International Journal of Mathematical Archive-6(5), 2015, 46-56
IJMA Available online through www.ijma.info ISSN 2229 – 5046

EFFECT OF POROSITY ON SIMULTANEOUS THERMAL AND MASS DIFFUSION IN MHD MIXED CONVECTION FLOW OVER A VERTICAL SURFACE

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(Received On: 21-04-15; Revised & Accepted On: 21-05-15)

ABSTRACT

The influence of porosity and radiation on simultaneous thermal and mass diffusion of an electrolytic solution past a hot vertical plate with ohmic heating and magnetic field has been examined in this paper.It is observed that, as the porosity of the bounding surface increases the velocityalsoincreases.Also, the velocity is found to be decreasing as the modified Grashoff number decreases. Further, due to increase in the porosity, the velocity is observed to be decreasing. In general it is observed that, the skin friction increases as the Grashoff number increases. In addition to the above it is observed that as magnetic field intensity is increases the skin friction decreases. Further, it is seen that the magnetic field intensity and skin friction are inversely related.

Keywords: *Heat and Mass transfer, Radiation, Skin friction.*

INTRODUCTION

Considerable attention has been paid to study the boundary layer behavior and heat transfer phenomena of a Newtonian fluid past a vertical plate which is embedded in a fluid saturated porous medium due to its extensive applications in science engineering and technology. The problem assumes greater significance due to its transport properties in porous media subject to heat transfer because of its highly non-linear coupled partial differential equations. The problem makes an important role in subjects of Physics, Chemistry and Chemical Technology due to demanding efficient transfer of mass over inclined beds and viscous flow.

It is known that liquids respond like elastic solids to impulses, which are very rapid compared to the time it takes for the molecular order associated with short range forces in the liquid to relax. After this, all liquids behave like viscous fluids with signals propagating by diffusion rather than by waves. For liquids with small molecules, this time of relaxation is estimated around 10^{-13} or 10^{-10} seconds depending on the fluids. Free convective flow involving complete heat and mass transfer occurs in several problems in chemical engineering. The problem assumes greater significance in designing of chemical processing equipment.

The engineering applications include chemical reaction in a reaction chamber, nuclear fossils, chemical vapor deposition on surfaces, cooling and heating of electrical and electronics appliances.In view of the importance of the problem due consideration has been given to the MHD flows where Cramer and Pai[1], contributed significantly.Chien-Hsin-Chen[2]studied the problem of combined heat and mass transfer of an electrically conducting fluid in MHD natural convection, adjacent to a vertical surface by considering theohmic effects. Further, Ghaly*et al*[3] had established that, at high operating temperature, radiation effects can be quiet significant.The effect of ohmic heating for a Newtonian fluid was examined extensively by Hossain[4]. Hossain and Takhar[5]examined the radiation effects on free and forced convection flows past a vertical plate which includes various physical aspects. Muthukumarswamy*et al*[6] studied heat and mass transfer effect on a moving plate in the presence of thermal radiation.

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MATHEMATICAL FORMULATION

The geometry is considered to be x*-axis is taken along the plate.y*-axis is considered to be perpendicular tox* axis and transverse constant magnetic field is applied in the direction of y*-axis. The length of the plate is considered to be sufficiently large so that thevariablesare independent of x*. Further, u* and v* are considered to be velocity components in the x* and y* directions respectively. The equations of continuity, momentum and energy in the presence of concentration and radiation as follows

$$\frac{dv*}{dy*}=0 \tag{1}$$

i.e $v^{*}=-v_{0}$ (constant) (2)

$$\rho v^{*}\frac{du*}{dy*}=\mu\frac{d^{2}u^{*}}{dy^{*2}}+\rho g\beta\left(T^{*}-T_{\infty}\right)-\sigma B_{0}^{2}u^{*}+\rho g\beta^{*}\left(C^{*}-C\infty\right) \tag{3}$$

$$\rho C_{p}v^{*}\frac{dT*}{dy*}=\kappa\frac{d^{2}T^{*}}{dy^{*2}}+\mu\left(\frac{du^{*}}{dy^{*}}\right)^{2}-\frac{\partial q_{r}^{*}}{\partial y^{*}}+\sigma B_{0}^{2}u^{*2} \tag{4}$$

$$v^{*}\frac{dC*}{dy*}=D\frac{d^{2}C^{*}}{dy^{*2}} \tag{5}$$

Here, g is the acceleration due to gravity, T* the temperature of the fluid near theplate, T∞ the free stream temperature, C* concentration, β the coefficient ofthermal expansion, κ the thermal conductivity, p* the pressure, Cp the specificheat of constant pressure, B0 the magnetic field coefficient, μ viscosity of thefluid, q_r* the radioactive heat flux, ρ the density, σ the magnetic permeability offluid V0 constant suction velocity, ν the kinematic viscosity and D molecular diffusivity.

