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Nonlinear MHD boundary layer flow of a liquid metal with heat transfer over a porous stretching surface with nonlinear radiation effects

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ABSTRACT

Nonlinear hydromagnetic two dimensional steady, laminar, boundary layer flow of a viscous, incompressible, electrically conducting and radiating liquid metal, with nonlinear radiation past a porous plate stretching with power-law velocity is analysed in the presence of a variable magnetic field. The liquid metal is assumed to be a gray, emitting, absorbing but non-scattering medium. Governing nonlinear partial differential equations are transformed to nonlinear ordinary differential equations by utilizing suitable similarity transformation. The resulting nonlinear ordinary differential equations are solved numerically using Fourth-Order Runge-Kutta shooting method along with the Nachtsheim-Swigert iteration for satisfaction of asymptotic boundary conditions. The numerical results for velocity and temperature distribution are obtained for different values of porosity parameter, velocity exponent parameter, magnetic interaction parameter, surface temperature parameter, radiation parameter and Prandtl number and are shown graphically. Numerically values of skin friction coefficient and nondimensional rate of heat transfer are also derived.

Keywords: MHD Hydromagnetic flow, porous stretching surface, variable magnetic field, nonlinear radiation effects and liquid metal.

Nomenclature

$B(x)$ -Variable applied magnetic induction.
M -Magnetic interaction parameter.
Pr -Prandtl Number.
S -Porosity parameter.
T -Temperature of the fluid.
m -Velocity exponent parameter.
p -Pressure of the fluid.
u, v -Velocity component of fluid in x and y direction.
$v_o(x)$-Variable injection velocity.
ρ -Density of the fluid.
ν -Kinematic viscosity.
K -Thermal conductivity.
η -Similarity variable
Ψ -Stream function.
θ -Dimensionless temperature.
B_O -Constant applied magnetic induction.
C_p -Specific heat at constant pressure.
T_w -Temperature of the heated surface.
T_∞ -Temperature of the ambient fluid.
q_r -Component of radiative flux.

INTRODUCTION

The study of two-dimensionless boundary layer flow and heat transfer over a porous stretching surface is very important as it finds many practical applications. In particular, suction blowing finds important role in industrial applications. Further, Convective boundary layer flows are often controlled by injecting or withdrawing fluid through a porous bounding heated surface. This can lead to enhanced heating or cooling of the system and can help to delay the transition from laminar to turbulent flow.

The interaction of forced convection with thermal radiation has increased greatly during the last decade due to its importance in many practical applications. Radiation heat transfer becomes more important with rising temperature levels and may be totally dominant over conduction and convection at very high temperature. Thus, thermal radiation is important in combustion applications (furnaces, rocket, nozzles, engines, etc.), in nuclear reactors and during atmospheric reentry of space vehicles.

In special, radiation effects on heat transfer over a stretching surface find newer applications in recent times due to its applications in space technology.

Sakiadis [1] studied theoretically the boundary layer on a continuous semi-infinite sheet moving steadily through an otherwise quiescent fluid environment. The boundary layer solutions of Sakiadis resulted in a skin friction of about thirty percent higher than that of Blasius [2] for the flow past a stretching flat plate.

Crane [3] analysed the flow over a linearly stretching sheet for the steady two dimensional problems. These types of flows usually occur in the drawing of plastic films and artificial fibers.

Carragher [4] analysed the same problem as crane to study heat transfer and obtained the Nusselt for the entire range of Prandtl number (Pr). Chakrabarti and Gupta [5] obtained the analytical solution for liner stretching problem with hydromagnetic effect. Dutta et.al. [6] considered the temperature field in flow a stretching sheet with uniform heat flux. Later, the effects of variable surface heat flux over the heat transfer characteristics of a linearly stretching sheet was anaylsed by Chen and Char [7], Vajravalu and Rollins [8] investigated the effect of Heat transfer in an electrically conduction fluid over a stretching surface

Convection heat transfer in a electrically conducting fluid with a constant transverse magnetic field was studied by Vajravalu and Neyfeh [9]. Magnetohydrodynamic heat transfer over a non-isothermal stretching sheet was analysed analytically by Chaim [10]. Elbashbeshy [11] investigated the heat transfer over a stretching surface with variable surface heat flux. Magyari and Keller [12] have analyzed the exponential stretching problem by discussing a further type of similarity solution of the governing equations.

Anjali Devi et.al. [13] have analyzed the problem of initial flow and heat transfer due to a suddenly stopped continuous moving plate. Viscous flow over a nonlinearly stretching sheet was studied by Vajravalu [14].

The effect of viscous flow and heat transfer over a nonlinearly stretching sheet was analyzed by Cortell [15]. Amkadni et.al. [16] analyzed the exact solution of magnetohydrodynamic steady state laminar flow of a viscous incompressible and electrically conducting fluid over a continuous permeable stretching surface. Further, the problem of the boundary layer flow of an incompressible viscous fluid over a non-linear stretching sheet was analyzed by Ghotbi [17]. Homotopy Analysis Method (HAM) is applied in order to obtained analytical solution of the governing nonlinear differential equations.

Afzal and Varshney [18], Kuiken [19] and Banks [20] considered the more general case sheet stretching with power-law velocity. The Eigen solution for this problem were further studied by Banks and Zaturska [21]. Andersson et.al. [22] studied the effect of hydromagnetic flow of a power-law fluid over a stretching sheet.

Noor Afzal [23] obtained several closed from solutions for the energy equation for a sheet stretching with a power-law velocity. The boundary layer flow due to a plate stretching with a power-law velocity disturbution in the presence of a transverse magnetic field was studied by Chiam [24]. Non-linear hydromagnetic flow and heat transfer over a surface stretching with a power-law velocity was discussed by Anjali Devi and Thiagarajan [25].

Smilarity solution of a MHD boundary layer flow past a continuous moving surface was analysed by Aly et.al. [26]. Here MHD boundary layer flow of viscous fluid over a permeable surface with a power law stretching velocity in the presence of a magnetic field applied normally to the surface is considered. Cortell [27] investigated the effect of viscous dissipation and radiation on the thermal boundary layer over a nonlinearly stretching sheet.

A similarity solution of the boundary layer equation for a nonlinearly stretching sheet was studied by Talay Akyildiz et.al. [28]. Heat and fluid flow due to non-linearly stretching surfaces was discussed by Cortell [29].

