MHD Memory Convective Flow through Porous Medium with Variable Suction in the presence of Radiation and Chemical Reaction

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ABSTRACT: - A free convective unsteady visco-elastic flow through porous medium bounded by an infinite vertical porous plate with variable suction, constant heat flux under the influence of transverse uniform magnetic field along with permeability in the presence of radiation and chemical reaction has been investigated in the present study. The suction velocity of the porous medium fluctuates with time about the constant mean. Approximate solutions for mean velocity, transient velocity, mean temperature and transient temperature, mean concentration and concentration of non-Newtonian flow are obtained. The effects of various parameters such as Pr (Prandtl number), Gr (Grashof number), M (Hartmann number), ω (frequency parameter) and k0 (permeability parameter) and F (radiation parameter) and KC (chemical reaction parameter) on the above are depicted. Expressions for fluctuating parts of velocity 'Mr' and 'Mi' are found and plotted graphically and effects of different parameters on them are discussed. Skin friction amplitude and phase are shown with the help of figures and are discussed in detail.

Keywords: Free convection, Walter's liquid B', permeability, radiation, concentration and suction.

I. INTRODUCTION

The phenomenon of free convection arises in the fluid when temperature and concentration changes cause density variation leading to buoyancy forces acting on the fluid elements.The mass transfer differences effect the rate of heat transfer. In industries, many transport processes exist in which heat and mass transfer take place simultaneously as a result of combined buoyancy effect of thermal diffusion and diffusion thermo chemical species. The phenomenon of heat and mass transfer frequently exists in chemically processed industries such as food processing and polymer production. Free convection flows are also of great interest in a number of industrial applications such as fiber and granular insulation geothermal system etc. Convection in porous media has applications in geothermal energy recovery, oil extraction, thermal energy storage and flow through filtering devices. Magneto-hydrodynamics is attracting the attention of many authors due to its application in geophysics. In engineering in MHD pumps, MHD bearing etc. at high temperature attained in some engineering devices. Since some fluids can emit and absorb thermal radiation, it is of interest to study the effect of magnetic field on the temperature distribution and heat transfer when the fluid is not only an electrical conductor but also when it is capable of emitting and absorbing thermal radiation. This is of interest because heat transfer by thermal radiation is becoming of great importance when we are concerned with space application and higher operating temperatures.

The growing need for chemical reactions in chemical and hydrometallurgical industries require the study of heat and mass transfer with chemical reaction. Chemical reactions occur in air or water due to the presence of foreign mass. It may be present by itself or as mixtures with air or water. In many chemical engineering processes, a chemical reaction occurs between a foreign mass and the fluid in which the plate is moving .These processes take place in numerous industrial applications such as polymer production, manufacturing of ceramics or glassware and food processing.

Soundalgekar and Takhar [1] studied the effects of radiation on the natural convection flow of a gas past a semi-infinite plate using the Cogly-Vincentine-Gillas equilibrium model. Takhar et.al.[2] also investigated the effect of radiation on MHD free convection flow past a semi-infinite vertical plate for same gas. Muthucumarswamy and Kumar [3] studied the thermal radiation effects on moving infinite vertical plate in presence of variable temperature and mass diffusion.Hussain et.al. [4] studied the effect of radiation on free convection on porous vertical plate.Chamkha el.al.[5] studied the effect of hydro-magnetic combined heat and mass transfer by natural convection from a permeable surface embedded in fluid Saturated porous medium.

Noushima et al. [6] have studied the hydro magnetic free convective Revlin-Ericksen flow through a porous medium

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with variable permeability. Suneetha et al. [7] studied the radiation and mass transfer effects on MHD free convective dissipative fluid in the presence of heat source / sink. Later Vasu et al. [8] studied the radiation and mass transfer effects on transient free convection flow of a dissipative fluid past semi-infinite vertical plate with uniform heat and mass flux. Prasad et al. [9] have studied the finite difference analysis of radioactive free convection flow past an impulsively started vertical plate with variable heat and mass flux. Seth et al. [10] studied the effects of rotation and magnetic field on unsteady coquette flow in a porous channel. Singh and Kumar [11] have studied the fluctuating heat and mass transfer on unsteady MHD free convection flow of radiating and reacting fluid past a vertical porous plate in slip-flow regime. Das et al. [12] have studied the mass transfer effects on unsteady hydro magnetic convective flow past a vertical porous plate in a porous medium with heat source. Reddy and Reddy [13] studied the mass transfer and heat generation effects on MHD free convective flow past an inclined vertical surface in a porous medium.

The effect of chemical reaction on heat and mass transfer in a laminar boundary layer flow has been studied under different conditions by several authors. The effect of a chemical reaction on moving isothermal vertical surface with suction has been studied by Muthucumarswamy [14].Manivannan et.al. [15] has investigated radiation and chemical reaction effects on isothermal vertical oscillatory plate with variable mass diffusion. Sharma et.al. [16] studied the influence of chemical reaction and radiation on unsteady MHD free convective flow and mass transfer through viscous incompressible fluid past a heated vertical plate immersed in porous medium in presence of heat source. Mahapatra et.al. [17] studied the effects of chemical reaction on free convection flow through a porous medium bounded by a vertical surface. Rajsekhar et.al.[18], Kishan and Srinivas[19],Anjalidevi and David[20],Kishan and Deepa[21] and Gaikwad and Rahuldev[22] studied the effects of various parameters on fluid flow. Recently, Suresh [23] extended the problem of Maharshi and Tak [24] to memory fluid i.e. Walter's liquid model B′ [27] with variable suction in the presence of radiation and permeability.

The aim of this paper is to extend the problem of Maharshi and Tak [24] to memory fluid i.e. Walter's liquid model B′ [28] with variable suction in the presence of radiation and chemical reaction. The mixture of polymethyl mehacrylate and pyridine at 25^0 C containing 30.5g of polymer per litre behaves very nearly as the above mentioned liquid.

