INTERNATIONAL JOURNAL OF COMPUTATIONAL MATHEMATICAL IDEAS
ISSN:0974-8652 / www.ijcmi.webs.com / VOL 2-NO1-PP 13-21 (2010)

MIXED CONVECTION IN A POROUS MEDIUM WITH MAGNETIC FIELD, VARIABLE VISCOSITY AND VARYING WALL TEMPERATURE

V. Lakshmi Prasannam[#], T.Raja rani[*], C.N.B.Rao[$]

[#]P. B Siddhardha P.G.College of arts and science, Vijayawada,
[*]Sri Vishnu Engineering College for Women, Bhimavaram. E-Mail: rajarani72@gmail.com
[$]S.R.K.R. Engineering College, Bhimavaram, Andhra Pradesh, India.

ABSTRACT

Effects of magnetic field and variable viscosity on similarity solutions of mixed convection adjacent to a vertical flat plate in a porous medium are studied numerically. Excess of plate temperature over the ambient temperature and the free stream are assumed to vary as power functions of x, where x is the distance measured along the plate. The flow and heat transfer quantities of the similarity solutions are found to be functions of C, λ, γ_μ, RP where C is magnetic interaction parameter, λ is power of index of the plate temperature, γ_μ is viscosity variation coefficient and *RP,* mixed convection parameter is ratio of the *Rayleigh number* to the $Pe'clet$ *number.* The cases of assisting flow and opposing flow are discussed. Dual solutions are found for negative values of *RP*, and ranges of values of *RP* are found for which either a unique solution, no solution or dual solutions exist. Skin friction and heat transfer coefficients are observed to diminish as the intensity of the magnetic field increases (or C takes diminishing values). The range of negative values of *RP* over which solutions exist is observed to increase with decreasing values of C as well as with increasing values of λ and γ_μ.

Key Words: Mixed Convection; Variable viscosity; Magnetic field; varying wall temperature
Mathematics Subject Classification Codes: 76S05; 76R10; 76R05; 76DXX

NOMENCLATURE

B_0 = Magnetic flux

C - Magnetic interaction parameter

f - Dimensionless stream function

g - Acceleration due to gravity

K – Permeability

K^* - Porous parameter, $\dfrac{L^2}{K}$

M^2 – Hartmann number, $\dfrac{B_0^2 L^2 \sigma}{\mu_f}$

p – Pressure

Pe_x – $Pe'clet$ *number*, $\dfrac{U_\infty x}{\alpha_m}$

Ra_x – *Rayleigh number*, $\dfrac{\rho_\infty K g \beta (T_o - T_\infty) x}{\mu_f \alpha_m}$

RP - Mixed convection parameter, $\dfrac{Ra_x}{Pe_x}$

T_0 - Temperature of plate

T_∞ - Ambient temperature

T_f - Reference temperature

u, v - Velocity components in x - and y - directions

U_∞ - Free stream velocity

x, y – Cartesian coordinates

Greek Symbols

α_m - Effective thermal diffusivity of the porous medium

β - Coefficient of thermal expansion

γ_μ - Viscosity variation coefficient

η - Similarity variable

θ - Dimensionless temperature

μ - Dynamic viscosity

ρ - Fluid density

ψ - Stream function

λ – Power of index of plate temperature

Subscripts

0 – condition at the plate
∞ - condition at infinity
f - condition at reference temperature
u - upper solution
l - lower solution

I.INTRODUCTION

Heat transfer studies in porous media find applications in several Engineering and technological systems (ref. [2]). In mixed convection flows, when the temperature of the plate varies as a power function of distance, similarity exists only if the free stream velocity also varies according to the same power function of distance as that of the plate temperature. In mixed convection flows, there arise four cases, of which two correspond to assisting flow and two to opposing flow (refer [10]), depending on the ambient and plate temperatures and the direction of the free stream. They are (i) hot plate assisting flow (ii) hot plate opposing flow (iii) cold plate assisting flow (iv) cold plate opposing flow. Of these four cases only two (i), (iv) are taken into consideration in this study.

