

## RESEARCH ARTICLE

### HEAT AND MASS TRANSFER OF AN UNSTEADY MHD PERISTALTIC FLOW IN A POROUS MEDIUM WITH CROSS DIFFUSION EFFECT

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#### ABSTRACT

In this work the significance of Cross Diffusion effect on unsteady MHD peristaltic flow in a porous medium with heat and mass transfer is investigated. The governing partial differential equations are transformed into dimensionless equations by using dimensionless quantities. Stream function, velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number are obtained. The results are discussed for various emerging parameters encountered in the problem under investigation. The importance of main parameters on the present study is explained graphically.

**Keywords:** Cross diffusion, Reynolds number, Peristaltic flow, Stream function, Eckert number.

#### 1. INTRODUCTION

The heat and mass transfer of an unsteady MHD flow attracted by the researchers, because it is most useful to many fields such as production process, chemical-engineering application of a physical and the peristaltic flow used in pump and other mechanical systems. The most important mechanism of fluid transport is peristalsis and it is formed by the propagation of a peristaltic wave on the channel walls.

Influence of wall flexibility and cross diffusion on the peristaltic transport of a MHD dissipative fluid in the presence of Joule heating are presented by Sucharitha, G. et al [1]. The effects of MHD couple stress fluid in peristaltic flow with the porous medium under the impact of slip, heat transfer and wall properties attempted by Sankad, G. C. and Nagathan, P.S. [2]. The heat and mass transfer effects on MHD flow of a steady viscous incompressible and electrically conducting fluid through a non-isothermal parallel flat wall the presence of Soret effect is investigated by Panneerselvi, R. and Subhasree, D. [3]. Raju, C.S.K. et al [4] analyzed the steady two dimensional flow over a vertical stretching surface in presence of aligned magnetic field, cross diffusion and radiation effect.

The influence of heat transfer on the peristaltic flow of a conducting PHAN-THIEN-TANNER fluid in an asymmetric channel with porous medium is studied by Vajravelu, K. et al [5]. Jayachandra Babu, M. and Sandeep, N. [6]

studied the presence of cross-diffusion effects on MHD non-newtonian fluid flow over a slandering sheet by viewing velocity slip. The effect of heat transfer and elasticity of flexible walls in swallowing food bolus through the oesophagus supposed to be jeffrey fluid is analyzed by Arun Kumar, M. et al [7]. Dheia, G. and Salih Al-Khafajy [8] constructed a mathematical model is constructed to study the effect of heat transfer and elasticity of flexible walls with the porous medium. The effect of heat transfer and inclined magnetic field on the peristaltic flow of williamson fluid in an asymmetric channel through porous medium is investigated by Ramesh, K. and Devakar, M. [9]. The effects of both wall slip conditions and heat transfer on the MHD peristaltic flow of a Maxwell fluid in a porous planar channel with elastic wall properties have been studied by Kalidas Das, [10].

Keeping in mind the importance of heat and mass transfer of an MHD Peristaltic fluid with cross diffusion effects in porous medium under the influence of inclined magnetic field, we have gone for a detailed study. The stream function is used to solve governing coupled non-linear partial differential equations.

#### 2. MODELLING OF THE PROBLEM

In this, the peristaltic transport of a viscous fluid in a two dimensional porous channel between two elastic walls is considered. The flow is generated by a peristaltic wave propagated along the elastic walls of the channel with a

constant speed  $c$ . Here, Joule heating diffusion and dissipation effects are considered. The dimensional of the uniform channel flow in a porous medium is given as the width of the

uniform channel  $2d$ , wave amplitude  $a$ . the angle of inclined magnetic field is taken as  $\alpha$ ,  $\bar{x}$  is the axial coordinate and  $\bar{y}$  is normal to it.

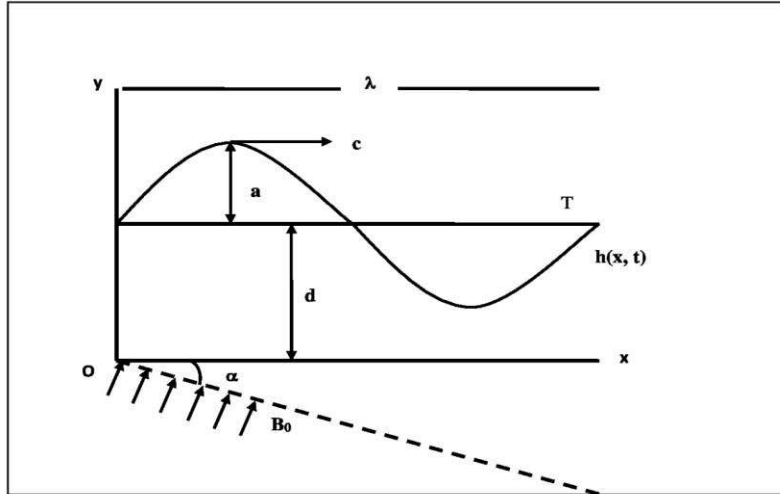


Fig. 1. Configuration of the Problem

The geometry of the surface wall is given as,

$$\bar{h}(\bar{x}, \bar{t}) = a \sin \frac{2\pi}{\lambda} (\bar{x} - c\bar{t}) + d \quad (1)$$

Consider the motion of the elastic wall as,

$$L(\eta) = p - p_0 \quad (2)$$

Here  $L$  denotes the flexible wall motion with viscosity damping force is given by,

$$L = -\tau \frac{\partial^3 \eta}{\partial x^3} + m \frac{\partial^3 \eta}{\partial x \partial t^2} + C \frac{\partial^2 \eta}{\partial x \partial t} \quad (3)$$