2. Formulation of the problem

We consider the flow of convective memory fluid through a porous medium bounded by an infinite vertical porous plate with constant heat flux under the influence of uniform transverse magnetic field. The x^* - axis is taken along the plate in the upward direction and y^* - axis normal to it. All the fluid properties are assumed to be constant, except that influence of the density variations with temperature is considered only in the body force term. The magnetic field of small intensity H_0 is induced in the y^* - direction. Since the fluid is slightly conducting, the magnetic Reynolds number is far lesser than unity; hence the induced magnetic field is neglected in comparison with the applied magnetic field following Sparrow and Cess [25]. The viscous dissipation and Darcy's dissipation terms are neglected for small velocities following Rudraiah et al. [26]. The flow in the medium is entirely due to buoyancy force. A chemically reactive species are emitted from the vertical surface in to a hydrodynamic flow field .It diffuses into the fluid when it undergoes a homogenous chemical reaction. The reaction is assumed to take place entirely in the stream. The fluid is a grey, absorbing-emitting radiation but non-scattering medium . So under these conditions the flow with variable suction is governed by the following equations:

$$v^* = -v_0(1+\varepsilon e^{i\omega t}) \qquad (1)$$

$$\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*} = g\beta_1(T^* - T_\infty{}^*) + g'\beta_2(c^* - c_\infty{}^*) + \vartheta\frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\vartheta u^*}{k_0^*(t)} - \beta\left(\frac{\partial^3 u^*}{\partial t^*\partial y^{*2}} + v^*\frac{\partial^3 u^*}{\partial y^{*3}}\right) - \left(\frac{\sigma\mu^2{}_e H^2{}_0}{\rho}\right)u^* \qquad (2)$$

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \frac{k^*}{\rho c_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y^*} \qquad (3)$$

$$\frac{\partial c^*}{\partial t^*} + v^*\frac{\partial c^*}{\partial y^*} = D_M\frac{\partial^2 C^*}{\partial y^{*2}} + D_T\frac{\partial^2 C^*}{\partial y^{*2}} - R^*((c^* - c_\infty{}^*)$$
(4)

The corresponding boundary conditions are

$$\left.\begin{array}{llll} y^* = 0,\ u^* = 0 & \frac{\partial T^*}{\partial y^*} = \frac{-q}{k}, & c^* = c_w^* + \varepsilon(c_w^* - c_\infty^*)e^{i\omega * t*}, & \\ y^* \to \infty; & u^* = 0, & T^* = T_\infty^*, & c^* = c_\infty^*, \end{array}\right\}$$
(5)

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$$-\frac{\partial q_r}{\partial y*} = 4d\sigma^*\left({T^*}^4_w - {T^*}^4\right) = 16d\sigma^*\, {T^*}^3_w({T^*}_w - T^*) \qquad (5')$$

Introducing the following non-dimensional quantities

$$y = \frac{y^* v_0}{\vartheta},\ t = \frac{t^* v_0^2}{4\vartheta},\quad \omega = \frac{4\vartheta\omega^*}{v_0^2},\quad u = \frac{u^*}{v_0},\quad G_r = \frac{g\beta_1 q\vartheta^2}{kv_0^4}$$

$$;P_r = \frac{\mu c_p}{k};\quad G_c = \frac{g'\beta_2 q\vartheta^2}{kv_0^4};\ s0 = \frac{D_T q}{(c_w^* - c_\infty^*)kv_0}$$

$$R_m = \frac{\beta v_0^2}{\vartheta^2};\quad M = \frac{\sigma\mu_e^2 H_0^2}{v_0^2\rho};\ \theta = \frac{(T^* - T_\infty^*)kv_0}{q\vartheta};\quad F = \frac{16d\sigma^* {T_w^*}^3\vartheta^2}{kv_0^2}$$

$$.\ k_0 = \frac{k_0^* v_0^2}{\vartheta^2};\ kc = \frac{R^*\vartheta}{v_0^2};\quad c = \frac{c^* - c_\infty^8}{c_w^* - c_\infty^*};$$

The equations (2) – (5) reduces to

$$\frac{1}{4}\frac{\partial u}{\partial t} - (1 + \varepsilon e^{i\omega t})\frac{\partial u}{\partial y} = G_r\theta + G_c c + \frac{\partial^2 u}{\partial y^2} - R_m\left\{\frac{1}{4}\frac{\partial^3 u}{\partial t\partial y^2} - (1 + \varepsilon e^{i\omega t})\frac{\partial^3 u}{\partial y^3}\right\} - \left(M + \frac{1}{k_0}\right)u \qquad (6)$$

$$\frac{1}{4}\frac{\partial\theta}{\partial t} - (1 + \varepsilon e^{i\omega t})\frac{\partial\theta}{\partial y} = \frac{1}{P_r}\frac{\partial^2\theta}{\partial y^2} - F\theta \qquad (7)$$

$$\frac{1}{4}\frac{\partial c}{\partial t} - (1 + \varepsilon e^{i\omega t})\frac{\partial c}{\partial y} = \frac{1}{s_c}\frac{\partial^2 c}{\partial y^2} + s_0\frac{\partial^2\theta}{\partial y^2} - k_c c \qquad (8)$$

$$y = 0,\quad u = 0,\quad c = 1 + \varepsilon e^{i\omega t}$$
$$y \to \infty;\quad u = 0,\quad c = 0 \qquad (9)$$

II. METHOD OF SOLUTION

Let us assume the solution of the form

$$\left.\begin{aligned} u(y,t) &= u_0(y) + \varepsilon e^{i\omega t}u_1(y) + ----\\ \theta(y,t) &= \theta_0(y) + \varepsilon e^{i\omega t}\theta_1(y) + -----\\ c(y,t) &= c_0(y) + \varepsilon e^{i\omega t}c_1(y) + ----- \end{aligned}\right] \qquad (10)$$

Substituting equation (10) in equations (7) – (9)

We get

$$R_m u_0''' + u_0'' + u_0' - \left(M + \frac{1}{k_0}\right)u_0 = -G_r\theta_0 - G_c c_0 \quad (11)$$

$$R_m u_1''' + \left(1 - \frac{iR_m\ \omega}{4}\right)u_1'' + u_1' - \left(M + \frac{1}{k_0} + \frac{i\omega}{4}\right)u_1 = -G_r\theta_1 - G_r c_1 - u_0' - R_m u_0''' \qquad (12)$$

$$\theta_0'' + P_r\theta_0' - P_r F\theta_0 = 0 \qquad (13)$$

$$\theta_1'' + P_r\theta_1' - P_r\left(F + \frac{i\omega}{4}\right)\theta_1 = -P_r\theta_0' \qquad (14)$$

$$c_0'' + s_c c_0' - k_c s_c c_0 = -\theta_0'' s_c s_0 \qquad (15)$$

$$c_1'' + s_c c_1' - s_c\left(k_c + \frac{i\omega}{4}\right)c_1 = -s_c c_0' - s_c s_0\theta_1''$$

$$y = 0,\quad u_0 = 0,\ u_1 = 0,\quad \theta_0' = -1,\quad c_0 = 1,\quad c_1 = 1$$
$$y \to \infty;\ u_0 = 0,\ u_1 = 0,\ \theta_0 = 0, \theta_1 = 0, c_0 = 0,\ c_1 = 0 \qquad (17)$$

