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THE EFFECTS OF VISCOUS DISSIPATION AND VARIABLE VISCOSITY ON MIXED CONVECTION BOUNDARY LAYER FLOW OVER A HORIZONTAL PLATE IN THE PRESENCE OF BLOWING OR SUCTION

N. Kishan & P. Amrutha
Assistant professor, Department of Mathematics, Osmania University,
Hyderabad - 500007, A.P., India.
Associate professor, St.Ann's College for Women, Mehdipatnam,
Hyderabad - 500028, A.P., India

Abstract

The effect of viscous dissipation and variable viscosity, blowing or suction on mixed convection flow of viscous incompressible fluid past a semi-infinite horizontal flat plate aligned parallel to a uniform free stream in the presence of the wall temperature distribution inversely proportional to the square root of distance from the leading edge have been numerically investigated. The governing equations of the flow are transformed into a system of coupled non-linear ordinary differential equations by using similarity variables. The similarity equations have been solved by using the implicit finite difference method. The effect of viscous dissipation, viscosity temperature parameter, the buoyancy parameter, the blowing or suction parameter and the Eckert number on the velocity and temperature profiles as well as on the Skin-friction coefficient and the Nusselt number are presented and discussed.

Key words: *Viscous Dissipation, Variable Viscosity, Mixed Convection, Blowing or Suction, implicit finite difference method.*

INTRODUCTION:

It is known that a flow situation where both free and forced convection effects are of comparable order is called mixed convection. The study of such a mixed convection flow finds application in several industrial and technical processes such as nuclear reactors cooled during emergency shutdown, solar central receivers exposed to winds, electronic devices cooled by fans and heat exchangers placed in a low-velocity environment. The simplest physical model of such a flow is the two dimensional laminar mixed convection flows along a vertical flat plate.

The effect of variable viscosity in the flow and heat transfer to a continuous moving flat plate is studied by Pop.I et al. (1992). Bagai (2004) investigated the effect of temperature dependent viscosity on heat transfer rates in the presence of internal heat generation, a similarity solution is proposed for the analysis of the steady free convective boundary layer over a non-isothermal axisymmetric body embedded in a fluid saturate porous medium. Seddeck M.A. et al. (2005), analyzed the Laminar mixed convective adjacent to vertical continuously stretching sheet with variable viscosity and variable thermal diffusivity. A.K.Al-Hadhrami et al. (2002), investigated the combined free and forced convection of a fully developed Newtonian fluid within a vertical channel composed of porous media when viscous dissipation effects are taken into consideration. The effects of conduction and viscous dissipation on natural convection flow of an incompressible, viscous and electrically conducting fluid in the presence of transverse magnetic field is studied by Abdullah-Al-Mamun et al. (2007).

Viscous and Joule heating effects on forced convection flow from radiate isothermal porous surface had been studied by Duwairi H.M (2005). M.A.El-Hakiem (2000), studied the effect of viscous dissipation, the thermal dispersion and Joule heating on MHD-free convection flow with a variable plate temperature in a micropolar fluid in the presence of uniform transverse magnetic field. The radioactive effects of magneto hydrodynamic natural convective flows saturated in porous media are studied by Mansour M.A. et al. (2001). Seddeck (2002), studied the effects of magnetic field and variable viscosity on steady two-dimensional laminar non-Darcy forced convection flow over a flat plate with variable wall temperature in a porous medium in the presence of blowing.

E.M. A .Elbashbesy et al. (2001) studied the mixed convection along a vertical plate with variable surface heat flux embedded in porous medium. Orhan Aydın et al. (2008), studied the laminar boundary layer flow over a flat plate embedded in a fluid-saturated porous medium in the presence of viscous dissipation, inertia effect and suction/injection. The flow of a viscous conducting fluid between two parallel plates of infinite length (one of which is at rest and the other moving parallel to itself with a linear axial temperature variation) under the influence of a uniform transverse magnetic field is studied by N. Bhaskara Reddy et al. (2003).

Kumari M (1998), studied the variable viscosity effects on free and mixed convection boundary-layer flow from a horizontal surface in a saturated porous medium - variable heat flux. Md.Abdus Sattar , (2007), studied the free and forced convection boundary layer flow past a porous medium bounded by a semi-infinite vertical porous plate. The problem of combined free-forced convection and mass transfer flow over a vertical porous flat plate, in presence of heat generation and thermal-diffusion, is studied numerically by M.S.Alam et al.

(2006). The effect of variable viscosity on combined forced and free convection boundary-layer flow over a horizontal plate with blowing or suction is studied by Mostafa M.A.Mohmoud (2007),.

Most of the above studies are based on the constant physical properties of the ambient fluid. However, it is known that these properties may change with temperature, especially fluid viscosity. To predict accurately the flow behavior and heat transfer rate, it is necessary to take this variation in viscosity into account. The effect of temperature dependent viscosity on the mixed convection flow from vertical plate is investigated by several authors (Hady F.M, et. Al (1996), Hossain A et. al (2000), Kandasamy, Ramasamy; Muhaimin et. al (2009) N. G. Kafoussius and E. W. Williams, (1995), Orhan Aydın and Ahmet Kaya, (2008)). In all the aforementioned analysis the effects of variable viscosity with variable dissipation have not been considered. The present study is to incorporate the idea that the effect of variable viscosity and viscous dissipation on combined forced and free convection boundary-layer flow over a horizontal plate with blowing or suction.

