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MHD and Mass Transfer Effect on Non-Newtonian Fluids Past a Vertical Plate Embedded Porous Medium

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Abstract

The effect of both the magnetic field and mass transfer on buoyancy induced flow over vertical plate embedded in a non-Newtonian fluid saturated porous medium has been modeled and analyzed. The power-law fluid model is used to characterize the non-Newtonian fluid behavior. Similarity solution for the transformed governing equations is obtained with prescribed variable surface heat flux. Numerical results for the details of the velocity, temperature and concentration profiles are presented. Excess surface temperature as well as concentration gradient at the wall associated with heat flux distributions, which are entered in tables, have been presented for different values of the power-law index n buoyancy ration B_1, magnetic field parameter Mn and the exponent λ as well as Lewis number Le.

Keywords: Porous media, mass transfer, magnetic field, non-Newtonian fluid.
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1. Introduction

The flow and heat transfer in an electrically conducting fluid permeated by a transverse magnetic field is of special interest and has many practical applications in manufacturing processes in industry. During the industrial stages, the production may need to be consolidated by internal heat generation. The heat transfer rates can be controlled using a magnetic field. One of the ways of studying magnetohydrodynamic heat transfer field is the electromagnetic field.

MHD flow of non-Newtonian fluids had been studied by Gorla et al., 1993. El-Amin and Mansour, 2001 studied the effects of magnetic field on buoyancy induced flow of non-Newtonian fluids over a horizontal plate embedded in a porous medium with variable surface temperature or with variable heat flux. The problem of buoyancy induced flow of non-Newtonian fluids in a porous medium past a vertical plate with non-uniform surface heat flux was studied by Mehta and Rao, 1994. Hossain and Ahmed 1990, studied the combined effect of forced and free convection with uniform heat flux in the presence of a strong magnetic field. El-Amin et al., 2001 investigated the influences of magnetic field on buoyancy induced flow over vertical flat plate embedded in a non-Newtonian fluid saturated porous medium. Rashad, 2008, studied influence of radiation on MHD free convection from vertical flat plate embedded in porous media with thermo phonetic deposition of particles. Pal and Talukdar, 2010a investigate buoyancy and chemical reaction effects on MHD mixed convection heat and mass transfer in a porous medium with thermal radiation and Ohmic heating. Abdul-Hakeem et al., 2010, studied magneto convective heat and mass transfer over a porous plate with effects of chemical reaction, radiation absorption and variable viscosity. Effects of thermal radiation and viscous dissipation on MHD viscoe-lastic free convection past a vertical isothermal cone surface with chemical reaction studied by El-Kabeir et al., 2012.

The problem of natural convection over a non-isothermal body of arbitrary shape embedded in a porous medium was studied by Nakayama and Koyama, 1991. Chen and Chen, 1988, presented similarity solutions for free convection on non-

Newtonian fluids over vertical surfaces in porous media. Mehta and Rao 1994 investigated the buoyancy induced flow of non-Newtonian fluids over a non-isothermal horizontal plate embedded in a porous medium. The problem of forced convection heat transfer on flat plate embedded in porous media for power-law fluids has been analyzed by Hady and Ibrahim, 1997. A similarity solution for free convection from a point heat source embedded in a non-Newtonian fluid saturated porous medium was presented by Nakayama 1993. Non-similar solutions for mixed convection in non-Newtonian fluids along horizontal surfaces in porous media were investigated by Gorla et al., 1997. Yang and Wang 1996, studied the problem of free convection heat transfer of non-Newtonian fluids over axisymmetric and two-dimensional bodies of arbitrary shape embedded in fluid saturated porous medium. A review of natural convective flows due to combined buoyant mechanisms in porous media was presented by Nield and Bejan, 1999. Angirasa et al., 1997, investigated combined heat and mass transfer by natural convection with opposing buoyancy effects in a fluid saturated porous medium. Rastogi and Poulikakos 1995, considered non-Newtonian fluid saturated porous media and presented similarity solutions for aiding flows with concentration. El-Amin et al 2004, studied combined effect of magnetic field and lateral mass transfer on non-Darcy axisymmetric free convection in a power-law fluid saturated porous medium. Mass transfer effects on the non-Newtonian fluids past a vertical plate embedded in a porous medium with non-uniform surface heat flux investigated by El-Hakiem and El-Amin, 2001. Cheng, 2009 studied the natural convection heat and mass transfer from a vertical truncated cone in a porous medium saturated with a non-Newtonian fluid with variable wall temperature and concentration. Chamkha, et al., 2011 studied the heat and mass transfer by non-Darcy free convection from a vertical cylinder embedded in porous media with temperature dependent viscosity. Natural convection boundary layer of non-Newtonian fluid about a permeable vertical cone embedded in porous medium saturated with a nanofluid studied by El-Hakiem, et al., 2011. El-Hakiem, 2014 studied the heat transfer from moving surfaces in a micro polar fluid with internal heat generation. The effect of radiation and double dispersion on mixed convection heat and mass transfer in non-Darcy porous medium; is investiggate by El-Hakiem, 2014.

