FINITE ELEMENT ANALYSIS OFCONVECTIVE HEAT AND MASS TRANSFER FLOW PAST A VERTICAL POROUS PLATE IN A ROTATING FLUID WITH CHEMICAL REACTION, DISSIPATION, SORET AND DUFOUR EFFECTS

S. Madhavi Latha[1] and Prof. D.R.V. Prasada Rao[2]
[1]Research Scholar , Department of Mathematics, Rayalaseema University, Kurnool, A.P, India
[2]Department of Mathematics, S.K.University, Anantapur, A.P, India

ABSTRACT

In this Paper, we analyse the combined influence of Soret, Dufour, on hydrodynamic non-linear convective heat and mass transfer flow of viscous electrically conducting fluid in a vertical rotating plate in the presence of transverse magnetic field. By employing finite element technique the equations governing the flow, heat and mass transfer have been solved. The velocity and temperature dissipations are analysed for different parametric values. The shear stress and rate of heat and mass transfer on the boundary are evaluated numerically for different variations.

Keywords : Heat and Mass Transfer, Porous Plate, Chemical Reaction, Dissipation, Soret and Durour Effects

1. INTRODUCTION:

The MHD fluid flow in a rotating channel is an interesting area in the study of fluid mechanics because of its relevance to various engineering applications. It is challenging approach to atmospheric science that exerts its influence of rotation to help in understanding the behavior of oceanic circulation and formation of galaxies. The effect of Coriolis force in the atmosphere is exposed to oceanic circulation and the formation of galaxies in taking into account the flow of electron is continuously liberated from the sun what is called “solar wind”. The MHD flow in the rotating environment leads to a startup process implying thereby a viscous layer at the boundary is suddenly set into motion and the rate of rotation becomes important in the application of various branches of geophysics, astrophysics and fluid engineering. Keeping these applications several authors (Mahendra Mohan [23], Mahendra Mohan and Srivastava [24], Sarojamma and Krishna [34], Krishna et.al. [21]., Seth and Ghosh [36], Agarwal and Dhanpal [2], Ghosh [36], El-Mistikawy et.al. [11], Hazim Ali Attia [14], Circar and Mukherjee [9], . Balasubramanyam [4] and Reddy [42])have discussed the effect of rotation on convective heat transfer and heat and mass transfer in different configurations under varied conditions.

In the last several years considerable attention has been given to the study of the Hydromagnetic thermal convection due to its numerous applications in geophysics and astrophysics. It is well known that in the geothermal region, gases are electrically conduction and that they undergo the influence of magnetic fluid. Gill and Casal [13] has theoretically investigated the natural convection effects in forced horizontal flows. Jana [19] has considered the effect of wall conductance as convective horizontal channel flow. Yen [43] has considered the same effect on magneto hydrodynamic heat transfer in a channel and has shown that the wall conductance entirely destabilizing influence on the flow, whereas the magnetic field stabilizes the flow. Nanda and Mohanti [29] have studied the effect of magnetic field in a rotating channel. Soundalgekar and Bhat [39] have investigated the MHD flow and heat transfer in viscous electrically conducting fluid in rotating channel with conducting fluid.

Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore, received a considerable amount attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously.Thermal diffusion effect has been utilized for isotopes separation in the mixture between gases with very light molecular weight (hydrogen and helium) and medium molecular weight. Keeping tgese applications in view several authors(Muthucumaraswamy and Ganesan [26],Deka et.al. [10], Muthucumaraswamy [25],Muthucumaraswamy and Meenakshisundaram [28],Chamkha [7], Raptis and Perdikis [33] , Ibrahim et. al. [15,Indudhar et. al. [16] , Cheena Kesavaiah et.al. [8]) have studied the free convection flow with soret ,chemical reaction and radiation absorption in different configutrations under varied conditions.

When heat and mass transfer occur simultaneously in a moving fluid, the relation between the fluxes and the driving potentials are of more intricate nature. Mass fluxes can be created by temperature gradients and this is the Soret effect or thermo-diffusion effect. (Adrian Postelnicu [1], Sreevani et. al. [41, Barletta [5] and Zanchini [44], Soundalgekar and Pop [40], Sivaiah et. al. [38]. Indudhar et. al. [17], Madhusudhan Reddy et. al. [22] ,Kamalakar et. al. [20] , Rajasekhar et. al. [32], Muthucumaraswamy et. al. [27], Jafarunnisa [18]'Alam et. al. [3], Srirangavani[40a] , Jayasuda[19a] , Bhuvanavijaya et al(6a) have discussed the combined influence of Soret and Dufour effects on convective heat and mass transfer in different configiurations.

In all the above investigations, the variation of density is taken in the linear form

$$\Delta\rho = -\rho\beta\,(\Delta T) \qquad (1.1)$$

where β is the co-efficient of thermal expansion and is 2,07 x 10^4 $(OC)^{-1+}$. This is valid for temperature variation near 20^0c. But this analysis is not applicable to the study of the flow of water at 4^0c, the density of water is a maximum at atmosphere pressure and the above relations (1.1) does not hold good. The modified form of (1.1) is applicable to water at 4^0c is given by

$$\Delta\rho = -\rho\,\gamma\,(\Delta T)^2 \qquad (1.2)$$

where γ = 8 x 10^{-6} $(OC)^{-2}$. Taking this fact into account, Goren [13a] showed in this case, similarity solutions for the free convection flow of water at 4^0c past a semi-infinite vertical plate exist. Govindarajulu [13b] showed that a similarity solution exist for the free convection flow of water at 4^oc from vertical and horizontal plates in the presence of suction and injection. Soundalgekar [12] obtained an approximate solution of the same problem using Kraman – Pohlhausen integral method. Datta [10a] has investigated the free convection of water at 4^0c form a horizontal plate when wall temperature varies as a power of distance along the plate. An approximate solution for velocity and temperature has been obtained by using Karman – Pohlhausen method together with the method of finding similarity solution. Using the relation (1.2) Sinha [38a] has analyzed the problem of fully developed free convection flow between vertical plates had in a circular pipe respectively. Following a quadratic density temperature variation Gupta, Dubey and Sharma [13c] have discussed the laminar free convection flow through coaxial circular cylinders with and without heat sources. Taking non-linear density temperature variation Sarojamma [34a] has analysed the hydromagnetic free convection flow in a cylindrical geometry. Sastri and Vajravelu [35b] have solved the problem of free convection between vertical walls by taking the non-linear density temperature variation, viz.,