Where

$\tau$  - the elastic tension in the wall

$m$  - the mass per unit area

$C$  - the coefficient of the viscous damping force

As per the assumption for this work, the governing equations and boundary conditions can be obtained as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (4)$$

$$\rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial p}{\partial x} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \mu \frac{u}{k} - \sigma u B_0^2 \cos^2 \alpha + \rho g \beta (T - T_0) + \rho g \beta' (C - C_0) \quad (5)$$

$$\rho \left( \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial p}{\partial y} + \mu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (6)$$

$$\rho \phi \left( \frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = \mu \left( \frac{\partial u}{\partial y} \right)^2 + k \left( \frac{\partial^2 T}{\partial y^2} \right) + \frac{D_m k_T}{C_s C_p} \left( \frac{\partial^2 C}{\partial y^2} \right) + \sigma B^2 u^2 \cos^2 \alpha \quad (7)$$

$$\left( \frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} \right) = D_m \left( \frac{\partial^2 C}{\partial y^2} \right) + \frac{D_m K_T}{C_p} \left( \frac{\partial^2 T}{\partial y^2} \right) \quad (8)$$

Here, the fluid velocities are  $u$  and  $v$  along  $x$  and  $y$  axis. As the plane is symmetrical, the normal velocity is zero. Here  $\rho, \mu$  denotesthefluiddensityandthecoefficient of viscosity of the fluid. Also  $p, T, C, \sigma$  represents the pressure, the temperature of the fluid, the concentration of the fluid and the electrical conductivity of the fluid.

Appropriate boundary conditions are given as follows,

$$\frac{\partial u}{\partial y} = 0, \quad \frac{\partial^3 u}{\partial y^3} = 0, \quad \frac{\partial T}{\partial y} = 0, \quad \frac{\partial C}{\partial y} = 0, \quad \text{at } y=0 \quad (9)$$

$$\frac{\partial^2 u}{\partial y^2} = 0, \quad T=T_0, C=C_0, \quad \text{at } y=h \quad (10)$$

$$\frac{\partial^2 u}{\partial y^2} - \left( M^2 \cos^2 \alpha + \frac{1}{k} \right) u - \left( E_1 \frac{\partial^3 \eta}{\partial x^3} + E_2 \frac{\partial^3 \eta}{\partial x \partial t^2} + E_3 \frac{\partial^2 \eta}{\partial x \partial t} \right) = 0, \quad \text{at } y=\eta(x,t) \quad (11)$$

From Mitra and Prasad [5], the dynamic boundary conditions are given as,

$$\frac{\partial}{\partial x} L(\eta) = -\rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \frac{\sigma u B_0^2 \cos^2 \alpha}{1 + m^2 \cos^2 \alpha}, \quad \text{at } y = \eta(x,t) \quad (12)$$

$$\text{Where } \frac{\partial}{\partial x} L(\eta) = \frac{\partial p}{\partial x} = -\tau \frac{\partial^3 \eta}{\partial x^3} + m \frac{\partial^3 \eta}{\partial x^3} + C \frac{\partial^3 \eta}{\partial x \partial t}$$

The dimensionless parameters used are,

$$x\lambda = \bar{x}, \quad yd = \bar{y}, \quad \psi cd = \bar{\psi}, \quad uc = \bar{u}, \quad vc = \bar{v}, \quad p = \frac{\partial^2 \bar{p}}{\mu c \lambda}, \quad \tau_{xy} = \frac{d \bar{\tau}_{xy}}{\mu c}, \quad \frac{ct}{\lambda}, \quad \delta = \frac{d}{\lambda},$$

$$\varepsilon = \frac{a}{d}, \quad \text{Re} = \frac{\rho cd}{\mu}, \quad \theta = \frac{T - T_0}{T - T_0}, \quad \phi = \frac{C - C_0}{C - C_0}, \quad \text{Sc} = \frac{\nu}{D_m}, \quad \text{Sr} = \frac{D_m K_T (C_1 - C_0)}{\mu C_p C_s (T_1 - T_0)}, \quad M = \sqrt{\frac{\sigma}{\mu}} B_0,$$

$$\text{Pr} = \frac{\rho v c_f}{K_0}, \quad \text{Ec} = \frac{c^2}{c_f (T_1 - T_0)}, \quad \text{Du} = \frac{D_m K_T (C_1 - C_0)}{\mu C_p C_s (T_1 - T_0)}, \quad E_1 = \frac{-\tau d^3}{\lambda^3 \mu}, \quad E_2 = \frac{m c d^3}{\lambda^3 \mu}, \quad E_3 = \frac{c d^3}{\lambda^2 \mu},$$

$$h = \frac{\bar{h}}{d} = (\varepsilon \sin 2\pi(x-t) + 1), \quad \text{Gr} = \frac{\nu g \beta (T_w - T_\infty)}{c^2}, \quad \text{Gm} = \frac{\nu g \beta (C_w - C_\infty)}{c^2}$$

Non-dimensional variables are introduced in the equations (4) – (8), after dropping the primes, we get,

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (14)$$

$$\text{Re } \delta \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = -\frac{\partial p}{\partial x} + \left( \delta^2 \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \frac{u}{k} - M^2 \cos^2 \alpha u + \text{Re } Gr\theta + Gm\phi \quad (15)$$

$$\text{Re } \delta \left( \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial p}{\partial y} + \delta^2 \left( \delta^2 \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (16)$$

$$\text{Re } \delta \left( \frac{C_1 - C_0}{C_1 - C_0} \right) \text{Pr} \left( v \frac{\partial \theta}{\partial y} \right) = Ec \text{Pr} \left( \frac{\partial u}{\partial y} \right)^2 + \left( \frac{\partial^2 \theta}{\partial y^2} \right) + Du \text{Pr} \left( \frac{\partial^2 \phi}{\partial y^2} \right) + M^2 \cos^2 \alpha u \text{Pr } Ec \quad (17)$$

$$\text{Re } \delta \left( v \frac{\partial \phi}{\partial y} \right) = \frac{1}{sc} \left( \frac{\partial^2 \phi}{\partial y^2} \right) + Sr \left( \frac{\partial^2 \theta}{\partial y^2} \right) \quad (18)$$

