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Effects of Thermal Radiation and Variable Fluid Viscosity on Stagnation Point Flow Past a Porous Stretching Sheet Embedded in Porous Medium With Partial Slip Condition

Research Article

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Abstract: The effects of thermal radiation and variable fluid viscosity on stagnation point flow past a porous stretching sheet embedded in a porous medium with partial slip condition are studied. The governing non-linear partial differential equation are transformed to a system of non-linear ordinary differential equation by using suitable similarity transformation. The transformed governing equation are solved numerically using Runge-Kutta method along with shoating technique the result are presented in the graphical form. The effects of various physical parameters on the velocity and temperature profiles are discussed.

Keywords: Temperature-dependent fluid viscosity, function stagnation point flow, thermal radiation, porous medium, partial slip condition.

1. Introduction

Near the stagnation region fluid motion exists on all solid bodies moving in a fluid. The stagnation region encounters the highest pressure, the highest heat transfer and the highest rate of mass deposition. The viscous fluid motion generated by a two-dimensional stagnation flow impinging on a plate was first examined by Hiemenz [1]. Later, the effect of suction on the Hiemenz flow was introduced by different researchers [2-5]. The study of heat transfer in stagnation point flow was considered by a few authors [6-11] in the hydrodynamic case. The influence of an external magnetic field on Hiemenz flow of an electrically conducting fluid was also considered by some authors [12-15]. Mahapatra et al. [16] analyzed the steady two-dimensional stagnation-point flow of an incompressible viscoelastic fluid over a flat deformable surface when the same is stretched in its own plane with a velocity proportional to the distance from the stagnation point. Xu et al. [17] studied the unsteady boundary layer flows of non-Newtonian fluids near a forward stagnation point. Hayat et al. [18-19] investigated the MHD stagnation point flow of an upper convected Maxwell fluid over a stretching surface and MHD flow of a micropolar fluid near a stagnation point towards a non-linear stretching surface.

Nagar et al. [20] studied the unsteady mixed convection boundary layer flow near the stagnation point as a vertical surface in a porous medium. Recently, Ishak et al. [21-23] analyzed mixed convection boundary layer flow near the two-dimensional

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stagnation-point flow of an incompressible fluid over a stretching vertical sheet. Pal [24] studied the radiation effect on mixed point flow. Singh et al. [25] discussed the mixed convection stagnation point flow in porous medium. Arial [26] discussed the slip effects on stagnation point flow of an elastico-viscous fluid. Rahimpaur et al. [27] presented analytic solution using HAM for stagnation point flow towards a shrinking sheet. Recently, Bhattacharyya et al. [28] analyzed the slip effects on stagnation point flow towards a shrinking sheet.

In all the papers mentioned above, the authors restricted their discussions by assuming the uniform fluid viscosity. However, it is known that some physical properties of fluid may change significantly with temperature (Pop et al. [29]). Abel et al. [30] the variation of properties with temperature has several practical applications in the field of metallurgy and chemical engineering.

The increase of temperature leads to a local increase in the transport phenomena by reducing the viscosity across the momentum boundary layer and so rate of heat transfer at the wall is also affected. Therefore, to predict the flow behaviour accurately it is necessary to take into account the viscosity variation for incompressible fluid. Gery et al. [31] and Mehta and Sood [30] showed that, when this effect is included the flow characteristics may change substantially compared to constant viscosity assumption for lubricating fluids heat generated by internal friction and the corresponding rise in the temperature affects the viscosity of the fluid and so the fluid viscosity can no longer be assumed constant. Mukhapadhyay et al. [33] investigated the MHD boundary layer flow with variable fluid viscosity over a heated stretching sheet.

The effects of temperature dependent viscosity and thermal conductivity on flow and heat transfer over a stretching surface in different law and heat transfer over a stretching surface in different flow situations and for different fluids, were carried out by El. Aziz [34]. Dandapat et al. [35], Salem [36], Mukhapadhyay and Layek [37], Prasad et al. [38] etc. the increase of temperature leads to the increase in the transport phenomena by reducing the viscosity across the momentum boundary layer and due to this, the heat transfer rate at the wall is also affected. The effects of variable fluid viscosity on stagnation point flow and heat transfer was discussed by Layek et al. [39].

Thermal radiation on flow and heat transfer process is also very important in the design of many advanced energy conversion system operating at high temperature. Thermal radiation effects may play an important role in controlling heat transfer in polymer processing industry where the quality of the final product depends to some extent, on the heat controlling factors thermal radiation effects become important when difference between the surface temperature and the ambient temperature is large. Pop et al. [40] theoretically investigated the steady two dimensional stagnation-point flow of an incompressible fluid over a stretching sheet considering radiation effects using the Rosselant approximation.