In the present work, it is proposed to study the effect of magnetic field and mass transfer on the non-Newtonian fluids past a vertical plate embedded in a porous medium with non-uniform surface heat flux. The power-law fluid model is used to charactenize the non-Newtonian fluid behavior. Similarity solution for the transformed governing equations is obtained with prescribed variable surface heat flux. The values of heat transfer coefficient and concentration gradient at the wall are determined.

2. Basic Equations

The present work was undertaken in order to investigate the problem of effect of magnetic field and mass transfer on buoyancy-induced flow over vertical flat plate embedded in a non-Newtonian fluid saturated porous medium. The $\bar{x}-$ coordinate is measured along the plate and $\bar{y}-$coordinate normal to it. The applied magnetic field is primarily in $\bar{y}-$ direction and varies in strength as a function in x. No externally generated electrical field is imposed. The magnetic Reynolds number of the flow is taken applied magnetics can be neglected. Under all these assumptions the governing equations for the flow and heat transfer are given by:

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

$$q^{n-1}\bar{u}=-\frac{K}{\mu}\left[\frac{\partial p}{\partial \bar{x}}+\rho g+\sigma B^2\bar{u}\right] \tag{2}$$

$$q^{n-1}\bar{v}=-\frac{K}{\mu}\frac{\partial p}{\partial \bar{y}} \tag{3}$$

$$\bar{u}\frac{\partial \bar{T}}{\partial \bar{x}}+\bar{v}\frac{\partial \bar{T}}{\partial \bar{y}}=\alpha\left(\frac{\partial^2 \bar{T}}{\partial \bar{x}^2}+\frac{\partial^2 \bar{T}}{\partial \bar{y}^2}\right) \tag{4}$$

$$\bar{u}\frac{\partial \bar{C}}{\partial \bar{x}}+\bar{v}\frac{\partial \bar{C}}{\partial \bar{y}}=D\left(\frac{\partial^2 \bar{C}}{\partial \bar{x}^2}+\frac{\partial^2 \bar{C}}{\partial \bar{y}^2}\right) \tag{5}$$

$$\bar{\rho}=\rho\left[1-\beta\left(\bar{T}-\bar{T}_\infty\right)-\beta^*\left(\bar{C}-\bar{C}_\infty\right)\right] \tag{6}$$

where $q^2=\bar{u}^2+\bar{v}^2$.

Subjected to the following boundary conditions:

$$\bar{y}=0:\quad \bar{v}=0,\quad \frac{\partial \bar{T}}{\partial \bar{y}}=-\frac{\bar{q}}{k},\quad \bar{C}=\bar{C}_w \quad \text{as} \quad \bar{y}\to\infty: \quad \bar{u}=0,\ \bar{T}=\bar{T}_\infty,\ \bar{C}=\bar{C}_\infty \tag{7}$$

where $\bar{u}$ and $\bar{v}$ are the Darcian velocity components in the $\bar{x}-$ and $\bar{y}-$directions, respectively, B is the applied magnetic field, k is the effective thermal conductivity of the saturated porous medium, p is the pressure, $\bar{T}$ is the temperature, $\bar{C}$ is species concentration, D is the chemical molecular diffusivity, K is the modified permeability of the porous medium, β is the thermal expansion coefficient, μ is the dynamic viscosity, $\overline{\rho}$ is the density, g is the acceleration due to gravity and α is the thermal diffusivity. The power-law fluid model is used to characterize the non-Newtonian fluid behavior. Christopher and Middleman 1965 and Dharmadhikari and Kale, 1985 proposed the following relationships for the permeability as a function of the power-law index n as follows:

$$\left[\frac{6}{25}\left\{\frac{n\varepsilon}{3n+1}\right\}^{n}\left\{\frac{\varepsilon d}{3(1-\varepsilon)}\right\}^{n+1}\right]$$

