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MHD OSCILLATORY FLOW IN A CHANNEL FILLED WITH POROUS MEDIUM IN THE PRESENCE OF CHEMICAL REACTION WITH MASS TRANSFER AND RADIATION

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Abstract

The mass transfer and interaction of radiation in an electrically coordinating fluid through a channel filled with a porous medium has received little curiosity. The study of oscillatory flow of an electrically coordinating fluid through a porous channel soaked with porous medium is important in many physiological flows. The skeletal material is usually a solid, but structure like foams are often usefully analyzed using concept of porous media. The concept of porosity is only straight forward for a poroelastic medium. Hence, an effort is made to explore the combined effects of a radiation and a transverse magnetic field on an unbalanced mass transfer flow with chemical reaction through a channel filled with non-uniform wall temperature and dripped porous medium. The equations of continuity, energy, diffusion, linear momentum which control the flow field are cracked by using an analytical method. The following effects: Prandtl number, Sherwood number and Nusselt number are solved graphically for temperature, velocity and concentration.

Keywords: *Mass Transfer, Radiation, Porous Medium, Combined Effects of a Radiation, Transverse Magnetic Field, And Analytical Method.*

1. Introduction

The study of convective heat and mass transfer from a solid body with particular geometries embedded in a fluid saturated porous medium has various and large applications in many areas of science and engineering such as geothermal reservoirs, drying of porous solids, chemical catalytic reactors, thermal insulators, nuclear waste repositories, heat exchanger devices, enhanced oil and gas recovery, underground energy transport etc. Ingham and Pop (1998) and Nield and Bejan (1998) granted a comprehensive account of the convective heat transfer and fluid flow over porous media. Bejan and Khair (1985) considered one of the most fundamental cases, namely buoyancy-induced heat and mass transfer from a vertical plate embedded in a saturated porous medium. Lai and Kulacki (1991) investigated coupled heat and mass transfer by mixed convection from an isothermal vertical plate in a porous medium. Yih (1997) evaluated the effect of transpiration on coupled heat and mass transfer in mixed convection over a vertical plate embedded in a saturated porous medium. Singh and Mathew (2012) suggested an oscillatory free convective flow through a porous medium in a rotating vertical porous channel.

2. MATHEMATICAL ANALYSIS

An unsteady two dimensional convective heat and mass transfer flow of a viscous, incompressible, electrically conducting optically thin fluid in a channel filled with saturated porous medium with chemical reaction is studied. A uniform applied homogenous magnetic field is treated in the transverse direction. It is assumed that the fluid has small electrical conductivity and the electromagnetic force formed is very small. A homogenous first order chemical reaction between fluid and the species concentration is considered, in which the rate of chemical reaction is directly proportional to the species concentration. A Cartesian coordinate system (x', y') is assumed, where x'-axis lies along the center of the channel and y'-axis in the normal direction. Then, under the normal Boussinesq's approximation, the equations governing flow field under consideration are,
Momentum equation:

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$$\frac{\partial u'}{\partial t'} = -\frac{1}{\rho}\frac{\partial P'}{\partial x'} + v\frac{\partial^2 u'}{\partial y'^2} - \frac{v}{K'}u' - \frac{\sigma_e B_o^2}{\rho}u' + g\beta(T' - T_o') + g\beta^*(C' - C_o') \quad (1)$$

Energy equation:

$$\frac{\partial T'}{\partial t'} = \frac{K}{\rho c_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y'} \quad (2)$$

Species equation:

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} - K_r'(C' - C_o') \quad (3)$$

The boundary conditions for the velocity, temperature and concentration fields are:

$u' = 0,\ T' = T_w', C' = C_w'$ on $y' = 1$

$u' = 0,\ T' = T_o', C' = C_o'$ on $y' = 0$ (4)

Where u' is the axial velocity, t' - the time, T' - the fluid temperature, P' - the pressure, g- the gravitational force, q_r – the radiative heat flux , β and β^* - the coefficient of volume expansion due to temperature and concentration , c_p – the specific heat at constant pressure, k the thermal conductivity, K' - the porous medium permeability coefficient, $B_0 = (\mu_e H_0)$ – the electromagnetic induction, μ_e – the magnetic permeability, H_0- the intensity of magnetic field, σ_e – the conductivity of the fluid, ρ – the fluid density and v – the kinematic viscosity coefficient.

