"HEAT AND MASS TRANSFER IN A VERTICAL CHANNEL THROUGH POROUS MEDIUM: INFLUENCE OF RADIATION AND SLIP CONDITIONS"

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ABSTRACT

This study numerically investigates simultaneous heat and mass transfer in a vertical channel filled with a porous medium, using a viscous, incompressible, and radiating fluid. The governing equations for heat and mass transfer are solved using an efficient finite-difference scheme to solve the ordinary differential equations. The study evaluates velocity, temperature, concentration, heat transfer rate, and mass transfer rate for various parameters, including magnetic field strength, suction, and slip conditions. Significant effects of magnetic field and suction parameters on fluid flow, heat transfer, and mass transfer characteristics are observed in the studied configuration. Additionally, for Bi > 0, an increase in the radiation parameter results in higher skin-friction values and lower Nusselt numbers.

Keywords: Convection, Heat transfer, Mass transfer, MHD, radiation effect.

1. INTRODUCTION

The important of heat and mass transfer occurs as a result of combined buoyancy effects of temperature and concentration differences through chemical species, which plays an important role in chemical engineering, aeronautics and geophysics. Some industrial applications are found in polymer production, food processing and drying as well as manufacturing of ceramics. [16,12] made comprehensive reviews of the studies of heat and mass transfer in relation to the above applications.

Considerable attention has been focused in recent years by various scientists and engineers the study problem involving the phenomena of heat and mass transfer with radiation effect. This is due to the fact that radiation effects on convection is quite important in the context of many practical applications such as in cooling and heating of channels, nuclear power plant, fire research, electrical power generation, nuclear reactors, gas turbines and nuclear waste disposal.

2.Review of literature.

1. Soundalgekar and Takher [20] studied the effect of radiation on the natural convection flow of a gas past a semiinfinite plate using the Coghy-Vincentine-Gilles equilibrium model. For the same gas,

2. Takher et al [22] conducted similar research on the effect of radiation on the MHD free convection flow past a semi-infinite vertical plate.
3. Hossain et al [11] considered the effect of radiation on the MHD free convection from a porous vertical plate.
4. Chamkha [6] described coupled heat and mass transfer by natural convection about a truncated cone in the presence of magnetic field and radiation. In another article,
5. Rajput and Kumar [19] presented the effect of radiation on MHD flow past an impulsively started vertical plate with variable heat and mass transfer.
6. Rajeshwara et al [18]A numerical study of the unsteady radiative, free convection flow with heat and mass transfer of an incompressible viscoelastic fluid past an impulsively started vertical plate using finite difference scheme of the Crank-Nicolson type
7. Suneetha and Baskhar [21] analyzed the effects of radiation and mass transfer on a laminar free convective flow of a viscous, incompressible, electrically conducting and chemically reacting fluid in the presence of heat generation.
8. Murali and Babu [15] examined the theoretical study of radiation effect on MHD convection flow past a vertical permeable moving plate.
9. Kishore et al [13]Most recently, the effects of radiation and chemical reaction on unsteady MHD free convection flow of a viscous fluid past an exponentially accelerated vertical plate was carried out by Kishore et al [13].
10. Goldstein [9] :the fluid flow through channels, Navier investigated a boundary condition of the fluid slip at a solid surface such that the velocity of the solid surface is proportional to the shear stress at the surface, that is $u = h\frac{\partial u}{\partial y}$, where h is the slip coefficient and u is the velocity along the x - axis.
11. Bhattacharyya et al [4]:The flow regime is called the slip flow regime and it is effects cannot be neglected due to it is importance in science, technology and industrialization, such as it is application in micro-channels and lubrication of mechanical device where a thin film of lubricant is attached to the surface slipping over one another or when the surfaces are coated with special coating in order to reduce the friction between them. The slip condition has been used in studies of fluid flow by many researchers.
12. Anderson [1]analyzed slip effects on boundary layer stagnation point flow and heat transfer towards a shrinking sheet. Important work on the effect of slip boundary condition on the flow of Newtonian fluid due to a stretching sheet
13. Aziz [3] considered MHD flow and heat transfer characteristics for the boundary layer flow over a permeable stretching sheet with thermal slip conditions. investigated the boundary layer slip flow over a flat plate with constant heat flux condition at the surface.
14. Mohammed and Suneetha [26] :discussed the effects of thermal diffusion and chemical reaction on MHD transient free convection flow past a porous vertical plate with radiation, temperature gradient heat source in slip flow regime.
15. Krishnendu [14]: presented a mathematical model to analyze the steady boundary layer slip flow and mass transfer with nth order chemical reaction past a porous plate embedded in a Darcy porous medium.
16. Chand et al. [7]: studied the combined effect of slip and jump boundary condition viscoelastic fluid with Soret effects. The theoretical analysis of unsteady hydrodynamic free convective flow of a viscoelastic fluid past an infinite vertical porous channel through a porous medium was recently,

