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Unsteady MHD Flow of Jeffrey Fluid over a Stretching Sheet Embedded in a Porous Medium with Suction

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Abstract: The effects of suction and thermal radiation on MHD flow of Jeffrey fluid over an unsteady stretching sheet are examined. The governing equations are transformed to ordinary differential equations by using similarity transformation and are solved numerically using Runge-Kutta fourth order in association with shooting technique. The effects of non dimensional governing parameters such as unsteady parameter, thermal radiation parameter, permeability parameter, magnetic parameter, heat source or sink parameter, Jeffrey parameter, suction parameter and Eckert number on velocity and temperature profiles are presented graphically while the skin friction coefficient and the local Nusselt number are represented numerically. It is found that present result have been good agreement with the existed studies under the some special cases.
***Keywords: Unsteady parameter; MHD; Jeffrey parameter; stretching sheet; heat transfer*.**

I. INTRODUCTION

Recently, interest in boundary layer flow and heat transfer over a stretching sheet has gained considerable attention because of its application in industry and manufacturing process. Such applications include polymer extrusion, drawing of copper wires, continuous stretching of plastic films and artificial fibers, hot rolling, wire drawing, glass fiber, metal extrusion and metal spinning. A large number of researchers are engaged with this rich area. Understanding the modeling the flows of non-Newtonian fluids are of both fundamental and practical significance in the industrial and engineering applications. The rheological characteristics of such fluids are important in the flows of nuclear fuel slurries, lubrication with heavy oils and greases, paper coating, plasma and mercury, fossil fuels, polymers etc.

Hayat et al. [1] have studied on MHD flow and heat transfer over permeable stretching sheet with slip conditions. Radiative flow of Jeffrey fluid in a porous medium with power law heat flux and heat source investigated by Hayat *et al.* [2]. Hayat *et al.* [3] analyzed three dimensional flow of a Jeffrey fluid over a linearly stretching sheet. Sohail Nadeem *et al.* [4] discussed effects of thermal radiation on the boundary layer flow of a Jeffrey fluid over an exponentially stretching surface. Heat and mass transfer in a Jeffrey fluid over a stretching sheet with heat source/sink was illustrated by Qasim [5]. Hayat *et al.* [6] presented boundary layer flow of a Jeffrey fluid with convective boundary conditions. Three dimensional flow of Jeffrey fluid with convective surface boundary conditions was discussed by Shehzad *et al.* [7]. Hayat *et al.* [8] analyzed on MHD stagnation point flow of Jeffrey fluid over a convectively heated stretching sheet. Simultaneous effects of heat and mass transfer on time dependent flow over a stretching surface was reported Hayat *et al.* [9]. Heat transfer analysis for fluid flow over an exponentially stretching porous sheet with surface heat flux in porous medium was investigated by Mandal *et al.* [10].

In all these above studies, the flow and temperature fields are considered to be at steady state. However, in some cases, the flow field, heat and mass transfer can be unsteady due to a sudden stretching of the sheet is gained attention of modern day researchers because of its increasing applications to many engineering problems. Hayat *et al.* [11] discussed unsteady three dimensional flow of couple stress fluid over a stretching surface with chemical reaction. Swati Mukhopadhyay *et al.* [12] investigated Casson fluid flow over an unsteady stretching surface. Mustafa *et al.* [13] examined unsteady boundary layer flow of nanofluid past an impulsively stretching sheet. Hayat *et al.* [14] presented an unsteady flow and heat transfer of Jeffrey fluid over a stretching sheet. Influence of thermal radiation on the unsteady mixed convection flow of a Jeffrey fluid over a stretching sheet was analyzed by Hayat *et al.* [15]. Radiation effects on the flow of powell-eyring fluid past an unsteady inclined stretching sheet with non uniform heat source/sink was investigated by Hayat *et al.* [16]. Ahmadi *et al.* [17] discussed a comprehensive analysis of the flow and heat transfer for a nanofluid over an unsteady stretching flat plate. Krishnendu Bhattacharyya *et al.* [18] studied an unsteady MHD boundary layer flow with diffusion and first order chemical reaction over a permeable stretching sheet with suction/blowing. Alsaadi *et al.* [19] has analyzed soret and dufour effects on the unsteady mixed convection flow over a stretching surface. Swati Mukhopadhyay [20] investigated effects of thermal radiation on Casson fluid flow and heat transfer over an unsteady stretching surface subjected to suction/blowing.

Santosh Chaudhary et al. [21] discussed effects of thermal radiation on hydromagnetic flow over an unsteady stretching sheet embedded in a porous medium in the presence of heat source/sink. Quinn Brewster [22] studied thermal radiative transfer and properties. Fazle Mabood et al. [23] reported on numerical study of unsteady Jeffrey fluid flow with magnetic field effect and variable fluid properties.MHD unsteady squeezing flow over a porous stretching plate developed Hayat et al. [24]. Unsteady MHD three dimensional flow with viscous dissipation and joule heating was studied by Hayat et al. [25]. Elbashbesy et al. [26] was discussed effects of thermal radiation and heat transfer over an unsteady stretching surface embedded in a porous medium in the presence of heat source/sink. Krishnendu Bhattacharyya et al. [27] studied unsteady MHD boundary layer flow with diffusion and first order chemical reaction over a permeable stretching sheet with suction/blowing. Mukhopadhyay [28] developed effect of thermal radiation on unsteady mixed convection flow and heat transfer over a porous stretching surface in porous medium.

The objective of the present study to investigate the effects of suction and thermal radiation on MHD flow of Jeffrey fluid over an unsteady stretching sheet. Numerical solution of the coupled non linear momentum and energy equations are obtained using fourth order Runge-Kutta method with shooting technique. The pertinent parameters on velocity and temperature are discussed through graphically. The skin friction coefficient and the local nusselt number are obtained numerically.

A. Mathematical Formulation Of The Problem

Consider an unsteady, two dimensional incompressible flow of Jeffrey fluid over an exponentially stretching surface. The x - axis is taken along the continuous stretching surface in the direction of motion with the slot as the origin and y -axis is perpendicular to it and the flow is confined in half plane $y > 0$ .A uniform magnetic field of strength B_0 is assumed to be applied normal to the stretching surface as, shown in Fig. 1. The magnetic Reynolds number is taken to be very small so the induced magnetic field is negligible. The surface is assumed to be highly elastic and is stretched in the x -direction with surface velocity $U_w = \dfrac{bx}{1-\gamma t}$ and surface temperature $T_w = T_\infty + \dfrac{b}{2vx^2}(1-\gamma t)^{-3/2}$ where b is the positive constant, x is the coordinate measured along the stretching surface, γ is the rate of stretching constant, t is the time, T_∞ is the free stream temperature and v is the kinematic viscosity .The governing equations of such type of flow are, in the usual notations

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

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + \upsilon\frac{\partial u}{\partial y} = \frac{v}{1+\lambda_1}\frac{\partial^2 u}{\partial y^2} - \frac{v}{(1+\lambda_1)K}u - \frac{\sigma B_0^2}{\rho}u \quad (2)$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + \upsilon\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} + \frac{Q}{\rho c_p}(T - T_\infty) + \frac{v}{(1+\lambda_1)c_p}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{\sigma B_0^2}{\rho c_p}u^2 \quad (3)$$

and the boundary conditions are

$$\left.\begin{aligned} & u = U_w(x,t),\ \upsilon = \upsilon_w(x,t) = \frac{\upsilon_0}{\sqrt{1-\gamma t}}, T = T_w(x,t)\ at\ y = 0 \\ & u \to 0, T \to T_\infty\ as\ y \to \infty \end{aligned}\right\} \quad (4)$$

where u and υ are the velocity components in the x and y directions respectively. K is permeability parameter, σ is electrical conductivity, ρ is the fluid density, T is the temperature of the fluid, k is thermal conductivity, c_p is the specific heat at constant pressure, q_r is the radiative heat flux, Q is the heat source when $Q > 0$ or heat sink when $Q < 0$, λ_1 is Jeffrey parameter and υ_w is the prescribed suction at the porous stretching surface and is given by $\upsilon_w(x,t) = \frac{\upsilon_0}{\sqrt{1-\gamma t}}$, υ_0 is a constant with $\upsilon_0 < 0$ corresponding to suction parameter.