It is assumed that the temperature of the walls T_o' , T_W' are high sufficient to induce radiative heat transfer. Following Cogley et al. (1968), it is assumed that the fluid is optically thin with a relatively low density and the radiative heat flux is given by:

$$\frac{\partial q_r}{\partial y'} = 4\alpha^2(T_o' - T'), \quad (5)$$

Where α – is the mean radiation absorption coefficient.

In order to write the governing equations and the boundary conditions in dimensionless form, the following non-dimensional quantities are introduced.

$$x = \frac{x'}{a}, y = \frac{y'}{a}, u = \frac{u'}{a}, t = \frac{t'U}{a}, Re = \frac{Ua}{v}$$

$$\theta = \frac{T' - T_o'}{T_W' - T_o'}, \phi = \frac{C' - C_o'}{C_W' - C_o'}, P = \frac{aP'}{\rho v U}, Da = \frac{K'}{a^2}$$

$$H^2 = \frac{a^2\sigma_e B_o^2}{\rho v}, Gr = \frac{g\beta(T' - T_o')a^2}{vU}, N^2 = \frac{4\alpha^2 a^2}{K}, Gc = \frac{g\beta^*(C' - C_o')a^2}{vU}$$

$$Pr = \frac{\rho v c_p}{k}, Sc = \frac{v}{D}, Kr = \frac{Kr'a}{U} \quad (6)$$

Where, U is the flow mean velocity and a being the width of the channel.

In view of the Eq. (6), the equations (1) – (3) reduce to the following dimensionless form:

$$Re\frac{\partial u}{\partial t} = -\frac{\partial P}{\partial x} + \frac{\partial^2 u}{\partial y^2} - (s^2 + H^2)u + Gr\theta + Gc\phi \quad (7)$$

$$Pr\frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + N^2\theta \quad (8)$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{ScRe}\frac{\partial^2 \phi}{\partial y^2} - Kr^2\phi \quad (9)$$

The corresponding boundary conditions are:

u= 0, θ = 1, ϕ = 1 on y=1

u= 0, θ = 0, ϕ = 0 on y=0 (10)

where *Gr, Gc, H, N, Pr, Re, Da, s= (1/Da), Sc, Kr* are thermal Grashoff number, solutal Grashof number, Hartmann number, Radiation parameter, Prandtl number, Reynolds number, Darcy number, porous medium shape factor parameter, Schmidth number and chemical reaction parameter respectively.

3. Solution of the problem

In order to solve Eqs. (7)- (10) for purely oscillatory flow, let

$-\frac{\partial P}{\partial x} = \lambda e^{i\omega t}$,u(y,t) = u_0(y) $e^{i\omega t}$, θ(y,t) = θ_0(y) $e^{i\omega t}$,

ϕ(y,t) = ϕ_0(y) $e^{i\omega t}$ (11)

Where λ is a constant and ω is the frequency of the oscillation.

Substituting the above expressions in Eq. (11) into Eqs. (7) –(10), we obtain,

$$\frac{d^2u_0}{dy^2} - m_3^2 u_0 = -\lambda - Gr\theta_0 - Gc\phi_0 \quad (12)$$

$$\frac{d^2\theta_0}{dy^2} + m_1^2\theta_0 = 0 \quad (13)$$

$$\frac{d^2\phi_0}{dy^2} + m_2^2\phi_0 = 0 \quad (14)$$

The corresponding boundary conditions are:

$u_0 = 0,\ \theta_0 = 1,\ \phi_0 = 1$ on $y=1$

$u_0 = 0,\ \theta_0 = 0,\ \phi_0 = 0$ on $y=0$ (15)

where

$$m_1 = \sqrt{N^2 - i\omega Pr}\ ,\quad m_2 = \sqrt{Kr^2 ScRe + i\omega ScRe}\ ,\quad m_3 = \sqrt{s^2 + H^2 + i\omega Re}$$

Solving the Eqs. (12)- (14) subject to boundary conditions (15), we obtain the fluid velocity, temperature and concentration as follows:

$$\theta(y,t) = \frac{\sin(m_1 y)}{\sin m_1} e^{i\omega t} \quad (16)$$

$$\phi(y,t) = \frac{\sinh(m_2 y)}{\sin m_2} e^{i\omega t} \quad (17)$$

$$u(y,t) = u_0(y)\, e^{i\omega t} \quad (18)$$

where

$$u_0(y,t) = \frac{Gr}{m_1^2+m_3^2}\left(\frac{\sin(m_1 y)}{\sin m_1} - \frac{\sinh(m_3 y)}{\sin h m_3}\right) + \frac{Gc}{m_2^2+m_3^2}\left(\frac{\sinh(m_3 y)}{\sinh m_3} - \frac{\sinh(m_2 y)}{\sinh m_2}\right) + \frac{\lambda \sin h(m_3 y)}{m_3^2 \sin m_3}(\cos m_3 - 1) + \frac{\lambda}{m_3^2}(1 - \cos h m_3\, y)$$

The skin-friction, Nusselt number and Sherwood number are essential physical parameters for this type of boundary layer flow.