The relevant boundary conditions are,

$$\frac{\partial u}{\partial y} = 0, \frac{\partial^3 u}{\partial y^3} = 0, \quad \text{at } y=0 \quad (19)$$

$$\frac{\partial^2 u}{\partial y^2} = 0, \quad \text{at } y = \eta(x, t) = (1 + \varepsilon \sin 2\pi(x - t)) \quad (20)$$

$$\begin{aligned} & -\text{Re } \delta \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) + \left( \delta^2 \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \frac{u}{k} - M^2 \cos^2 \alpha u + \text{Re } Gr\theta + \text{Re } Gm\phi \\ & = \left( E_1 \frac{\partial^3 \eta}{\partial x^3} + E_2 \frac{\partial^3 \eta}{\partial x \partial t^2} + E_3 \frac{\partial^2 \eta}{\partial x \partial t} \right), \text{ at } y = \eta(x, t) \quad (21) \end{aligned}$$

### 3. METHOD OF SOLVING THE PROBLEM

Considering the wavelength of the peristaltic wave to be large and the Reynolds number to be small, equation (14) - (18) reduces to the form

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (22)$$

$$\frac{\partial p}{\partial x} = \frac{\partial^2 u}{\partial y^2} - \left( \frac{1}{k} + M^2 \cos^2 \alpha \right) u \quad (23)$$

$$\frac{\partial p}{\partial y} = 0 \quad (24)$$

$$\frac{\partial^2 \theta}{\partial y^2} + Br \left( \left( \frac{\partial u}{\partial y} \right)^2 + M^2 u^2 \cos^2 \alpha \right) + \text{Pr } Du \left( \frac{\partial^2 \phi}{\partial y^2} \right) = 0 \quad (25)$$

$$\frac{\partial^2 \phi}{\partial y^2} + ScSr \left( \frac{\partial^2 \theta}{\partial y^2} \right) = 0 \quad (26)$$

By introducing the stream function,

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

The equations (22) - (26) becomes,

$$\frac{\partial p}{\partial x} = \frac{\partial^3 \psi}{\partial y^3} - \left( \frac{1}{k} + M^2 \cos^2 \alpha \right) \frac{\partial \psi}{\partial y} \quad (27)$$

$$\frac{\partial p}{\partial y} = 0 \quad (28)$$

$$\frac{\partial^2 \theta}{\partial y^2} + Br \left( \left( \frac{\partial^2 \psi}{\partial y^2} \right)^2 + M^2 \cos^2 \alpha \left( \frac{\partial \psi}{\partial y} \right)^2 \right) + Pr Du \left( \frac{\partial^2 \phi}{\partial y^2} \right) = 0 \quad (29)$$

$$\frac{\partial^2 \phi}{\partial y^2} + ScSr \left( \frac{\partial^2 \theta}{\partial y^2} \right) = 0 \quad (30)$$

and the corresponding boundary conditions are obtained as,

$$\frac{\partial^2 \psi}{\partial y^2} = \frac{\partial \theta}{\partial y} = \frac{\partial \phi}{\partial y} = 0, \text{ at } y=0 \quad (31)$$

$$\frac{\partial \psi}{\partial y} = 0, \theta = 0, \phi = 1, \text{ at } h = (\varepsilon \sin 2\pi(x-t) + 1) \quad (32)$$

$$\frac{\partial^3 \psi}{\partial y^3} - \left( \frac{1}{k} + M^2 \cos^2 \alpha \right) \frac{\partial \psi}{\partial y} - \left( E_1 \frac{\partial^3 h}{\partial x^3} + E_2 \frac{\partial^3 h}{\partial x \partial t^2} + E_3 \frac{\partial^2 h}{\partial x \partial t} \right) = 0, \text{ at } y = h \quad (33)$$

By differentiating equation (27) with respect to y, we get,

$$\frac{\partial^4 \psi}{\partial y^4} - \left( \frac{1}{k} + \frac{M^2 \cos^2 \alpha}{1 + m^2 \cos^2 \alpha} \right) \frac{\partial^2 \psi}{\partial y^2} = 0, \quad (34)$$

By solving the equations (29), (30) and (34), with boundary conditions (31), (32) and (33). We attain the stream function and the velocity, the temperature and the concentration,

$$\psi = \frac{c_1}{p} \left( \frac{\sinh(\sqrt{p}y)}{\sqrt{p} \cosh(\sqrt{p}h)} \right) - y \quad (35)$$

$$u = \frac{\partial \psi}{\partial y} = \frac{c_1}{p} \left( \frac{\cosh(\sqrt{p}y)}{\cosh(\sqrt{p}h)} - 1 \right) \quad (36)$$

$$\theta = \frac{-Brc_1^2}{(1 - SrSc Pr Du)p(\cosh \sqrt{ph})^2} \left( \frac{(\cosh \sqrt{py})^2}{4p} \left( \frac{M^2}{p} + 1 \right) + \frac{y^2}{4} \left( \frac{M^2}{p} - 1 \right) \right) + \frac{M^2}{p} \left( \frac{(\cosh \sqrt{ph})^2 y^2}{2} \right) - \frac{2 \cosh \sqrt{ph}}{p} (\cosh \sqrt{py}) + A \quad (37)$$

$$\phi = \frac{ScSrBrc_1^2}{(1 - SrSc Pr Du)p(\cosh \sqrt{ph})^2} \left( \frac{(\cosh \sqrt{py})^2}{4p} \left( \frac{M^2}{p} + 1 \right) + \frac{y^2}{4} \left( \frac{M^2}{p} - 1 \right) \right) + \frac{M^2}{p} \left( \frac{(\cosh \sqrt{ph})^2 y^2}{2} \right) - \frac{2 \cosh \sqrt{ph}}{p} (\cosh \sqrt{py}) + B \quad (38)$$