Equations (11) and (12) are third order differential equations when Rm ≠ 0 and we have two boundary conditions, so we follow Beard and Walter's [29] and assume u_0 and u_1 of the form

$$u_0 = u_{01} + R_m u_{02} + 0(R_m^2) \qquad (18)$$

$$u_1 = u_{11} + R_m u_{12} + 0(R_m^2) \qquad (19)$$

Putting u_0 and u_1 from (18) and (19) in (11) and (12) and comparing the terms independent of R_m and coefficients of R_m, and neglecting those of $o(R_m^2)$ we get

$$u_{01}'' + u_{01}' - \left(M + \frac{1}{k_0}\right)u_{01} = -G_r\theta_0 - G_c c_0 \quad (20)$$

$$u_{01}''' + u_{02}'' + u_{02}' - \left(M + \frac{1}{k_0}\right)u_{02} = 0 \qquad (21)$$

$$u_{01}'' + u_{11}' - \left(M + \frac{1}{k_0} + \frac{i\omega}{4}\right)u_{11} = -G_r\theta_1 - G_c c_1 - u_{01}' \qquad (22)$$

$$\left.\begin{aligned}\frac{\partial\theta}{\partial y} &= -1,\\ \theta &= 0,\end{aligned}\right\}$$

$$u_{11}''' - \frac{i\omega}{4}u_{11}'' + u_{12}'' + u_{12}' - \left(M + \frac{1}{k_0} + \frac{i\omega}{4}\right)u_{12} = -u_{02}' - u_{01}''' \qquad (23)$$

With boundary equations

$$\left.\begin{aligned} y = 0,\quad & u_{01} = 0\quad u_{02} = 0\quad u_{11} = 0,\quad u_{12} = 0\\ y \to \infty;\quad & u_{01} = 0,\quad u_{02} = 0,\ u_{11} = 0,\ u_{12} = 0 \end{aligned}\right\} \qquad (24)$$

The velocity, temperature and mass fields are given by

$$u = u_0 + \varepsilon u_1 = u_{01} + R_m u_{02} + \varepsilon(u_{11} + R_m u_{12}) \qquad (25)$$

$$\theta = \theta_0 + \varepsilon\theta_1 \qquad (26)$$

$$c = c_0 + \varepsilon c_1 \qquad (27)$$

Taking real part of solution for the velocity field and temperature field. These can be expressed in terms of fluctuating part as

$$u(y,t) = u_0(y) + \varepsilon(M_r\cos\omega t - M_i\sin\omega t) \quad (28)$$

$$\theta = \theta_0(y) + \varepsilon(N_r\cos\omega t - N_i\sin\omega t) \quad (29)$$

Where

$$M_r + iM_i = u_1(y) \quad (30)$$

$$N_r + iN_i = \theta_1(y) \quad (31)$$

The expressions of transient velocity and transient temperature for $\omega t = \pi / 2$ are given by

$$u\left(y,\frac{\pi}{2\omega}\right) = u_0(y) - \varepsilon M_i \quad (32)$$

$$\theta\left(y,\frac{\pi}{2\omega}\right) = \theta_0(y) - \varepsilon N_i \quad (33)$$

The skin friction at the plate in terms of amplitude and phase is given by

$$C_f = \frac{\tau_\omega}{\varrho v_0^2} = \left(\frac{\partial u}{\partial y}\right)_{y=o} = (B_2 - G_1)(m_1 + m_5) + G_2(m_3 - m_5) + R_m\left[(B_2 - G_1)\{T_1(m_1 - m_6)\} + (B_2 - G_1 + G_2)\frac{m_5^3}{1-2m_5} + G_2\{T_3(m_3 - m_6\}\right] + \varepsilon|\lambda|\cos(\omega t + \alpha) \quad (34)$$

Where

$\lambda_r + i\lambda_i = \lambda$ and $\tan\alpha = \frac{\lambda_i}{\lambda_r}$

III Result and Discussion

We observe from Figure 1 that for all values considered of Prandtl number Pr, Hartmann number M, Permeability number k_0 and Radiation parameter F, the mean transient velocity decreases for $k_c > 0$ and increases for $k_c < 0$ if the value of Gr is decreased. It is observed that mean transient velocity for $k_c < 0$ is always greater than mean transient velocity for $k_c > 0$ .The mean transient velocity increases if values of m and F are increased , decreases if values of M and m are increased and increases if value of k_0 is increased for fixed values of other parameters. Figure 2 represents the transient velocity profile for Prandtl number Pr, frequency ω, Hartmann number M, Grashof number Gr, permeability k_0 , radiation parameter F and chemical reaction parameter k_c . It is observed that transient velocity is also always greater for $k_c < 0$ than for $k_c > 0$ .It is also observed that transient velocity increases in the presence of F and k_c and it increases with increase of m and decreases with the increase of M.Transient velocity also increases due to increase in F and m simultaneously.

Figure 3 and Figure 4 represent the fluctuating parts of transient velocity and it is found that M_r and M_i are both positive for all values of Pr, ω, M, Gr,k_0 , F and k_c .It is observed that Mi decreases and Mr increases with increasing of m and but both Mr and Mi increase if M is increased and same trend is observed when F is increased. It is also observed that values of Mi rises sharply at the vicinity of the plate and then falls sharply as one moves away from the plate whereas Mr rises moderately at the vicinity of the plate and then falls moderately as one moves away from the plate .

Figure 5 represents mean concentration of the flow field. It is observed that mean concentration increases for $k_c < 0$ and decreases for $k_c > 0$ .If Sr is doubled concentration increases in both the cases but increase is more in case of $k_c < 0$ than for $k_c > 0$ .Figure 6 represents concentration of the main flow field. It is observed that concentration increases for $k_c < 0$ and decreases for $k_c > 0$ .Concentration further decreases in both the cases but decrease in concentration is less in case of $k_c < 0$ as compared to the concentration in case of $k_c > 0$ if value of F is doubled.