$$\Delta\rho = -\rho\beta g\,(T - T_e) - \rho\beta_1(T - T_e)^2 \qquad (1.3)$$

Where β_0 and β_1 are the constants. This relation includes both the relationships (1.1) and (1.2). Gilpin [12a] has used a density temperature relation which is similar to relation (1.3) and has shown the existence of Quasi – steady modes of convection for some temperature below 4^0c. A similar relation introduced by Varrier and Tien [17] have been used to predict the heat transfer results in the case of water for temperature between o^0c and 20^0c. Bhargawa and Agarwal [5a] have investigated the fully developed laminar free convection flow in the presence of constant heat sources in a circular pipe taking the same density temperature relationship (1.3). It is found that the flow and heat transfer both depend up on a new parameter $\gamma = \left(\frac{\beta_1}{\beta_0}\right)\Delta T$ in addition to the heat source parameter and free convection parameter k.

In this chapter we analyse the combined influence of Soret,Dufour, on hydrodynamic non-linear convective heat and mass transfer flow of viscous electrically conducting fluid in a vertical rotating plate in the presence of transverse magnetic field. By employing finite element technique the equations governing the flow, heat and mass transfer have been solved. The velocity and temperature dissipations are analysed for different parametric values. The shear stress and rate of heat and mass transfer on the boundary are evaluated numerically for different variations.

2. FORMULATION OF THE PROBLEM:

We consider a steady hydromagnetic heat and mass transfer flow of a viscous electrically conducting along an infinite vertical plate y=0 in a rotating system. The flow is also assumed to be moving with a uniform velocity U_∞, which is in the x-direction, is taken along the plate in the upward direction and the y-axis is normal to it. Initially the plate is at rest, after that the whole system is allowed to rotate with a constant angular velocity Ω about the y-axis. The temperature and the species concentration at the plate are constantly raised from T_∞ and C_∞ to T_w and C_w respectively, where T_∞ and C_∞ are the temperature and species concentration of the uniform flow respectively.

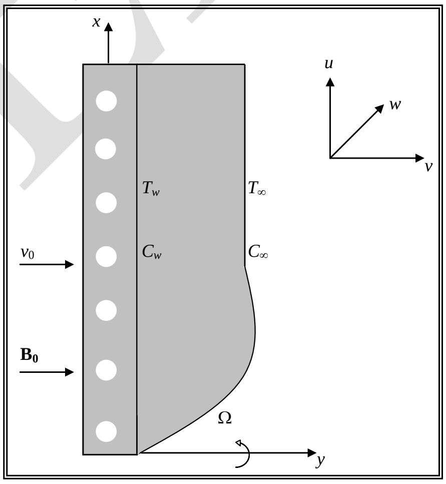

Fig.1 : Physical configuration and coordinate system

The physical configuration considered here is shown in Figure 1. It is assumed that the plate is semi-infinite in extent and hence all the physical quantities depend on y and x.

Thus accordance with the above assumptions and Boussinesq's approximation, the basic equations relevant to the problem

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

$$\left.\begin{aligned} u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} &= \nu\frac{\partial^2 u}{\partial y^2} + \beta_0 g(T - T_\infty) + \beta_1 g(T - T_\infty)^2 + \beta_0^* g(C - C_\infty) + \beta_1^* g(C - C_\infty)^2 \\ &\quad + 2\Omega w - \frac{\sigma B_0^2}{1+m^2}((U - u)) \end{aligned}\right| \tag{2}$$

$$u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}=\nu\frac{\partial^2 w}{\partial y^2}+2\Omega(U_o-u)-\frac{\sigma B_0^2}{1+m^2}w \tag{3}$$

(3

$$\begin{aligned} u\frac{\partial T}{\partial x}v\frac{\partial T}{\partial y}&=\frac{k_f}{\rho C_p}\frac{\partial^2 T}{\partial y^2}+\frac{\nu}{C_p}((\frac{\partial u}{\partial y})^2+(\frac{\partial w}{\partial y})^2)+\\ &+\frac{\sigma B_o^2}{\rho}((U_o-u)^2+w^2)+\frac{D_m k_T}{C_s C_p}\frac{\partial^2 C}{\partial y^2}\end{aligned} \tag{4}$$

$$u\frac{\partial C}{\partial x}v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}+\frac{D_m K_T}{T_m}\frac{\partial^2 T}{\partial y^2}-\gamma^{'}(C-C_\infty) \tag{5}$$

The boundary conditions for the problem are

$$\begin{aligned} &u=0,\ v=v_o,\ w=0, T=T_w, C=C_w \quad at\ y=0\\ &u=U_0 \qquad w=0, T\to T_\infty, C\to C_\infty\ \ as\ \ y\to\infty\end{aligned} \tag{6}$$

