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MHD stagnation-point flow past a stretching sheet through porous media with heat source/sink

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Abstract

The steady boundary layer MHD stagnation- point flow past a stretching sheet through porous media with heat source /sink is investigated. The surface temperature of the sheet is taken time dependent. The governing equations are transformed into self-similar ordinary differential equations by adopting similarity transformations and then the converted equations are solved numerically by Runge-Kutta fourth order method. Special emphasis has been given to the parameters of physical interest which include velocity ratio parameter, Prandtl number, magnetic parameter, porous matrix,temperature index parameter and heat source parameter. The results obtained for velocity, temperature and skin friction are shown in tables and graphs. The comparison of the present results with the existing numerical solutions in a liming sense is also shown and this comparison is very good.

Keywords:

Stretching sheet, Stagnation point, Porous sheet, MHD flow, Runge-Kutta fourth order.

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1. Introduction

The flow over a stretching surface has wide range of applications in engineering and several technological purposes. This type of flow is frequently appears in many industrial and engineering processes and in those cases, the qualities of the final products depend to a great extent on the rate of cooling. So, to get better product the heat transfer should be controlled. Such a system is used in a wide variety of manufacturing processes such as crystal growing, plastic extrusion, continuous casting etc. Crane [1] computed an exact similarity solution for the boundary layer flow of a Newtonian fluid towards an elastic sheet which is stretched with the velocity proportional to the distance from the origin. The heat and mass transfer on a stretching sheet with suction or blowing was studied by Gupta and Gupta [2]. Dutta et al. [3] analyzed the temperature distribution in the flow over a stretching sheetwith uniform heat flux. McLeod and Rajagopal [4] has then been used by Troy et al. [5] to investigate uniqueness of flow ofan incompressible second-order fluid past a stretching sheet. To do it, Troy et al. [5] have reduced the governing equation to a first-order Ricatti equation followed by an appropriate analysis. After this pioneering work, the flow field over a stretching surface has drawn considerable attention and a good amount of literature has been generated on this problem [6 - 8]. Chiam [9] investigated the stagnation-point flow towards a stretching sheet and found no boundary layer structure near the sheet. Mahapatra and Gupta [10] reinvestigated the same stagnation-point flow towards a stretching sheet and found two kinds of boundary layer near the sheet depending on the ratio of the stretching and straining rates. The stagnation-point flow over stretching sheet was further investigated by Mahapatra and Gupta [11], Nazar et al.

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[12], Hayat et al. [13], where they explore some important properties. Andersson [14] in-vestigated the MHD flow of a viscoelastic fluid past a stretching surface in the presence of a uniform transverse magnetic field.

MHD flows play an important role in the motion of fluids. Normally, a uniform magnetic field is applied normal to the plate which is maintained at a constant temperature. The steady MHD mixed convection flow of a viscoelastic fluid in the neighborhood of two-dimensional stagnationpoints with a magnetic field has been investigated by Kumari and Nath[15]. The stagnation region encounters the highest pressure, the highest heat transfer, and the highest rates of mass deposition. Attai [16] has made an analysis of the steady laminar flow in a porous medium of an incompressible viscous fluid impinging on a permeable stretching surface with heat generation. The steady magneto hydrodynamic (MHD) mixed convection stagnation point flow towards a vertical surface immersed in an incompressible micropolarfluid with prescribed wall heat flux was investigated by Bachok[17] They have transformed the governing partial differential equations into a system of ordinary differential equations, which is then solved numerically by a finite-difference method. Hayd[18] have studied the boundary layer equations for axisymmetric point flow of power-law electrically conducting fluid through a porous medium with transverse magnetic field. . Stagnation point flow of a micropolar fluid towards a stretching sheethas been discusse. Xu et al. [19] examined the unsteady boundary layer flow of a micropolar fluid near the forward stagnation point of a plane surface. Some other studies on stagnation flows are discussed in [20–21]. Eladahak and Ghonain [22] studied the radiation effect on heat transfer of a micropolar fluid through a porous medium. The steady boundary layer flow of a micropolar fluid through a porous medium by using generalized Darcy's law has been examined by Raptis [23].

The aim of the present paper is to discuss the analytic solution for unsteady MHD stagnation-point flow past a stretching sheet through porous media with heat source/sink. The method employed for the analytic solution of nonlinear problem is Runge-Kutta fourth order method.

