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Study of MHD Oblique Stagnation Point Assisting Flow on Vertical Plate with Uniform Surface Heat Flux

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***Abstract*—**The aim of this paper is to study the oblique stagnation point flow on vertical plate with uniform surface heat flux in presence of magnetic field. Using Stream function, partial differential equations corresponding to the momentum and energy equations are converted into non-linear ordinary differential equations. Numerical solutions of these equations are obtained using Runge-Kutta Fehlberg method with the help of shooting technique. In the present work the effects of striking angle, magnetic field parameter, Grashoff number, the Prandtl number on velocity and heat transfer characteristics have been discussed. Effect of above mentioned parameter on the position of stagnation point are also studied.

***Keywords*—**Heat flux, Oblique stagnation point, Mixed convection, Magneto hydrodynamics

I. Introduction

THE stagnation flow of an incompressible viscous fluid over vertical surface is important in various processes. The technical process concerning extrusion of polymer sheets, rolling and manufacturing artificial fibers, involves the stagnation point flow. In stagnation point flow, a rigid wall or a stretching surface occupies the entire horizontal axis. The fluid domain is normal to that axis and the fluid strikes on that surface either orthogonal or at some angle of incidence. This simple model of oblique stagnation point would enable us to understand how a boundary layer begins to develop.

Mixed (combined forced and free) convection in stagnation flows is very important. The buoyancy forces take place when the temperature difference between the two walls and the free stream is becomes high. These forces modify the flow and the thermal fields significantly. In such flows, the local heat transfer rate and local skin friction can be significantly enhanced or diminished in comparison to the pure forced convection case. Depending on the forced flow direction, the buoyancy forces may assist or oppose the forced flow. This results in increase or decrease in heat transfer rate. These results have been discussed by Chamkha [1], Chamkha and Issa [2], Kumari [3], Aydin and Kaya [4], and Prasad et al. [5].Present research field has attracted many researchers in recent years due to its applications. The study of magneto hydrodynamic flow of an electrically conducting fluid caused by the deformation of the walls of a vessel containing a fluid is of considerable interest in modern metallurgical and metal-working processes. Magnetic field enhances the velocity gradient and heat transfer rate at surfaces due to the increase in the Lorentz force. Attia [6] investigated effect of increasing magnetic field on velocity boundary layer thickness. Kumari and Nath [7], [8] investigated the MHD effects on Maxwell fluids for steady and unsteady cases. They found that velocity gradient at the surface and heat transfer increase with magnetic parameter. Singh *et al.* [9], [10] reported effect of magnetic parameter and radiations on stretching sheet for steady and unsteady flow. Ziya et al. [11], [12] investigated Magnetohydrodynamic free convection flow of a viscous fluid through inclined porous plate in the presence of high temperature. All the above mentioned studies confined their discussions by assuming orthogonal flow. However, it is known that the fluid may incident at some angle on the surface. The angle of incidence of fluid leads to a local increase/ decrease in the transport phenomena. Therefore, to predict the flow behavior accurately it is necessary to take into account non-orthogonal flows for incompressible fluids.

Grosan et al. [13] and Singh et al. [14] analyzed the magneto-hydrodynamic oblique stagnation-point flow on a flat plate and stretching sheet, respectively. It was found that the magnetic parameter causes a shift in the position of the stagnation-point. Lok et al. [15], [16] investigated the non-orthogonal stagnation-point for Newtonian and non-Newtonian flows towards a sheet. They found that the position of stagnation point depend on stretching sheet parameter and angle of incidence. Mahapatra et al. [17] and Labropulu et al. [18], [19] analyzed oblique stagnation point flow of incompressible visco-elastic fluid towards a stretching sheet. Tilley and Weidman [20] studied interaction between two planar oblique stagnation–point flow of different immiscible fluid. The study of heat transfer and flow field is necessary for determining the quality of the final product. Amaouche and Boukari [21] studied the influence of thermal convection on non-orthogonal stagnation point flow.