Skin friction, Nusselt number and Sherwood number at the wall are defined by,

$$\tau = \left( \frac{\partial u}{\partial y} \right)_{y=h}$$

$$\tau = \frac{c_1}{\sqrt{p}} \left( \frac{\sinh \sqrt{ph}}{\cosh \sqrt{ph}} \right)$$

$$Nu = - \left( \frac{d\theta}{dy} \right)_{y=h}$$

$$Nu = \frac{Brc_1^2}{(1 - ScSr Pr Du)p(\cosh \sqrt{ph})^2} \left( \frac{(\sinh \sqrt{ph})^2}{2\sqrt{p}} \left( 1 + \frac{M^2 \cos^2 \alpha}{p} \right) + \frac{h}{2} \left( \frac{M^2 \cos^2 \alpha}{p} - 1 \right) \right) + \frac{M^2 \cos^2 \alpha}{p} \left( (\cosh \sqrt{ph})^2 h - \frac{2 \cosh \sqrt{ph}}{\sqrt{p}} \sinh \sqrt{ph} \right)$$

$$Sh = - \left( \frac{d\phi}{dy} \right)_{y=h}$$

$$Sh = - \frac{SrScBrc_1^2}{(1 - ScSr Pr Du)p(\cosh \sqrt{ph})^2} \left( \frac{(\sinh \sqrt{ph})^2}{2\sqrt{p}} \left( 1 + \frac{M^2 \cos^2 \alpha}{p} \right) + \frac{h}{2} \left( \frac{M^2 \cos^2 \alpha}{p} - 1 \right) \right) + \frac{M^2 \cos^2 \alpha}{p} \left( (\cosh \sqrt{ph})^2 h - \frac{2 \cosh \sqrt{ph}}{\sqrt{p}} \sinh \sqrt{ph} \right)$$

Where,

$$c_1 = -8\epsilon\pi^3 \left( (E_1 + E_2) \cos 2\pi(x-t) - \frac{E_3}{2\pi} \sin 2\pi[x-t] \right)$$

$$p = \frac{1}{k} + M^2 \cos^2 \alpha$$

$$A = 1 + \frac{-Br c_1^2}{(1 - Sr Sc Pr Du) p (\cosh \sqrt{ph})^2} \left( \frac{(\cosh \sqrt{py})^2}{4p} \left( \frac{M^2}{p} + 1 \right) + \frac{y^2}{4} \left( \frac{M^2}{p} - 1 \right) \right) + \frac{M^2}{p} \left( \frac{(\cosh \sqrt{ph})^2 y^2}{2} \right) - \frac{2 \cosh \sqrt{ph}}{p} (\cosh \sqrt{py})$$

$$B = 1 - \frac{Sc Sr Br c_1^2}{(1 - Sr Sc Pr Du) p (\cosh \sqrt{ph})^2} \left( \frac{(\cosh \sqrt{py})^2}{4p} \left( \frac{M^2}{p} + 1 \right) + \frac{y^2}{4} \left( \frac{M^2}{p} - 1 \right) \right) + \frac{M^2}{p} \left( \frac{(\cosh \sqrt{ph})^2 y^2}{2} \right) - \frac{2 \cosh \sqrt{ph}}{p} (\cosh \sqrt{py})$$

#### 4. RESULTS AND DISCUSSION

The impact of relevant parameter on the flow characteristics are reproduced with the help of graphs. In this study, we used the fixed values of various parameters as  $x = 0.01$ ,  $t = 0.01$ ,  $s = 0.2$ ,  $E_1 = 0.2$ ,  $E_2 = 0.2$ ,  $E_3 = 0.1$ ,  $Pr = 0.71$ ,  $Br = 0.2$ ,  $Sc = 0.22$ ,  $Sr = 0.2$ ,  $Du = 0.2$ ,  $m = 0.2$ ,  $n = 0.5$ .

The velocity profile for different amplitude parameters ( $s$ ) is shown in figure 2. It is clear from the figure that the velocity profile increases in ( $s$ ) has increasing function and the velocity profile for various magnetic parameters ( $M$ ) is shown in figure 3. It is noticed the velocity profile is decreasing with increasing Magnetic parameter ( $M$ ).

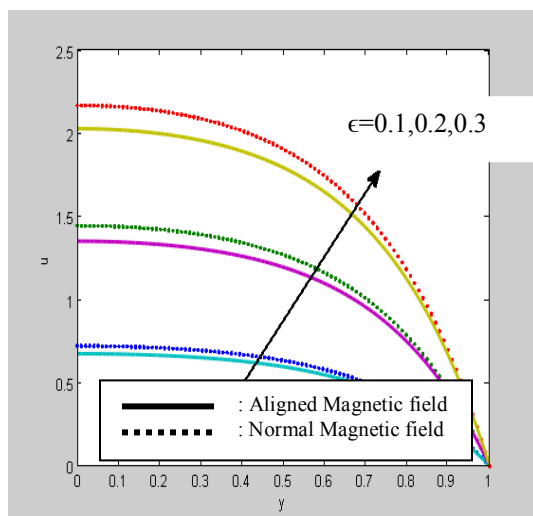


Fig. 2. Velocity Profiles for different  $\epsilon$

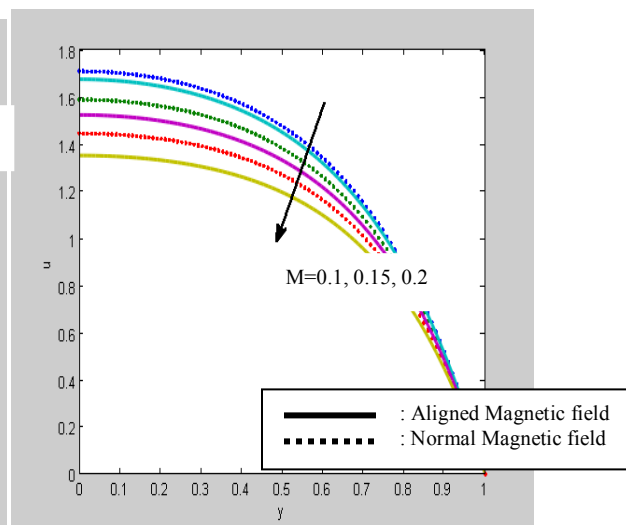
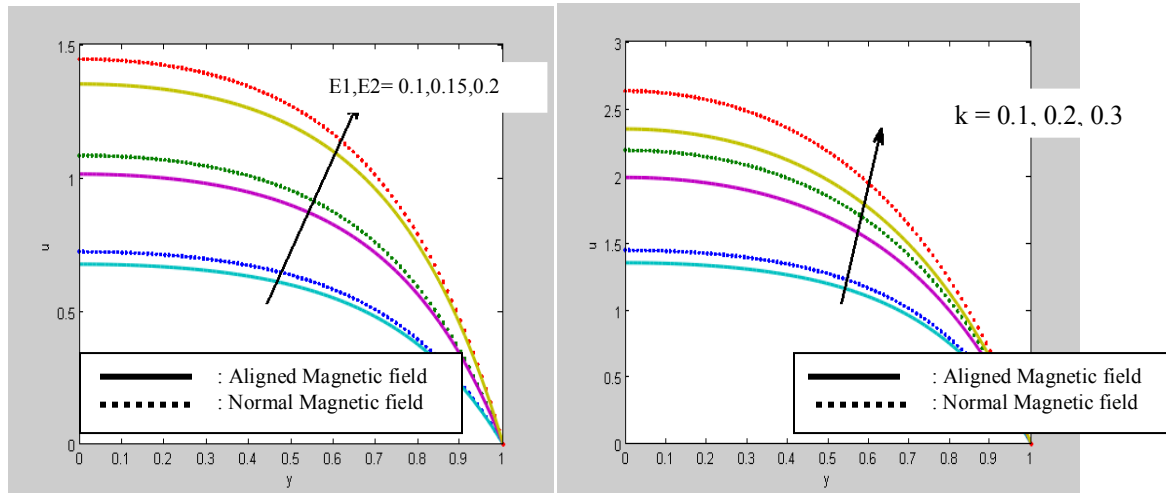


