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Numerical Investigation of Heat and Mass Transfer in Radiative Magnetohydrodynamic Flow with Chemical Reaction

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Abstract

Numerical investigation is carried out to analyze the heat and mass transfer in magnetohydrodynamic flow over a stretching sheet in the presence of thermal radiation and chemical reaction. The governing equations are transformed as ordinary differential equations using self suitable transformations, further these equations are solved numerically using shooting technique. The influence of pertinent parameters namely, magnetic field parameter, thermal radiation parameter, chemical reaction parameter, thermal and mass Grashof numbers etc., on velocity, temperature and concentration fields are discussed with the assistance of graphs. Numerical results are presented to discuss the behaviour of friction factor along with heat and mass transfer rate. Results shows that thermal radiation parameter have tendency to enhance the thermal boundary layer thickness.

1. Introduction

The hydromagnetic flow and heat exchange over a stretching surface has considered for practical applications in industrial and engineering. For instance streamlined expulsion of plastic sheet, paper creation, glass blowing, metal turning, drawing plastic films, aerodynamic expulsion of plastic sheet, condensation process of metallic plate in a cooling bath and expulsion of a polymer sheet from a colour. The MHD boundary layer flow due to an exponentially stretching sheet in presence of radiation was discussed by Ishak [1]. The MHD flow over a stretching sheet with thermal radiation and thermal conductivity was analyzed by Cortell [2]. The impacts of thermal radiation and chemical reaction on the study of two-dimensional stagnation point flow over a viscous incompressible electrically conducting fluid over a stretching surface with suction in the presence of heat generation was analyzed by Krishna *et al.*, [3]. Mansour *et al.*, [4] explored the impacts of chemical reaction, thermal stratification, Soret number and Dufour number on MHD free convective heat and mass exchange of a thick, incompressible and electrically leading fluid on a vertical stretching surface embedded in a saturated porous medium. Afify [5] explained the MHD free convective flow of viscous incompressible fluid and mass transfer over a stretching sheet with chemical reaction. The heat and mass transfer in thermophoretic radiative hydromagnetic flow over an exponentially stretching surface embedded in porous medium with internal heat generation or absorption, viscous dissemination and infusion impacts was outlined by Sandeep and Sulochana [6]. Raju and Sandeep [7] were concentrated on the influence of induced magnetic field and thermal radiation on nanofluid flow past a stretching surface. The heat transfer qualities of a two dimensional consistent of hydromagnetic characteristic convection flow of a nanofluid over a non linear stretching sheet taking in to an record the effects of radiation and convective boundary conditions has been researched numerically by Rahman and Eltayed [8]. A numerical examination of insecure magnetohydrodynamic blended convective boundary layer flow of a nanofluid over an exponentially stretching sheet in porous medium is displayed by Anwar *et al.*, [9]. The effects of aligned magnetic field, thermal radiation, heat generation or absorption, viscous

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dissipation, heat sources and chemical reaction on the flow of a nanofluid past exponentially stretching surface in porous medium was examined by Sulochana *et al*., [10]. The effects of magnetohydrodynamic free convection flow of heat and mass exchange of non-Newtonian fluid along a stretching surface with viscous dissipation has been analyzed by Saha and Samad [11]. The enduring of two dimensional radiative MHD boundary layer flow of an incompressible, viscous electrically conducting fluid brought about by a nonisothermal linearly stretching surface in saturated porous medium in the presence of viscous dissipation and chemical reaction was clarified by Ibrahim [12]. The heat and mass transfer of an incompressible steady laminar MHD stagnation point flow over a stretching surface in the presence of heat generation or absorption and chemical reaction effects was depicted by Freidoonimehr *et al*., [13]. An unsteady magnetohydrodynamic heat and mass transfer viscous incompressible fluid flow over a stretching sheet embedded in a porous medium with variable viscosity and thermal conductivity have been analyzed by Hunegnaw and Kishan [14]. The heat and mass transfer of a boundary layer flow through porous medium in the presence of heat source and chemical reaction have been analyzed by Nayak [15]. The effects of viscous dissipation and radiative heat transfer in nanofluid with the influence of magnetic field over a rotating stretching surface has been researched by Wahiduzzaman *et al*., [16]. The steady of two-dimensional flow through a vertical stretching surface in the presence of aligned magnetic field and radiation effects was analyzed by Raju *et al*., [17]. Gopi and Jat [18] were expressed the effects of radiation and viscous dissipation on MHD through an unsteady stretching surface in the presence of uniform magnetic field in the porous medium. The flow of a Newtonian fluid over an impermeable stretching sheet embedded in a porous medium with the force law surface speed and variable thickness in the presence of thermal radiation was studied by Khader and Megahed [19].