Following the work of Sattar [37], a transformation is now made as

$$u_1=U_0-u \quad \Rightarrow u=U_0-u_1 \tag{7}$$

Equations (1)-(.5) and the boundary conditions (6), respectively, transform to

$$-\frac{\partial u_1}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{8}$$

$$\begin{aligned} (U_0-u_1)\frac{\partial u_1}{\partial x}+v\frac{\partial u_1}{\partial y}&=\nu\frac{\partial^2 u_1}{\partial y^2}-\beta_0 g(T-T_\infty)-\beta_1 g(T-T_\infty)^2-\\ &-\beta_0^* g(C-C_\infty)-\beta_1^* g(C-C_\infty)^2+2\Omega w-\frac{\sigma B_0^2}{1+m^2}(u_1)\end{aligned} \tag{9}$$

$$(U_0-u_1)\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}=\nu\frac{\partial^2 w}{\partial y^2}+2\Omega u_1-\frac{\sigma B_0^2}{1+m^2}w \tag{10}$$

$$\begin{aligned} (U_0-u_1)\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}&=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}+\frac{\nu}{C_p}\left(\left(\frac{\partial u_1}{\partial y}\right)^2+\left(\frac{\partial w}{\partial y}\right)^2\right)-\\ &-Q_H(T-T_\infty)+\frac{D_m k_T}{C_s C_p}\frac{\partial^2 C}{\partial y^2}+\frac{\sigma B_o^2}{\rho C_p(1+m^2)}(u_1^2+w^2)\end{aligned} \tag{11}$$

$$(U_0-u_1)\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}+\frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2}-K_c^{'}C \tag{12}$$

$$\begin{aligned} &u_1=U_0, v=v_o(x), w=0, T=T_w, C=C_w \qquad at\ \ y=0\\ &u_1=0 \qquad w=0, T\to T_\infty, C\to C_\infty \qquad as\ y\to\infty\end{aligned} \tag{13}$$

Where u, v, w are the velocity components in the x, y, z directions respectively, ν is the kinematics viscosity, g is the acceleration due to gravity, ρ is the density, β is the coefficient of Volumetric thermal expansion, $\beta^\bullet$ is the Volumetric mass expansion. T, $T_{w,}$, T_∞ are the temperature of the fluid inside the thermal boundary layer, the plate temperature and the fluid temperature in the free stream respectively, while C, C_w, C_∞ are the corresponding concentrations. Also, K^1 is the permeability of the porous medium. k is the thermal conductivity of the medium, Dm is the coefficient of mass diffusivity, Cp is the specific heat constant pressure, Tm is the mean fluid temperature, k_T is the thermal diffusion ratio, Cp is the concentration and other symbols have their usual meaning, C_s is the concentration susceptibility and other symbols have their usual meaning.

In order to solve equations (10)-(12) under the boundary conditions (13),we adopt the well-defined similarity analysis to attain similarity solutions.
For this purpose, the following similarity transformations are now introduced:

$$\eta = y\sqrt{\frac{U_o}{2\nu x}} \quad , g_o(\eta) = \frac{w}{U_o} \quad , \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty} , \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}$$

$$\psi = \sqrt{2\nu x U_0}\, f(\eta) \qquad , u_1 = \frac{\partial \psi}{\partial y} = U_o f^{'}(\eta) \quad , \frac{u}{U_0} == 1 - f^{'}(\eta) \tag{14}$$

Now for reasons of similarity, the plate of concentration is assumed to be

$$C_w(x) = C_o + \bar{x}(C_0 - C_\infty) \tag{15}$$

where C_0 is considered to be mean concentration and $\bar{x} = \frac{xU_o}{\nu}$

The continuity equation (2.1) then yields

$$v = \frac{\partial \psi}{\partial x} = -\sqrt{\frac{\nu U_o}{2x}(\eta f^{'}(\eta) - f(\eta))} \tag{16}$$

Also we have $f_w = v_o(x)\sqrt{\frac{2x}{\nu U_0}}$ (17)

Where f_w is the suction parameter or transpiration parameter and clearly in (17) $f_w < 0$ corresponds to suction and $f_w > 0$ corresponds to injection at the plate. From equations (9)-(13) and (14)-(19), we have the following dimensionless ordinary coupled non-linear differential equations.

$$f^{'''} + (\eta - f) f^{''} - Gr(\theta(1+\alpha_1\theta) + N\phi(1+\alpha_2\phi)) - M^2(f') = 0 \tag{18}$$

$$g_0^{''} + (\eta - f)g_0^{'} + Rf^{'} - M^2 g_0 = 0 \tag{19}$$

$$\begin{aligned}\theta^{''} + P_r(\eta - f)\theta^{'} + P_r E_c((f^{''})^2 + (g_o^{'})^2) + P_r E_c M((f^{'})^2 + (g_o)^2) - \\ -Q\theta + Du\,\theta'' + (g_o)^2) = 0\end{aligned} \tag{20}$$

$$\phi^{''} + Sc(\eta - f)\phi^{'} + 2Sc(f^{1} - (1+\gamma))\phi + Sc\, S_r \theta^{''} = 0 \tag{21}$$

With the corresponding boundary conditions

$$\begin{aligned} &f = f_{w,} \;\; f^{'} = 1, g_0 = 0, \theta = 1, \phi = 1 \qquad at \;\; \eta = 0 \\ &f^{'} = 0 \qquad\quad g_0 = 0, \theta = 0, \phi = 0 \qquad as \;\; \eta \to \infty \end{aligned} \tag{22}$$

where $G_r = \frac{2\beta g(T_w - T_\infty)x^3}{\nu^2}, N = \frac{\beta^{\bullet} g(C_w - C_\infty)}{(T_w - T_\infty)},$

$$D^{-1} = \frac{2\nu x}{kU_0}, M = \frac{2x\sigma B_0^2}{\rho U_0} \;\; , \;\; R = \frac{4\Omega x}{U_0}$$

$$Q = \frac{Q_H}{C_p k_f} \quad , \; P = \frac{\rho \nu C_p}{k_f}, \;\; E_c = \frac{U_0^2}{C_p(T_w - T_\infty)}$$

$$Sc = \frac{\nu}{D_m}, \; \alpha_1 = \frac{\beta_1(T_w - T_\infty)}{\beta_0} \;\; , \alpha_2 = \frac{\beta_1^*\,(C_w - C_\infty)}{\beta_0^*}$$

$$N = \frac{\beta_1^*\,(C_w - C_\infty)}{\beta_1(T_w - T_\infty)}, S_r = \frac{D_m k_T(T_w - T_\infty)}{C_s C_p(C_w - C_\infty)}, \qquad Du = \frac{D_m k_T(C_w - C_\infty)}{T_m(T_w - T_\infty)}$$

$$\gamma = \frac{k_c(C_w - C_\infty)}{U_0}, \quad Q_1 = \frac{Q_1^{'}(C_w - C_\infty)}{(T_w - T_\infty)}$$

For the computational purpose and without loss of generality ∞ has been fixed as 8.The whole domain is divided into 11 line elements of equal width, each element being three nodded.