Nomenclature

C_f	Wall skin friction coefficient	f	Dimensionless stream function
B_0	Strength of magnetic field	k_p	Porosity parameter
M	Magnetic parameter	Nu_x	Local Nusselt number
q_w	Surface heat flux	S	Heat source\sink
Re_x	Local Reynolds number	T	Temperature
T_w	Constant temperature at the sheet	T_∞	Ambient fluid temperature
U_∞	Free stream velocity	U_w	Stretching velocity of the sheet
u, v	Velocity components	p_r	Prandtl number

Greek symbols

η	Similarity variable	ε	Velocity ratio parameter
θ	Dimensionless temperature	ψ	Stream function
σ	Electrical conductivity of the fluid	τ_w	Shear stress
υ	Kinematic fluid viscosity	ρ	Fluid density
μ	Dynamic viscosity	k	Thermal conductivity

2. Mathematical Analysis

Consider a steady two-dimensional flow of an incompressible and electrically conducting fluid towards the stagnation point on a porous stretching surface in the presence of magnetic field of strength B_0 applied in the positive y direction as shown in Fig. 1.The stretching velocity $U_w(x)$ and the free stream velocity $U_\infty(x)$ are assumed to vary proportional to distance x from the stagnation point, that is $U_w(x) = ax$ and $U_\infty(x) = bx$ where a, b are constants with $a > 0, b \geq 0$. The surface of the sheet is subjected to a prescribed temperature $T_w(x) = T_\infty + cx^n$, where T_∞ is the ambient fluid temperature and c and n are constants with $c > 0$. The induced magnetic field is negligible due to small Reynolds number. Under the usual boundary layer approximations, the equations governing the problem of steady, incompressible and viscous flow are

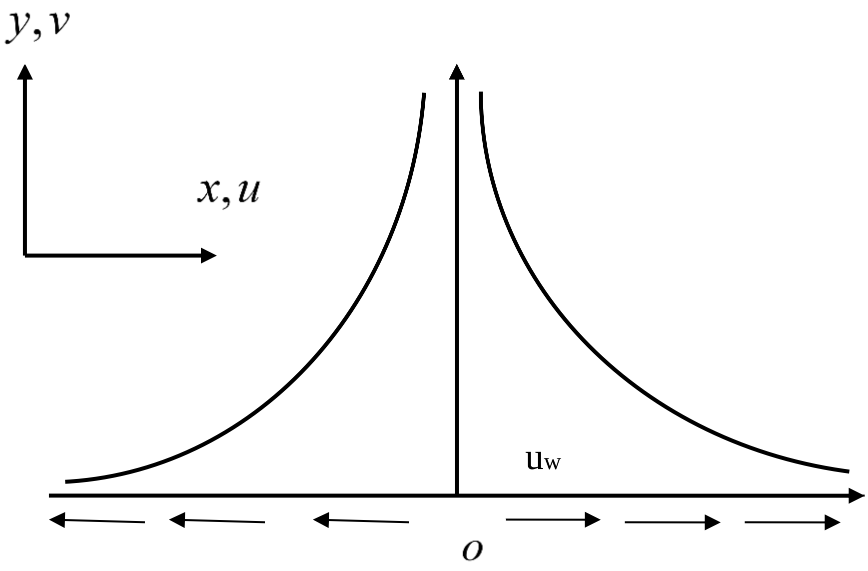

Fig.1 Physical model and co-ordinate system

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = U_\infty \frac{dU_\infty}{dx} + \upsilon \frac{\partial^2 u}{\partial y^2} + \left(\frac{\sigma B_0^{\,2}}{\rho} + \frac{\upsilon}{k_p^{\,'}}\right)(U_\infty - u) \quad (2)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha \frac{\partial^2 T}{\partial y^2} + S(T - T_\infty) \quad (3)$$

The appropriate boundary conditions are

$$\left.\begin{array}{lll} u = U_w(x), & v = 0, T = T_w(x) & at\ y = 0, \\ u \to U_\infty(x), & T \to T_\infty & as\ y \to \infty, \end{array}\right\} \quad (4)$$

3. Solution of the flow field

Equation (1) is satisfied if we chose a dimensionless stream function $\psi(x, y)$ so that

$$u = \frac{\partial \psi}{\partial y}, \quad v = -\frac{\partial \psi}{\partial x}. \tag{5}$$

We now introduce the following dimensionless quantities; the mathematical analysis of the problem is simplified by introducing the following similarity transforms:

$$\eta = y\sqrt{\frac{a}{\upsilon}}, \quad \psi(x,y) = x\sqrt{\upsilon a}\, f(\eta), \quad \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty} \tag{6}$$

Using the similarity transformation quantities, the governing Eqs. (1)–(3) are transformed to the ordinary differential equation as follows:

$$\left.\begin{aligned} & f''' + ff'' - f'^2 + \varepsilon^2 + (M + \frac{1}{k_p})(\varepsilon - f') = 0, \\ & \frac{1}{p_r}\theta'' + f\theta' - nf'\theta + S\theta = 0 \end{aligned}\right\} \tag{7}$$

With boundary conditions

$$\left.\begin{aligned} & f(\eta) = 0, \quad f'(\eta) = 1, \theta(\eta) = 1 \qquad at \;\; \eta = 0, \\ & f'(\eta) \to \varepsilon, \quad \theta(\eta) \to 0 \qquad as \;\; \eta \to \infty, \end{aligned}\right\} \tag{8}$$

Where $\varepsilon = b/a$ is the velocity ratio parameter, $p_r = \upsilon/\alpha$ is the prandtl number, $M = \sigma B_0^2/(\rho a)$ is the magnetic parameter, k_p is the porous matrix, and S is the heat source/sink. The primes denote differentiation with respect to η.