In view of the important of suction injection, several studied were made for the steady laminar flow of a viscous, incompressible and electrically conducting fluid over a stretching porous surface.

Bankoff [30] pointed out that heat transfer coefficients in film boiling could be substantially improved by continuously removing fluid through a porous heated surface. Gupta and Gupta [31] studied the heat and mass transfer over an isothermal stretching sheet with suction and blowing. Later, Grubka and Bobba [32] investigated related problem with a power-law temperature distribution along a linearly stretching sheet.

Exact solution for hydromagnetic boundary layer flow and heat transfer over a continuous, moving, flat surface with uniform suction and internal heat generation/absorption were obtained by Vajrevalu [33]. Cha'o-kuang Chen and Ming-I Char [34] investigated the effect of heat transfer of a continuous, stretching surface with suction or blowing Ahamed and Mubeen [35] investigated the boundary layer flow of an incompressible viscous fluid past a stretching plate with suction. The dependence of the boundary layer thickness and the Nusselt number on suction velocity was discussed by them. Ali [36] extended Banks work for a porous stretching surface for different values of suction parameter. Furthermore, a stretching surface subject to suction or injection was studied by Ali [37] for uniform and variable surface temperature.

The steady flow of a power-law fluid past on infinite porous flat plate subjected to suction or blowing with heat transfer for the case when the plate is held at a constant temperature was analyzed by Gupta et al. [38].

Tak and Lodha [39] investigated flow and heat transfer due to a stretching porous surface in the presence of transverse magnetic field with viscous dissipation effects. Anjali Devi and Ganga [40] analysed MHD nonlinear flow and heat transfer over a stretching porous surface of constant heat flux.

Many excellent theoretical models have been developed for radiative- convection flows and radiative-conductive transport. Plumb et.al. [41] analysed the effect of horizontal cross-flow and radiation on natural convection from vertical heated surface in saturated porous media. The thermal radiation of a gray fluid which is emitting and absorbing in laminar, steady boundary layer flow over an isothermal horizontal flat plate in a non-stretching medium has been examined by Chen et.al. [42].

The effect of radiation on heat transfer problems has been studied by Hossain and Takhar [43], Takhar et.al. [44] and Hossain et.al. [45]. Chamkha [46] studied the thermal radiation and buoyancy effects on hydromagnetic flow over an acceleration permeable surface with heat source and sink. In this work they have considered the vertical plate problem and used the Taylor series expansion and considered only the linear terms in the temperature. Ghaly and Elbarbary [47] have investigated the radiation effect on MHD free convection flow of a gas on a stretching surface with a uniform stream.

Effect of radiation on MHD steady asymmetric flow of an electrically conducting fluid past a stretching porous sheet has been analysed analytically by Ouaf [48], Mukhopadhyay and Layek [49] investigated the effects of thermal radiation and variable fluid viscosity on free convection flow and heat transfer past a porous stretching surface. The effect of unsteady MHD heat and mass transfer free convection flow of polar fluids past a vertical moving porous plate in a porous medium with heat generation and thermal diffusion was analysed by Satyasagar and Dubey [50].
Mass transfer effects on MHD viscous flow past an impulsively started infinite vertical plate with constant mass flux was studied by Saravana et al [51]. Srinivasulu and Bhaskar Reddy [52] studied the thermo-diffusion and diffusion-thermo effects on MHD boundary layer flow past an exponential stretching sheet with thermal radiation and viscous dissipation. Reddy et al [53] have presented the radiation and chemical reaction effects on free convection MHD flow through a porous medium bounded by vertical surface. In most of the above mentioned studies, the radiation term appears in linear form.

Elbashbeshy [54] analysed the radiation effect on heat transfer over a stretching surface by taking into account of the full form of radiation term. Recently, Swati Mukhopadhyay [55] investigated the effect of boundary layer flow and heat transfer over a porous moving plate in the presence of thermal radiation, taking into account of the full from of radiation term. Recently, effects of variable viscosity and nonlinear radiation on MHD flow with heat transfer over a surface stretching with a power-law velocity was analysed by Anjali Devi and David Maxim Gururaj [56].

The unique thermophysical properties of liquid metals make them attractive option for cooling of surface with extremely high thermal load. Such surface occur, e.g., in the receivers of concentrating solar power (CSP) plants. While liquid metals are intensively studied as cooling liquid in special research applications like particle sources, transmutation systems.

Kazuyukiueno et.al [57] analysed two-dimensional channel flow of liquid metal in the presence of progressing alternating transverse magnetic field. Linear stability analysis for high-velocity boundary layer in liquid metal magnetohydrodynamic flows was analysed by A.L. Ting and J.S. Walker [58].

L. Buhler [59] investigated liquid metal flow in arbitrary thin-walled channels under a strong transverse variable magnetic field. Heat transfer in liquid metals with electric currents and magnetic field: The conduction case was discussed by Gita Talmage [60].

Combined effect of magnetic field and viscous dissipation on a power-law fluid over plate with variable surface heat flux embedded in a porous medium was analysed by M. F. El-Amin [61]. Xiao-Yong Luo et.al. [62] analysed numerical study of MHD effect on liquid metal free jet under complex magnetic fields.

O. Anwar Beg et.al. [63] analysed the effect of nonsimilar, laminar, steady, electrically-conducting forced convection liquid metal boundary layer flow with induced magnetic field. Numerical simulation of MHD effects on convective heat transfer characteristics of flow of liquid metal in annular tube was analysed by J.S. Rao and Hari sankar [64]. Nonlinear hydromagnetic flow of a liquid metal with heat transfer over a stretching surface with radiation effects was analysed by S.P. Anjali Devi and A. David Maxim Gururaj [65].

But so far no attempt has been made on nonlinear radiation effects on MHD flow of an electrically conducting, radiating liquid metal with heat transfer over a porous horizontal nonlinearly stretching surface and hence the present work is carried out due to its immense applications.

2. Formulation of the Problem

Consider coupled radiation and forced convection along a horizontal porous stretching surface which is kept at uniform temperature T_w and moving with velocity $u_w = u_o x^m$ (where u_o and *m* are constants) through and stationary liquid metal. The liquid metal is assumed to be a gray, emitting, absorbing and electrically conducting, but non scattering medium at temperature T_∞. A variable magnetic field is applied normal to the horizontal surface $B(\vec{x}) = B_o x^{\frac{m-1}{2}}$ in accordance with Chiam [24].