MHD plays an essential part in agriculture, petroleum industries, geophysics and astrophysics. MHD flow has application in meteorology, solar physics and in movement of earth’s centre. The influence of thermal radiation and chemical reaction on two dimensional steady magnetohydrodynamic flow of a nanofluid past a permeable stretching sheet in the presence of suction/ injection was investigated by Sandeep and Sulochana [20]. The investigation of viscous dissipation and thermal radiation on the stagnation point flow of viscous fluid impelled by an exponentially stretching surface was discussed by Iqbal *et al*., [21]. The influence of viscous dissipation on MHD boundary layer flow and heat transfer of a dusty fluid in a porous medium over an exponentially stretching sheet was experimented by Pavithra and Gireesha [22]. The influence of non-uniform heat source, mass exchange and chemical reaction on an precarious blended convection boundary layer flow of a magnetic fluid past a stretching sheet in the presence of viscous dissipation have be depicted by Sandeep and Sulochana [23]. The magnetohydrodynamic boundary layer flow and heat transfer of an incompressible, viscous and electrically conducting fluid, the flow is considered over a stretching sheet in the presence of transverse magnetic field with heat source/sink was analyzed by Pantokratoras [24]. Yirga and Shankar [25] have been investigated the convective heat and mass transfer in nanofluid flow through a porous media because of an stretching sheet subjected to the magnetic field, viscous dissipation, chemical reaction and soret effects. An insecure magnetohydrodynamic boundary layer flow and heat transfer of a fluid over a stretching sheet in the presence of viscous dissipation and heat source was contemplated by Gnaneswara Reddy *et al*., [26]. The magnetohydrodynamic flow and heat transfer of a couple stress fluids over oscillatory stretching sheet embedded in a porous medium in the presence of heat source or sink was clarified by Ali *et al*., [27]. An unsteady magnetohydrodynamic radiative flow and heat transfer qualities of a dusty nanofluid over an exponentially permeable stretching surface in nearness of volume division of dust and non particles was considered by Sandeep *et al*., [28]. The chemical responsive solute dispersion in MHD boundary layer flow over a penetrable stretching sheet with suction/blowing depicted by Bhattacharyya and Layek [29]. The magnetohydrodynamic blended convection flow close to a stagnation point area over a nonlinear stretching sheet with velocity slip and recommended surface heat flux is examined by Shen *et al.*, [30]. The magnetohydrodynamic mixed convection stagnation point flow, heat and mass transfer of a nanofluid over a non-isothermal stretching sheet in presence of incited magneticfield, radiation, chemical reaction, suction and heat sources have been analyzed by Sandeep and Sulochana [31]. The effects of heat generation or retention on magnetohydrodynamic stagnation point flow and heat transfer over a porous stretching surface with prescribed surface heat flux was studied by Jalilpour *et al.*, [32]. The influence of thermal radiation, viscous dissipation and magneticfield on the boundary layer flow of a nanofluid past a nonlinear permeable stretching sheet was expressed by Sandeep *et al.*, [33]. The influence of thermal radiation on magnetohydrodynamics flow through a stretching porous surface was analyzed by Yahaya and Simon [34]. Wang [35] examined the stagnation flow towards a stretching sheet and found that the convective heat transfer diminishes with the convective heat transfer decrease in the boundary layer thickness.

In this study, we investigated the heat and mass transfer in magnetohydrodynamic flow over a stretching sheet in the presence of thermal radiation and chemical reaction. The governing equations are transformed as ordinary differential equations using self suitable transformations, further these equations are solved numerically using shooting technique. The influence of pertinent parameters namely, magnetic field parameter, thermal radiation parameter, chemical reaction parameter, thermal and mass Grashof numbers *etc.*, on velocity, temperature and concentration fields are discussed with the assistance of graphs. Numerical results are presented to discuss the behaviour of friction factor along with heat and mass transfer rate.

2. Mathematical Formulation

Consider a steady, two-dimensional laminar flow of a viscous, incompressible and electrically leading fluid past a stretching sheet. The stretching sheet is thought to be permeable in order to give way for possible wall fluid suction/injection. By utilizing two equivalent and inverse strengths along the horizontal direction, with the influence of a uniform magnetic field normal to the plate, the uniform magnetic field as a result of velocity of the electrically leading fluid is immaterial. The physical model of the present study is appeared in Figure 1.

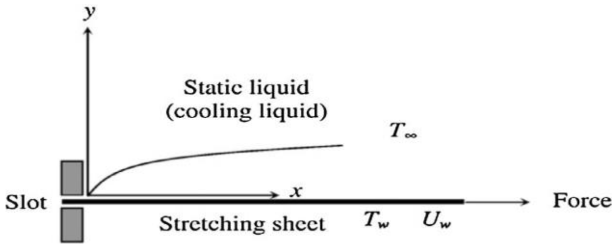

Figure 1. Schematic Representation of the Physical Model and Coordinates System

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}-\sigma B_0^2(x)u+g\beta_T(T-T_\infty)+g\beta_c(C-C_\infty)-\frac{\upsilon}{k}u \ , \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{\beta^* u}{\rho c_p}(T_\infty - T)+\frac{16\sigma^*}{3\rho c_p k^*}T_\infty^3\frac{\partial^2 T}{\partial y^2}\ , \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}-K_r(C-C_\infty)\ , \tag{4}$$

Subjected to the following boundary conditions:

$$u=ax,\ v=v_w,\ T=T_w(x)=T_\infty+A_1x,\ \ C=C_\infty+A_2x \qquad at \qquad y=0\ ,$$

$$u\to 0,\ T\to T_\infty,\ C\to C_\infty \qquad as \qquad y\to\infty\ , \tag{5}$$