(Christopher and Middleman 1965)

$$\mathrm{K}=\left[\frac{2}{\varepsilon}\left\{\frac{d\varepsilon^2}{8(1-\varepsilon)}\right\}^{n+1}\left\{\frac{6n+1}{10n-3}\right\}\left\{\frac{16}{75}\right\}^{3(10n-3)/(10n+11)}\right] \tag{8}$$

(Dharmadhikari and Kale 1985)

where d is the particle diameter while ε is the porosity. When $n<1$ the model describes pseudoplastic behavior, whereas $n>1$ represents dilatant behavior.

As the thermal boundary layer is thin, the boundary layer approximations analogous to classical boundary layer theory can be applied. The experimental and numerical studies on convective heat transfer in a porous medium show the thermal boundary layers exist adjacent to the heated or cooled surfaces (Nield and Bejan, 1999). The normal component of the seepage velocity near the boundary is small compared with the other component of the seepage velocity and the derivatives of any quantity in the normal direction are large compared with derivatives of the quantity in direction of the wall. Invoking the Boussinesq approximation, the pressure can be eliminated from Eqs. (2) and (3). Under these assumptions, therefore the basic governing equations are given by:

$$\frac{\partial\overline{u}}{\partial\overline{x}}+\frac{\partial\overline{v}}{\partial\overline{y}}=0 \tag{9}$$

$$\left|\overline{u}\right|^{n-1}\overline{u}=\frac{\rho Kg\beta}{\mu}(\overline{T}-\overline{T}_\infty)+\frac{\rho Kg\beta^*}{\mu}(\overline{C}-\overline{C}_\infty)-\frac{K\sigma B^2}{\mu}\overline{u} \tag{10}$$

$$\overline{u}\frac{\partial\overline{T}}{\partial\overline{x}}+\overline{v}\frac{\partial\overline{T}}{\partial\overline{y}}=\alpha\frac{\partial^2\overline{T}}{\partial\overline{y}^2} \tag{11}$$

$$\overline{u}\frac{\partial\overline{C}}{\partial\overline{x}}+\overline{v}\frac{\partial\overline{C}}{\partial\overline{y}}=D\frac{\partial^2\overline{C}}{\partial\overline{y}^2} \tag{12}$$

The following dimensionless variables are as follows:

$$x=\frac{\overline{x}}{L},\quad y=\frac{\overline{y}Ra^{1/2}}{L},\quad u=\frac{\overline{u}L}{\alpha Ra},\quad v=\frac{\overline{v}L}{\alpha Ra^{1/2}},$$
$$T=\frac{(\overline{T}-\overline{T}_\infty)}{q_0L},\ C=\frac{x^{n(2\lambda+1)/(2n+1)}(\overline{C}-\overline{C}_\infty)}{(\overline{C}_w-\overline{C}_\infty)}. \tag{13}$$

where, Ra is the modified Rayleigh number defined by:

$$Ra=\frac{L}{\alpha}\left[\frac{\rho Kg\beta q_0L}{\mu k}\right]^{1/n} \tag{14}$$

and hence the dimensionless equations are given as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{15}$$

$$\left|u\right|^{n-1}u=T+B_1C-Mn^*.u \tag{16}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{\partial^2T}{\partial y^2} \tag{17}$$

$$u\left[\frac{\partial C}{\partial x}-\frac{n(2\lambda+1)C}{(2n+1)x}\right]+v\frac{\partial C}{\partial y}=\frac{1}{Le}\frac{\partial^2C}{\partial y^2} \tag{18}$$