The physical quantities are:

Skin friction coefficient $C_f = \dfrac{\tau_w}{\rho U_w^2 / 2}$

Local Nusselt number $Nu_x = \dfrac{xq_w}{k(T_w - T_\infty)}$

The wall shear stress $\tau_w = \mu(\dfrac{\partial u}{\partial y})_{y=0}$

The surface heat flux $q_w = -k(\dfrac{\partial T}{\partial y})_{y=0}$

The local Reynolds number $\mathrm{Re}_x = \dfrac{U_w x}{\upsilon}$

Special case

When $\varepsilon = 0$, the closed form solution is

$$f(\eta) = \frac{1}{\sqrt{1 + M + \frac{1}{k_p}}}(1 - e^{\sqrt{1+M+\frac{1}{k_p}}\eta}) \tag{9}$$

Using (9) the temperature equation of (7) subject to boundary condition (8) is given by

$$\theta(\eta) = e^{-\frac{p_r}{\sqrt{1+M+\frac{1}{k_p}}}\eta} \frac{F(\gamma - n, \gamma + 1, -\gamma e^{-\sqrt{1+M+\frac{1}{k_p}}\eta})}{F(\gamma - n, \gamma + 1, -\gamma)}, \tag{10}$$

Where $\gamma = \dfrac{p_r}{1 + M + \frac{1}{k_p}}$ and $F(a, b, z)$ denote the confluent hypergeometric function.

$$F(a,b,z)=1+\sum_{n=1}^{\infty}\frac{a_n}{b_n}\frac{z^n}{n!}$$

$$a_n=a(a+1)(a+2)....(a+n-1),$$

$$b_n=b(b+1)(b+2)....(b+n-1),$$

The skin friction coefficient $f''(0)$ and the Nusselt number $-\theta'(0)$ can be shown to given by

$$\left.\begin{aligned} f''(0)&=-\sqrt{1+M}\\ \theta'(0)&=\frac{p_r}{\sqrt{1+M}}\left[-1+\frac{\gamma-n}{\gamma+1}.\frac{F(\gamma+1-n,\gamma+2,-\gamma)}{F(\gamma-n,\gamma+1,-\gamma)}\right]\end{aligned}\right\} \quad (11)$$

4. Numerical Results and Discussion

Table1. Skin friction coefficient, Nusselt number for the various thermo-physical parameters.

		$f''(0)$	$-\theta'(0)$			$f''(0)$	$-\theta'(0)$
M	K_p	$\varepsilon=0.1, P_r=1, n=1, S=0$		M	K_p	$\varepsilon=0.1, P_r=1, n=1, S=0.5$	
0	100	-0.97377	1.021028	0	100	-0.97377	0.6255
0	0.5	-1.59812	0.904811	0	0.5	-1.59812	0.264829
1	100	-1.32417	0.952124	1	100	-1.32417	0.429455
1	0.5	-1.83394	0.868752	1	0.5	-1.83394	0.121819
n	K_p	$\varepsilon=0.1, P_r=1, M=1, S=0.5$		ε	K_p	$n=1, P_r=1, M=1, S=0.5$	
-0.5	100	-1.32417	-2.6968	0.1	100	-1.32417	0.429455
-0.5	0.5	-1.83394	-16.5073	0.1	0.5	-1.83394	0.121819
1	100	-1.32417	0.429455	2	100	2.251303	1.341884
1	0.5	-1.83394	0.121819	2	0.5	2.653976	1.361664
P_r	K_p	$n=1, \varepsilon=1, M=1, S=0.5$					
0.7	100	-1.32417	0.323544				
0.7	0.5	-1.83394	0.141104				
1	100	-1.32417	0.429455				
1	0.5	-1.32417	0.121819				

