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Combined effect of thermophoresis chemical reaction thermo diffusion and diffusion thermo on the convective heat and mass transfer flow of a viscous electrically conducting fluid through a porous medium bounded by semi infinite vertical plate

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ABSTRACT

In this analysis we investigate the effect of chemical reaction, thermo diffusion and diffusion thermo on the convective heat and mass transfer flow of a viscous electrically conducting fluid through a porous medium bounded by a semi-infinite vertical plate at $\eta = 0$ with thermophoresis. The equations governing the flow heat and mass transfer are solved by employing Galerkine-finite element analysis with three nodded line segments.

Introduction

Radiative convective flows have gained attention of many researchers in recent years. This is justified by the fact that the radiative flows of an electrically conducting fluid with high temperature in the presence of magnetic field plays a vital role in many engineering, industrial and environment processes e.g. heating and cooling chambers, fossil fuel combustion energy processes, evaporation from large open water reservoirs, astrophysical flows, solar power technology and space vehicle re-entry. More applications and a good insight into the subject are given by Rashad [1], Sanyal and Adhikari [2], Muthucumaraswamy and Kulandaivel [3], Prasad and Reddy [4], Singh and Kumar [5] and Raptis and Perdikis [6]. Chamkha [7] considered the problem of steady, hydromagnetic boundary layer flow over an accelerating semi-infinite porous surface in the presence of natural radiation, buoyancy and heat generation or absorption. Analytical model of MHD mixed convective radiating fluid with viscous dissipative heat have been presented by Ahmed and Batin [8]. Soundalgekar [9] investigated oscillatory MHD flow and heat transfer effects on the channel. Ali *et al*. [10] studied the radiation effect on free convectionboundary layer flow over horizontal surfaces, using the Rosseland diffusion approximation. Soundalgekar and Takhar [11] have studied radiation effects on free convection flow of a gas past a semi-infinite flat plate. Theoretical analysis of radiative effects on transient free convection heat transfer past a hot vertical surface in porous media was presented by Ghosh and Beg [12]. Kim and Fedorov [13] studied transient mixed radiative convection flow of a micropolar fluid past a semi-infinite vertical porous plate. Hossain and Rees [14] investigated free convection from isothermal inclined plates to horizontal plates. The interaction of free convection and radiation on boundary layer flows with fluid suction through the porous wall was investigated by Hossain *et al*. [15]. Yih [16] studied the radiation effect on natural convection about a truncated cone. EL-Hakim and Rashad [17] used Rosseland diffusion approximation in studying the effect of radiation on free convection from a vertical cylinder embedded in a fluid-saturated porous medium. Raptis and Massalas [18] analyzed the effects of radiation on the oscillatory flow of a gray gas, absorbing-emitting in the presence of induced magnetic field. Beg and Ghosh [19] investigated an analytical study for MHD flow of radiating fluid with oscillatory surface temperature and secondary flow effects.

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Prasad and Reddy [4] studied radiation and mass transfer effects on an unsteady MHD free convection flow past a semi-infinite plate through porous medium.

If two regions in a mixture are maintained at different temperatures so that there is a flux of heat, it has been found that a concentration gradient is set up. In a binary mixture, one kind of a molecule tends to travel toward the hot region and the other kind toward the cold region. This is called the “Soret effect”. Eckert and Drake [20] have pointed out that in a convective fluid when the flow of mass is caused by a temperature difference one cannot neglect the thermal diffusion effect (commonly known as Soret effect) due to its practical application in engineering and science. Usually this effect has a negligible influence on mass transfer, but it is useful in the separation of certain mixtures. Thermal diffusion effect or Soret effect has been utilized for isotope separation and in mixtures between gases with very light molecular weight and medium molecular weight (air) and it was found to be of a magnitude that it cannot be neglected. More physical insight into the problem is given by Sparrow and Cess [21] and Renuka *et. al.* [22]. Reddy and Reddy [23] investigated Soret and Dufour effects on steady MHD free convective flow past an infinite plate. Soret effects due to natural convection between heated inclined plates have been investigated by Raju *et al.* [24].

Formulation of the problem

We consider a steady, laminar, hydromagnetic combined heat and mass transfer by natural convection flow along a continuously moving semi-infinite permeable flat plate that is inclined with an acute angle α from the vertical. With x-axis measured along the plate, a magnetic field of uniform strength Bo is applied in the y direction which is normal to the flow direction .Fluid suction is imposed at the plate surface. A heat source is placed within the flow to allow for possible heat generation effects. The fluid is assumed to be Newtonian, electrically conducting and heat generating. The temperature of the surface is held uniform at T_w which is higher than the ambient temperature T_∞. The species concentration at the surface is maintained uniform at C_w, which is taken to be zero and that of the ambient fluid is assumed to be C_∞. The effects of thermophotesis are being taken into account to help in the understanding of the mass deposition variation on the surface. We further assume that

(i) The mass flux of particles is sufficiently small so that the main stream velocity and temperature fields are not affected by the thermophysical processes experienced by the relatively small number of particles,

(ii) Due to the boundary layer behavior the temperature gradient in the *y* direction is much larger than that in the *x* direction and hence only the thermophoretic velocity component which is normal to the surface is of importance,

(iii) The fluid has constant kinematic viscosity and thermal diffusivity, and that the Boussinesq approximation may be adopted for steady laminar flow,

(iv)The particle diffusivity is assumed to be constant, and the concentration of particles is sufficiently dilute to assume that particle coagulation in the boundary layer in negligible and

(v) The magnetic Reynolds number is assumed to be small so that the induced magnetic field is negligible in comparison to the applied magnetic field.