and the boundary conditions become

$$\text{at } y=0:\ v=0,\ \frac{\partial T}{\partial y}=-Q(x),\ C=x^{-n(2\lambda+1)/(2n+1)}$$
$$\text{as } y\to\infty:\ u=0,\ T=0,\ C=0. \tag{19}$$

where, $B_1=\frac{k\beta^*(\overline{C}_w-\overline{C}_\infty)}{q_0L\beta}x^{-n(2\lambda+1)/(2n+1)}$ is the buoyancy ratio and $Mn^*=\frac{\alpha kRa\sigma B^2}{\rho g\beta q_0L^2}$, assuming that the surface heat flux vary according to the power-law $Q(x)=x^{\lambda}$. Also, for the similarity to be possible we choose the strength of the magnetic field in the form $B=\frac{B_0}{x^{(1-n)(2\lambda+1)/(4n+2)}}$ as Gorla et al., 1993. However the defining the stream function $\psi(x,y)$, is introduced which satisfies the continuity equation (15) with $u=\frac{\partial\psi}{\partial y},\ v=-\frac{\partial\psi}{\partial x}$. Proceeding with the analysis; we introduce the following similarity transformations:

$$\eta=yx^{(\lambda-n)/(2n+1)},\qquad \psi=x^{(\lambda+n+1)/(2n+1)}f(\eta),$$
$$T=x^{n(2\lambda+1)/(2n+1)}\theta(\eta),\qquad C=x^{n(2\lambda+1)/(2n+1)}\gamma(\eta) \tag{20}$$

Introducing expressions in Eq. (20) into Eqs. (16)-(19), the transformed governing equations may be written as:

$$\left|f'\right|^{n-1} f' = \theta + B_1\gamma - Mn.f' \tag{21}$$

$$\theta'' + \frac{\lambda+n+1}{2n+1} f\theta' - \frac{n(2\lambda+1)}{2n+1} f'\theta = 0 \tag{22}$$

$$\frac{\gamma''}{Le} + \frac{\lambda+n+1}{2n+1} f\gamma' = 0 \tag{23}$$

with the boundary conditions:

$$f(0)=0, \qquad \theta'(0)=-1, \qquad \gamma(0)=1, \qquad f'(\infty)=\theta(\infty)=\gamma(\infty)=0 \tag{24}$$

where $Mn = \dfrac{\alpha k Ra \sigma B_0^2}{\rho g \beta q_0 L^2}$ is the magnetic field parameter and $Le = \dfrac{\alpha}{D}$ is the Lewis number. It is noteworthy that, the governing non-dimensional parameter Mn may be interpreted as the ratio between the electromagnetic forces and the gravity forces calculated with the Boussinesq approximation. Primes in the above equations denote differentiation with respect to η. For practical applications, it is usually the velocity components are of interest. These are given by:

$$u = x^{(2\lambda-1)/(2n+1)} f'(\eta) \tag{25}$$

$$v = -x^{(\lambda-n-1)/(2n+1)}\left[\frac{\lambda-n-1}{2n+1}\eta f' + \frac{\lambda+n}{2n+1} f\right]... \tag{26}$$

The expression of the excess surface temperature T_s is given by

$$T_s = x^{-n(2\lambda+1)/(2n+1)}\theta(0). \tag{27}$$

The local mass flux is given by

$$j_w = -D\left.\frac{\partial \bar{C}}{\partial \bar{y}}\right|_{\bar{y}=0} \tag{28}$$

Therefore, Sherwood number is defined by

$$Sh = \frac{j_w \bar{x}}{D(\bar{C}_w - \bar{C}_\infty)} = -\frac{Ra^{1/2}}{L} x^{(\lambda+n+1)/(2n+1)}\gamma'(0). \tag{29}$$

3. Results and Discussion

The fourth-order Range-Kutta method with shooting technique is used to solve the system of ordinary differential equations in Eq. 21-23 along with the boundary conditions in Eq. 24. The step size $\Delta\eta = 0.05$ is used while obtaining the numerical solution with $\eta_{\max} = 12$ and five decimal accuracy as the criterion for convergence. Numerical computations are carried out for Mn=0, 1, 2, $0.5 \le n \le 1.5$, $-2.0 \le B_1 \le 2.0$, $0.1 \le Le \le 10$, $0.01 \le \lambda \le 0.5$.