Where $T_w(x)$ is as the wall temperature, a is the stretching rate which is constant and v_w is wall suction when (v_w<0) and the injection when (v_w>0). Also u, v and T are the velocity and Temperature components along x and y axes respectively, g is the acceleration due to gravity, C_p is the specific heat at constant pressure, υ is the kinematic viscosity, α is the thermal diffusivity of the fluid, β is the coefficient of thermal expansion, ρ is the fluid density, B_0 is the applied magnetic induction, k_l is the rate of chemical reaction, σ^* is termed as Stefan-Boltzmann constant and k^* is as the mean absorption coefficient. To obtain the similarity solutions of equations (1) - (4) subjected to the boundary conditions equation (5). In terms of the stream function the velocity components are:

$$u=\frac{\partial\psi}{\partial y},\qquad v=-\frac{\partial\psi}{\partial x} \tag{6}$$

Using the transformations

$$\eta=y\sqrt{\frac{a}{\upsilon}},\qquad \psi=\sqrt{\upsilon a}\,xf(\eta),\qquad \theta=\frac{T-T_\infty}{T_w-T_\infty},\quad \phi=\frac{C-C_\infty}{C_w-C_\infty}, \tag{7}$$

Equations (1) – (5) reduces to

$$f'''+ff''+f'^2+Gr\theta+Gc\phi-M^2f'-\lambda f'=0\ , \tag{8}$$

$$\frac{R+1}{Pr}\theta''+f\theta'-(1+\delta_x)f'\theta=0\ , \tag{9}$$

$$\frac{1}{Sc}\phi''+f\phi'-Kr\phi=0\ , \tag{10}$$

With the boundary conditions

$$f(0)=S,\qquad f'(0)=1,\qquad \theta(0)=1,\qquad \phi(0)=1,\qquad f'(\infty)=1,$$
$$\theta(\infty)=0,\qquad \phi(\infty)=0\ , \tag{11}$$

$$M=\left(\frac{\sigma}{\rho_a}\right)^{\frac{1}{2}}B_0,\qquad Gr=g\beta_T\frac{(T_w-T_\infty)}{a^2x},\quad Gc=g\beta_c\frac{(C_w-C_\infty)}{a^2x},\quad \Pr=\frac{\upsilon}{\alpha},$$

$$R=\frac{16\sigma^*T_\infty^3}{3K^*K},\qquad \delta_x=\frac{\beta^*x}{\rho c_p},\qquad Kr=\frac{K_l}{a},\qquad Sc=\frac{\upsilon}{D_B},\qquad \lambda=\frac{\upsilon}{ka}$$

Where the notation prime denotes with respect to η and M is the magnetic field parameter, Gr is the Grashof number, Pr is the Prandtl number, R is the radiation parameter, Kr is the chemical reaction parameter, Sc is the Schmidt number and β^* is the Thermal radiation parameter and heat generation/absorption coefficients respectively.

The physical quantities of interest the skin-friction coefficient, the local Nusselt number and reduces the Sherwood number are calculated respectively by the following equations.

$$C_f(\mathrm{Re}_x)^{0.5}=-f''(0) \tag{12}$$

$$Nu(\mathrm{Re}_x)^{0.5}=-\theta'(0) \tag{13}$$

$$Sh(\mathrm{Re}_x)^{0.5}=-\phi'(0) \tag{14}$$

Where $\mathrm{Re}_x=\frac{ax^2}{\upsilon}$ is the local Reynolds number.

3. Result and Discussion

The system of non linear ordinary differential equations (8) to (10) with boundary conditions (11) are solved by using shooting technique. For numerical computations we considered the non-dimensional parameter values as $M = R = 1$, $kr = 0.5$, $Pr = 6$, $Sc = 0.6$, $Gr = Gc = 0.5$, $\lambda = 0.5$. Figures 2-4 shows the influence of magnetic field parameter (M) on velocity $f'(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles of the flow. It is clear that an increase in the magnetic field parameter (M) decreases the velocity $f'(\eta)$ and increases the temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles of the flow. This is due to the Lorentz's for acts opposite to the flow direction. Figures 5-6 illustrates the effects of radiation (R) parameter on the velocity $f'(\eta)$ and temperature $\theta(\eta)$ profiles of the flow. It is observed a hike in the velocity and temperature profiles for higher values of the radiation parameter. Generally, an increase in the radiation parameter releases the heat energy to the flow, these causes to develop the momentum and thermal boundary layer thickness.

Figures 7-9 shows the effect of permeability parameter (K) on velocity $f'(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles. It is noticed from the figures that increasing in the porosity parameter declines the velocity profile and enhances the temperature and concentration profiles. Normally, increasing the porous parameter releases the internal heat to the flow and widens the porous layers, causes to develop the momentum boundary layer. Figure 10 illustrates the effects of chemical reaction parameter (Kr) on the concentration profile of the flow. It is clear that an increase in the chemical reaction parameter declines the concentration profile of the flow.

Figures 11-12 it is noticed that an increase in porosity parameter (δ_x), reduces the velocity $f'(\eta)$ and temperature $\theta(\eta)$ profiles. The reason behind this is an increase in porosity parameter means widen the holes of the porous medium as a result the resistive force acts opposite to the flow and there is a fall in velocity profiles. Figure 13 depict the effect of Schmidt number (*Sc*) on concentration $\phi(\eta)$ profile. We noticed form the figure that the higher values of Schmidt number reduces the concentration boundary layers. Figures 14-16 shows the velocity $f'(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles for different values of Suction/injections (*S*). It observed from the figures that the velocity $f'(\eta)$, temperature and concentration profiles of the flow are reduced by increasing the Suction/injection parameter.

