MHD EFFECT ON BOUNDARY LAYER FLOW OF AN UNSTEADY INCOMPRESSIBLE MICROPOLAR FLUID OVER A STRETCHING SURFACE

D. Chenna Kesavaiah[1], G. Bhaskar Reddy[2], Anindhya Kiran[3], Dr. Nookala Venu[4]

[1, 3]Department of Basic Sciences & Humanities, Vignan Institute of Technology and Science, Deshmukhi (V), Pochampally (M), Yadadri-Bhuvanagiri (Dist), T.S-508284, India
Email: chennakesavaiah@gmail.com

[2]Department of Science & Humanities, A M Reddy Memorial College of Engineering and Technology, Petlurivaripalem (V), Narasaraopet (M), A.P.-522601, India
Email: drgbhaskarreddy@gmail.com

[4]Department of Electronics and Communication Engineering, Balaji Institute of Technology and Science (Autonomous), Narsampet, Warangal, TS -506331, India
Email: venunookala@gmail.com

ABSTRACT

The present investigation is the effect of magnetohydrodynamic on unsteady boundary layer flow of an incompressible micropolar fluid over a stretching surface when the sheet is stretched in its own plane with time dependent is studied. The governing partial differential equations are solved by Adams predictor-corrector method. The results for various parameters involving in governing equations are discussed by graphically.

Key words: Unsteady Flow, MHD, Micropolar Fluid, Stretching Sheet

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INTRODUCTION

The fluid dynamics over a stretching surface is important in extrusion process. The production of sheeting material arises in a number of industrial manufacturing process and includes both metal and polymer sheets. Examples are numerous and they include the cooling of an infinite metallic plate in a cooling bath, the boundary layer along material handling conveyers, the aerodynamic extrusion of plastic sheets, the boundary layer along a liquid film in condensation process, paper production, glass blowing, metal spinning, and drawing plastic films, to name just a few. The quality of the final product depends on the rate of heat transfer at the stretching surface. As many as we observed some of the authors demonstrated by (Ariman et. al, 1973) has been considered Microcontinum fluid mechanics- a review,(Anjalidevi and Ganga, 2010) expressed their ideas on dissipation effects on MHD nonlinear flow and heat transfer past a porous medium with prescribed heat flux, (Crane, 1970) motivated study on flow past a stretching plane, (Eringen, 1964) illustrated on simple micropolar fluids, (Eringen, 1966). Theory of micropolar fluids, (Gorla, 1983) observed on micropolar boundary layer flow at stagnation point on a moving wall, (Guram and Smith, 1980), expressed their views on stagnation flows of micropolar fluids with strong and weak interaction, (Ishak et. al, 2008) intended their plane on heat transfer over a stretching surface with variable surface heat flux in micropolar fluids, (Magyari and Keller, 1999) abstracted on heat and mass transfer in the boundary layers on an exponentially stretching continuous surface, (Magyari and Keller, 2000) worked on exact solutions for self – similar boundary – layer flows induced by permeable stretching surfaces.

On the other hand, it is well known that the theory of micropolar fluids has generated a lot of interest and many flow problems have been studied. The theory takes into account the microscopic effects arising from the local structure and micro-motions of the fluid elements and provides the basis for a mathematical model for non-Newtonian fluids which can be used to analysis the behavior of exotic lubricants, polymers, liquid crystals, animal bloods and colloidal or suspension solutions, etc. Since introduced by Eringen many researchers have considered various problems in micropolar fluids. Consideration of the above application many authors were expressed their ideas; we considered some of authors of them. (Nazar et. al, 2004) expressed on stretching point flow of a micropolar fluid towards a stretching sheet, (Noor, 1992) illustrated on heat transfer from a stretching sheet, (Rajeshwari and Nath, 1992) motivated study on unsteady flow over a stretching surface in a rotating fluid, (Roslinda Nazr et. al, 2008) expressed on unsteady boundary layer flow over a stretching sheet in a micropolar fluid, (Sharma and Singh, 2009) motivated study on the effect of variable thermal conductivity and heat source/ sink on MHD flow near a stagnation point on linearly stretching sheet, (Sriramulu et. al. 2001) explained in detailed information on steady flow and heat transfer of a viscous incompressible fluid flow through porous medium over a stretching sheet, (shak, et. al, 2008) deliberated on magnetohydrodynamic (MHD) flow and heat transfer due to a stretching cylinder, a thoughtful study on three dimensional MHD flow of Casson fluid in porous medium with generation by (Shehzad et. al, 2016). (Khalid et. al, 2018) measured the influence of wall couple stress in MHD flow of a micropolar fluid in a porous medium with energy and concentration transfer, (Fatunmbu and Adeniyan, 2018) observed MHD stagnation point flow of micropolar fluids past a permeable stretching plate in porous media with thermal radiation chemical reaction and viscous dissipation, (Makinde et. al, 2016) studied on analysis of MHS nanofluid flow over a convectively heated permeable vertical plate embedded in a porous medium, (Makinde et. al, 2017) analyzed the effect of nonlinear thermal radiation on MHD boundary layer flow and melting heat transfer of micropolar fluid over a stretching surface with fluid particles suspension, (Rundora nd Makinde, 2016) presented the analysis of unsteady MHD reactive flow of non-Newtonian fluid through a porous saturated medium with asymmetric boundary conditions, (Chenna Kesavaiah et. al, 2021) expressed the radiative MHD Walter’s Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source,