17. , Nityananda and Rajendra [17]: examined the effect of slip condition on unsteady MHD oscillatory flow in a channel filled with saturated porous medium in the presence of transverse magnetic field and radiative heat and mass transfer.
18. Gbadeyan and Dada [8]: investigated radiation and heat transfer effects on MHD non-Newtonian unsteady flow in a porous medium with slip condition.
19. Ahmed and Kishore [24]: reported MHD mass transfer flow past a vertical porous plate embedded in a porous medium in a slip flow regime with thermal radiation and chemical reaction
20. Loganathan and Sivapoornapriya [25] studied radiation and chemical reaction effects on unsteady natural convection flow of a micropolar fluid past a vertical moving porous plate. Inspite of all these studies, it is observed that radiative transport is often comparable, and hence associated with that of convective heat and mass transfer in several practical applications. Therefore it is of great significance to the researchers to study heat and mass transfer with radiation effect and slip condition.

2. MATHEMATICAL FORMULATION

Consider a one-dimensional unsteady MHD laminar boundary layer flow of a viscous, incompressible and radiating fluid along a vertical channel in a porous medium. A uniform transverse magnetic field B_0 is taken to be acting along the ' y - axis. The ' x - axis is taken along the plate in the vertically upward direction and ' y - axis is perpendicular to the wall of the plate in the direction of the applied uniform magnetic field (see fig. 1). The fluid has constant viscosity, constant thermal conductivity and constant chemical reaction. It is assumed that the viscous dissipation is negligible and there is no applied voltage, which implies the absence of an electric field.

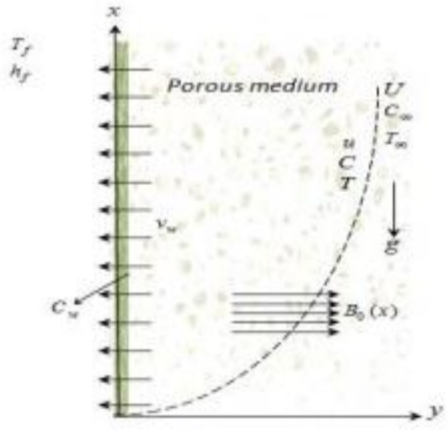

Figure 1. Physical configuration of the problem

The Rosseland approximation is used to describe the radiative heat flux. By the above assumptions, the governing equations of the flow are given by:

$$\frac{\partial u}{\partial y} = 0 \qquad (2.1)$$

$$-V_w \frac{\partial u}{\partial y} = v \frac{\partial^2 u}{\partial y^2} + g\beta_T(T - T_\infty) + g\beta_c(C - C_\infty) + \frac{v}{K}(U - u) + \frac{\sigma B_0^2 (U-u)}{\rho} \qquad (2.2)$$

$-V_w \frac{\partial T}{\partial y} = \frac{k}{\rho c_p} \frac{\partial^2 T}{\partial y^2} + \frac{v}{c_p} (\frac{\partial u}{\partial y})^2 + \frac{\sigma B_0^2}{\rho c_p} (U - u)^2 - \frac{1}{\rho c_p} \frac{\partial q_r}{\partial y}$ (2.3)

$-V_w \frac{\partial C}{\partial y} = D \frac{\partial^2 C}{\partial y^2} - R(C - C_\infty)$(2.4)

The corresponding initial and boundary condition are prescribed as follow :

y= 0:u =0,$- k \frac{dT}{dy} = h_f(\mathrm{T_f} - T); C = C_w$ (2.5)