Reference [6] discussed the effect of variable viscosity on convective heat transfer in three different cases of natural convection, mixed convection and forced convection, taking fluid viscosity to vary inversely with temperature. However, the authors have confined their attention to the assisting flow case only. Reference [2] studied mixed convection boundary layer flow on a vertical surface in a porous medium, when both the temperature of the plate and the free stream velocity vary as the same power function of distance along the plate. Similarity solutions were found to be functions of two parameters λ and ε where λ is the power of index of the plate temperature and ε, the mixed convection parameter is the ratio of the *Rayleigh* number to the *Pe'clet* number. Both assisting flow and opposing flow were discussed. Ranges of the values of ε for different values of λ were presented for which either a unique solution, dual solutions or no solution exist. The effects of λ and ε on the flow and heat transfer characteristics were discussed. Reference [4] discussed mixed convection boundary layer flow over a vertical surface for the Darcy model when viscosity varies inversely as a linear function of temperature. Results of both assisting flow and opposing flow were presented which were discussed as functions of the mixed convection parameter ε and variable viscosity parameter θ_c. In the opposing flow case, the existence of dual solutions and boundary layer separation were noticed.

There has been increasing attention to the study of magnetic field on convection flows in porous media as pointed out in [8]. Reference [7] studied free convection at a vertical plate in a porous medium in the presence of magnetic field, variable physical properties and varying plate temperature. Magnetic field effects on the free convection and mass transfer flow through a porous medium with constant suction and constant heat flux has been discussed in [1]. The effect of magnetic field and varying plate temperature on convective heat transfer past a vertical plate in porous medium has been discussed in [9]. Magneto hydrodynamic mixed convection flow has been analyzed in an annular region filled with a fluid saturated porous medium in [3]. A transverse magnetic field which acts radially is created by a stationary electric current that flows through a cylindrical shaped electrical cable present in the annular region. The effect of non uniform magnetic field on the flow and heat transfer of the Darcy model is discussed. Magneto hydrodynamic free convection in a horizontal cavity filled with a fluid saturated porous medium with internal heat generation has been studied in [5]. Assuming that the magnetic field is inclined at angle γ with the horizontal plane, the flow and heat transfer are discussed as functions of inclination angle γ, Hartmann number *Ha, Rayleigh* number *Ra* and aspect ratio *a.*

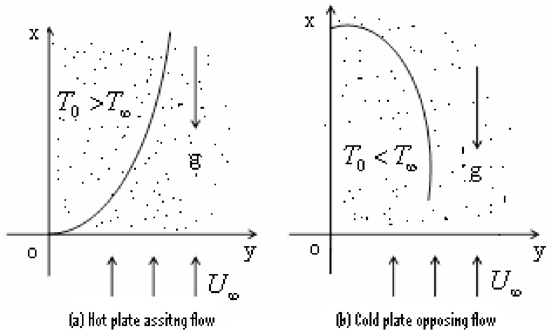

Fig-1. Physical model and coordinate system

In the present paper the effects of magnetic field, variable viscosity and varying plate temperature on mixed convection at a vertical plate in a porous medium are studied. The plate temperature and the free stream velocity are assumed to vary as power functions of distance (x) along the plate, viscosity is assumed to vary as a linear function of temperature and a magnetic field is assumed to act normal to the plate. Similarity solutions are obtained for the problem and both assisting flow and opposing flow are discussed. In the opposing flow case, dual solutions (referred to as upper and lower solutions) are obtained for certain values of the mixed convection parameter *RP* and ranges of values of *RP* are also obtained for which either a unique solution, dual solutions or no solution exist. Significant differences are noticed between the flow and heat transfer quantities related to the upper and lower solutions.

II. FORMULATION AND SOLUTION

Let a flat plate be embedded vertically in a porous medium saturated with a viscous incompressible homogeneous fluid. The porous medium is assumed to be homogeneous and is in thermal equilibrium with the surrounding fluid. Let a magnetic field of uniform strength be applied in a direction normal to the plate. Let *X*-axis be taken along the plate and *Y*-axis perpendicular to it. The temperature of the plate (T_0) is assumed to vary as a power function of distance along the plate, as $T_0 = T_\infty + A\,x^\lambda$ where T_∞ is temperature of the ambient fluid, A is a constant and λ is a real number. Fluid viscosity is assumed to be a function of temperature as $\mu = \mu_f\, s_\mu(t)$, where μ_f is viscosity evaluated at the film temperature, $s_\mu(t) = 1 + \left(\frac{d\mu}{dt}\right)_f (T - T_f)$ and $T_f\left(= \frac{T_0 + T_\infty}{2}\right)$ is the film temperature.

A viscosity variation coefficient γ_μ is introduced as

$$\gamma_\mu = \frac{1}{\mu_f}\left(\frac{d\mu}{dT}\right)_f (T_0 - T_\infty).$$

Density of the fluid is assumed to be a function of temperature only in the body force term. The ambient fluid flows with a velocity U_∞ parallel to the vertical plate, the flow being vertically upwards. The physical model and coordinate system are presented in figure1.The governing equations of the present analysis and the boundary conditions are well known and are not presented here.