MATHEMATICAL FORMULATION:

Let us consider the steady two-dimensional laminar free and forced convection flow of a viscous incompressible fluid over a semi-infinite horizontal flat plate aligned parallel to a uniform free stream with velocity u_∞, density ρ_∞ and temperature T_∞ in the presence of wall temperature distribution $T_w(\bar{x}) = \bar{x}^{-\frac{1}{2}}$. The $\bar{x}$ - axis is measured from the leading edge along the plate and $\bar{y}$ is normal to it. We assume that property variation with temperature is limited to velocity and density. The temperature dependent density is taken in the buoyancy force term in the momentum equation only. Considering the viscous dissipation and under Boussinesq approximation, the two-dimensional boundary layer equation for the mixed convection flow of fluid past a semi-infinite horizontal plate may be written as Pop I (2001)..

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0 \tag{1}$$

$$\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{v}}{\partial \bar{y}} = -\frac{1}{\rho_\infty}\frac{\partial \bar{p}}{\partial \bar{x}} + \frac{1}{\rho_\infty}\frac{\partial}{\partial \bar{y}}\left(\bar{\mu}\frac{\partial \bar{u}}{\partial \bar{y}}\right) \tag{2a}$$

$$-\frac{1}{\rho_\infty}\frac{\partial \bar{p}}{\partial \bar{y}} = g\beta(T - T_\infty) \tag{2b}$$

$$\bar{u}\frac{\partial T}{\partial \bar{x}}+\bar{v}\frac{\partial T}{\partial \bar{y}}=\frac{1}{\rho_\infty c_\rho}\frac{\partial}{\partial \bar{y}}(k\frac{\partial T}{\partial \bar{y}})+\bar{\mu}(\frac{\partial \bar{u}}{\partial \bar{y}})^2 \tag{3}$$

Where $\bar{u}$ and $\bar{v}$ the velocity components in the $\bar{x}$ and $\bar{y}$ directions respectively, $\bar{\mu}$ is the viscosity of the fluid, T is temperature of the fluid in the boundary layer, g is the acceleration due to gravity, β is the coefficient of volumetric expansion, $\bar{p}$ is the pressure, k is the thermal conductivity and c_ρ is the specific heat at constant pressure.

The boundary conditions to be satisfied are given by

$$\bar{y}=0: \quad \bar{u}=0, \quad \bar{v}=v_w, \quad T=T_w(\bar{x}) \tag{4}$$

$$\bar{y}\to\infty: \quad \bar{u}\to u_\infty, \quad \bar{p}\to o, \quad T\to T_\infty$$

For viscous fluid, Ling and Dbbys (1987), and Lai Kulachi (1990), suggest that the viscosity $\bar{\mu}$ dependents on temperature T of the force

$$\bar{\mu}=\frac{\mu_\infty}{(1+\gamma(T-T_\infty))} \quad \text{or} \quad \frac{1}{\bar{\mu}}=\alpha(T-T_r) \tag{5}$$

With $\alpha=\frac{T}{\mu_\infty}$, $T_r=T_\infty-\frac{1}{\gamma}$ (6)

Where α and T_r are constants and their values depend on the reference state of the fluid. In general $\alpha<0$ for gases and $\alpha>0$ for liquids.

Introducing the following non-dimensional variable in the equations (1) – (3):

$$x=\frac{\bar{x}}{l}, \quad y=\frac{\sqrt{\mathrm{Re}}}{l}\bar{y}, \quad T_w(\bar{x})=T_\infty+T^*/\sqrt{\bar{x}}$$

$$\eta=\frac{y}{x^{\frac{1}{2}}}, \quad \psi=v_\infty\sqrt{\mathrm{Re}\,x}\,f(\eta), \quad v_\infty=\frac{\mu_\infty}{\rho_\infty} \tag{7}$$

$$T-T_\infty=T^*\frac{\theta(\eta)}{\sqrt{x}}, \quad \bar{p}-p_\infty=\rho u_\infty^2 p(\eta)$$

Where Re is the Reynolds number, T^* represents a characteristic temperature difference between the plate and the free stream and l is a reference length, we get

$$2\mu f'''+2\mu' f''+ff''+\lambda\eta\theta=0 \tag{8}$$

$$2\theta''+p_r(f'\theta+f\theta'+Ec(f'')^2\theta)=0 \tag{9}$$

Where $\mu = \frac{\bar{\mu}}{\mu_\infty}$, μ_∞ is the viscosity of the ambient fluid and the prime denotes differentiation with respect to η.

Introducing equation (5) in equations (8) and (9), we have

$$f''' - \frac{\theta'}{(\theta-\theta_r)} f'' - \frac{2(\theta-\theta_r)}{\theta_r}(ff'' + \lambda\eta\theta) = 0 \quad (10)$$

$$2\theta'' + p_r(f'\theta + f\theta' + Ec(f'')^2\theta) = 0 \quad (11)$$

Where θ_r is the constant viscosity-temperature parameter given by

$$\theta_r = \frac{T_r - T_w}{T_w - T_\infty} = \frac{1}{\gamma(T_w - T_\infty)} \quad (12)$$

$p_r = \frac{v_\infty}{k_\infty}$ is the Prandtl number, $\lambda = \frac{gl\beta T^*}{\sqrt{\mathrm{Re}\,u_\infty^2}}$ is the mixed convection parameter and $Ec = \frac{2\mu \mathrm{Re}^2 U_\infty}{l^2(T - T_\infty)}$ is the Eckert number.