Under the above assumptions, the governing equations(see Selim et al. [25] and Chen [26]) for this problem can be written as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad \text{(Equation of Continuity)} \qquad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)\cos\alpha-g\beta^{\bullet}(C-C_\infty)\cos\alpha-\frac{\sigma B_0^2}{\rho}u-(\frac{\mu}{k})u$$

$$\text{(Equation of Momentum)} \qquad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{\lambda_g}{\rho c_p}\frac{\partial^2 T}{\partial y^2}+K_{12}\frac{\partial^2 C}{\partial y^2}-\frac{\partial(q_R)}{\partial y} \qquad \text{(Equation of Energy)} \qquad (3)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-\frac{\partial}{\partial y}(V_T C)+k_{11}\frac{\partial^2 T}{\partial y^2}-k_1' C \qquad \text{(Equation of Diffusion)} \qquad (4)$$

where *u*, *v* are the velocity components in the *x* and *y* directions respectively, ν is the kinematic viscosity, *g* is the acceleration due to gravity, ρ is the density of the fluid, β is the volumetric coefficient of thermal expansion, T, T_w and 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 and C_∞ are the corresponding concentrations, σ is the electrical conductivity, B_0 is the magnetic induction, λ_g is the thermal conductivity of fluid c_p is the specific heat at constant pressure, *D* is the molecular diffusivity of the species concentration,k_{11},k_{12} are cross diffusivities and V_T is the thermophoretic velocity.

The appropriate boundary conditions for the above model are as follows:

$u = U_0$, $v = \pm v_w(x)$, $T = T_w$, $C = C_w = 0$ at $y = 0$ (5a)

$u = 0$, $T = T_\infty$, $C = C_\infty$ as $y \to \infty$ (5b) where U_0 is the uniform plate velocity and $v_w(x)$ represents the permeability of the porous surface where its sign indicates suction (<0) or blowing (>0). Here we confine our attention to the suction of the fluid through the porous surface and for these we also consider that the transpiration function variable $v_w(x)$ is of the order of $x^{-1/2}$.

By using Rosseland approximation, the raddiative heat flux is given by

$$q_r = -\frac{4\sigma^\bullet}{3\beta_R}\frac{\partial T'^4}{\partial y} \tag{6a}$$

and by Taylor's expansion we get

$$T'^4 \cong 4T_e^3 T - 3T_e^4 \text{ after neglecting higher order terms.} \tag{6b}$$

$\sigma^\bullet$ is the Stefan-Boltzman constant and β_R is the mean absorption coefficient.

The effect of thermophoresis is usually prescribed by means of an average velocity that a particle will acquire when exposed to a temperature gradient. For boundary layer analysis it is found that the temperature gradient along the plate is much lower than the temperature gradient normal to the surface, i.e., $\frac{\partial T}{\partial y} >> \frac{\partial T}{\partial x}$. So the component of thermophoretic velocity along the plate is negligible compared to the component of its normal to the surface. As a result, the thermophoretic velocity V_T, which appears in equation (4), can be written as:

$$V_T = -kv\frac{\nabla T}{T_{ref}} = -\frac{kv}{T_{ref}}\frac{\partial T}{\partial y} \tag{7}$$

where k is the thermophoretic coefficient which ranges in value from 0.2 to 1.2 as indicated by Batchelor and Shen[27] and is defined from the theory of Talbot et al.[28] by:

$$k = \frac{2C_s(\lambda_g/\lambda_p + C_t Kn)[1 + Kn(C_1 + C_2 e^{-c_3/Kn})]}{(1+3C_m Kn)(1+2\lambda_g/\lambda_p + 2C_t Kn)} \tag{8}$$

where C_1, C_2, C_i, C_m, C_s, C_t are constants λ_g and λ_p are the thermal conductivities of the fluid and diffused particles, respectively and Kn is the Knudsen number.

At thermophoretic parameter τ can be defined (see Mills et al. [29] and Tsai [30]) as follows:

$$\tau = -\frac{k(T_w - T_\infty)}{T_{ref}} \tag{9}$$

Typical values of τ are 0.01, 0.1 and 1.0 corresponding to approximate values of $-k(T_w - T_\infty)$ equal to 3.30 and 300 K for a reference temperature of $T_{ref} = 300$ K.

In order to obtain similarity solution of the problem we introduce the following non - dimensional variables:

$$\eta = y\sqrt{\frac{U_0}{2\nu x}}, \psi = \sqrt{2\nu x U_0}\, f(\eta)\ \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \phi(\eta) = \frac{C}{C_\infty} \tag{9a}$$

Where ψ is the stream function that satisfies the continuity equation (1).Since $\frac{\partial \psi}{\partial y}$ and $v = \frac{\partial \psi}{\partial x}$ we have from equation (9a)

$$u = U_0 f' \quad and \quad v = \sqrt{\frac{\nu U_0}{2x}}(f - \eta f') \tag{9b}$$

Here prime denotes ordinary differentiation with respect to η.

Now substituting equation (9) in equations (2) – (4) we obtain the following ordinary differential equations which are locally similar:

$$f''' + ff'' + Gr(\theta + N\phi)\cos\alpha - \alpha_1\theta - (M^2 + D^{-1})f' = 0, \tag{10}$$

$$\theta''(1 + 4/3N_1) + Pr\, f\,\theta' = 0 \tag{11}$$

$$\phi'' + Sc(f - \tau\theta')\phi' - Sc\tau\phi\theta'' = -ScSo\ \theta'' - \gamma\theta \tag{12}$$

The boundary conditions (5) then turn into

$$f = f_w, \quad f' = 1, \quad \theta = 1, \phi = 0 \quad \text{at} \quad \eta = 0 \tag{13a}$$

$$f' = 1, \quad \theta = 0, \phi = 1 \quad \text{at} \quad \eta \to \infty \tag{13b}$$

where $f_w = -v_w(x)\sqrt{\frac{2x}{\nu U_0}}$ is the dimensionless wall mass transfer coefficient such that $f_w>0$ indicates wall suction and $fw<0$ indicates wall injection.

The dimensionless parameters introduced in the above equations are defined as follows:

$M = \frac{\sigma \beta_0^2 x}{pU_0}$ (Local magnetic field parameter) $Gr = \frac{g\beta(T_w - T_\infty)2x}{U_0^2}$ (Local Grashof number)

$D^{-1} = \frac{\nu x}{kU_\infty}$ (Darcy parameter) $N = \frac{\beta^{\bullet}\Delta C}{\beta \Delta T}$ (Buoyancy ratio)

$N_1 = \frac{\beta_R \lambda_g}{4\sigma^{\bullet} T_\infty^3}$ (Radiation parameter) $\Pr = \frac{\nu\rho c_p}{\lambda_g}$ (Prandtl number)

$Sc = \frac{\nu}{D_1}$ (Schmidt number) $\tau = \frac{k(T_w - T_\infty)}{T_{ref}}$ (Thermophoretic parameter).