Taking the free stream velocity as $U_\infty = b\,x^\lambda$ where b is a constant, introducing $P\acute{e}clet$ number (Pe_x) and nondimensional functions f, θ together with a similarity variable η through the relations

$$\left.\begin{aligned} Pe_x &= \frac{U_\infty x}{\alpha_m} \\ f(\eta) &= \frac{\psi}{(2\alpha_m x^{\lambda+1})^{\frac{1}{2}}} \\ \theta(\eta) &= \frac{T - T_\infty}{T_0 - T_\infty} \\ \eta &= \frac{y}{x}\left(\frac{x^{\lambda+1}}{2\alpha_m}\right)^{\frac{1}{2}} \end{aligned}\right\} \quad (1)$$

the governing equations in the mixed convection case are obtained as

$$\left[1 + C\gamma_\mu\left(\theta - \frac{1}{2}\right)\right] f'' + C\,\gamma_\mu\, f'\,\theta' = C\,(RP)\,\theta' \quad (2)$$

$$\theta'' - 2\lambda\, f'\theta + (1+\lambda)\, f\,\theta' = 0 \quad (3)$$

where

$$C = \frac{K^2}{K^2 + M^2},$$

$$M^2 = \frac{B_0^2 L^2 \sigma}{\mu_f},$$

$$Ra_x = \frac{\rho_\infty K\, g\, \beta (T_0 - T_\infty) x}{\mu_f\, \alpha}, \text{ and}$$

$$RP = \frac{Ra_x}{Pe_x}.$$

The boundary conditions in terms of f and θ are

$$\left.\begin{array}{l} at\ \eta = 0, \quad \theta = 1, \quad f = 0, \\ as\ \eta \to \infty, \ \theta \to 0, \ f' \to 1 \end{array}\right\}$$

(4)

Equation (2) can be integrated once using the condition on f' at infinity to get

$$f' = \frac{\left(1 - \frac{C\gamma_\mu}{2}\right) + C(RP)\theta}{\left[1 + C\gamma_\mu\left(\theta - \frac{1}{2}\right)\right]}$$

(5)

Evaluating at $\eta = 0$, we get the slip velocity $f'(0)$ as

$$f'(0) = \frac{2(1 + C(RP)) - C\gamma_\mu}{2 + C\gamma_\mu}.$$

If $\gamma_\mu = 0$ then $f'(0) = 1 + C(RP)$

III.a **PARAMETERS OF THE PROBLEM AND THEIR EFFECT ON THE FLOW AND HEAT TRANSFER:**

The flow and heat transfer depend on the parameters γ_μ, λ, *C* and *RP* where *RP* is the ratio of the *Rayleigh* number to the *Pe′clet* number.

The constant *A* appearing in the expression for the temperature of the plate can take positive as well as negative values and, as a result, the temperature of the plate can be higher or lower than the ambient temperature. In the present work, these correspond to assisting flow and opposing flow respectively. For liquids (except for water near $4^0\,C$) the parameter γ_μ takes negative values when $T_0 > T_\infty$ and takes positive values when $T_0 < T_\infty$, while for gases it is vice versa. Irrespective of the values of T_0 and T_∞, zero value of γ_μ corresponds to constant viscosity case. In this paper, solutions are found for the values -1, 0, and 1 of γ_μ.

The mixed convection parameter *RP* takes positive values for assisting flow and negative values for opposing flow. When *RP* is zero, the results correspond to the forced convection case. Calculations are done for a wide range of positive and negative values of *RP*. Enhanced flow can correspond to an increase in the value of *RP,* as an increase in the value of the parameter can be due to an increase in the temperature difference ($T_0 - T_\infty$).

To determine certain important values for λ, the total heat convected in the flow, $Q(x)$ at any down stream location x is considered.

$$Q(x) = \int_0^\infty \rho\, C_p \beta (T - T_\infty)\, u\, dy \ .$$

This can be seen to be proportional to $x^{\frac{3\lambda+1}{2}}$, like in the free convection case(ref. [7]). For uniform heat flux surface, $Q(x)$ should vary linearly with x and so $\lambda = \frac{1}{3}$. For an adiabatic surface, $Q(x)$ should be independent of x and so $\lambda = \frac{-1}{3}$. Zero value of λ corresponds to the isothermal case. In this study solutions are found for the values $-0.3,\ -0.2,\ 0,\ 0.3,\ 0.5\ and\ 1$ of λ. When A is positive, an increase in the value of λ can correspond to an increase in the temperature of the plate, and, in a broader sense, it can result in enhanced flow.