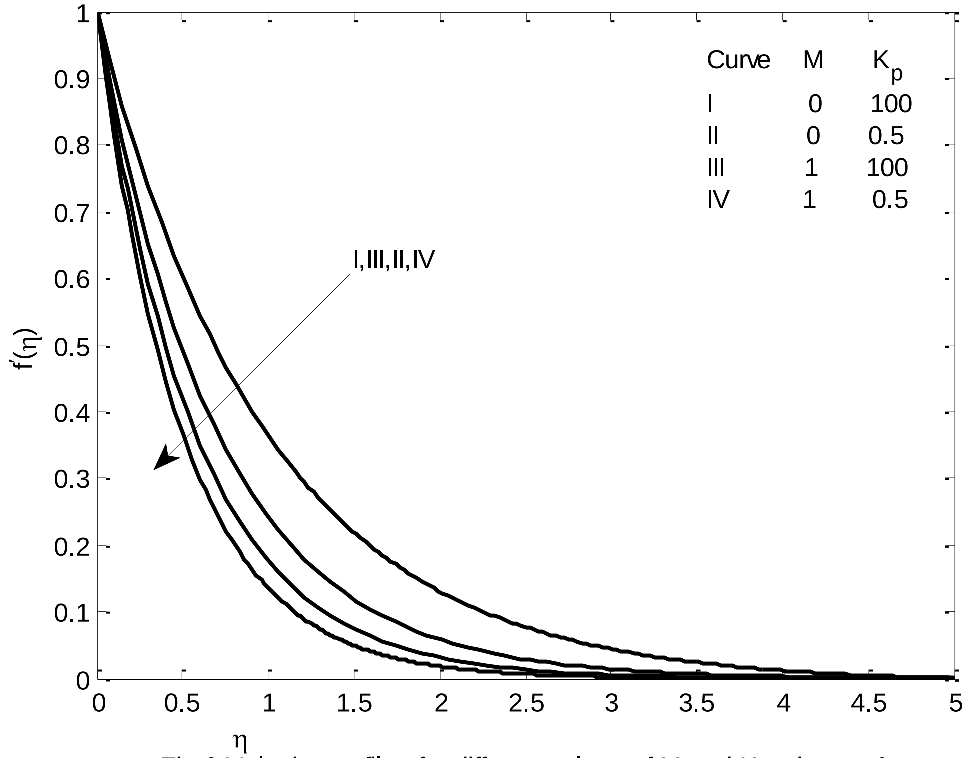

Fig.2 Velocity profiles for different values of M and K_p when ε=0

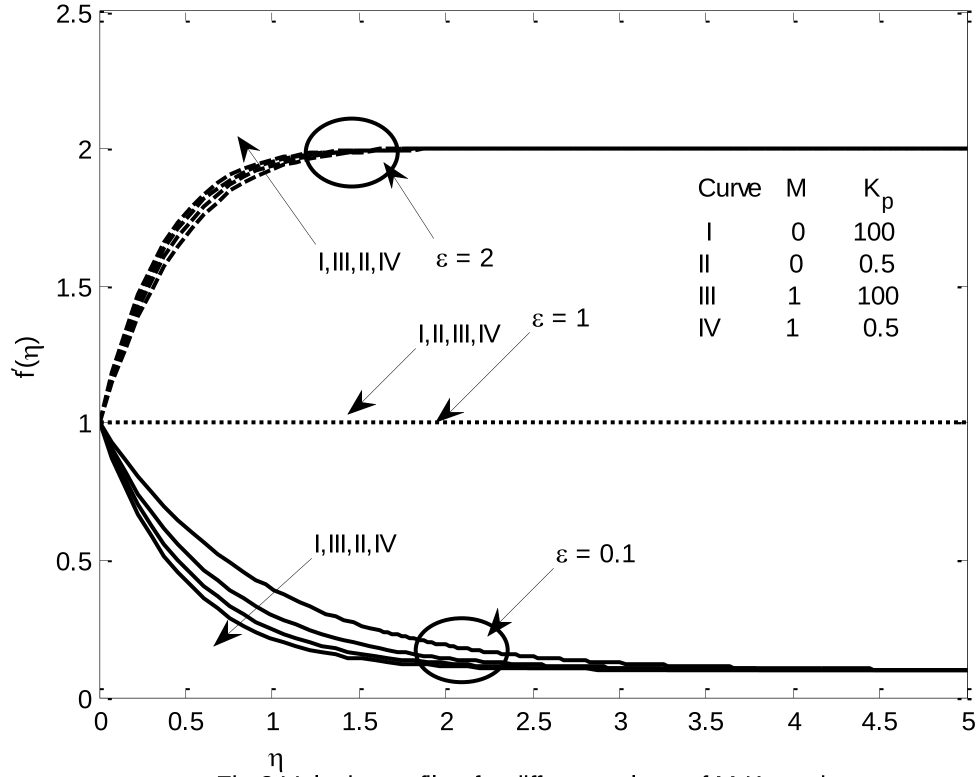

Fig.3 Velocity profiles for different values of M,K_p and ε

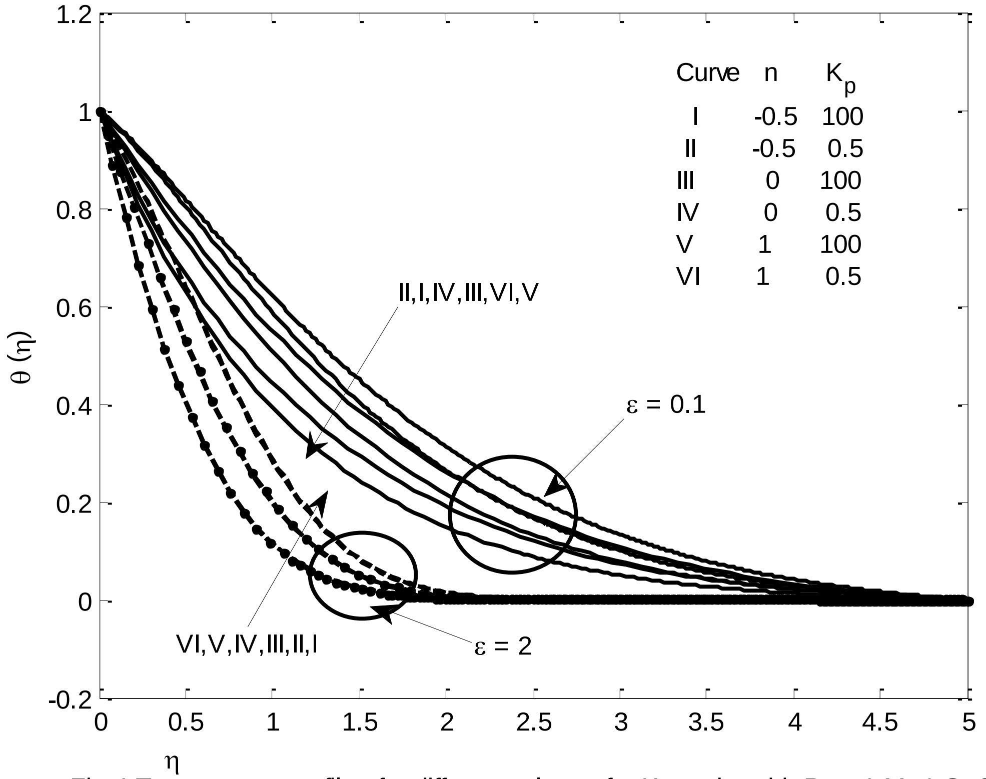