$So = \frac{k_{11} C_\infty}{\lambda_g (T_w - T_\infty)}$ (Soret parameter) $\alpha = \frac{\mu C_p Q x}{U_\infty}$ (Inclination parameter)

$\gamma = k_1'$ (Chemical reaction parameter) $\lambda = f_w$ (Suction parameter)

The skin-friction coefficient (τ_w), wall heat transfer coefficient (or local Nusselt number (Nu)) and wall deposition flux (or the local Stanton number (Sh)) are important physical parameters. These can be obtained from the following expressions:

$$Cf_x \operatorname{Re} x^{\frac{1}{2}} = \frac{\tau_w}{pU_0^2} = f''(0), \tau_w = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{14}$$

$$Nu_x \operatorname{Re} x^{\frac{1}{2}} = \frac{xq_w}{(T_w - T_\infty)\lambda_g} = \frac{1}{2}\theta'(0), q_w = -\lambda_g\left(\frac{\partial T}{\partial y}\right)_{y=0} \tag{15}$$

$$St_x Sc \operatorname{Re} x^{\frac{1}{2}} = \frac{J_s}{U_0 C_\infty} = \theta'(0),\ J_s = -D\left(\frac{\partial C}{\partial y}\right)_{y=0} \tag{16}$$

where $\operatorname{Re} = \frac{U_0 2x}{\nu}$ is the local Reynolds number.

Results and discussion of the numerical results

In this analysis we investigate the effect of chemical reaction, thermo diffusion and diffusion thermo on the convective heat and mass transfer flow of a viscous electrically conducting fluid through a porous medium bounded by a semi-infinite vertical plate at $\eta = 0$ with variable electrically conductivity. The equations governing the flow heat and mass transfer are solved by employing Galerkin-finite element analysis with three nodded line segments

The axial velocity f' is shown in figs.1-4 for different values of G, M, D^{-1}, N, N_1, Sc, So, τ, α , λ and γ . Fig. 1-4 represents the variation of f' with M shows that higher the Lorentz force larger $|f'|$ and for further higher Lorentz forces smaller $|f'|$ Also lesser the permeability of the porous medium larger $|f'|$ in the entire flow region. The variation of f' with buoyancy ratio N shows that when the molecular buoyancy force dominates over the thermal buoyancy force $|f'|$ enhances in the flow region when buoyancy forces are in the same direction and for the forces acting in opposite direction $|f'|$ depreciates in the flow region. Higher the radiative heat flux larger $|f'|$ in the flow region (fig.1). With respect to Sc we find that lesser the molecular diffusivity smaller $|f'|$ in the flow region. Also $|f'|$ depreciates with increase in $So > 0$ and enhances with $So < 0$ (fig.2). With respect to chemical reaction parameter γ we find that $|f'|$ reduces in the degenerating chemical reaction case and in generating chemical reaction case $|f'|$ reduces with increase in $|\gamma| \le 1.5$ and enhances with $|\gamma| \ge 2.5$ (fig.3). The effect of thermophoretic parameter τ on f′ is shown in fig. 4. It is found that the axial velocity f′ depreciates in the flow region (0 ≤ η ≤ 5) and enhances for away from the boundary with τ ≤ 0.05 and for higher τ ≥ 0.07, we notice depreciation in the region (0 ≤ η ≤ 5) and enhances in the remaining flow region.

The transverse velocity (f) is shown in figs.5-8 for different parameter values. From fig.5 we find higher the Lorentz force larger $|f|$. When the molecular buoyancy force dominates over the thermal buoyancy force $|f|$ enhances when buoyancy forces are in the same direction and for the forces acting in opposite directions $|f|$ depreciates in the flow region.

With respect to N_1 shows that the transverse velocity depreciates with $N_1 \leq 4$ and enhances with higher $N_1 \geq 6$. Fig.6 represents the transverse velocity with Sc and So. The transverse velocity depreciates with Sc. Also $|f|$ enhances with $So > 0$ and depreciates with $|So|$. The variation of f with the Darcy parameter D^{-1} shows that lesser the permeability of porous medium larger $|f|$ in the flow then $|f|$ reduces in the degenerating case and in the generating case $|f|$ reduces with $|\gamma| \leq 1.5$ and enhances with $|\gamma| \geq 2.5$ (fig.7). Also f experiences depreciation with increase in the thermophoretic parameter τ (fig.8).

The non-dimensional temperature θ is shown in figs.9-12 for different parametric values. We follow the convention that the non-dimensional temperature is positive or negative according as the actual temperature is greater/lesser than T_∞. The variation of θ with Hartman number M, buoyancy ratio N is shown in fig.9. It is found that higher the Lorentz force larger the actual temperature and for further higher Lorentz force smaller the actual temperature. When the molecular buoyancy force dominates over the thermal buoyancy force the actual temperature experiences an enhancement irrespective of the directions of the buoyancy forces. Also an increase in the thermal radiation parameter N_1, leads to a depreciation in the actual temperature with respect to Sc . We find that lesser the molecular diffusivity smaller the actual temperature. The actual temperature depreciates with increase in $So > 0$ and enhances with $|So|$ (<0) (fig.10). From fig.11 we find that lesser the permeability of the porous medium smaller the actual temperature and for further lowering of the permeability larger the actual temperature. The variation of θ with chemical reaction parameter γ shows that the actual temperature enhances in the degenerating chemical reaction case and reduces in the generating chemical case (fig.11). An increase n the thermophoretic parametric τ leads to a depreciation in the actual temperature (fig.12).