Figures 17-19 depicts the effect of thermal Grashof number (*Gr*) on velocity $f'(\eta)$, temperature $\theta(\eta)$ and concentration $\phi(\eta)$ profiles of the flow. It is evident that with the increase in thermal Grashof number we observed enhancing the velocity profile and depreciation in the temperature and concentration profiles of the flow. This is due to the fact that an increase in the thermal Grashof number develops the buoyancy forces, these forces reduces the thermal and concentration boundary layer thickness.

Table 1 demonstrates the influence of various physical parameters on friction factor, Nusslet number and Sherewood number. It is evident from the table that with increasing the magneticfield parameter, permeability parameter and Grashof number reduces the friction factor, rate of heat and mass transfer. But we observed that increase in chemical reaction parameter and Schmidt number depreciation in the friction factor, heat transfer rate and increase in mass transfer rate. An increase in radiation parameter enhances the heat transfer and declines the friction factor and mass transfer rate.

Table 1. Variation in $f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ for Different Non-Dimensional Parameters

M	R	K	δ_x	S	Gr	Kr	Sc	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
1								-0.270379	0.998729	0.925863
3								-1.205736	0.880201	0.882369
5								-1.825761	0.809001	0.858762
7								-2.310539	0.759842	0.843340
	0.5							-0.333065	1.198046	0.920426
	1							-0.270379	0.998729	0.925863
	1.5							-0.222420	0.869860	0.930138
	2							-0.184400	0.778891	0.933573
		1						-1.379262	0.859427	0.875310
		2						-1.956448	0.795155	0.854352
		3						-2.418385	0.749756	0.840245
		4						-2.811881	0.715480	0.829896
			0					-0.243884	0.885369	0.927931
			0.2					-0.254950	0.931927	0.927066
			0.4					-0.265382	0.976841	0.926253
			0.6					-0.275240	1.020261	0.925484
				-0.5				0.282337	0.825964	0.611921
				0				0.042458	0.904625	0.756631
				0.5				-0.270379	0.998729	0.925863
				1				-0.648458	1.113326	1.118647

					0			-0.840974	0.915002	0.895150
					0.2			-0.781238	0.924987	0.898597
					0.4			-0.722222	0.934508	0.901942
					0.6			-0.663866	0.943613	0.905193
						1		-1.169963	1.877235	1.335966
						2		-1.200327	1.860930	1.572354
						3		-1.223268	1.851540	1.772832
						4		-1.241564	1.845327	1.950289
							0.5	-0.234122	1.007010	0.826074
							1	-1.150428	1.901872	1.166426
							1.5	-1.207108	1.864989	1.569053
							2	-1.250126	1.846085	1.942239

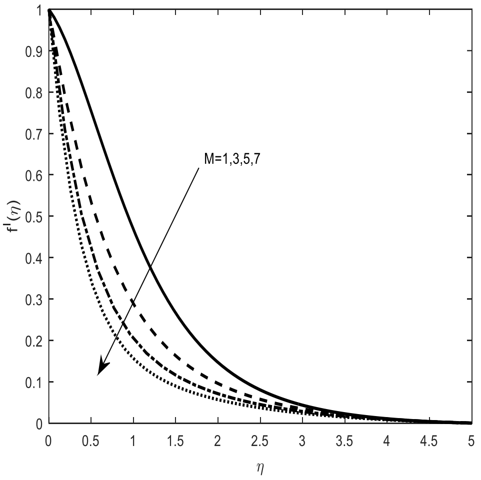

Figure 2. Velocity Profiles $f'(\eta)$ for Various Values of Magnetic Field Parameter M

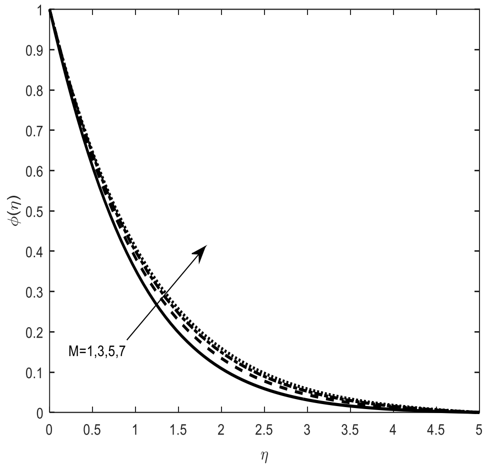

Figure 4. Concentration Profiles $\phi(\eta)$ for Various Values of Magnetic Field Parameter *M*

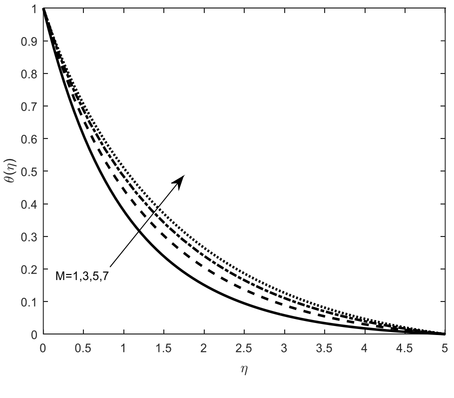

Figure 3. Temperature Profiles $\theta(\eta)$ for Various Values of Magnetic Field Parameter *M*