The boundary conditions are

$$y^{*}=0:u^{*}=0,T^{*}=T_{w},C^{\infty}=C$$

$$y^{8}\to\infty:u^{*}\to 0,T^{*}\to T_{\infty},C^{*}\to C_{\infty}. \tag{6}$$

Introducing the following non-dimensional quantities

$$y=\frac{\mathrm{v}_{0}\ \mathrm{y}*}{\mathrm{v}},\quad u=\frac{\mathrm{u}*}{v_{0}},M^{2}=\frac{\mathrm{B}_{0}^{2}\mathrm{v}^{2}\sigma}{\mathrm{v}_{0}^{2}\mu} \tag{7}$$

$$\Pr=\frac{\mu C_{p}}{\kappa},\quad \theta=\frac{\mathrm{T}^{*}-\mathrm{T}_{\infty}}{\mathrm{T}_{\mathrm{w}}-\mathrm{T}_{\infty}},\quad C=\frac{C^{*}-C_{\infty}}{C-C_{\infty}} \tag{8}$$

$$E=\frac{V_{0}^{2}}{C_{P}(T_{W}-T_{\infty})} \tag{9}$$

$$Gr=\frac{\rho g\beta v^{2}(T_{w}-T_{\infty})}{v_{0}^{3}\mu} \tag{10}$$

$$Sc=\frac{v}{D},\quad Gm=\frac{\rho g\beta^{*}(C-C_{\infty})}{v_{0}^{3}}\quad\text{and}\quad F=\frac{4v\mathrm{I}^{1}}{\rho C_{P}V_{0}^{2}} \tag{11}$$

$$\frac{d^{2}u}{dy^{2}}+\frac{du}{dy}-M^{2}u=-Gr\theta-GmC+\frac{u}{k1} \tag{12}$$

$$\frac{d^{2}\theta}{dy^{2}}+\Pr\frac{d\theta}{dy}-F\Pr\theta+\Pr E\left(\frac{du}{dy}\right)^{2}+\Pr EM^{2}u^{2}=0 \tag{13}$$

$$\frac{d^{2}C}{dy^{2}}+Sc\frac{dC}{dy}=0 \tag{14}$$

where,
Gr = Grashoff number,
$\Pr$ = Prandtl number,
M = Magnetic parameter,
F = Radiation parameter,
Sc = Schmidt number,
E = Eckert number.
$k1 =$ porosity of fluid bed

The respective boundary condition in the dimensionless form are given to be

$$y = 0 : u = 0, \theta = 1, C = 1, \; y \to \infty : u \to 0, \theta \to 0 \tag{15}$$

The physical variables u, θ and C can be expanded in the power of Eckertnumber (E). This can be possible physically as E for the flow of anincompressible fluid is always less than unity. It can be interpreted physically asthe flow due to the Joules dissipation is super imposed on the main flow. Hence we can assume

$$\begin{aligned} u(y) &= u_0(y) + Eu_1(y) + 0(E^2) \\ \theta(y) &= \theta_0(y) + E\theta_1(y) + 0(E^2) \\ C(y) &= C_0(y) + EC_1(y) + 0(E^2) \end{aligned} \tag{16}$$

The coefficient of like powers of E, we have

$$u_0'' + u_0' - \left(M^2 + \frac{1}{k1} \right) u_0 = -Gr\theta_0 - GmC_{0,} \tag{17}$$

$$\theta_0'' + \Pr \theta_0' = F \Pr \theta_0 \tag{18}$$

$$C_0'' + ScC_0' = 0 \tag{19}$$

$$u_1'' + u_1' - \left(M^2 + \frac{1}{k1} \right) u_1 = -Gr\theta_1 - GmC_1 \tag{20}$$

$$\theta_1'' + \Pr \theta_1' - F \Pr \theta_1 + \Pr u_0'^2 + \Pr M^2 u_0^2 = 0 \tag{21}$$

$$C_1'' + ScC_1' = 0 \tag{22}$$

The related boundary conditions will now be

$$\begin{aligned} & y = 0 : u_0 = 0, u_1 = 0, \theta_0 = 0, \theta_1 = 0, \\ & C_0 = 0, C_1 = 0 \\ & y \to \infty : u_0 = 0, u_1 \to 0, \theta_0 = 0, \theta_1 \to 0, C_0 = 0, C_1 \to 0. \end{aligned} \tag{23}$$