The authors in the present paper studied the steady two-dimensional buoyancy induced mixed convection opposing flow of a viscous incompressible fluid striking at different

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angles of incidence on a vertical semi-infinite flat plate. Fluid flow is considered in presence of magnetic field with uniform surface heat flux.

II. Formulation of Problem

The physical model considered here consist of a viscous, incompressible, steady, two-dimensional mixed convection flow of an electrically conducting fluid striking at some angle of incidence γ on a vertical semi-infinite flat plate. A constant magnetic field B_O is applied in y- direction as shown in Figure 1.

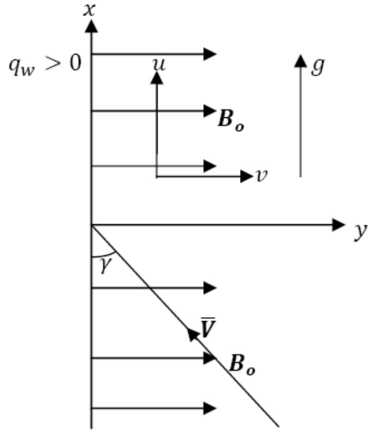

Fig. 1 Physical Model of the Problem

The coordinate system in Figure 1 is such that x represents the vertical distance or the distance along the surface and y represents the horizontal distance or the distance normal to the surface. Far away from the plate, the velocity and the temperature of the uniform main stream are, $\bar{V} = a\sin\gamma(xi - yj) + b\cos\gamma\, yi,$ and T_∞ respectively, where i and j are unit vectors along the x and y axes, a and b are the positive constant with dimension (time)$^{-1}$. The entire surface of the plate is maintained at a constant heat flux q_W. The viscous dissipation, Joule heating and induced magnetic field are neglected. The governing equations of continuity, momentum and energy under above assumptions with Boussinesq approximation are

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\sigma B_O^2 u}{\rho} + g\beta(T - T_\infty) \tag{2}$$

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

and

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

where u and v are velocity components along x and y axes respectively, ν is kinematic viscosity, σ is electrical conductivity, p is the pressure, T is temperature of the plate, ρ is density of the fluid, β is coefficient of thermal expansion, g is acceleration due to buoyancy and α is the thermal diffusivity.

Boundary conditions are:

$$u = v = 0, \quad \frac{\partial T}{\partial y} = -\frac{q_W}{k} \qquad at\;\; y = 0$$

$$u = ax\sin\gamma + by\cos\gamma,\, v = -ay\sin\gamma, \quad T \to T_\infty \quad as\;\; y \to \infty \tag{5}$$

where, k is coefficient of thermal conductivity. This flow model is called favorable flow for $0 \le \gamma \le \pi/2$ and unfavorable flow for $\pi/2 < \gamma \le \pi$. Case $\gamma = \pi/2$, is known as orthogonal flow.

Eliminating pressure terms from (2) and (3), we get the following equations

$$\frac{\partial u}{\partial y}\frac{\partial u}{\partial x} + u\frac{\partial^2 u}{\partial y\partial x} + \frac{\partial v}{\partial y}\frac{\partial u}{\partial y} + v\frac{\partial^2 u}{\partial y^2} = \frac{\partial u}{\partial x}\frac{\partial v}{\partial x} + u\frac{\partial^2 v}{\partial x^2} + \frac{\partial v}{\partial y}\frac{\partial v}{\partial x} + v\frac{\partial^2 v}{\partial x\partial y} + Zg\beta\frac{\partial T}{\partial y} - \frac{\sigma B_0^2}{\rho}\frac{\partial u}{\partial y} + \nu\left(\frac{\partial^3 u}{\partial y\partial x^2} + \frac{\partial^3 u}{\partial y^3} - \frac{\partial^3 v}{\partial x^3} - \frac{\partial^3 v}{\partial x\partial y^2}\right). \tag{6}$$

Let $\bar{\psi}$ is Stream function defined as $u = \partial\bar{\psi}/\partial y$ and $v = -\partial\bar{\psi}/\partial x$. Introducing the dimensionless variables defined as

$$\xi = \frac{x}{l},\;\; \eta = \frac{y}{l},\;\; ,\;\; \theta = \frac{T - T_\infty}{\frac{q_W l}{k}} \text{ and } \psi = \frac{\bar{\psi}}{\nu},$$

where $l = \nu^{1/2}\left((a\sin\gamma)^2 + (b\cos\gamma)^2\right)^{-1/4}$.