3. FINITE ELEMENT ANALYSIS

The method basically involves the following steps:

(1) Division of the domain into elements, called the finite element mesh.
(2) Generation of the element equations using variational formulations.
(3) Assembly of element equations as in step 2.
(4) Imposition of boundary conditions to the equations obtained in step 3
(5) Solution of the assumed algebraic equations.

If h^i, f^i, g^i, θ^i, ϕ^i are the approximate values of h,f,g,θ,ϕ ,then we define the Error residals E_h^i ,E_f^i , E_g^i , E_θ^i *and* E_ϕ^i as

$$E_f^i = \frac{df^i}{dy} - h^i \tag{23}$$

$$E_h^i = \frac{d}{dy}\left(\frac{dh^i}{dy}\right) + (\eta - f)\frac{dh^i}{dy} - Gr(\theta^i(1+\alpha_1\theta^i) + N\phi^i(1+\alpha_2\phi^i)) - M^2(h^i) \tag{24}$$

$$E_{go}^i = \frac{d}{dy}\left(\frac{dhi}{dy}\right) + (\eta - f)\frac{dh^i}{dy} + Rh^i - M^2 g_0' \tag{25}$$

$$\begin{aligned} E_\theta^i = {} & \frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) + P_r(\eta - f)\frac{d\theta}{dy} + P_r E_c\left(\left(\frac{dh}{dy}\right)^2 + \left(\frac{dg^i{}_0}{dy}\right)^2\right) + P_r E_c M((h^i)^2 + (g^i{}_o)^2) - \\ & - Q\theta^i + Du\frac{d}{dy}\left(\frac{d\phi^i}{dy}\right) + (g^i{}_o)^2) \end{aligned} \tag{26}$$

$$E_\phi^i = \frac{d}{dy}\left(\frac{d\phi}{dy}\right) + Sc(\eta - f)\left(\frac{d\phi}{dy}\right) + 2Sc(h - (1+\gamma))\phi + Sc\, S_r \frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) \tag{27}$$

Where

$$h^i = \sum_{k=1}^{3} h_k \psi_k, \quad f^i = \sum_{k=1}^{3} f_k \psi_k \tag{28}$$

$$g^i = \sum_{k=1}^{3} g_k \psi_k, \quad \theta^i = \sum_{k=1}^{3} \theta_k \psi_k, \quad \phi^i = \sum_{k=1}^{3} \phi_k \psi_k$$

These errors are orthogonalized to the weight function over the domain ei under Galerkinr finite element technique. We choose the approximation functions as the weight functions. The resulting local stiffness matrices are assembled into global matrices using inter-element continuity ,boundary and equilibrium conditions to obtain the coupled global matrices in terms of the global nodal values of h,f,go,θ,ϕ .The ultimate coupled global matrices are solved to determine the unknown global nodal values of the velocity, temperature and concentration in fluid region. In solving these global matrices an iterative procedure has been adopted to obtain the effect of various forces acting on the fluid system.

The assumed equations can be solved by any of the numerical technique viz. Gaussian elimination, LU Decomposition method etc.

Issue 7, Vol. 3 (May 2017)
ISSN 2249-6149

4. SKIN FRICTION COEFFICIENT, NUSSELT NUMBER AND SHERWOOD NUMBER

The quantities of chief physical interest are the skin friction coefficients, the Nusselt Number and the Sherwood number. The wall skin frictions are defined by

$\tau_x = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0}$ *and* $\tau_z = \mu\left(\frac{\partial w}{\partial y}\right)_{y=0}$ which are proportional to

$\left(\frac{\partial^2 f}{\partial \eta^2}\right)_{\eta=0}$ *and* $\left(\frac{\partial g_0}{\partial \eta}\right)_{\eta=0}$

The Nusselt Number is defined by $Nu = \frac{1}{\Delta T}\left(\frac{\partial T}{\partial y}\right)_{y=0}$ which is proportional to $\left(\frac{\partial \theta}{\partial \eta}\right)_{\eta=0}$

The Sherwood Number is defined by $Sh = \frac{1}{\Delta C}\left(\frac{\partial C}{\partial y}\right)_{y=0}$ which is proportional to $\left(\frac{\partial \phi}{\partial \eta}\right)_{\eta=0}$

The numerical values of the skin friction coefficients, the Nusselt Number and the Sherwood Number are sorted in tables 6.1-6.12.

5. DISCUSSION OF THE NUMERICAL RESULTS:

We analyse the effect of rotation, Hall currents, soret and Dufour effects on convective heat and mass transfer flow in a rotating fluid past a vertical porous plate. The velocity, temperature and concentrations are analysed graphically for different variations.

