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Full Length Research Paper

Effects of thermal radiation and magnetic field on unsteady mixed convection flow and heat transfer over a porous stretching surface in the presence of internal heat generation/absorption

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The problem of magneto-hydrodynamic unsteady mixed convective flow and heat transfer of an electrically conducting fluid over a porous stretching surface in the presence of heat generation/absorption and thermal radiation has been investigated. It is assumed that the unsteadiness is caused by the impulsive motion of the free stream velocity and by sudden increase in the surface temperature. The nonlinear partial differential equations of continuity, momentum, and energy are reduced to nonlinear ordinary differential equations .Numerical solutions of these equations are obtained with the help of shooting method. A comparison with available data from the open literature as well as the exact solution for the steady-state case of the present problem is made, and found to be in good agreement.

Key words: Unsteady stretching surface, mixed convection, magnetic field, thermal radiation, internal heat generation or absorption.

INTRODUCTION

The continuous moving surface heat transfer problem has many practical applications in industrial manufacturing processes. Since the pioneering work of Sakiadis (1961), various aspects of the problem have been investigated by many authors.

The steady boundary layer flow due to stretching with linear velocity was investigated by Crane (1970). Vleggaar (1977) and Gupta and Gupta (1977) analyzed the stretching problem with constant surface temperature, while Soundalgekar and Ramana (1980) investigated the constant surface velocity. Grubka and Bobba (1985) have analyzed the stretching problem for a surface moving with a linear velocity and with a variable surface temperature. Ali (1994) reported flow and heat characteristics on a stretched surface subject to power law velocity and temperature distributions. The flow field of a stretching wall with a power-law velocity variation was discussed by Banks (1983).

Ali (1995) and Elbashbeshy (1998) extended Bank's work for a porous stretched surface for different values of the injection parameter .Chen (1998), carried out an analysis to study mixed convection flow over a stretching surface. Nazar et al. (2004) presented the development of the two-dimensional boundary layer flow in the region of stagnation point on a stretching surface. Elbashbeshy and Bazid (2000) studied the heat transfer over a continuously moving plate embedded in porous medium. All the aforementioned studies consider the steady-state problem. But in certain practical problems, the motion of the stretched surface may start from the rest. In these problems, the unsteady or transient aspects become more interesting. The unsteady heat transfer problems over a stretching surface, which is started impulsively from rest or is stretched with a velocity that depends on

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time, are considered. Andersson et al. (2000), presented a new similarity solution for the temperature field is devised, which transforms the time-dependent thermal energy equation to an ordinary differential equation. Elbashbeshy and Bazid (2004) presented an exact similarity solution for unsteady momentum and heat transfer flow whose motion is caused solely by the linear stretching of a horizontal stretching surface. Also Elbashbeshy and Bazid (2003), studied the heat transfer over an unsteady stretching surface with internal heat generation. In recent years, numerous investigations have been conducted on the magneto-hydrodynamic flows and heat transfer because of its important applications in metallurgical industry. In the presence of a transverse magnetic field, the flow and heat transfer over a stretching surface have been investigated by (Chandran et al., 1996; Pop and Na, 1998; Mukhopadhyay et al., 2005; Andersson et al., 1992; Chen, 2008). On the other hand, the effect of radiation on boundary layer flow and heat transfer problems can be quite significant at high operating temperature. In view of this, Elbashbeshy and Dimian (2002) and Hossain et al. (1999, 2001), studied the thermal of a gray fluid which emitting and absorbing radiation in a non-scattering medium. Elbashbeshy (2000), investigated the radiation effect on heat transfer over a stretching surface. In all the previous investigations, the effects of internal heat generation or absorption on heat transfer were not analyzed. Elbashbeshy (2003) investigated the heat transfer over a stretching surface with internal heat generation. Later, Attia and Seddeek (2007) studied the effect of uniform suction or injection on two-dimensional stagnation point flow toward a stretching surface with internal heat generation /absorption. Since no attempt has been made to analyses the effects of thermal radiation and magnetic field on unsteady boundary layer mixed convection flow and heat transfer over a vertical stretching surface in the presence of heat generation / absorption.

The aim of the present work is to study the effects of thermal radiation and magnetic field on unsteady mixed convection flow and heat transfer over a vertical porous stretching surface in the presence of internal heat generation or absorption.