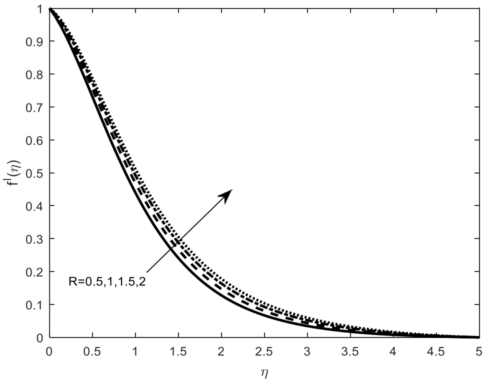

Figure 5. Velocity Profiles $f'(\eta)$ for Various Values of Radiation Parameter R

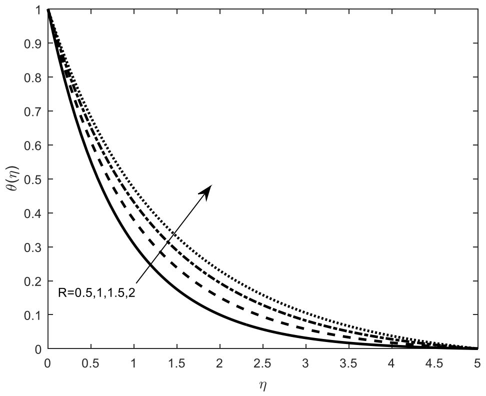

Figure 6. Temperature Profiles $\theta(\eta)$ for Various Values of Radiation Parameter *R*

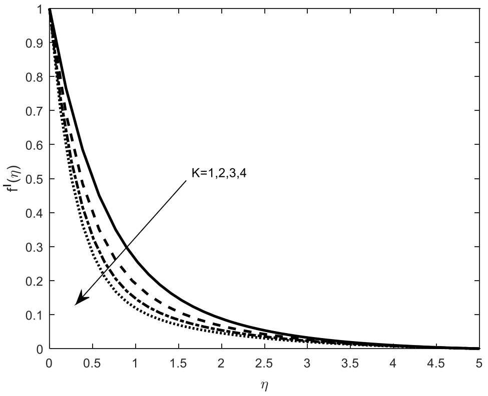

Figure 7. Velocity Profiles $f'(\eta)$ for Various Values of Permeability Parameter *K*

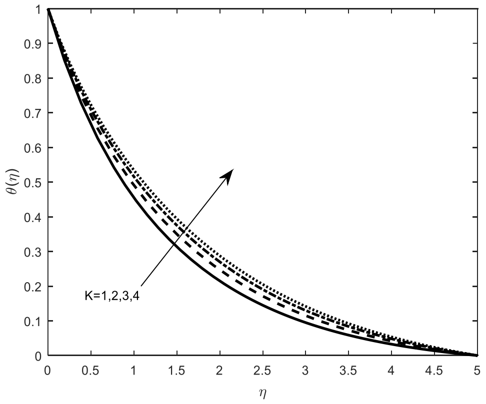

Figure 8. Temperature Profiles $\theta(\eta)$ or Various Values of Permeability Parameter *K*

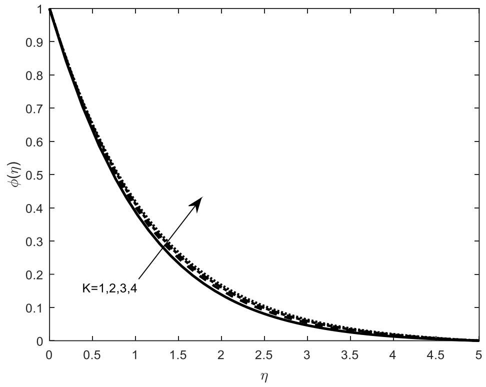

Figure 9. Concentration Profiles $\phi(\eta)$ for Various Values of Permeability Parameter *K*

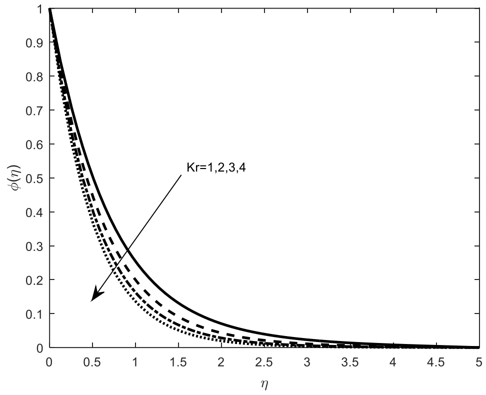

Figure 10. Concentration Profiles $\phi(\eta)$ for Various Values of Chemical Reaction Parameter *Kr*

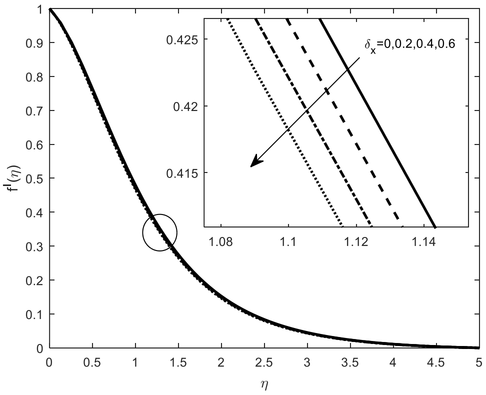

Figure 11. Velocity Profiles $f'(\eta)$ for Various Values of Porosity Parameter δ_x