Numerical results of the excess surface temperature and the concentration gradient at the wall for varying values of Mn, n, B_1, Le and λ are presented in Tables 1-4. From Table (1) it is obvious that, an increase in the values of n and Le enhances the excess surface temperature, so, an increases of magnetic field parameter Mn enhances it, for all values n and Le, but, it reduces the absolute values of concentration gradient at the wall. Also, it clear that, an increases in the value of n reduces the absolute values of concentration gradient at the wall but, it is clear that, the absolute values of concentration gradient at the wall increase as the parameter Le increases, for all cases of the power-law index n.

Table 1. Values of $\theta(0)$ and $-\gamma(\grave{0})$ for selected values of Mn, n and Le with $B_1 = 1.0$ and $\lambda = 0.3$

		Mn=0.0		Mn=1.0		Mn=2.0	
n	Le	$\theta(0)$	$-\gamma(\grave{0})$	$\theta(0)$	$-\gamma(\grave{0})$	$\theta(0)$	$-\gamma(\grave{0})$
0.8	0.1	0.82237	0.30946	1.15730	0.28383	1.37190	0.27524
	1.0	0.87773	0.78271	1.20410	0.58062	1.41206	0.50298
	10.	1.02490	2.95574	1.34475	2.13251	1.54661	1.80292
1.0	0.1	0.84976	0.30515	1.13932	0.28308	1.34251	0.27478
	1.0	0.89766	0.74269	1.18227	0.57168	1.38006	0.49755
	10.	1.02561	2.71325	1.31237	3.06668	1.50739	1.76393
1.2	0.1	0.86852	0.30214	1.12489	0.28252	1.31888	0.27443
	1.0	0.91053	0.71562	1.16485	0.56510	1.35455	0.49353
	10.	1.02344	2.55525	1.28697	2.01864	1.47674	1.73580
1.5	0.1	0.88765	0.29896	1.10783	0.28190	1.29097	0.27405
	1.0	0.92285	0.68809	1.14444	0.55796	1.32456	0.48916
	10.	1.01869	2.39976	1.25767	2.96918	1.44162	1.70627

Table 2. Values of $\theta(0)$ and $-\gamma(\grave{0})$ for selected values of B_1, Mn, and Le with $n = 0.5$ and $\lambda = 0.01$

		Mn=0.0		Mn=1.0		Mn=2.0	
B_1	Le	$\theta(0)$	$-\gamma(\grave{0})$	$\theta(0)$	$-\gamma(\grave{0})$	$\theta(0)$	$-\gamma(\grave{0})$
-2.0	0.1	2.64513	0.25755	2.80251	0.25636	2.90550	0.25563
	1.0	2.59771	0.33500	2.75242	0.32700	2.86225	0.31199
	10.	2.05396	0.98791	2.29998	0.97000	2.47312	0.91910
-0.5	0.1	1.61978	0.27170	1.95654	0.26580	2.15296	0.26304
	1.0	1.58476	0.50700	1.93588	0.42600	2.13241	0.39280
	10.	1.45420	2.07500	1.82373	1.59500	2.04114	1.38802
0.0	0.1	1.31465	0.28081	1.71617	0.27047	1.94156	0.26630
	1.0	1.31465	0.60301	1.71617	0.47377	1.94156	0.42541
	10.	1.31465	2.54935	1.71617	1.79981	1.94156	1.53439
0.5	0.1	1.04670	0.29471	1.50585	0.27611	1.75129	0.27007
	1.0	1.08647	0.72411	1.53495	0.52457	1.77507	0.46029
	10.	1.96850	3.05961	1.62538	1.99816	1.85597	1.67509
2.0	0.1	0.54669	0.38939	1.05626	0.29962	1.31975	0.28415
	1.0	0.64536	1.21226	1.15007	0.69069	1.40235	0.57189
	10.	0.92866	4.74084	1.41863	2.55429	1.65621	2.06664

Table 3. Values of $\theta(0)$ and $-\gamma(\grave{0})$ for selected values of B_1, Mn and Le for the Newtonain fluid (n=1) and $\lambda = 0.5$