EQUATIONS OF MOTION

Consider an unsteady two-dimensional mixed convection boundary layer flow of an incompressible viscous liquid along a vertical porous stretching surface with velocity $U_w(x,t) = \frac{cx}{1-\alpha t}$ and with temperature distribution $T_w = T_\infty + \frac{T_0 cx}{2\nu(1-\alpha t)^2}$ (Andersson et al. (2000). Here the stretching surface is subjected to such amount of tension which does not alter the structure of the porous material. A uniform magnetic field of strength B_0 is applied normal to the stretching surface which produces magnetic effect in the x-axis .The fluid is assumed to be gray, emitting and absorbing, but non-scattering medium. The continuity, momentum and energy equations governing such type of flow are written as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} + g\beta(T - T_\infty) - \frac{\sigma B_0^2}{\rho}u \quad (2)$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} + \frac{Q_0}{\rho c_p}(T - T_\infty) \quad (3)$$

with the boundary conditions

$$u = U_w, v = V_w, \text{ at } y = 0$$

$$u \to 0,\ T \to T_\infty \text{ at } y \to \infty \quad (4)$$

where $V_w = -\sqrt{\frac{c\nu}{1-\alpha t}}$ is the velocity of suction $(V_w > 0)$. By using Rosseland diffusion approximation for radiation, $q_r = -\frac{4\sigma_s}{3k^*}\frac{\partial T^4}{\partial y}$, we assume that the temperature difference within the flow is such that T^4 may be expanded in a Taylor's series. Expanding T^4 about T_∞ and neglecting higher orders we get $T^4 = 4T_\infty^3 T - 3T_\infty^4$. Now Equation (3) becomes

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \left(\frac{k}{\rho c_p} + \frac{16\sigma_s T_\infty^3}{3\rho c_p k^*}\right)\frac{\partial^2 T}{\partial y^2} + \frac{Q_0}{\rho c_p}(T - T_\infty) \quad (5)$$

The equation of continuity is satisfied if we choose a stream function $\psi(x, y)$ such that

$$u = \frac{\partial \psi}{\partial y}, \quad v = -\frac{\partial \psi}{\partial x} \quad (6)$$

We introduce now the following dimensionless similarity variables

$$\eta = \sqrt{\frac{c}{\nu(1-\alpha t)}}\, y, \qquad (7)$$
$$\psi(x, y) = \sqrt{\frac{c\nu}{(1-\alpha t)}}\; xf(\eta),$$
$$T = T_\infty + T_0\left[\frac{cx}{2\nu(1-\alpha t)^2}\right]\theta(\eta).$$

Substituting into (2) and (5), we obtain the following set of ordinary differential equations

$$f''' + ff'' - f'^2 - A(f' + \frac{1}{2}\eta f'') - \lambda\theta - Mf' = 0 \qquad (8)$$

$$\theta'' + \frac{\Pr}{(1+R)}[f\theta' - f'\theta + \delta\theta - \frac{A}{2}(4\theta + \eta\theta')] = 0 \qquad (9)$$

The boundary conditions (4) now become

$$\eta = 0: \quad f(0) = f_0, \quad f'(0) = 1 \quad and \quad \theta = 1,$$
$$\eta \to \infty: \quad f' \to 0, \quad \theta \to 0, \qquad (10)$$

Where $f_0 = -V_w\sqrt{\frac{1-\alpha t}{c\nu}}$, $f_0 > 0$ corresponding to suction.

The physical quantity of interest in this problem is the skin friction coefficient C_f and the local Nusselt number Nu_x, which are defined as

$$C_f = \frac{2\mu(\frac{\partial u}{\partial y})_{y=0}}{[\rho U_w^2]}, \quad Nu_x = -\frac{x(\frac{\partial T}{\partial y})_{y=0}}{T_w - T_\infty}$$
$$\frac{1}{2}C_f\sqrt{\mathrm{Re}_x} = f''(0), \quad Nu_x/\sqrt{\mathrm{Re}_x} = -\theta'(0)$$
(11)

NUMERICAL METHOD

The aforementioned Equations (8) and (9) with boundary conditions (10) are solved by converting them to an initial value problem. We set

$$f' = z, \quad z' = p, \quad \theta' = q,$$

$$p' = Az + \frac{1}{2}A\eta p + \lambda\theta + Mz + z^2 - fp \qquad (12)$$

$$q' = \Pr[2A\theta + \frac{1}{2}A\eta q - fq + z\theta - \delta\theta]/[1+R] \qquad (13)$$

With boundary conditions

$$f(0) = S, f'(0) = 1, \theta(0) = 1 \qquad (14)$$

In order to integrate (12) and (13) as an initial value problem, we require a value for $p(0),\ i.e\ f''(0)\ and\ q(0)\ i.e\ \theta'(0)$, but no such values are given in the boundary. The suitable guess values for $f''(0)\ and\ \theta'(0)$ are chosen and then integration is carried out. We compare the calculated values for f' and θ at $\eta = 20$ (say) with the given boundary condition $f'(20) = 0$ and $\theta(20) = 0$ and adjust the estimated values, $f''(0)\ and\ \theta'(0)$, to give a better approximation for the solution.