Equation (2.2.7) transforms the boundary condition (2.2.4) into

$$\eta = 0: \quad f = f_w, \quad f' = 0, \quad \theta = 1 \quad (13)$$

$$\eta \to \infty: \quad f' \to 1, \quad \theta = 0$$

Where $f_w = -2\sqrt{x}v_w$ is the blowing (<0) or the suction (>0) parameter.

Applying the Quasi–linearization technique (1965) to the non-linear equation (7), we obtain as

$$f''' + Af'' + Bf = D_1 \quad (14)$$

Where $A = -(2\frac{\theta-\theta_r}{\theta_r}F + \frac{\theta'}{\theta-\theta_r})$; $B = -2\frac{\theta-\theta_r}{\theta_r}F''$;

$$D_1 = 2\frac{\theta-\theta_r}{\theta_r}(\lambda\eta\theta - FF'')$$

Where F is assumed to be known function. Using an implicit finite difference scheme for the equation (14), and (11) we get the following

$$\mathrm{f}[\mathrm{i}+2] + \mathrm{a}_0[i]f[i+1] + b_0[i]f[i] + c_0[i]f[i-1 = d_0[i] \quad (15)$$

$$\mathrm{a}_1[i]\theta[i+1] - b_1[i]\theta[i] + c_1[i]\theta[i-1] = 0 \quad (16)$$

Where

$a_0[i] = -3 + hA[i]$

$b_0[i] = 3 - 2hA[i] + h^3 B[i]$

$c_0[i] = -1 + hA[i]$

$d_0[i] = h^3 D_1[i]$

$a_1[i] = 2 + \frac{h}{2} \Pr f[i]$

$b_1[i] = 4 - \Pr h^2 F'[i] + h^2 Ec (F''[i])^2$

$c_1[i] = 2 - \frac{h}{2} \Pr f[i]$

Here h represents the mesh size taken as h = 0.02. The system of equations (15) & (16) have been solved by Gauss-Seidel iteration method and numerical values are carried out after executing the computer program for it. A step size of $\Delta\eta$ = 0.001 was selected to be satisfactory for a convergence criterion of 10^{-7} in nearly all cases.

The shearing stress at the plate is defined by

$$\tau_w = \bar{\mu}\left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)_{\bar{y}=0} \tag{17}$$

The local skin-friction coefficient is defined by

$$C_f = \frac{2\tau_w}{\rho_\infty u_\infty^2} = 2\sqrt{\mathrm{Re}}\, \frac{\theta_r}{(\theta_r - 1)}\, f''(0, \theta_r) \tag{18}$$

Where Re is the local Reynolds number

The local Nusselt number is defined by

$$Nu = -\sqrt{\mathrm{Re}}\,\theta'(0, \theta_r) \tag{19}$$

RESULTS AND DISCUSSION

In order to analyze the results, the numerical computation has been carried out using the method described in the previous section for various values of the parameters such as fluid viscosity temperature parameter, θ_r, mixed convection parameter, λ, the blowing or suction parameter, f_w, the buoyancy parameter, Prandtl number Pr and the Eckert number, Ec. For illustration of the results numerical values are plotted in the figures 1- 10. The physical explanations of the appropriate change of parameters are given below.

The effect of mixed convection parameter λ and the temperature parameter θ_r on dimensionless velocity f' and temperature θ in the presence of suction f_w = 0.5 is shown in figs. (1) & (2) The increase in the values of λ the velocity profiles increases, while the temperature profiles decreases. With the increase of temperature parameter θ_r, the velocity profiles increases where as the temperature profiles decreases. Similar observations have seen the effect of temperature parameter θ_r and the mixed convection parameter λ on velocity and temperature profiles in the presence of blowing f_w = -0.5, from figs. (3) & (4).

The influence of the blowing and suction parameter f_w on velocity profiles f' and temperature profiles θ is shown in figs. (5) & (6) respectively. It is seen from this figures that as f_w decreases the velocities and the temperature profiles are decreased.

Figures (7) & (9) show that with the increase in the values of Eckert number, Ec the velocity profiles f' decrease in both cases in the presence of suction (f_w = 0.5) and blowing (f_w = -0.5). The viscous dissipation effect on velocity profiles is more when the mixed convection parameter λ = 2.0 compared with λ = 0.5.

The effect of Eckert number, Ec on temperature profiles is shown in figs. (8) & (10) for suction (f_w = 0.5) and blowing (f_w = -0.5) respectively. It is observed that the temperature profiles increases with the increase of Ec for both cases.

It is observed from table 1 that the numerical values of $f''(0)$ and $\theta'(0)$ in the present paper when Ec = 0 are in good agrument with results obtained by Mostafa A.A. Mahmoud [78]. They have used the Ruge-Kutta fourth order method with Newton- Raphson iteration method. The scheme employed in the present paper is implicit finite-difference method along with Thomas algorithm.

Table 1 Computation of $f''(0)$ for various values of λ

λ	**Mostafa A.A.Mahmoud**	**Present**
0	0.3320	0.3325
1.2	0.5516	0.5546
0.2	0.7740	0.7735
1.0	1.0545	1.0547

The skin-friction coefficient and Nusselt number presented by equations (18) and (19) are directly proportional to $f''(0)$ and -$\theta'(0)$ respectively. The effects of λ, f_w, θ_r and Ec on $f''(0)$ and -$\theta'(0)$ have been presented through table 2. From the table it is noticed that in the prescience of blowing or suction the Skin-friction coefficient increases as either λ or θ_r increases. For fixed values of λ and θ_r, the Skin-friction coefficient increases with the increase of blowing parameter and decreases with increase of suction parameter. Also, it is found from the table that the heat transfer -$\theta'(0)$ at the plate increases due to increase in the blowing parameter, while it increases as the suction parameter increases.