Equation of Continuity (1) is also satisfied by $u(\xi,\eta)$ and $v(\xi,\eta)$ defined as above and, (6) and (4) reduces to,

$$\left(\frac{\partial^2}{\partial\xi^2} + \frac{\partial^2}{\partial\eta^2}\right)\left(\frac{\partial^2\psi}{\partial\xi^2} + \frac{\partial^2\psi}{\partial\eta^2}\right) + \frac{\partial\psi}{\partial\xi}\frac{\partial}{\partial\eta}\left(\frac{\partial^2\psi}{\partial\xi^2} + \frac{\partial^2\psi}{\partial\eta^2}\right) - \frac{\partial\psi}{\partial\eta}\frac{\partial}{\partial\xi}\left(\frac{\partial^2\psi}{\partial\xi^2} + \frac{\partial^2\psi}{\partial\eta^2}\right) + Gr\frac{\partial\theta}{\partial\eta} - M\frac{\partial^2\psi}{\partial\eta^2} = 0 \tag{7}$$

$$\frac{\partial\psi}{\partial\eta}\frac{\partial\theta}{\partial\xi} - \frac{\partial\psi}{\partial\xi}\frac{\partial\theta}{\partial\eta} = \frac{1}{\Pr}\left(\frac{\partial^2\theta}{\partial\xi^2} + \frac{\partial^2\theta}{\partial\eta^2}\right) \tag{8}$$

respectively. Where $Pr = \nu / \alpha$ is the Prandtl number, $Gr = g\,\beta q_W\, l^4 / k\nu^2$ is Grashoff number based on the heat flux $q_W > 0$ and $M = \sigma B_o^2 l^2 / \rho\nu$ is magnetic field parameter. We seek solution of (7) in the form of $\psi = \xi\, f(\eta) + g(\eta)$, where the function $f(\eta)$ and $g(\eta)$ are referring to the normal and tangential component of the flow. Therefore, velocity components are given by,
$u(\xi,\eta) = \xi\, f'(\eta) + g'(\eta)$ and $v(\xi,\eta) = -f(\eta)$.
From (7) and (8), we have

$$f'''(\eta) + f(\eta)f''(\eta) - f'(\eta)^2 - Mf'(\eta) + \sin^2\gamma = 0 \qquad (9)$$

$$g'''(\eta) + f(\eta)g''(\eta) - f'(\eta)g'(\eta) - M[g'(\eta) - \eta\cos\gamma] - Gr\,\theta'(\eta) = 0 \qquad (10)$$

$$\theta''(\eta) + \Pr F(\eta)\theta'(\eta) = 0 \qquad (11)$$

and boundary conditions becomes,

$$f(0) = 0,\ f'(0) = 0,\ g(0) = 0,\ g'(0) = 0,\ \theta'(0) = -1 \ \ at\ \eta = 0$$
$$f'(\infty) \to \sin\gamma,\ g''(\infty) \to \cos\gamma,\ \theta(\infty) \to 0\ as\ \eta \to \infty. \qquad (12)$$