Figure 7 represents the mean temperature for Prandtl number Pr and Radiation parameter F and it is observed that mean temperature decreases with increasing of F. Figure 8 represents the effect of Pr and F on the temperature profile for fixed values of k_0,M,Gr and

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frequency ω and it is observed that temperature decreases with increasing of F.

For phase and amplitude of the skin friction we observe from Figure 9 and Figure 10 that phase tanα remains positive for different values of k_c, F and frequency ω .This means that there is always a phase lead. It is observed that values of tanα are greater for $k_c < 0$ than the values of tanα for $k_c > 0$ .The phase tanα increases with increasing of F for $k_c < 0$ and for $k_c > 0$ .The amplitude IλI decreases with increasing of F for $k_c < 0$ and for $k_c > 0$.

IV. Nomenclature

u, v, --- dimensionless velocity components of the fluid; θ ---- dimensionless fluid temperature ;

u^*, v^* -- velocity components of the fluid ; M ---- Hartmann number ;

T^* ---- temperature of the fluid; T^*_∞ --- temperature of fluid away from the plate ;

C_p --- specific heat at constant pressure; v_0 - suction velocity

x^*, y^* -- Co-ordinate axis ; x, y -- dimensionless co-ordinate axis

T^*_∞ -- Temperature of fluid away from the plate; G_r --- Grashof number

T^*_w -- Temperature of fluid at the plate ; , ω ------ the frequency of fluctuation

R_m --- magnetic Reynolds number; β_1 ---- coefficient of thermal expansion

D_M -----co-efficient of mass diffusivity D_T ----- co-efficient of thermal diffusivity

k^* --- thermal conductivity; H_0 ---------- magnetic intensity

P_r --- Prandtl number; ϑ ---- kinematic viscosity

ρ ----- density; μ_e ---- magnetic permeability

q ---- heat flux at the plate; σ ---- electrical conductivity

F ---- radiation parameter; β ----- kinematic visco-elasticity,

k_0 ----- dimensionless permeability parameter; t^* --- time;

t --- dimensionless time; k_0^* ----- permeability parameter

S_o ------- soret number c^* ----- concentration of the fluid

V Figures :-

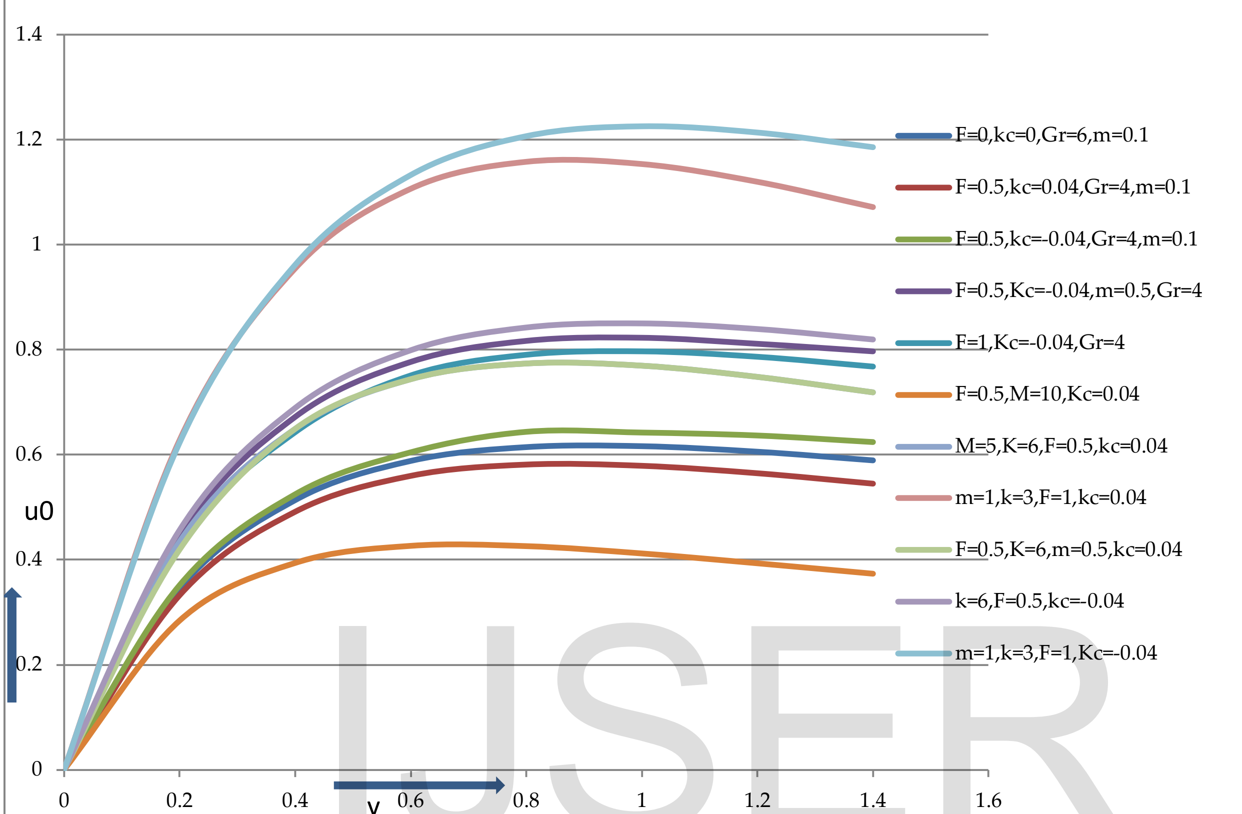

Figure 1: Mean Transient Velocity Profile for Pr.=0.71,M=5,Gr=4.,k =3,Gc=4,sc=0.22,S0=0.4