Fig.4 Temperature profiles for different values of n,K_p and ε with P_r = 1,M=1,S=0

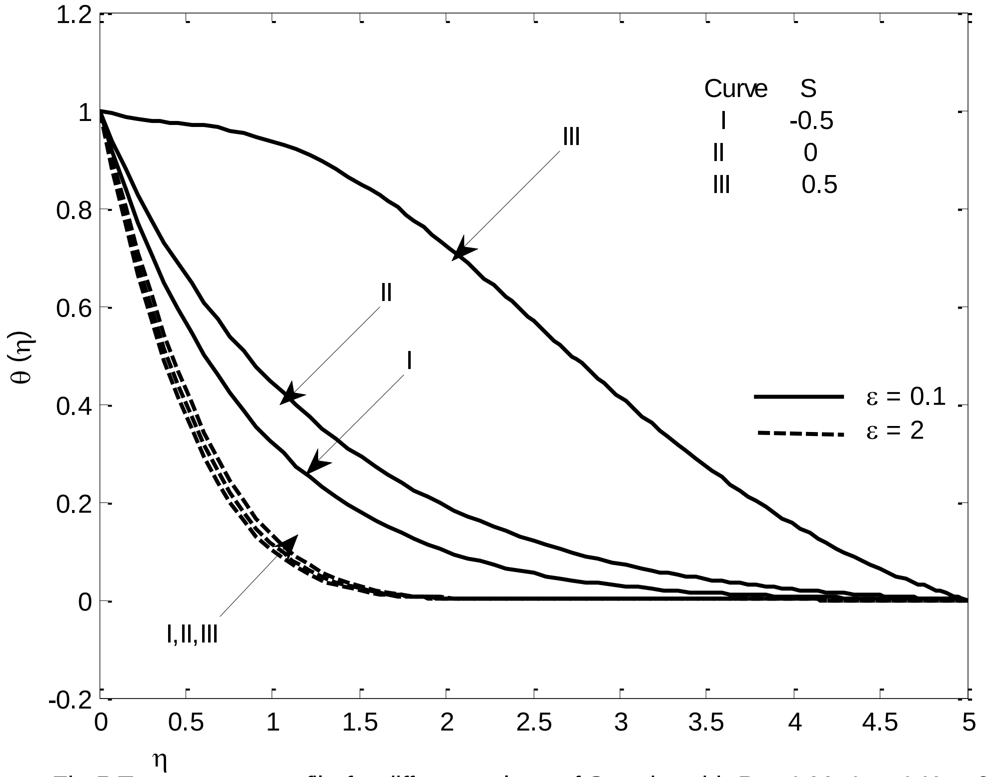

Fig.5 Temperature profile for different values of S and ε with P_r =1,M=1,n=1,K_p =0.5