The x-axis runs along the continuous surface in the direction of motion and y-axis perpendicular to it.

The following assumptions are made

1. Flow is two-dimensional, steady and laminar.
2. The fluid has constant physical properties.
3. The usual boundary layer assumptions are made [M.E. Ali [36]]. and
4. The radiation dissipation in the x-axis is negligible in comparison with that in the y-axis following the lines of Michael F. Modest (Radiative Heat Transfer. Page 696) [66].

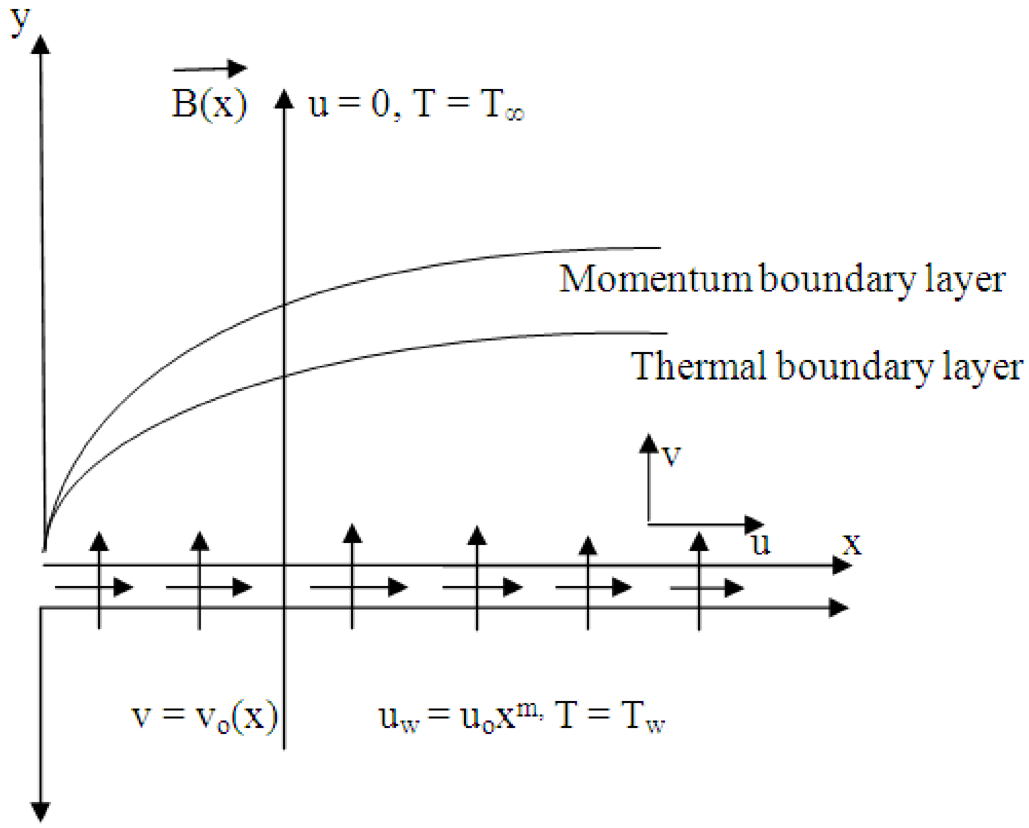

Figure .1. The coordinate system and the physical model

The continuity, momentum, and energy conservation equations under the above assumption are written as follows:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-\left(\frac{\sigma B^2(x)}{\rho}\right)u \qquad (2)$$

where

$$B(x)=B_o x^{\frac{(m-1)}{2}}$$

$$\rho C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=K\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y} \qquad (3)$$

With the associated boundary conditions

$$y=0,\ u_w=u_o x^m, v=v_o(x),\ T=T_w \qquad (u_o\rangle 0)$$
$$y\to\infty,\ u=0, T=T_\infty \qquad (4)$$

where the quantities $u, v, ...$ etc have the meaning as mentioned in the literature, $v_o(x)$ is the variable injection velocity, given by $v_o(x)=c\sqrt{\frac{\nu u_w}{x}}$.

The radiative heat flux term is simplified by using the Roseland diffusion approximation (Hossian .et.al. [45]) and accordingly

$$q_r = -\frac{16\sigma^* T^3}{3\alpha^*}\frac{\partial T}{\partial y} \tag{5}$$

Where σ^* is the Stefan-Boltzmann constant, α^* is the Rosseland mean absorption coefficient.

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

$$u = \frac{\partial \psi}{\partial y} \quad \text{and} \quad v = -\frac{\partial \psi}{\partial x} \tag{6}$$

Introduction the usual similarity transformation [M.E. Ali [36]]

$$\eta(x, y) = y\sqrt{\frac{m+1}{2}}\sqrt{\frac{u_o x^{m-1}}{\nu}}, \quad \psi(x, y) = \sqrt{\frac{2}{m+1}}\sqrt{\nu u_o x^{m+1}}\, f(\eta). \tag{7}$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \quad \theta_w = \frac{T_w}{T_\infty} \tag{8}$$

Equations (2) and (3) can be written as

$$f''' + ff'' - \frac{2m}{m+1} f'^2 - M^2 f' = 0 \tag{9}$$

Where $M = \sqrt{\dfrac{2\sigma B_o^{\,2}}{\rho u_o (m+1)}}$ is the magnetic interaction parameter.

$$\{1 + \frac{4}{3R^*}(1 + (\theta_w - 1)\theta)^3\}\theta'' + \frac{4}{R^*}(1 + (\theta_w - 1)\theta)^2(\theta_w - 1)\theta'^2 + \Pr f\theta' = 0 \tag{10}$$

Where $R^* = \dfrac{K\alpha^*}{4\sigma^* T_\infty^{\,3}}$ with boundary conditions

$$\begin{aligned} &f(0) = -S, \quad f'(0) = 1, \quad \theta(0) = 1; \\ &f'(\infty) = 0, \quad \theta(\infty) = 0 \end{aligned} \tag{11}$$

Where $S = \sqrt{\dfrac{2}{1+m}}C$ is the Porosity Parameter. C is a non dimensional constant. (For Injection $S > 0$ and For Suction $S < 0$).