A physical quantity of interest is the skin friction, or shear stress τ_W at the wall, which is defined as

$$\tau_W = \mu\left(\frac{\partial u}{\partial x} + \frac{\partial u}{\partial y}\right)\Bigg|_{y=0}, \text{ or}$$

$$\tau_W = \mu(\xi\ f''(0) + g''(0)) \qquad (13)$$

The dividing streamlines $\psi = 0$ and the curve $u = 0$ intersect the wall at the stagnation point where $\tau_W = 0$, hence the location of stagnation point ξ_S is given by,

$$\xi_S = -\frac{g''(0)}{f''(0)} \qquad (14)$$

III. Numerical Simulation

The set of non-linear coupled differential equations (9), (10) and (11) subject to the boundary conditions (12), constitute a two-point boundary value problem. In order to solve these equations numerically, we follow numerical shooting technique with Runge–Kutta–Fehlberg integration scheme. In this method it is most important to choose the appropriate finite values of $\eta \to \infty$. The solution process is repeated with another large value of η_∞ until two successive values of $f''(0)$, $g''(0)$, and $\theta(0)$ differ only after a desired digit signifying the limit of the boundary along η. The last value of η_∞ is chosen as appropriate value of the limit $\eta \to \infty$ for that particular set of parameters. The three ordinary differential equation (9), (10) and (11) were first converted into a set of eight first-order simultaneous equations. To solve this system we require eight initial conditions but we have only five initial conditions $f(0)$ and $f'(0)$ on $f(\eta)$, $g(0)$ and $g'(0)$ on $g(\eta)$, and one initial condition $\theta'(0)$ on $\theta(\eta)$. Still there are three initial conditions $f''(0)$, $g''(0)$ and $\theta(0)$ are not prescribed. However the values of $f'(\eta)$, $g''(\eta)$ and $\theta(\eta)$ are known at $\eta \to \infty$. Now we employ the numerical shooting technique where these three ending boundary conditions were used to produce three unknown initial conditions at $\eta = 0$. Finally, the problem has been solved numerically using Runge-Kutta Fehlberg integration scheme.

IV. Results and Discussions

In the absence of an analytical solution of a problem, numerical solution is indeed an obvious and natural choice. Thus, the governing boundary layer and thermal boundary layer equations (9), (10) and (11) with boundary conditions (12), are solved using Runge-Kutta Fehlberg method with shooting technique. Different values of M, Pr, γ and Gr taking step size 0.001 used for numerical simulation. While numerical simulation, step size 0.002 and 0.003 were also checked and values of $f''(0)$, $g''(0)$ and $\theta(0)$ were found in each case correct up to six decimal places. Hence the scheme used in this paper is stable and consistent. It is worth mentioning that small values of $\Pr\,(<<1)$ physically corresponds to liquid metals, while $\Pr \approx 1$ corresponding to diatomic gases including air. On the other hand, $\Pr >> 1$ corresponds to high viscosity oils and $\Pr \approx 7$ corresponds to water at room temperature. Due to decoupled boundary layer equation (9), it is found that there is only a unique value of reduced skin friction for orthogonal flow, $f''(0) = 1.232547$ which is very good agreement with the value $f''(0) = 1.232588$ found by Hiemenz as described by [15].

TABLE I
VALUES OF $f''(0)$ FOR DIFFERENT VALUES OF ANGLE OF INCIDENCE γ AND MAGNETIC FIELD PARAMETER M.

γ	Value of $f''(0)$			
	$M = 0$	$M = 2$	$M = 3$	$M = 5$
$\gamma = \pi/2$	1.232547	0.673195	0.563531	0.442988
$\gamma = \pi/3$	0.993354	0.510987	0.425230	0.333031
$\gamma = \pi/4$	0.732891	0.345180	0.285313	0.222559
$\gamma = \pi/5$	0.555448	0.240682	0.197979	0.154020

Effect of striking angle γ on flow has been shown in Figure 2 and Table I. It is found that boundary layer thickness increase as striking angles increases for favorable flow whereas thermal boundary layer thickness decrease as striking angle γ increases as shown in Figure 3. Values of boundary layer separation part ξ_S for assisting flow are given in Table V and VI for $\Pr = 0.71$ and $Gr = 0,\ 2$. Table V has been calculated with the help of Table[I-III] and (14). It has been observed from Table V that stagnation point shifts towards origin as striking angle increased from $\pi/5$ to $\pi/3$ for any value of Gr. Stagnation point move away from origin as magnetic parameter increased. Grashoff number Gr gives the effect of buoyancy. Thus, it is the dominant parameter in free convection. Effect of Gr can be seen from Table V and Table

VI that, in presence of buoyancy parameter ($Gr = 2$) shifting of stagnation point is more pronounced than absence of buoyancy parameter ($Gr = 0$) .