The non-dimensional concentration (C) is shown in fig.13-16 for different parametric variations. We follow the convention the non- dimensional is positive or negative according as the actual concentration is greater/lesser than C_∞ . For different variations of the parameters the actual concentration is lesser than C_∞ . From fig.13 we find that higher the Lorentz force larger the actual temperature and for further higher Lorentz force lager the actual concentration. When the molecular buoyancy force dominates over the thermal buoyancy force the actual concentration enhances when buoyancy forces are in the same direction and for the forces acting in opposite directions the actual concentration depreciates in the flow region. An increase in the thermal radiation parameter N_1 results in a depreciation in the actual concentration. The variation of C with Sc shows that lesser the molecular diffusivity smaller the larger the actual concentration. The actual concentration enhances $So > 0$ and reduces with $So < 0$ (fig.14). From fig.15 we find that lesser the permeability of porous medium smaller the actual concentration and for further lowering of the permeability we notice an enhancement in the concentration. The variation of C with chemical reaction parameter γ the actual concentration enhances in the degenerating chemical reaction case while in the generating chemical reaction case it enhances with $|\gamma| \leq 1.5$ and reduces with higher $|\gamma| \geq 2.5$. The variation of C with thermophoretic parameter shows that the actual concentration reduces everywhere in the region except in $0 < \eta < 1$ where it enhances (fig.16).

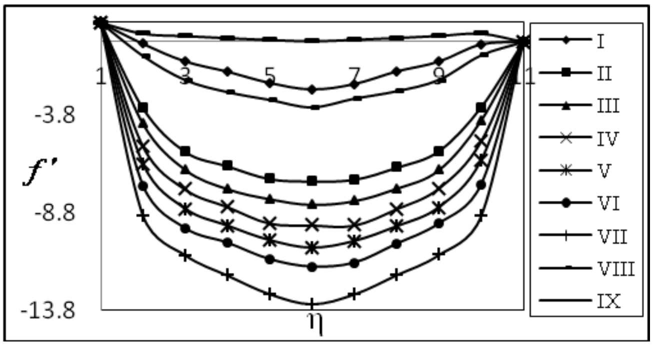

Fig.1. Variation of f^{1} with M, N_1 and N

	I	II	III	IV	V	VI	VII	VIII	IX
M	0.5	2.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5
N_1	2	2	2	4	6	10	2	2	2
N	1	1	1	1	1	1	2	-0.5	-1

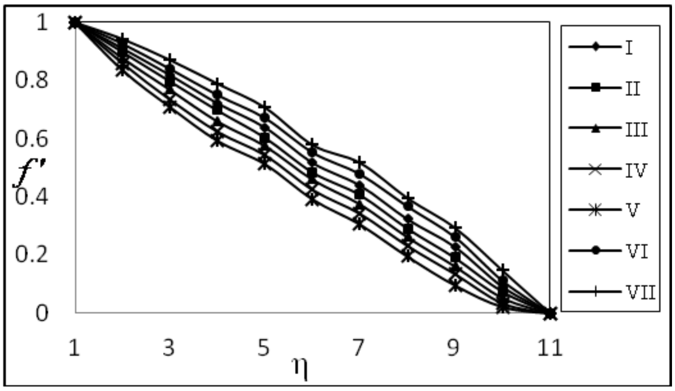

Fig.2. Variation of f^{1} with Sc and So

	I	II	III	IV	V	VI	VII
Sc	0.24	0.6	1.3	2.01	0.24	0.24	0.24
So	0.5	0.5	0.5	0.5	1	-0.5	-1

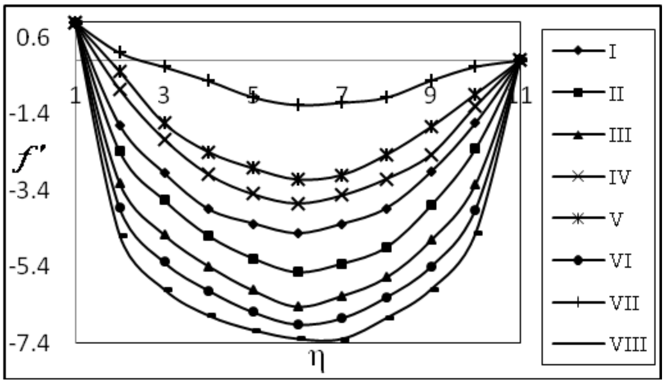

Fig.3. Variation of f^{1} with D^{-1} and γ

	I	II	III	IV	V	VI	VII	VIII
D^{-1}	10^2	$3x10^2$	$5x10^2$	10^2	10^2	10^2	10^2	10^2
γ	0.5	0.5	0.5	1.5	2.5	-0.5	-1.5	-2.5

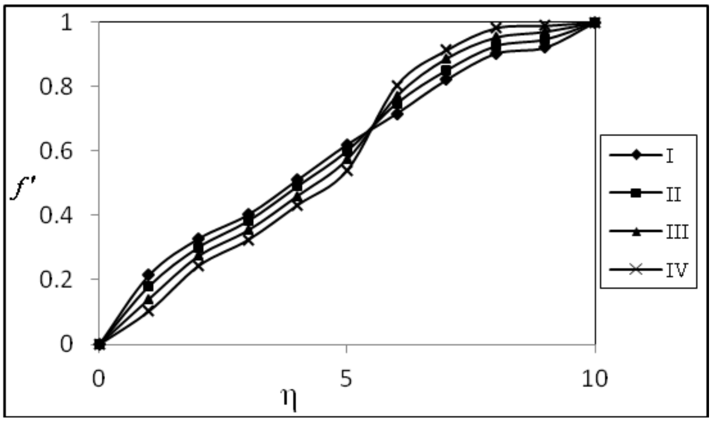

Fig.4.Variation of f' with τ

	I	II	III	IV
τ	0.01	0.03	0.05	0.07

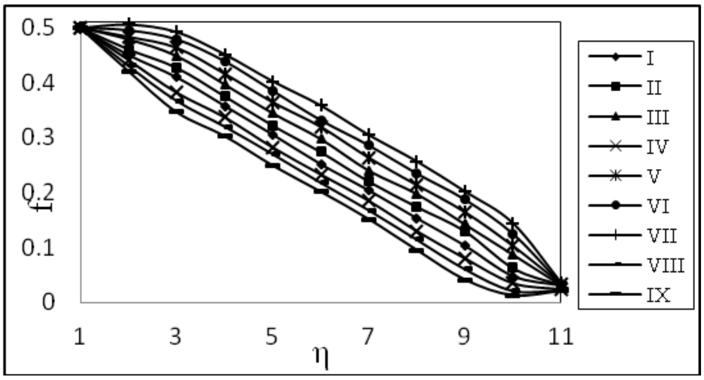

Fig.5. Variation of f with M, N_1 and N

	I	II	III	IV	V	VI	VII	VIII	IX
M	0.5	2.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5
N_1	2	2	2	4	6	10	2	2	2
N	1	1	1	1	1	1	2	-0.5	-1