When there is no magnetic field, the parameter *C* takes the value unity and for increasing intensity of the magnetic field, the parameter takes values smaller than unity. In the present study, solutions are found for the values 0.1, 0.5 and 1 of *C*. Reduced flow can be expected for smaller values of *C* or for increased intensity of the magnetic field as the magnetic field lines obstruct the flow.

The effect of simultaneous variation of the values of the parameters on the flow and heat transfer are presented in the discussion.

III.b. NUMERICAL SOLUTION: The equations for f and θ, i.e., equations 3,5 are integrated numerically subject to appropriate boundary conditions by Runge-Kutta-Gill method (Ref. [10]), together with a shooting technique. The accuracy of the method is tested by comparing appropriate results of the present analysis with available results. Our results for *C* =1 and γ_μ=0 (i.e., no magnetic field, constant viscosity) are in very good agreement with those of in ref. [2]. Also our results for *C* =1, γ_μ=0 and λ=0 (i.e., no magnetic field, constant viscosity and isothermal plate) agree very well with those of ref. [4].

IV. DISCUSSION OF THE RESULTS:

Qualitatively interesting results related to the shear stress, heat transfer coefficient, velocity and temperature are presented, some of them in the form of tables I,II and others in the form of figures 2 to 11. Quantities such as the Nusselt number and drag coefficient can be readily obtained from the heat transfer coefficient and skin friction. Variations in $f'(0), f''(0)$ *and* '$-\theta'(0)$' for positive values of *RP* are presented in table I. Skin friction $f''(0)$ can be observed to be negative for positive values of *RP* for all values of the other parameters under consideration. Absolute value of $f''(0)$ decreases with increasing values of *RP* and γ_μ while it increases with increasing values of *C*..

TABLES

Table- I Variations in $f'(0), f''(0)$ &'$-\theta'(0)$ for positive values of *RP*

RP	λ	C	γ_μ	$f'(0)$	$f''(0)$	$-\theta'(0)$
0.1	0.5	0.5	-1	1.733333	-0.07008	*1.0512239*
0.1	0.5	0.5	0	1.05	-0.04498	*0.899628087*
0.1	0.5	1.0	-1	3.2	-0.2501501	*1.2507507*
1.0	0.5	0.5	-1	2.333333	-0.77919	*1.168788215*
1.0	-0.2	0.5	-1	2.333333	-0.37289	0.5593302
10.0	0.5	0.5	-1	8.333333	-13.2453898	*1.986808465*
10.0	*0.5*	*0.5*	*0*	*6.0*	*-9.0675828*	*1.813516557*

Table- II Existence of solutions for negative values of *RP*

Parameters / Types of solution	$C=0.5$, $\lambda=0.5$, $\gamma_\mu=1.0$	$C=0.5$, $\lambda=0.0$, $\gamma_\mu=1.0$	$C=0.5$, $\lambda=0.5$, $\gamma_\mu=-1.0$	$C=1.0$, $\lambda=0.0$, $\gamma_\mu=0.0$	$C=1.0$, $\lambda=0.5$, $\gamma_\mu=0.0$
No solution	$RP<-2.1$	$RP<-2.0$	$RP<-3.3$	$RP<-1.354$	$RP<-1.4$
Dual solution	$-2.1<RP<-0.1$	$-2.0<RP<-1.6$	$-3.3<RP<-1.1$	$-1.354<RP<-1.1$	$-1.4<RP<-0.1$
Single solution	$RP=0$	$-1.6<RP<0$	$-1.1<RP<0$	$-1.1<RP<0$	$RP=0$

Heat transfer coefficient '$-\theta'(0)$' takes increasing values with increasing values of *RP* and *C* while it takes decreasing values with increasing values of γ_μ. In table II are presented the ranges of values of *RP* for which either no solution, a single solution or dual solutions exist. The range of values can be seen to be more for gasses than for liquids. The range can also be seen to increase with increasing values of λ. The range decreases with increasing values of γ_μ in the isothermal case ($\lambda = 0$) while it increases with γ_μ when λ takes positive values.

In the following, more attention is paid to the discussion of the dual solutions of the opposing flow case. For a given value of *RP,* the solution corresponding to a relatively larger value of $f''(0)$ is referred to as the upper solution and the one corresponding to a smaller value of $f''(0)$ as the lower solution.