TABLE II
VALUES OF $g''(0)$ FOR DIFFERENT VALUES OF ANGLE OF INCIDENCE γ AND MAGNETIC FIELD PARAMETER M WHEN $Gr = 0$ AND $\Pr = 0.71$.

γ	Value of $g''(0)$ when $Gr = 0$ *and* $\Pr = 0.71$.			
	$M = 0$	$M = 2$	$M = 3$	$M = 5$
$\gamma = \pi/2$	0000000	0000000	0000000	0000000
$\gamma = \pi/3$	0.303986	0.476635	0.489487	0.496290
$\gamma = \pi/4$	0.430050	0.683305	0.696812	0.703562
$\gamma = \pi/5$	0.492542	0.788989	0.800624	0.806185

TABLE III
VALUES OF $g''(0)$ FOR DIFFERENT VALUES OF ANGLE OF INCIDENCE γ AND MAGNETIC FIELD PARAMETER M WHEN $Gr = 2$ AND $\Pr = 0.71$.

γ	Value of $g''(0)$ when $Gr = 2$ *and* $\Pr = 0.71$.			
	$M = 0$	$M = 2$	$M = 3$	$M = 5$
$\gamma = \pi/2$	2.461249	2.788737	2.782362	2.668363
$\gamma = \pi/3$	3.145002	3.650082	3.605141	3.409448
$\gamma = \pi/4$	3.905048	4.408292	4.257602	3.916950
$\gamma = \pi/5$	4.661233	4.990125	4.717270	4.240459

TABLE IV
VALUES OF $\theta(0)$ FOR DIFFERENT VALUES OF ANGLE OF INCIDENCE γ AND MAGNETIC FIELD PARAMETER M WHEN $Gr = 0$ AND $\Pr = 0.71$.

γ	Value of $\theta(0)$ when $Gr = 0$ *and* $\Pr = 0.71$.		
	$M = 0$	$M = 2$	$M = 5$
$\gamma = \pi/2$	2.005102	2.734561	3.453440
$\gamma = \pi/3$	2.153887	3.005146	3.723532
$\gamma = \pi/4$	2.380482	3.389551	4.054505
$\gamma = \pi/5$	2.603000	3.718932	4.297356

TABLE V
VALUE OF STAGNATION POINT ξ_S FOR DIFFERENT MAGNETIC FIELD PARAMETER M AND ANGLE OF INCIDENCE γ WHEN $Gr = 0$, $\Pr = 0.71$.

γ	Value of ξ_S when $Gr = 0$, $\Pr = 0.71$			
	$M = 0$	$M = 2$	$M = 3$	$M = 5$
$\gamma = \pi/3$	-0.3060	-0.9328	-1.1511	-1.4902
$\gamma = \pi/4$	-0.5868	-1.9796	-2.4422	-3.1612
$\gamma = \pi/5$	-0.8867	-3.2781	-4.0439	-5.2343

TABLE VI
VALUE OF STAGNATION POINT ξ_S FOR DIFFERENT MAGNETIC FIELD PARAMETER M AND ANGLE OF INCIDENCE γ WHEN $Gr = 2$, $\Pr = 0.71$.

γ	Value of ξ_S when $Gr = 2$, $\Pr = 0.71$			
	$M = 0$	$M = 2$	$M = 3$	$M = 5$
$\gamma = \pi/2$	-1.9968	-4.1425	-4.9373	-6.0235
$\gamma = \pi/3$	-3.1660	-7.1431	-8.4780	-10.2376
$\gamma = \pi/4$	-5.3283	-12.7709	-14.9225	-17.5996
$\gamma = \pi/5$	-8.3918	-20.7332	-23.8271	-27.5318