$y \to \infty : u \to U , T \to T_\infty \; C \to C_\infty$ (2.6)

The Radiative heat flux $q_r$under Roseland approximation by Brewster [5] has the form:

$q_r = -\frac{4\sigma}{3k} \frac{\partial T}{\partial y}$ (2.7)

(2.7) where ' σ_0 is the Stefan-Boltzmann constant and ' k is the mean absorption coefficient. We assume that the temperature differences within the flow are so small that T^4 can be expressed as a linear function of the temperature. This is 130 accomplished by expanding T^4in a Taylor series about ' T_0 and neglecting the higher order terms. Thus

T$\cong 4T_\infty^3$ T - $3T_\infty^3$ (2.8)

Using equations (2.7) and (2.8) in equation (2.4) we obtain:

$-V_w \frac{\partial T}{\partial y} = \frac{k}{\rho c_p} \frac{\partial^2 T}{\partial y^2} + \frac{v}{c_p} (\frac{\partial u}{\partial y})^2 + \frac{\sigma B_0^2}{\rho c_p} (U - u)^2 - \frac{16\sigma T_\infty^3}{3\rho c_p k} \frac{\partial^2 T}{\partial y^2}$(2.9)

where ' u and ' v are the Darcian velocity components in the x - and y - directions respectively, t is the time, g is the acceleration due to gravity, ν is the kinematic viscosity, β is the coefficient of volume expansion, ρ the density of the fluid, σ is the scalar electrical conductivity, β is the volumetric coefficient of expansion with concentration, C_p is the specific heat capacity at constant pressure, k is the permeability of the porous medium, k_0 is the dimensionless thermal conductivity of the ambient fluid, α is a constant depending on the nature of the fluid, R is the dimensionless chemical reaction, D is the coefficient of molecular diffusivity, r q is the radiative heat flux in the y - direction, B_0 is the magnetic induction of constant strength. ' T and ' T_0 are the temperature of the fluid inside the thermal boundary layer and the fluid temperature in the free stream respectively, while ' C and ' C_0 are the corresponding concentrations. To obtain the solutions of equations (2.2), (2.4) and (2.5) subject to conditions (2.9) in non-dimensional forms, we introduce the following non-dimensional quantities

$\eta = \frac{v_w y}{v}$, f $= \frac{u}{v_w}$, Y $= \frac{y}{H}$, $\theta = \frac{T - T_\infty}{T'_w - T'_0}$, h $= \frac{y'}{H}$, $C = \frac{C' - C'_0}{C'_w - C'_0}$,Pr $= \frac{\eta \rho c_p}{k}$, Sc $= \frac{V}{D}$

k $= \frac{k^* u_0}{v H^2}$,M $= \frac{\sigma B_0^2}{K_0}$,$\lambda = \frac{\Upsilon v^2}{D v_w^2}$, Gr $= \frac{g \beta_t (T_f - T_\infty) v}{v_w^3}$, R$= \frac{4\sigma^* T_\infty^3}{k k^*}$, $\emptyset = \frac{C - C_\infty}{C_w - C_\infty}$,

Gc $= \frac{g \beta_t (C_w - C_\infty) v}{v_w^3}$; F $= \frac{U}{v_m}$, k $= \frac{K V_w^2}{v^2}$, M$= \frac{\sigma v B_0^2}{\rho c}$, Bi $= \frac{v h_f}{k v_m}$

where Pr is the Prandtl number, Sc is the Schmidt number, M is the magnetic field parameter, G_r is the thermal Grashof number, G_c is the solutal or mass Grashof number, λ is the variable thermal conductivity, γ is the variable suction parameter, R is the radiation parameter, K_r is the chemical reaction parameter, k is the permeability parameter, h is the slip parameter, t is the dimensionless time while u and v are dimensionless velocity components in x - and y - directions respectively.