Table 2. Values of $f''(0)$ and $-\theta'(0)$ for various values of θ_r, λ and f_w with Pr= 0.72

λ	f_w	θ_r	$f''(0)$	$-\theta'(0)$
0.2	0.2	2	0.40234	0.07186
0.5	0.2	2	0.5648	0.07186
2.0	0.2	2	1.0945	0.07186
0.2	-0.2	2	0.4019	-0.07186
0.5	-0.2	2	0.5935	-0.07186
1.0	-0.2	2	1.1824	-0.07186
0.5	0.5	2	0.5621	0.1801
0.5	0.5	4	0.7540	0.1801
0.5	0.5	6	0.8119	0.1801
0.5	-0.5	2	0.6404	-0.1801
0.5	-0.5	4	0.7045	-0.1801
0.5	-0.5	6	0.7222	-0.1801

CONCLUSIONS:

Under the assumption of temperature dependent viscosity the present method gives solutions for steady incompressible boundary layer flow over a heated surface in the presence of viscous dissipation. The results pertaining to the present study indicate that the temperature dependent fluid viscosity plays a significant role in shifting the fluid away from the wall. The effect of Eckert number on a viscous incompressible conducting fluid is seen in suppressing the velocity of the field f', which in turn causes the enhancement of the temperature field.

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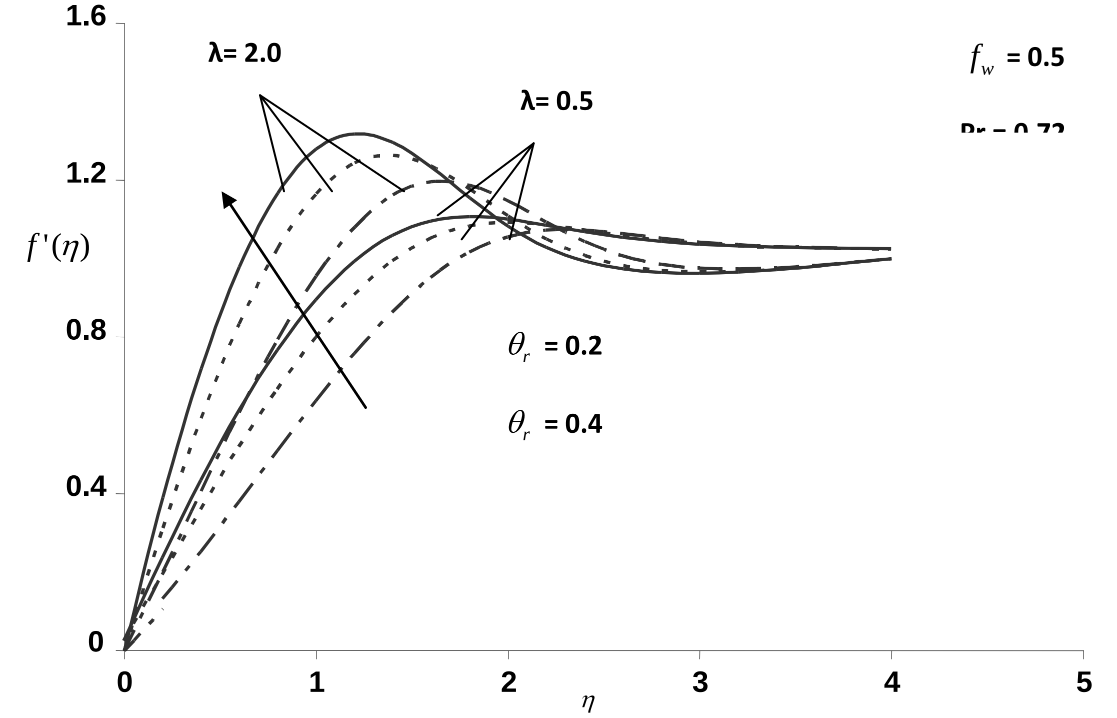

