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Research Article

THERMAL RADIATION AND OSCILLATING PLATE TEMPERATURE EFFECTS ON MHD UNSTEADY FLOW PAST A SEMI-INFINITE POROUS VERTICAL PLATE UNDER SUCTION AND CHEMICAL REACTION

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ABSTRACT
Effects of plate temperature oscillation on the unsteady free convective flow of an incompressible, electrically conducting fluid along a semi-infinite vertical porous plate subjected to a transverse magnetic field in the presence of a first order chemical reaction and thermal radiation is studied. An improved computational method is employed to the prevailing analytic technique of computation for the unsteady part of the velocity, temperature and concentration. Results are obtained for the mean steady flow and the unsteady flow for the velocity, temperature, concentration .Tabulated values for the mean Skin friction, mean heat transfer and mean mass transfer ,phases of transient velocity, temperature and concentration, amplitude and phases of Skin Friction, coefficient of heat transfer and coefficient of mass transfer are presented. Graphical results for the mean flow and the transient flow are displayed for various values of the magnetic, chemical reaction, radiation and suction parameter.

Key Words: *Oscillating, Unsteady, Vertical Plate, Chemical Reaction, Radiation, Schmidt Number*

INTRODUCTION
Free convection arises in the fluid when temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. The most common example of free convection is the atmospheric flow which is driven by temperature differences. Sometimes along with the free convection currents caused by difference in temperature the flow is also affected by the differences in concentration or material constitution. This type of flow has applications in many branches of science and engineering. The study of such flow under the influence of magnetic field has attracted the interest of many investigators in view of its application in MHD generators, plasma studies, nuclear reactors, geothermal energy extractions and boundary layer control in the field of aerodynamics (Gholizadeh, 1990; Muthucumaraswamy, 2006; Chaudhury, 2007; Alam *et al*., 2009) have studied such flows.
In several processes involving high temperature such as space and nuclear technologies, radiation effects are very common and this changes the behavior of the boundary layer flow considerably. The inclusion of radiation effects in the energy equation leads to a highly nonlinear partial differential equation. The radiative heat flux term in the energy equation can be simplified to a great extent by invoking the Rosseland diffusion approximation which provides one of the most straight forward simplifications of the differential equations governing such flows by considering the optically thick radiation limit. Hossain *et al.*, (2001); Pathak, (2006); Grosan,(2007); Palani ,(2009); Reddy, (2009) have done significant work on the effects of thermal radiation on free and mixed convection flow by invoking Rosseland approximations.
However, in nature it is rather impossible to find pure fluid unless special efforts are made to obtain it. The most common fluids like water, air etc. is contaminated with impurities like CO_2, C_6H_6, H_2SO_4 etc. and generally we have to consider presence of such foreign masses while studying flows past different bodies. In such a case the density difference in the fluid is caused by material constitution in addition to temperature differences. The common example of such a flow is the atmospheric flow which is driven appreciably by both temperature H_2O and concentration differences. When such contaminant is present in

the fluid under consideration there does occur some chemical reaction e.g. air and benzene react chemically, so also water and sulfuric acid. During such chemical reactions, there is always generation of heat. But when the foreign mass present in the fluid at very low level, we can assume a first order chemical reaction and the heat generated due to chemical reaction can be very negligible. Das *et al*.,(1998);Muthucumaraswami,(2003);Muthucumaraswami *et al*., (2006); Al-Odat, (2007); Muthucumaraswami, (2008) have done significant works by taking into account a first order chemical reaction on flow past vertical surfaces. In most of the earlier works the temperature of the plate was assumed to be constant or varying linearly with time. However in the works of Soundalgekar, (1971); Soundalgekar, (1977); Pop,(1982); Helmy, (1998); Das *et al*., (1999); Vighnesam *et al*., (2001); Jaiswal, (2001); Hossain *et al*., (2001); Sharma, (2003); Sharma,(2005); Sharma *et al*.,(2007); Chaudhury, (2008) analytical studies were carried out by assuming a periodic variation of temperature of the plate or an oscillating temperature about a mean temperature in free and mixed convection flow. Laplace Transform technique was the most widely adopted method in most of the earlier works. The aim of the present work is to undertake numerical studies and extend the work of Das *et al*., (1991) by adopting numerical methods and investigate the effects of thermal radiation and plate temperature oscillation on unsteady MHD free-forced mixed convection flow of viscous incompressible and conducting fluid past a vertical plate incorporating a first order chemical reaction when the temperature of the plate oscillates in time about a constant mean temperature.

FORMULATION OF THE PROBLEM

Let u' be the velocity of the fluid in the x' direction taken along the infinite vertical plate and y' coordinate is taken normal to the plate. The fluid is assumed to be gray, emitting and absorbing but non scattering medium. The radiative heat flux term in the x' direction is considered negligible in comparison with that in the y'direction. Initially the plate and the fluid are at same temperature T'_∞ and concentration C'_∞.The coordinate system and the flow configuration is shown in fig1. At time $t' > 0$, the plate is given an impulsive motion in the vertical direction against the gravitational field with uniform velocity U_0 and the plate temperature and species concentration level near the plate is raised to T'_w and C'_wrespectively. Moreover at this stage an unsteady component $\varepsilon(T'_w - T'_\infty)e^{i\omega' t'}$where $\varepsilon \ll 1$ is the amplitude of oscillation, is assumed to be superimposed on this constant mean temperature T'_w of the plate. A magnetic field of uniform strength $B_0$is applied normal to the plate along the y' direction assuming a constant suction velocity v_0 normal to the plate and the induced magnetic field is assumed to be negligible. Since the plate is considered infinite in the x' direction, all physical quantities will be independent of x'.Under these assumptions, the physical variables are functions of y' and t' only. Then neglecting viscous dissipation and assuming variation of density in the body force term (Boussinesq's approximation) the problem under consideration is governed by the following set of equations:

$$\frac{\partial v'}{\partial y'} = 0 \quad (1)$$

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) - \frac{\sigma B_0^2}{\rho}u' \quad (2)$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'} \quad (3)$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} - k_1(C' - C'_\infty) \quad (4)$$

with the initial and boundary conditions:

$u' = 0, T' = T'_\infty, C' = C'_\infty$ for all $y', t' \leq 0$

$u' = U_0, T' = T'_w + \varepsilon(T'_w - T'_\infty)e^{i\omega' t'}$,

$C' = C'_w + \varepsilon(C'_w - C'_\infty)e^{i\omega' t'}$at $y' = 0, t' > 0$

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as (5)

All the physical variables used above are defined in the nomenclature.

From equation (1) we get , which gives the suction velocity normal to the plate. The radiative heat flux term in the energy equation is simplified by utilizing the Rosseland diffusion approximation for an optically thick boundary layer as

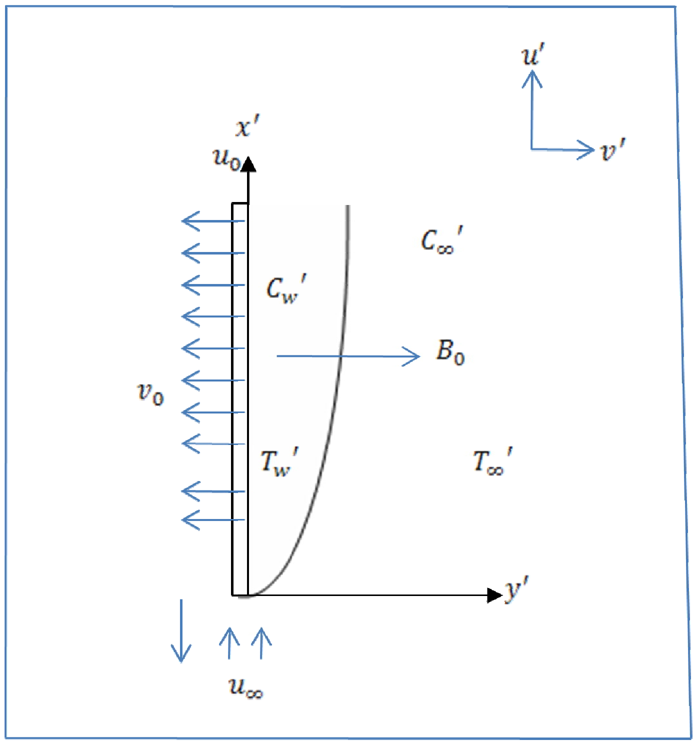

Figure 1: Flow configuration

where is the Stefan Boltzmann constant and is the mean absorption coefficient. If we assume the temperature difference within the flow as sufficiently small then we may simplify the nonlinearity in by expressing as a linear function of temperature. This is accomplished by expanding in a Taylor series about and neglecting the higher order terms which gives us