Using Rosseland approximation for radiation (Brewster [22]), the radiative heat flux is simplified as

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \quad (5)$$

where σ^* and k^* are the Stefan-Boltzmann constant and the mean absorption coefficient respectively.

Assuming that the temperature differences within the flow is such that the term T^4 may be expressed as a linear function of temperature. Hence, expanding T^4 in a Taylor series about T_∞ and neglecting higher-order terms we obtain

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \quad (6)$$

Using equation (5) and (6) the equation (3) reduces to

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + \upsilon\frac{\partial T}{\partial y} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2} + \frac{16\sigma^* T_\infty^3}{3k^*\rho c_p}\frac{\partial^2 T}{\partial y^2} + \frac{Q}{\rho c_p}(T - T_\infty) + \frac{v}{(1+\lambda_1)c_p}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{\sigma B_0^2}{\rho c_p}u^2 \quad (7)$$

We now introduce the stream function $\psi(x,y)$ as

$$u = \frac{\partial \psi}{\partial y}, \; \upsilon = -\frac{\partial \psi}{\partial x} \quad (8)$$

equation (8) the continuity equation (1) is satisfied automatically. The momentum and energy equations (2) and (7) can be transformed into the corresponding ordinary differential equations by introducing the following similarity transformations (Elbashbeshy and Emam [27]):

$$\psi(x,y) = \sqrt{\frac{vb}{(1-\gamma t)}}\; x f(\eta) \quad (9)$$

$$\eta = \sqrt{\frac{b}{v(1-\gamma t)}}\; y \quad (10)$$

$$T = T_\infty + \frac{b}{2vx^2}(1-\gamma t)^{-3/2}\theta(\eta) \quad (11)$$

where $f(\eta)$ is the dimensionless stream function, η is the similarity variable, y is the coordinate measured along normal to the stretching surface and $\theta(\eta)$ is the dimensionless temperature.

Finally we obtained the self-similar equations are

$$\frac{1}{1+\lambda_1}f''' + ff'' - f'^2 - A\left(\frac{\eta f''}{2} + f'\right) - \left(\frac{\lambda}{1+\lambda_1} + M\right)f' = 0 \quad (12)$$

$$\left(1 + \frac{4}{3R}\right)\theta'' + \Pr\left\{f\theta' - \frac{A}{2}(\eta\theta' + 3\theta) + 2f'\theta + \delta\theta + \frac{Ec}{1+\lambda_1}f''^2 + MEcf'^2\right\} = 0 \quad (13)$$

With the boundary conditions are

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$$\left.\begin{array}{l} f = S,\ f' = 1, \theta = 1\, at\, \eta = 0 \\ f' \to 0, \theta \to 0\, as\, \eta \to \infty \end{array}\right\} (14)$$

where primes denote differentiation with respect to η. $A = \frac{\gamma}{b}$ is the unsteadiness parameter, $\lambda = \frac{v^2 \operatorname{Re}_x}{KU_w^2}$ is the permeability parameter, $\operatorname{Re}_x = \frac{U_w x}{v}$ is the local Reynolds number, $M = \frac{\sigma B_0^2 v \operatorname{Re}_x}{\rho U_w^2}$ is the magnetic parameter, $R = \frac{kk^*}{4\sigma^* T_\infty^3}$ is the thermal radiation parameter, $\Pr = \frac{\mu c_p}{k}$ is the Prandtl number, $\delta = \frac{Qv^2}{\mu c_p} \frac{\operatorname{Re}_x}{U_w^2}$ is the heat source or sink parameter, $Ec = \frac{U_w^2}{c_p (T_w - T_\infty)}$ is the Eckert number, λ_1 is the Jeffrey parameter and $S = -\frac{\upsilon_0}{\sqrt{vb}}$ is the suction parameter $S > 0(\upsilon_0 < 0)$.

B. Local Skin Friction and Nusselt Number

The physical quantities of interest are the local skin friction coefficient C_f and the local Nusselt number Nu_x which are defined as

$$C_f = \frac{\frac{\mu}{1+\lambda_1}\left(\frac{\partial u}{\partial y}\right)_{y=0}}{\frac{\rho U_w^2}{2}} (15)$$

$$Nu_x = \frac{-x}{T_w - T_\infty}\left(\frac{\partial T}{\partial y}\right)_{y=0} (16)$$

which are the present case, can be expressed in the following forms

$$C_f = \frac{2}{\sqrt{\operatorname{Re}_x}} \frac{f''(0)}{1+\lambda_1} (17)$$

$$Nu_x = -\sqrt{\operatorname{Re}_x}\theta'(0) (18)$$

Numerical values of the function $f''(0)$ and $\theta'(0)$ which represent the wall shear stress and the heat transfer rate at the surface respectively for various values of the parameter are presented in Tables 1 and 2.

II. RESULTS AND DISCUSSION

In this paper, the effects of suction and thermal radiation on MHD flow of Jeffrey fluid over an unsteady stretching sheet are analyzed. The boundary value problem containing coupled equations in velocity and temperature is solved numerically by shooting technique with Range-Kutta fourth order using MATLAB. The effects of Jeffrey parameter λ_1, thermal Radiation parameter R, Magnetic parameter M, unsteady parameter A, permeability parameter λ, suction parameter S, Prandtl number $\Pr$, heat source or sink parameter δ and Eckert number Ec are depicted through graphs on velocity and temperature profiles.

In order to assure the accuracy of the applied numerical scheme the computed values of Skin friction coefficient $\frac{f''(0)}{1+\lambda_1}$ and local Nusselt number $-\theta'(0)$ are compared with the available results of Santosh Chaudhary *et al.* [21] and Elbashbeshy et *al.* [26] in Table 1, Table 2 and have found in excellent agreement.

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The influence of unsteady parameter A on the velocity $f'(\eta)$ and the temperature $\theta(\eta)$ profiles in the presence of Jeffrey parameter λ_1, suction parameter S and the absence of Jeffrey parameter λ_1,suction parameter S at the boundary are shown in Fig 2 and Fig 3. We analyzed the velocity and the thickness of the boundary layer decreases as well as temperature and the thermal boundary layer thickness are decreases for both cases with the increasing values of the unsteady parameter A.

The effect of permeability parameter λ on the velocity $f'(\eta)$ and the temperature $\theta(\eta)$ profiles in the presence of Jeffrey parameter λ_1, suction parameter S and the absence of Jeffrey parameter λ_1 suction parameter S at the boundary are shown in Fig 4 and Fig 5. We observed that the velocity and the momentum boundary layer thickness decreases as well as the temperature and the thermal boundary layer thickness decrease for both cases with the increasing values of the permeability parameter λ.

The influence of magnetic parameter M on the velocity $f'(\eta)$ and the temperature $\theta(\eta)$ profiles in the presence of Jeffrey parameter λ_1, suction parameter S and the absence of Jeffrey parameter λ_1 suction parameter S at the boundary are shown in Fig 6 and Fig 7.We reported that the velocity and temperature decreases for both cases with the increasing values of the magnetic parameter M .While in Fig.7 a reverse phenomenon occurs for $\eta > 3$. Moreover, the effects of a transverse magnetic field on an electrically conducting fluid gives rise to a resistive force called the Lorentz force. This force has the tendency to slow down the fluid motion.

The effect of Jeffrey parameter λ_1 on the velocity $f'(\eta)$ and the temperature $\theta(\eta)$ profiles in the presence of suction parameter S and the absence of suction S at the boundary are shown in Fig 8 and Fig. 9. It is represented that for both cases the velocity and the thickness of the boundary layer decreases as well as temperature and the thermal boundary layer thickness is decrease with increasing values of Jeffrey parameter λ_1.