The electrically conducting fluid and magnetic properties are sufficiently studied in magnetohydrodynamics has specific applications in engineering science, metallurgical industry electromagnetic pump, power generation and meter. Hydromagnetic movements have a major part of study in the fields of the aerospace, astronomical and planetary magnetosphere. The cleansing of liquid metals form non-metallic presence through the use of the attractive field is another basic components of magnetohydrodynamics. In view of the above applications some researcher are studied (Rami Reddy et. al, 2021) measured the hall effect on MHD flow of a viscoelastic fluid through porous medium over an infinite vertical porous plate with heat source, (Chenna Kesavaiah and Venkateswarlu, 2020) expressed the chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, (Mallikarjuna Reddy et. al, 2019) explained on radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, (Srinathuni Lavanya and Chenna Kesavaiah, 2017) observed on heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, Mallikarjuna Reddy et. al, 2018) has been considered the effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, (Chenna Kesavaiah and Sudhakaraiah, 2014) has been studied the effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, (Rajaiah et. al, 2015) illustrated the chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium, (Chenna Kesavaiah et. al, 2013) observed the natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (Chenna Kesavaiah and Satyanarayana, 2013) motivated study on MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, (Chenna Kesavaiah et. al, 2013) abstracted on radiation and Thermo - Diffusion effects on mixed convective heat and mass transfer flow of a viscous dissipated fluid over a vertical surface in the presence of chemical reaction with heat source, (Karunakar Reddy et. al, 2013) measured on MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, (Ch Kesavaiah et. al, 2013) studied in detailed on effects of radiation and free convection currents on unsteady Couette flow between two vertical parallel plates with constant heat flux and heat source through porous medium,

In view of the above investigation is the effect of magnetohydrodynamic on unsteady boundary layer flow of a compressible micropolar fluid over a stretching surface when the sheet is stretched in its own plane with time dependent is studied. The governing partial differential equations are solved by Adams predictor-corrector method.

MATHEMATICAL ANALYSIS

We considered the flow of an incompressible micropolar fluid in the region $y>0$ driven by a plane surface located at $y=0$ with a fixed end at $x=0$. It is assumed that the surface is stretched in the $x-$direction such that the $x-$component of the velocity varies linearly along it, i.e. $u_w(x)=cx$, where c is an arbitrary constant and $c>0$. The clarified two - dimensional equations governing the flow are the equations of the continuity, momentum equations undergoing the influence of externally exploit transverse magnetic field in the boundary layer steady laminar and incompressible micropolar fluids are:

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

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\left(\frac{\mu+k}{\rho}\right)\frac{\partial^2 u}{\partial y^2}+\frac{k}{\rho}\frac{\partial \omega}{\partial y}-\frac{\sigma B^2{}_0}{\rho}u \qquad (2)$$

$$\rho j\left(\frac{\partial\omega}{\partial t}+u\frac{\partial\omega}{\partial x}+v\frac{\partial\omega}{\partial y}\right)=\gamma\frac{\partial^2\omega}{\partial y^2}-k\left(2\omega+\frac{\partial u}{\partial y}\right) \quad (3)$$