Recently, Hayat and Mustafa [41] discussed the effects of radiation on unsteady mixed convection flow of Jeffrey fluid over a stretching sheet of lute, in another paper, Hayat et al. [42] analyzed the simultaneous effects of magnetic field and thermal radiation on mixed convection stagnation-point flow of power-law fluid. Swati Mukhopadhyay [43] studied effects of thermal radiation and variable fluid viscosity on stagnation point flow past a porous stretching sheet. In all the above mentioned studies, no attention has been given to the effect of partial slip of the flow over a stretching sheet.

The very recent work of Wang [44] takes into consideration the influence of partial slip on the flow of a viscous fluid over a stretching sheet, he obtained the solution numerically. placeCityAnderson [45] discussed the partial slip effects on the flow characteristics of a viscous fluid by finding an exact analytical solution for the problem considered by Wang [44] . P.D. Ariel et al. [46] an analysis is carried out to study the flow characteristics in an elastico-viscous fluid over a stretching sheet with partial slip. Motivated by the above investigations, in this work, we deal with the effects of thermal radiation and variable fluid viscosity on stagnation point flow past a porous stretching sheet embedded in porous medium with partial slip condition. All of above we seem that present paper has not investigated yet.

2. Mathematical Formulation

We consider the two-dimensional steady flow of an incompressible viscous liquid, near a stagnation-point at a porous surface coinciding with the plane y = 0 the flow being confined to $y > 0$, we introduce two equal and opposite force along the x-axis so that the wall is stretched keeping the origin fixed. The temperature of the sheet is different from that of the ambient medium. The fluid viscosity is assumed to vary with temperature while the fluid properties are assumed constants. The continuity, momentum and energy equation governing such type of flow are written as

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

$$\begin{aligned} u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} &= U\frac{dU}{dx} + \frac{1}{\rho}\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) - \frac{\mu}{\rho k}u \\ &= U\frac{dU}{dx}\frac{1}{\rho}\frac{\partial \mu}{\partial T}\frac{\partial T}{\partial y}\frac{\partial u}{\partial y} + \frac{\mu}{\rho}\frac{\partial^2 u}{\partial y^2}\frac{\mu}{\rho k_1}u \end{aligned} \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = k\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \tag{3}$$

with boundary condition

$$\left.\begin{aligned} &u = cx + L\tfrac{\partial u}{\partial y};\ v = v_w;\ T = T_w;\ at\ y = 0 \\ &u \to U(x);\ T \to T_\infty \qquad as\ y \to \infty \end{aligned}\right\} \tag{4}$$

where k is coefficient of thermal diffusivity k_1 is coefficient of thermal conductivity and $q_r = -\frac{4\sigma}{3k*}\frac{\partial T^4}{\partial y}$; σ is the Stefan-Boltzmann constant and k* is the absorption coefficient $T^4 = 4T_\infty^3 T - 3T_\infty^4$: $U(x) = ax$ stands for the stagnation-point velocity in the inviscid free stream, C_p is the specific heat, ρ is the fluid density; μ is coefficient of fluid viscosity; q_r is the relative heat flux, L is slip coefficient.

3. Analysis

The continuity equation (1) is identically satisfied by stream function $\psi(x, y)$, defined as $u = \frac{\partial \psi}{\partial y}$; $v = -\frac{\partial \psi}{\partial x}$ and temperature dependent fluid viscosity is given by $\mu = \mu * [b_1 + b_2(T_w - T]$ where μ^* is coefficient of viscosity far away from that b_1, b_2 are constant, $b_2 > 0$. For the solution of momentum and energy equation, the following dimensionless variables are defined

$$\left.\begin{aligned} &\theta = \tfrac{T - T_\infty}{T_w - T_\infty};\ \eta = (c/\nu)^{1/2} y \\ &\psi = x\sqrt{\nu c}\, f'(\eta) \end{aligned}\right\} \tag{5}$$