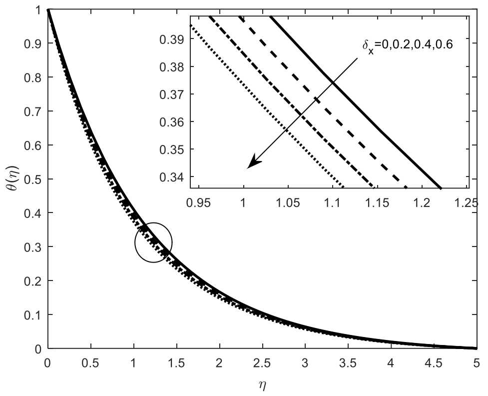

Figure 12. Temperature Profiles $\theta(\eta)$ for Various Values of Porosity Parameter δ_x

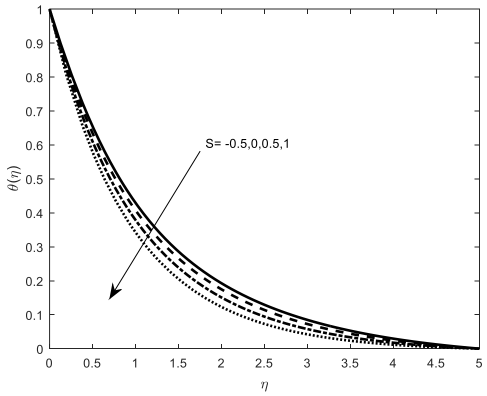

Figure 15. Temperature Profiles $\theta(\eta)$ for Various Values of Squeeze Number *S*

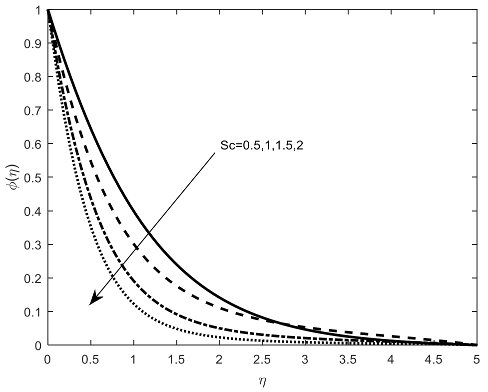

Figure 13. Concentration Profiles $\phi(\eta)$ for Various Values of Schmidt Number *Sc*

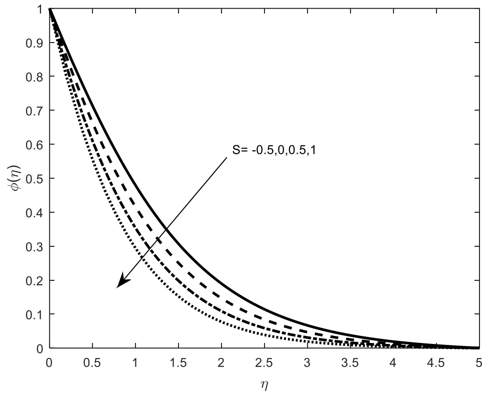

Figure 16. Concentration Profiles $\phi(\eta)$ for Various Values of Squeeze Number *S*

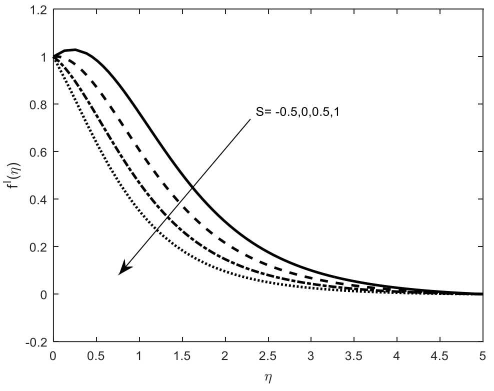

Figure 14. Velocity Profiles $f'(\eta)$ for Various Values of Squeeze Number *S*

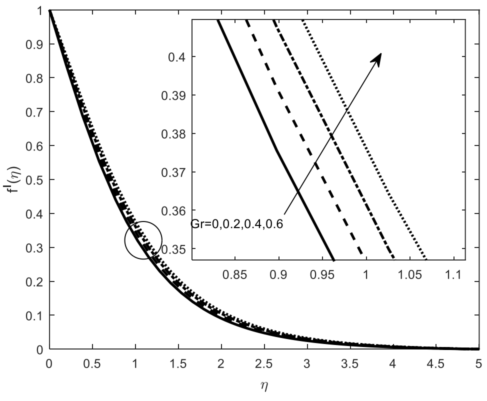

Figure 17. Velocity Profiles $f'(\eta)$ for Various Values of Grashof Number *Gr*

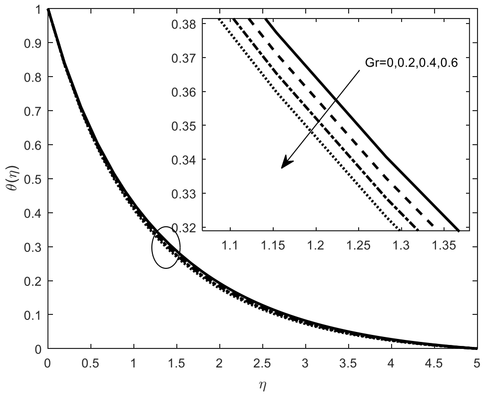

Figure 18. Temperature Profiles $\theta(\eta)$ for Various Values of Grashof Number *Gr*