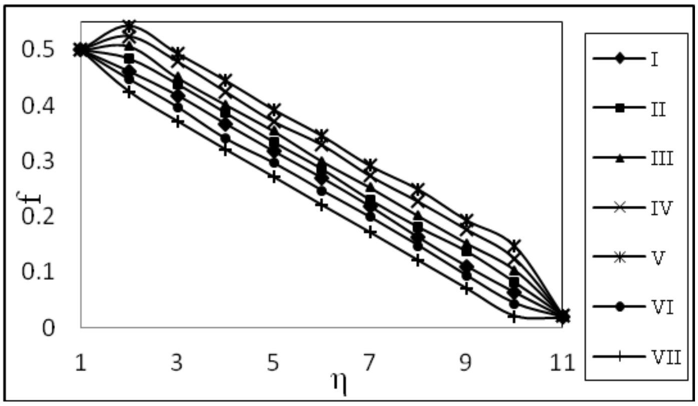

Fig.6. Variation of f with Sc and So

	I	II	III	IV	V	VI	VII
Sc	0.24	0.6	1.3	2.01	0.24	0.24	0.24
So	0.5	0.5	0.5	0.5	1	-0.5	-1

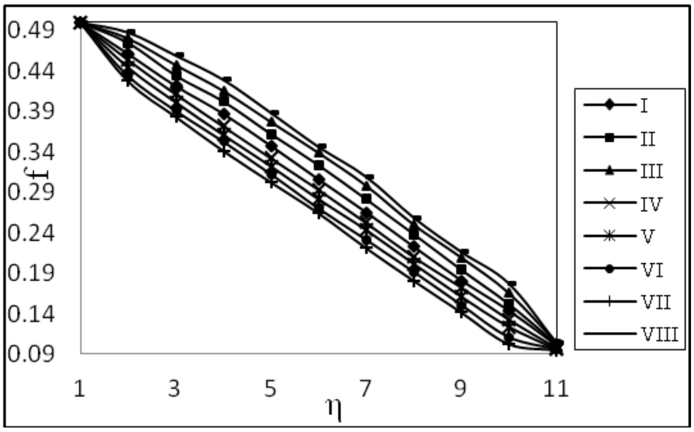

Fig.7. Variation of f with D^{-1} and γ

	I	II	III	IV	V	VI	VII	VIII
D^{-1}	10^2	$3x10^2$	$5x10^2$	10^2	10^2	10^2	10^2	10^2
γ	0.5	0.5	0.5	1.5	2.5	-0.5	-1.5	-2.5

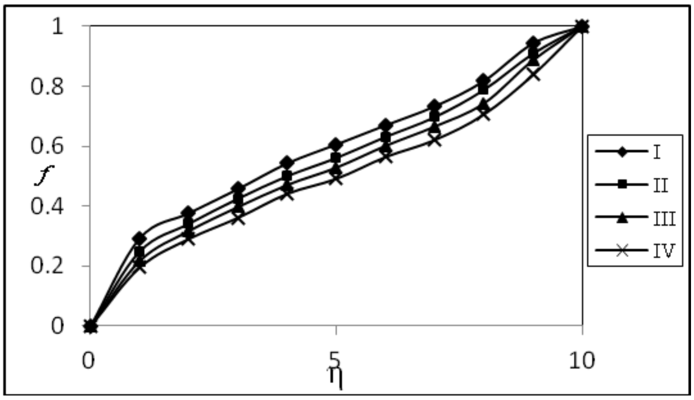

Fig.8.Variation of f with τ

	I	II	III	IV
τ	0.01	0.03	0.05	0.07

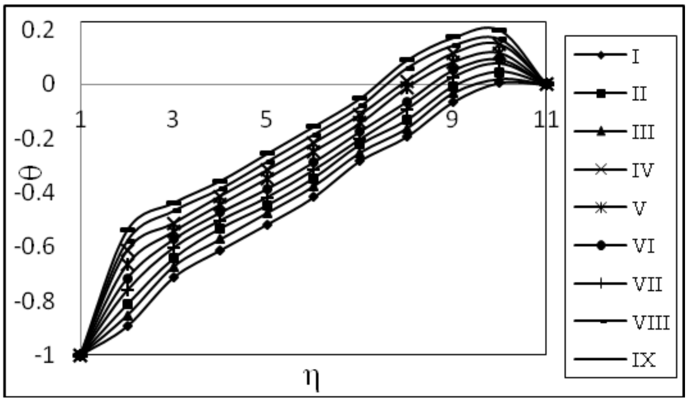

Fig.9. Variation of θ with M, N_1 and N

	I	II	III	IV	V	VI	VII	VIII	IX
M	0.5	2.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5
N_1	2	2	2	4	6	10	2	2	2
N	1	1	1	1	1	1	2	-0.5	-1