Fig. 3. Velocity Profiles for various  $M$

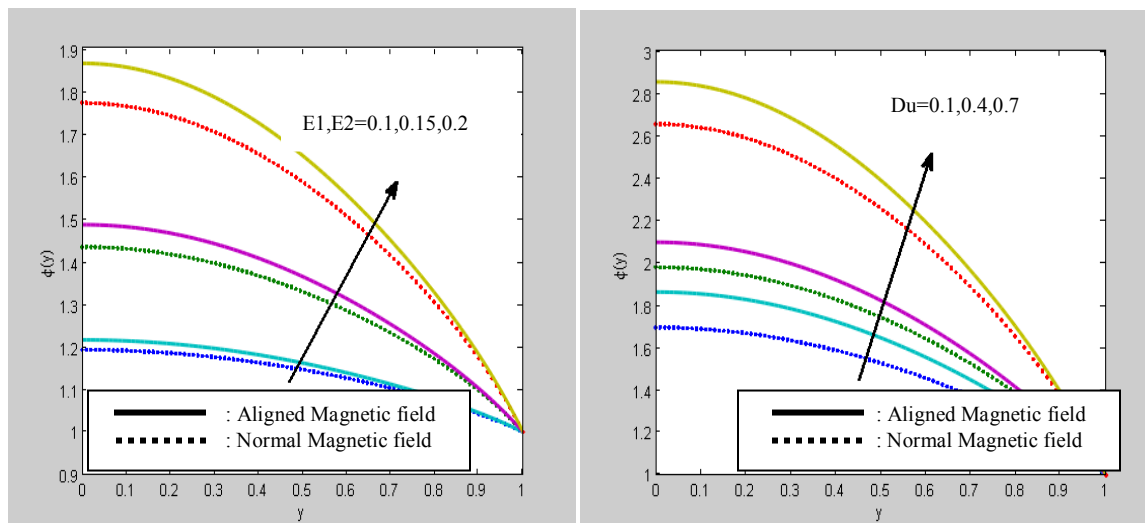
The velocity profile for distinct Elasticity parameters ( $E_1, E_2$ ) is shown in figure 4 and it is also clear that the velocity profile increases with increasing wall tension ( $E_1$ ) and mass characterization ( $E_2$ ).

The velocity profile for various permeability parameter ( $k$ ) increases and is shown in figure 5.



**Fig.4. Velocity Profiles for distinct  $E_1, E_2$  Fig. 5. Velocity Profiles for different  $k$**

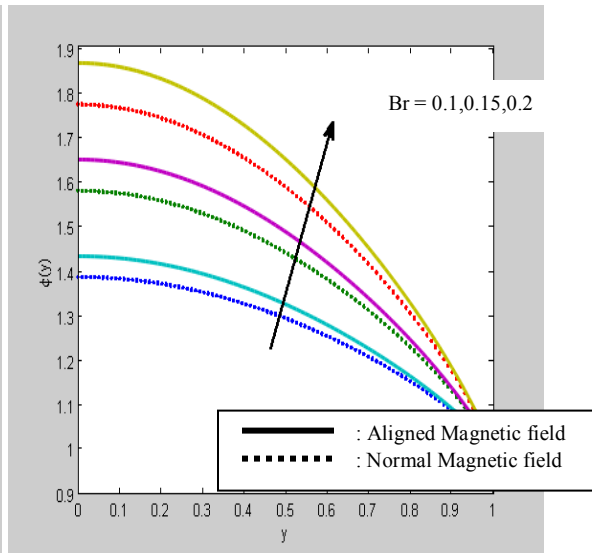
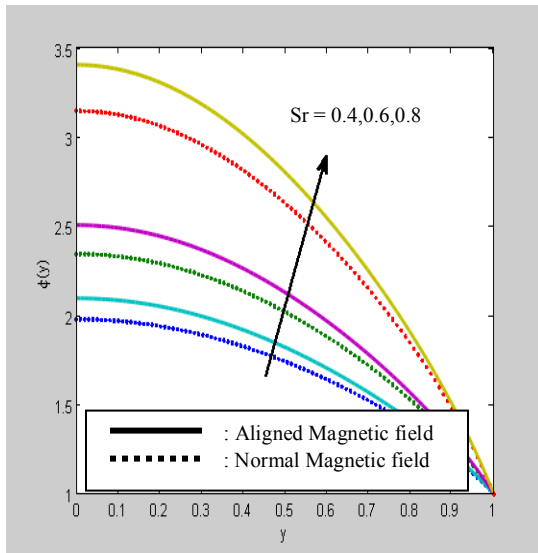
The temperature profile for different Elasticity parameters ( $E_1, E_2$ ) is shown in figure 6 and this figure shows that enhances of wall tension ( $E_1$ ) and mass characterization ( $E_2$ ) increase the temperature profile. The temperature profile for distinct Dufour number ( $Du$ ) is shown in figure 7. It describes that, the rising values of crossdiffusion boost the thermal field.