Initial and boundary conditions

$t\le 0: u=v=\omega=0$, for any x, y

$$\left.\begin{array}{l} v=0,\ u=u_w(x)=cx \\ \omega=-n\dfrac{\partial u}{\partial y}\end{array}\right\} \text{ at } y=0 \quad (4)$$

$$u\to 0,\omega\to 0 \quad \text{as} \quad y\to\infty;\ t>0$$

where u and v are the velocity components along the $x-$and $y-$axes, respectively, t is time, ω is the microrotation or angular velocity whose direction of rotation is in the $xy-$ plane, μ is dynamic viscosity, ρ is density, j is microinertia per unit mass, γ is spin gradient viscosity and k is vortex viscosity. Further, n is a constant and $0\le n\le 1$. The case $n=0$, which indicates N=0 at the wall represents concentrated particle flows in which the microelements close to the wall surface are unable to rotate. This case is also known as the strong concentration of microelements. The case $n=\frac{1}{2}$ indicates the vanishing of anti – symmetric part of the stress tensor and denotes weak concentration of microelements. The case $n=1$ is used for the modeling of turbulent boundary layer flows. We shall consider here both cases of $n=0$ and $n=\frac{1}{2}$.

Where u, v are velocity components, x, y are Cartesian co-ordinates μ is dynamic viscosity, ρ is density of the fluid, γ is Spin gradient, k is vortex viscocity, n is constant, j is micro-inertia, N is micro rotation, K is matériel parameter, B_0 is applied magnetic field, M is magnetic field parameter , σ electrical conductivity

Introducing the new variables as

$$\left.\begin{array}{l}\psi=(cv)^{1/2}\xi^{1/2}xf(\xi,\eta), \\ \omega=(c/v)^{1/2}\xi^{-1/2}cxg(\xi,\eta) \\ \eta=\left(c/v^{1/2}\right)^{1/2}\xi^{-1/2}y, \quad \xi=1-e^{-\tau},\tau=ct\end{array}\right\}(5)$$

where ψ is the stream function defined in the usual way as

$u=\frac{\partial\psi}{\partial y}$ and $v=-\frac{\partial\psi}{\partial x}$, and identically satisfy equation (1).

Substituting equation (5) in to equations (2) and (3) gives

$$(1+K)f'''+(1-\xi)\frac{\eta}{2}f''+\xi\left(ff''-f'^2-Mf'\right)+Kg'=\xi(1-\xi)\frac{\partial f'}{\partial\xi} \quad (6)$$

$$\left(1+\frac{K}{2}\right)g''+(1-\xi)\left(\frac{1}{2}g+\frac{\eta}{2}g'\right)+\xi\left(fg'-f'g\right)-K\xi\left(2g+f''\right)=\xi(1-\xi)\frac{\partial g}{\partial\xi} \quad (7)$$

where $K=\frac{k}{\mu}$ is the material parameter,

assume that $\gamma=\left(\mu+\frac{k}{2}\right)j=\mu\left(1+\frac{K}{2}\right)j$

and $j=\frac{v}{c}$, respectively.

The boundary conditions equation (4) becomes

$$\begin{array}{ll} f(\xi,0)=0,\ f'(\xi,0)=1, & \\ g(\xi,0)=-nf''(\xi,0) & (8) \\ f'(\xi,\infty)=0, \qquad g(\xi,\infty)=0 & \end{array}$$

The physical quantity of interest in this problem is the skin friction coefficient C_f, which is defined as

$$C_f=\frac{\tau_w}{\rho u_w^2/2}, \quad (9)$$

Where τ_w is the skin friction, given by

$$\tau_w = \left[(\mu + k)\frac{\partial u}{\partial y} + k\omega \right]_{y=0} \qquad (10)$$

Using variables equation (5) in equations (9) and (10), we obtain

$$C_f \operatorname{Re}_x^{1/2} = \xi^{-1/2}\left[1+(1-n)K\right] f''(\xi,0) \qquad (11)$$

Further, we can obtain some particular cases of this problem.

(i) Early unsteady flow

For advanced unsteady flow $0<\tau<<1$, we have $\xi \approx 0$, so equations (6) and (7) reduce in the leading order approximation to

$$(1+K) f''' + \frac{\eta}{2} f'' + Kg' = 0 \qquad (12)$$

$$\left(1+\frac{K}{2}\right) g'' + \frac{\eta}{2} g' + \frac{1}{2} g = 0 \qquad (13)$$

The boundary conditions (8) become

$$\begin{array}{ll} f(0)=0,\ f'(0)=1, g\ (0)=-n f''(0) & \\ f'(\infty)=0, & g(\infty)=0 \end{array} \qquad (14)$$