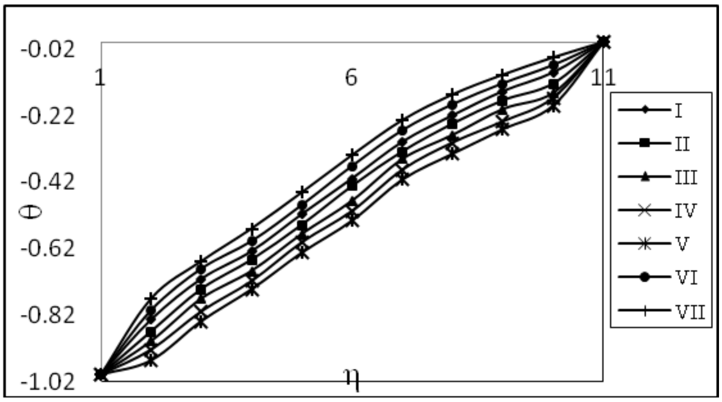

Fig.10. Variation of θ with Sc and So

	I	II	III	IV	V	VI	VII
Sc	0.24	0.6	1.3	2.01	0.24	0.24	0.24
So	0.5	0.5	0.5	0.5	1	-0.5	-1

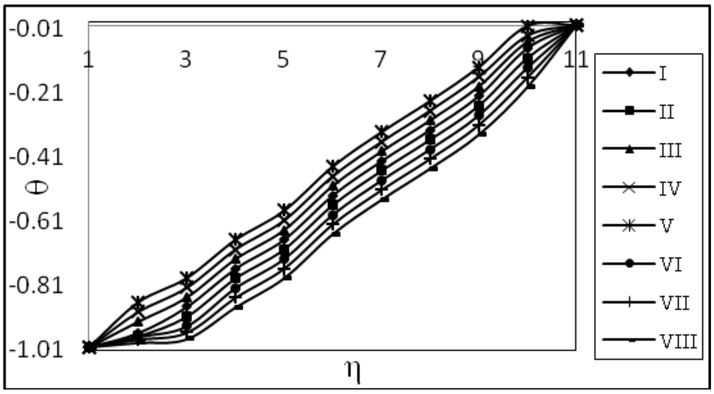

Fig.11. Variation of θ with D^{-1} and γ

	I	II	III	IV	V	VI	VII	VIII
D^{-1}	10^2	$3x10^2$	$5x10^2$	10^2	10^2	10^2	10^2	10^2
γ	0.5	0.5	0.5	1.5	2.5	-0.5	-1.5	-2.5

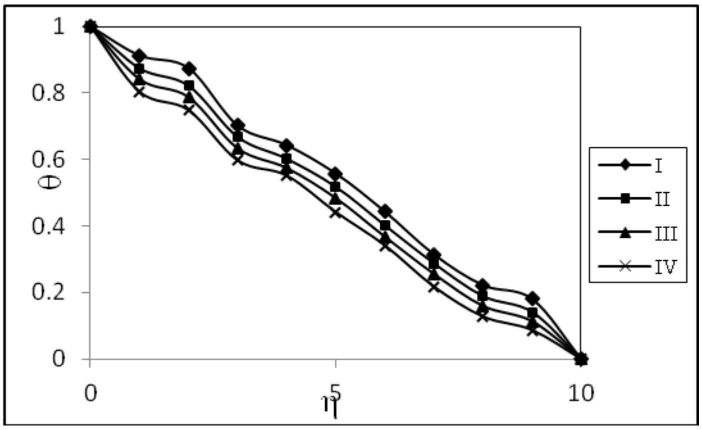

Fig.12.Variation of θ with τ

	I	II	III	IV
τ	0.01	0.03	0.05	0.07

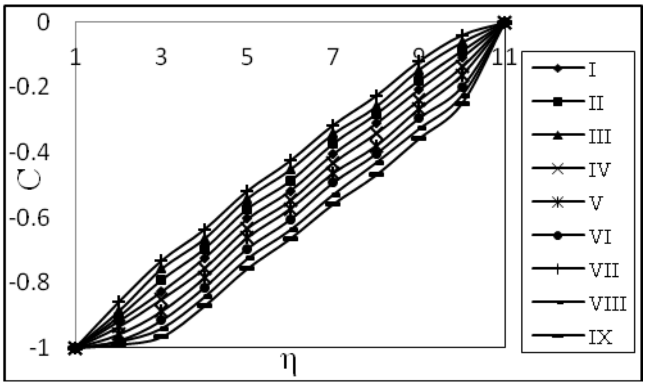

Fig.13. Variation of C with M, N_1 and N

	I	II	III	IV	V	VI	VII	VII	IX
M	0.5	2.5	4.5	0.5	0.5	0.5	0.5	0.5	0.5
N_1	2	2	2	4	6	10	2	2	2
N	1	1	1	1	1	1	2	-0.5	-1

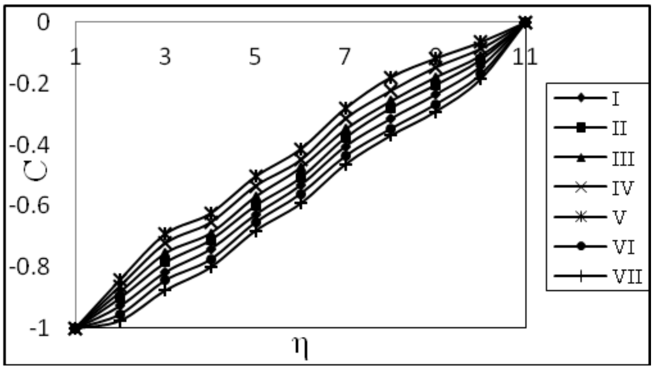

Fig.14. Variation of C with Sc and So

	I	II	III	IV	V	VI	VII
Sc	0.24	0.6	1.3	2.01	0.24	0.24	0.24
So	0.5	0.5	0.5	0.5	1	-0.5	-1

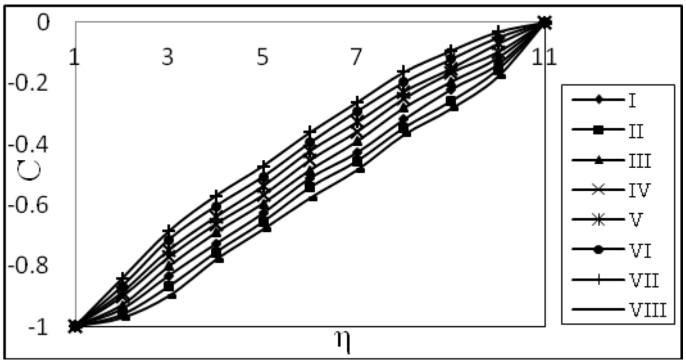

Fig.15. Variation of C with D^{-1} and γ

	I	II	III	IV	V	VI	VII	VIII
D^{-1}	10^2	$3x10^2$	$5x10^2$	10^2	10^2	10^2	10^2	10^2
γ	0.5	0.5	0.5	1.5	2.5	-0.5	-1.5	-2.5

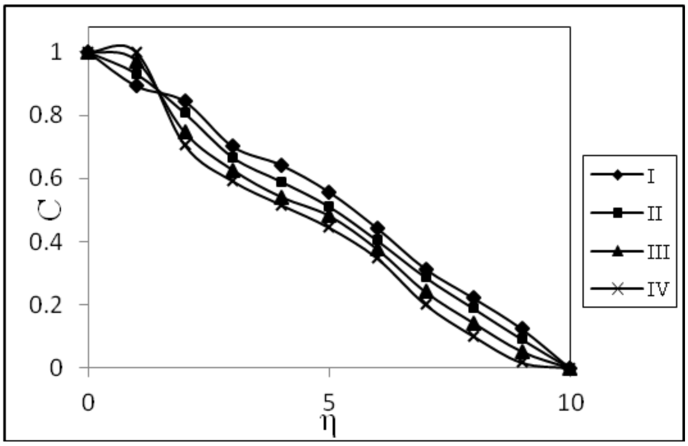

Fig.16.Variation of C with τ

	I	II	III	IV
τ	0.01	0.03	0.05	0.07

The skin-friction coefficient (τ_w)on the wall $\eta = 0$ is shown in tables.1-2 for different values of G, M, D^{-1}, N, N_1, τ, Sc, So, α, λ and γ.It is found that the skin-friction coefficient τ_w with Soret parameter So shows that $|\tau_w|$ enhances with increase in $So > 0$ and depreciates with $|So|$. The variation of τ_w with thermophoretic parameter τ shows that the stress enhances in the heating case and reduces in the cooling case with increase in τ(table-1).The variation of τ_w with chemical reaction parameter γ shows that $|\tau_w|$ depreciates in the degenerating chemical reaction case while in the generating case $|\tau_w|$ enhances with $|\gamma| \le 1.5$ and depreciates with $|\gamma| \ge 2.5$ .Higher the radiative heat flux smaller $|\tau_w|$ at η=0 (table-2)

The rate of heat transfer (Nu) at $\eta = 0$ is shown in tables.3-4 for different parametric values. The variation of Nu with Soret parameter So shows that the rate of heat transfer enhances in the heat case and depreciates in cooling case with increase in $So > 0$ and a reversed effect is observed in the behaviour of $|Nu|$ with $|So|$. |Nu| depreciates in the heating case and enhances in the cooling case with increase in the thermophoretic parameter τ at η = 0 (table-3).With respect to chemical reaction parameter γ we find that the rate of heat transfer reduces for $G > 0$ and enhances for $G < 0$ in the degenerating chemical reaction case while in the generating case it enhances for $G > 0$ and depreciates $G < 0$ with $|\gamma| \le 1.5$ and for higher $|\gamma| \ge 2.5$ a reversed effect is noticed in the behaviour of $|Nu|$. Lesser the molecular diffusivity larger $|Nu|$ in the heating case and smaller $|Nu|$ in the cooling case (table-4).

The rate of mass transfer (Sh) at $\eta = 0$ is shown in tables.5-6 for different parametric values. It is found that the rate of mass transfer enhances with increase in $|G|$. The variation of Sh with Soret parameter So shows that the rate of mass transfer with increase in $|So|$. Also |Sh| enhances with increase in the thermophoretic parameter τ(table-5). The rate of mass transfer depreciates for $G > 0$ and enhances for $G < 0$ in both degenerating and generating chemical reaction cases. The variation of Sh with radiation parameter N_1 shows that higher the radiative heat flux ($N_1 \le 4$) larger $|Sh|$ in the heating case and smaller in the cooling case and for further higher radiative heat flux $|Sh|$ depreciates for $G > 0$ and enhances for $G < 0$ (table-6).

Table 1.
Skin-friction (τ_w) at η = 0

G	I	II	III	IV	V	VI	VII
10^3	1.0403	1.9412	1.2385	1.375	1.0951	1.1580	1.1730
$3x10^3$	-5.8201	-6.11273	-5.2256	-4.9284	-4.6586	-3.2749	-2.2755
-10^3	7.9001	7.9997	7.7025	7.6034	4.3515	3.8412	3.1296
$-3x10^3$	14.7610	15.0582	14.1665	13.8693	5.6980	4.1244	3.8321
So	0.5	1	-0.5	-1	0.5	0.5	0.5
τ	0.01	0.01	0.01	0.01	0.03	0.05	0.07

Table 2.
Skin-friction (τ_w) at $\eta = 0$

G	I	II	III	IV	V	VI	VII	VIII
10^3	0.8403	0.6296	0.6194	0.9807	-1.3513	1.2626	0.7255	0.6705
3x10^3	-5.8201	-4.0521	-3.7827	-5.9988	-9.9950	-2.1533	-6.2173	-7.5674
-10^3	7.9001	7.8513	7.8015	7.9603	9.2923	6.6784	6.3664	5.3265
-3x10^3	14.7610	12.9930	12.7237	14.9398	18.9360	11.0943	3.1583	2.4705
γ	0.5	1.5	2.5	-0.5	-1.5	-2.5	0.5	0.5
N_1	2	2	2	2	2	2	4	6

Table 3.
Nusselt Number (Nu) at $\eta = 0$

G	I	II	III	IV	V	VI	VII
10^3	-6.3090	-6.3433	-6.2317	-6.1875	-7.0889	-7.4662	-7.6177
3x10^3	-5.7429	-5.9132	-5.1086	-6.0868	-6.0647	-6.1930	-6.3062
-10^3	-6.5478	-6.5380	-6.5681	-6.5785	-6.4763	-6.2527	-6.1070
-3x10^3	-6.1953	-6.1823	-6.2219	-6.2356	-6.1492	-6.1010	-6.0968
So	0.5	1	-0.5	-1	0.5	0.5	0.5
τ	0.01	0.01	0.01	0.01	0.03	0.05	0.07