Solving the above set of equations we get

$$u_0(y) = A_5\left(e^{-A_4 y} - e^{-A_1 y}\right) + A_6\left(e^{-A_4 y} - e^{-Scy}\right), C_0 = e^{-Scy},$$

$$u_1(y) = B_{17}e^{-A_4 y} - B_{10}e^{-A_1 y} + B_{11}e^{-2A_1 Y} + B_{12}e^{-2A_4 y} - B_{13}e^{-A_{10} y} + B_{14}e^{-2Scy} - B_{15}e^{-B_1 y} + B_{16}e^{-B_2 y}$$

$$\theta_1 = B_9 e^{-A_1 y} - B_3 e^{-2A_1 y} - B_4 e^{-2A_4 y} + B_5 e^{-A_{10} y} - B_6 e^{-2Scy} + B_7 e^{-B_1 y} - B_8 e^{-B_2 y}$$

where

$$A_1 = \frac{\Pr + \sqrt{\Pr^2 + 4F\Pr}}{2}$$

$$A_2 = \frac{-\Pr + \sqrt{\Pr^2 + 4F\Pr}}{2}$$

$$A_3 = \frac{-1+\sqrt{1+4\left(M^2+\frac{1}{k1}\right)}}{2}$$

$$A_4 = \frac{1+\sqrt{1+4\left(M^2+\frac{1}{k1}\right)}}{2}$$

$$A_5 = \frac{Gr}{(\mathrm{A1-A4})(\mathrm{A1+A3})}$$

$$A_6 = \frac{Gm}{\left(\mathrm{Sc}^2 - Sc - \left(M^2+\frac{1}{k1}\right)\right)}$$

$$A_7 = \Pr A_5^2 A_4^2$$

$$A_8 = \Pr A_5^2 A_1^2$$

$$A_9 = 2\Pr A_1 A_4 A_5$$

$$A_{10} = A_1 + A_4$$

$$B_1 = A_4 + Sc$$

$$B_2 = A_1 + Sc$$

$$B_3 = \frac{\Pr A_5^2\left(A_1^2+M^2\right)}{4A_1^2 - 2A_1 \Pr - F\Pr}$$

$$B_4 = \frac{\Pr\left(A_4^2+M^2\right)\left(A_5+A_6\right)^2}{\left(2A_4 - A_1\right)\left(2A_4 + A_2\right)}$$

$$B_5 = \frac{2\Pr A_5 (A_5+A_6)(A_1A_4+M^2)}{(A_{10}-A_1)(A_{10}-A_3)}$$

$$B_6 = \frac{\Pr A_6^2 (Sc^2+M^2)}{4Sc^2 - 2Sc\Pr - F\Pr}$$

$$B_7 = \frac{2\Pr A_6\left(A_5+A_6\right)\left(A_4 Sc + M^2\right)}{B_1^2 - \Pr B_1 - F\Pr}$$

$$B_8 = \frac{2\Pr A_5 A_6\left(A_1 Sc + M^2\right)}{B_2^2 - \Pr B_2 - F\Pr}$$

$$B_9 = B_3 + B_4 - B_5 + B_6 - B_7 + B_8$$

$$B_{10} = \frac{Gr\mathrm{B}_9}{\left(\mathrm{A}_1 - A_4\right)\left(A_1 + A_3\right)}$$

$$B_{11} = \frac{Gr\mathrm{B}_3}{\left(2\mathrm{A}_1 - A_4\right)\left(2A_1 + A_3\right)}$$

$$B_{12} = \frac{GrB_4}{4A_4^2 - 2A_4 - \left(M^2+\frac{1}{k1}\right)}$$

$$B_{13} = \frac{GrB_5}{(A_{10}-A_4)(A_{10}+A_2)}$$

$$B_{14} = \frac{GrB_6}{4Sc^2 - 2Sc - \left(M^2 + \frac{1}{k1}\right)}$$

$$B_{15} = \frac{GrB_7}{B_1^2 - B_1 - (M^2 + \frac{1}{k1})}$$

$$B_{16} = \frac{GrB_8}{B_2^2 - B_2 - \left(M^2 + \frac{1}{k1}\right)}$$

$$B_{17} = B_{10} - B_{11} - B_{12} + B_{13} - B_{14} + B_{15} - B_{16}$$

The skin friction on the plate is given by:

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = A_5(A_1 - A_4) + A_6(Sc - A_4) - E\begin{bmatrix} A_4B_{17} - A_1B_{10} + 2A_1B_{11} + 2A_4B_{12} - A_{10}B_3 \\ +2A_4B_{12} - A_{10}B_3 + 2ScB_{14} - B_{15}B_1 + B_{16}B_2 \end{bmatrix}$$

RESULTS AND CONCLUSIONS

1. While Schmidt numberis held constant the effect of porosity on velocity field has been illustrated in fig 1, fig 2 and fig3. In general it is observed that, as the porosity of the bounding surface increases then the velocity is noticed to be increasing.
2. For a fixed Modified Grashoff number the effect of porosity on the velocity profiles has been illustrated in fig 4, fig 5 and fig 6. It is seen that the velocity increases as the porosity increases. Also, as the modified Grashoff number decreases the velocity is noticed to be decreasing.
3. Fig 7, fig 8 and fig9 depicts the influence of porosity on velocity profiles. It is observed that as the porosity increases, the velocity is found to be decreasing. Also, as the Grashoff number decreases the velocity decreases.
4. Fig 10 and fig 11 shows the consolidated effect of porosity and Grashoff number. In general it is observed that, as the Grashoff number increases the skin friction increases. In particular as the porosity increases the skin friction decreases.
5. For a given value of Schmidt number, the consolidated effect of Modified Grashoff number with respect to the porosity on the skin friction has been illustrated in fig 12 and fig 13. It is observed that as the Modified Grashoff number increases the skin friction also increases. In addition to be above as the Schmidt number increases the dispersion in the skin friction profiles is found to be significant.
6. A combined effect of magnetic parameter and porosity for a given value of Schmidt number on the skin friction is depicted in fig 14 and fig15. In addition to the above, it is noticed that, as the magnetic field intensity is increased, the skin friction decreases. Further, it is noticed that the magnetic field intensity and the skin friction are inversely related.
7. Fig 16 and fig 17 shows the consolidated effect of Prandtl number and porosity on the skin friction. In each of these cases, in general the Prandtl number and skin friction are inversely related to each other.