The quantities of practical interest in this study are the skin friction coefficient, Nusselt number and Sherwood number.there fore with help of normalized parameters the ordinary differential equations (2.2) (2.4) to (2.6) are converted to simplified ordernary differential which are defined as

$$-\frac{df}{d\eta} = \frac{d^2 f}{d\eta^2} + \mathrm{Gr}\theta + \mathrm{Gc}\theta + \mathrm{M}(\mathrm{F} - \mathrm{f}) + \frac{F-f}{k} \quad (2.11)$$

$$-\frac{d\theta}{d\eta} = \frac{1}{Pr}\frac{d^2\theta}{d\eta^2} + \mathrm{Gr}\theta + \mathrm{Ec}\left(\frac{df}{d\eta}\right)^2 + \mathrm{M}Ec(F - f)^2 \quad (2.12)$$

$$-\frac{d\theta}{d\eta} = \frac{1}{Sc}\frac{d^2\theta}{d\eta^2} - \frac{\lambda}{Sc}\phi \quad (2.13)$$

$$\eta = 0,\ \mathrm{f} = 0,\ \frac{d\theta}{d\eta} = \mathrm{Bi}[\theta - 1]\phi = 1 \qquad ((2.14)$$

$$\mathrm{C_f} = \frac{2}{F^2} f'(0) \qquad (2.15)$$

$$,\ \mathrm{Nu} = \frac{hv}{kv_w} = \frac{T_{f-}\ T_\infty}{T_{W-}\ T_\infty}\theta'(0) = -\frac{\theta'(0)}{\theta(0)},$$

Where T_W is the plate surface temperature

$$\mathrm{Sh} = -\frac{h_m v}{Dv_w} = -\theta'(0)$$

Where h_m is the convection mass transfer coefficient .

3. SOLUTION METHODOLOGY

In this study, an efficient numerical scheme ordinary differential equations order method has been employed to investigate the problem defined by equations (2.2)to (2.4) and (2.5) and (2.9). The effects of pertinent parameters are discussed for the dimensionless velocity, temperature, concentration, skin friction coefficient and the rate of heat and mass transfer. The step size and convergence criteria are chosen to be 0.001 and 10^{-6} respectively. For this purpose the values of F,Pr and Sc as those in [9]are 0.5,0.72 and 0.24 respectively and also the value of K, λ,M,E_c,G_r, G_c is 0.1

4. RESULTS AND DISCUSSION

The governing the flow were solved numerically. Numerical computations have been carried out for different values of physical parameters such as Gr and Gc, thermal and solutalGrashof's numbers; M, magnetic parameter; k, permeability parameter; R, radiation parameter; h, slip condition parameter; λ , variable thermal conductivity; γ , suction parameter; Kr , chemical reaction parameter; Pr, Prandtl number and Sc, Schmidt number. The effects of the emerging parameters on the dimensionless velocity, temperature, concentration, skin friction, the rate of heat transfer and mass transfer are investigated.

Figure 2 shows that the values of velocity increase with increasing the Biot number because of a rise in convective heat transfer to the fluid on the right side of the wall and decrease with increasing the magnetic parameter because of exerting a drag force on the fluid by the magnetic field.

Figure 3. Due to the high convective heat transfer to the cold fluid, it is clear that the temperature of the fluid increases with increasing the Biot number.

Figure 4 is made to demonstrate the effect of permeability parameter on the velocity and temperature profiles. It is observed that increasing the permeability parameter is concluded retarding effect of porous medium on the flow.

Figure 5 The effect of Eckert number ,where the temperature and velocity values are increased by increasing this number.

Figures 6 and 7. It is clear that increasing these numbers leads to increase in the thermal and mass buoyancy forces. Hence, the velocity and temperature increase with increasing the thermal and mass transfer Grashof numbers.

Figure 8 gives the effects of the Schmidt number and reaction rate parameter on concentration profiles. The Schmidt number is defined as the ratio of momentum diffusivity and mass diffusivity. Thus, increasing the Schmidt number is leading to a fall in the concentration values.

Figure 9 the values of the velocity are increased under the effect of the radiation parameter. Furthermore,

Figure 10 shows clearly that the temperature of the fluid increases with increasing the radiation parameter

Figures 11 and 12 that skin-friction increases whereas the Nusselt number decreases with increase in radiation parameter. that the values of skin-friction increase with increasing the Biot number. Moreover, the skin-friction is almost constant, $C_f \approx 9.60$, for different values of radiation parameter for the case $B_i = 0$.

Table 1. Comparison of values of $f'(0)$, $\theta'(0)$, and $\phi'(0)$, with R = 0.