The changes in skin friction with negative values of the mixed convection parameter *RP* are shown in figures 2(a),2(b) for different values of the parameters *C,* λ and γ_μ**.** The corresponding changes in heat transfer coefficient are shown in figures 3(a),3(b) respectively. One curve each corresponding to ref. [2] are presented in figures 2(a),2(b) and one curve corresponding to ref.[4] in fig.3(a). From the figures the range of values of *RP* over which solutions exist can be seen to be more when fluid viscosity is taken to be temperature dependent than when it is constant. Similarly the range is more in the presence of magnetic field than in its absence. In the isothermal case, when viscosity is a constant as well as variable and in the presence as well as absence of magnetic field, $f''(0)$ is observed to be positive. For $C = 0.5, \lambda = 0, \gamma_\mu = 0$ single solution exists for $-2.1 \le RP \le 0$, dual solutions exist for $-2.7 \le RP \le -2.0$ and no solution for $RP \le -2.7$. Like the skin friction $f''(0)$, the heat transfer coefficient also takes positive values when $\lambda = 0$ (see figures 2(a) and 3(a)). Except for magnitude, behaviour of skin friction and heat transfer coefficient when $\gamma_\mu = 1$ are similar to the corresponding ones when $\gamma_\mu = 0$.

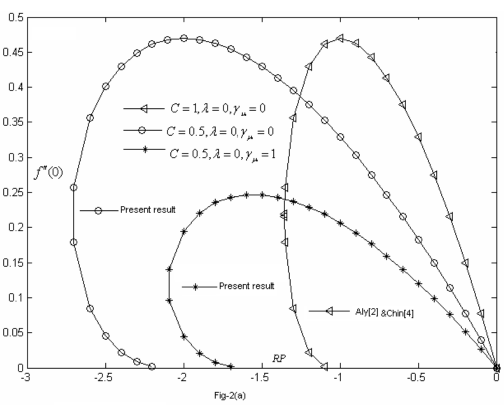

Fig-2(a)

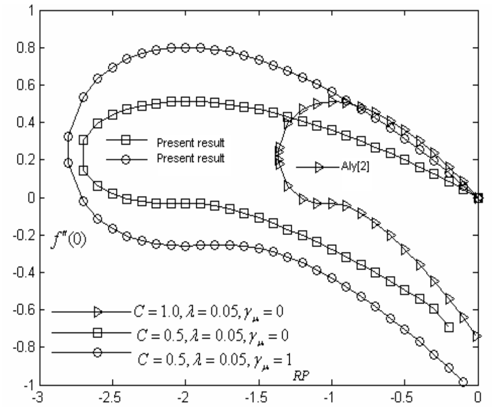

Fig-2(b)

Fig-2, Variation of $f''(0)$ for negative values of RP

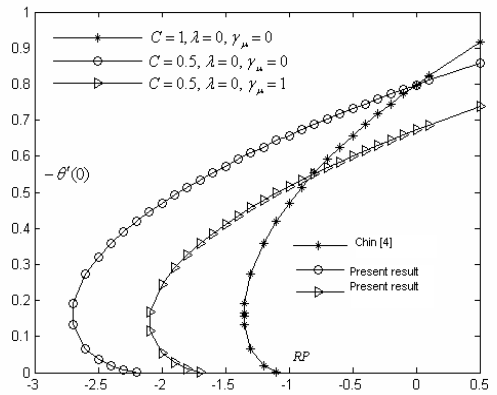

Fig-3(a)

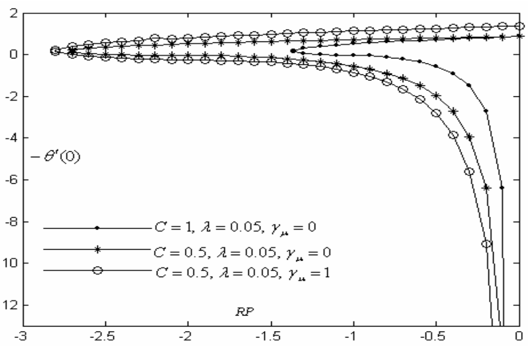

Fig-3(b)