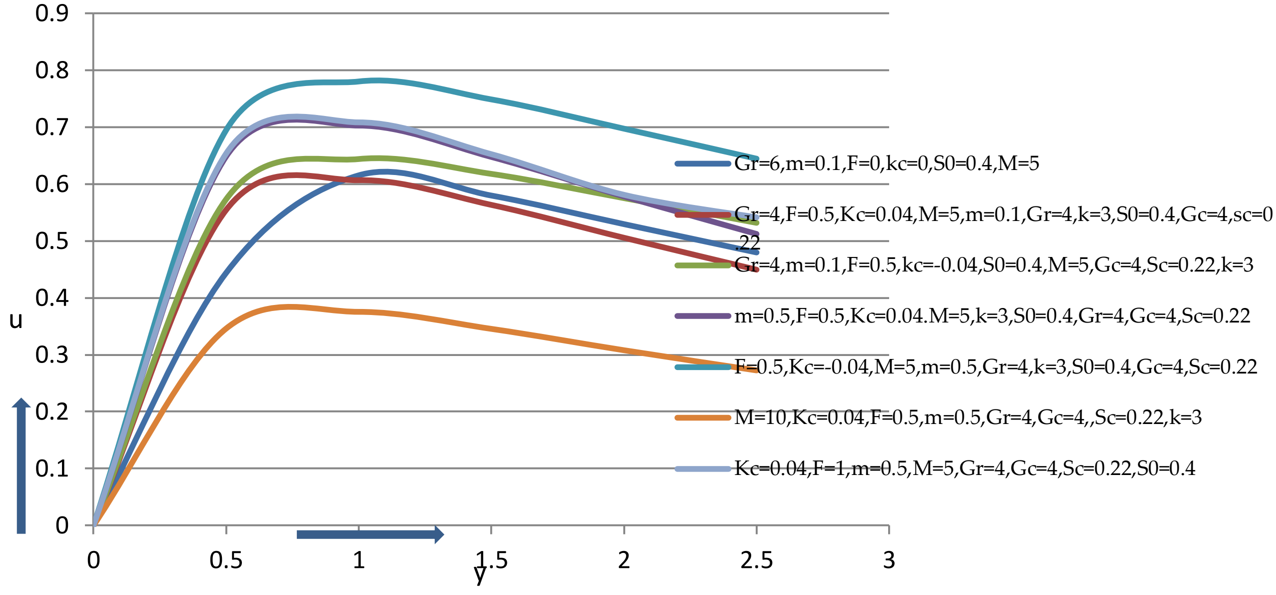

Figure 2:Transient velocity Profile for Pr.=0.71,ω=5, and ωt=π/2.

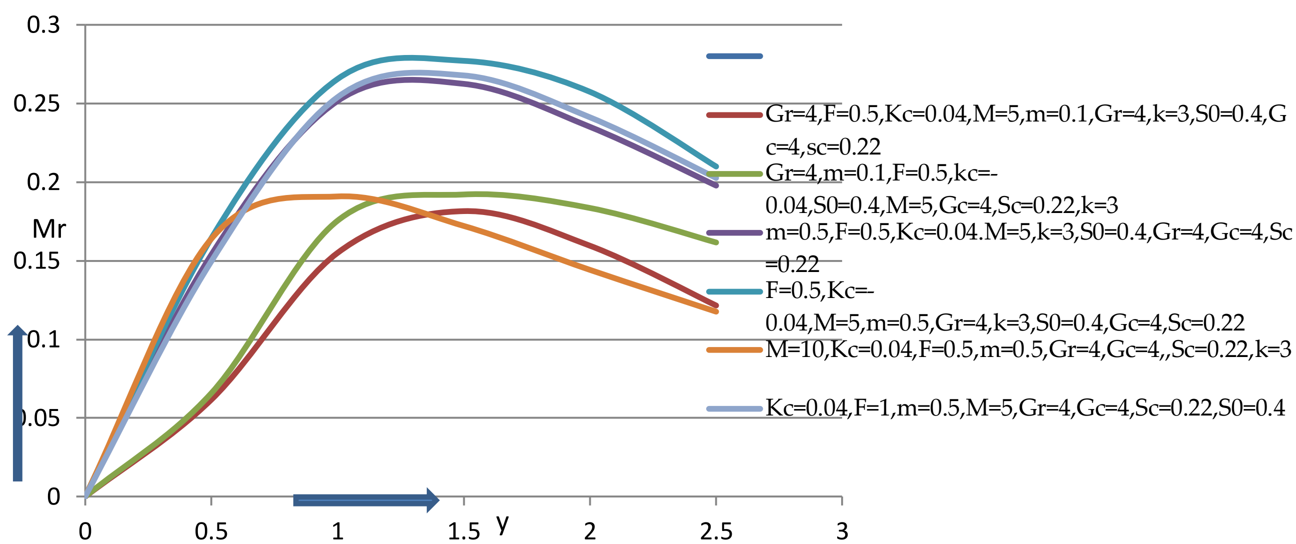

Figure 3:Fluctuating parts of velocity Profile for Pr.=0.71,ω=5, and ωt=π/2.

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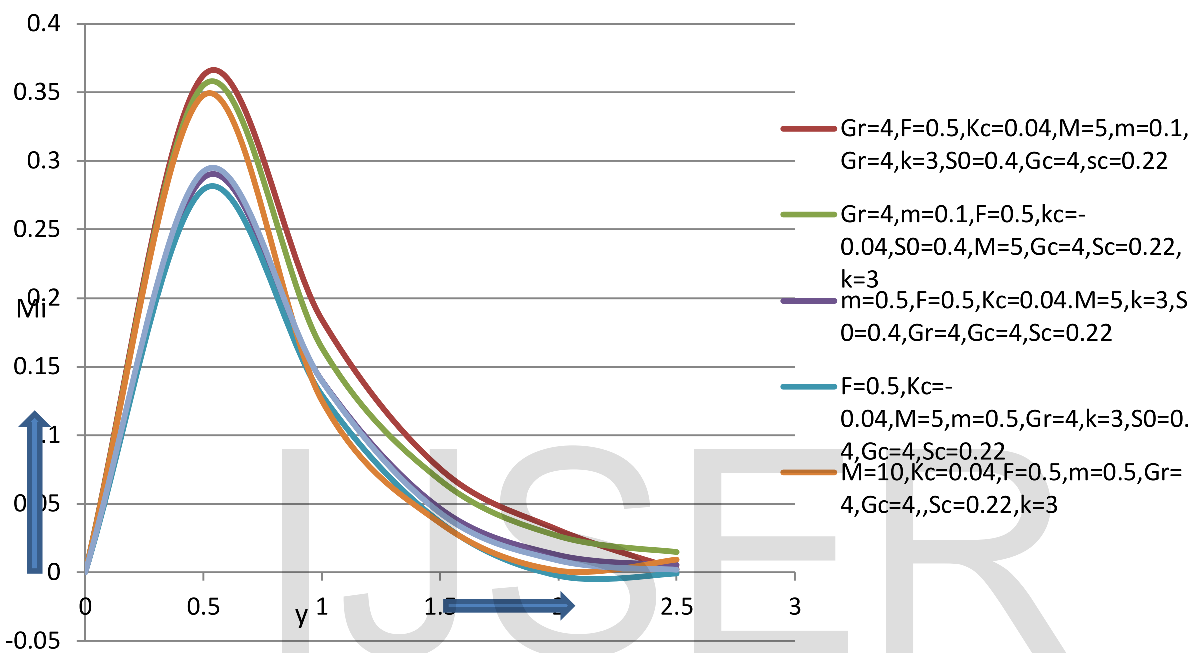

Figure 4:Fluctuating parts of velocity Profile for Pr.=0.71,ω=5, and ωt=π/2.