		Mn=0.0		Mn=1.0		Mn=2.0	
B_1	Le	$\theta(0)$	$-\gamma(\grave{0})$	$\theta(0)$	$-\gamma(\grave{0})$	$\theta(0)$	$-\gamma(\grave{0})$
-1.0	0.1	1.65209	0.26446	1.86823	0.26171	2.02080	0.26007
	1.0	1.58976	0.42457	1.82124	0.38412	1.98267	0.36206
	10.	1.34979	1.58574	1.61140	1.35859	1.79282	1.22299
0.0	0.1	1.11081	0.20331	1.39774	0.19296	1.57400	0.26685
	1.0	1.11081	0.56939	1.39774	0.45562	1.57400	0.43013
	10.	1.11081	2.22624	1.39774	1.75873	1.57400	1.52870
1.0	0.1	0.79312	0.30797	1.06622	0.28453	1.25925	0.27579
	1.0	0.83883	0.75997	1.10819	0.58304	1.29651	0.50640
	10.	0.96371	2.77455	1.23655	2.11124	1.38296	1.80151

Table 4. Values of $\theta(0)$ and $-\gamma(\grave{0})$ for selected values of B_1 , λ and Mn with $Le = 0.1$ and $n = 0.8$

		Mn=0.0		Mn=1.0		Mn=2.0	
B_1	λ	$\theta(0)$	$-\gamma(\grave{0})$	$\theta(0)$	$-\gamma(\grave{0})$	$\theta(0)$	$-\gamma(\grave{0})$
2.0	0.01	0.70991	0.34103	1.06359	0.29560	1.29364	0.28242
	0.3	0.62288	0.35133	0.93557	0.30028	1.14183	0.28553
	0.5	0.57885	0.35852	0.87054	0.30361	1.06397	0.28776
1.0	0.01	0.92490	0.30522	1.29634	0.28163	1.53065	0.27369
	0.3	0.82237	0.30947	1.15730	0.28383	1.37190	0.27524
	0.5	0.76963	0.31260	1.08519	0.28544	1.28896	0.27642
0.5	0.01	1.08742	0.29101	1.45411	0.19964	1.68009	0.26976
	0.3	0.97931	0.29288	1.30933	0.20113	1.52230	0.27074
	0.5	0.92345	0.29433	1.23439	0.20231	1.43958	0.27147
0.0	0.01	1.29689	0.27990	0.81474	0.19232	1.85207	0.26673
	0.3	1.18951	0.28018	0.73614	0.19267	1.70048	0.26673
	0.5	1.13347	0.28045	0.69570	0.19303	1.62005	0.26712
-1.0	0.01	1.84715	0.26560	2.10248	0.26223	2.27280	0.26031
	0.3	1.75773	0.26489	1.98700	0.26197	2.14358	0.26024
	0.5	1.71185	0.26457	1.92741	0.26187	2.07619	0.26015

Fig. 1 and 2 illustrate the velocity fields, for different values of the parameters Mn , Le , B_1 and λ . From Fig. 1, we observe that an increase in the magnetic field Mn reduce the velocity maximum, while, an increases in Lewis number Le enhances it. In Fig. 2, it is that, an increases in the buoyancy ratio B_1 enhances the velocity maximum, while, an increases in the parameter λ reduces it.

Fig. 1: Variation velocity profiles for varying Mn and Le at n=0.8, B_1=1.0 and λ=0.3