Knowing the velocity field, the skin-friction at both the walls of the channel can be obtained, which in non-dimensional form is given by:

$$\tau = -\mu\left(\frac{\partial u}{\partial y}\right)_{y=0,1}$$

$$= \frac{Gr}{m_1^2+m_3^2}\left(\frac{m_1\cos(m_1 y)}{\sin m_1} - \frac{m_3\cos h(m_3 y)}{\sinh m_3}\right) + \frac{Gc}{m_2^2-m_3^2}\left(\frac{m_3\cos h(m_3 y)}{\sinh m_3} - \frac{m_2\cos h(m_2 y)}{\sinh m_2}\right) e^{i\omega t}$$

$$+ \frac{Gc}{m_2^2-m_3^2}\left(\frac{\lambda\cos h(m_3 y)}{m_3 \sinh m_3} - (\cosh m_3 - 1)\right) e^{i\omega t} - \frac{Gc}{m_2^2-m_3^2}\left(\frac{\lambda}{m_3}\sinh m_3\, y\right) e^{i\omega t} \quad (19)$$

Knowing the temperature field, the rate of heat transfer coefficient at both walls of the channel can be attained, which in the terms of the Nusselt number, is given by:

$$Nu = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0,1} = -\left(\frac{m_1 \cos m_1 y}{\sin m_1}\right) e^{i\omega t} \quad (20)$$

Knowing the concentration field, the rate of mass transfer coefficient at both walls of the channel can be attained, which in the terms of the Sherwood number, is given by:

$$Sh = -\left(\frac{\partial\phi}{\partial y}\right)_{y=0,1} = -\left(\frac{m_2 \cos m_2 y}{\sinh m_2}\right) e^{i\omega t} \quad (21)$$

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4. Results and Discussion

i. Velocity increases with the increases in radiation parameter Gc, E, Gr
ii. Velocity increases with the decrease in Pr, Sc, w
iii. The temperature increase with increase in N,E
iv. The temperature decrease with decrease in Pr, w
v. The concentration increase with decrease in J and increase with Sc

5. Conclusion

We analyze the effects of chemical reaction reaction, thermal radiation and heat source on MHD oscillatory visco-elastic flow in a channel filled with porous medium. The equations of momentum, energy and diffusion which govern the flow field are solved by using a regular perturbation method.

i. Velocity increases with the increases in radiation parameter Gc, E, Gr
ii. Velocity increases with the decrease in Pr, Sc, w
iii. The Temperature increase with increase in N, E
iv. The Temperature decrease with decrease in Pr, w
v. The concentration increase with decrease in J and increase with Sc

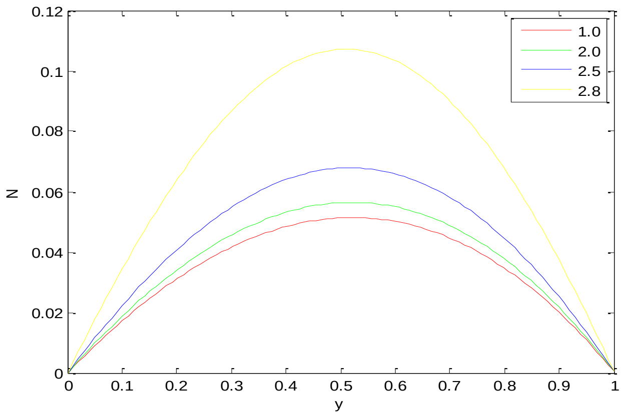

Figure:1 Effect of N velocity

Pr=2.2,E=1.04,i=0.05,w=0.04,S=0.05,H=0.06,t=0.5,Gr=0.1, Gc=0.1,Sc=0.5,N=1.0,2.0,2.5,2.8