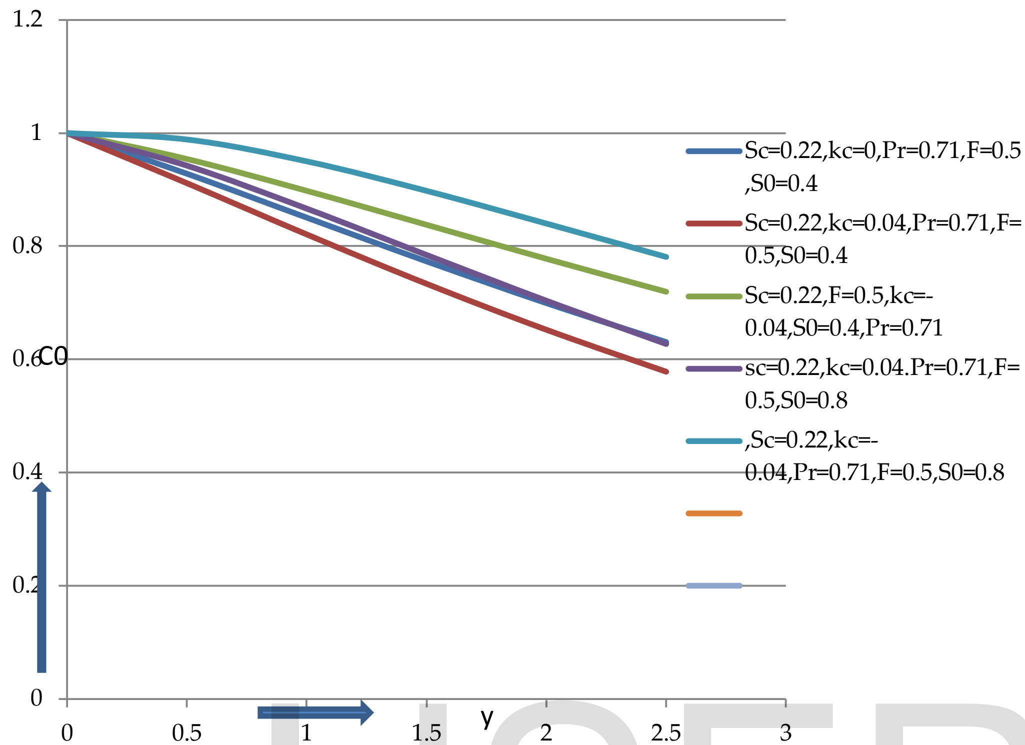

Figure 5:Mean Concentration Profile for Pr.=0.71,ω=5, and $\omega t=\pi/2$.

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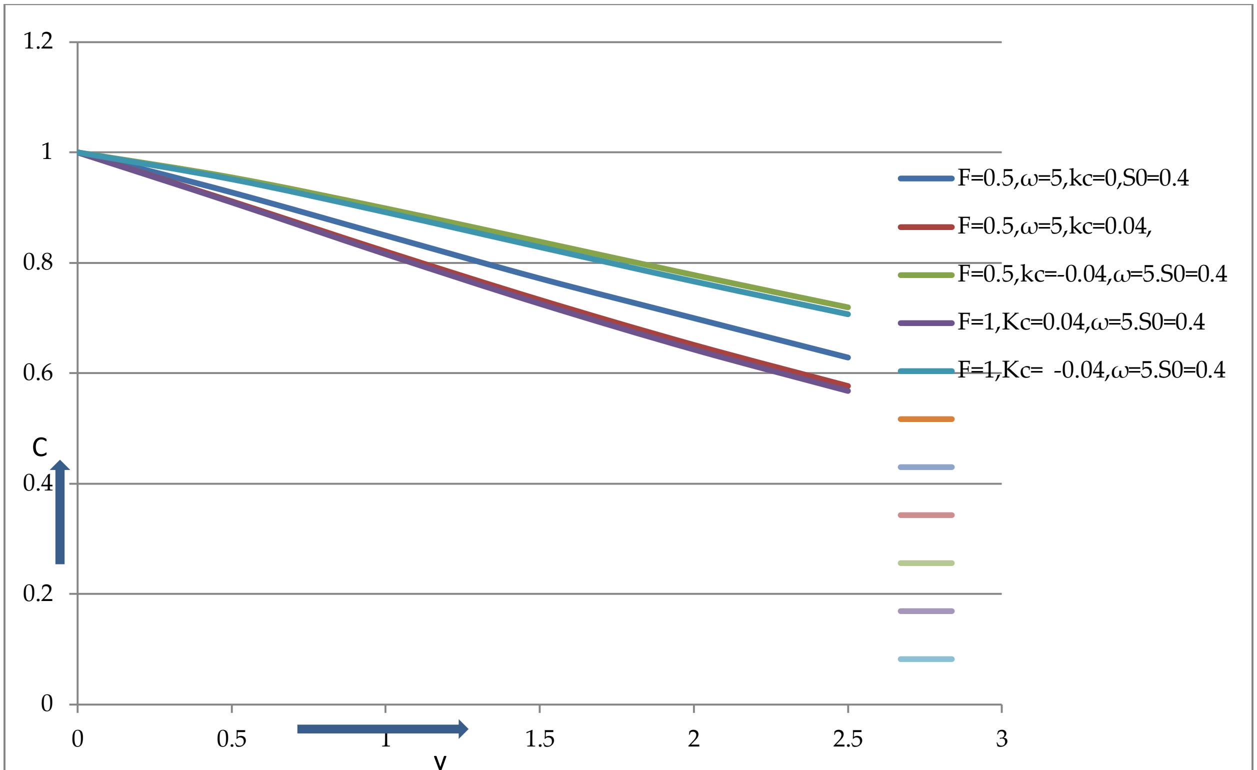