We further introduce the following non-dimensional quantities in equations (1)-(4):

(6)

With the help of (6), the governing equations (1)-(4) along with the boundary conditions (5) reduce to

(7)

(8)

$$\frac{\partial\varphi}{\partial t} - \chi\frac{\partial\varphi}{\partial y} = \frac{1}{Sc}\frac{\partial^2\varphi}{\partial y^2} - \gamma\varphi \quad (9)$$

With the following initial and boundary conditions:

$$u = 0, \theta = 0, C = 0 \text{ at } y = 0, t \le 0$$
$$u = 1, \theta = 1 + \varepsilon e^{i\omega t}, \ \varphi = 1 + \varepsilon e^{i\omega t} \text{ at } y = 0, t > 0$$
$$u \to 0, \theta \to 0, \varphi \to 0, y \to \infty, t > 0 \quad (10)$$

SOLUTION OF THE PROBLEM

Assuming small amplitude oscillations $(\varepsilon \ll 1)$,we can represent the velocity u, temperature θ and concentration φ near the plate ,we want to solve the equations (7)-(9) by employing purturbative technique as follows:

$$u(y,t) = u_0(y) + \varepsilon u_1(y)e^{i\omega t}$$
$$\theta(y,t) = \theta_0(y) + \varepsilon\theta_1(y)e^{i\omega t}$$
$$\varphi(y,t) = \varphi_0(y) + \varepsilon\varphi_1(y)e^{i\omega t} \quad (11)$$

Substituting (11) in (7)-(9), equating coefficients of harmonic and non harmonic terms and neglecting the coefficients of ε^2, we get:

$$u_0'' + \chi u_0' - Mu_0 = -G\theta_0 - G^*\varphi_0 \quad (12)$$
$$u_1'' + \chi u_1' - (M + i\omega)u_1 = -G\theta_1 - G^*\varphi_1 \quad (13)$$
$$\theta_0'' + \chi\left(\frac{Pr}{1+R}\right)\theta_0' = 0 \quad (14)$$
$$\theta_1'' + \chi\left(\frac{Pr}{1+R}\right)\theta_1' = \left(\frac{Pr}{1+R}\right)i\omega\theta_1 \quad (15)$$
$$\varphi_0'' + \chi Sc\varphi_0' = \gamma Sc\varphi_0 \quad (16)$$
$$\varphi_1'' + \chi Sc\varphi_1' = (\gamma + i\omega)Sc\varphi_1 \quad (17)$$

Here primes denote differentiation with respect to y. The corresponding boundary conditions now become:

$$u_0 = 1, u_1 = 0, \theta_0 = 1, \theta_1 = 1, \varphi_0 = 1, \varphi_1 = 1 \text{ at } y = 0$$
$$u_0 \to 0, u_1 \to 0, \theta_0 \to 0, \theta_1 \to 0, \varphi_0 \to 0, \varphi_1 \to 0 \text{ as } y \to \infty \quad (18)$$

We attempt to solve equations (12)-(17) under the boundary conditions (18) for the mean flow and unsteady flow separately.

The Mean Flow

Physically u_0, θ_0 and φ_0 represent the mean velocity, mean temperature and mean concentration respectively. The mean flow is governed by the equations (11), (13) and (15) under the boundary conditions (17). These equations are solved numerically using Matlab7 for different values of the parameters M, γ, G, G^* and Sc. It is evident that the mean flow is independent of Pr and values for G and G^* are chosen arbitrarily. Schmidt number quantifies the relative effectiveness of momentum and mass transport by diffusion as opposed to the Prandtl number which embodies the ratio of momentum diffusivity to thermal diffusivity. The value of Schmidt number is chosen in such a way that they represent the diffusing chemical species of most common interest in air (Table 1). The Schmidt number for water is usually high and hence we have chosen it as 500.The values of mean Skin Friction (τ_m), mean temperature (q_m) and mean concentration (h_m) for different values of the magnetic parameter, chemical reaction parameter, radiation parameter and suction parameter are shown in Table2- Table5 respectively. The velocity, temperature and concentration profiles for the mean flow are shown in Fig2-Fig9 respectively.

The Unsteady Oscillatory Flow

The unsteady flow is governed by equations (13),(15) and (17) under the boundary conditions (18).

For computational ease and further analysis, we express the unsteady components u_1, θ_1 and φ_1 as the sum of the in-phase and out-of-phase components as:

$$(u_1, \theta_1, \varphi_1) = (u_r, \theta_r, \varphi_r) + i(u_i, \theta_i, \varphi_i) \quad (19)$$

In view of (19), the equations (13),(15) and (17) can further be simplified by equating the real and imaginary parts:

$$u_r'' + \chi u_r' - Mu_r + \omega u_i = -G\theta_r - G^*\varphi_r \quad (20)$$
$$u_i'' + \chi u_i' - Mu_i - \omega u_r = -G\theta_i - G^*\varphi_i \quad (21)$$
$$\theta_r'' + \chi\left(\frac{Pr}{1+R}\right)\theta_r' = -\left(\frac{Pr}{1+R}\right)\omega\theta_i \quad (22)$$
$$\theta_i'' + \chi\left(\frac{Pr}{1+R}\right)\theta_i' = \left(\frac{Pr}{1+R}\right)\omega\theta_r \quad (23)$$
$$\varphi_r'' + \chi Sc\varphi_r' = \gamma Sc\varphi_r - \omega Sc\varphi_i \quad (24)$$
$$\varphi_i'' + \chi Sc\varphi_i' = \gamma Sc\varphi_i + \omega Sc\varphi_r \quad (25)$$

The boundary conditions for (20)-(24) become:

$$u_r = 0, \theta_r = 1, \varphi_r = 1, \ u_i = 0, \theta_i = 0, \varphi_i = 0 \text{ at } y = 0 \text{ and}$$
$$u_r \to 0, \theta_r \to 0, \varphi_r \to 0, u_i \to 0, \theta_i \to 0, \varphi_i \to 0 \text{ as } y \to \infty \quad (26)$$

In the velocity distribution relation $u(y,t) = u_0(y) + \varepsilon u_1(y)e^{i\omega t}$, the real part of the unsteady component $\varepsilon u_1 e^{i(\omega t+\alpha_1)}$ is $\varepsilon(u_r\cos\omega t - u_i\sin\omega t) = \varepsilon|u_1|\cos(\omega t + \alpha_1) = \varepsilon\sqrt{u_r^2 + u_i^2}\cos(\omega t + \alpha_1)$ which lags or leads over fluctuations by an angle α_1. Similarly, temperature θ and concentration φ lags or leads over fluctuations by angles α_2 and α_3 respectively where the real parts of the unsteady components $\varepsilon\theta_1 e^{i(\omega t+\alpha_2)}$ and $\varepsilon\varphi_1 e^{i(\omega t+\alpha_3)}$ are:

$$\varepsilon(\theta_r\cos\omega t - \theta_i\sin\omega t) = \varepsilon|\theta_1|\cos(\omega t + \alpha_2) = \varepsilon\sqrt{\theta_r^2 + \theta_i^2}\cos(\omega t + \alpha_2)$$

and $\varepsilon(\varphi_r\cos\omega t - \varphi_i\sin\omega t) = \varepsilon|\varphi_1|\cos(\omega t + \alpha_3) = \varepsilon\sqrt{\varphi_r^2 + \varphi_i^2}\cos(\omega t + \alpha_3)$ respectively.