**Fig.6. Temperature Profiles  $E_1, E_2$  Fig. 7. Temperature Profiles for distinct  $Du$**

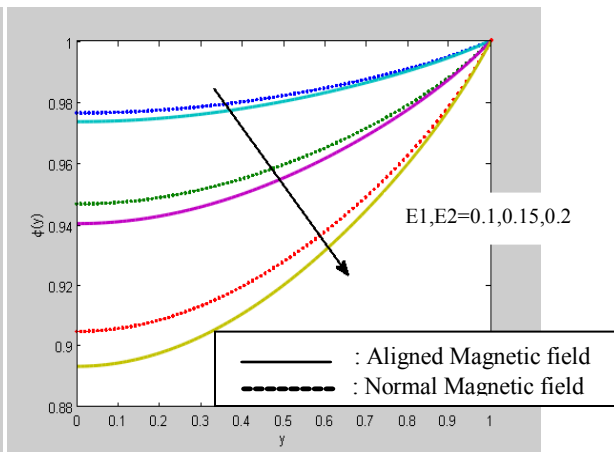
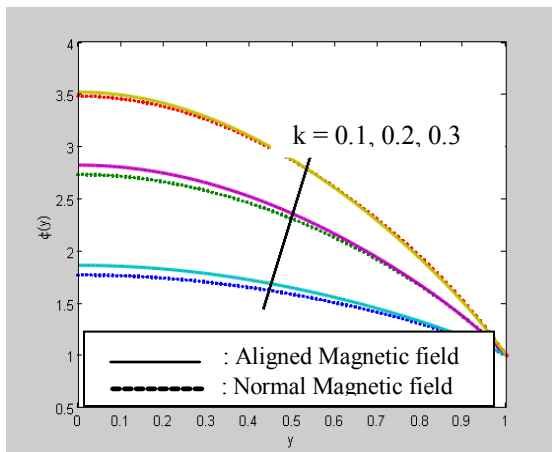
The temperature profile for different values of Soret number ( $Sr$ ) and Brinkmann number ( $Br$ ) are shown through figures 8 and 9. It is explained clearly from the figure that temperature profile is enhanced with the increase in these two parameters.





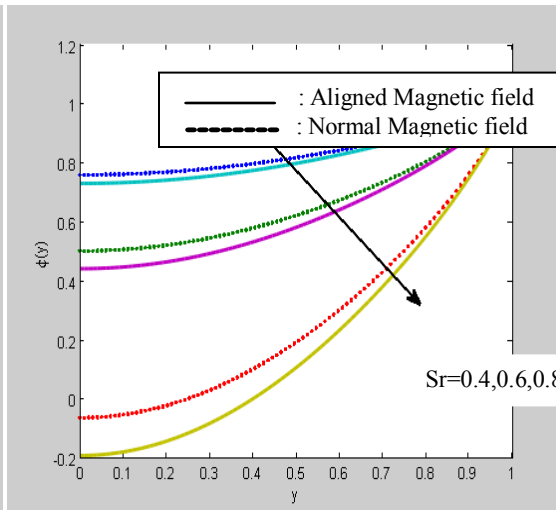
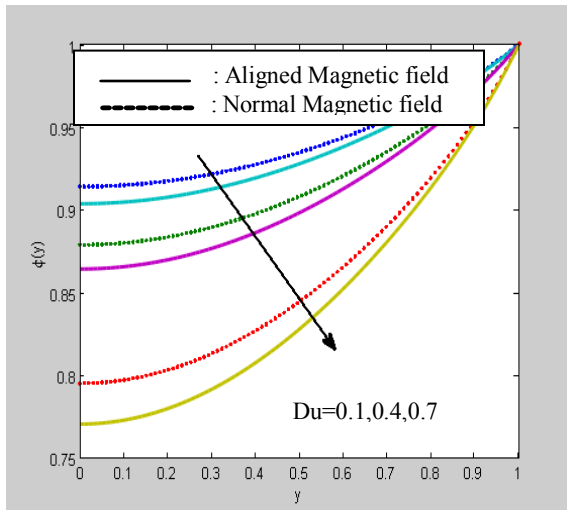
**Fig. 8. Temperature Profiles for different Sr** **Fig.9. Temperature Profiles for Br**

The temperature profile for different permeability parameter ( $k$ ) is shown in figure 10 respectively. It is clear that raising the values of  $k$  increases the temperature profile. The concentration profiles for various Elasticity parameters ( $E_1, E_2$ ) is shown in figure 11 and it shows that in increasing wall tension ( $E_1$ ) and mass characterization ( $E_2$ ) reduce the concentration profile.



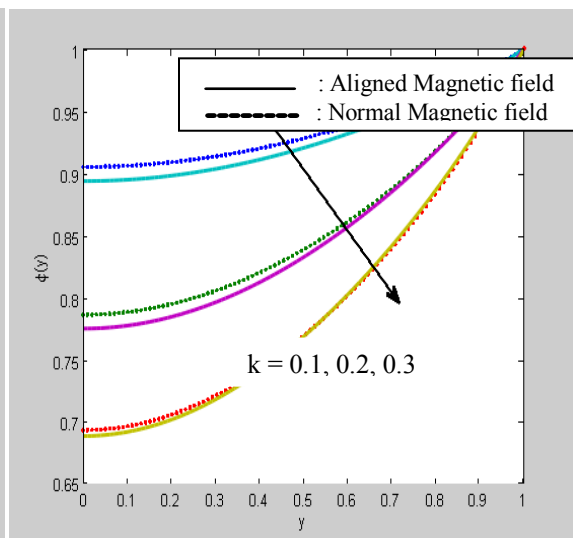
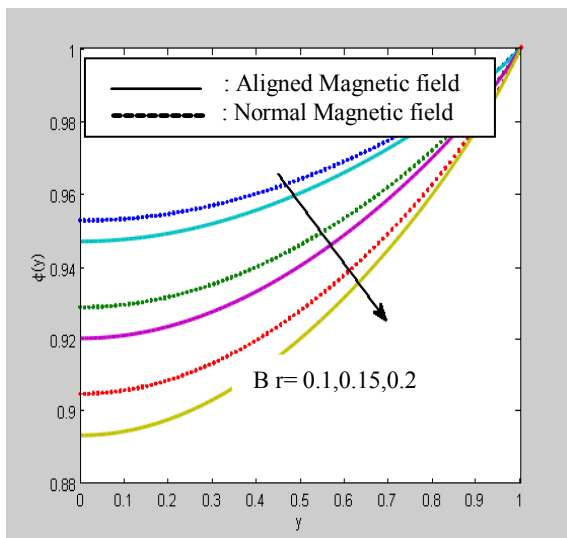
**Fig.10. Temperature profiles for distinct k** **Fig.11. Concentration Profiles for E1,E2**