Table 4.
Nusselt Number (Nu) at $\eta = 0$

G	I	II	III	IV	V	VI	VII	VIII
10^3	-6.4090	-6.0944	-6.0578	-6.2329	-6.3251	-5.0377	-6.6243	-7.1785
3x10^3	-5.7429	-5.3671	-5.2672	-6.4201	-6.8053	-6.6994	-6.6742	-7.4654
-10^3	-6.5478	-6.6275	-6.6392	-6.5969	-6.5332	-6.6438	-6.4709	-6.3785
-3x10^3	-6.1953	-6.2947	-6.3082	-6.2283	-6.1042	-6.3599	-6.0762	-6.0325
γ	0.5	1.5	2.5	-0.5	-1.5	-2.5	0.5	0.5
N_1	2	2	2	2	2	2	4	6

Table 5.
Sherwood Number (Sh) at $\eta= 0$

G	I	II	III	IV	V	VI	VII
10^3	-7.9666	-7.8044	-8.2746	-8.4209	-6.7490	-6.6968	-6.5194
3x10^3	-11.8462	-11.7977	-11.8652	-11.9745	-8.5615	-8.5068	-8.4289
-10^3	-9.9192	-9.9759	-9.8131	-9.7635	-9.8702	-9.8040	-9.7730
-3x10^3	-10.5187	-10.5916	-10.3827	-10.3192	-10.4762	-10.4178	-10.3757
So	0.5	1	-0.5	-1	0.5	0.5	0.5
τ	0.01	0.01	0.01	0.01	0.03	0.05	0.07

Table 6.
Sherwood Number (Sh) at $\eta= 0$

G	I	II	III	IV	V	VI	VII	VIII
10^3	-7.9696	-6.8389	-5.8373	-8.5308	-8.3756	-8.4184	-8.1372	-8.0890
3x10^3	-11.8462	-11.6630	-10.7005	-11.4392	-11. 1575	-11.9115	-11.0557	-10.9823
-10^3	-9.9192	-9.9331	-9.9748	-9.4295	-11.4139	-9.8934	-9.9262	-9.9890
-3x10^3	-10.5187	-10.5338	-10.5535	-9.4697	-11.5895	-10.4246	-10.6449	-10.8990
γ	0.5	1.5	2.5	-0.5	-1.5	-2.5	0.5	0.5
N_1	2	2	2	2	2	2	4	6

Conclusions:

An attempt has been made to investigate the effect of chemical reaction, thermo-diffusion and diffusion thermo on the convective heat and mass transfer flow of a viscous electrically conducting fluid through a porous medium bounded by a semi-infinite vertical plate with thermophoresis. Using Galerkine finite element analysis with three nodded line segments the governing equations have been solved and flow characteristics are discussed for different variations.

(i). Lesser the permeability of the porous medium larger $\left|f'\right|$ in the entire flow region. The variation of f' with buoyancy ratio N shows that when the molecular buoyancy force dominates over the thermal buoyancy force $\left|f'\right|$ enhances in the flow region when buoyancy forces are in the same direction and for the forces acting in opposite direction $\left|f'\right|$ depreciates in the flow region. Higher the radiative heat flux larger $\left|f'\right|$ in the flow region. $\left|f'\right|$ depreciates with increase in $So > 0$ and enhances with $So < 0$. With respect to chemical reaction parameter γ we find that $\left|f'\right|$ reduces in the degenerating chemical reaction case and in generating chemical reaction case $\left|f'\right|$ reduces with increase in $|\gamma| \le 1.5$ and enhances with $|\gamma| \ge 2.5$. The effect of thermophoretic parameter τ on f'.It is found that the axial velocity f′ depreciates in the flow region (0 ≤ η ≤ 5) and enhances for away from the boundary with τ ≤ 0.05 and for higher τ ≥ 0.07, we notice depreciation in the region (0 ≤ η ≤ 5) and enhances in the remaining flow region.

(ii). When the molecular buoyancy force dominates over the thermal buoyancy force $\left|f\right|$ enhances when buoyancy forces are in the same direction and for the forces acting in opposite directions $\left|f\right|$ depreciates in the flow region. With respect to N_1 shows that the transverse velocity depreciates with $N_1 \le 4$ and enhances with higher $N_1 \ge 6$. Also $\left|f\right|$ enhances with $So > 0$ and depreciates with $|So|$. $\left|f\right|$ reduces in the degenerating case and in the generating case $\left|f\right|$ reduces with $|\gamma| \le 1.5$ and enhances with $|\gamma| \ge 2.5$. Also f experiences depreciation with increase in the thermophoretic parameter τ .

(iii). When the molecular buoyancy force dominates over the thermal buoyancy force the actual temperature experiences an enhancement irrespective of the directions of the buoyancy forces. Also an increase in the thermal radiation parameter N_1, leads to a depreciation in the actual temperature. The actual temperature depreciates with increase in $So > 0$ and enhances with $|So|$ (<0). We find that lesser the permeability of the porous medium smaller the actual temperature and for further lowering of the permeability larger the actual temperature. The variation of θ with chemical reaction parameter γ shows that the actual temperature enhances in the degenerating chemical reaction case and reduces in the generating chemical case. An increase n the thermophoretic parametric τ leads to a depreciation in the actual temperature.

(iv). When the molecular buoyancy force dominates over the thermal buoyancy force the actual concentration enhances when buoyancy forces are in the same direction and for the forces acting in opposite directions the actual concentration depreciates in the flow region. An increase in the thermal radiation parameter N_1 results in a depreciation in the actual concentration. The actual concentration enhances $So > 0$ and reduces with $So < 0$. We find that lesser the permeability of porous medium smaller the actual concentration and for further lowering of the permeability we notice an enhancement in the concentration. The variation of C with chemical reaction parameter γ the actual concentration enhances in the degenerating chemical reaction case while in the generating chemical reaction case it enhances with $|\gamma| \le 1.5$ and reduces with higher $|\gamma| \ge 2.5$. The variation of C with thermophoretic parameter τ shows that the actual concentration reduces everywhere in the region except in $0 < \eta < 1$ where it enhances.

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