Equation (2) and (3) reduce to

$$[b_1 + A(1-\theta)]f''' + ff'' - Af''\theta' - f'^2 + \frac{a^2}{c^2} - [b_1 + A(1-\theta)]k_1 f' = 0 \tag{6}$$

and

$$\frac{1}{Pr}\left(1+\frac{4}{3N}\right)\theta^{''}+f\theta^{'}=0 \tag{7}$$

with boundary conditions

$$\left.\begin{array}{l} f^{'}\ =1+\ \ell\, f^{''}(\eta)\,;\, f\ =\ S:\theta\ =1\; at\; \eta=0 \\ and\;\; f^{'}\ \to\ a/c\,;\theta\ \to\ 0 \quad as\;\eta\ \to\ \infty \end{array}\right\} \tag{8}$$

when

$$\begin{aligned}
S &= -v_w \\
A &= b_2(T_w - T_\infty) \\
Pr &= \frac{\nu}{k}\ \text{ (Prandtl number)} \\
N &= \frac{k\ k*}{4\sigma T_\infty^3} \\
\ell &= L\left(\sqrt{\frac{c}{\nu}}\right)\ \text{ (slip parameter)} \\
S &= -\frac{v_w}{\nu c}\ \text{ (suction/blowing as S > 0 (S < 0) S = 0 the sheet is impermeable)}
\end{aligned}$$

if $k_1 = 0$ and $\ell = 0$ this paper becomes Swati Mukhopadhyay.

4. Numerical Method for the Solution

The set of non-linear O.D.E. (7) and (8) along with boundary condition (**??**) were solved numerically using Runge-Kutta fourth order algorithm with a systematic guessing of $f^{''}(0)$ and $\theta^{'}(0)$ by showing technique until the boundary condition at infinity are satisfied. The step size $\Delta\eta = 0.001$ is used while obtaining the numerical solution and accuracy up to seventh decimal place, which vary sufficient for converses. In this method we choose suitable finite value whereas depend on the values of the parameters used. The contour were done by programme which uses a symbolic and computational computer language method.

5. Result and Discussion

Present results are compared with some of earlier published result in some limiting cases are shown in Tables.

Table 1 shows the Values of skin-friction $[f^{''}(0)]$ for several values of a/c with S = 0, $b_1 = 1$; A = 0; $N = \infty$ (in the absence of radiation); Pr = 0.7, $k_1 = 0$; $\ell = 0$

a/c	$-f''(0)$	
	Swati Mukhopadhyay	**Presnet**
0.1	-0.9694	-0.9693
0.2	-0.9181	-0.9180
0.5	-0.6674	-0.6671
2.0	2.0175	2.0174
3.0	4.7293	4.7290

Table 1:

Table 2 shows the Values of skin-friction $[f^{''}(0)]$ for several values of a/c and A with S = 0, $b_1 = 1$; $N = \infty$; Pr = 0.05; $k_1 = 0$ and $\ell = 0$

A	**a/c → 0.1**	**0.5**	**2.0**	**3.0**	**Present**			
	Swati Mukhopadhyay				**a/c → 0**	**0.5**	**2.0**	**3.0**
0.5	-0.2601	-0.5051	1.8011	4.5012	-0.2600	-0.5050	1.8000	4.5001
1	-0.3011	0.5701	2.2101	4.8011	-0.3010	-0.5700	2.2100	4.8000
3	-0.3401	-0.6101	2.8002	4.9101	-0.3401	-0.6105	2.8001	4.9101
5	-0.4502	-0.6211	2.8211	5.1112	-0.4500	-0.6212	2.8211	5.112
7	-0.4912	-0.6312	2.9011	5.2101	-0.4911	-0.6311	2.9013	5.2101

Table 2:

Table 3 shows the Values of wall temperature $[-\theta^{''}(0)]$ for several values of a/c and Pr with S = 0; $b_1 = 1$; A = 0; $N = \infty$ and $\ell = 0$

a/c	**0.05**	**0.5**	**Present**	
	Swati Mukhopadhayaya		**-0.05**	**0.5**
0.1	0.081	0.382	0.082	0.382
0.2	0.099	0.406	0.098	0.405
0.5	0.136	0.473	0.135	0.472
1.0	0.178	0.563	0.178	0.562
2.0	0.242	0.708	0.241	0.709
3.0	0.289	9.829	0.289	0.825