The concentration profile for various Dufour number ( $Du$ ) is shown in figure 12. It is clear that the concentration profile suppresses the field with the increase in Dufour number. The concentration profile for various Soret number ( $Sr$ ) is shown in figure 13. It is understood from the figure that, the concentration profile decreases with the increase in Soret number.



**Fig. 12. Concentration Profiles for Du Fig. 13. Concentration Profiles for Sr**

In concentration profile, decreasing values of Brinkmann number ( $Br$ ) declines the concentration profile and shown through figure 14. The concentration profile for different permeability parameter ( $k$ ) is shown through figure 15. It is noticed that, for both cases concentration profile decreases.



**Fig. 14. Concentration Profiles for Br Fig. 15. Concentration profiles for different k**

The Skin friction coefficient for various ( $s$ ) is shown in figure 16. It is clear to notice that the rise of these parameters decreases the Skin friction coefficient. The nature of Nusselt number for distinct values of  $Du$ ,  $Sr$ ,  $Br$  and  $m$  is shown through figure 17 to figure 19. It is noticed that, increase in these parameters enhances Nusselt number.

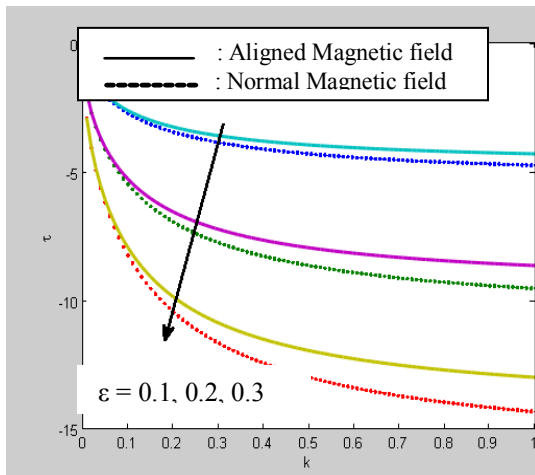


Fig. 16. Skin friction coefficient for  $\epsilon$

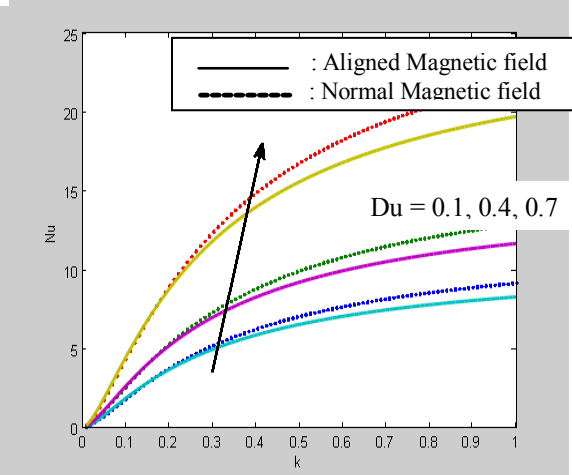


Fig. 17. Nusselt number for various  $Du$

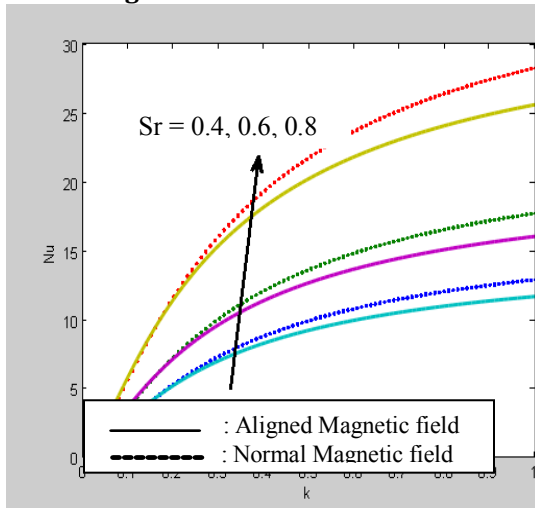


Fig. 18. Nusselt number for different  $Sr$

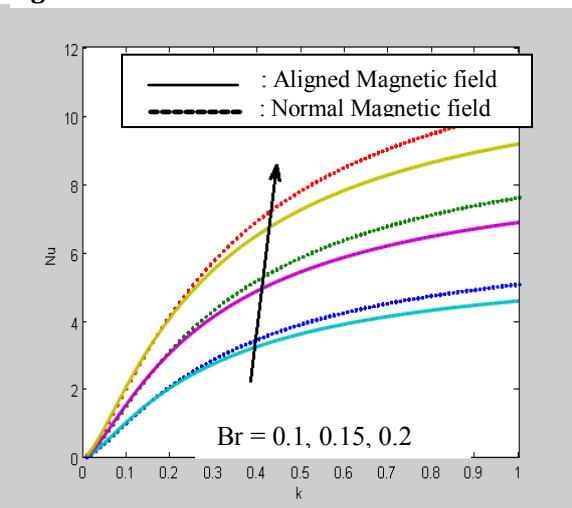


Fig. 19. Nusselt number for various  $Br$

The nature of Sherwood number for distinct values of  $Du, Sr, Br$  and  $\epsilon$  is shown in through figure 20 to figure 22. It is clear from the figures that, increase of these parameters decreases the Sherwood number profile.