We take the series of values for, $f''(0)\ and\ \theta'(0)$, and apply the fourth order Runge – Kutta method with step size h = 0.01. The aforementioned procedure is repeated until we get the results up desired degree of accuracy, 10^{-5}.

RESULTS AND DISCUSSION

The transformed momentum Equation (8) and the energy Equation (9) subject to the boundary condition (10) were solved numerically by applying the fourth- order Runge – Kutta integration scheme with the Newton Raphson shooting technique. Numerical calculations are carried out for fluid having Prandtl number of $0.72, 1, 10$ with various values of $M(0, 0.1, 0.5, 1)$, $A(0, 0.1, 0.2, 0.3)$, $R(1, 3, 5, 10)$, $\lambda(0, 0.1, 0.2, 0.3)$ and $\delta(-1, -0.5, 0, 0.1, 0.5)$. In order to check the accuracy of the numerical solution procedure used a comparison of local Nusselt number are made with that Elbashbeshy (1998) and Ishak et al. (2009) and results are tabulated in Table 1. The comparison of present results of local Nusselt number and the skin friction coefficient with that

Table 1. Comparison of local Nusselt number for $A=0$ and $\lambda=\delta=M=R=0$ at different values of Prandtl number $\Pr$ and suction/ injection parameter f_0 with previously published data.

A	f_0	Pr	Elbashbeshy (1998)	Ishak et al. (2009)	Present result
0	-1.5	0.72		0.4570	0.4570
0	-1.5	1.0		0.5000	0.5000
0	-1.5	10		0.6452	0.6452
0	0	0.72	0.8161	0.8086	0.8086
0	0	1.0	1.0000	1.0000	1.0000
0	0	10	3.7202	3.7202	3.7204
0	1.5	0.72		1.4944	1.4944
0	1.5	1.0		2.0000	2.0000
0	1.5	10		16.0842	16.0635

Ishak et al. (2008) and Chien (2009) in the presence of magnetic field at $A=R=\delta=0$ and $\lambda=\Pr=1$ are shown in Table 2. From this Tables 1 to 2, we note that there is a close agreement with these approaches and thus verifies the accuracy of the method used. We note from Tables 3 to 5 and Figures 1 to 3 that the skin friction coefficient $f''(0)$ decreases with the increase of unsteadiness parameter A, magnetic field parameter M and increases with mixed convection parameter λ, heat generation/absorption parameter δ and thermal radiation parameter R. The local Nusselt number $-\theta'(0)$ increases with the increase of unsteadiness parameter A and mixed convection parameter and decreases with the increase of heat generation/absorption parameter δ, thermal radiation parameter R and magnetic field parameter M. Figure 4 present horizontal velocity profile for various values of A when $\Pr=0.72, R=5, M=\lambda=0.1$ and $\delta=0.1$. We observe from Figure 4 that the velocity decreases with the increase of the unsteadiness parameter A. It is interesting to note that the thickness of the boundary decreases with increasing values of A. We observe from Figure 5 that the temperature is found to decrease with the increase of η. Significant change in the rate of decrease of the temperature for increasing values of A is noticed. Temperature at a point of the surface decreases significantly with the increase of A, that is, rate of heat transfer increases with increasing unsteadiness parameter A. The effect of the thermal radiation parameter R on velocity and the temperature is illustrated in Figures 6 and 7, for the same governing parameters as specified in Figure 4. It is found that velocity increases as the thermal radiation parameter R increases. Also, the temperature increases as thermal radiation parameter R increases. This is agreement with the physical fact that the thermal boundary layer thickness increases with increasing R. Figures 8 and 9 present velocity profile and temperature profile for various values of mixed convection parameter λ when $\Pr=0.72, R=5, M=0.1$, A = 0.1 and $\delta=0.1$. The velocity increases with increasing values of mixed convection parameter λ, while the temperature decreases with values of mixed convection parameter λ, at $\lambda=0$ gives the result of forced convection case. The effect of the magnetic parameter M on the velocity profile is illustrated in Figure 10 for $\Pr=0.72, R=5, \lambda=0.1$ A = 0.1 and $\delta=0.1$. It is seen that the presence of magnetic field causes higher restriction to the fluid, which reduced the fluid velocity. The effect of the magnetic parameter M on the temperature profile is illustrated in Figure 11. It is obvious that the temperature gradient at the surface decreases and accordingly the temperature and thermal boundary layer thickness increases. Figure 12 present velocity profile for different values of heat generation/absorption parameter δ. The velocity profiles increases with increasing heat generation/absorption δ at heat generation ($\delta=0.1, 0.5$) when M = 0.1, R = 5, Pr = 0.72 $A=0.3$ and $\lambda=0.1$. Figure 13 present velocity profile for different values of heat generation/absorption parameter δ. As compared to the case of no heat generation/absorption δ, one can see that when the heat is generated $(\delta>0)$ the temperature increases with increasing heat generation/absorption δ. However, the opposite trend is revealed for heat generation/absorption δ $(\delta<0)$. In Figure 14, it is seen