Table : Skin friction, Nusselt ,Sherwood number at η=0

Parameter		**τx(0)**	**τz(0)**	**Nu(0)**	**Sh(0)**
N	**1.0**	-3.0044	0.00677984	0.41435	1.16263
	2.0	-5.51361	-0.0725762	0.523665	1.38354
	-0.5	-1.46206	0.0495605	0.340769	1.04556
	-1.5	-3.41585	-0.00954057	0.447123	1.23144
Fw	**0.2**	-3.0044	0.00677984	0.41435	1.16263
	0.4	-4.36939	-0.023013	0.209804	1.25009
	-0.2	-5.44257	-0.0885173	0.935497	1.09202
	-0.4	-8.69346	-0.188599	1.50692	0.769379
R	**0.5**	-3.0044	0.00677984	0.41435	1.16263
	1.0	-4.34356	-0.0669015	0.207266	1.24451
	1.5	-5.33573	-0.479686	0.926972	1.07773
	2.0	-8.69896	-2.08034	1.496	0.789024
Ec	**0.01**	-3.0044	0.00677984	0.41435	1.16263
	0.03	-4.38445	-0.024268	0.0632135	1.44401
	0.05	-5.44632	-0.0943035	0.485253	1.85191
	0.07	-10.0705	-0.301131	-1.25992	5.7176
γ	**0.5**	-3.0044	0.00677984	0.41435	1.16263
	1.5	-4.03476	-0.0273946	0.458661	1.5872

Parameter		**τx(0)**	**τz(0)**	**Nu(0)**	**Sh(0)**
	-0.5	-5.8547	-0.0856551	0.547014	1.06192
	-1.5	-9.88653	-0.059792	0.212033	1.38736
Sr/Du	**2.0/0.03**	-3.0044	0.00677984	0.41435	1.16263
	1.5/0.04	-4.13633	-0.0312567	0.466098	1.25645
	1.0/0.06	-5.56126	-0.0666063	0.496392	1.35241
	0.6/0.1	-10.4152	-0.136393	0.252542	1.48262
α_1	**0.01**	-3.0044	0.00677984	0.41435	1.16263
	0.02	-4.41766	-0.0397376	0.507769	1.26283
	0.03	-6.49747	-0.0906215	0.570095	1.41817
	0.05	-12.4122	-0.166286	0.286114	1.95976
α_2	**0.01**	-3.0044	0.00677984	0.41435	1.16263
	0.02	-4.35133	-0.0378261	0.504939	1.25664
	0.03	-6.28473	-0.0857864	0.564728	1.39995
	0.05	-11.5146	-0.150889	0.290809	1.86933

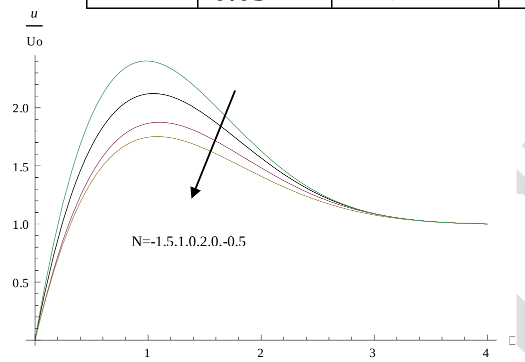

Fig.2a.variation of (u/U0) with N
M=0.5,D-1=0.2,G=2,Sc=1.3,So=2,Du=0.03,Pr=0.71,γ=0.5
α1=0.01;α2=0.01;

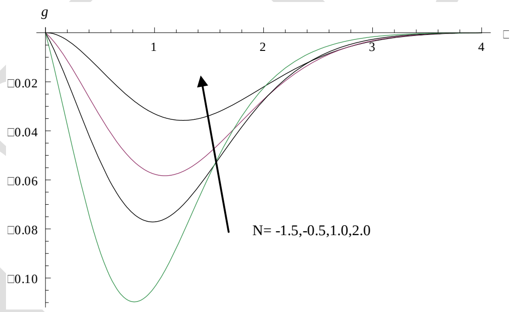

Fig2b Variation of g with N
M=0.5,D-1=0.2,G=2,Sc=1.3,So=2,Du=0.03,Pr=0.71,γ=0.5
α1=0.01;α2=0.01

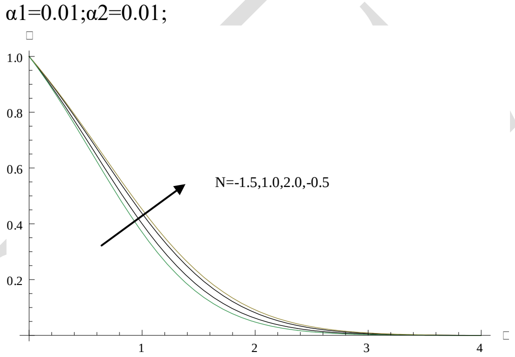

Fig.2c Variation of θ with N
M=0.5,D-1=0.2,G=2,Sc=1.3,So=2,Du=0.03,Pr=0.71,γ=0.5
α1=0.01;α2=0.01

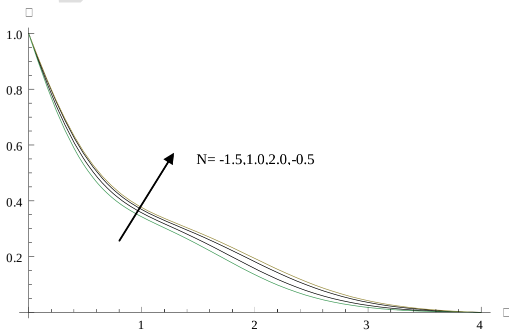

Fig.2d Variation of ϕ with N
M=0.5,D-1=0.2,G=2,Sc=1.3,So=2,Du=0.03,Pr=0.71,γ=0.5
α1=0.01;α2=0.01

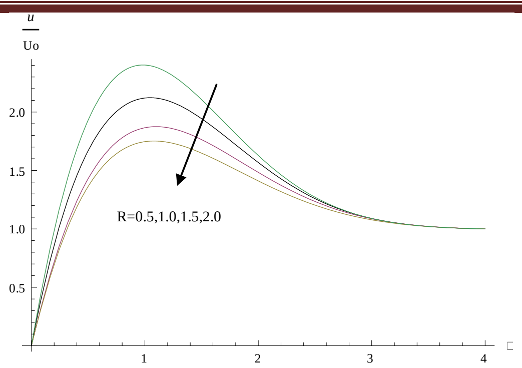

Fig3a.variation of (u/U_0) with R
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,Pr=0.71,γ=0.5 α1=0.01;α2=0.01;