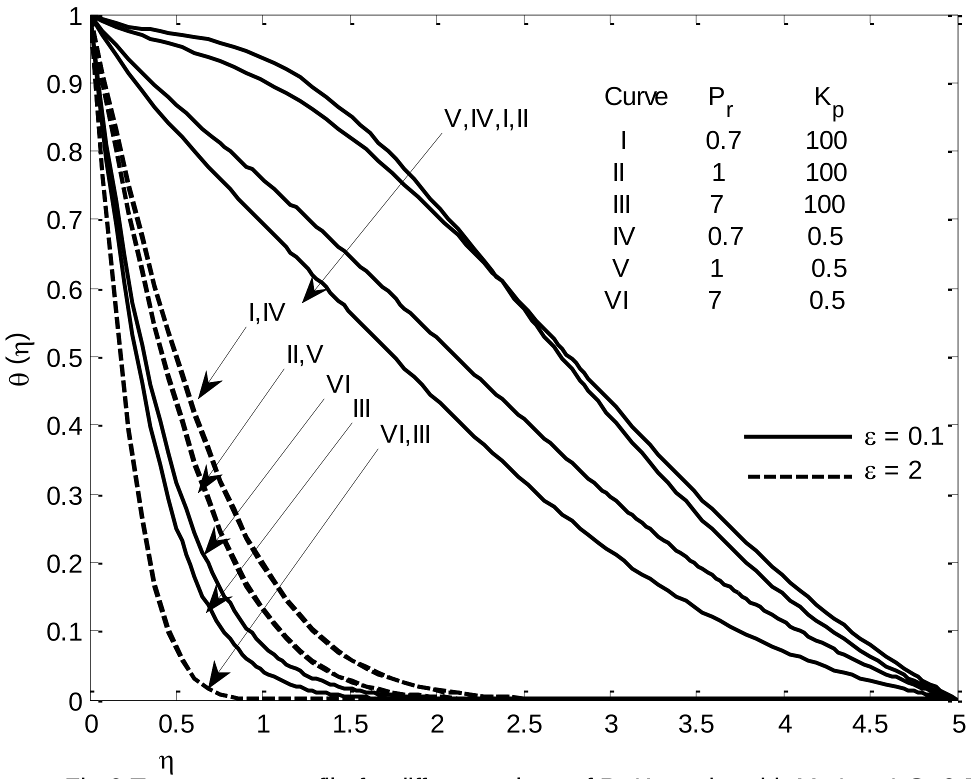

Fig.6 Temperature profile for different values of P_r,K_p and ε with M=1,n=1 S=0.5

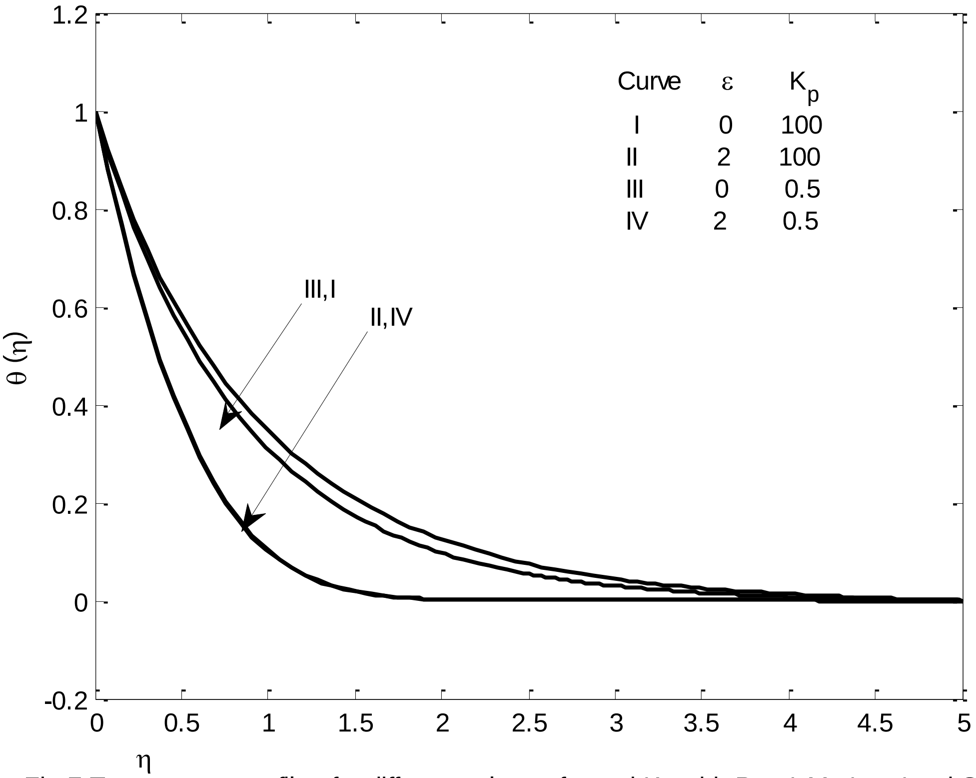

Fig.7 Temperature profiles for different values of ε and K_p with P_r =1,M=1,n=1and S=0.5