Here $(|u_1|, \alpha_1)$, $(|\theta_1|, \alpha_2)$ and $(|\varphi_1|, \alpha_3)$ denote the amplitudes and phases of oscillation for velocity, temperature and concentration profiles of the unsteady flow respectively. The phases are given by the relations: $\alpha_1 = \tan^{-1}\left(\frac{u_i}{u_r}\right)$, $\alpha_2 = \tan^{-1}\left(\frac{\theta_i}{\theta_r}\right)$ and $\alpha_3 = \tan^{-1}\left(\frac{\varphi_i}{\varphi_r}\right)$

Taking only the real parts of the velocity, temperature and concentration fields, they can be expressed in terms of their fluctuating parts as:

$$u = u_0 + \varepsilon(u_r\cos\omega t - u_i\sin\omega t) \quad (27)$$
$$\theta = \theta_0 + \varepsilon(\theta_r\cos\omega t - \theta_i\sin\omega t) \quad (28)$$
$$\varphi = \varphi_0 + \varepsilon(\varphi_r\cos\omega t - \varphi_i\sin\omega t) \quad (29)$$

The transient velocity, temperature and concentration for $\omega t = \frac{\pi}{2}$ are:

$$u = u_0 - \varepsilon u_i \quad (30)$$
$$\theta = \theta_0 - \varepsilon\theta_i \quad (31)$$
$$\varphi = \varphi_0 - \varepsilon\varphi_i \quad (32)$$

The transient velocity, temperature and concentration for $\omega t = \pi$ are:

$$u = u_0 - \varepsilon u_r \quad (33)$$
$$\theta = \theta_0 - \varepsilon\theta_r \quad (34)$$
$$\varphi = \varphi_0 - \varepsilon\varphi_r \quad (35)$$

Knowing the velocity field, from the practical point of view the physical quantities of interest are:

Skin friction coefficient (τ)

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y}\right)_{y=0} + i\varepsilon e^{i\omega t}\left(\frac{\partial u_1}{\partial y}\right)_{y=0} \quad (36)$$

Splitting (18) into real and imaginary parts and taking real parts only, the expression for τ in terms of amplitude B and phase angle α_4 is given by,

$\tau = \tau_m + \varepsilon|B|\cos(\omega t + \alpha_4)$ (37)

where $|B| = \sqrt{\{u_r'(0)\}^2 + \{u_i'(0)\}^2}$, $\alpha_4 = \tan^{-1}\left(\frac{u_i'(0)}{u_r'(0)}\right)$ and

$\tau_m = u_0'(0)$ = Mean-Skin friction (38)

Coefficient of heat transfer (q)

$$q = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0} = -\left(\frac{\partial\theta_0}{\partial y}\right)_{y=0} - i\varepsilon e^{i\omega t}\left(\frac{\partial\theta_1}{\partial y}\right)_{y=0}$$

(39)

Splitting (21) into real and imaginary parts and taking real parts only, the expression for q, in terms of amplitude H and phase angle α_5 is given by

$q = q_m + \varepsilon|H|\cos(\omega t + \alpha_5)$ (40)

where $|H| = \sqrt{\{\theta_r'(0)\}^2 + \{\theta_i'(0)\}^2}$, $\alpha_5 = \tan^{-1}\left(\frac{\theta_i'(0)}{\theta_r'(0)}\right)$ and

$q_m = \theta_0'(0)$ = Mean-heat transfer (41)

Table 1: The Thermodynamic and transport properties at 25^0C and 1 atm

Thermodynamic and transport properties at 25^0C and 1 atm	Species	Sc
Air	H_2	0.24
	He	0.30
	H_2O	0.60
	NH_3	0.78
	CO_2	1.002
	CH_3OH	1.0
	C_8H_{10}	2.0
	Cl_2	617
Water	H_2O	500

Table 2

M	τ_m	q_m	h_m
0	3.1400		
3	0.0409	-1.7101	-1.6204
6	-1.0999		
10	-2.1054		

Coefficient of mass transfer (h):

$$h = -\left(\frac{\partial\varphi}{\partial y}\right)_{y=0} = -\left(\frac{\partial\varphi_0}{\partial y}\right)_{y=0} - i\varepsilon e^{i\omega t}\left(\frac{\partial\varphi_1}{\partial y}\right)_{y=0} \quad (42)$$

Table 3

γ	τ_m	q_m	h_m
0	-0.4392		-1.0045
2	-0.7003	-3.7100	-2.0027
5	-0.8172		-2.7947
7	-0.8608		-3.1964

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Table 4

R	τ_m	q_m	h_m
0	1.6575	-0.7202	
2	0.1110	-2.7100	-1.6204
5	-0.4916	-5.7100	
8	-0.7218	-8.7100	

Table 5

χ	τ_m	q_m	h_m
0	2.5327	-0.1667	-1.0010
1	0.6082	-1.7101	-1.6204
3	-2.1663	-5.1300	-3.3088
6	-5.5358	-10.2600	-6.1743