The magnetic parameter M represents the importance of magnetic field on the flow. The presence of transverse magnetic field sets in Lorentz force, which results in retarding force on the velocity field and therefore as magnetic parameter increases, so does the retarding force and hence the velocity decrease. This is shown in Figure 4. Same effect is on temperature that can be seen from Figure 5. Value of

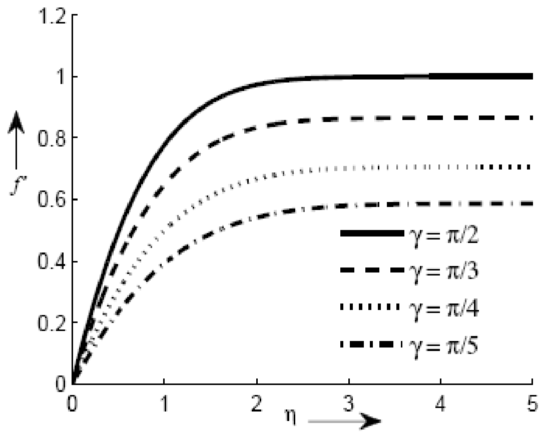

Fig. 2 Velocity profile $f'(\eta)$ versus η for different values γ when $M = 0$.

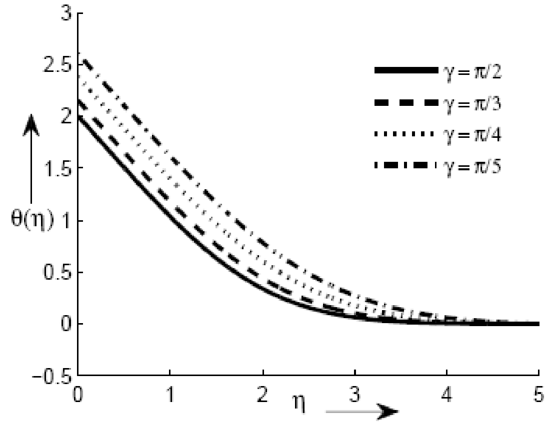

Fig. 3 Temperature profile $\theta(\eta)$ versus η for different values γ when $\Pr = 0.71$ and $Gr = 0$.

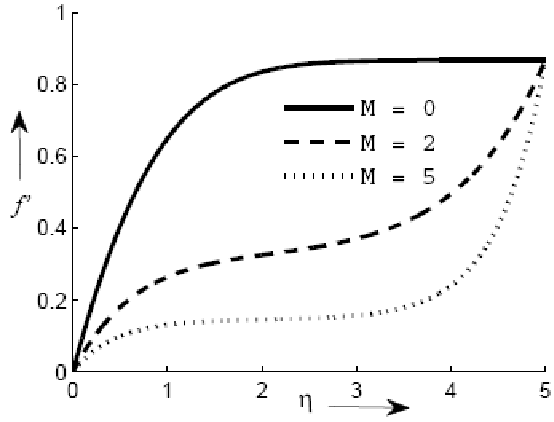

Fig. 4 Velocity profile $f'(\eta)$ versus η for different values M when $\gamma = \pi/3$.

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$f''(0)$ for favorable flow is decreases as magnetic parameter increase as shown in Table I. It is observed from Table IV that $\theta(0)$ increases with increase in magnetic parameter.

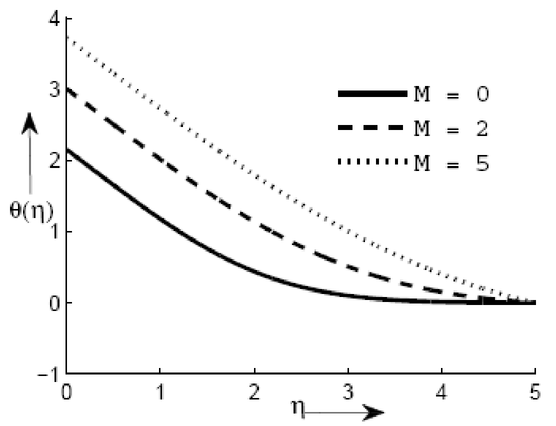

Fig. 5 Temperature profile $\theta(\eta)$ versus η for different values M when $\Pr = 0.71, Gr = 0$ and $\gamma = \pi/3$.