3. Solution of the Problem

Equations (9) and (10) are nonlinear differential equations which constitute the nonlinear boundary value problem, it has to be reduced to an initial value problem. This is done by using shooting method.

Equations (9) and (10) are solved numerically subject to (11) using Fourth-Order Runge-Kutta shooting method. The crux of the problem is that we have to make an initial guess for the values of $f''(o)$ and $\theta'(0)$ to initiate the shooting process. The success of the procedure depends very much on how good this guess is. For different values of $\theta_w, R^*, M, \Pr$ and S, different initial guesses were made into account of the convergence. Numerical results are obtained for several values of the physical parameter and $\theta_w, R^*, M, \Pr$ and S.

RESULTS AND DISCUSSION

The numerical solution of nonlinear hydromagnetic boundary layer liquid metal flow and heat transfer over a stretching surface has been obtained by Fourth-Order Runge-Kutta shooting method along with the Nachtsheim-Swigert iteration by fixing several values for physical parameters.

Numerical values as depicted graphically by means of figures for velocity $f'(\eta)$, temperature distribution $\theta(\eta)$ for several set of values of the porosity parameter S ,velocity exponent parameter m, magnetic interaction parameter M , radiation parameter R^*, surface temperature parameter θ_w and Prandtl number $\Pr$.

In the absence of magnetic field and porosity the results are identical to those of Elbashbeshy [54] and in the absence of porosity parameter the results are identical to those of S.P. Anjali Devi and A. David Maxim Gururaj [65], which are justified through Figures 2, 3, 4 and 5.

Figure.6. displays the plot of dimensionless velocity $f'(\eta)$ for different values of M . It is noted that as magnetic interaction parameter M increases, transverse velocity $f'(\eta)$ decreases elucidating the fact that the effect of magnetic field is to decelerate the velocity.

The effects of velocity exponent parameter m over the dimensionless velocity field $f'(\eta)$ is shown in the graph of Fig.7. It is observed that the effect of velocity exponent parameter is to reduce the velocity.

Figure.8. illustrates the effects of radiation parameter R^* over the dimensionless temperature $\theta(\eta)$. It is observed that the effect radiation parameter is to reduce the temperature, elucidating the fact that the thermal boundary layer thickness decreases as R^* increases.

The effect of surface temperature parameter θ_w over the dimensionless temperature $\theta(\eta)$ is shown in Fig.9. Increasing surface temperature parameter θ_w is to increase the temperature.

Prandtl number variation over the dimensionless temperature profile is elucidated through Fig.10. As Prandtl number $\Pr$ increases, the temperature $\theta(\eta)$ decreases, illustrates the fact that the effect of Prandtl number is to decrease the temperature in the presence of magnetic field. Furthermore, the effect of Prandtl number is to reduce the thickness of thermal boundary lay

The non-dimensionless velocity profile the different values of suction / injection are shown through Fig.11. In the case of injection, the dimensionless velocity increases as injection parameter increases. Whereas the opposite trend is observed .In case of suction so as to decreases the velocity for increasing value of suction parameter. It is also noted that effect of injection is to thicken the boundary layer, whereas the effect of suction is to decreases the boundary layer.

Figure.12. shows effect of suction / injection over dimensionless temperature $\theta(\eta)$ .In the presence of magnetic field, it is evident that Fig.12.the effect of suction decreases the temperature $\theta(\eta)$ on the other hand effect of injection to increases the temperature. Furthermore thickness of the thermo magnetic layer is reduced due to the effect of suction, whereas its thickness is increased due to the effect of injection. However, effect of injection is more dominant over the temperature than that of suction.