The influence of suction parameter S on the velocity $f'(\eta)$ and the temperature $\theta(\eta)$ profiles in the presence of Jeffrey parameter λ_1 and in the absence of Jeffrey parameter λ_1 are shown in Fig. 8 and Fig. 9. We have seen that for both cases the velocity and the thickness of the boundary layer decreases as well as the temperature and the thermal boundary layer thickness is decrease with increasing values of suction parameter S.

The temperature profiles $\theta(\eta)$ for different values of the thermal radiation parameter R, the Prandtl number $\Pr$, the heat source or sink parameter δ and the Eckert number Ec in the in the presence of Jeffrey parameter λ_1, suction parameter S and the absence of Jeffrey parameter λ_1 suction parameter S at the boundary are shown in Figures 10-13. It may be observed that for both cases the temperature and the thermal boundary layer thickness is decreases with the increasing values of the thermal radiation parameter R, the Prandtl number $\Pr$, while the reverse phenomenon occurs for heat source or sink parameter δ and the Eckert number Ec.

III. CONCLUSIONS

A numerical model is developed to investigate the heat transfer effects on MHD flow of Jeffrey fluid over an unsteady stretching sheet with mass suction is studied. The governing partial differential equations for the flow and temperature fields are reduced to a system of coupled nonlinear differential equations. Finally the set of ordinary differential equations are solved using shooting method. Further numerical results for the skin friction coefficient and the rater of heat transfer at the surface are in closed agreement with the results which were obtained by earlier researchers in the absence of Jeffrey parameter and suction parameter.

A. We conclude that the velocity as well as the surface gradient decreases with increasing values of the unsteady parameter A, the permeability parameter λ ,the suction parameter S, the Jeffrey parameter λ_1 and the magnetic parameter M . Moreover the velocity increases with an increase in the value of the unsteadiness parameter for $\eta > 3$.

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B. The thermal boundary layer thickness as well as the rate of heat transfer decreases with the increasing values of unsteady parameter A, the permeability parameter λ, Jeffrey parameter λ_1, suction parameter S at the surface, the magnetic parameter M, the thermal radiation parameter R while it increases with an increase in the values of the heat source or sink parameter δ and Eckert number Ec.

C. From Table 1 represents that the skin friction coefficient $\frac{f''(0)}{1+\lambda_1}$ decreases with the increasing values of the unsteady parameter A, permeability parameter λ keeping other parameters are constant. Further it is observed that the values of the local skin friction coefficient $\frac{f''(0)}{1+\lambda_1}$ are always negative for all the values of physical parameters considered.

A	λ	Elbashbeshy and Emam [26]	Santosh Chaudhary [21]	Present Study
0.4	0.1	1.17853	1.17862910	1.178581
0.8	0.1	1.30035	1.30044740	1.300354
0.8	0.3	1.37550	1.37559607	1.375502
0.8	0.5	1.44668	1.44676744	1.446673
0.8	0.7	1.51445	1.51454348	1.514448

D. Physically, positive sign of skin friction coefficient $\frac{f''(0)}{1+\lambda_1}$ implies that the fluid exerts a drag force on the sheet and negative sign implies the opposite meaning.

E. Table 2 illustrates that the unsteady parameter A, the permeability parameter λ and the heat source or sink parameter δ on the rate of heat transfer $-\theta'(0)$ at the surface. From this table it is observed that the rate of heat transfer $-\theta'(0)$ decreases with increasing values of the unsteady parameter A, the permeability parameter λ and the heat source or sink parameter δ keeping other parameters as constant. It is also evident that the rate of heat transfer $-\theta'(0)$ is negative for all the values of physical parameters considered. This means that there is a heat flow from the wall.

Table 1: Comparison of $-\frac{f''(0)}{1+\lambda_1}$ for distinct values of A, λ and M. For fixed values of

$$R = 0.3,\ d = -0.5, M = 0, Ec = 0.01, \Pr = 10, \lambda_1 = 0, S = 0$$

Table 2: Comparison of $-\theta'(0)$ for various values of A, λ, M, δ, R, $\Pr$, and Ec. For fixed values of $\lambda_1 = 0$ and $S = 0$

A	λ	M	R	Pr	δ	Ec	Elbashbeshy and Emam [26]	Santosh Chaudhary [21]	Present study
0.4	0.1	0	0.3	10	-0.5	0	0.53765	0.53781852	0.537692
0.8	0.1	0	0.3	10	-0.5	0	0.98601	0.98623175	0.986015
0.8	0.3	0	0.3	10	-0.5	0	1.00056	1.00077724	1.000563
0.8	0.5	0	0.3	10	-0.5	0	1.01364	1.01385453	1.013641
0.8	0.7	0	0.3	10	-0.5	0	1.02552	1.02573274	1.025521
0.8	0.1	0	0.3	10	-0.2	0	0.73898	0.73920476	0.738980

0.8	0.1	0	0.3	10	0.2	0	0.31343	0.31368315	0.313438
0.8	0.1	0	0.3	10	0.4	0	0.02044	0.02072673	0.020459