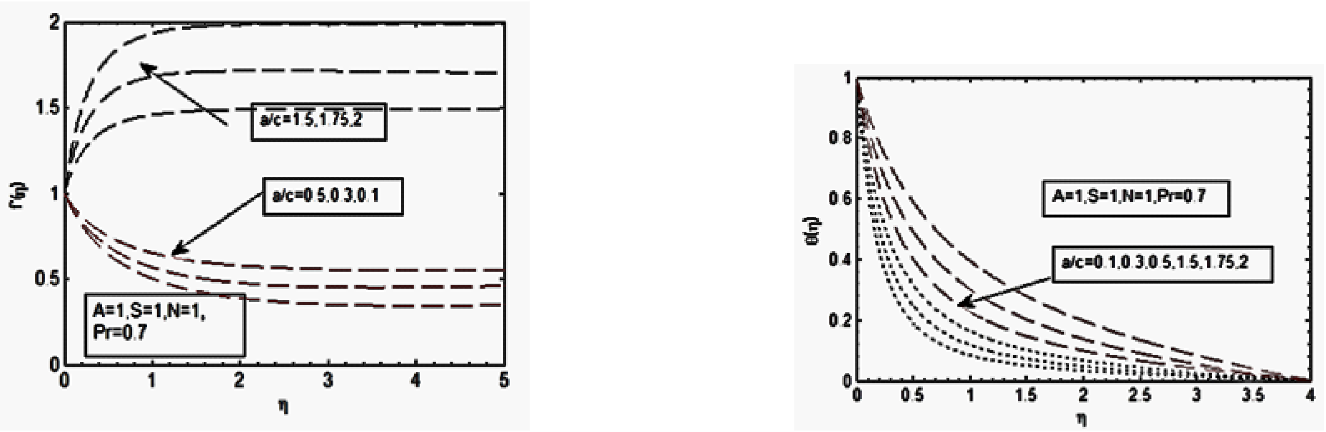
Table 3:

To analyze the results, numerical computations have been carried out by using the method described in the previous section for various values of velocity ratio parameter (a/c), temperature dependent fluid viscosity parameter (A), suction parameter (S), thermal radiation parameter (N) and the Prandtl number Pr. For illustrations of the results, numerical values are plotted in Figs. 1(a) to 5. In all the figures we have $b_1 = 1$. It is seen that the horizontal velocity increases with the increase of a/c [Fig.1(a)]. It is evident from this figure that when $a/c > 1$, the flow has a boundary layer structure increase in a/c, for $a/c > 1$, the straining motion near the stagnation region increases so the acceleration of the external stream increases which causes to decrease the thickness of the boundary layer with increase in a/c and as a result the horizontal velocity increases. For all values of a/c considered, the temperature is found to decrease with the increase in η [Fig.1(b)] and consequently the thickness of thermal boundary layer decreases. Significant change is there in the rate of decrease of temperature for different values of a/c when $a/c < 1$. Temperature of a point on the sheet also decreases with increase in a/c when a/c > 1. The thermal boundary layer becomes thinner with the increase of a/c. Fig. 2(a) show the effects of suction ($S > 0$) on the horizontal velocity for two different set of values of $a/c = 0.3$ and $a/c = 1.5$. Hence $S = 0$ presents non-porous surface. For $a/c = 0.3$ (< 1) the effect of suction is to decrease the horizontal velocity. The physical explanation for such a behaviour is that when stronger suction is applied, the heated fluid is based towards the wall and the fluid is retarded due to high influence of the viscosity. Fig. 2(b) it is very clear that the dimensionless temperature decreases due to suction.

The explanation for such a behaviour is that the fluid at ambient conditions is brought closer to the surface and the thermal boundary layer thickness is reduced. This causes a increase in the rate of heat transfer the thermal boundary layer is thicker in the case of suction as compared to the case of impermeability [fig.2(b)]. The effects of temperature dependent fluid viscosity on velocity distribution, and temperature are presented in fig. 3(a) and 3(b). The velocity curves show the velocity curves show that the rate of transport decreases with increasing distance (η) of the sheet. With increasing A, fluid viscosity decreases causing an increment of velocity boundary layer thickness. Away from the stagnation point, fluid velocity increases with increasing A for $a/c < 1$ [Fig. 3(a)] but opposite nature is noted for $a/c > 1$. Figure 3(b) exhibits the temperature profiles for several values of A. In each case, temperature is found to decrease with the increase of η until it vanishes asymptotically at $\eta = 10$.