Table 2. Comparison of $-f''(0)$ and $-\theta'(0)$ for different values of magnetic parameter M when $\Pr = 1$, $A = R = \delta = f_0 = 0$ and $\lambda = 1$.

M	Ishak et al. (2008)		Chien-Hsin (2009)		Present result	
	$-f''(0)$	$-\theta'(0)$	$-f''(0)$	$-\theta'(0)$	$-f''(0)$	$-\theta'(0)$
0	0.5607	1.0873	0.56075	1.08727	0.5608	1.0873
0.01	0.5658	1.0863	0.56584	1.08626	0.5658	1.0863
0.04	0.5810	1.0833	0.58102	1.08326	0.5810	1.0833
0.25	0.6830	1.0630	0.68302	1.06301	0.6830	1.0630
1	1.0000	1.0000	1.00000	1.00000	1.0000	1.0000
4	1.8968	0.8311	1.89677	0.83113	1.8969	0.8316
25	4.9155	0.4702	4.91553	0.47024	4.9196	0.4724

Table 3. Results of skin friction coefficient $-f''(0)$ and the local Nusselt number $-\theta'(0)$ for different values of unsteadiness parameter A and magnetic parameter M at $\delta = 0.5$, $\Pr = 0.72$, λ = 0.1, $f_0 = 1$ and R = 5.

A	0		0.1		0.3	
M	$-f''(0)$	$-\theta'(0)$	$-f''(0)$	$-\theta'(0)$	$-f''(0)$	$-\theta'(0)$
0	1.3798	0.1638	1.486	0.2585	1.6148	0.3666
0.2	1.5002	0.1269	1.5914	0.2429	1.7047	0.3613
0.4	1.6089	0.1029	1.6859	0.2293	1.7874	0.3569

Table 4. Results of skin friction coefficient $-f''(0)$ and the local Nusselt number $-\theta'(0)$ for different values of unsteadiness parameter A and heat generation/absorption parameter δ at $\Pr = 0.72$, λ = 0.1, M = 0.1, $f_0 = 1$ and R = 5.

A	0		0.1		0.3	
δ	$-f''(0)$	$-\theta'(0)$	$-f''(0)$	$-\theta'(0)$	$-f''(0)$	$-\theta'(0)$
-1	1.5514	0.4996	1.6001	0.5265	1.6878	0.576
-0.5	1.5354	0.4152	1.5884	0.4489	1.6808	0.5084
0	1.5024	0.2945	1.5678	0.3462	1.6704	0.4263
0.1	1.4893	0.2588	1.5611	0.3195	1.6676	0.407

Table 5. Results of skin friction coefficient $-f''(0)$ and the local Nusselt number $-\theta'(0)$ for different values of radiation parameter R and mixed convection parameter λ when $\Pr = 0.72$, $\delta = 0.5$, M = 0.1, $f_0 = 1$ and A = 0.1.

λ	0.1		0.2		0.3	
R	$-f''(0)$	$-\theta'(0)$	$-f''(0)$	$-\theta'(0)$	$-f''(0)$	$-\theta'(0)$
1	1.5837	0.4831	1.4969	0.5397	1.4173	0.5718
5	1.4894	0.1147	1.3828	0.1997	1.2776	0.2330
10	1.4800	0.0769	1.3348	0.1201	1.2186	0.1494

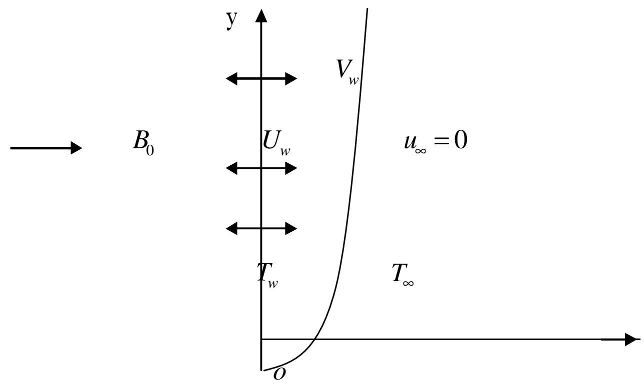

Figure 1. Physical model and coordinate system.