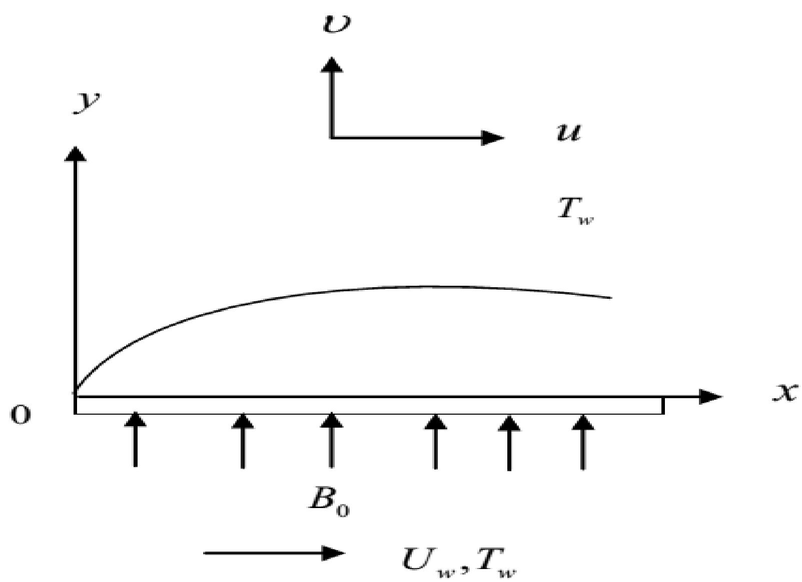

Fig1. Physical Model

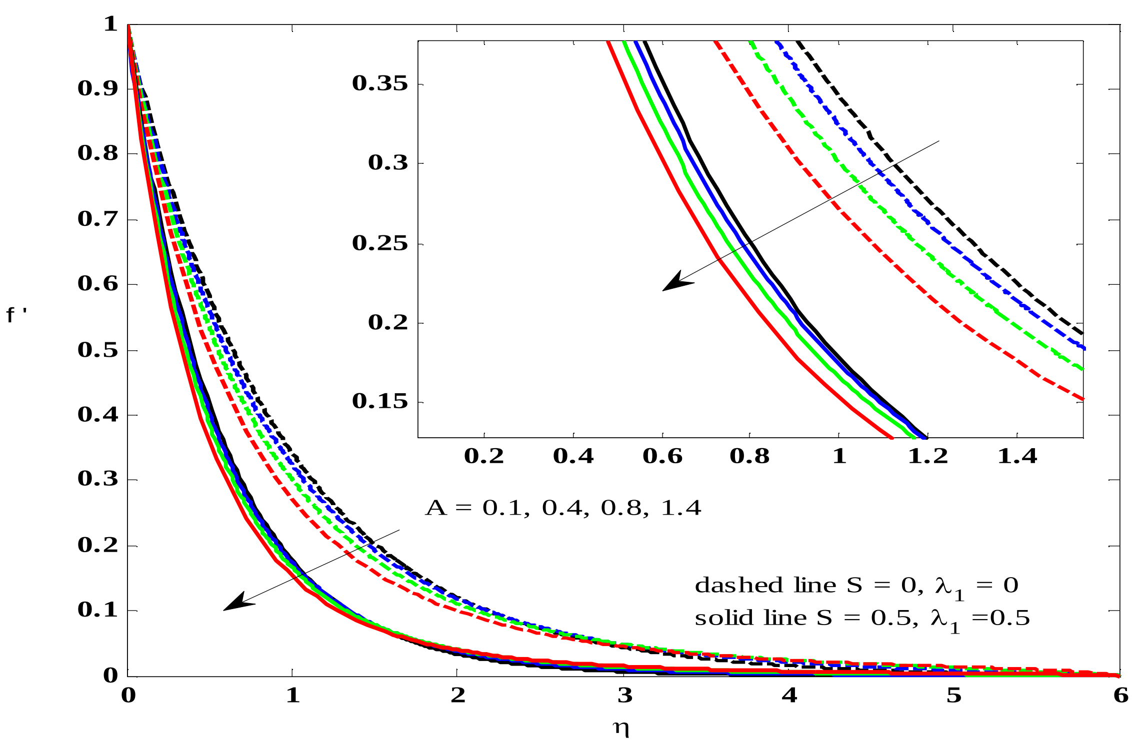

Fig 2. Velocity profiles against η for various values of A with $R = 0.3, \lambda = 0.1, M = 0.01, Ec = 0.01, \delta = -0.5$ and $\Pr = 10$.

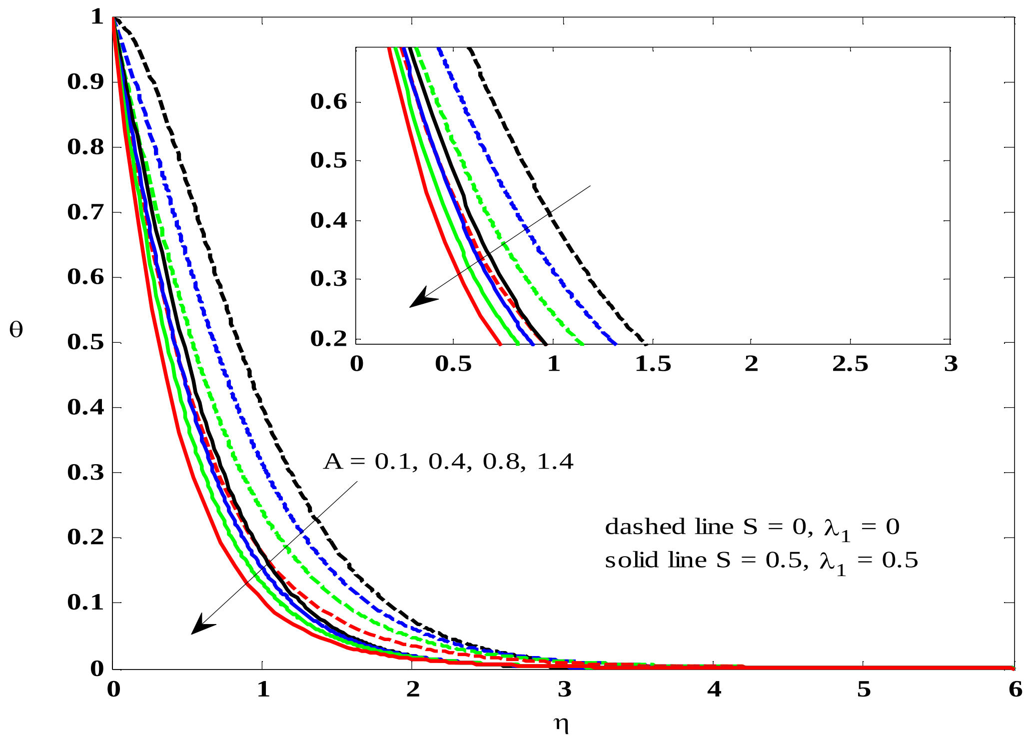

Fig 3.Temperature profiles against η for various values of A with $Ec = 0.01, R = 0.3, \lambda = 0.1, \ \delta = -0.5, \Pr = 10$ and $M = 0.01$

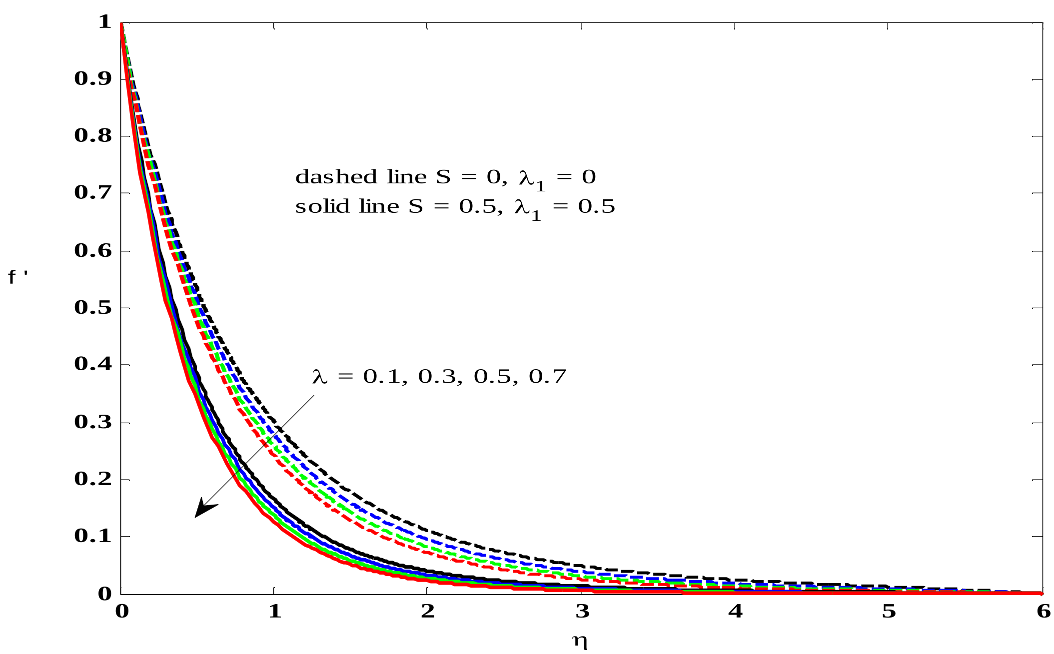

Fig 4. Velocity profiles against η for various values of λ with $R = 0.3, A = 0.8, M = 0.01, Ec = 0.01, \delta = -0.5$ and $\Pr = 10$.

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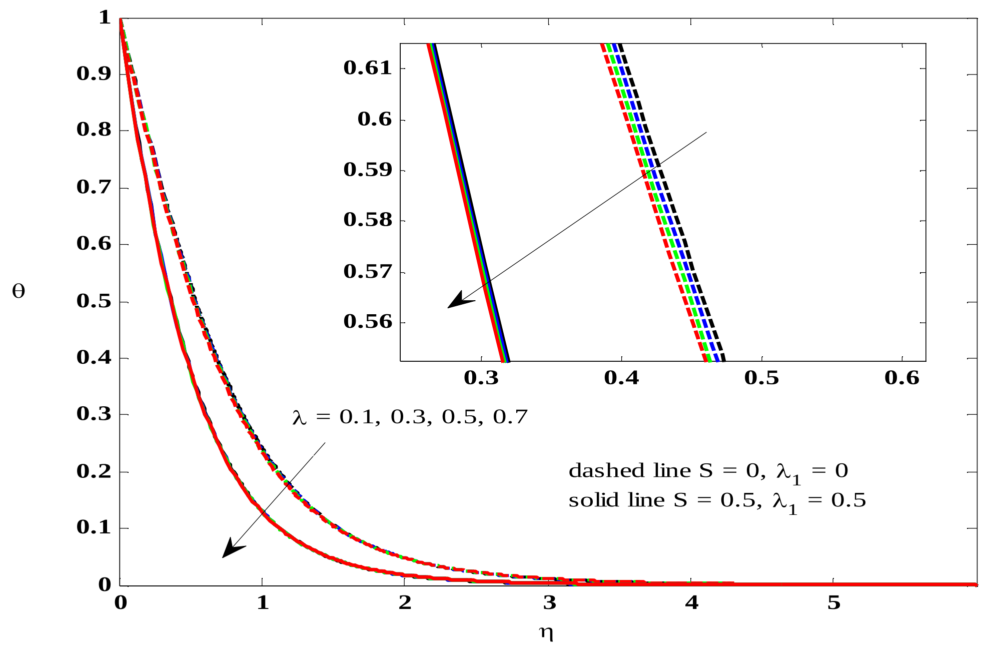

Fig 5. Temperature profiles against η for various values of λ with $R = 0.3, M = 0.01, A = 0.8, Ec = 0.01, \delta = -0.5$ and $\Pr = 10$.