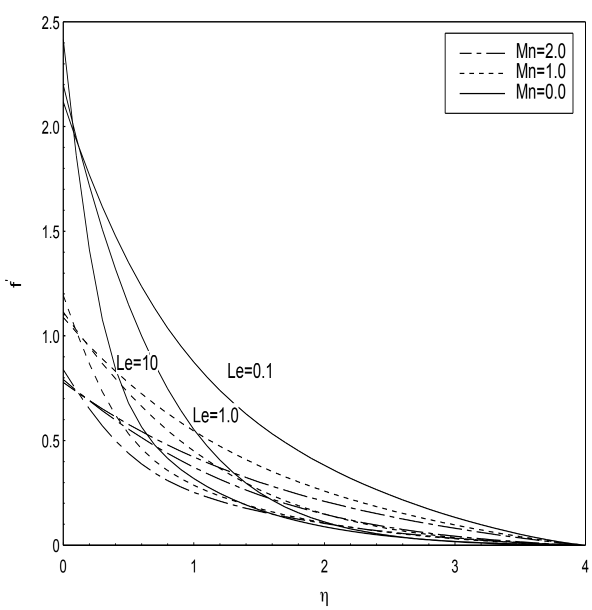
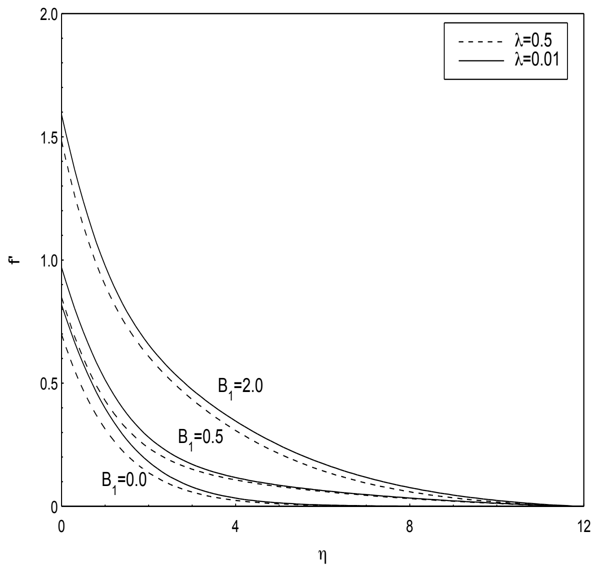


Fig. 2: Variation of velocity profiles for varying λ and B_1 with n=8.8, Mn=1.0 and Le=0.1



Figures 3 and 4 show the temperature profiles for different values of the given parameters. We observe from Fig. 3 that, as Le and Mn increase the temperature profile increase. It is noteworthy that, the increases in the parameters B_1 and λ reduces the temperature profiles, as shown in Fig. 4.

Fig. 3: Variation of temperature profiles for varying Mn and Le with n=0.8, B_1=1.0 and λ=0.3

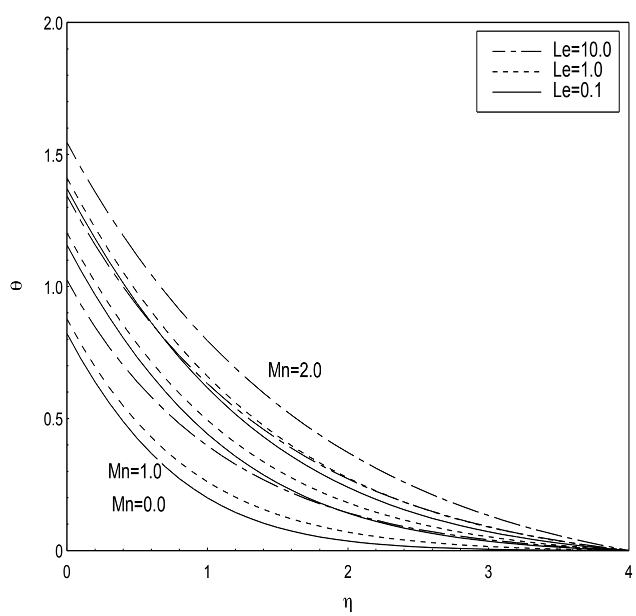


Fig. 4: Variation of temperature profiles for varying of λ and B_1 with n=0.8, Mn=1.0 and Le=0.1

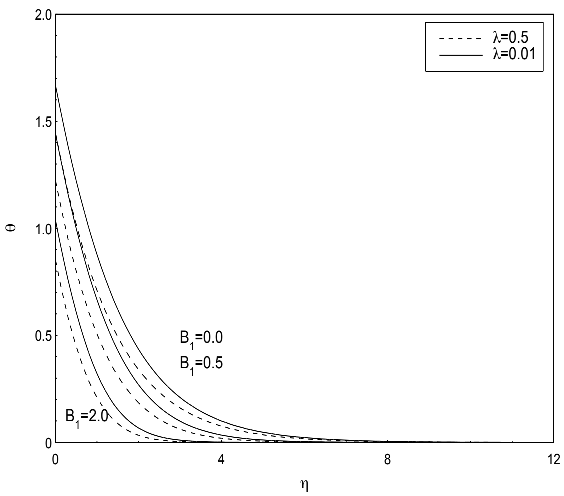


Fig. 5 and 6 illustrate the concentration distributions for various values of the given parameters. In Fig. 5, we observe that, an increases in Mn enhances the concentration, while, they decrease as Le increases. From Fig. 6, it is clear that, as parameters B_1 and λ increase the concentration profiles decrease.