Fig-3, Variation of $-\theta'(0)$ for negative values of RP

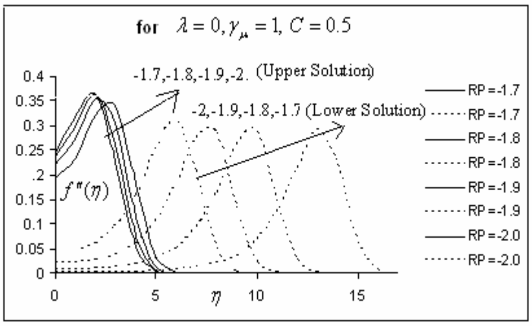

Fig-4(a) for liquids

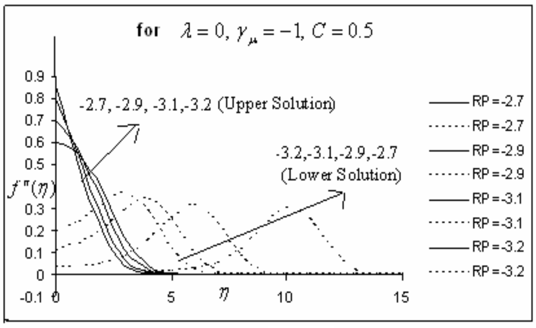

Fig-4(b) for gases

Fig-4 Variation of Shear stress for Upper and Lower solutions

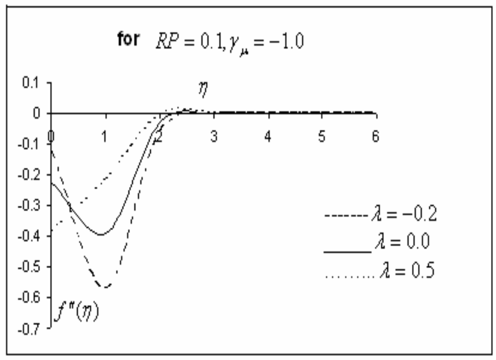

Fig-5(a) for liquids

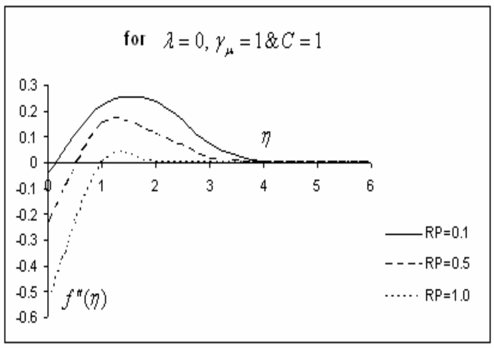

Fig-5(b) for gases

Fig-5 Variation of Shear stress for positive values of 'RP'

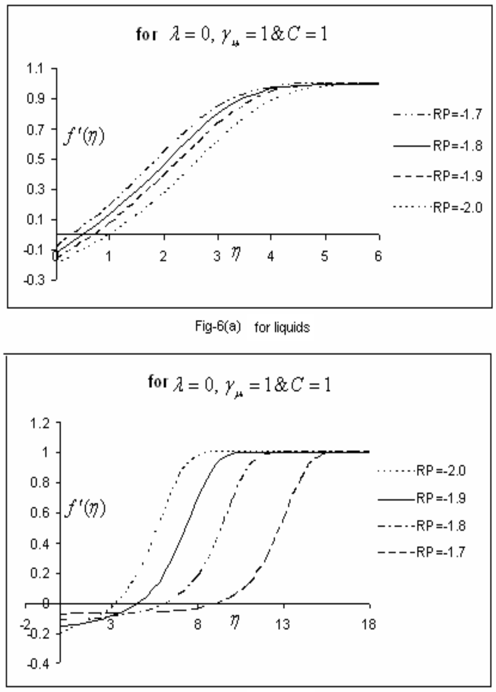

Fig-6(a) for liquids

Fig-6(b) for gases

Fig-6 Fluid velocity for upper and lower solutions for (liquids)

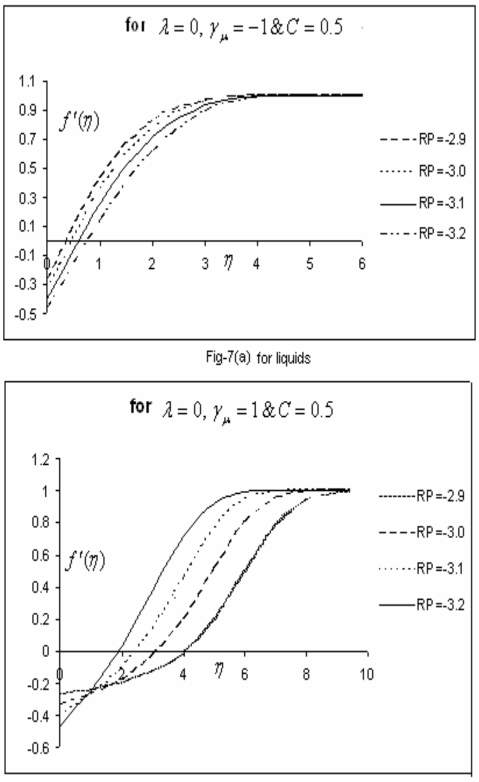

Fig-7(a) for liquids

Fig-7(b) for gases

Fig-7 Fluid velocity for upper and lower solutions for (for gases)