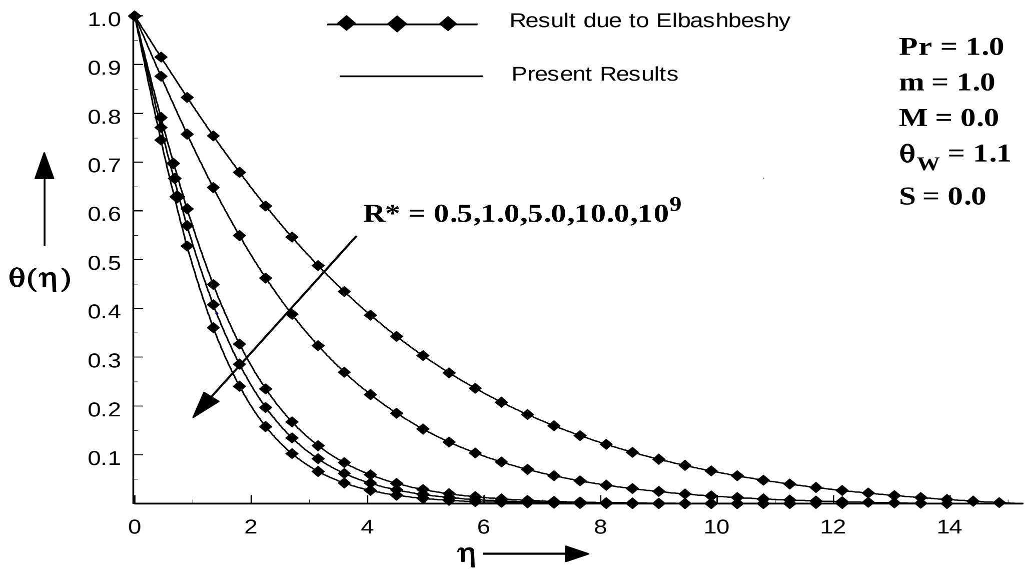

Fig .2. Temperature profiles for different R*

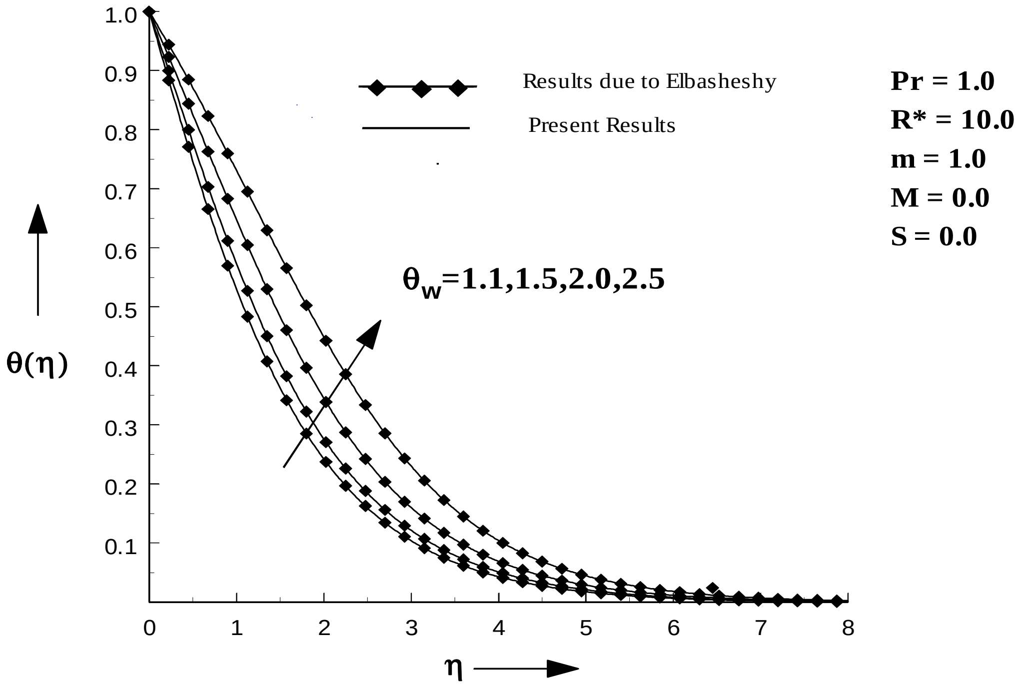

Fig.3.Temperature profiles for diffe rent θ_w

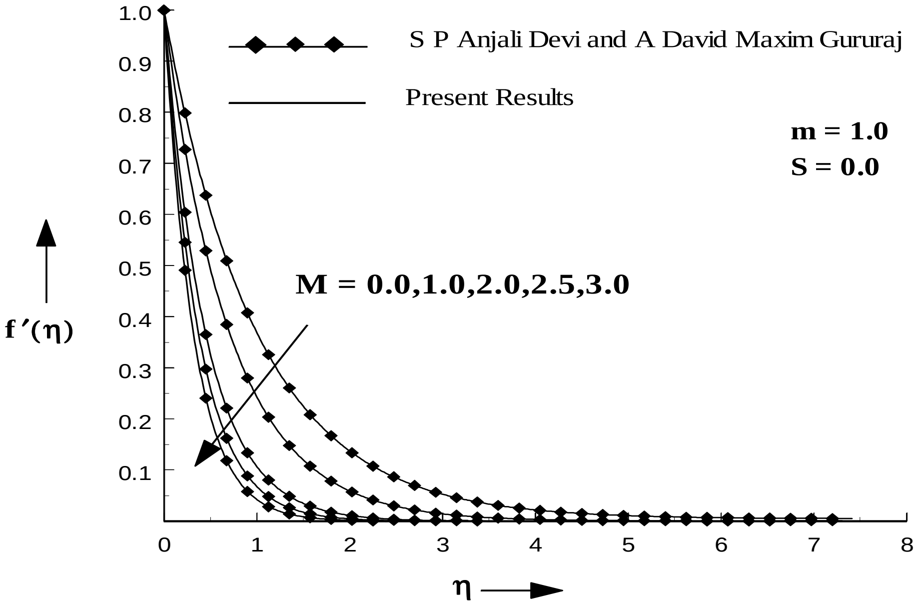

Fig.4. Velocity profiles for different M

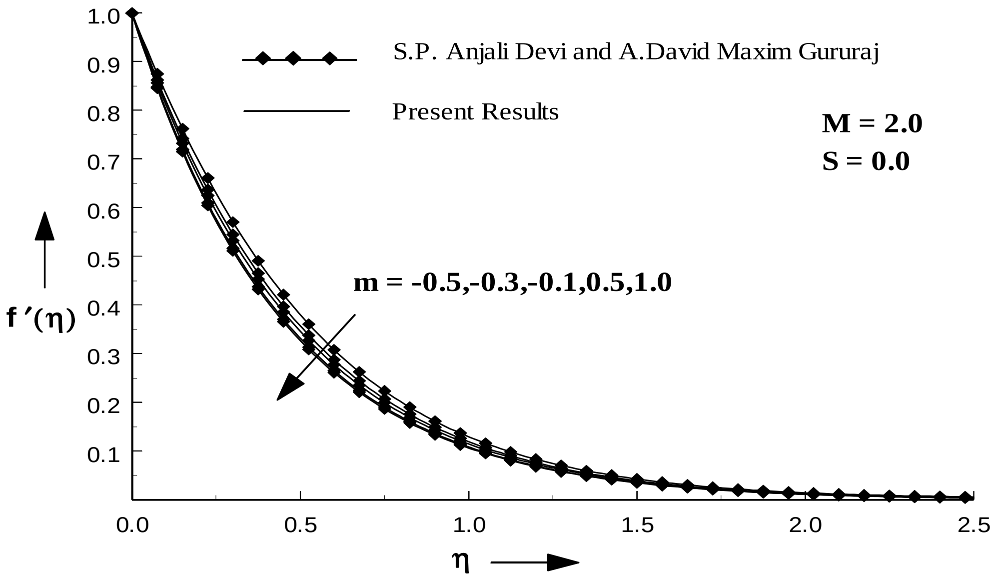

Fig.5. Velocity profiles for different m

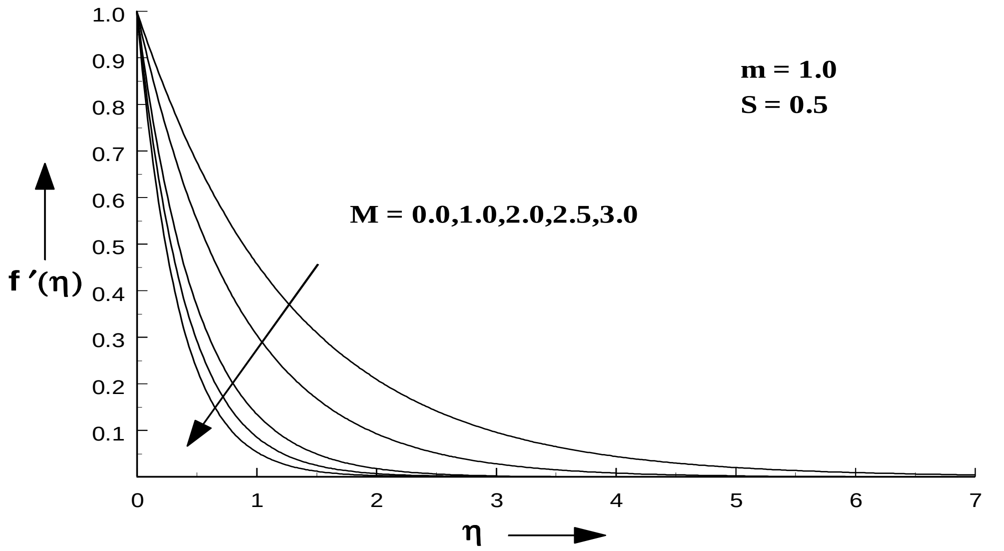

Fig.6. Velocity profiles for different M

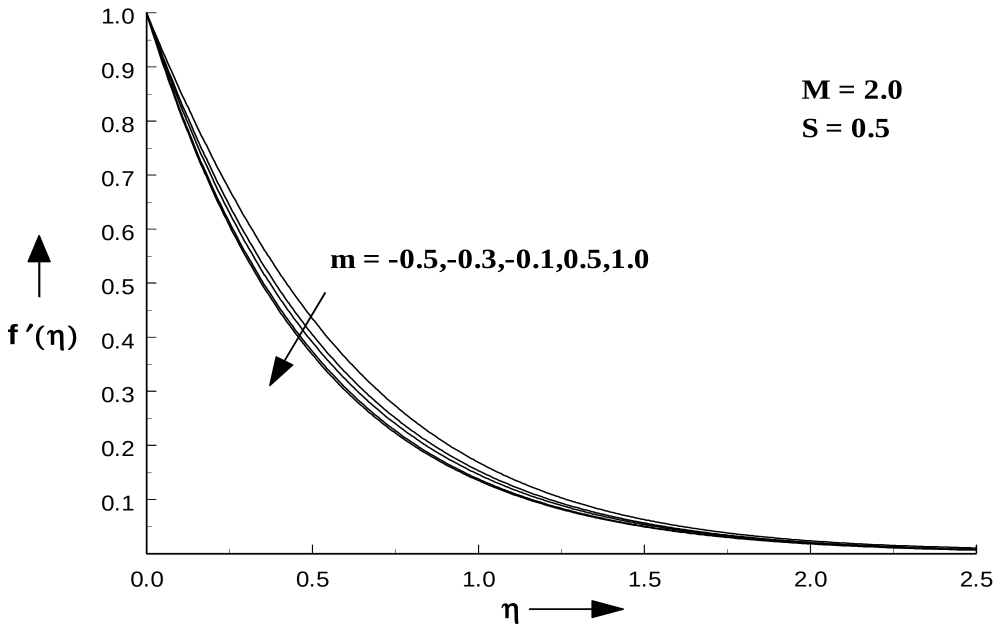

Fig 7. Velocity profiles for different m

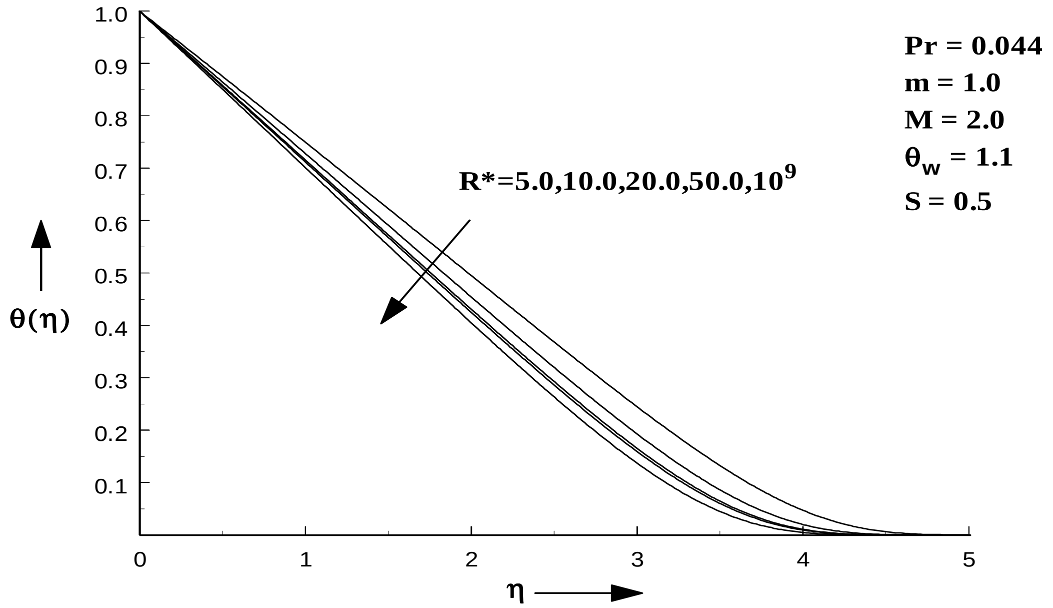

Fig.8. Temperature profiles for different R*

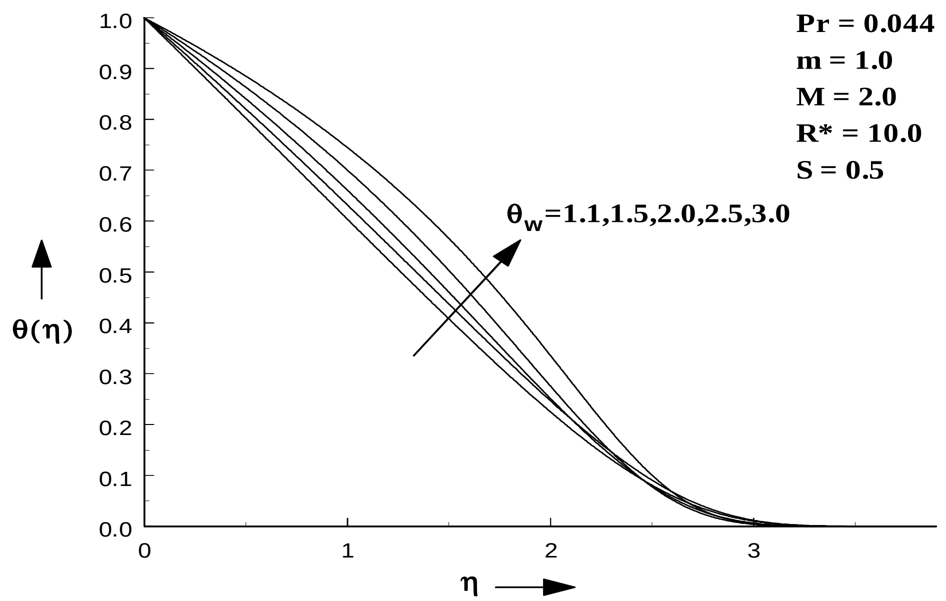

Fig.9. Temperture profiles for different θ_w

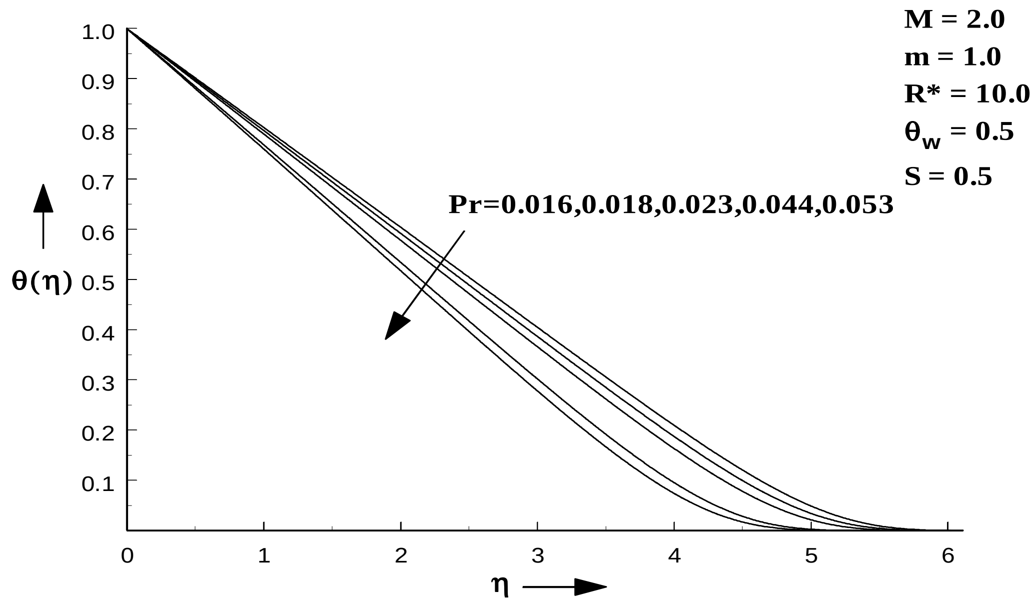

Fig.10. Temperature profile for different Pr

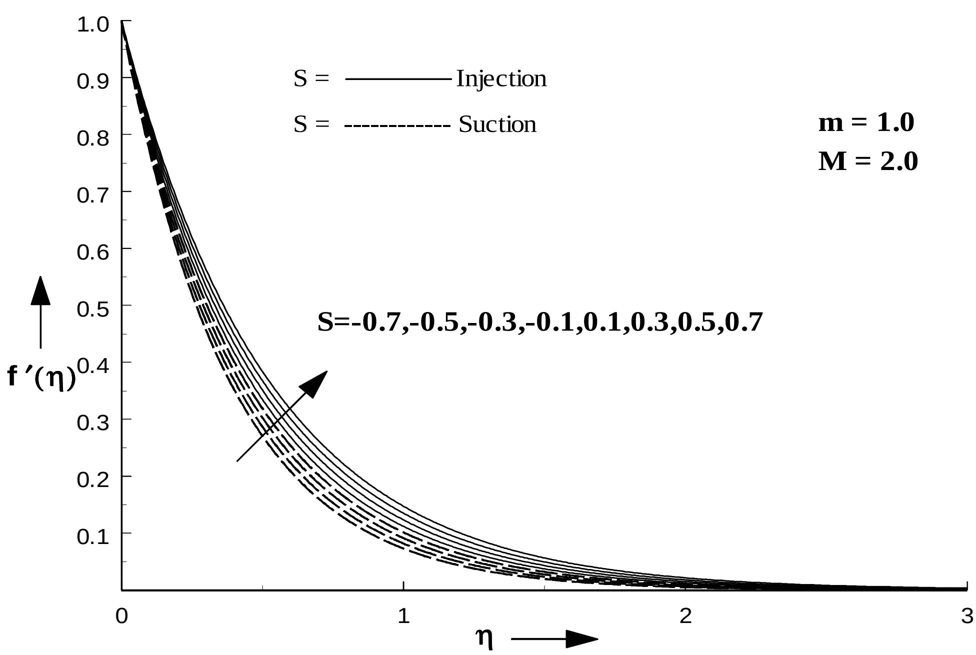

Fig.11. Velocity profiles for different S

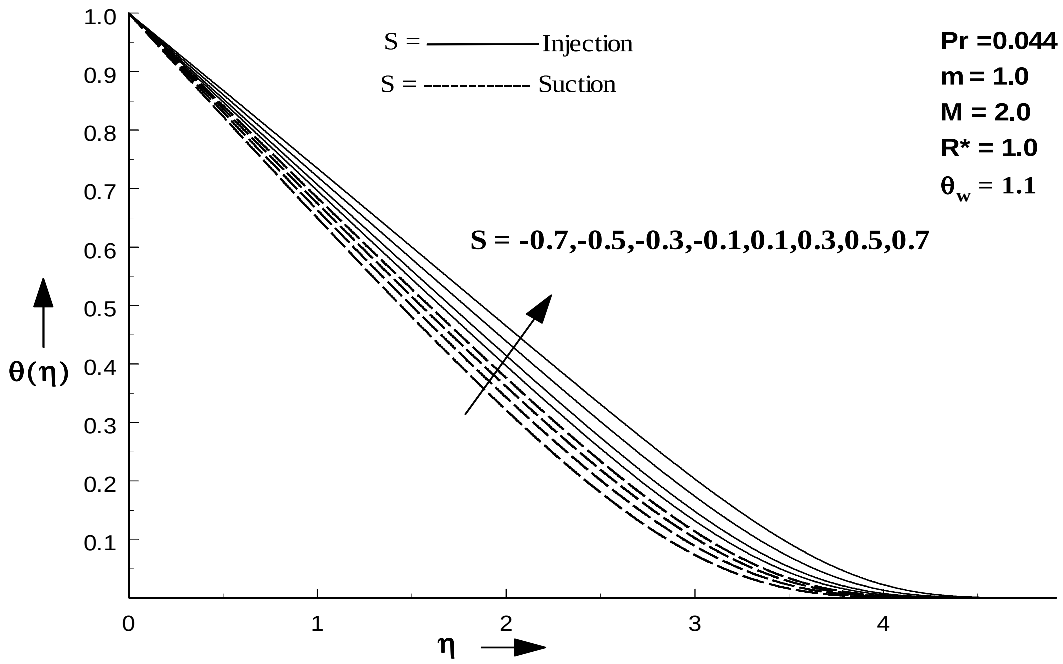

Fig.12. Temperature profiles for different S

Table.1 Effect of velocity exponent parameter, magnetic interaction parameter and suction parameter on skin friction coefficient for a stretching surface for the case of suction presented in table. From this table, it can be clearly seen that the skin friction coefficient increases in magnitude with increase in suction parameter in magnetic interaction parameter M and velocity exponent parameter m.

Table-1 For the case of Suction Variation of $f''(0)$ for different values of m, M & -S

-S	m	M	$f''(0)$
-0.1	1.0	2.0	**-2.28663**
-0.3			**-2.39109**