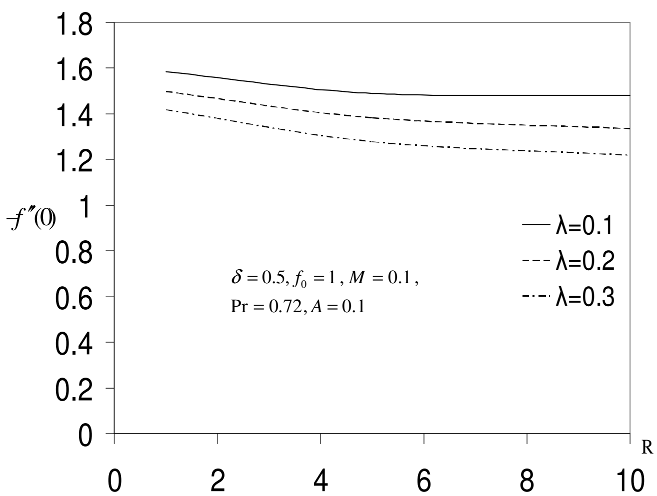

Figure 2. Variation of the skin friction coefficient as a function of R for various values of λ.

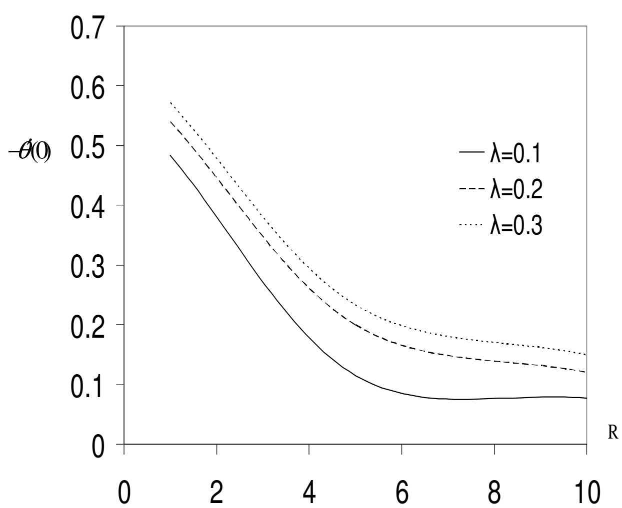

Figure 3. Variation of the rate of heat transfer coefficient as a function of R for various values of λ.

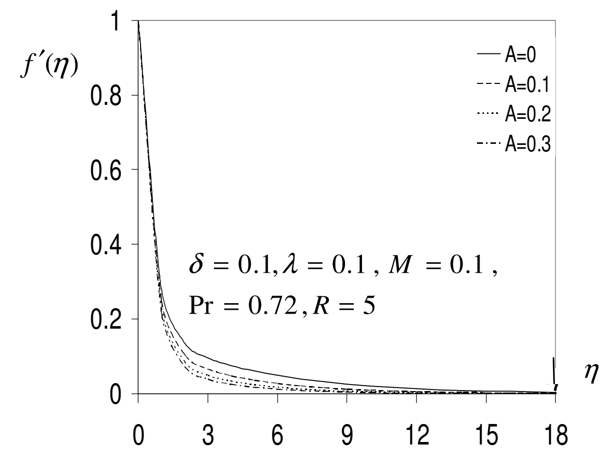

Figure 4. Velocity profiles for different values of unsteadiness parameter A at $f_0 = 1$.

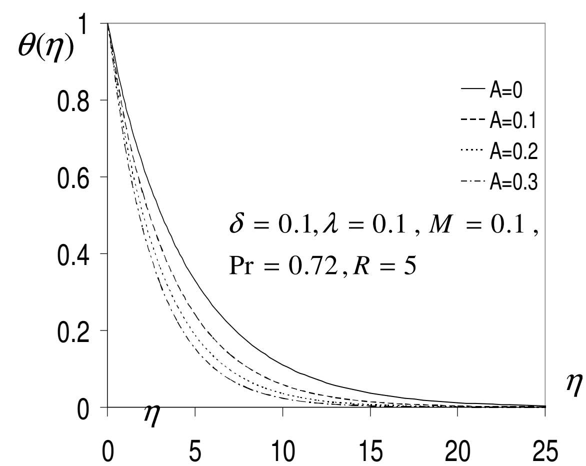

Figure 5. Temperature profiles for different values of unsteadiness parameter A at $f_0 = 1$.

