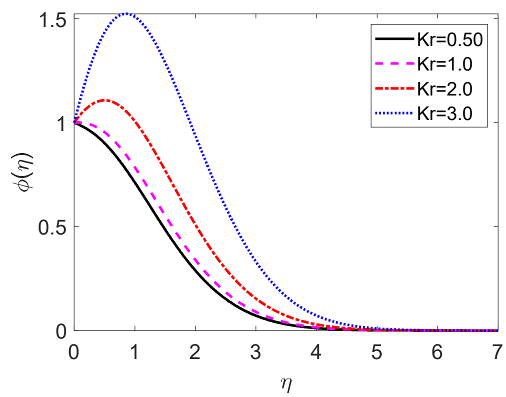

Figure 11: Velocity profile for chemical reaction parameter (Kr).

4. LOCAL SKIN FRICTION COEFFICIENT, HEAT, AND MASS TRANSFER RATES

The mass transfer rate $(-\phi'(0))$, heat transfer rate $(-\theta'(0))$, and local skin friction coefficient $(f'(0)$ are also presented in tabular forms to clarify the inner properties of the fluid flow. These thermo-physical quantities have practical significance in fluid phenomena. The impacts of different amounts of the non-dimensional numbers or parameters such as chemical reaction parameter (Kr), Prandtl number (Pr), and magnetic parameter (M) on the above physical quantities have been explained in Tables 1 to 3.

Table 1 exhibits the impacts of the chemical reaction parameter (Kr) on the heat transfer rate, skin friction coefficient, and mass transfer rate. We discovered that both the mass transfer rate and local skin-friction coefficient upgrade with rising amounts of Kr, whereas no influence of Kr is detected on the heat transfer rate. The table further describes that the local skin-friction coefficient and the mass transfer rate are increased by about 23 % and 283%, respectively for growing values of Kr (0.5-2.0).

Table 1: The skin friction coefficient, heat transfer rate, and mass transfer rate for several amounts of Kr.

Kr	$f'(0)$	$-\theta'(0)$	$-\phi'(0)$
0.5	10.0746012675587	1.18771638498749	0.108384307585017
1.0	10.6308460072469	1.18771638498749	0.304517595901003
2.0	12.3436548189885	1.18771638498749	0.412549899759227
3.0	16.3283480036201	1.18771638498749	1.174182154488240

Table 2: The skin friction coefficient, heat transfer rate, and mass transfer rate for several amounts of Pr.

Pr	$f'(0)$	$-\theta'(0)$	$-\phi'(0)$
0.71	10.0746012675587	1.18771638498749	0.108384307585017
1.0	9.70079454648772	1.46476825346278	0.108384307585017
10.0	8.24679036301379	5.51391564841237	0.108384307585017

The properties of the Prandtl number (Pr) on the heat transfer rate, skin friction coefficient, and mass transfer rate are revealed in Table 2. The graph shows that the skin-friction coefficient declines for upward quantities of Pr, but an opposite behavior is noticed for heat transfer rates. Furthermore, no influence of Pr on mass transfer rates is seen for higher amounts of Pr. The skin-friction coefficient reduces by about 18 % while heat transfer rates enhance by about 364% for rising values of Pr (0.71-10.0).

Table 3: The skin friction coefficient, heat transfer rate, and mass transfer rate for several amounts of M.

M	$f'(0)$	$-\theta'(0)$	$-\phi'(0)$
0.5	10.0746012675587	1.18771638498749	0.108384307585017
1.5	8.193465777170270	1.18771638498749	0.108384307585017
3.0	6.253589824145780	1.18771638498749	0.108384307585017
4.0	5.301658227901080	1.18771638498749	0.108384307585017

Table 3 demonstrates how the magnetic parameter (M) affects the heat transfer rate, skin friction coefficient, and mass transfer rate. We have perceived that only the coefficient of local skin friction diminishes for growing amounts of M (0.05-4.0) but no impact of M is observed on both heat and mass transfer rates. We further noticed that the skin friction coefficient declines by about 47 % for rising values of M (0.5-4.0).

5. CONCLUSIONS

The properties of chemical reaction parameters on unsteady MHD convective transport passing a vertical porous sheet have been investigated in this article. The following conclusions can be made based on our numerical findings:

- With rising suction levels, the fluid velocity, temperature, and concentration reduce.
- The fluid motion declines with growing amounts of the magnetic field.
- The fluid temperature and motion lessen for rising amounts of Prandtl number.
- The fluid velocity and concentration diminish with growing amounts of Schmidt number but the concentration field enhances very close to the wall.
- For growing amounts of chemical reaction parameters, the fluid motion and concentration enhance significantly.

- The coefficient of skin friction and the mass transfer rates are increased by about 23 % and 283%, respectively for growing values of Kr (0.5-2.0).

NOMENCLATURE

MHD	hydromagnetic	u	velocity component in the x-axis
C	fluid concentration	T	The temperature of the fluid
T_w	wall temperature	B_0	uniform magnetic field
g	acceleration due to gravity	ρ	fluid density
C_w	wall concentration	T_∞	free stream temperature
C_∞	free stream concentration	υ	kinematic viscosity
k	thermal conductivity	C_p	specific heat at constant pressure
$v(t)$	suction velocity	$U_0(t)$	uniform surface velocity
D_m	mass diffusivity coefficient	T_m	fluid mean temperature
k_T	thermal diffusion ratio	C_s	concentration susceptibility
σ	similarity parameter	v_0	suction and blowing
G_r	local Grashof number	G_m	modified local Grashof number
M	Magnetic force parameter	Pr	Prandtl number
Df	Dafour number	Sr	Soret number
Sc	Schmidt number	t	Time
τ	Shear stress	N_u	Nusselt number
S_h	Sherwood number	$f(\eta)$	non-dimensional velocity
$\theta(\eta)$	non-dimensional temperature	$\phi(\eta)$	non-dimensional concentration
K^*	The chemical reaction rate of spices concentration	Kr	chemical reaction parameter
v	velocity component in the y-axis,	$\theta'(0)$	heat transfer rate
$f'(0)$	local skin friction coefficient	$\phi'(0)$	mass transfer rate

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