-0.5			**-2.50000**
-0.7			**-2.61329**
-0.5	**-0.5**	2.0	**-2.02964**
	-0.3		**-2.22064**
	-0.1		**-2.31987**
	0.5		**-2.45196**
	1.0		**-2.50000**
-0.5	1.0	**0.0**	**-1.27859**
		1.0	**-1.68613**
		2.0	**-2.50000**
		2.5	**-2.95416**
		3.0	**-3.42214**

Table.2 provides the variation of skin friction coefficient due to the effect of, m, M and *S* for a stretching surface for the case of injection. It seen that the effect of m *and* M over the skin friction coefficient is to increases it in magnitude whereas skin friction coefficient decreases in magnitude for increasing *S*.

Table-2 For the case of Injection Variation of $f''(0)$ for different values of m, M & S

S	m	M	$f''(0)$
0.1	1.0	2.0	**-2.18663**
0.3			**-2.09109**
0.5			**-2.00000**
0.7			**-1.91329**
0.5	**-0.5**	2.0	**-1.48025**
	-0.3		**-1.69537**
	-0.1		**-1.80478**
	0.5		**-1.94853**
	1.0		**-2.00000**
0.5	1.0	**0.0**	**-0.78074**
		1.0	**-1.18614**
		2.0	**-2.00000**
		2.5	**-2.45416**
		3.0	**-2.92214**

Table-3 For the case of suction Variation of $\theta'(0)$ for different values of m, -M & S

Pr	R*	-S	$\theta'(0)$
0.016	5.0	-0.5	**-0.24510**
0.018			**-0.24833**
0.023			**-0.26040**
0.044			**-0.29408**
0.053			**-0.30609**
0.044	**5.0**	-0.5	**-0.28991**
	10.0		**-0.30683**
	20.0		**-0.31412**
	50.0		**-0.32765**
	10^9		**-0.33632**

Table-4 For the case of Injection Variation of $\theta'(0)$ for different values of Pr & R*

Pr	R*	-S	$\theta'(0)$
0.016	5.0	-0.5	**-0.28504**
0.018			**-0.29264**
0.023			**-0.30364**