Fig. 5: Variation of concentration profiles for varying Mn and Le with n=0.8, B_1=1.0 and λ=0.3

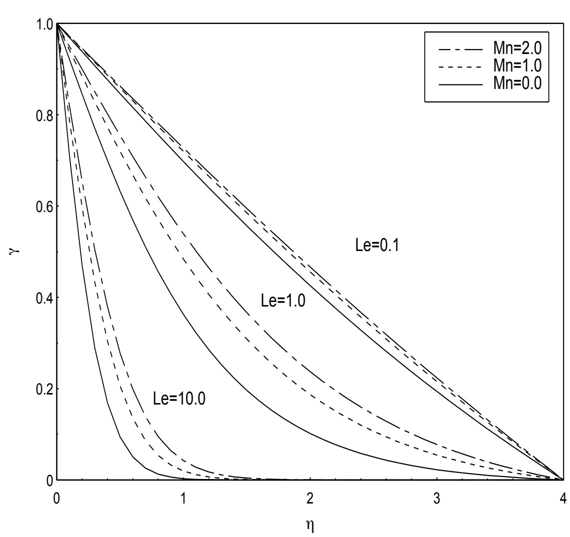
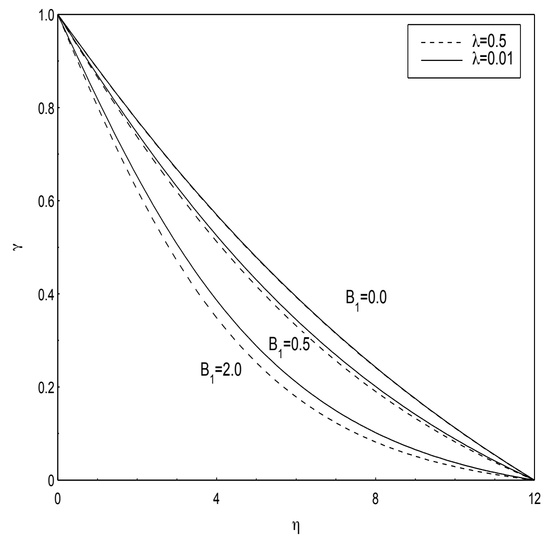


Fig. 6: Variation of concentration profiles for varying λ and B_1 with n=0.8, Mn=1.0 and Le=0.1



List of Symbols

B : applied magnetic field
B_0 : magnetic field intensity
B_1 : buoyancy ratio
$\overline{C}$: species concentration
C : dimensionless concentration
D : chemical molecular diffusivity
d : pore diameter
f : dimensionless stream function
g : gravitational acceleration
j_w : local mass flux
K : modified permeability of porous medium
k : thermal conductivity
L : length of the plate
Le : Lewis number
Mn : magnetic parameter
n : fluid power-law index
p: pressure of the fluid
q : surface heat flux
Ra : local Rayleigh number
Sh : Sherwood
$\overline{T}$: temperature
T : dimensional temperature
T_s : excess surface temperature
$\overline{u}, \overline{v}$: velocity components
u, v : dimensionless velocity components
$\overline{x}, \overline{y}$: space coordinates

x, y : dimensionless space coordinates
α : molecular thermal diffusivity
β : coefficient of thermal expansion
β^* : volumetric coefficient of expansion
γ : concentration function in similarity transformation
σ : electrical conductivity
ε : porosity pole
η : dimensionless similarity variable
λ : exponent associated with the surface heat flux
θ : temperature function in similarity transformation
μ : dynamic viscosity
ρ : density of the fluid
ψ : stream function

Superscripts

' differentiation with respect to η

Subscripts

w : surface conditions at the wall
∞ : conditions far away from the wall

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