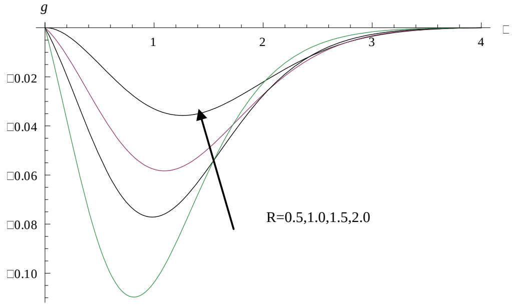

Fig.3b Variation of g with R
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03, Pr=0.7,γ=0.5,G=2,α1=0.01;α2=0.01

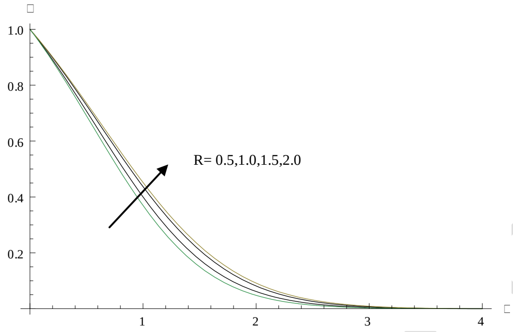

Fig.3c Variation of θ with R
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03, Pr=0.71,γ=0.5,α1=0.01;α2=0.01,G=2,

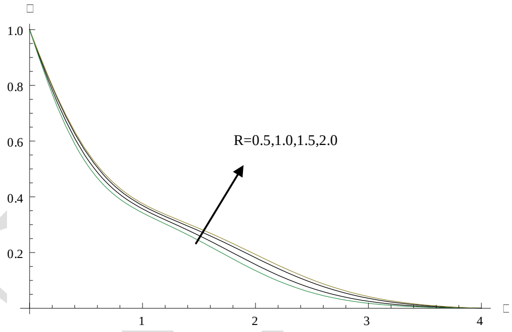

Fig.3d Variation of ϕ with R
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03, Pr=0.71,γ=0.5,α1=0.01;α2=0.01,G=2

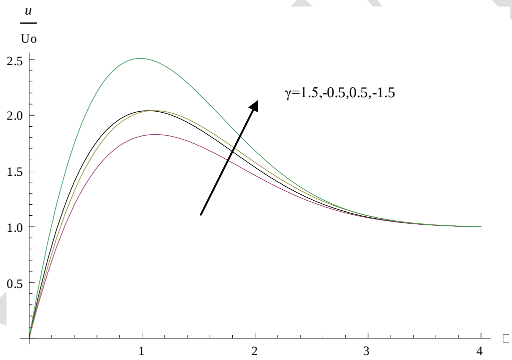

Fig.4a.variation of (u/U_0) with γ
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03, Pr=0.71,R=0.5,α1=0.01;α2=0.01;G=2

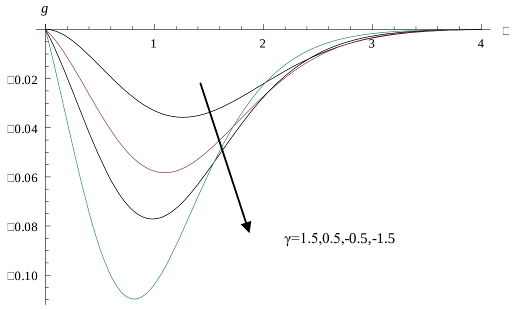

Fig.4b Variation of g with γ
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03, Pr=0.71,R=0.5,α1=0.01;α2=0.01

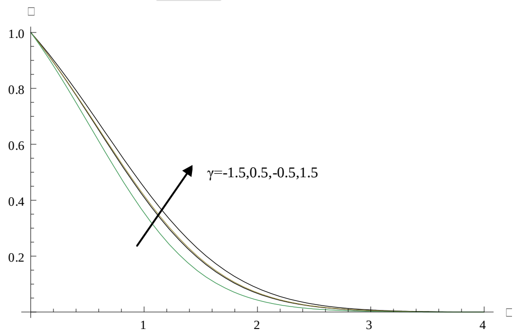

Fig.4c Variation of θ with γ
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03, Pr=0.71,R=0.5,α1=0.01;α2=0.01,G=2

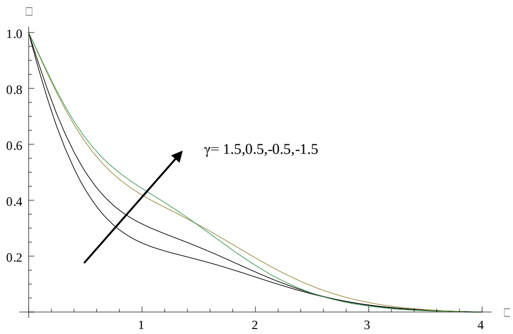

Fig.4d Variation of ϕ with γ
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03, Pr=0.71,R=0.5,α1=0.01;α2=0.01

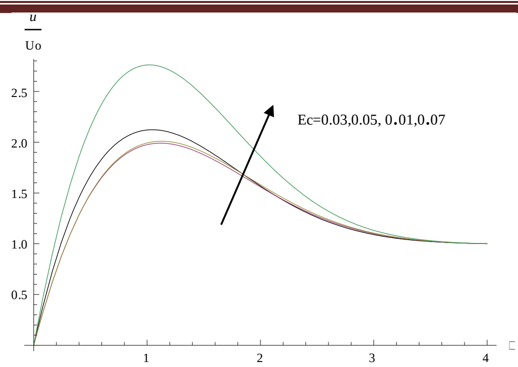

Fig5a.variation of (u/U_0) with Ec
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α1=0.01;α2=0.01;R=0.5,G=2

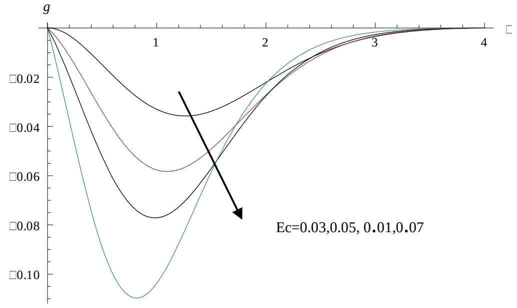

Fig.5b Variation of g with Ec
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α1=0.01;α2=0.01,G=2