Fig. 1 Velocity profiles for different values of λ and θ_r

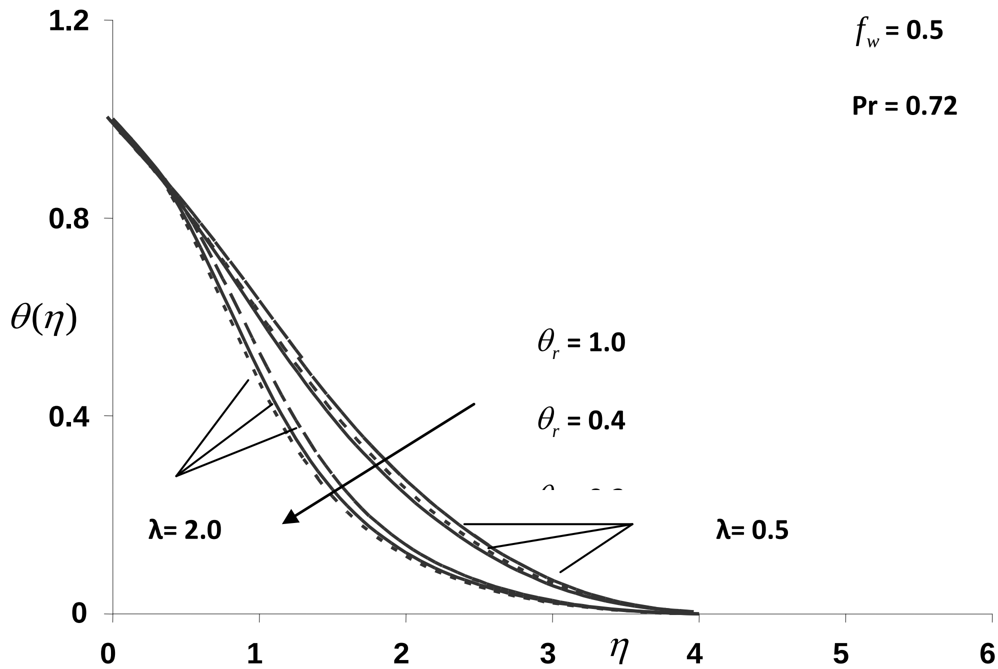

Fig. 2 Temperature profiles for different values of λ and θ_r

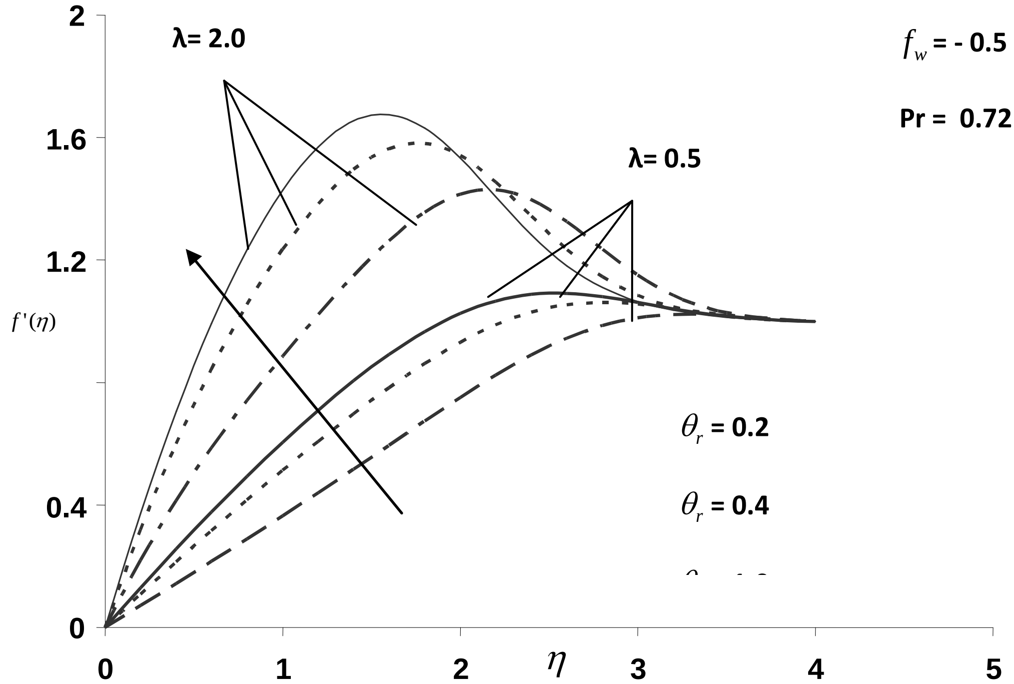

Fig. 3 Velocity profiles for different values of λ and θ_r