Bi	M.A.Hossian,M.A.Alim [9]			Present results		
	$f'(0)$	$-\theta'(0)$	$-\phi'(0)$,	$f'(0)$	$-\theta'(0)$	$-\phi'(0)$
0	1.873	0.000	0.432	1.888	0.000	0.452
1	1.903	0.345	0.432	1.900	0.385	0.452
2	1.903	0.345	0.432	1.900	0.385	0.452
10	1.917	0.645	0.452	1.917	0.645	0.452

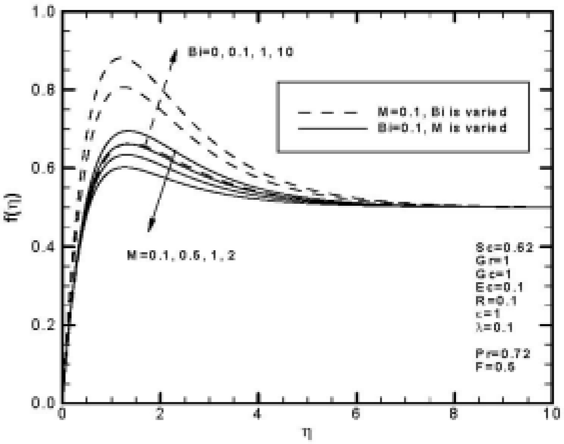

Figure 2. Velocity profiles for different values of Biot number and magnetic parameter.

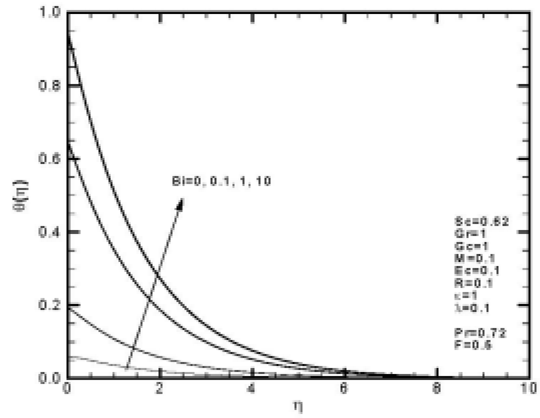

Figure 3. Figure 3. Temperature profiles for different values ofBiot number.

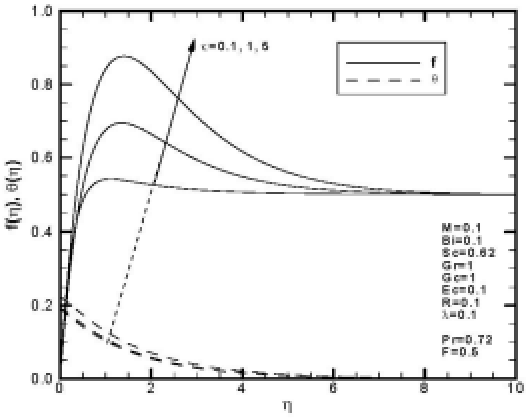

Figure 4. Effect of κ on the velocity and temperature profiles

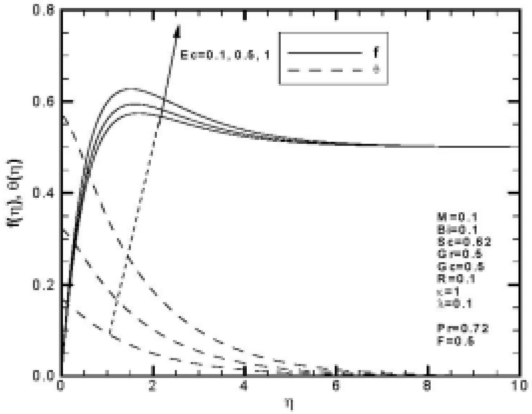

Figure 5. Effect of Ec on the velocity and temperature profiles

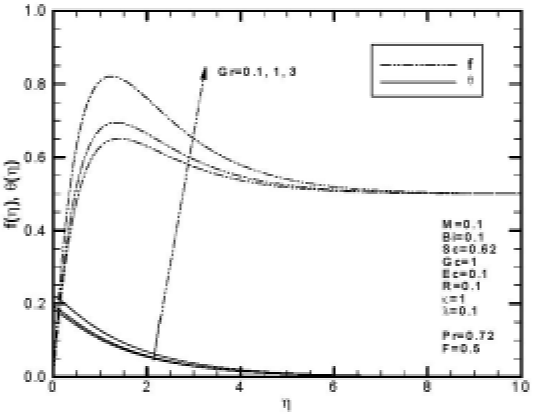

Figure 6. Effect of Gr on the velocity and temperature profiles.