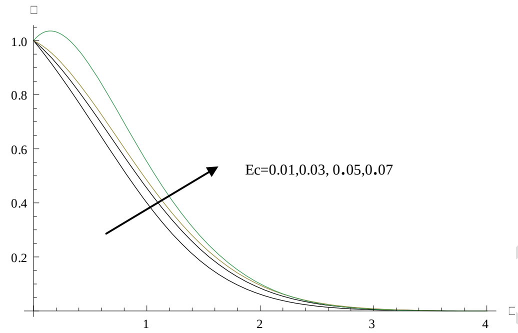

Fig5c Variation of θ with Ec
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α1=0.01;α2=0.01,R=0.5

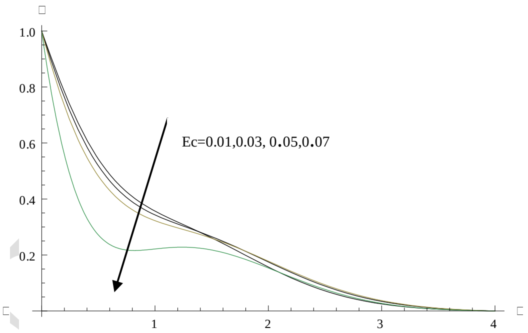

Fig.5d Variation of ϕ with Ec
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,R=0.5;α1=0.01;α2=0.01

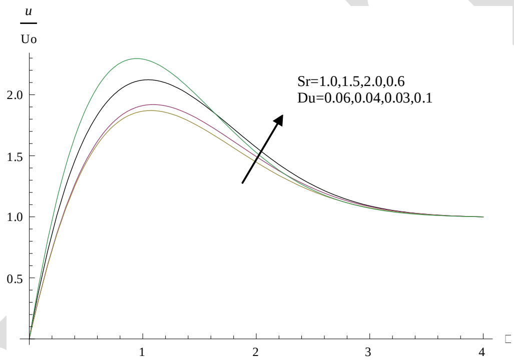

Fig.6a.variation of (u/U0) with Sr&Du
M=0.5,D-1=0.2,N=1,Sc=1.3,R=0.5,G=2
Pr=0.71,γ=0.5,α1=0.01;α2=0.01;Ec=0.01

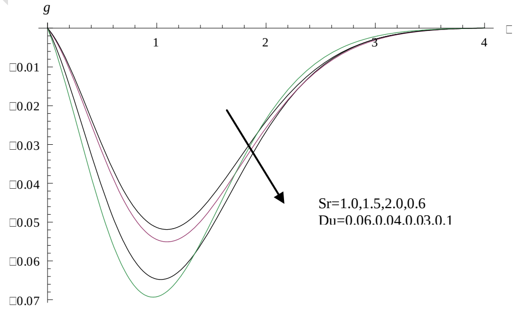

Fig.6b Variation of g with Sr&Du
M=0.5,D-1=0.2,N=1,Sc=1.3,R=0.5,Pr=0.71,
γ=0.5,α1=0.01;α2=0.01,Ec=0.01,G=2

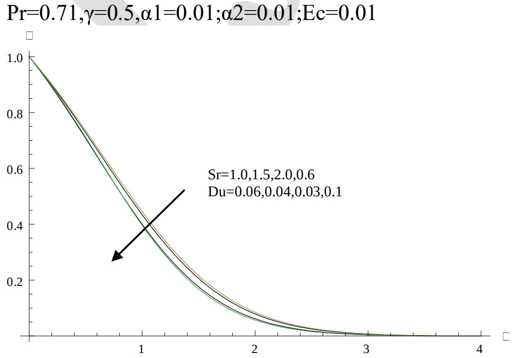

Fig.6c Variation of θ with Sr&Du
M=0.5,D-1=0.2,N=1,Sc=1.3,R=0.5,G=2,Pr=0.71,
γ=0.5,α1=0.01;α2=0.01.G=2,Ec=0.01

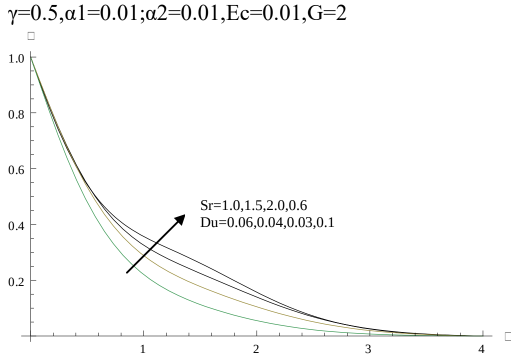

Fig.6d Variation of ϕ with Sr&Du
M=0.5,D-1=0.2,N=1,Sc=1.3,R=0.5,G=2,Pr=0.71,
γ=0.5,α1=0.01;α2=0.01,Ec=0.01

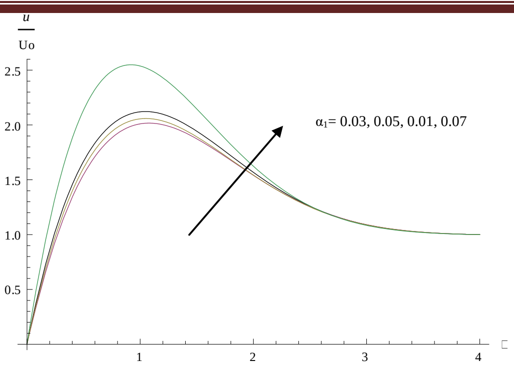

Fig.7a.variation of (u/U0) with α1
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α2=0.01;R=0.5,G=2