(ii) Final steady- state flow

For this case, $\xi = 1$ and equations (6) and (7) take the following forms:

$$(1+K) f''' + f f'' - f'^2 - Mf' + Kg' = 0 \qquad (15)$$

$$\left(1+\frac{K}{2}\right) g'' + f g' - f' g - K(2g + f'') = 0 \qquad (16)$$

Subject to the boundary conditions

$$\begin{array}{ll} f(0)=0,\ f'(0)=1, g\ (0)=-n f''(0) & \\ f'(\infty)=0, & g(\infty)=0 \end{array} \qquad (17)$$

METHOD OF SOLUTION

To solve the equations (6) and (7), we have convert into a system of five first order equations, we have at $\xi + \Delta\xi$,

$$(y_1 \to f, y_4 \to g), y_1' = y_2, y_2' = y_3$$

$$y_3' = \frac{1}{(1+k)}\left[\begin{array}{l} \xi(1-\xi) y_2(\xi+\Delta\xi) - y_2(\xi) \\ -(1-\xi)\frac{\eta}{2} y_3 \\ +\xi\left(y_1 y_3 - y^2{}_2 - M * y_2\right) - k y_5 \end{array} \right]$$

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$$y_4' = y_5 \quad and$$

$$y_5' = \frac{1}{\left(1+\frac{k}{2}\right)}\left[\begin{array}{l} \xi(1-\xi)\frac{y_4(\xi+\Delta\xi) - y(5)}{\Delta\xi} \\ -(1-\xi)\left(\frac{1}{2} y_4 + \frac{\eta}{2} y_5\right) \\ -\xi\left(y_1 y_5 - y_2 y_4\right) \end{array} \right]$$

Early unsteady flow is obtained by solving these equations with $\xi = 0$. For $\xi > 0$, the above equations reflect a fully implicit scheme with respect to ξ. In both cases, assuming $y_3(\xi,0) = \alpha$ and $y_5(\xi,0) = \beta$, the above system is solved up to $\eta_{\max}(\approx \infty)$.

To solve α and β by Newton –Raphson method. We need $\frac{\partial y_2}{\partial \alpha}, \frac{\partial y_4}{\partial \alpha}, \frac{\partial y_2}{\partial \beta}$ and $\frac{\partial y_4}{\partial \beta}$ at $\eta = \eta_{\max}$, these quantities are obtained by solutions

$$y_1' = y_2, y_2' = y_3$$

$$y_3' = \frac{1}{(1+k)}\left[\begin{array}{l} \xi(1-\xi)\frac{\partial y_2(\xi+\Delta\xi)}{\Delta\xi} \\ -(1-\xi)\frac{\eta}{2} y_3 + \xi\left(y_1 Y_3 + Y_1 y_3\right. \\ \left. -2 y_2 Y_2 - M * y_2\right) - k y_5 \end{array} \right]$$

$$y_4' = y_5 \quad and$$

$$y_5' = \frac{1}{\left(1+\frac{k}{2}\right)}\left[\begin{array}{l}\xi(1-\xi)\dfrac{y_4(\xi+\Delta\xi)}{\Delta\xi} - (1-\xi)\left(\dfrac{1}{2}y_4 + \dfrac{\eta}{2}y_5\right) \\ +\xi\left(y_1Y_5 + Y_1y_5 - y_2Y_1 - Y_2y_1\right)\end{array}\right]$$

once with

$y_1(0) = y_2(0) = 0, y_3(0) = 0, y_4(0) = -n$, $y_5(0) = 0$ and another time with

$y_1(0) = y_2(0) = 0, y_2(0) = 0,$

$y_3(0) = 0, y_4(1) = 0, y_5(0) = 1$

This system converging in about three iterations displays correct values of α and β. The system of Ordinary differential equation is solved by Adams predictor- corrector methods of fourth order. Perfection is ensured by solving with different $\Delta\xi, \eta_{\max}$, $\Delta\eta$