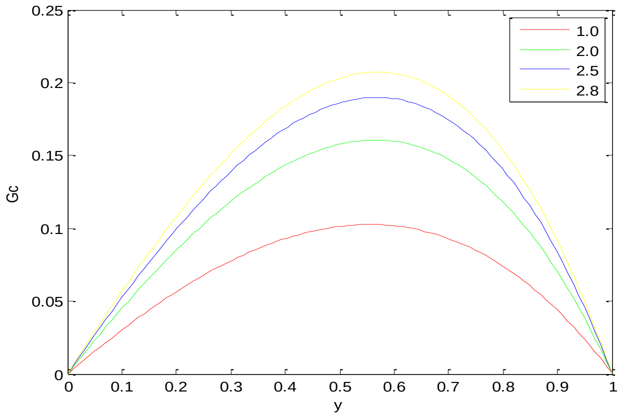

Figure:2 Effect of Gc velocity

Pr=2.2,E=1.04,i=0.05, w=0.04, S=0.05, H=0.06,

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t=0.5,Gr=0.1, N=0.1,Sc=0.5,Gc=1.0,2.0,2.5,2.8

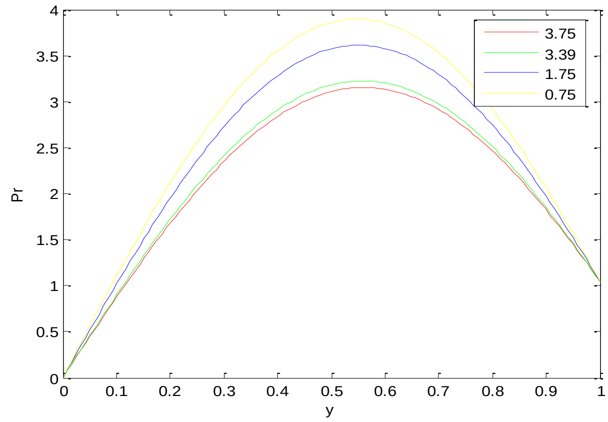

Figure:3 Effect of Pr velocity

N=2.2,E=1.04,i=0.05,w=0.04,S=0.05,H=0.06,t=0.5,Gr=0.1, Gc=0.1,Sc=0.5,Pr=1.0,2.0,2.5,2.8

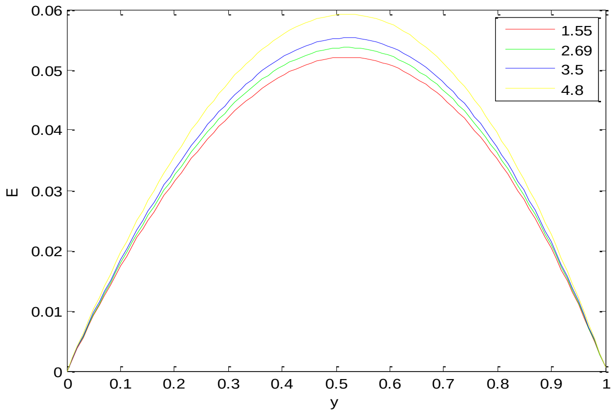

Figure:4 Effect of E velocity

N=2.2,Pr=1.04,i=0.05,w=0.04,S=0.05,H=0.06,t=0.5,Gr=0.1, Gc=0.1,Sc=0.5,E=1.0,2.0,2.5,2.8

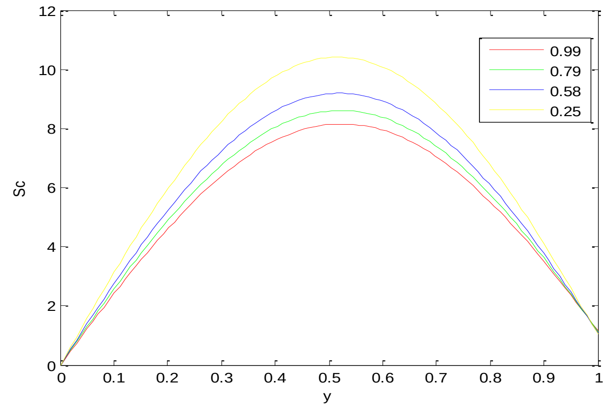

Figure:5 Effect of Sc velocity

N=1.04,Pr=2.2,i=0.05,w=0.04,S=0.05,H=0.06,t=0.5,Gr=0.1, Gc=0.1,Sc=0.5,Sc=0.99,0.79,0.58,0.25