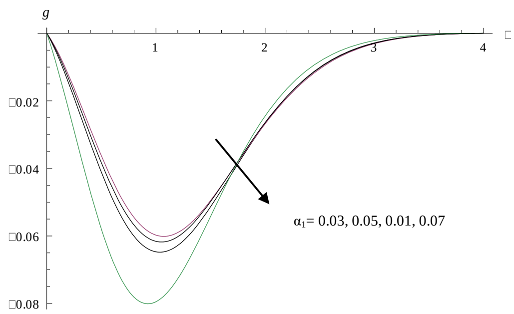

Fig.7b Variation of g with α1
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,;α2=0.01,R=0.5;G=2

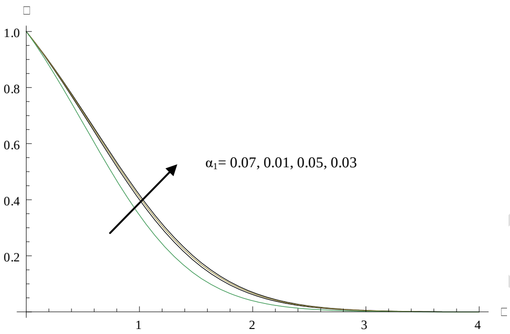

Fig.7c Variation of θ with α1
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α2=0.01=0.5;G=2

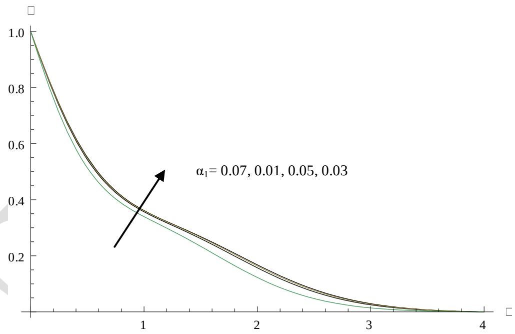

Fig.7d Variation of ϕ with α_1
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α2=0.01,R=0.5,G=2

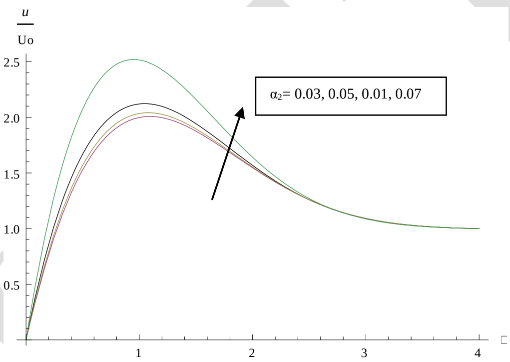

Fig.8a.variation of (u/U0) with α2
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α1=0.01R=0.5,G=2

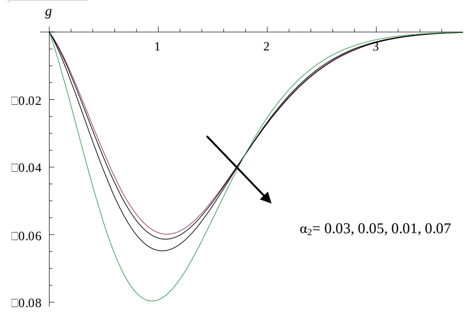

Fig.8b Variation of g with α2
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5, α1=0.01;R=0.5,G=2

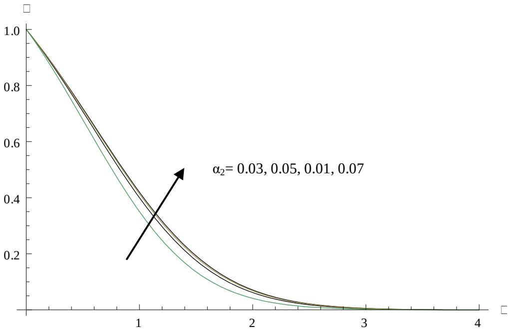

Fig.8c Variation of θ with α2
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α1=0.01;R=0.5,G=2

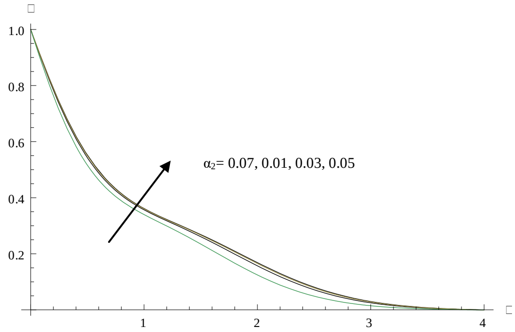

Fig.8d Variation of ϕ with α2
M=0.5,D-1=0.2,N=1,Sc=1.3,So=2,Du=0.03,
Pr=0.71,γ=0.5,α1=0.01;R=0.5,G=2

The important conclusions of this analysis are

1] The velocity components, temperature and concentration reduce with increase in the buoyancy ratio N irrespective of the directions of the buoyancy forces.

2]. Higher the rotation parameter R, smaller the primary velocity, larger the cross velocity, temperature and concentration .The skin friction, Nusselt number and Sherwood number decrease with R

3]. Higher the dissipation larger the velocity components, temperature and smaller the concentration. The skin friction increases, the rate of heat and mass transfer reduces at the wall with Ec.

4]. Higher the radiation absorption Q1,larger the velocity components and smaller the temperature ,concentration. The skin friction and Sherwood number increase and the Nusselt number reduces on the wall with Q1.

5]. An increase in Forchheimer number F enhances the velocity components and reduces the temperature and concentration. The skin friction, the rate of heat and mass transfer increases with F.

6]. Increasing the soret parameter So(or decreasing Dufour parameter Du) reduces the velocity components, temperature and concentration. The skin friction reduces and the rate of heat and mass transfer enhances with increasing So(or decreasing Du).

7]. The velocity components ,temperature and concentration reduces in the degenerating chemical reaction and enhances in the generating case.

8]. Higher the values of non-linear temperature or concentration gradient smaller the primary and cross velocity. The temperature and concentration enhances with smaller values of $\alpha 1$, $\alpha 2$ and increases with higher values of $\alpha 1$, $\alpha 2$.

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