0.044			**-0.33271**
0.053			**-0.34952**
0.044	**5.0**	-0.5	**-0.24674**
	10.0		**-0.26870**
	20.0		**-0.28167**
	50.0		**-0.28569**
	10^9		**-0.29662**

Table.3 The dimensionless rate of heat transfer against $\Pr$, R^* and $-S$ for the case of suction is presented in table. This table elucidates that dimensionless rate of heat transfer increases in magnitude with increases in $\Pr$ and R^*.

Table.4 Displays effect of $\Pr$ and R^* over the dimensionless rate of heat transfer for the case of injection. It can be absorbed from this table that the effect of $\Pr$ and R^* over $\theta'(0)$ is to increases the magnitude for their increasing values.

CONCLUSION

In general the flow field and temperature distribution are effected by the physicial parameter. In the absence of magnetic field and porosity, the results are identical to those of Elbashbeshy [54]. Further in the absence of porosity the results are identical to those of S.P.Anjali Devi and A. David Maxim Gururaj [65].

The following conclusions are made in view of the above results and discussions

- It seen that thickness of the thermal boundary layer proves to be substantially larger than the thickness of the momentum boundary layer which is a unique phenomena for liquid metal.
- It is found that the effect of magnetic field is to decelerate the velocity. This result qualitatively agrees with the expectation since the Lorentze force which opposes the flow increases as M increases and leads to enhanced deceleration of the flow.
- The effect of velocity exponent parameter is to decreases the velocity and increases in magnitude the skin friction coefficient for both suction and injection.
- Effect of thermal radiation is to reduce the temperature and the temperature is found to increases with the increases surface temperature parameter.
- Thermal boundary layer thickness decreases with increasing Prandtl number.
- Dimensionless velocity increases for increasing suction parameter, whereas the velocity decreases for decreasing injection parameter.
- It is observed that if injection to decrease the temperature. On the other hand the effect of injection is to decrease the temperature.
- Effect of magnetic field is to reduce the skin friction coefficient for both suction and injection for increasing velocity exponent parameter.
- It is noted that for increasing Prandtl number $\Pr$ and radiation parameter R^*, the dimensionless rate of heat transfer decreases for increasing magnetic interaction parameter M for both suction and injection.
- It is seen that the skin friction coefficient decreases with increases in magnetic interaction parameter M and suction parameter S.
- It is seen that effect of velocity exponent parameter m is to decreases the skin friction coefficient whereas the effect of S is to increase the skin friction coefficient.
- In the case of suction and injection the dimensionless rate of heat transfer decreases for an increase in $\Pr$ and R^*.

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