FIGURES

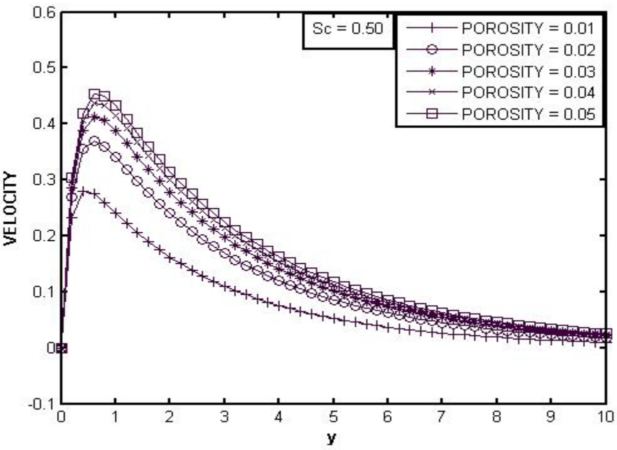

Figure-1: Effect of porosity on Velocity Profiles

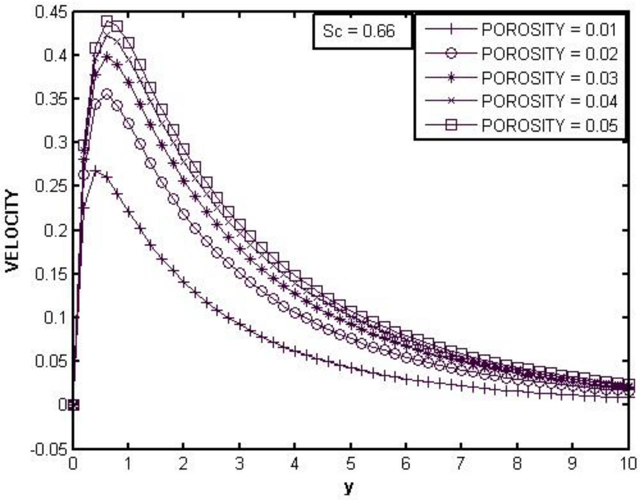

Figure-2: Influence of porosity on Velocity

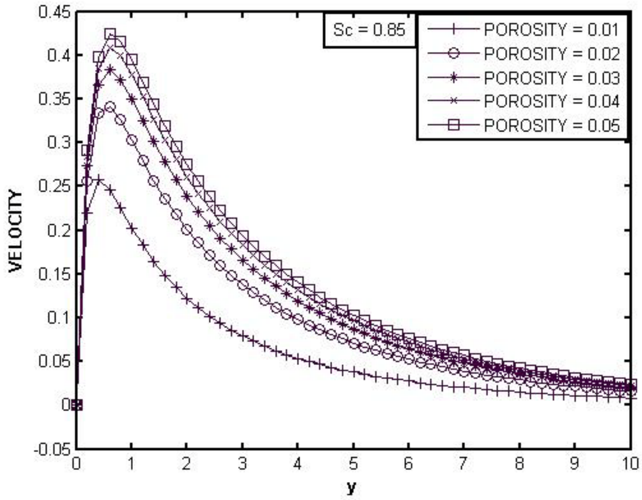

Figure-3: Effect of porosity on Velocity

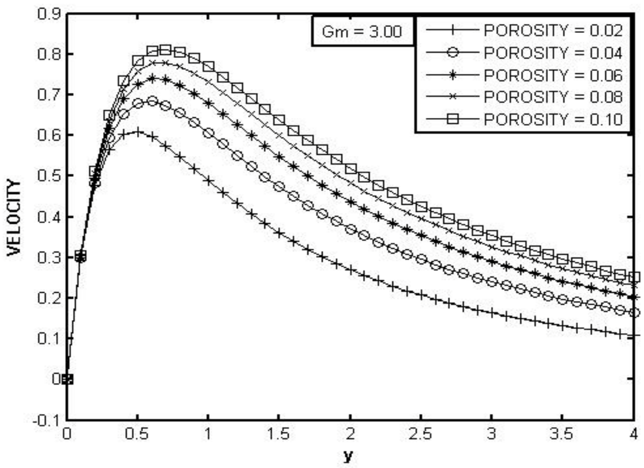

Figure-4: Effect of porosity a on Velocity Profiles

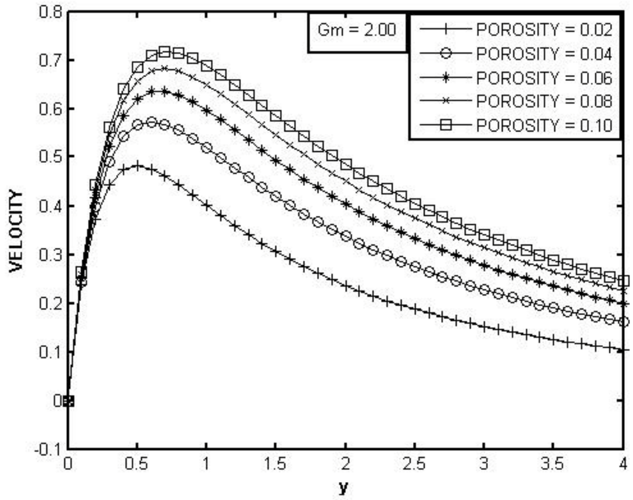

Figure-5: Effect of porosity on Velocity Profiles