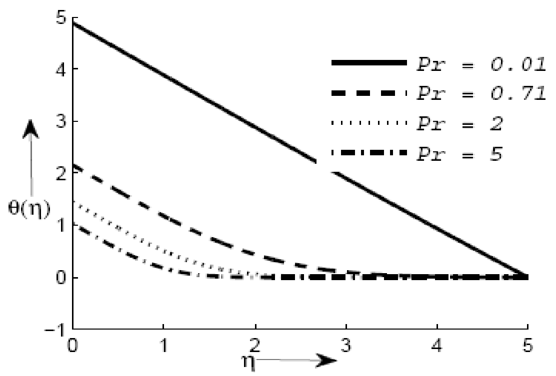

Fig. 6 Temperature profile $\theta(\eta)$ versus η for different values $\Pr$ when $Gr = 0$ and $\gamma = \pi/3$.

TABLE VII
VALUES OF $\theta(0)$ FOR DIFFERENT VALUES OF PRANDTAL NUMBER $\Pr$, GRASHOF NUMBER Gr AND MAGNETIC FIELD PARAMETER M WHEN $\gamma = \pi/3$.

Pr	Value of $\theta(0)$ when $\gamma = \pi/3$.			
	$Gr = 0$		$Gr = 2$	
	$M = 0$	$M = 2$	$M = 0$	$M = 2$
Pr = 0.01	4.881763	4.949856	4.881762	4.949856
Pr = 0.71	2.153887	3.005146	2.153886	3.005152
Pr = 2	1.444979	2.015458	1.444988	2.015452
Pr = 5	1.030096	1.404208	1.029961	1.404171

It is observed from Figures (6) that the temperature profile decreases with an increase in the Prandtl number $\Pr$ for striking angle $\gamma = \pi/3$. This is in agreement with the physical fact that at higher Prandtl number, fluid has a thinner thermal boundary layer and this increases the gradient of temperature. Value of $\theta(0)$ decreases as Prandtl number increase as shown in Table VII.

V. CONCLUSION

The two dimensional oblique stagnation point flow on vertical plate with uniform surface heat flux in presence of magnetic field is studied. A numerical solution for the governing equations is obtained which allows the computation of the flow and heat transfer characteristics for various values of the magnetic parameter, striking angle, Grashoff number and the Prandtl number. The main results of the paper can be summarized as follows:

1) The velocity boundary layer thickness decreases as striking angle decreases.
2) Stagnation point shifts towards origin as striking angle increases.
3) Thermal boundary layer thickness increases as striking angle decreases.
4) Velocity and temperature decrease as magnetic field increases.
5) Temperature decreases with increase in the Prandtl number.
6) In absence of bounacy forces stagnation point moves to left of origin, while in presence it moves right of origin as striking angle decreases.
7) Stagnation point move away from origin as magnetic parameter increases.

These results have potential technological applications in liquid-based systems.