Figure 6: Concentration Profile for Pr,F, Kc,S0,ω

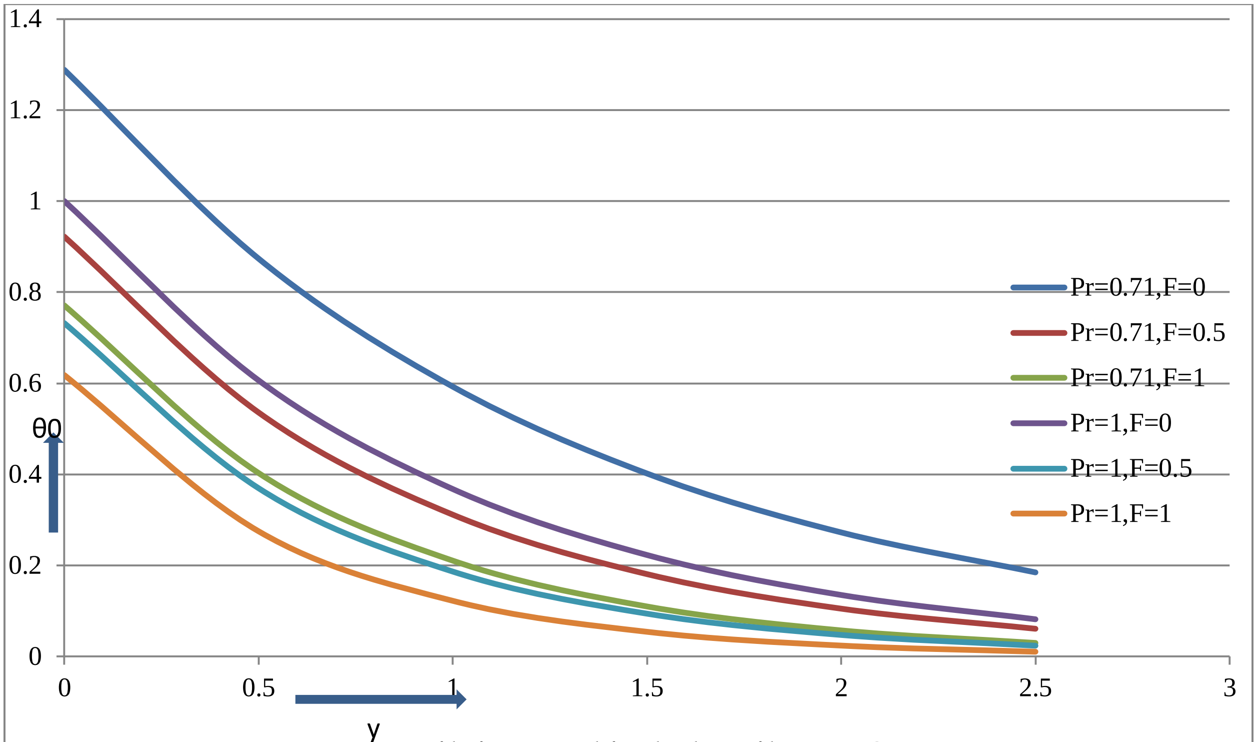

Figure 7:Mean Temperature Profile for Pr,F and fixed values of k=3,M=5,Gr=4.

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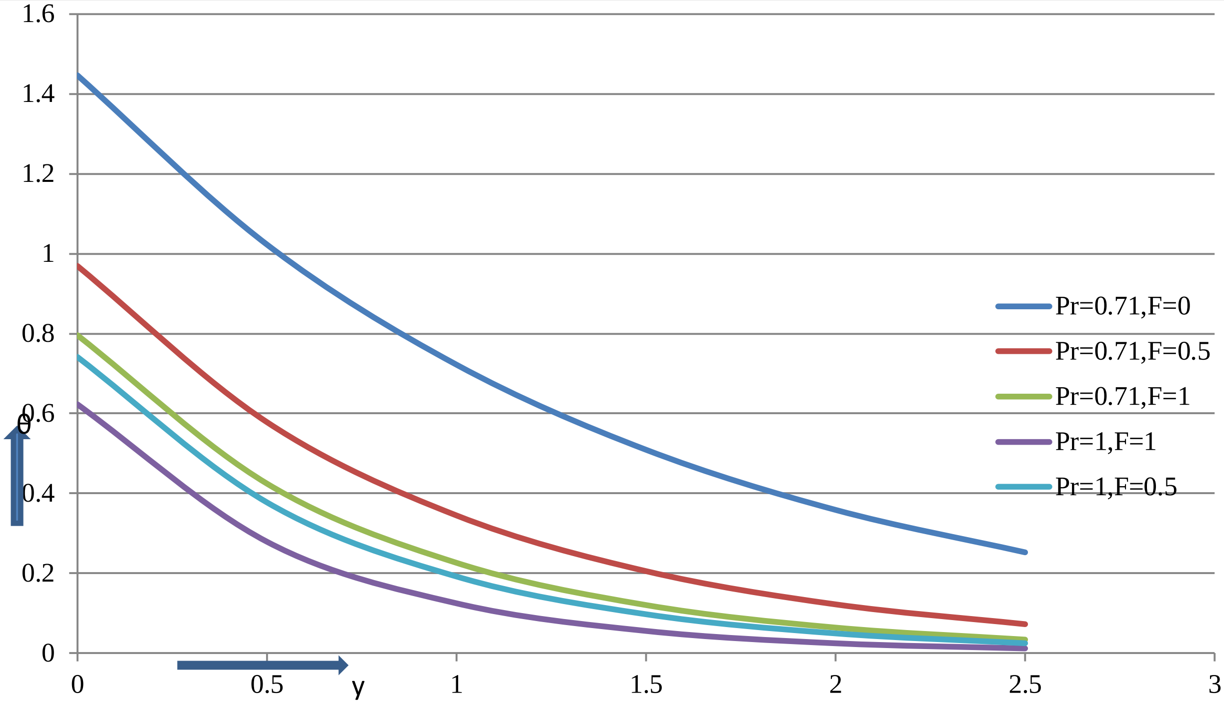

Figure 8: Temperature Profile for Pr,F and fixed values of k=3,M=5,Gr=4,ω=5,ωt=π/2.