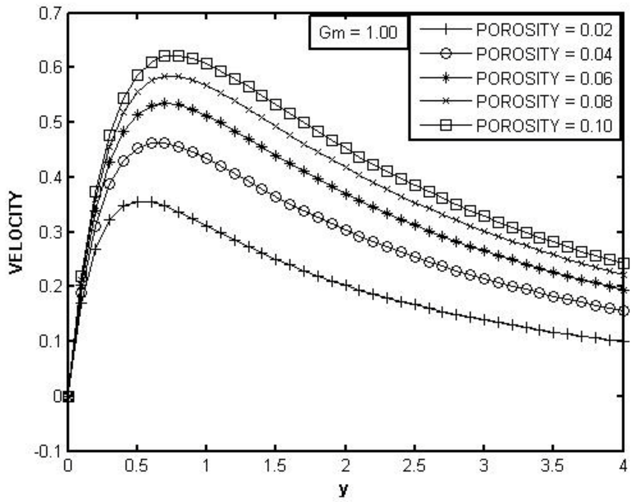

Figure-6: Influence of porosity on Velocity Profiles

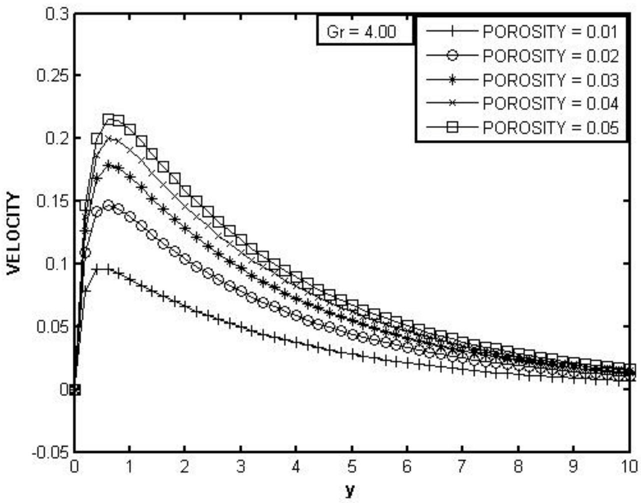

Figure-7: Combined effect of porosity and Grashoff number on Velocity Profiles

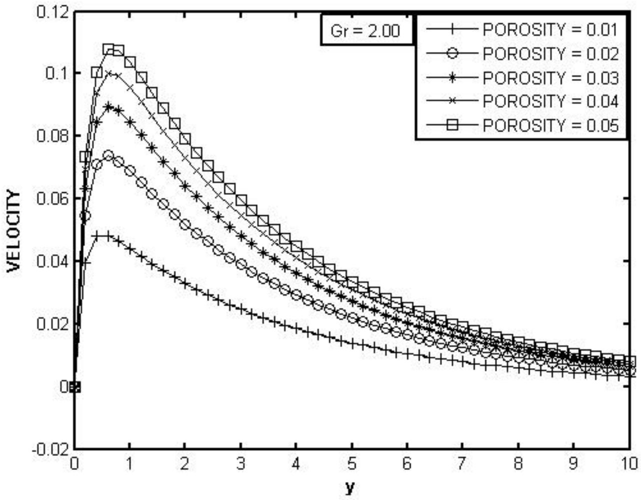

Figure-8: Influence of porosity on Velocity Profiles

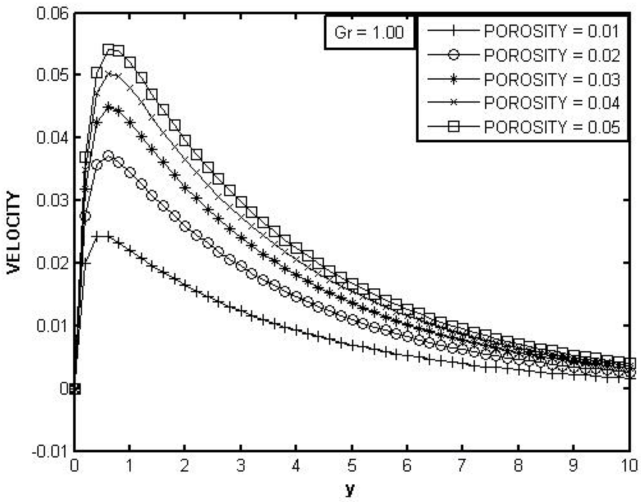

Figure-9: Effect of porosity on Velocity Profiles

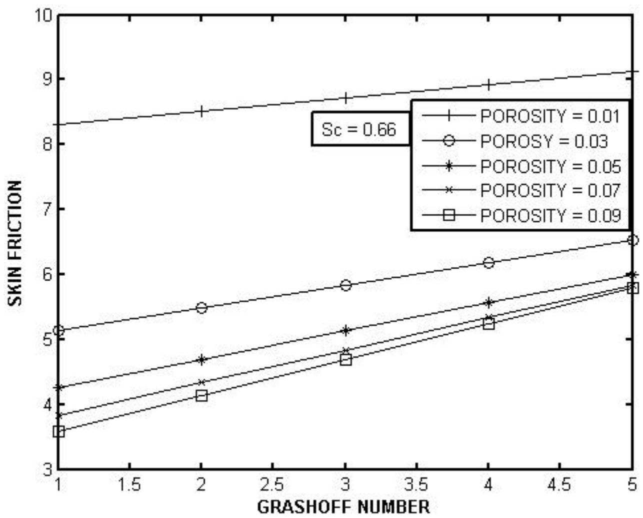