REFERENCES

[1] Chamkha A.J., "Hydromagnetic mixed convection stagnation flow with suction and blowing," *International Communications in Heat and Mass Transfer*, vol. 25, pp 417-426, 1998.
[2] Chamkha A.J. and C. Issa, "Mixed convection effects on unsteady flow and heat transfer over a stretched surface," *International Communications in Heat and Mass Transfer*, vol. 26, pp 717-727, 1999.
[3] Kumari M., "Variable viscosity effects on free and Mixed convection boundary-layer flow from a horizontal surface in a saturated porous medium-variable heat flux," *Mechanics Research Communications*, vol. 28, pp 339-348, 2001.
[4] Aydin O. and A. Kaya, "Mixed convection of a viscous dissipating fluid about a vertical flat plate," *Applied Mathematical Modelling*, vol. 31, pp 843-853, 2007.
[5] Prasad K.V., K. Vajravelu and P.S. Datti, "Mixed convection heat transfer over a non-linear stretching surface with variable fluid properties," *International Journal of non-linear Mechanics*, vol. 45, pp 320-330, 2010.
[6] Attia H. A., "Hydromagnetic stagnation point flow with heat transfer over a permeable surface," *The Arabian Journal for Science and Engineering*, vol. 28, 107-112, 2003.
[7] Kumari M. and G. Nath, "Unsteady MHD mixed convection flow over an impulsively stretched permeable vertical surface in a quiescent fluid." *International Journal of non-linear Mechanic*, vol. 45, pp 310-319, 2010
[8] Kumari M. and G. Nath, "Steady mixed convection stagnation-point flow of upper convected Maxwell fluids with magnetic field," *International Journal of non-linear Mechanic*, vol. 44, pp 1048-1055, 2009.
[9] Singh P., N.S. Tomer, and D. Sinha, "Numerical study of heat transfer over stretching surface in porous media with transverse magnetic field," *Proceeding of International Conference on Challenges and application of Mathematics in Sciences and Technology,* ISBN 023- 032-875-X, 2010, 422-430.

[10] Singh P., A. Jangid, N.S. Tomer and D. Sinha, "Effects of Thermal Radiation and Magnetic Field on Unsteady Stretching Permeable Sheet in Presence of Free Stream Velocity ," *International Journal of Engineering and Mathematical Sciences*, vol. 6, no.3, pp 163-169, 2010
[11] Ziya U., M. Kumar and V. Bisht, "Radiation heat transfer effect on a moving semi-infinite tilted porous heated plate with uniform suction in the presence of transverse magnetic field," *Ganita*, vol. 60, no. 1, pp 69-79, 2009.
[12] Ziya U. and M. Kumar, "Transient MHD free convection flow of an incompressible viscous dissipative fluid through inclined porous plate." *International J Essential Sciences*, vol. 2, no. 2, 18-27, 2008.
[13] Grosan T., I. Pop, C. Revnic, and D.B. Ingham, "Magnetohydrodynamic oblique stagnation-point flow," *Meccanica*, vol. 44, pp 565–572, 2009.
[14] Singh P., N.S. Tomer, S. Kumar and D. Sinha, "MHD oblique stagnation-point flow towards a stretching sheet with heat transfer," *International Journal of Applied Mathematics and Mechanics,* vol. 6, no.13, pp 94-111, 2010.
[15] Lok Y.Y., N. Amin, and I. Pop, "Mixed convection near a non-orthogonal stagnation point flow on a vertical plate with uniform surface heat flux," *Acta Mechanica*, vol. 186, pp 99–112, 2006.
[16] Lok Y.Y., N. Amin, and I. Pop, "Mixed convection flow near a non-orthogonal stagnation point towards a stretching vertical plate," *International Journal of Heat and Mass Transfer*, vol. 50, pp 4855-4863, 2007.
[17] Mahapatra T.R., S.K. Nandy, and A.S. Gupta, "Magneto-hydrodynamic stagnation-point flow of a power-law fluid towards a stretching surface," *International Journal of Non-Linear Mechanics*, vol. 44, pp 124-129, 2009.
[18] Labropulu F., D. Li, and I. Pop, "Non-orthogonal stagnation-point flow towards a stretching surface in a non-Newtonian fluid with heat transfer," *International Journal Thermal Sciences*, vol. 49, pp 1042-1050, 2010.
[19] Li D., F. Labropulu, and I. Pop, "Oblique stagnation-point flow of a viscoelastic fluid with heat transfer," *International Journal of Non-Linear Mechanics*, vol. 44, pp 1024 – 1030, 2009.
[20] Tilley B.S. and P.D. Weidman, "Oblique two-fluid stagnation-point flow," *European Journal of Mechanics*, vol. 17, pp 205-217, 1998.
[21] Amaouche M. and D. Boukari, "Influence of thermal convection on non-orthogonal stagnation point flow." *International Journal of Thermal Sciences*, vol. 42, pp.303-310, 2003.