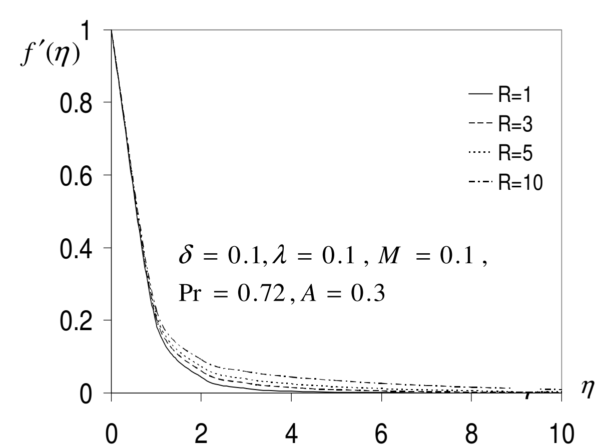

Figure 6. Velocity profiles for different values of radiation parameter R at $f_0 = 1$.

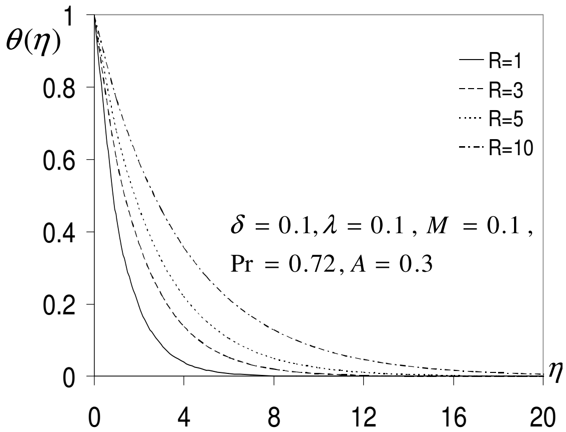

Figure 7. Temperature profiles for different values of radiation parameter R at $f_0 = 1$.

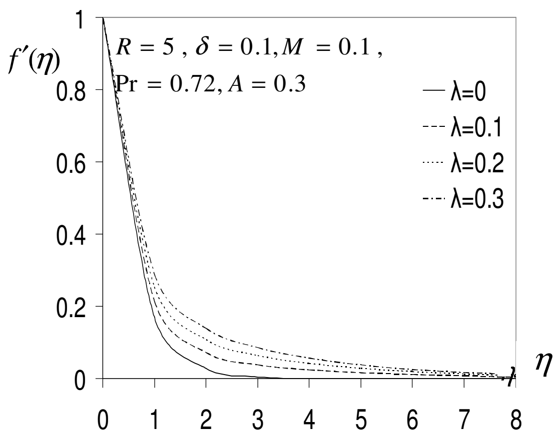

Figure 8. Velocity profiles for different values of mixed convection parameter λ at $f_0 = 1$.

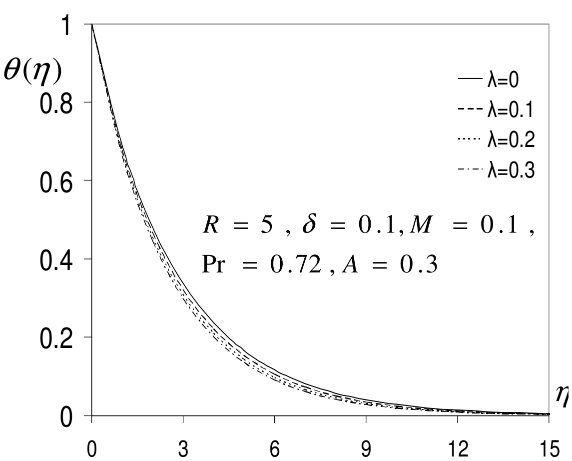

Figure 9. Temperature profiles for different values of mixed convection parameter λ at $f_0 = 1$.