It may be easily seen that at any location except very near to the wall, value of a becomes lower and lower with the increase of the parameter A for $a/c = 0.3$ (< 1) but variation of temperature is not significant for $a/c = 1.5$ (> 1) the increase of temperature-dependent fluid viscosity parameter A induces a decrease of thermal boundary layer thickness and results in the decrease of temperature profile $\theta(\eta)$. Increase in the values of viscosity parameter has the tendency to decrease the thermal boundary layer thickness, which causes to decrease the values of θ as shown in Fig. 3(b). From Fig. 4(a) it is very clear that, with the increasing values of radiation parameter N, the thermal boundary layer thickness decreases and the heat flux at the surface increases since the temperature profiles become sleeper. The effect of radiation parameter N(for both $a/c < 1$ and $a/c > 1$) at a particular point (at a fixed value of η) is to reduce the temperature significantly in the flow region. The increase in radiation parameter is equivalent to the release of heat energy from the flow region and so the fluid temperature decreases as the thermal boundary layer thickness becomes thinner. Fig. 5 exhibits the nature of temperature profiles with variable values of Prandtl number Pr. An increase in Prandtl number reduces the thermal boundary layer thickness. Prandtl number signifies the ratio of momentum diffusivity to thermal diffusivity. This figure implies that an increase of Prandtl number Pr results in a decrease of temperature distribution at a particular point.

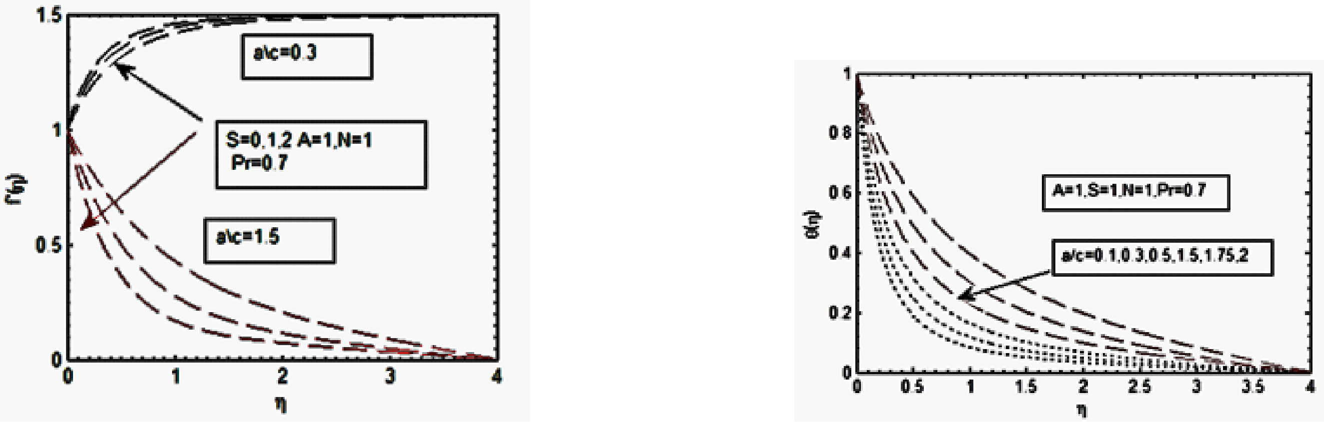
This is due to the fact that there would be a decrease of thermal boundary layer thickness with increasing values of Prandtl number Pr. Temperature distribution approaches to zero in the free stream region (Fig. 5). The effect of the permeability parameter k_1 on the velocity field is exhibited in Fig.6. As the porosity of the medius increases, the value of k_1 decreases. However, this change in the velocity near the surface is the maximum are faraway from the surface, this change is small and finally approaches zero. Thus an increase in the permeability parameter k_1 leads to an decrease of the horizontal velocity profile, which enhances deceleration of the flow. In Fig. 7 the main stream velocity, has been plotted against η of various values of ℓ where as the slip parameter increases in magnitude, permitting the more fluid to slip past the sheet, the flow show down for distances close to the sheet.



(a) velocity profiles for several values of velocity ratio parameter a/c with l=0 and k1=0.

(b) temperature profiles for several values of velocity ratio parameter a/c, l=0 and k1=0.