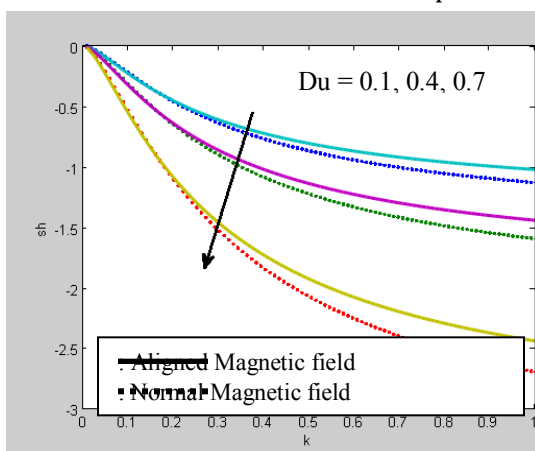


Fig. 20. Sherwood number for different  $Du$

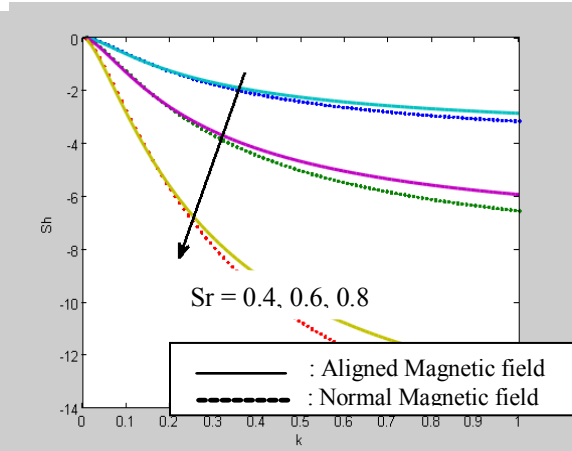


Fig. 21. Sherwood number for  $Sr$

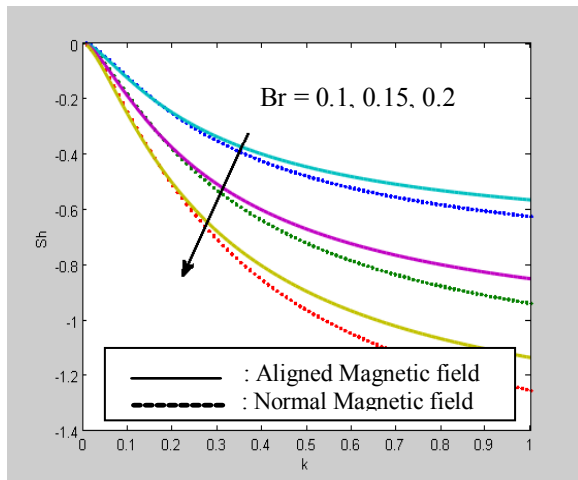


Fig. 22. Sherwood number for Br

## 5. CONCLUSION

In this study, exact solution for the stream function, the velocity profile, the temperature profile and the concentration profile in the existence of Cross diffusion effect, and Permeability parameter on an unsteady MHD flow are constructed.

The effect of heat and mass transfer on Cross diffusion of an unsteady MHD flow is analyzed in detail. Graphical results reveal the consequence of the various dimensionless parameters which exists in the problem under analysis.

The succeeding results are made based on the results and discussion:

- \* As amplitude ratio ( $s$ ) increases, the mean velocity profile also increases and same results arise for wall tension ( $E_1$ ) and mass characterization ( $E_2$ ).
- \* With the increase in Permeability parameter ( $k$ ), the mean velocity profile also increases.
- \* With the increase in wall tension ( $E_1$ ) and mass characterization ( $E_2$ ), the temperature profile increases. The same results are obtained for Dufour number ( $Du$ ), Soret number ( $Sr$ ) and Brinkman number ( $Br$ ).
- \* As Permeability parameter ( $k$ ) increases, the temperature profile increases.
- \* Increase in wall tension ( $E_1$ ) and mass characterization ( $E_2$ ), decreases the concentration profile. The same results

appear for Dufour number ( $Du$ ), Soret number ( $Sr$ ) and Brinkman number ( $Br$ ).

- \* Increase in Permeability parameter ( $k$ ), decreases the concentration profile.
- \* Increase in ( $s$ ), the skin friction ( $\tau$ ) decreases.
- \* With the increase in Dufour number ( $Du$ ), Soret number ( $Sr$ ) and Brinkman number ( $Br$ ), the Nusselt number ( $Nu$ ) increases.
- \* With the increase in Dufour number ( $Du$ ), Soret number ( $Sr$ ) and Brinkman number ( $Br$ ), the Sherwood number ( $Sh$ ) decreases.

## Nomenclature:

$x, y$	- Cartesian co-ordinates
$u, v$	- Fluid velocity
$\mu$	- pressure, viscosity
$d, a$	- mean width of the channel, amplitude
$\lambda, c$	- wavelength, wave speed
$\sigma, \nu$	- electrical conductivity, kinematic viscosity
$T, s$	- temperature, amplitude ratio
$\rho, t$	- density of the fluid, time
$CB$	- coefficient of volume expansion
$\theta, \phi$	- Non-dimensional temperature, Non-dimensional concentration
$M, G$	- Magnetic parameter, gravitational force
$C_p$	- specific heat
$C_s$	- concentration viscosity
$Bo$	- magnetic field
$KT$	- diffusion ratio
$D_m$	- mass diffusion coefficient
$Sr$	- Soret parameter
$Sc$	- Schmidt number
$Du$	- Dufour parameter
$Br$	- Brinkman number
$Gr$	- Grashof number for heat transfer
$G_m$	- Mass Grashof number
$Pr$	- Prandtl number
$Re$	- Reynolds number
$E_1, E_2, E_3$	- Elasticity temperature
$To, T1$	- concentration fluid at lower and upper walls
$Co, C1$	- temperature of fluid at lower and upper walls

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