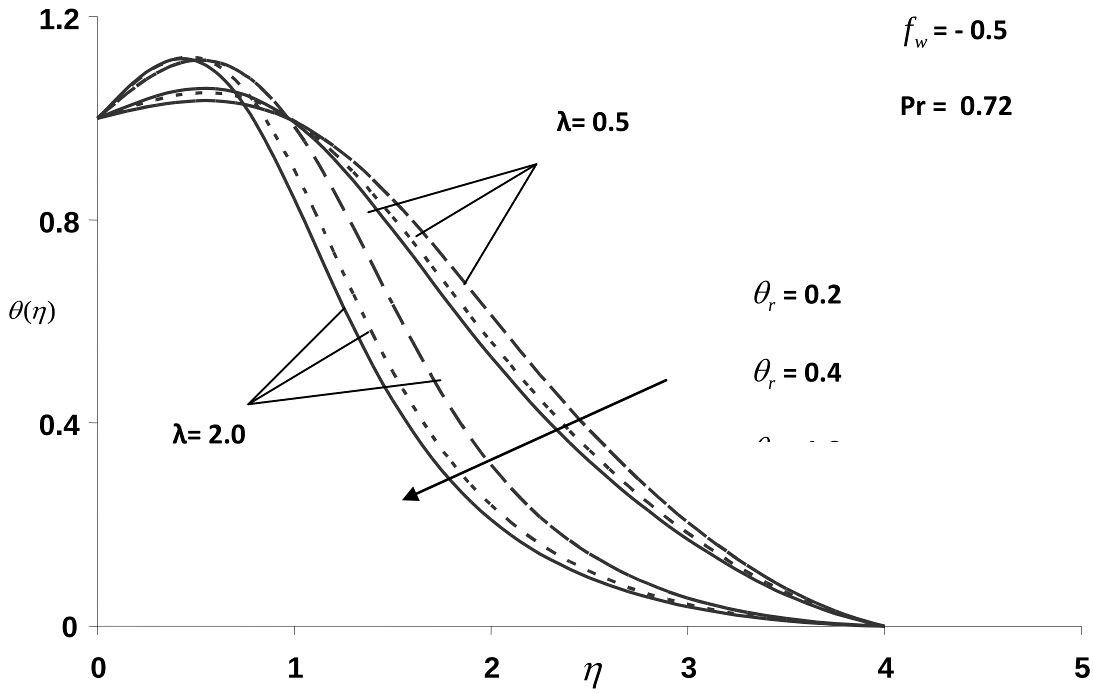

Fig. 4 Temperature profiles for different values of λ and θ_r

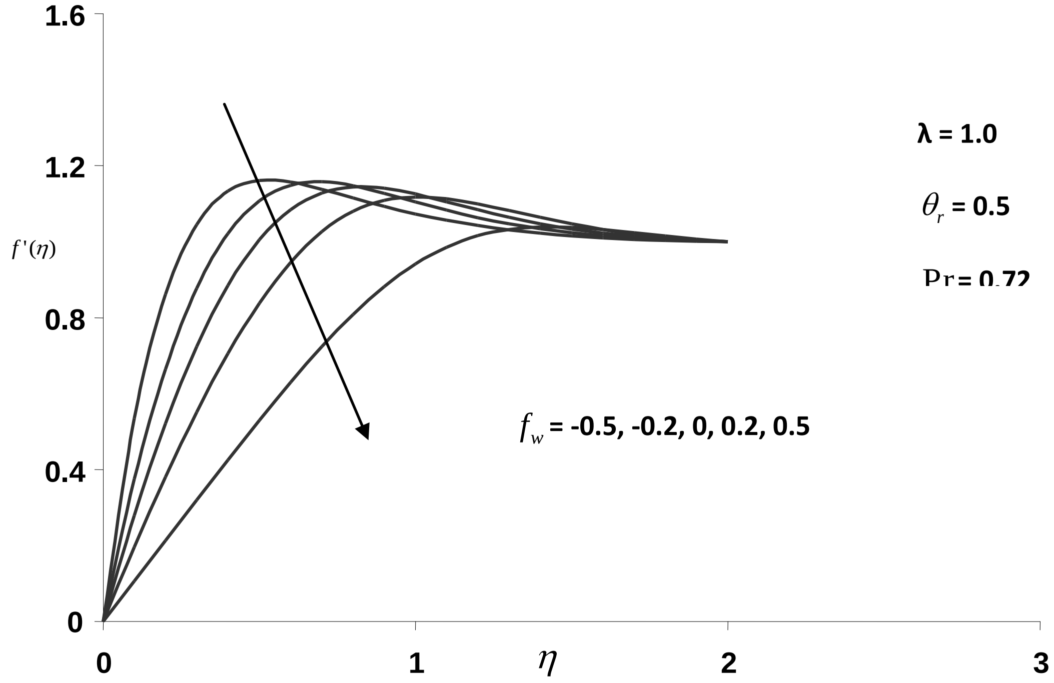

Fig. 5 Velocity profiles for different values of f_w

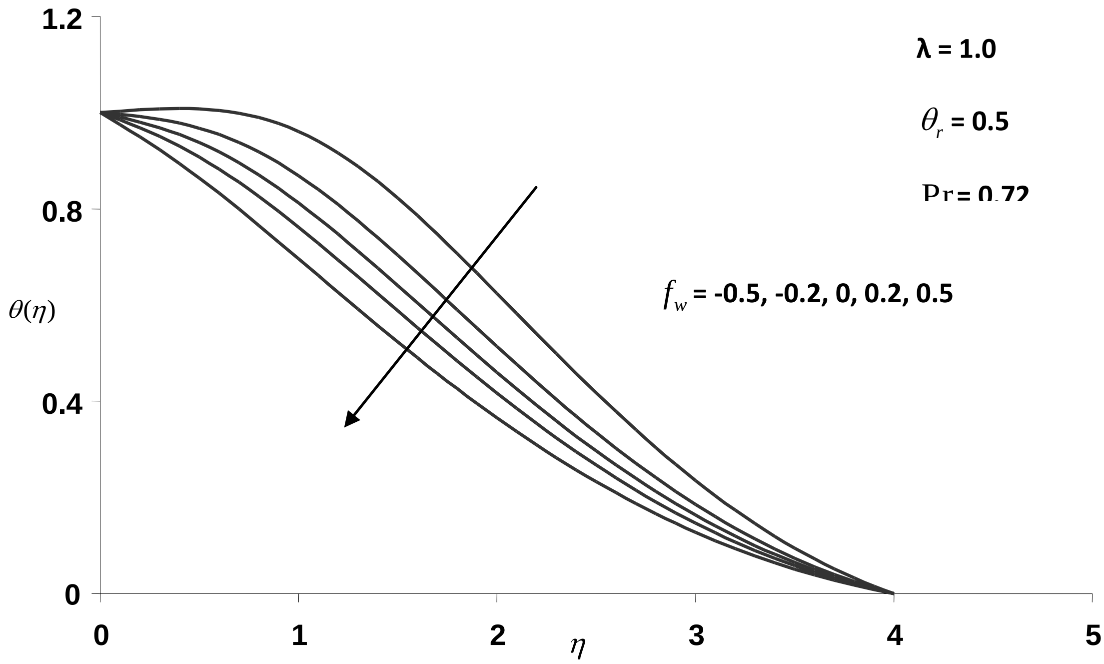