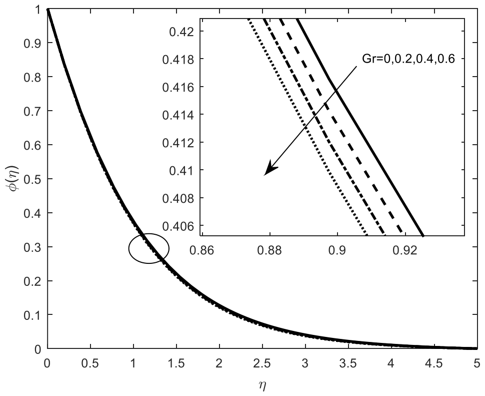

Figure 19. Concentration Profiles $\phi(\eta)$ for Various Values of Grashof Number *Gr*

4. Conclusions

The conclusions of the present study as follows:

- An increase in magnetic field parameter reduces the friction factor, heat and mass transfer rate.
- A raise in the Radiation parameter enhances the momentum and thermal boundary layer thickness.
- An increase in the chemical reaction parameter reduces the friction factor and enhances the mass transfer rate.
- The enhancement in porosity parameter declines the heat and mass transfer rate.

References

[1] Ishak, “MHD boundary layer flow due to an exponentially stretching sheet with radiation effect”, Sains Malaysiana, vol. 40, **(2011)**, pp. 391-395.

[2] R. Cortell, “Heat transfer in a fluid through a porous medium over a permeable stretching surface with thermal radiation and variable thermal conductivity”, Can. J. Chem. Eng., vol. 90, **(2012)**, pp. 1347-1355.

[3] P. M. Krishna, N. Sandeep and V. Sugunamma, “Effects of radiation and chemical reaction on MHD convective flow over a permeable stretching surface with suction and heat generation”, Walailak Journal of Science and Technology, vol. 11, no. 12, **(2014)**.

[4] M. A. Mansour, N. F. Anssary and A. M. Aly, “Effects of chemical reaction and thermal stratification on MHD free convective heat and mass transfer over a vertical stretching surface embedded in a porous media considering Soret and Dufour numbers”, Journal of Chemical Engineering, vol. 145, no. 2, **(2008)**, pp. 340-345.

[5] A. Afify, “MHD free convective flow and mass transfer over a stretching sheet with chemical reaction”, Heat Mass Transfer, vol. 40, **(2004)**, pp. 495-500.

[6] N. Sandeep and C. Sulochana, “Dual solutions of radiative MHD nanofluid flow over an exponentially stretching sheet with heat generation/absorption”, Applied Nanoscience, vol. 5, **(2015)**.

[7] C. S. K. Raju and N. Sandeep, “Effects of induced magnetic field and nonlinear radiation on Williams on nano fluid past stretching surface”, International Journal of Applied Engineering Research, Accepted, **(2016)**.

[8] M. M. Rahman and I. A. Eltayeb, “Radiative heat transfer in a hydromagnetic nanofluid past a non-linear stretching surface with convective boundary condition”, Springer Science+Bussiness Media Dordrech, vol. 48, **(2012)**, pp. 601-615.

[9] O. Anwar Beg, M. S. Khan I. Karim, M. M. Alam and M. Fedows, “Explicit numerical study of hydromagnetic mixed convective nanofluid flow from an exponentially stretching sheet in porous media”, Applied Nanoscience, vol. 4, **(2014)**, pp. 943-957.

[10] C. Sulochana, N. Sandeep, V. Sugunamma and B. Rushi Kumar, “Aligned magnetic field and crossdiffusion effects of a nano fluid over an exponentially stretching surface in porous medium”, Applied Nano Sci., **(2015)**.

[11] K. C. Saha and M. A. Samad, “Effects of viscous dissipation on MHD free convective flow heat and mass transfer of non-newtonian fluids along a continuously moving stretching sheet”, Research journal of Applied science, Engineering and Technology, vol. 9, **(2015)**, pp. 1058-1073.

[12] S. M. Ibrahim, “Effects of chemical reaction on dissipative radiative MHD flow though a porous medium over a nonisothermal stretching sheet”, Hindawi Publishing Corporation Journal of Industrial Mathematics, **(2014)**, pp. 1-10.

[13] N. Freidoonimehr, M. M. Rashidi and B. Jalipour, “MHD stagnation point flow past a stretching/shrinking sheet in the presence of heat generation/absorption and chemical reaction effects”, Journal of Braz. Soc. Mech. Sc. Eng, **(2015)**, pp. 1-10.

[14] D. Hunegnaw and N. Kishan, “Unsteady MHD heat and mass transfer flow over stretching sheet in porous medium with variable properties considering viscous dissipation and chemical reaction”, American Chemical Science Journal, vol. 4, **(2014)**, pp. 901-917.

[15] M. K. Nayak, “Chemical reaction effects on MHD viscoelastic fluid over a stretching sheet through porous medium”, Springer Science+Business Media Dordrecht, **(2015)**, pp. 1-13.

[16] M. Wahiduzzaman, M. Shakhaoath Khan, P. Biswas, I. Karim and M. S. Uddin, “Viscous dissipation and radiation effects on MHD Boundary layer flow of a nanofluid past a rotating stretching sheet”, Applied Mathematics, vol. 6, **(2015)**, pp. 547-567.