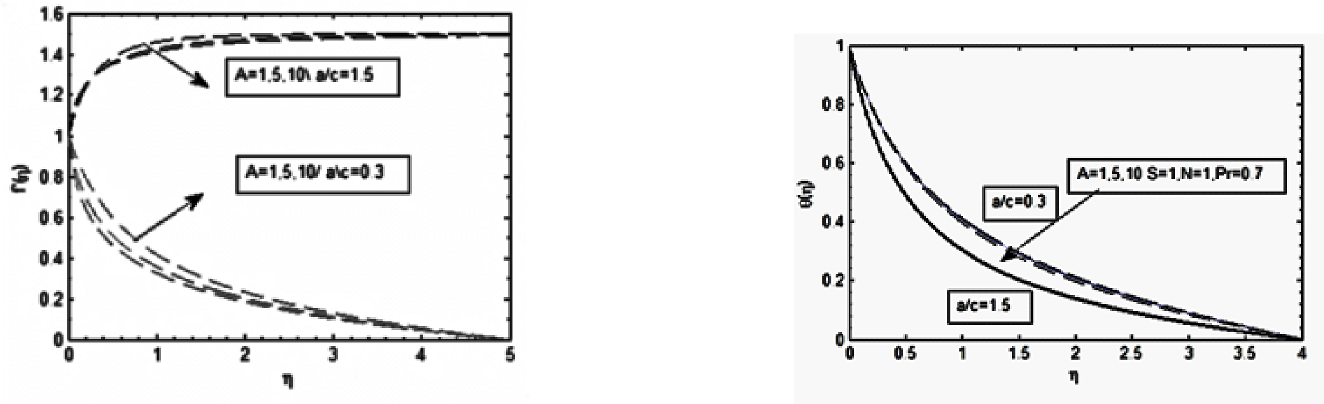
Figure 1:



(a) velocity profiles for several values of velocity suction parameter S with l=0 and k1=0.

(b) temperature profiles for several values of suction parameter S, l=0 and k1=0.

Figure 2:



(a) velocity profiles for several values of temperature dependent viscosity parameter A with l=0 and k1=0.

(b) temperature profiles for several values of temperature dependent velocity parameter A, l=0 and k1=0.

Figure 3:

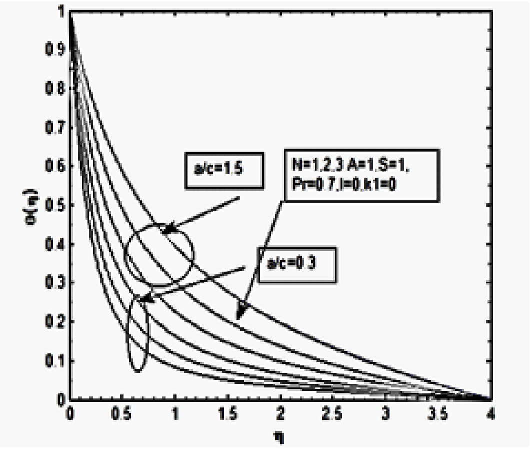


Figure 4: Temperature profiles for several values or radiation parameter N.

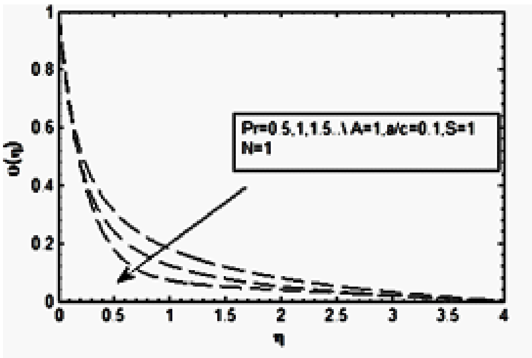


Figure 5: Temperature profiles for several values of Prandtl number Pr with l=0 and k1=0.

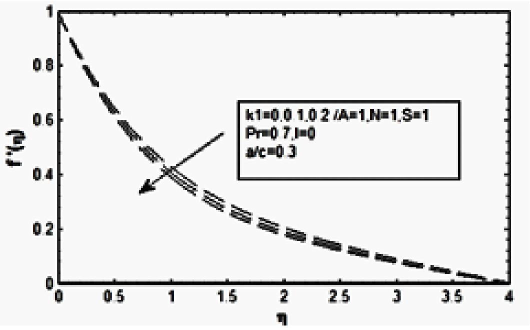


Figure 6: velocity profile for several values of permeability parameter k1.

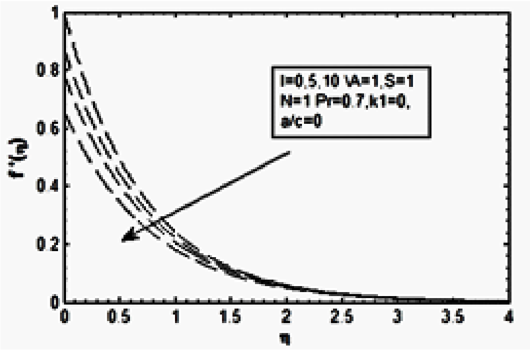


Figure 7: Effect of slip parameter l on axial velocity profiles with k1=0.

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