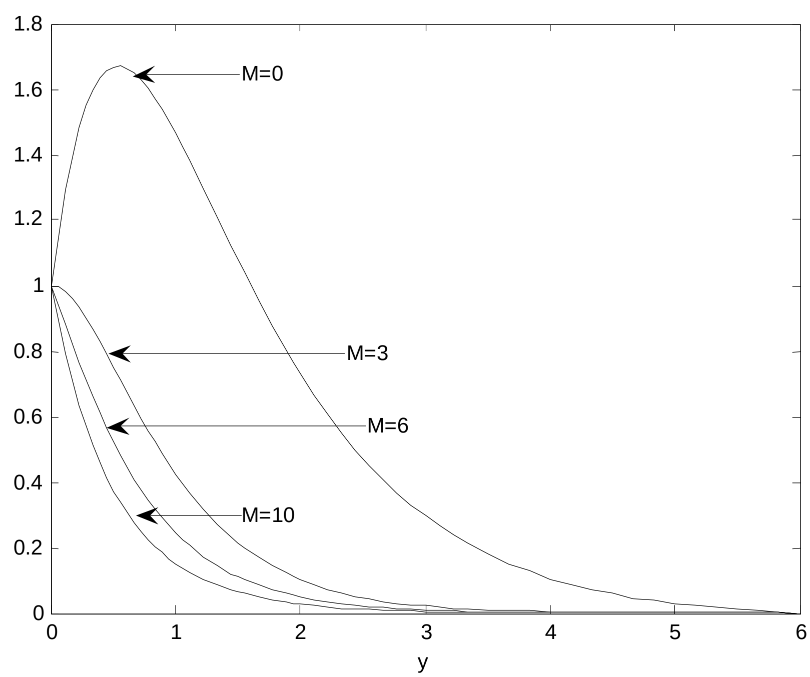

Figure 2: Magnetic Effect on Mean Velocity Profile

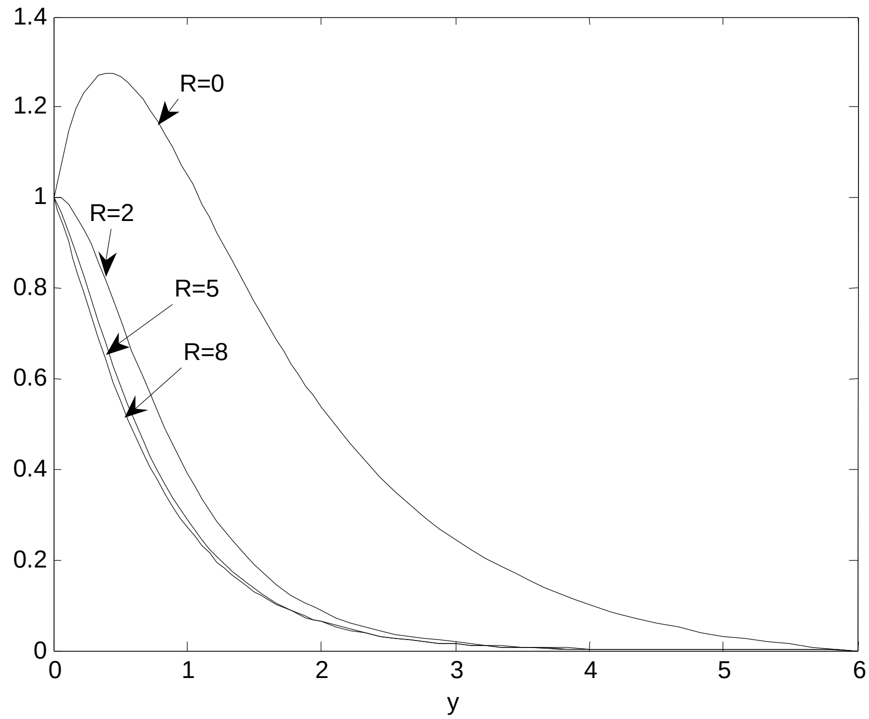

Figure 3: Radiation Effect on Mean Velocity Profile

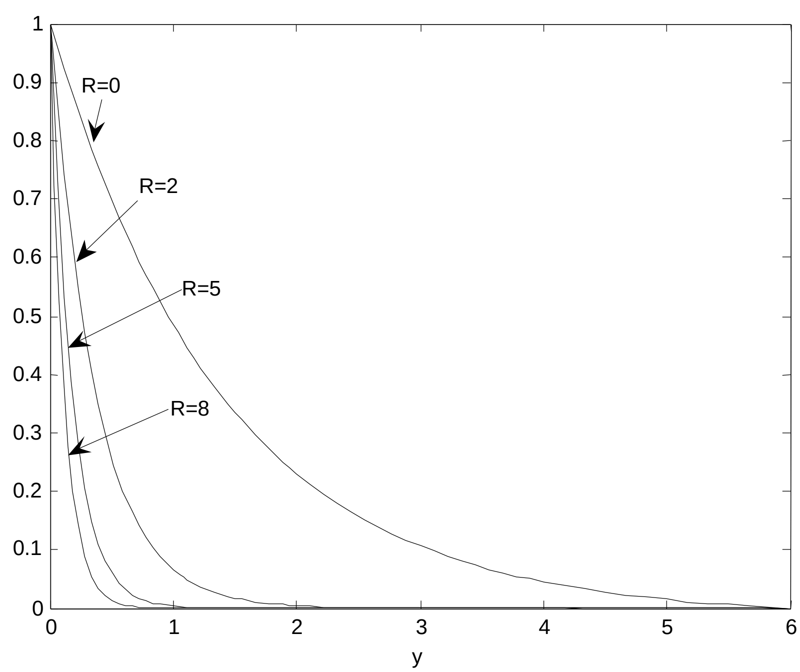

Figure 4: Radiation Effect on Mean Temperature Profile

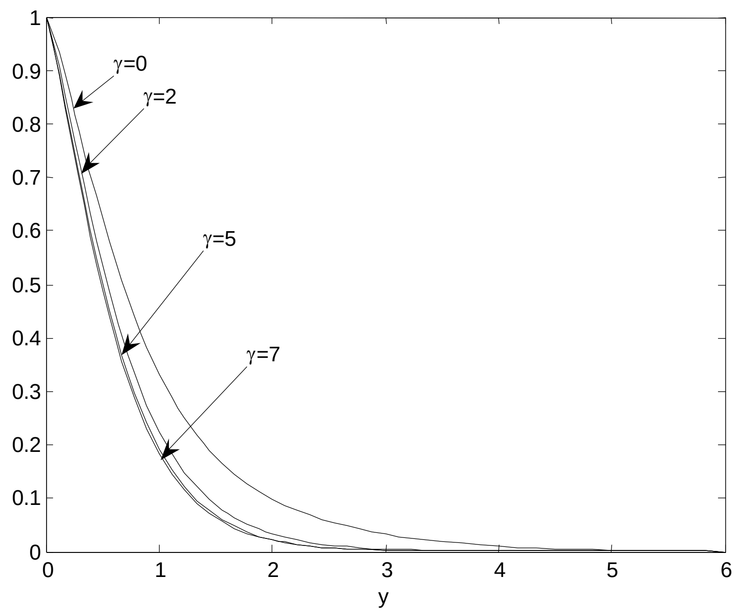

Figure 5: Chemical Reaction Effect on Mean Velocity Profile

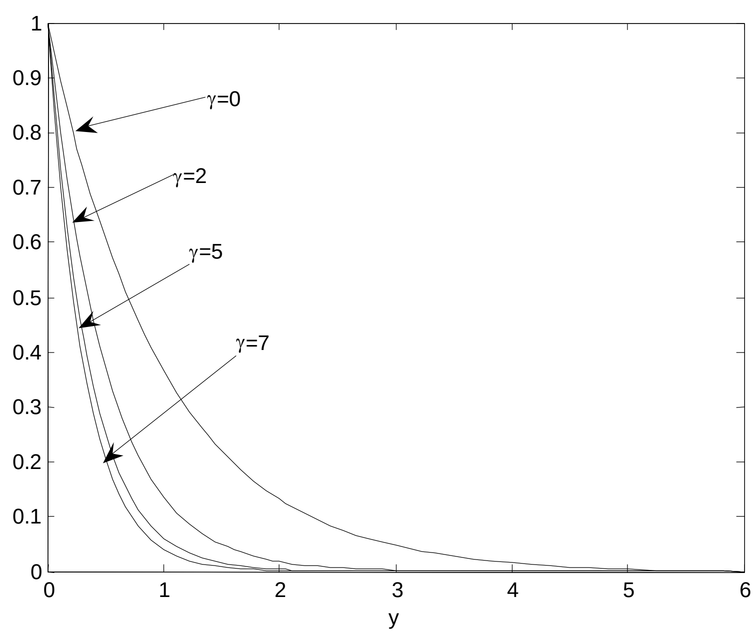

Figure 6: Chemical Reaction Effect on Mean Concentration Profile

Splitting (24) into real and imaginary parts and taking real parts only, the expression for h in terms of amplitude N and phase angle α_6 is given by

$$h = h_m + \varepsilon|N|\cos(\omega t + \alpha_6) \quad (43)$$

where $|N| = \sqrt{\{\varphi_r'(0)\}^2 + \{\varphi_i'(0)\}^2}$, $\alpha_6 = \tan^{-1}\left(\frac{\varphi_i}{\varphi_r}\right)$, and