Fig. 6 Temperature profiles for different values of f_w

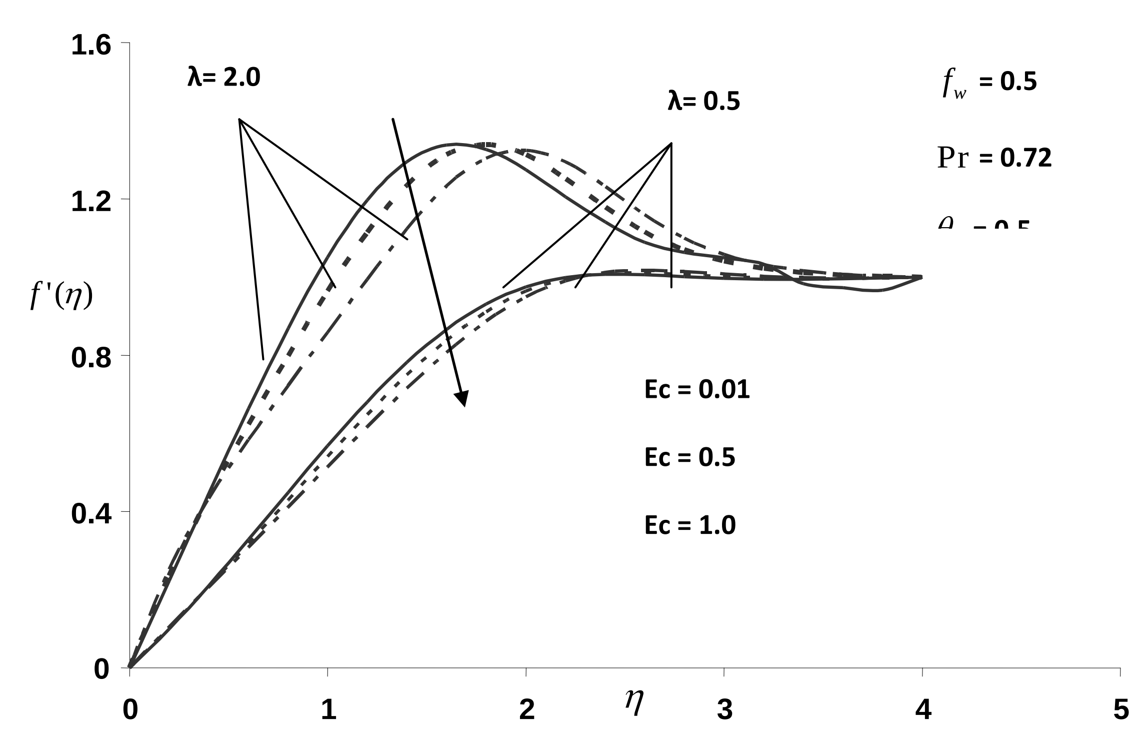

Fig. 7 Velocity profiles for different values of Eckert number Ec

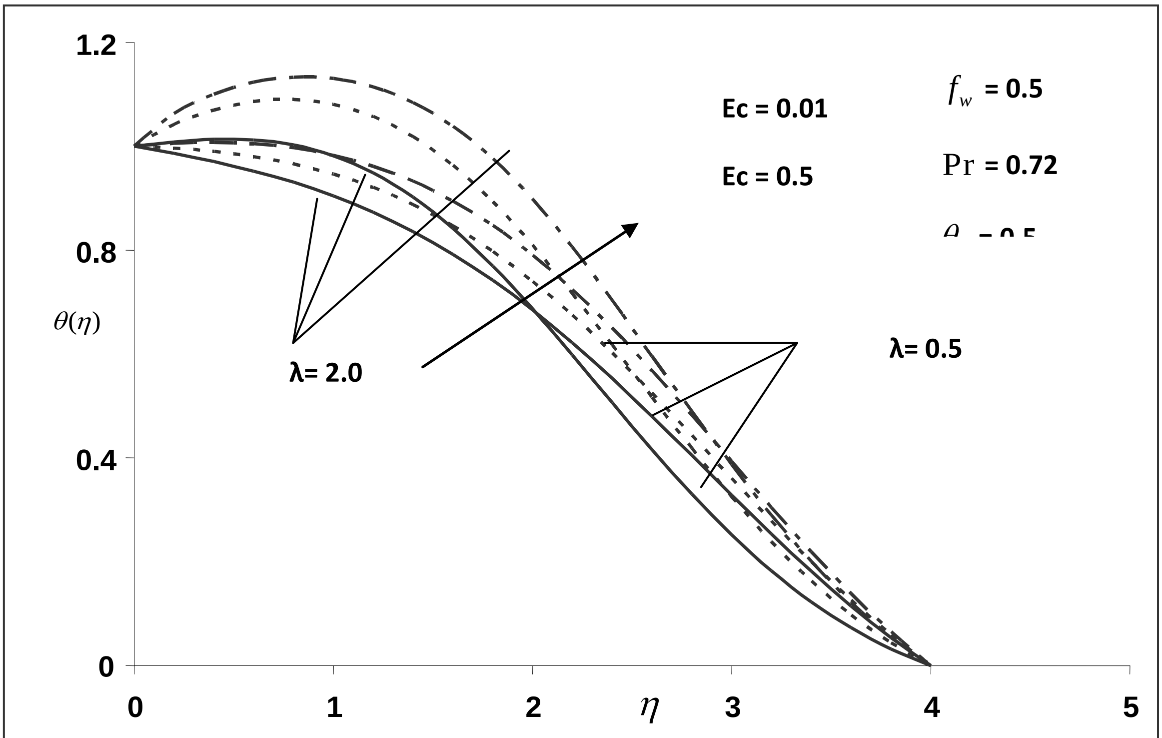

Fig. 8 Temperature profiles for different values of Eckert number Ec