Figure-10: Effect of porosity and Grashoff number on Skin Friction

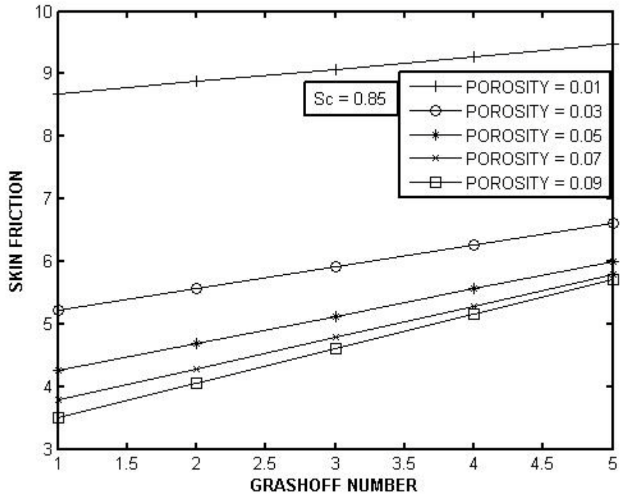

Figure-11: Influence of porosity on Skin friction

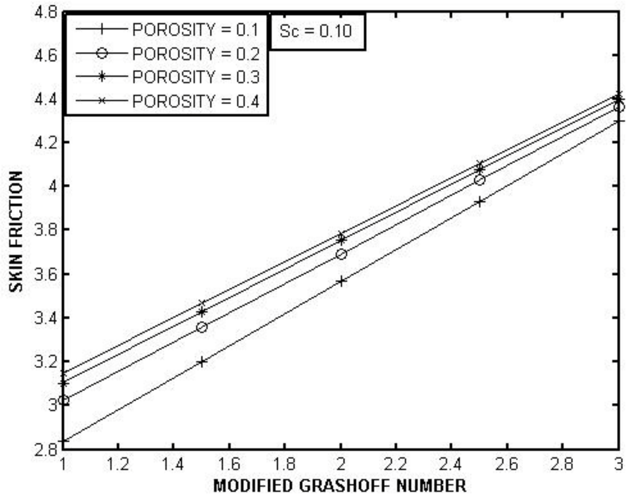

Figure-12: Effect of Modified Grashoff number on skin friction

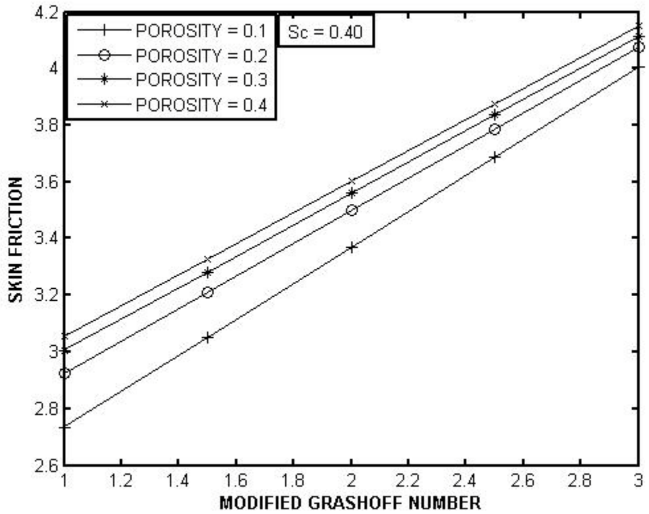

Figure-13: Influence of Porosity on skin friction

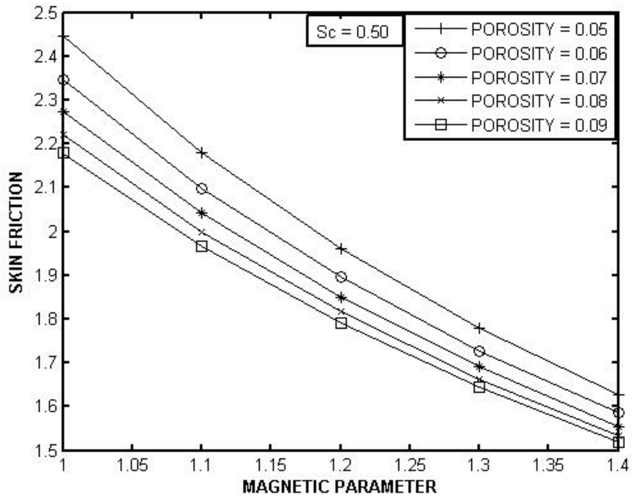