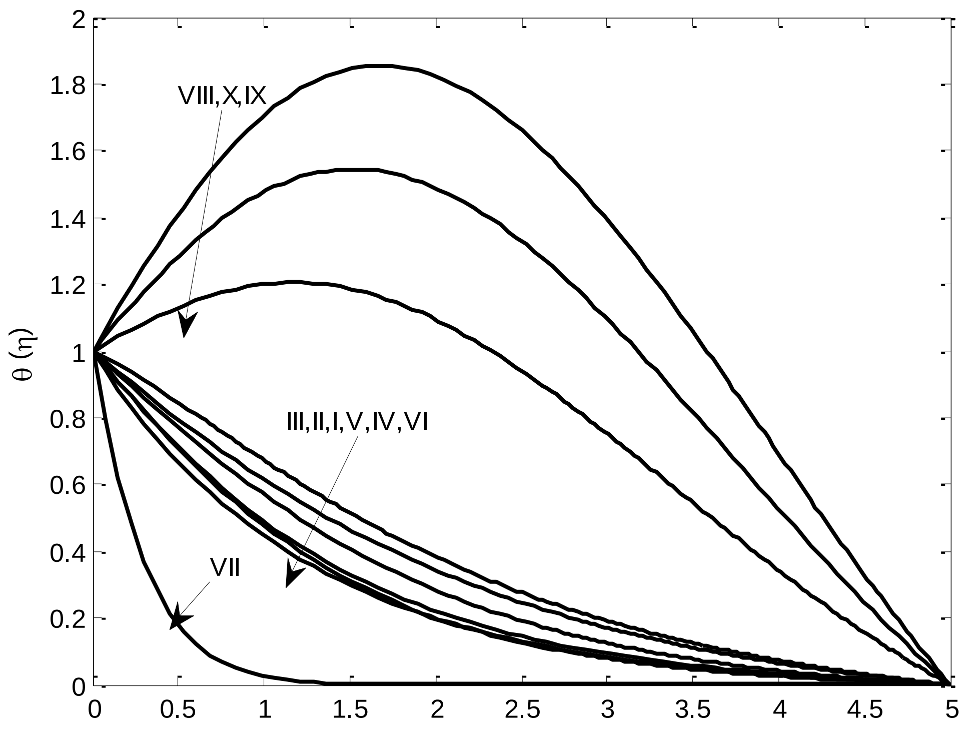

Fig.8 Temperature profiles for different values of M,K_p,n,S,p_r for ε=0

Curve No.	M	K_p	n	p_r	S
I	0	100	0	0.7	0
II	1	100	0	0.7	0
III	1	100	-0.5	0.7	0
IV	1	100	-0.5	0.7	-0.5
V	1	0.5	-0.5	0.7	-0.5
VI	1	0.5	0.5	0.7	-0.5
VII	1	0.5	0.5	7	-0.5
VIII	1	0.5	0.5	0.7	0.5
IX	1	100	0.5	0.7	0.5
X	2	100	0.5	0.7	0.5

The formulation of the problem that account for, MHD stagnation-point flow past a stretching sheet through porous media with heat source/sinkwas accomplished The Equations (7)-(8) are solved numerically using the fourth order Runge-Kutta method implemented on a computer program written in Matlab. A convenient step size was chosen to obtain the desired accuracy. The values for the velocity and temperature profiles and the skin-friction coefficients, Nusselt numbers have been obtained and tabulated for various parametric conditions, as presented in **Table 1**.

The present study considers the steady two-dimensional MHD stagnation point flow towards a stretching sheet through a porous medium with variable surface temperature .The main aim of the following discussion is to bring out the effect of permeability’s of the medium and plate temperature on the flow phenomena.

The heat generation/absorption contribute significance for heat transfer case. Another aspect of the present study is the saturated porous media which is very widely used to insulate a heated body to maintain the temperature. These are considered to be useful in diminishing the natural free convection which would otherwise occur intensely on the vertical surface.

In the present study the solution is not only affected by the parameter i.e. porous matrix but also the velocity ratio $\varepsilon = b/a$ in case of Ishak et al.[24] .Moreover Ishak et al.[24] claimed the unique velocity and temperature profile for $\varepsilon < 1 \, and \, \varepsilon > 1$. The numerical computation is made for both velocity and temperature distribution. The analytical solution that is Kummer's function is used in a particular case taking $\varepsilon = 0$.
The following discussion presents the effects of various parameters exhibiting above phenomena.

Fig.2 presents the velocity distribution exhibiting the effect of the porous matrix and magnetic parameter in a particular case when the velocity ratio $\varepsilon = 0$.It is observed that the presence of magnetic field retards the velocity profile in the absence of porous matrix $\left(K_p = 100\right)$.Since presence of magnetic field produces Lorentz force which usually resists the motion of the field .From (curve I and II) and (III and IV) it is clear that the presence of porous matrix decelerate the profile in the both presence/absence of magnetic field.