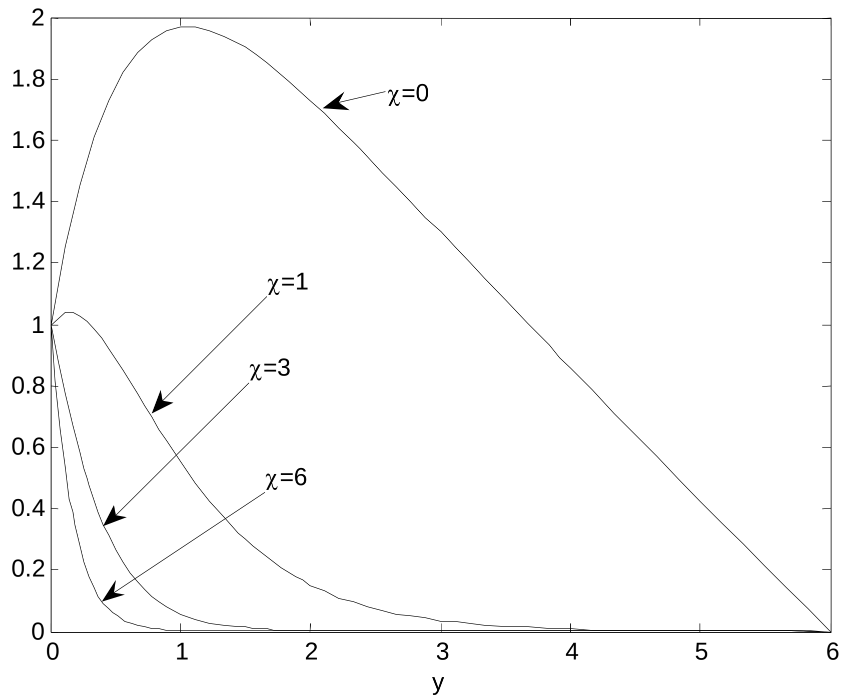

Figure 7: Effect of Suction on Mean Velocity Profile

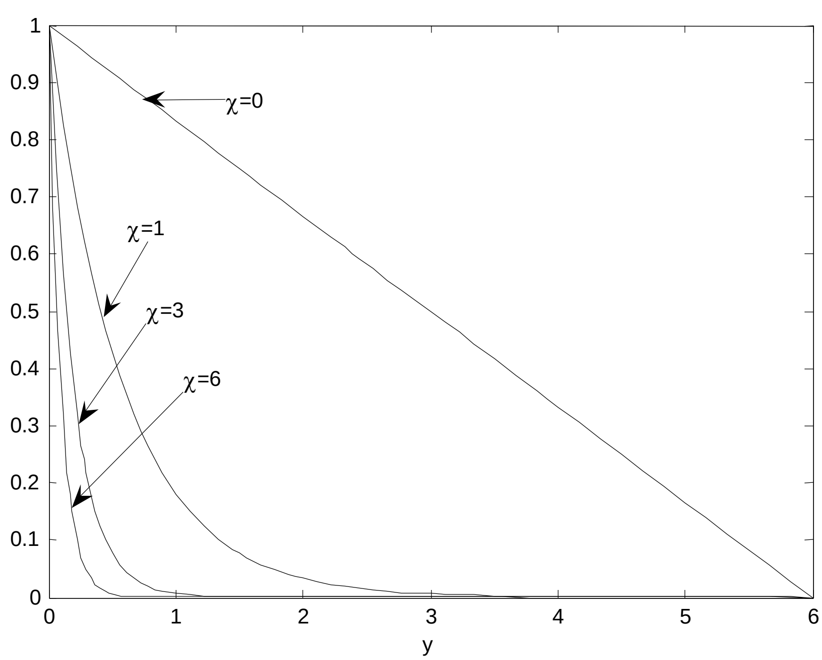

Figure 8: Effect of Suction on Mean Temperature Profile

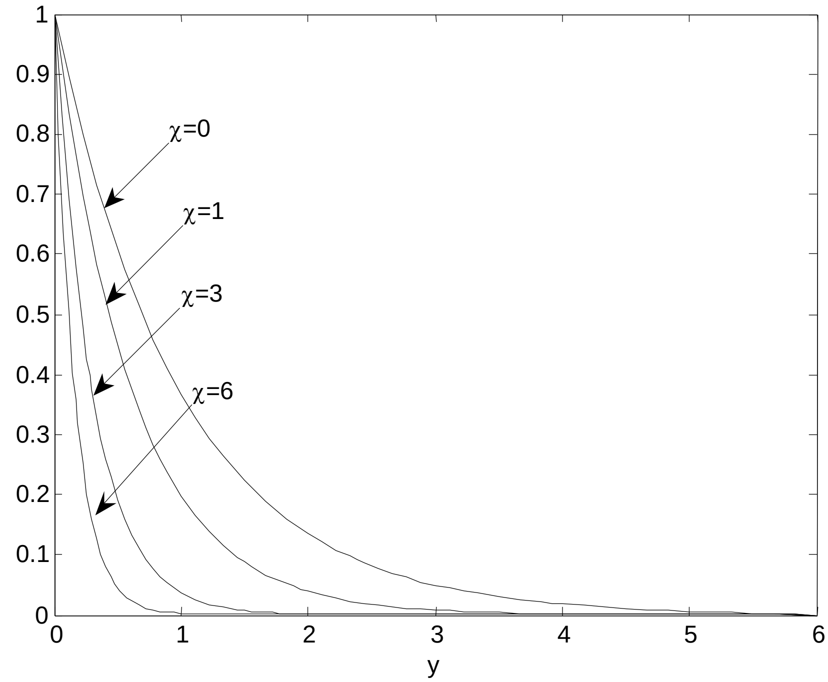

Figure 9: Effect of Suction on Mean Concentration Profile

Table 6

M	α_1	α_2	α_3	$\|B\|$	α_4	$\|H\|$	α_5	$\|N\|$	α_6
0	-0.3874	-0.3051	-0.2456	3.0400	1.3114				
3	-0.3131	-0.2230	-0.1686	2.5364	1.1032	1.4644	0.6915	2.6852	0.5478
6	-0.3310	-0.3000	-0.2165	2.4348	0.8147				
10	-0.2645	-0.3119	-0.2317	2.7458	0.5207				

Table 7.

γ	α_1	α_2	α_3	$\|B\|$	α_4	$\|H\|$	α_5	$\|N\|$	α_6
0	-0.4227	-0.2752	-0.2622	2.6078	1.1863			2.6256	0.6285
2	-0.4244	-0.2554	-0.2136	2.5686	1.1842	1.0070	0.7183	2.7780	0.4759
5	-0.4444	-0.2517	-0.1564	2.5262	1.1747			3.1660	0.3217
7	-0.3988	-0.2390	-0.1025	2.5085	1.1674			3.4523	0.2587