[17] C. S. K. Raju, N. Sandeep, C. Sulochana, V. Sugunamma and M. Jayachandra Babu, “Radiation, inclined magnetic field and cross diffusion effects on flow over a stretching surface”, Journal of Nigerian Mathematical Society, vol. 34, **(2015)**, pp. 169-180.

[18] G. Chand and R. N. Jat, “Viscous dissipation and radiation effects on MHD flow and heat transfer over an unsteady stretching surface in a porous medium”, Thermal Energy and power Engineering, vol. 3, **(2014)**, pp. 266-272.

[19] M. M. Khader and A. M. Megahed, “Differential transformation method for studying flow and heat transfer due to stretching sheet embedded in porous medium with variable thickness, variable thermal conductivity and thermal radiation”, Appl. Math. Mech. Engl. Ed., vol. 35, **(2014)**, pp. 1387-1400.

[20] N. Sandeep and C. Sulochana, “MHD flow over a permeable stretching/shrinking sheet of a nanofluid with suction/injection”, Alexandria Engineering Journal, vol. 55, **(2016)**, pp. 819-827.

[21] Z. Iqbal, M. Qasim, M. Awais, T. Hayat and S. Asghar, “Stagnation point flow of an exponentially stretching sheet in the presence of viscous dissipation and thermal radiation”, Journal of Aerospace engineering, vol. 29, **(2016)**, pp. 1-6.

[22] G. M. Pavithra and B. J. Gireesha, “Effects of viscous dissipation on hydromagnetic fluid flow and heat transfer in a porous medium at an exponentially stretching sheet with fluid-particle suspension”, Afr. Mat., vol. 26, **(2015)**, pp. 419-432.

[23] N. Sandeep and C. Sulochana, “Dual solutions for unsteady mixed convection flow of MHD micropolar fluid over a stretching sheet with non-uniform heat source/sink”, Engineering Science and Technology, an International Journal, vol. 18, **(2015)**, pp. 738-745.

[24] A. Pantokratoras, “Unsteady MHD boundary-layer flow and heat transfer due to stretching sheet in the presence of heat source or sink”, Computers & Fluids, vol. 70, **(2012)**, pp. 21-28.

[25] Y. Yirga and B. Shankar, “MHD flow and heat transfer of nanofluid through a porous media due to stretching sheet with viscous dissipation and chemical reaction effects”, International Journal for Computational Methods in Engineering Science and Mechanics, vol. 16, **(2015)**, pp. 275-284.

[26] M. Gnaneswara Reddy, P. Padma and B. Shankar. “Effects of viscous dissipation and heat source on unsteady MHD flow over a stretching sheet”, Ain Shams Engineering Journal, vol. 6, **(2015)**, pp. 1195-1201.

[27] N. Ali, S. U. Khan, M. Sajid and Z. Abbas, “MHD flow and heat transfer of couple stress fluid over an oscillatory stretching sheet with heat source/sink in porous medium”, Alexandria Engineering Journal, vol. 55, **(2016)**, pp. 915-924.

[28] N. Sandeep, C. Sulochana and B. Rushi Kumar, “Unsteady MHD radiative flow and heat transfer of a dusty nanofluid over an exponentially stretching surface”, Engineering Science and Technology, an International Journal, vol. 19, **(2016)**, pp. 227-240.

[29] K. Bhattacharyya and G. C. Layek, “Chemically reactive solute distribution in MHD boundary layer flow over a permeable stretching sheet with suction or blowing”, Chemical Engineering Communications, vol. 197, **(2010)**, pp. 1527-1540.

[30] M. Shen, F. Wang and H. Chen, “MHD mixed convection slip flow near a stagnation-point on a nonlinearly vertical stretching sheet”, Boundary value problems, DOI10.1186/s 13661-015-0340-6, **(2015)**.

[31] N. Sandeep and C. Sulochana, “Dual solutions for MHD stagnation-point flow of a nanofluid over a stretching surface with induced magnetic field”, International Journal of Science and Engineering, vol. 9, **(2015)**, pp. 1-8.

[32] B. Jalilpour, S. Jafarmadar and D. D. Ganji, “MHD stagnation flow towards a porous stretching sheet with suction or injection and prescribed surface heat flux”, Journal of Braz. Soc. Mech. Sci. Eng., vol. 37, **(2015)**, pp. 837-847.

[33] N. Sandeep, C. Sulochana and B. Rushi Kumar, “MHD Boundary layer flow and heat transfer past a stretching/shrinking sheet in a nanofluid”, Journal of Nanofluids, vol. 4, **(2015)**, pp. 1-6.

[34] S. D. Yahaya and K. D. Simon, “Effects of buoyancy and thermal radiation on MHD flow over a stretching porous sheet using homotopy analysis method”, Alexandria Engineering Journal, vol. 54, **(2015)**, pp. 705-712.

[35] C. Y. Wang, “Stagnation flow towards a shrinking sheet”, International Journal of Non-Linear Mech., vol. 43, **(2008)**, pp. 377-382.

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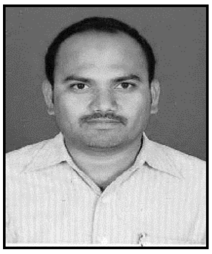

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