Figure-14: Effect of Magnetic parameter on skin friction

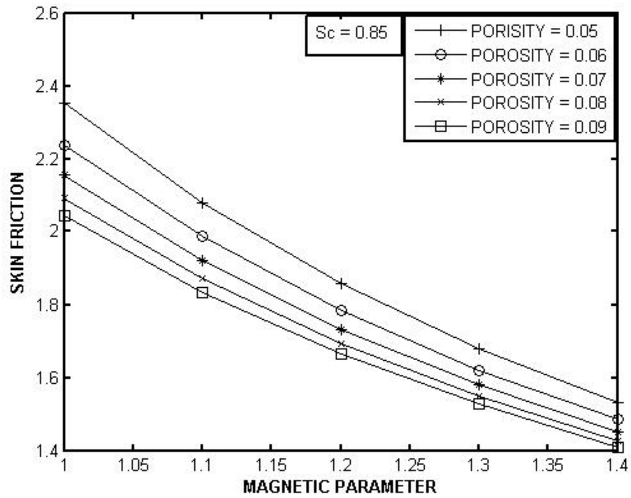

Figure-15: Influence of Magnetic parameter on skin friction

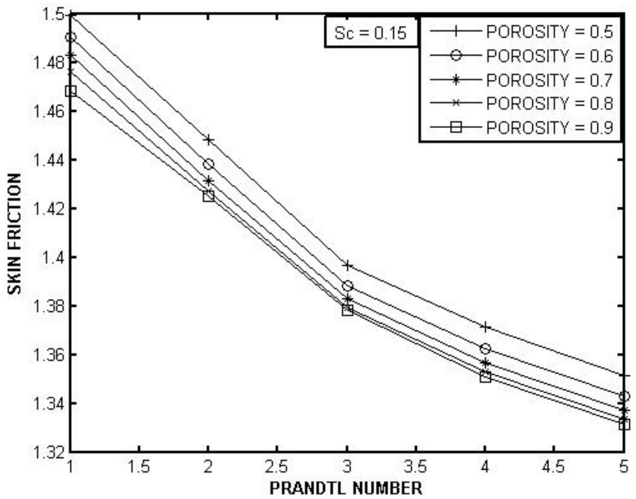

Figure-16: Effect of Prandtl number on skin Friction

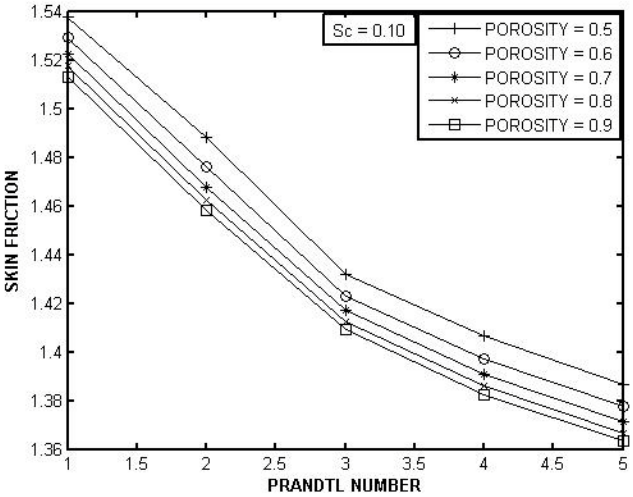

Figure-17: Influence of Prandtl number on skin friction

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Source of support: Nil, Conflict of interest: None Declared