Unlike in the isothermal case, when the plate temperature is variable (for

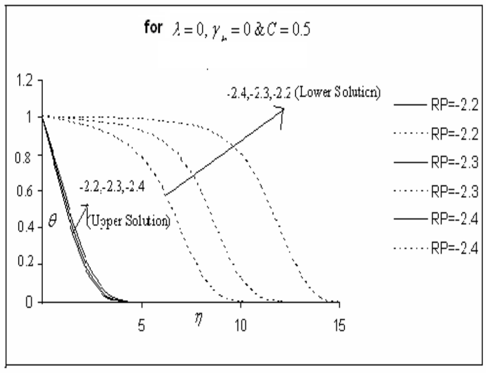

Fig-8 Fluid temperature for upper and lower solutions

example $\lambda = 0.05$), $f''(0)$ is observed to take both positive and negative values with changing negative values of *RP,* and dual solutions exist for a wide range of values of *RP.* For *C* =0.5, λ=0.05 and γ_μ=0 the range over which solutions exist is $-2.7 \le RP \le -0.1$. Like the skin friction, heat transfer coefficient also takes both positive and negative values with changing values of *RP*, when $\lambda = 0.05$.

Plots of shear stress for the upper and lower solutions for different values of the parameters are shown in the figures 4(a),4(b),5(a) and 5(b). Considerable differences can be noticed in the behaviour of the shear stress for the upper and lower solutions (see figures 4(a) and 4(b)). Curves of figure 4(a) correspond to those for liquids while those of figure 4(b) correspond to gases. From figures 5(a) and 5(b) and also from numerical results, it can notice that, for positive values of *RP,* the shear stress at the plate becomes negative thereby indicating separation of the boundary layer.

Fluid velocity profiles for the two solutions of the opposing flow case are presented in figures 6(a), 6(b) (for liquids) and in figures 7(a) and 7(b) (for gases). It can be observed that the hydrodynamic boundary layer thickness of the lower solution is much larger than that of the upper solution. Qualitative differences between the two solutions can also be observed in the vicinity of the plate. Fluid temperature profiles corresponding to the upper and lower solutions are presented in figure 8 for certain negative values of *RP*. It can be noticed that thermal boundary layer thickness of the lower solution is much larger than that of the upper solution. Variations in the lower solutions with changing values of the parameters are significant than those in the other solution. From figure 9, $f''(0)$ can be seen to

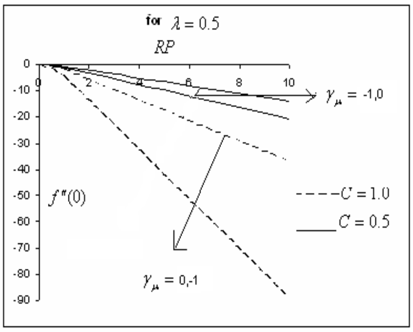

Fig-9 Variation of $f''(0)$ for positive values of RP

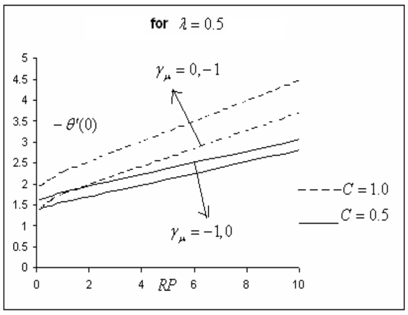

Fig.10 Variation of '$-\theta'(0)$' for positive values of RP

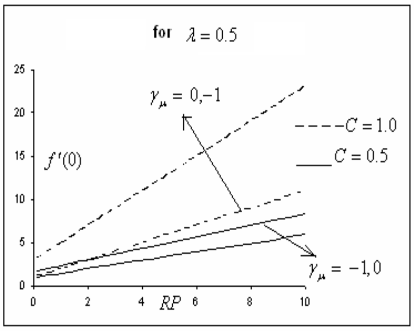

Fig.11 Slip velocity for positive values of RP

diminish as γ_μ changes from 0 to -1, and takes smaller values in the absence of the magnetic field. From figures 10,11 heat transfer coefficient ($-\theta'(0)$) and slip velocity ($f'(0)$) can be seen to increase as γ_μ changes from 0 to -1, and both the quantities assume larger values in the absence of magnetic field.