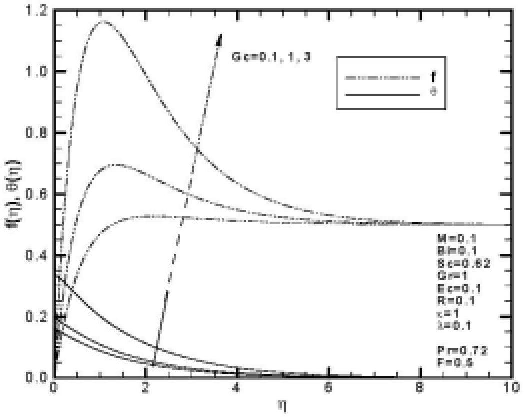

Figure 7. Effect of Gc on the velocity and temperature profiles.

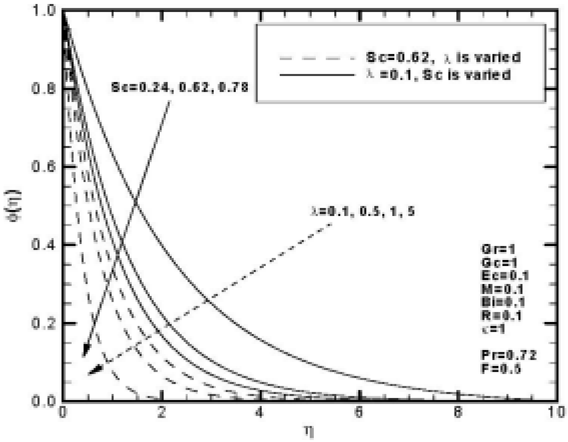

Figure 8. Effect of Sc and λ on the concentration profiles.

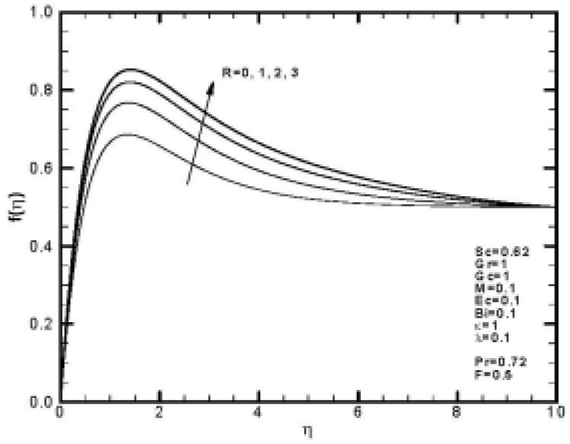

Figure 9. Effect of radiation on the velocity profiles.

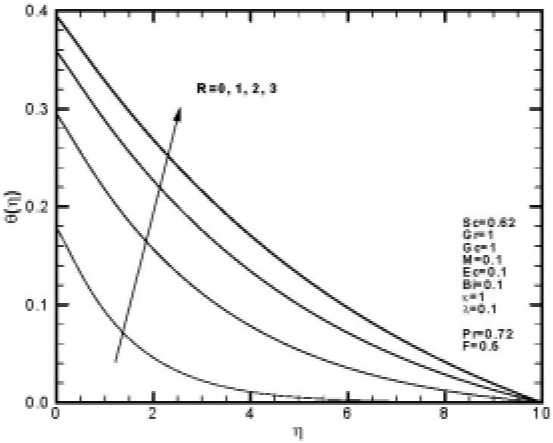

Figure 10. Effect of radiation on the temperature profiles.