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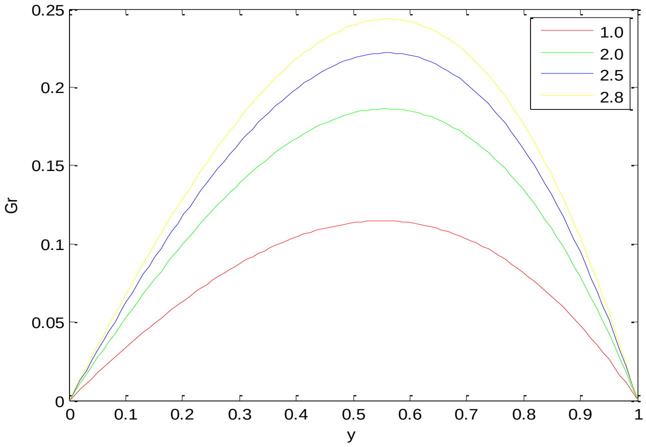

Figure:6 Effect of Gr velocity

Pr=2.2,E=1.04,i=0.05,w=0.04,S=0.05,H=0.06,t=0.5,Gc=0.1, N=0.1,Sc=0.5,Gr=1.0,2.0,2.5,2.8

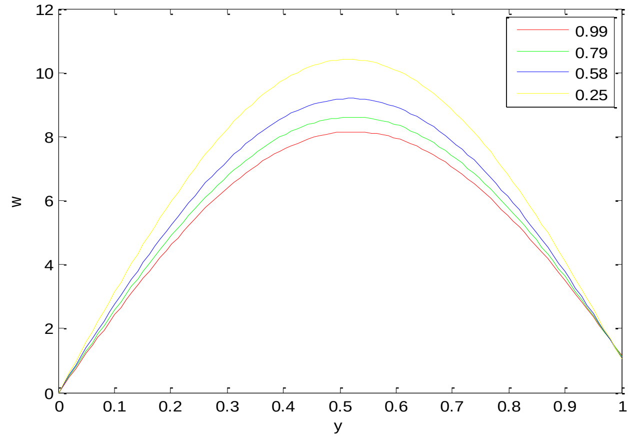

Figure:7 Effect of w velocity

Pr=2.2,E=1.04,i=0.05,Gr=0.04,S=0.05,H=0.06,t=0.5,Gc=0.1, N=0.1,Sc=0.5,w=0.99,0.79,0.58,0.25

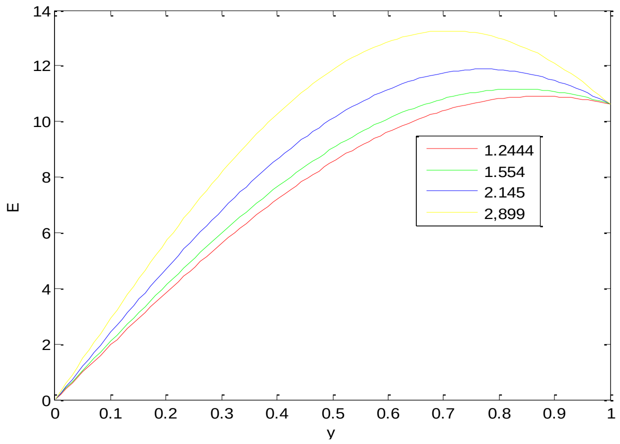

Figure:8 Effect of E on Temperature

E=1.2444,1.554,2.145,2.899, N=1.75, Pr=0.97, w=3.14, t=2.15, i=0.35,

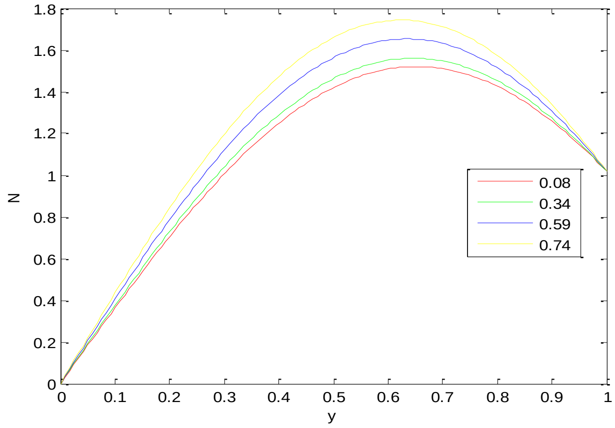

Figure: 9 Effect of N on Temperature
N=0.08,0.34,0.59.0.74, t=0.35, E=5.8,Pr=0.1,w=0.1,i=0.5