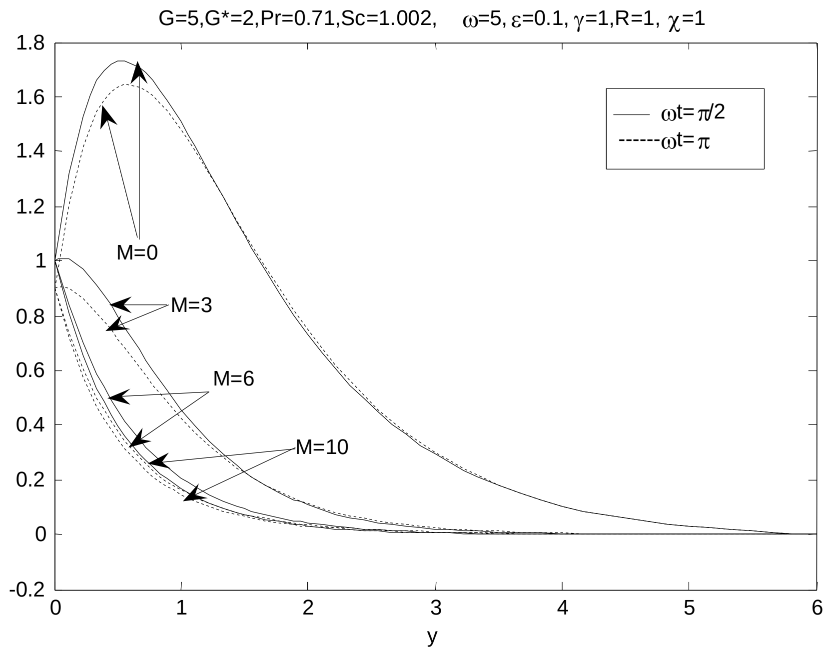

Figure 10: Magnetic Effect on Transient Velocity Profile

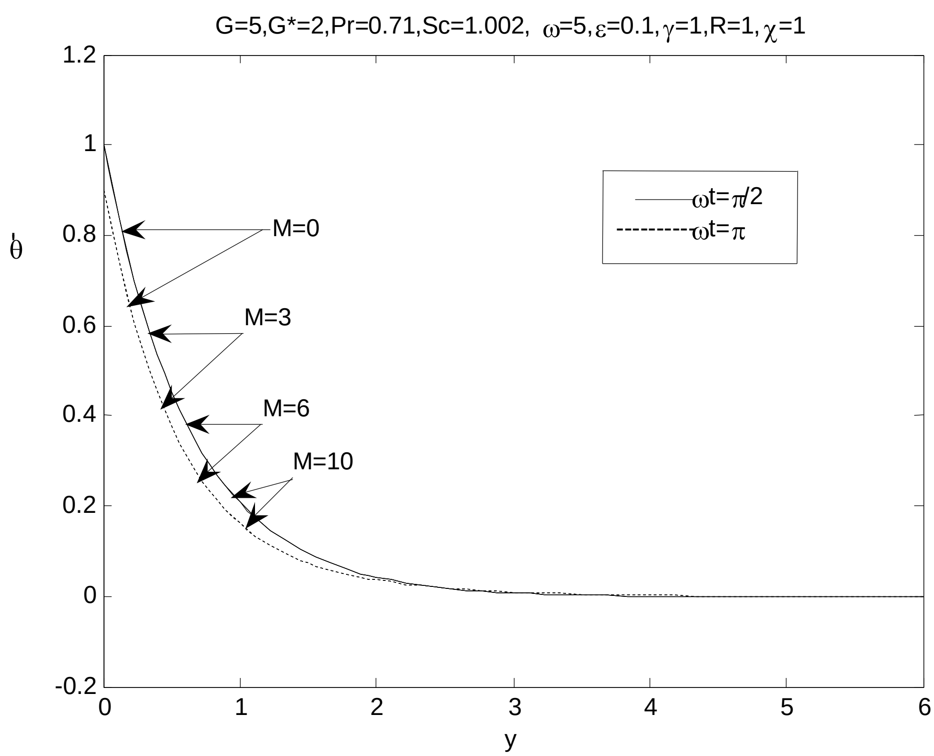

Figure 11: Magnetic Effect on Transient Temperature Profile

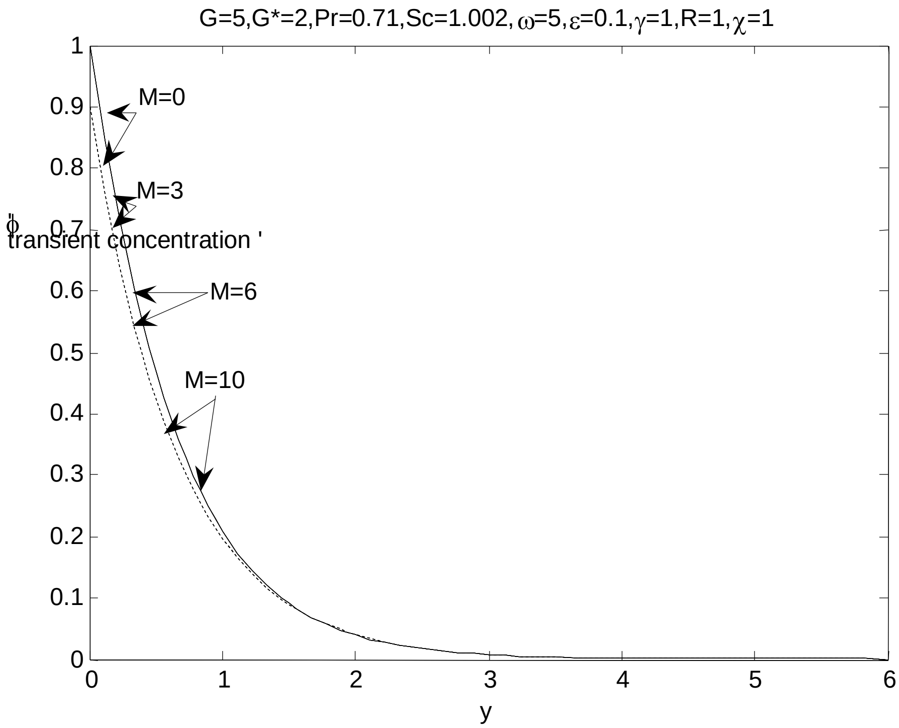

Figure 12: Magnetic Effect on Transient Concentration Profile

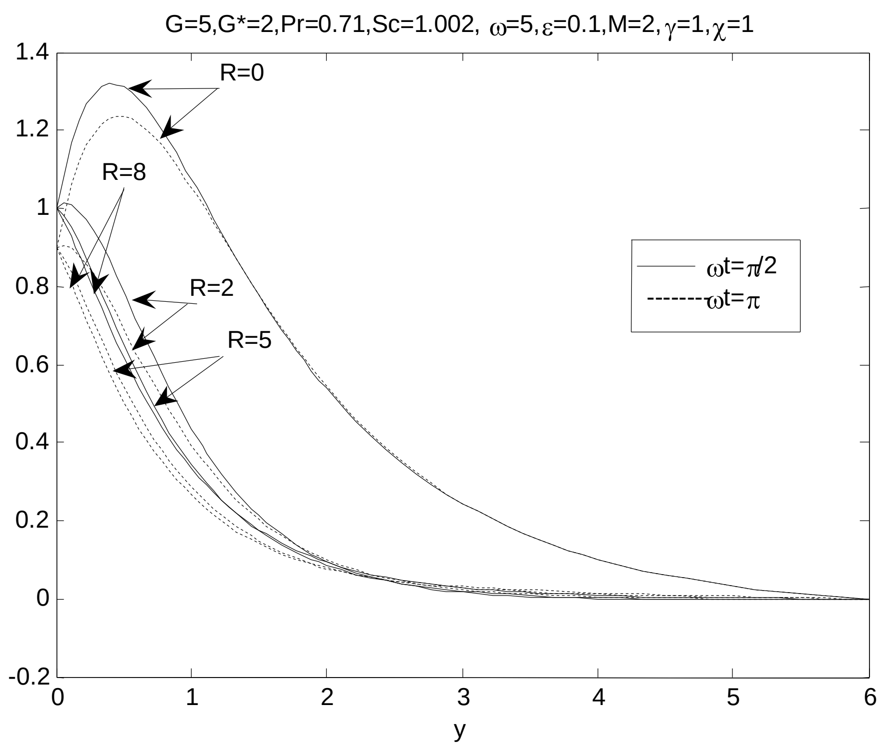

Figure 13: Magnetic Effect on Transient Velocity Profile

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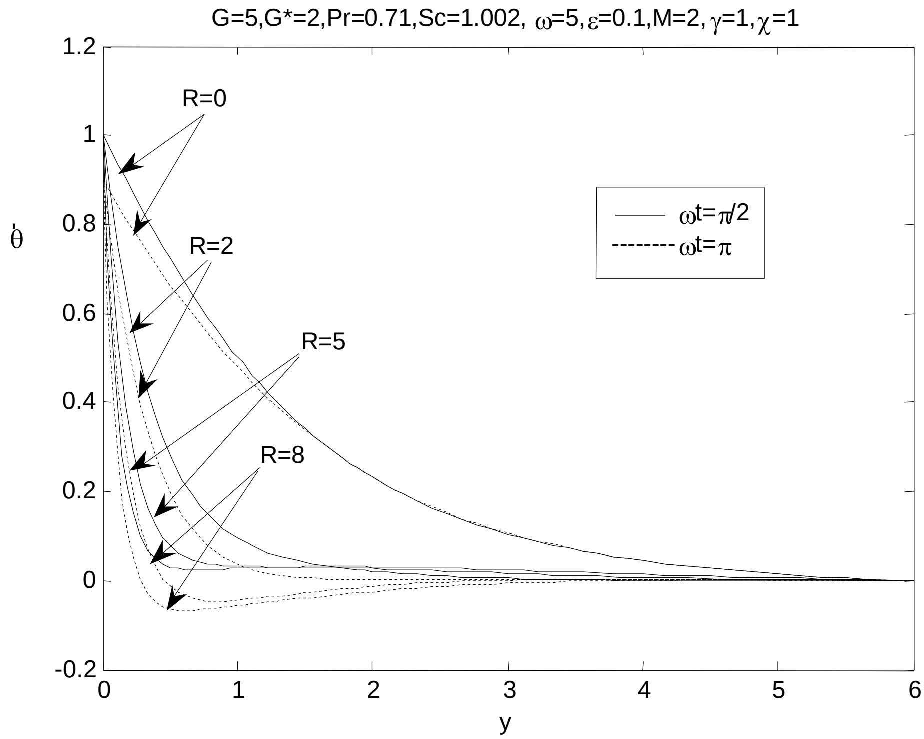