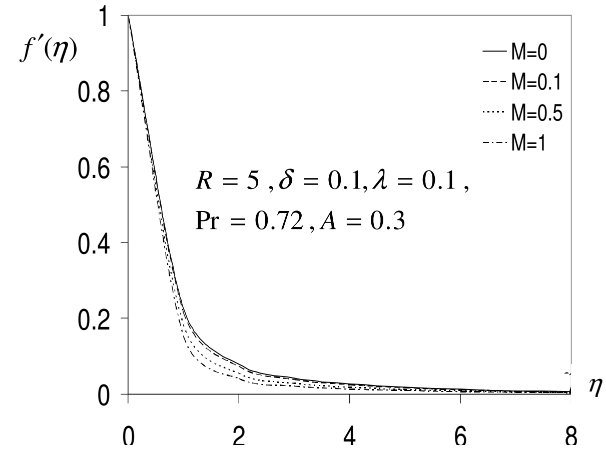

Figure 10. Velocity profiles for different values of magnetic parameter M at $f_0 = 1$.

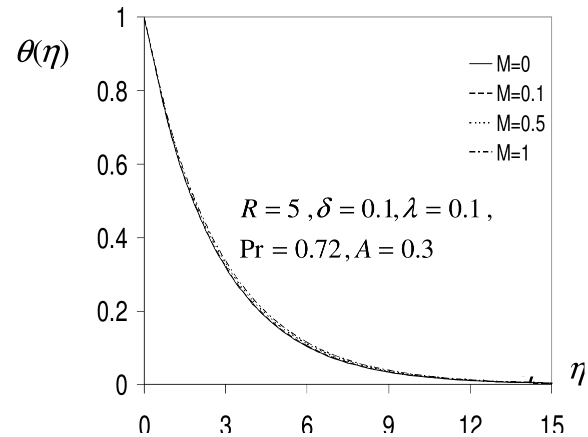

Figure 11. Temperature profiles for different values of magnetic parameter M at $f_0 = 1$.

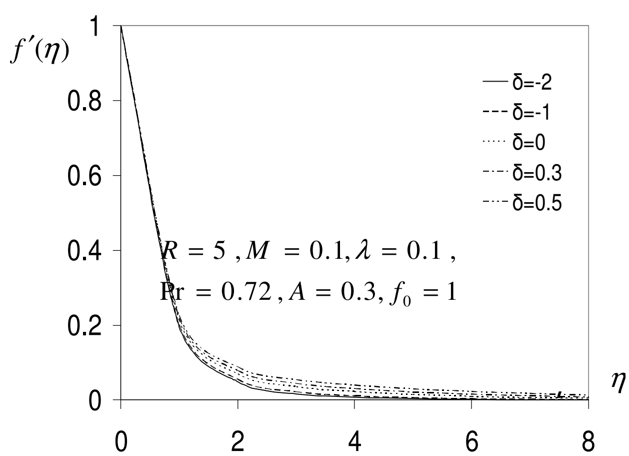

Figure 12. Velocity profiles for different values of heat generation/absorption parameter δ.

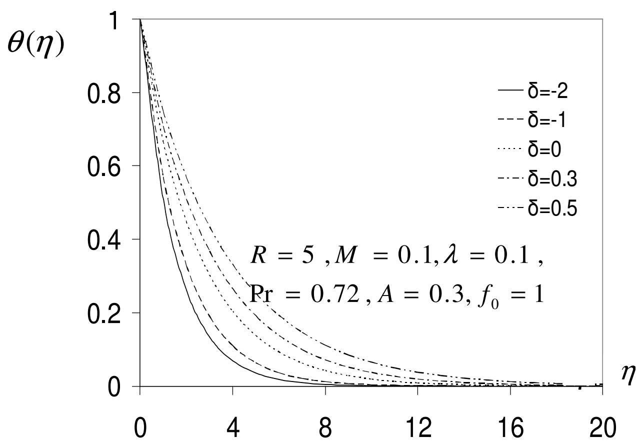

Figure 13. Temperature profiles for different values of heat generation/absorption parameter δ .

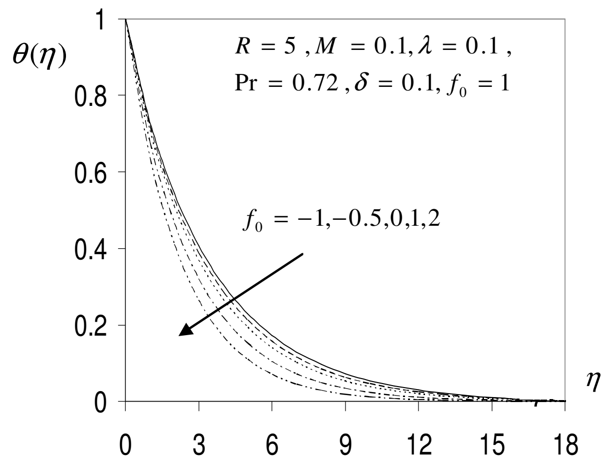

Figure 15. Temperature profiles for different values of suction/injection parameter A = 0.3.