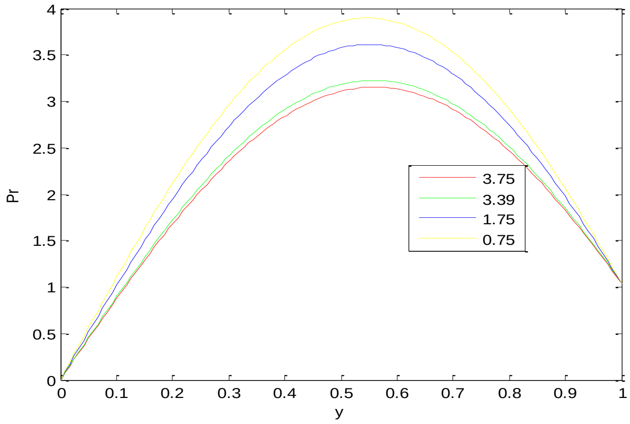

Figure: 10 Effect of Pr on Temperature

Pr=3.75,3.39,1.75,0.75, N=1.75, N=2.2,E=3.5, w=0.25, i=0.5,t=0.31

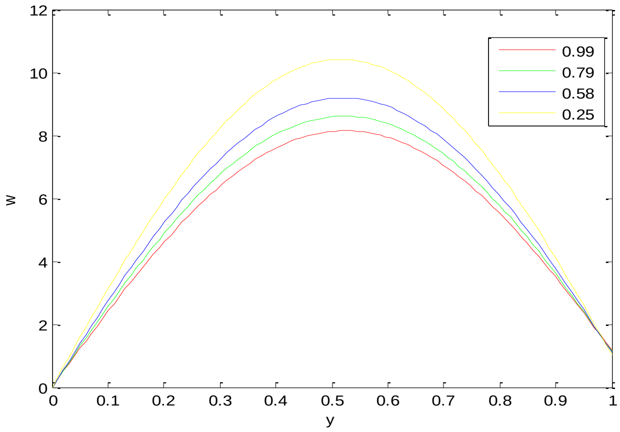

Figure: 11 Effect of won Temperature

w=0.99,0.79,0.58,0.25,t=0.31,i=0.51,N=2.2,E=4.5

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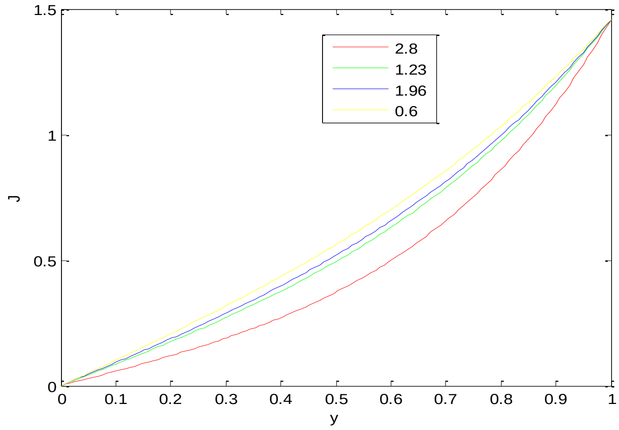

Figure:12 Effect of J on concentration
J=2.8,1.23,1.96,0.6 t=0.7, 0.6, sc=0.5

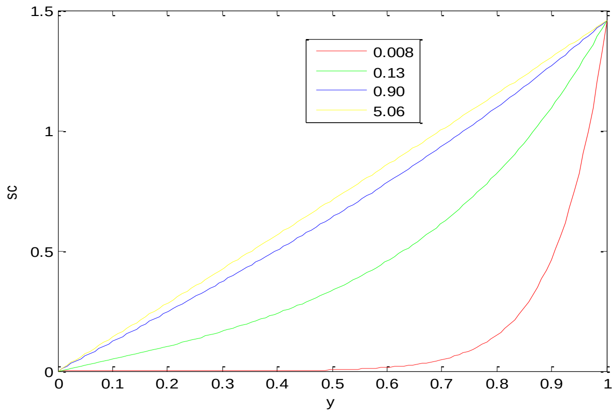

Figure:13 Effect of Sc concentration
Sc=0.008,0.13,0.90,5.06, t=0.7, w=0.6, i=0.9, J=0.5

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