Figure 14: Radiation Effect on Transient Temperature Profile

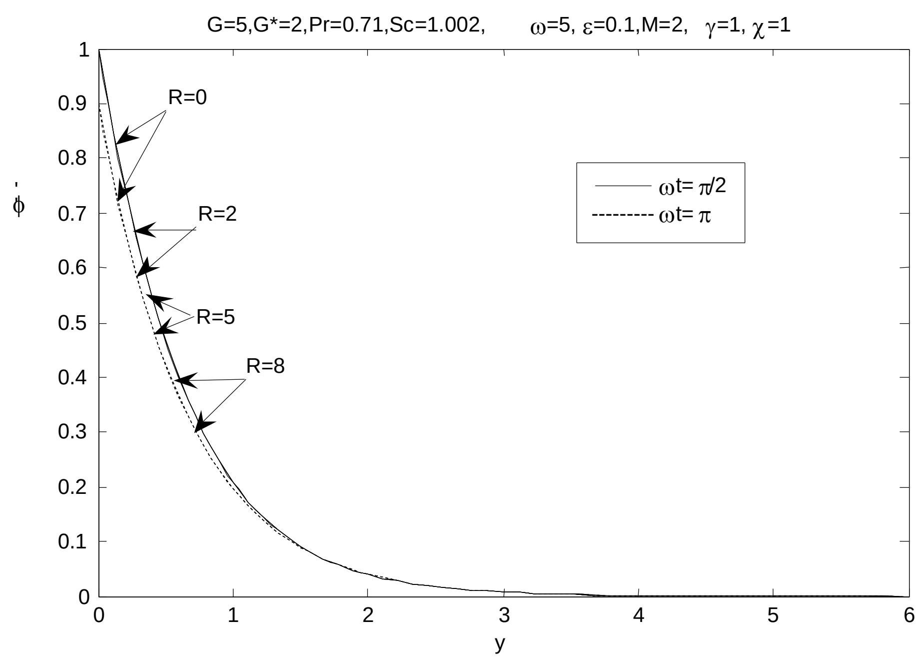

Figure 15: Radiation Effect on Transient Concentration Profile

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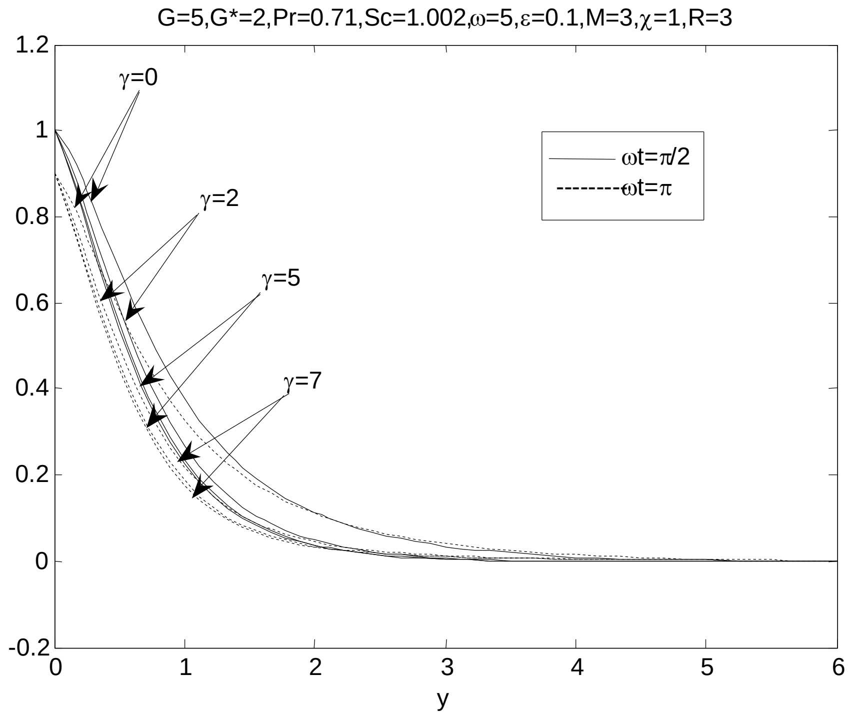