V.COMPARISION WITH AVAILABLE RESULTS:

Results of the present analysis agree well with appropriate results of references[2] and [4]. In figures 2 and 3 of our analysis are shown curves for C = 1, λ=0 and γ_μ=0 which coincide with those presented in references [2] and [4]. Comparison of numerical results of our analysis with those presented in table 2 of reference [4] has revealed excellent agreement between the results of the two works for C = 1, λ=0 and γ_μ=0.

VI.CONCLUSIONS:

Assisting flow (*RP* Positive)

1. For fixed values of λ, C, γ_μ, as *RP* increases there is an increase in the magnitudes of $f''(0)$ and '$-\theta'(0)$'. Increase in '*RP*' can mean increase in the buoyancy force and and this can cause an increase in fluid velocity and hence an increase in the skin friction and heat transfer coefficient.

2. For fixed values of γ_μ, RP & λ, $f''(0)$ as well as '$-\theta'(0)$' decrease as '*C*' decreases (i.e., as the intensity of the magnetic field increases).

Opposing flow (*RP* Negative)

1. '$-\theta'(0)$' decreases with diminishing values of *RP*. This may be due to the buoyancy force that works against the flow and hence the retardation in the heat transfer process.

2. $f''(0)$ takes positive as well as negative values for certain values of the parameters. Positive values of $f''(0)$ imply that the fluid exerts a dragging force on the surface and negative values imply the opposite.

3. Dual solutions exist for certain values of *RP*. Significant differences are observed between upper and lower solutions. Ranges of values of *RP* for which unique solution or dual solutions exist is observed to change considerably with changing values of the parameters.

ACKNOWLEDGEMENTS

T.Raja Rani wishes to thank the authorities of Sri Vishnu Engineering College for Women and also authorities of S.R.K.R Engineering College for their encouragement and also for providing the facilities for research. T.Raja Rani also conveys her thanks to Mr.K.S.Sreenivasa babu of S.R.K.R.Engineering College for his help in numerical computations.

REFERENCES

[1] Acharya.M, Dash.G.C and Singh.L.P., Magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux, Indian J pure appl. Math., vol.31(1),pp.1-18,2000.

[2] Aly,E.H, Elliot,L, Ingham,D.B, Mixed convection boundary-layer flow over a vertical surface embedded in a porous medium, European Journal of Mechanics B/Fluids., vol.22, pp. 529-543, 2003.

[3] Barletta.A, Lazzari.S, Magyare.E and Pop.I, Mixed convection with heating effects in a vertical porous annulus with a radially varying Magnetic field, Int. J. Heat. Transfer., vol.51, pp.5777-5784, 2008.

[4] Chin,K,E, Nazar,R, Arifin,N.M, Pop,I, Effect of Variable Viscosity on mixed convection boundary layer flow over a vertical surface embedded in a porous medium, International Communications in Heat and Mass Transfer., vol.34,pp. 464-473, 2007.

[5]Gorsan.T, Revnic.C, Pop.I and Ingham.D.B, Magnetic field and internal heat generation effects on the Free convection in a rectangular cavity filled with a porous medium, International Communications in Heat and Mass Transfer, vol 52, pp.1525-1533,2009.

[6] Lai,F.C, and Kulacki,F.A,(1990), The Effect of Variable Viscosity on Convective Heat Transfer along a Vertical Surface in a Saturated Porous medium, Int.J.Heat Mass Transfer. vol.33, pp.1028- 1031,1990.

[7] Lakshmi Prasannam.V, Raja Rani,T and C.N.B.Rao, Free convection in a porous medium with magnetic field, variable physical properties and varying wall temperature, accepted for publication in International Journal of Computational Mathematical ideas.

[8] Nield.D.A, Bejan.A, Convection in Porous Media, Third ed., Springer, New York,2006.

[9] Sobha.V.V and Ramakrishna.K, Convective Heat Transfer Past a Vertical Plate Embedded in a Porous Medium with an Applied Magnetic Field, IE(I) Journal-MC, 84, pp.133-134, 2003.

[10] White,F.M, Viscous Fluid Flow, McGraw-Hill Inc., New York, 1974.

[11] Vafai,K., Hand Book of Porous Media,2nd Ed, Taylor & Francis, New York.pp.379-381,2005.