RESULTS AND DISCUSSION

The transformed equations (6) and (7) satisfying the boundary conditions (8) were solved numerically using the Adams predictor-corrector method for several values of the material parameter. Numerical results for Skin friction coefficients, the velocity distribution and microrotation distribution are shown graphically. To validate our method we have compared the Skin friction coefficients $C_f \operatorname{Re}^{1/2}{}_x$ values is shown in Table, there is very good agreement between the results when we solved fully unsteady boundary layer equations and final steady state equations. Though computations have been carried out for various values of the n and the material parameter (K) are presented. The velocity distribution of initial flow $(\xi = 0)$ and unsteady flow $(0 < \xi \le 1)$ for various values of material parameter with $n = 0$ and $n = 1/2$ is illustrated graphically in **figure (1)** respectively. From this figure it is observed that the velocity boundary layer thickness increases with the increasing values of material parameter, for both the cases $n = 0$ and $n = \frac{1}{2}$. The **figure (2)** represent for final steady state flow $(\xi = 1)$ for the cases $n = 0$ and $n = \frac{1}{2}$ respectively. It is observed from the figures that the velocity increases with the increase of material parameter. The velocity distribution of fully developed unsteady flow $(0 < \xi < 1)$ and final steady state flow $(\xi = 1)$ is depicted in the **figure (3)** for the cases $n = 0, K = 1.0$ and $n = \frac{1}{2}$, respectively. These figures show that the velocity profiles corresponding to increasing of $\xi\,(0 < \xi \le 1)$ approach the final steady profile corresponding to $\xi = 1$. It has seen that there is a smooth transition from small time solution $(\xi \approx 0)$ to large time solution $(\xi = 1)$. The magnetic field parameter (M), effect is given in **figure (4)** for the velocity distribution $f'(\eta)$ of final steady flow $(\xi = 1)$ with $K = 1$ and $n = 0$. The velocity distribution of final steady state flow $(\xi = 1)$ for various magnetic field values with $K = 1$, $n = 0$ is explained in **figure (4).** It is obvious that existence of magnetic field decelerates the velocity profiles. **Figures (5) – (6)** expresses microrotation distribution for various values of material parameter, n for steady state and unsteady state flow. The microrotation distribution of final steady state flow $(\xi = 1)$ is increases with the increase of the material parameter is observed from **figure (5)** when $n = 0$. The microrotation distribution of final steady state flow $(\xi = 1)$ with $n = \frac{1}{2}$ is shown in **figure (6),** from which the microrotation decreases as material parameter increases in the vicinity of the plate where as it increases as one moves away from it. **Figure (7)** describes the microrotation distribution of fully developed unsteady flow for $n = 0$ and $K = 1$

for $0 < \xi \leq 1$. It is noticed that the microrotation distribution as parabolic distribution and increases with the increase of ξ.

Table (1): Skin friction coefficient $\left(C_f \operatorname{Re}^{\frac{1}{2}} x \right)$ versus ξ

S. no	K	$n = 0$	$n = \frac{1}{2}$
1	0	-1.0055	-1.0048
2	1	-1.4065	-1.2300
3	2	-1.6757	-1.4654
4	4	-2.0094	-1.8366

Conclusions:

- It is clear from the figures that the microrotation effects are more pronounced.
- The microrotation profile for is different as compared to it has a parabolic distribution, where as it has continuously decreases.
- The microrotation distribution of final steady flow is to increase near the plate, where as it decreases far away from the plate with the effect of magnetic field are observed.

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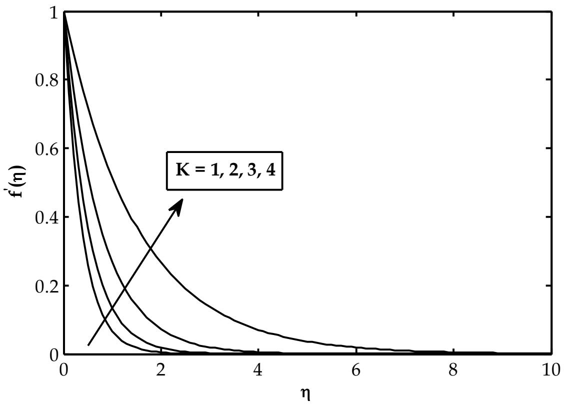