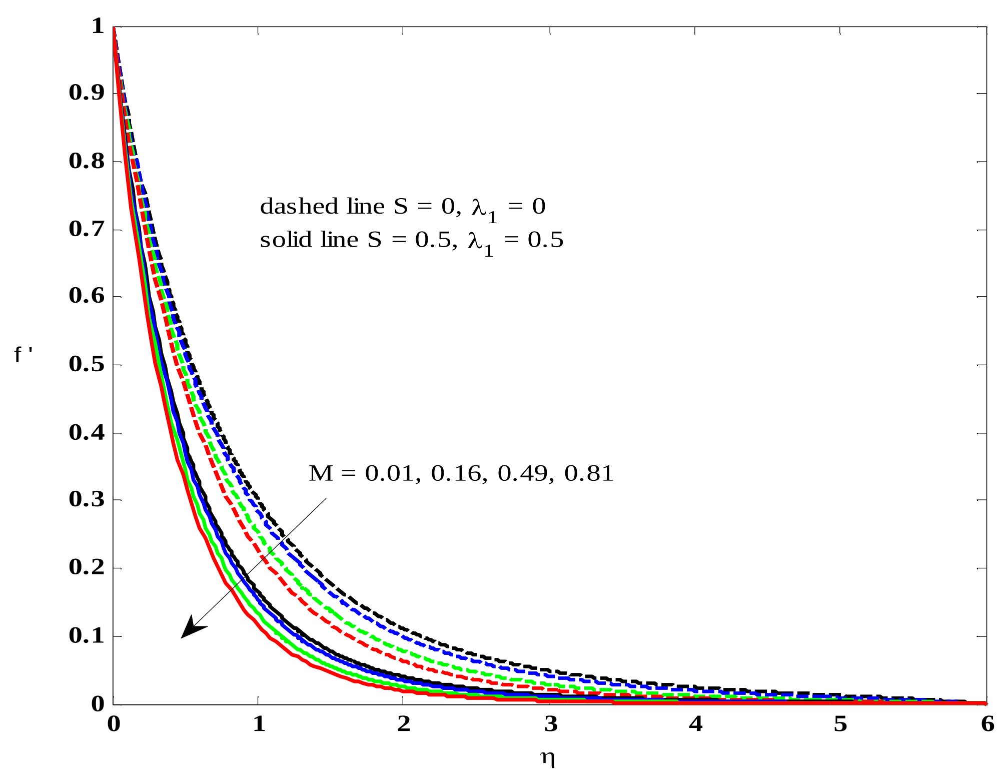

Fig 6. Velocity profiles against η for various values of M with $R = 0.3, A = 0.8, \lambda = 0.1, Ec = 0.01, \delta = -0.5$ and $\Pr = 10$.

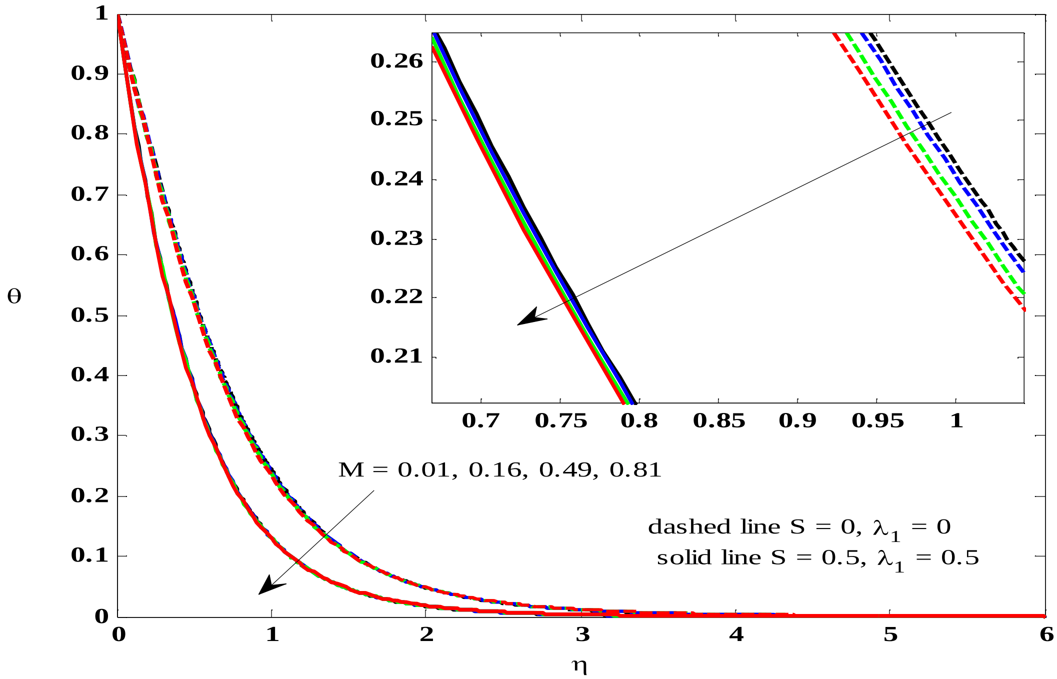

Fig 7. Temperature profiles against η for various values of M with $R = 0.3, \lambda = 0.01, A = 0.8, Ec = 0.01, \delta = -0.5$ and $\Pr = 10$.

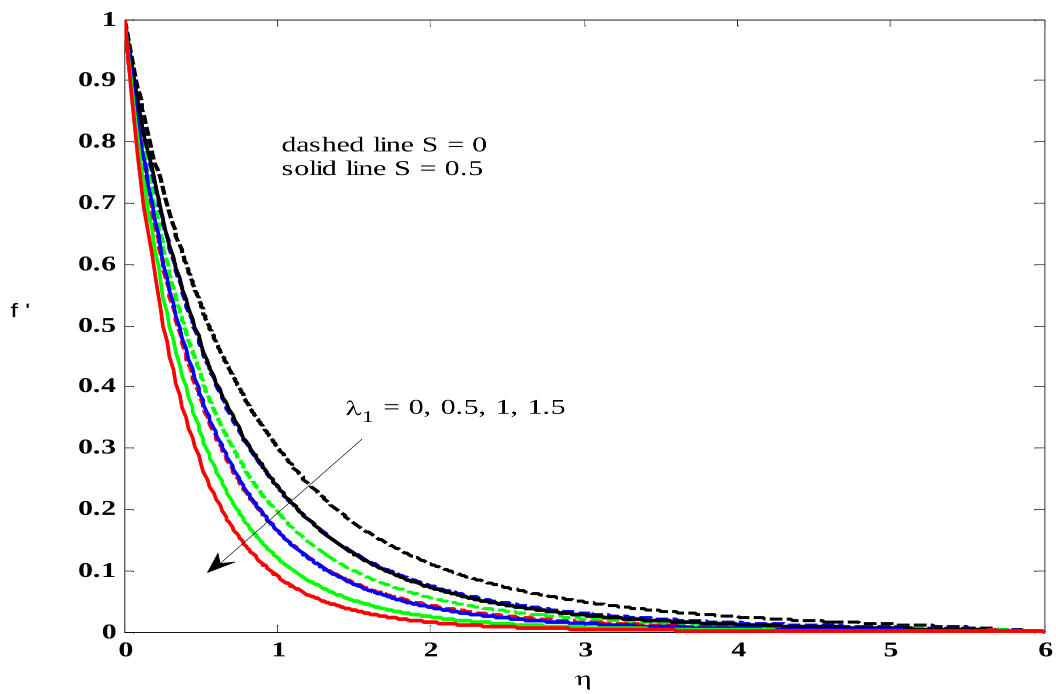

Fig 8. Velocity profiles against η for various values of λ_1 with $Ec = 0.01, R = 0.3, \lambda = 0.1, A = 0.8, \delta = -0.5, \Pr = 10$ and $M = 0.01$