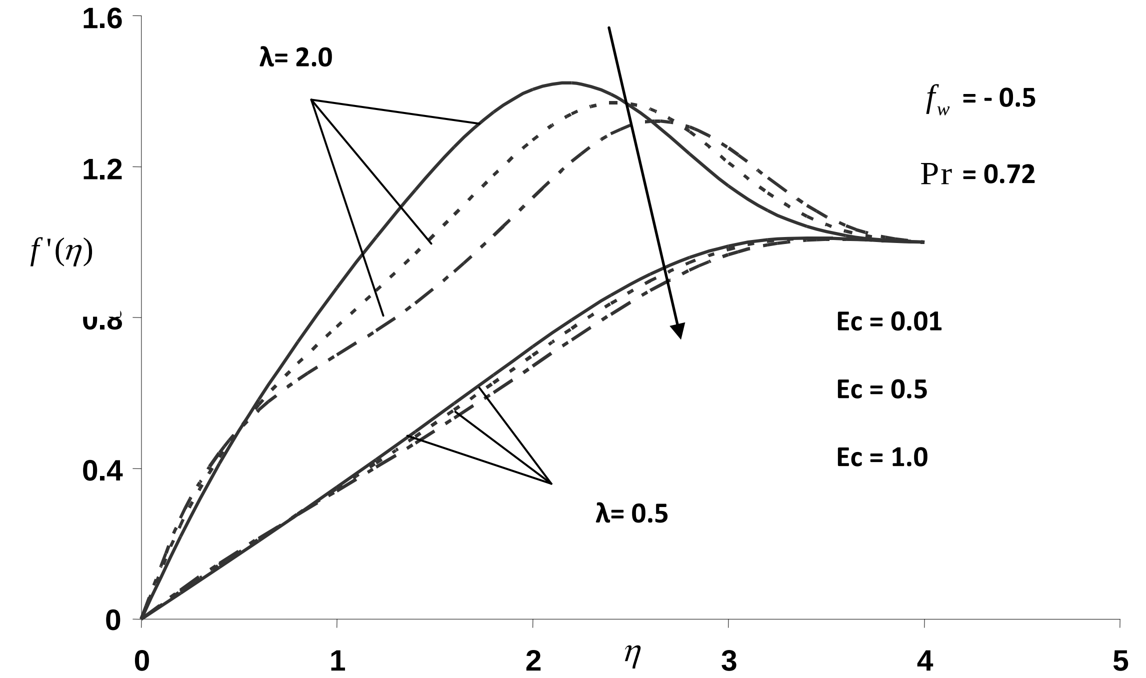

Fig. 9 Velocity profiles for different values of Eckert number Ec

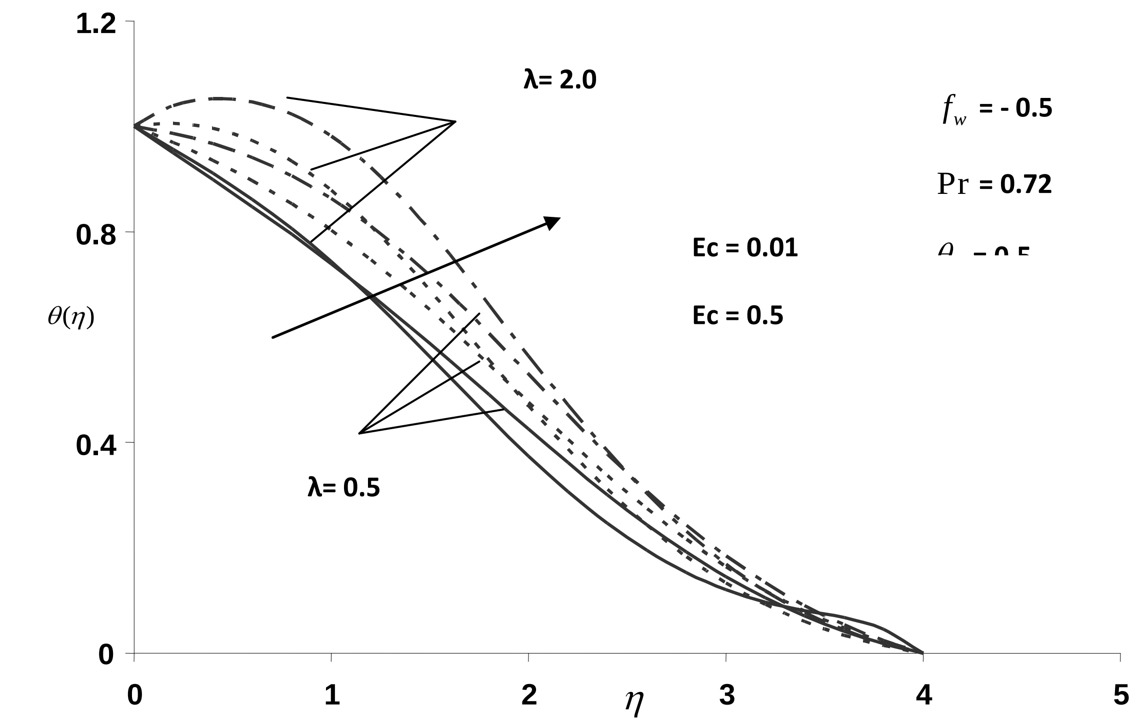

Fig.10 Temperature profiles for different values of Eckert number Ec