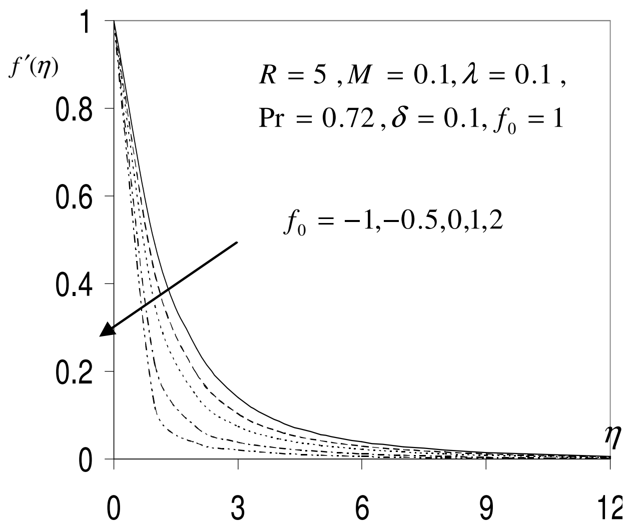

Figure 14. Velocity profiles for different values of suction/injection parameter at A = 0.3.

that with increasing suction parameter $(f_0 > 0)$, fluid velocity is found to decrease, that is, suction causes to decrease the velocity of the fluid in the boundary layer region. This effect acts to decrease the wall shear stress. Increase in suction causes progressive thinning of the boundary layer. The physical explanation for such behaviour is as follows, in case of suction the heated fluid is pushed towards the wall where the buoyancy forces can act to retard the fluid due to high influence of the viscosity, this effect acts to decrease the wall shear stress. As shown in Figure 15, the temperature in the boundary layer also decreases with increasing suction parameter $(f_0 > 0)$. The thermal boundary thickness decreases with suction parameter $(f_0 > 0)$, which causes an increase in the rate of heat transfer. The physical explanation for such behaviour is that the fluid is brought closer to the surface and reduces the thermal boundary layer thickness in case of suction.

Conclusions

The present study gives the solutions for unsteady mixed convection flow and heat transfer of an electrically conducting fluid over a vertical porous stretching surface in the presence of internal heat generation or absorption and thermal radiation .An appropriate similarity transformation was used to transform the system of time-dependent partial differential equations to set ordinary differential equations, which are then solved numerically using shooting method. The numerical solution indicated that:

1. The local Nusselt number $-\theta'(0)$ increases with the unsteadiness parameter A, suction parameter f_0 , and mixed convection parameter λ but decreases with the magnetic parameter M, heat generation/absorption parameter δ and thermal radiation parameter R.
2. The skin friction coefficient at the surface increases with heat generation/absorption parameter δ, mixed convection parameter λ and thermal radiation parameter R but decreases with unsteadiness parameter A, suction parameter f_0 , and the magnetic parameter M.
3. The velocity increases with an increase in the value of mixed convection parameter λ, thermal radiation parameter R and heat generation/absorption parameter δ while decreases with increase of magnetic parameter M, suction parameter f_0 , and unsteadiness parameter A.

4. The temperature decreases with an increase in the value of mixed convection parameter λ, suction parameter f_0 , and unsteadiness parameter A while increases with increase of radiation parameter R, magnetic parameter M and heat generation/absorption parameter δ.

Nomenclature: A, Unsteadiness parameter; B_0, magnetic field strength; c, constant; C_f, skin-friction coefficient; c_p specific heat; f dimensionless stream function; f_0 suction parameter; g, gravitational acceleration; k, thermal conductivity; k^* mean absorption coefficient; M magnetic field parameter; Nu Nusselt number; $\Pr$, Prandtl number; Q_0, heat source or sink; q_r, radiative heat flux; R, thermal radiation parameter; R_e , local Reynolds number; T, temperature of the fluid; T_0, reference temperature $(0 \le T_0 \le T_w)$; T_w, surface temperature; T_∞, free stream temperature; t, time; U_w, surface velocity; u, fluid velocity in the x-direction; V_w, velocity of suction; v, fluid velocity in the y-direction; x, y, Cartesian coordinates along the surface and normal to it, respectively.

Greek symbols: α, constant; β, coefficient of thermal expansion; η, similarity variable; θ, dimensionless temperature; ρ, density; σ , electrical conductivity; σ_s, Stefan-Boltzmann constant; ψ, stream function: μ, dynamic viscosity; ν , kinematic viscosity;

Subscripts: /, differentiation with respect to η; w, condition at the surface; ∞, condition far away from the surface.

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