Fig.3 exhibits the effect of $\varepsilon, M \, and \, K_p$ on velocity profile. In particular ε is taken to be $\varepsilon = 0.1\left(\varepsilon < 1\right), \varepsilon = 2(\varepsilon > 1), \varepsilon = 1$.The case of Ishak et al.[24] has been shown for verification. It is interesting to observe that, for $\varepsilon > 1$, ε increases implies stretching velocity increases the velocity profile in both the presence/absence of $M \, and \, K_p$ (dash lines). But when $\varepsilon < 1$,the reverse effect is encounted. In particular if $\varepsilon = 1$ i.e. stretching velocity is equal to stretching rate, the velocity becomes linear (dotted line) irrespective of the value for $M \, and \, K_p$.The present result is in good agreement with the result of Ishak et al.[24].

The effect of $n, K_p \, and \, \varepsilon$ on temperature distribution are shown in Fig.4 for both $\varepsilon < 1(\varepsilon = 0.1)$ and $\varepsilon > 1(\varepsilon = 2)$ in the absence of heat source parameter $S = 0$. In particular for different values of $n \, and \, K_p = 100$ are the particular case of Ishak et al.[24].The value of P_r is taken to be 1 ,where as viscosity and conductivity of the fluid enjoy the same property. It is remarked that for $\varepsilon = 0.1(\varepsilon < 1)$ porous matrix enhance the temperature profile in the thermal boundary layer where as increasing value of n from negative to positive (-0.5 to 1) decreases the profile at its all points. This reveals that the presence of porous matrix $K_p = 0.5$ act as an insulator to the surface, preventing energy loss as a result temperature increases. But the reverse effect occurs in case of $\varepsilon = 2(\varepsilon > 1)$. The profile is asymptotic in nature and result is in good agreement with the result of Ishak et al.[24].

Fig.5 illustrate the variation of heat generation/absorption parameter on the temperature profile in the presence of porous matrix and taking $P_r = 1, n = 1, M = 1$ are fixed. For $\varepsilon = 0.1$,heat generation parameter $S > 0(S = 0.5)$ enhance the temperature profile whereas increase in absorption leads to decrease in the temperature at all points. The reverse trend occurs in case of $\varepsilon = 2$ (dotted). Further, it is also clear that the temperature profile is more pronounced with $\varepsilon = 0.1$ as that of $\varepsilon = 2$,i.e. decrease velocity ratio cause an increase in temperature in the boundary layer.

Temperature distribution for different values of P_r in the presence/absence of K_p is displayed in Fig.6. Taking $M = 1, n = 1, S = 0.5$ as fixed for both $\varepsilon < 1(\varepsilon = 0.1) \, and \, \varepsilon > 1(\varepsilon = 2)$. It is seen that, in the absence of $K_p(K_p = 100)$ the high prandtl number fluid causes lower thermal diffusivity and hence reduces the temperature at all points in the thermal boundary layer. P_r Means slow rate of thermal diffusion. Thus it may conclude that thinning of thermal boundary layer thickness in the consequence of fluid with slow rate of thermal diffusion in the presence of magnetic field and porous matrix.

The effect of velocity rate, ε and porous matrix are exhibited in Fig.7 for $P_r = 1, M = 1, n = 1 \, and \, S = 0.5$ .It is clear that an increase in velocity rate in both the presence/absence of porous matrix decreases the profile. Whereas absence of $\varepsilon(\varepsilon = 0)$ porous matrix decelerate the temperature and presence of $\varepsilon(\varepsilon = 2)$ K_p has no significant effect on the boundary layer. In particular $\varepsilon = 0, K_p = 100$ (curve I),the present study is in good agreement with the result of Ishak et al.[24]. The profile is asymptotic in nature to meet the boundary condition.

The flow characteristics of the boundary surface are vital in deforming the flow stability and hence skin friction calculation is important in present study. Table 1 presents the skin friction coefficient and rate of heat transfer at the stretching surface. From table 1 it is clear that skin friction coefficient and Nusselt number both decreases with an increase in magnetic parameter M in the presence/absence of K_p and source parameter S .Where as reverse effect is encountered for the increasing value of n and ε . It is interesting to note that P_r has a dual character. Increase in P_r rate of heat transfer increases.

Thus, in case of stretching sheet prandtl number fluid causes a thermal instability at the surface.

5. Conclusion

Provide From the above discussions we conclude the following:

Presence of magnetic field produces a Lorentz force of electromagnetic origin, which is a resistive force, as a result of which the velocity decreases.The combining effect contributes to significant rise in the velocity boundary layer at all points in its flow domain for both the absence/ presence of porous matrix for particular case i.e. $(\varepsilon > 1)$ but reverse affect is encountered for $(\varepsilon < 1)$ .Thinning of thermal boundary layer thickness in the consequence of fluid with slow rate of thermal diffusion in the presence of magnetic field and porous matrix. In case of stretching sheet prandtl number fluid causes a thermal instability at the surface.Skin friction coefficient and Nusselt number both decreases with an increase in magnetic parameter M in the presence/absence of K_p and source parameter S .Where as reverse effect is encountered for the increasing value of n and ε .

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