Figure 16: Chemical Reaction Effect on Transient Velocity Profile

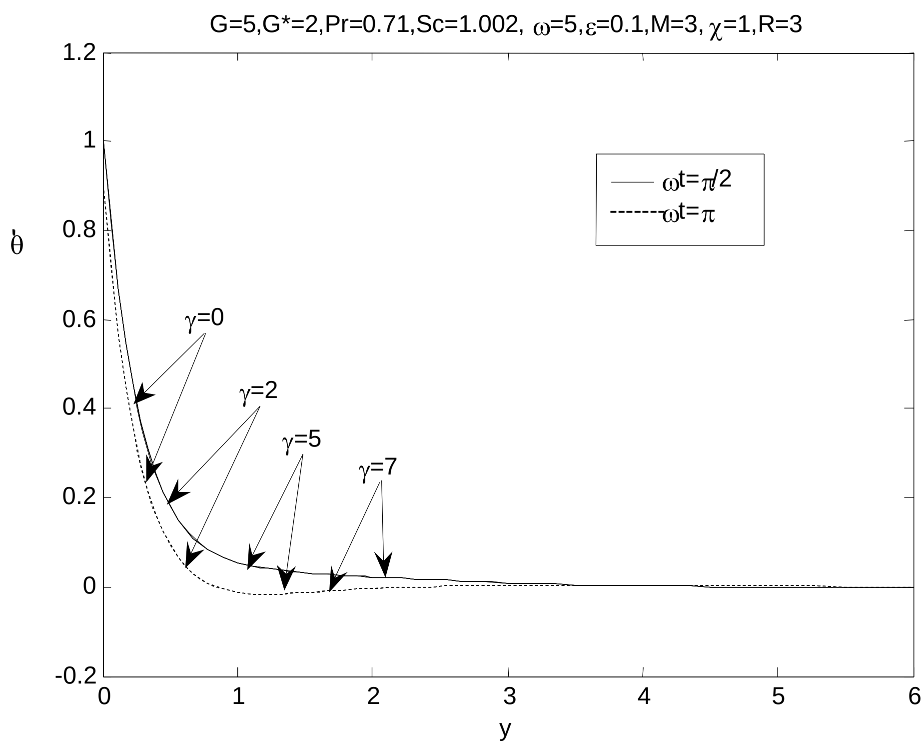

Figure 17: Chemical Reaction Effect on Transient Temperature Profile

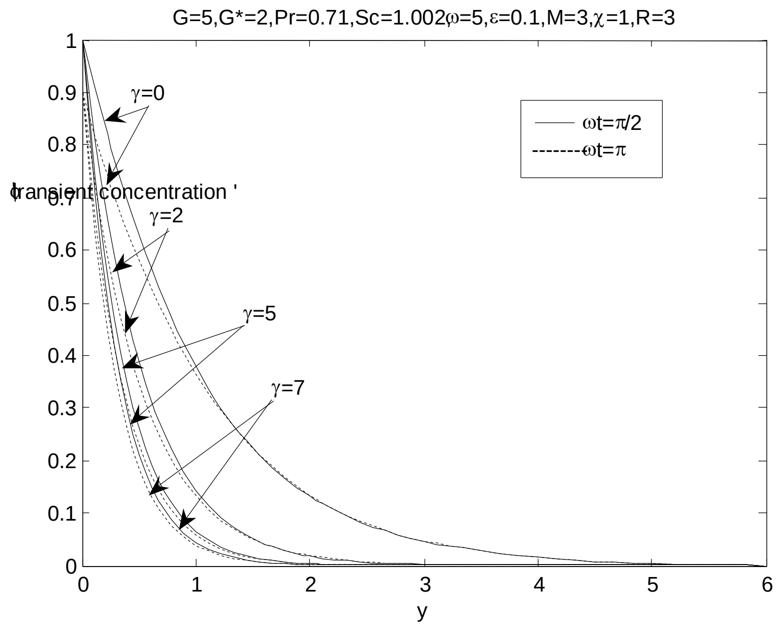

Figure 18: Chemical Reaction Effect on Transient Temperature Profile

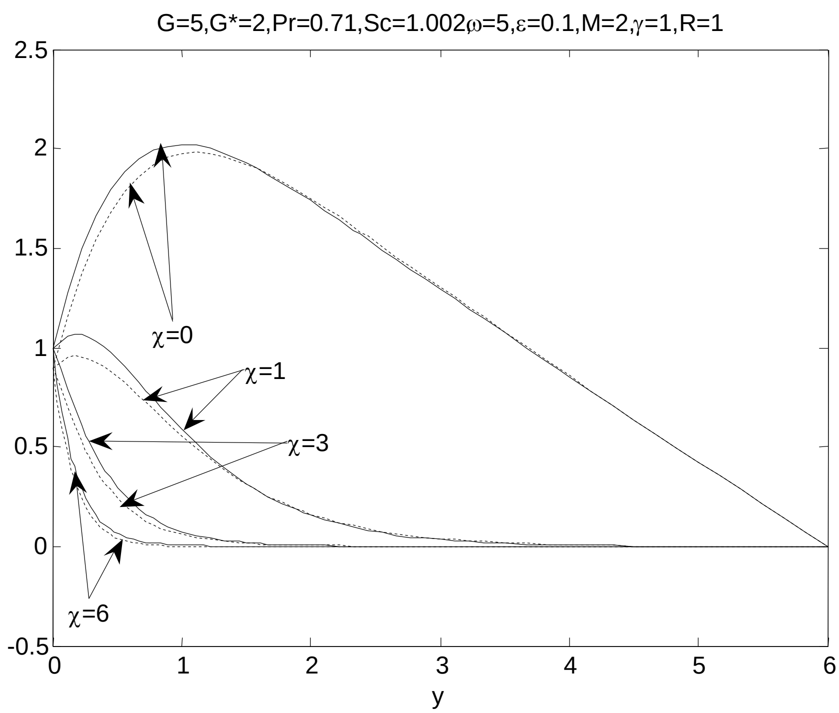

Figure 19: Effect of Suction Ontransient Velocity Profile

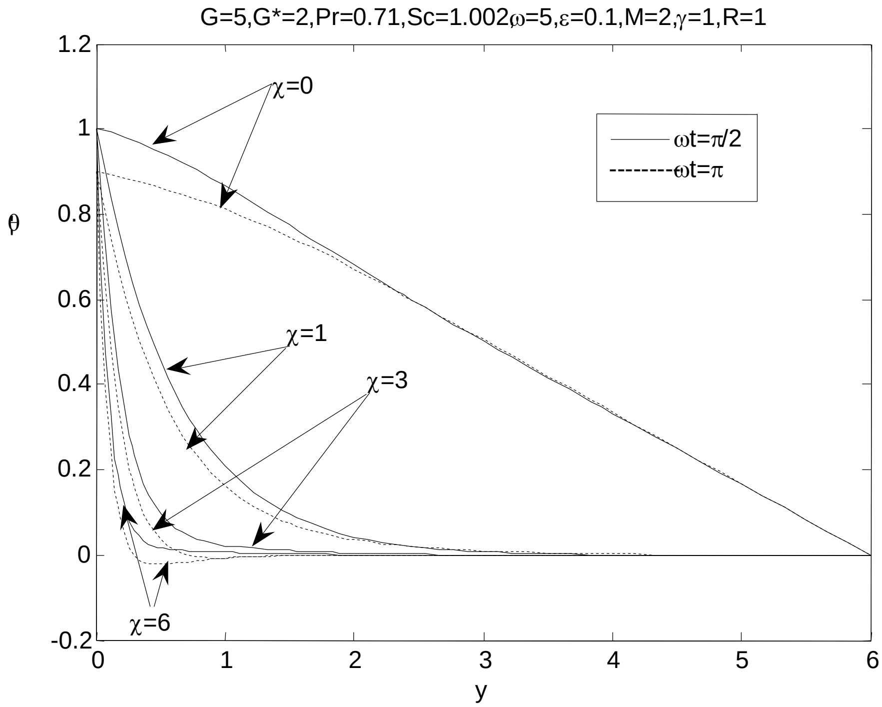

Figure 20: Effect of Suction On transient Temperature Profile

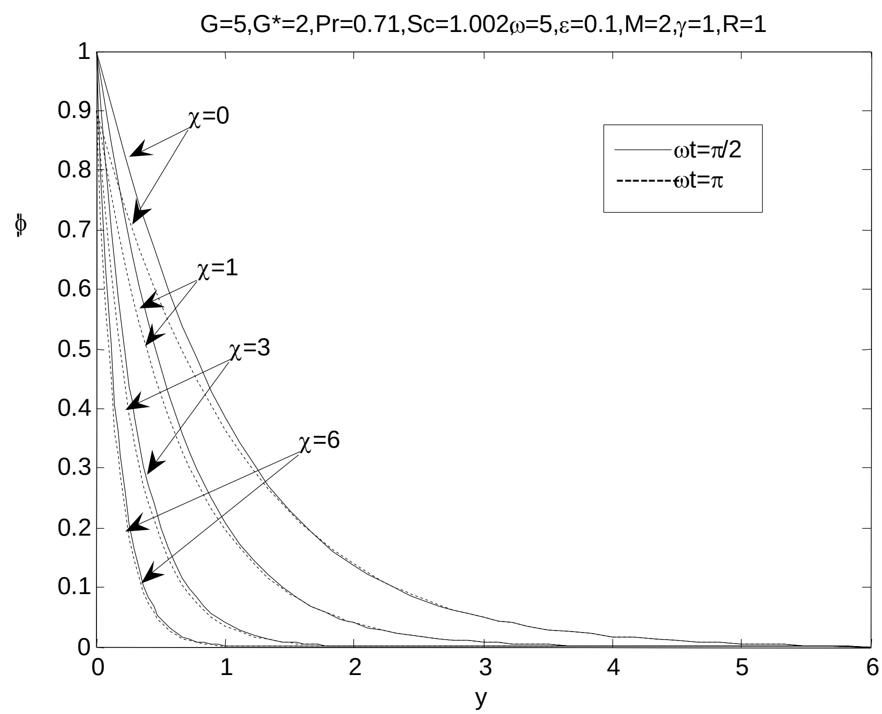

Figure 21: Effect of Suction On transient Concentration Profile

Table8

R	α_1	α_2	α_3	$\|B\|$	α_4	$\|H\|$	α_5	$\|N\|$	α_6
0	-0.3782	-0.2750	-0.2313	2.5714	1.1009	2.1543	0.6530		
2	-0.3892	-0.2809	-0.2072	2.7236	1.2349	1.1748	0.7086	2.6852	0.5478
5	-0.3754	-0.2613	-0.2021	2.8180	1.3019	0.8145	0.7306		
8	-0.3996	-0.2596	-0.1976	2.8769	1.3341	0.6598	0.7488		

Table9

χ	α_1	α_2	α_3	$\|B\|$	α_4	$\|H\|$	α_5	$\|N\|$	α_6
0	-0.3224	-0.2800	-0.2348	2.4588	1.3705	1.3323	0.7854	2.2603	0.6867
1	-0.4075	-0.2732	-0.2328	2.6659	1.1888	1.4644	0.6915	2.6852	0.5478
3	-0.3455	-0.2120	-0.1357	3.1774	0.8024	1.7797	0.5108	3.8338	0.3089
6	-0.1577	-0.1212	-0.0511	4.9281	0.3203	2.4396	0.2898	6.3130	0.1220

$h_m=\varphi_0{}'(0)$ =Mean-mass transfer (44)

The numerical values of the phase angles of transient velocity (α_1), temperature (α_2) and concentration (α_3) profiles for the unsteady part of the flow along with the amplitudes and phases of Skin friction ($|B|, \alpha_4$), coefficient of heat transfer ($|H|, \alpha_5$) and coefficient of mass transfer ($|N|, \alpha_6$) are presented in Table6-Table9. The transient velocity, temperature and concentration profiles are shown in Fig10-Fig21 respectively.

NOMENCLATURE

β coefficient of thermal expansion,
β^* coefficient of thermal expansion with concentration ,
G thermal Grashof number
G^* mass Grashof number
ε amplitude of oscillation
C_P specific heat at constant pressure,
ω dimensionless frequency,
χ suction parameter
B_0 magnetic field strength
(u, v) dimensionless velocity components
u' velocity along x' direction
v' velocity along y' direction
u_∞ free stream fluid velocity
T_∞' free stream temperature
T_w' temperature at the plate
T dimensionless temperature
T' fluid temperature
ω' frequency,
ρ density,
θ dimensionless temperature,
ϕ dimensionless species concentration,
C_∞' species concentration in the free stream,
C_W' concentration at the wall,
g acceleration due to gravity,
Pr Prandtl number
M magnetic parameter
v_0 suction velocity
γ chemical reaction parameter
Sc Schmidt number
ν kinematic viscosity
k thermal conductivity
k_1 chemical reaction constant
u_0 plate velocity
α thermal diffusivity
D mass diffusion coefficient
R radiation parameter

Research Article

CONCLUSIONS

The mean velocity is reduced due to application of magnetic field but the mean temperature and concentration is unaltered.

The mean velocity and mean temperature levels are lowered due to radiation effect but the mean concentration level remained unchanged.

Chemical reaction tend to reduce the mean velocity and mean concentration levels but the mean temperature remains constant.

Suction has a profound influence on all of the velocity, temperature and concentration fields with a lowering effect.

The amplitude and phase of the Skin friction gradually decreases with an increase in the magnetic field strength but the amplitude and phases of the coefficient of heat transfer and mass transfer remains unaltered.

Chemical reaction tend to reduce the amplitude and phase of the Skin friction but the phase of the coefficient of mass transfer reduces while the amplitude increases.

Radiation increases the amplitude and phase of the Skin friction and coefficient of heat transfer but amplitude and phase of the coefficient of mass transfer remains unchanged.

Suction increases the amplitude but reduces the phase of the Skin friction and coefficient of heat transfer but the amplitude of the coefficient of mass transfer increases while the phase is gradually lowered.

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