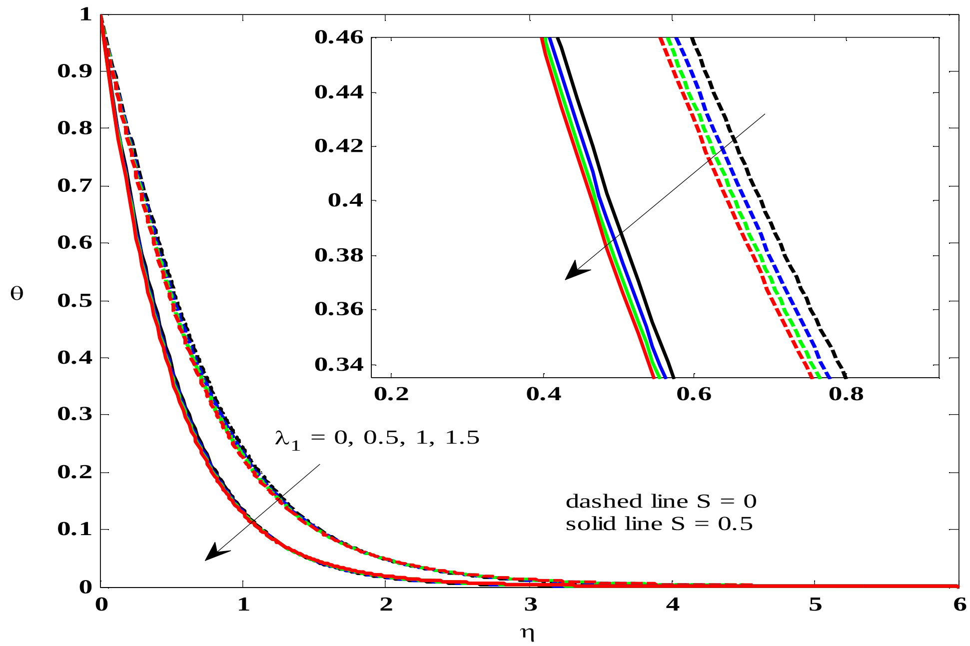

Fig 9. Temperature profiles against η for various values of λ_1 with
$Ec = 0.01, R = 0.3, \lambda = 0.1, A = 0.8, \ \delta = -0.5, \Pr = 10$ and $M = 0.01$.

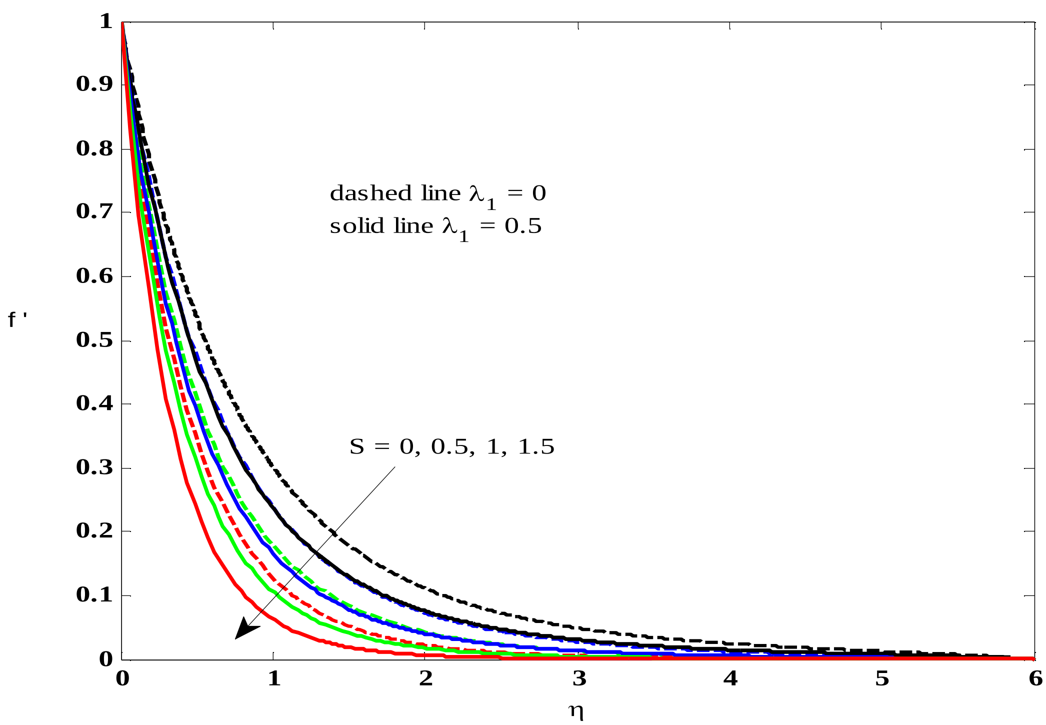

Fig 10. Velocity profiles against η for various values of S with
$R = 0.3, A = 0.8, \lambda = 0.1, Ec = 0.01, \delta = -0.5, \Pr = 10$ and $M = 0.01$.

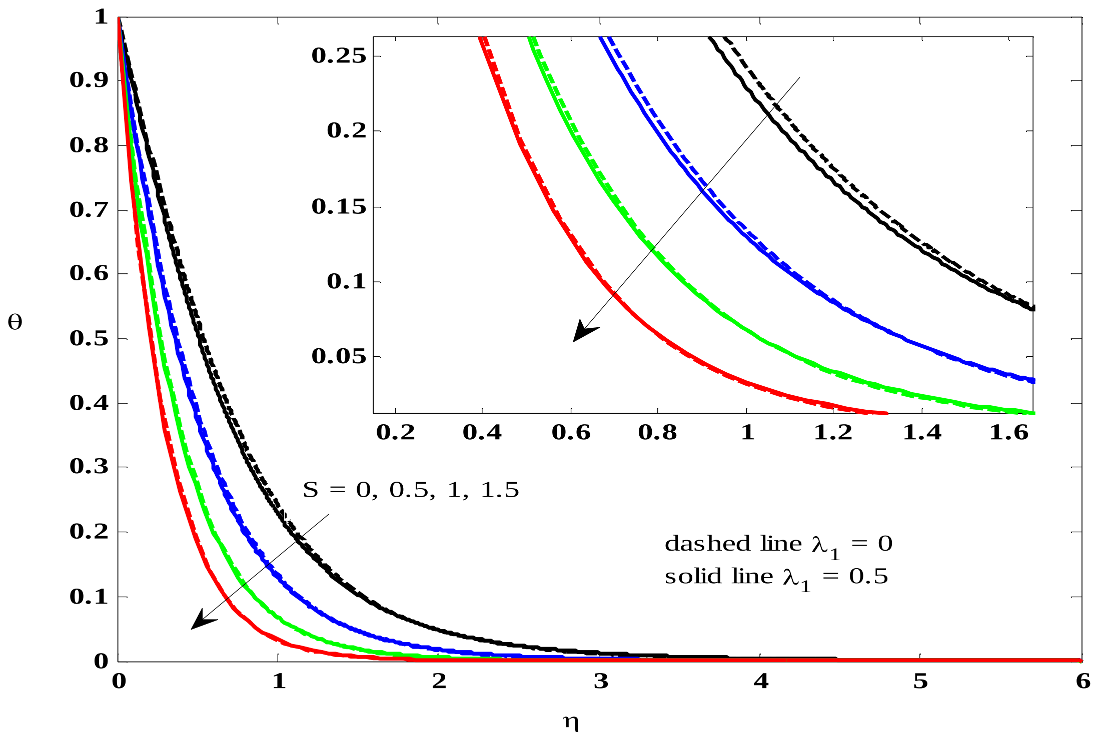

Fig 11. Temperature profiles against η for various values of S with
$Ec = 0.01, R = 0.3, \lambda = 0.1, A = 0.8, \delta = -0.5, \Pr = 10$ and $M = 0.01$