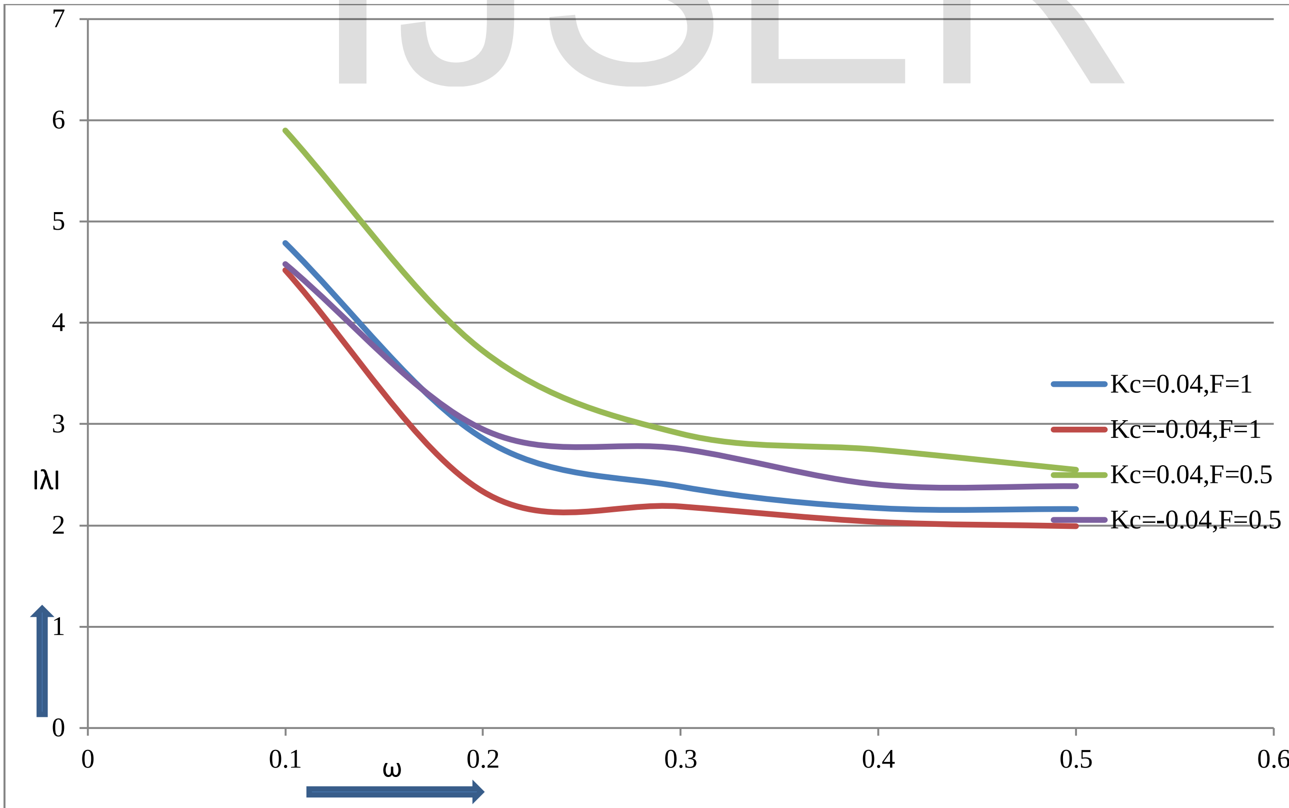

Figure 9: Amplitude for Pr=0.71,Gc=4,m=0.1S0=0.4, k=3,M=5,Gr=4,

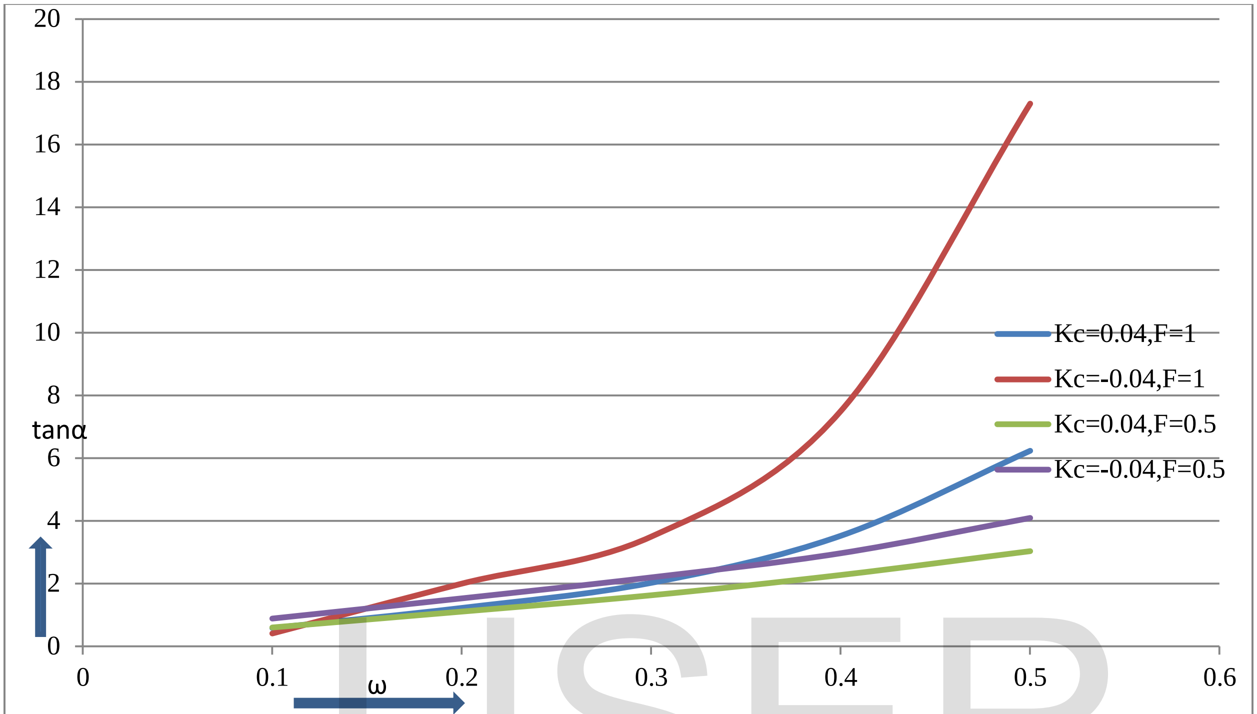

Figure 10: Phase for Pr=0.71,Gc=4,m=0.1S0=0.4, k=3,M=5,Gr=4,

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