Fig. (1): Velocity of initial flow for various values of K

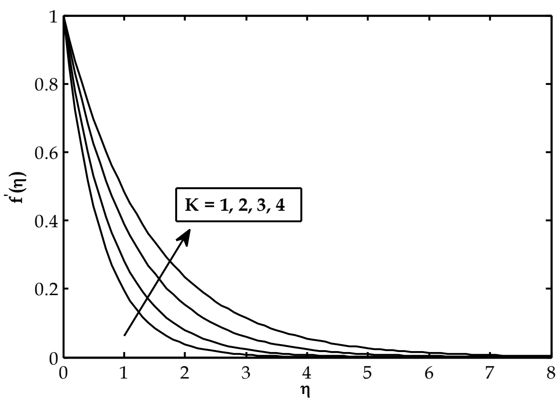

Fig. (2): Velocity of final steady- state flow for K

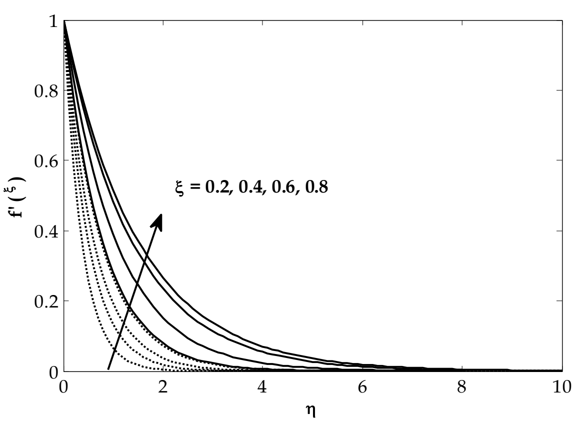

Fig. (3): Velocity of fully developed unsteady flow for ξ

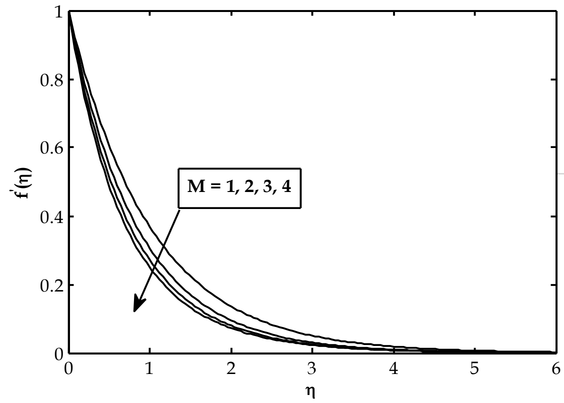

Fig. (4): Velocity of final steady- state flow for M

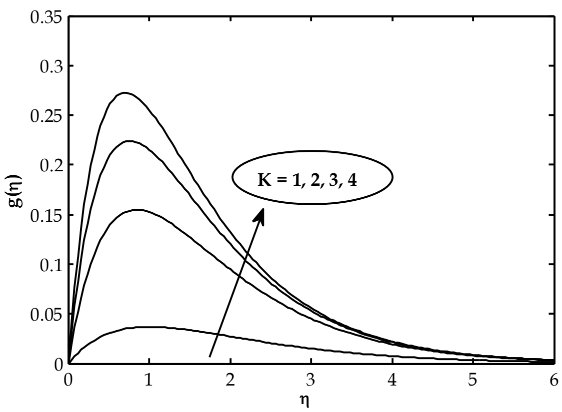

Fig. (5): Micro rotation of final steady – state flow for K

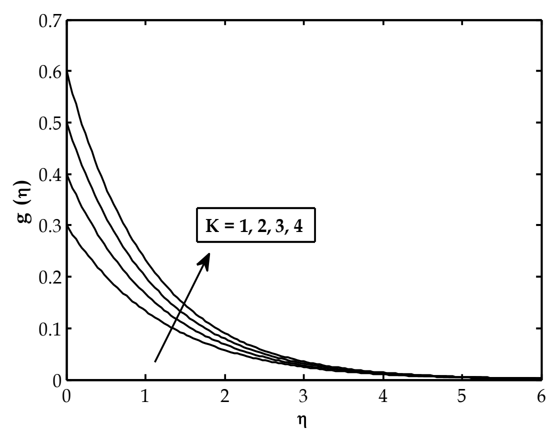

Fig. (6): Micro rotation of final steady- state flow for K

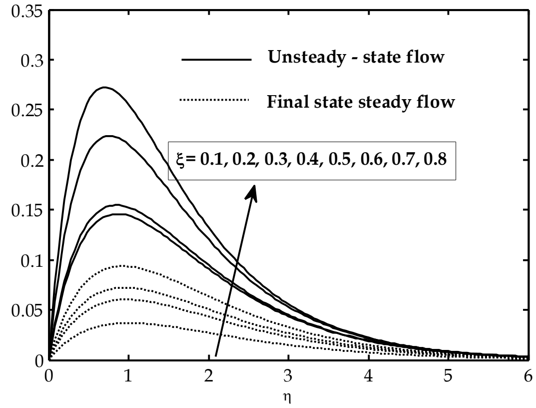

Fig. (7): Micro rotation of full developed unsteady flow for ξ