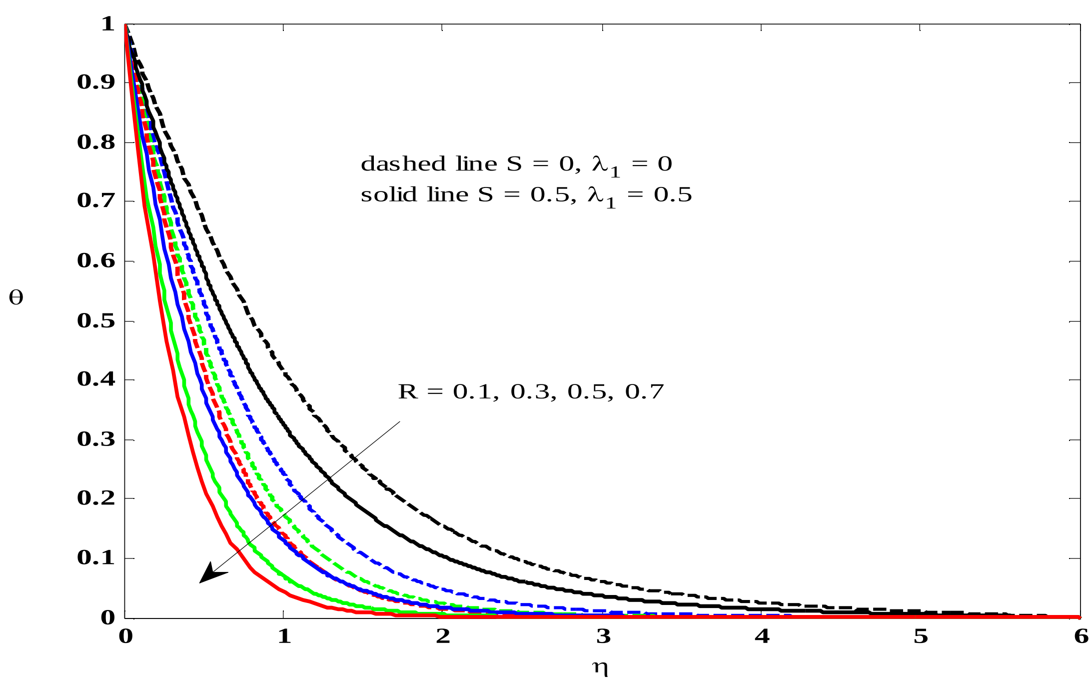

Fig 12. Temperature profiles against η for various values of R with
$M = 0.01, A = 0.8, \lambda = 0.1, Ec = 0.01, \delta = -0.5$ and $\Pr = 10$.

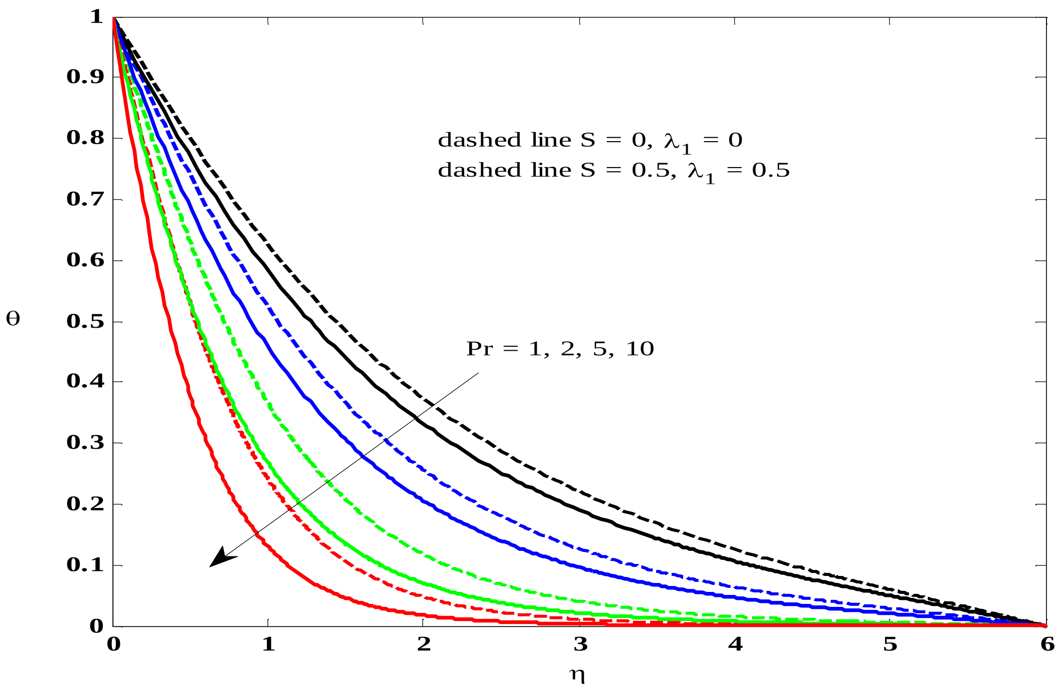

Fig 13. Temperature profiles against η for various values of $\Pr$ with $R = 0.3, \lambda = 0.1, A = 0.8, Ec = 0.01, \delta = -0.5$ and $M = 0.01$.

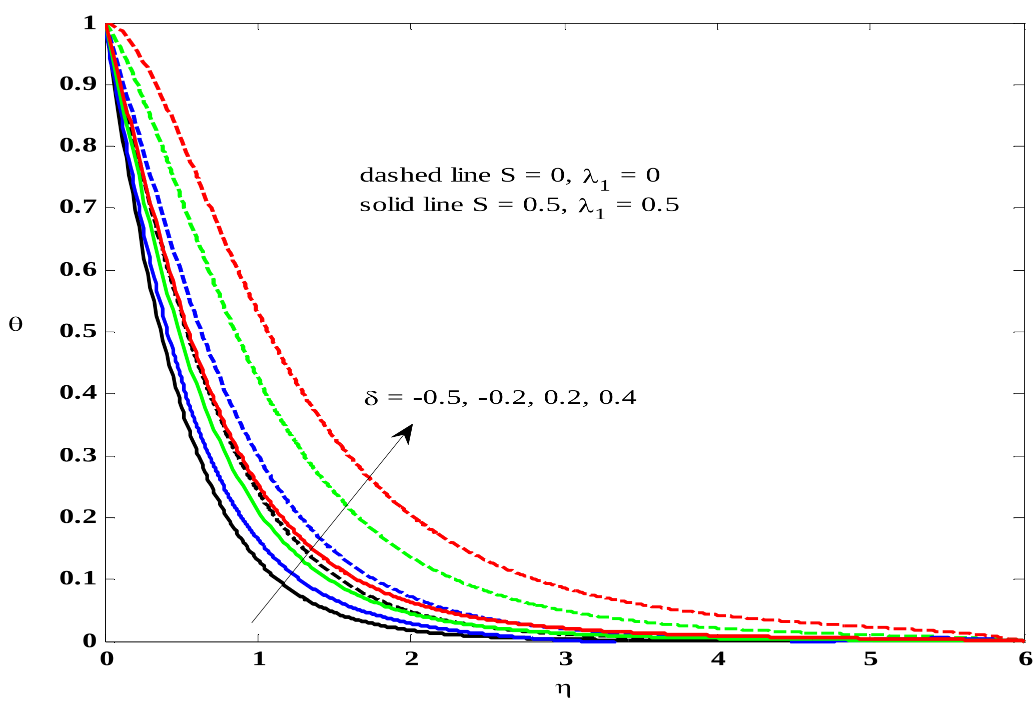

Fig 14. Temperature profiles against η for various values of δ with $R = 0.3, \lambda = 0.1, A = 0.8, Ec = 0.01, \Pr = 10$ and $M = 0.01$.