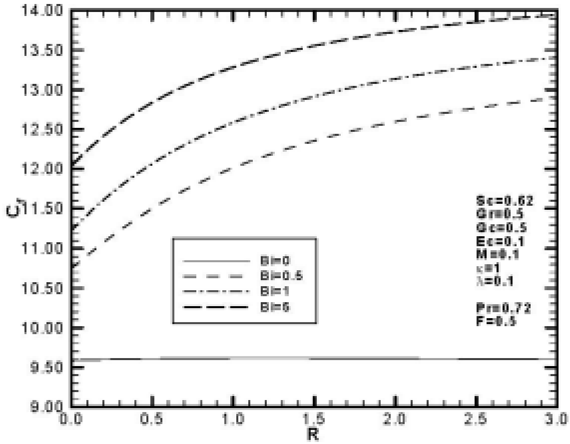

Figure 11. Variations in Cf with R for various values of Bi.

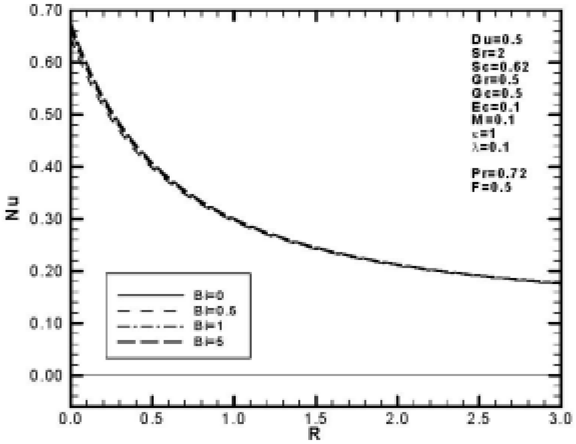

Figure 12. Variations in Nu with R for various values of B_i.

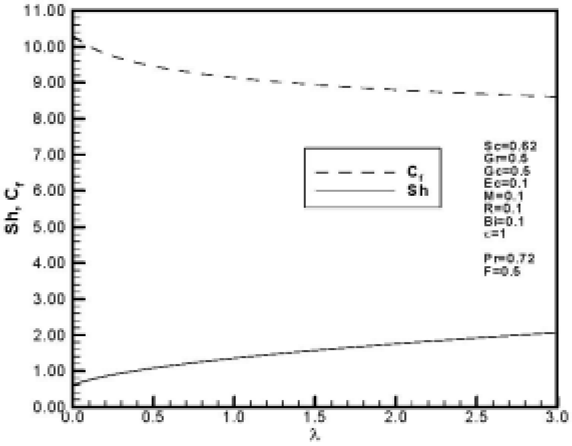

Figure 13. Variations in C_f and S_h with λ.

5. CONCLUSIONS

The research of heat and mass transmission with the consideration of radiation effect and slip condition has been addressed theoretically. An effective numerical technique of ordinary differential equations is utilized to solve the governing equations numerically. The presentation of governing parameters' impacts on the properties of mass transfer, temperature, concentration, skin friction, and rate of heat is done both numerically and graphically. Based on these findings, we deduce that

The velocity profile enhances for the increase in the values of Gc, Gr, λ and γ while the contrast trend is found on M, k, R, h and Pr.

The temperature profile decreases with increase in Pr and R.

The concentration profile decreases with increase in ,λγ and Kr while accelerates for an increase in Sc.

High values of M, Gc, Gr, k, h and γ appreciate skin friction. However, the Prandtl number, radiation and variable thermal conductivity influences the values of the rate of heat and mass transfer.

It is assumed that the physics of flow along vertical channels can serve as the foundation for numerous scientific and engineering applications with the aid of our current model. The solutions to the current issue are also quite interesting from a geophysics perspective, especially in some geothermal regions. Additionally, the study identifies uses for high-temperature production procedures, which are crucial for complicated polymers.

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NOMENCLATURE :

C Concentration
Cf skin friction
M magnetic field parameter
g gravitational acceleration, m.s-2
$C_p$specific heat, J. kg-1. K-1
D mass diffusivity
G_rGrashof number
$G_c$solutalGrashof number
Nu local Nusselt number along the heat
Pr Prandtl number

Sc Schmidt number
k porous parameter
R radiation parameter
Kr chemical reaction parameter
T Sh u, v x, y temperature
Sherwood number velocities in the x and y-direction cartesian
coordinates along the plate
B_0 magnetic field of constant strength