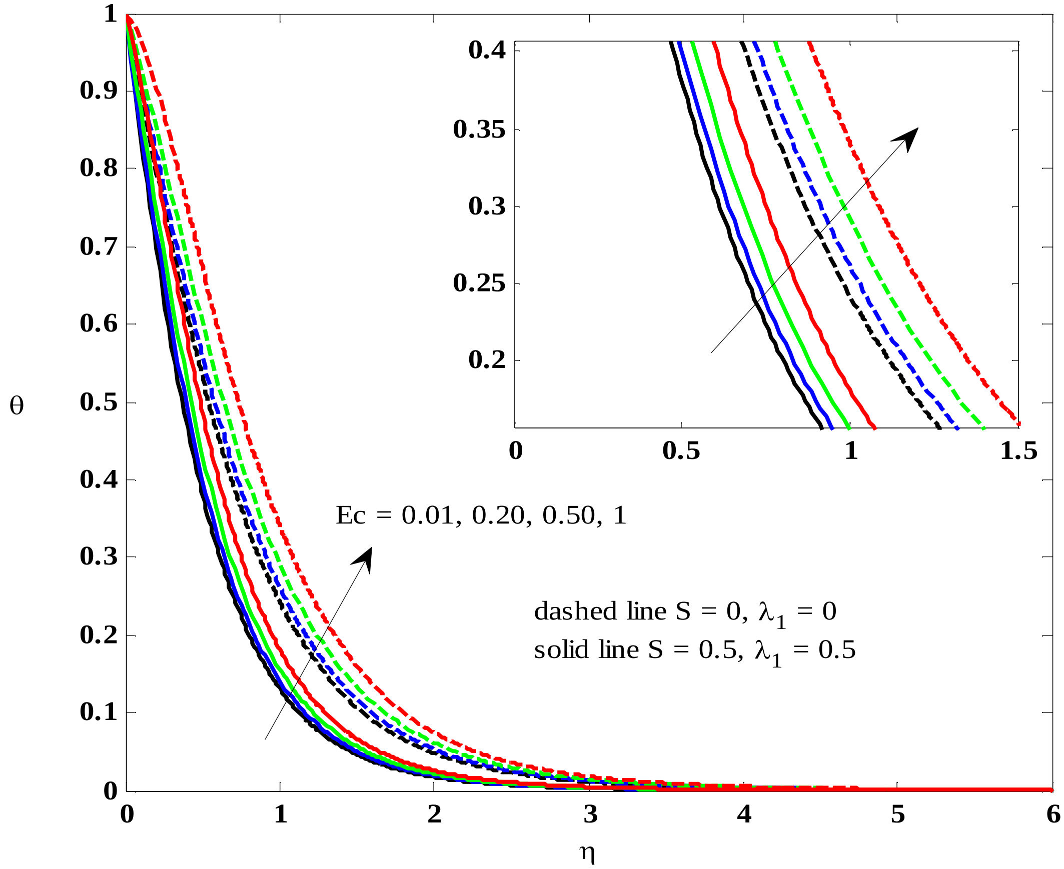

Fig 15. Temperature profiles against η for various values of Ec with

$R = 0.3, \lambda = 0.1, A = 0.8, \delta = -0.5, \Pr = 10$ and $M = 0.01$.

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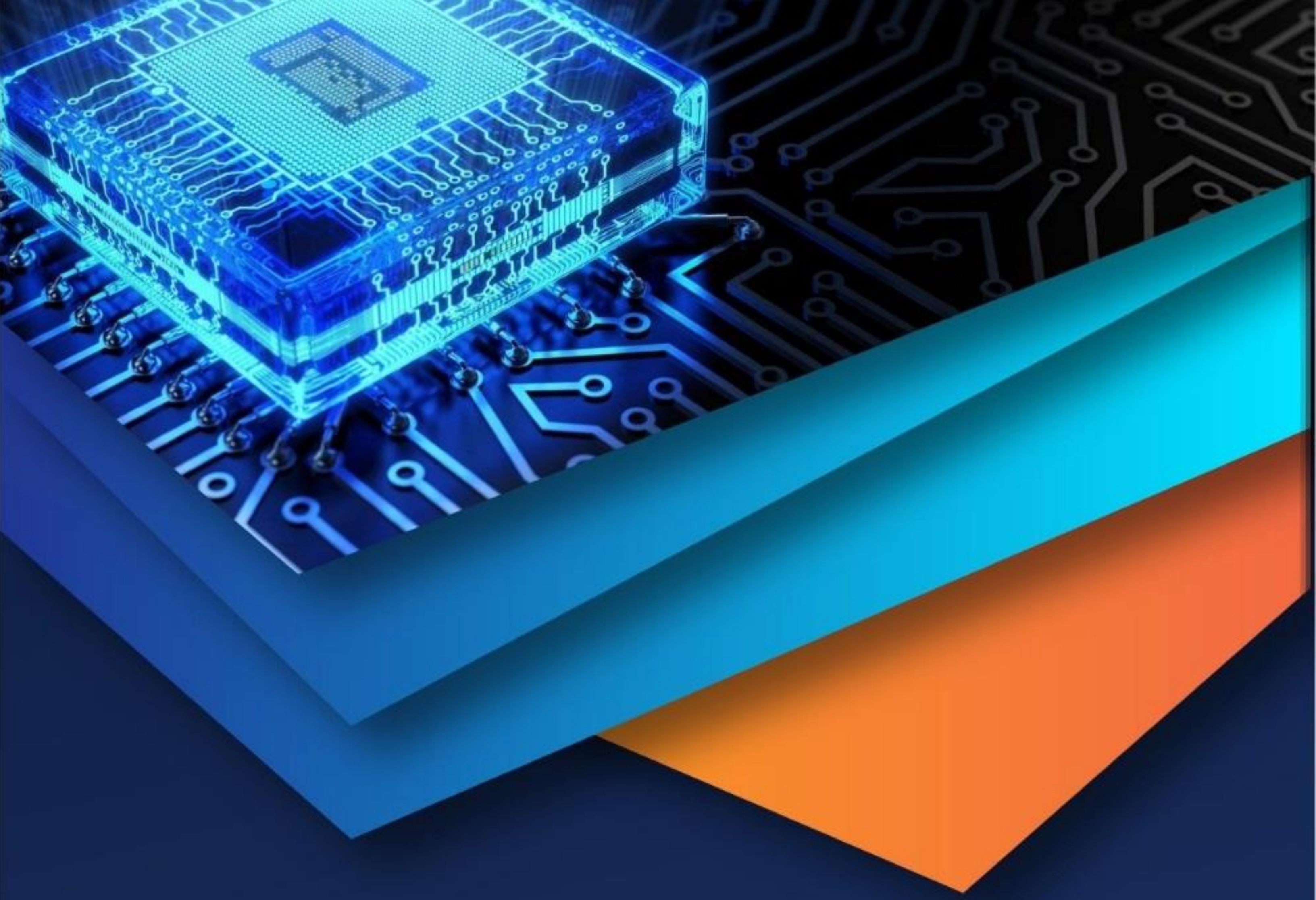

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