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A Numerical Study of Hall Current Effect on the Blood Flow through a Multiple Stenosed Artery

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Abstract: The present analysis gives an idea about the Hall current effect on an unsteady Magneto Hydro Dynamic flow of an incompressible viscous, electrically steering fluid through a vertically symmetric artery but horizontally non-symmetric arterial with a mild stenosis. Numerical observations of the laminar flow of a power law fluid in a multiple stenosed artery, in the existence of transverse magnetic field. Now, Hall current effect is taken in to consideration. The transformed governing equations in the present study were solved numerically by using FDM. Effect of stenosis, magnetic field M, the Hall current parameter 'm', and power law fluid index 'n' on the velocity profiles, the wall shear stress and the axial flow are presented graphically.

Keywords: Blood Flow, Stenosis, Hall Parameter, FDM Method, Power Law Fluid.

INTRODUCTION

As per the record of WHO, there is an estimation that more than 17 million deaths are taking place annually due to cardiovascular related complications. WHO also warned that the foremost cause of deaths will persist cardiovascular diseases globally and a very dominant subject of scientific research. This death toll may be 23.3 million by 2030. The coronary heart disease and cerebrovascular disease are the two main causes of the associated deaths.

In mammals the existence of stenosis in the arteries, is very common. By data of the Framingham trial nearly50% of males and 30% of females over 40 years in age will develop coronary artery disease. Coronary artery disease is most commonly due to atherosclerosis. Due to cardiovascular disease the developed world facing half of all deaths while the developing world facing a quarter of deaths, which is result of hypertension. The diseases develop by atherosclerosis have been modeled to study the flow of blood through stenosed arteries and analyzed experimentally and theoretically. The internal blood flow opposes because of cholesterol deposition and connective tissues production in the arterial wall by plaques.

The heart attack generally follows when blood flow is restricted or blocked to the heart and the problem of stroke follows when blood flow restricted or blocked to the brain. Chakravarty S. *et al*. [1] construct a mathematical model for elastic cylindrical tube like artery with overlapped stenosis and inclosing a viscos-elastic fluid representing blood. The study reveals the variations among the volumetric flow rate, the wall shear stress and resistance impedance with the time. Haldar and Ghosh [2] have detected through an indented tube the influence of magnetic field on blood flow in the existence of erythrocytes. The object of the study was to understand the effect on blood flow characteristics by of an externally imposed homogeneous magnetic field through a single confined blood vessel. This analysis showed theoretical results about velocity, minute expenditure of the blood, wall shear stress and pressure gradient.

Das Vigyani and Btra R L [3] studied the influence of the yield stress on blood flow by assuming that flow of blood is non-Newtonian through an arteriosclerotic blood vessel that walls are rigid and permeable. In this study they obtained the variation of the flow resistance, Casson number, and wall shear stress with permeability parameters are calculated with growth of different sizes of the arteriosclerotic lesions. Bali *et al*. [4] calculated the effect of resistance to flow of blood in the existence of magnetic field through a stenotic artery.

Mekheimer Kh. S. *et al.* [5] investigated magnetic field impact and Hall current impact on blood flow via a stenotic artery. They took a micro-polar model of blood flow via a horizontal non-symmetrical but vertically symmetric artery having a mild stenosis. The results shows that as the values of the parameter defining the stenosis shape and the

Hall parameter increases the resistance to flow decreases whereas on the other hand the resistance to flow increases with the Hartmann number increases. Finally they examined the Hartmann's number effect and Hall current effect on the velocity profile. Ikbal *et al.* [6] observed in the presence of magnetic field the action of non-Newtonian blood flow through a stenosed artery. Present mathematical models signify the theoretical study about atherosclerotic arteries with non-Newtonian blood flow throughout a stenosed artery in the existence of a transverse magnetic field. The rheology of the flowing blood is characterized by means of a generalized Power law fluid model. The result shows inclusively on the basis of numerical computations the mathematical analysis has been performed and found that effects of Hartmann's number (M), Power law index (n), generalized Reynolds number ReG/, and seriousness of the stenosis on several parameters like flow velocity, flux and wall shear stress by using their graphical demonstrations so that we can authenticate the applicability of the suggested mathematical model.

Gaurav *et al.* [7] analyzed the numerical study of magnetic field having multiple stenoses. They observed the overlapping stenosis and externally applied magnetics field which is affected by the flow characteristics. Das S and Jha R N [8] studied the Hall current effect on shaky hydro-magnetic flow that was persuaded by an eccentric- concentric cycle of a disk and a fluid at infinity. In this work they found that Hall parameter raises the velocity component and the minor values of time converses more swiftly than the general solution.

Abdullah I *et al.* [9] perceived the effect of magnetic field and Hall current to the blood velocity and LDL transfer. He considered a mathematical model, assuming blood as a Newtonian fluid and artery having a cosine shape stenosis. They found in this study that Hall parameter increases concentration decreases and velocity increases.

Formulation of the problems

Consider a viscous incompressible non-Newtonian and electrically leading fluid with viscosity μ and density ρ in finite tube length L with multiple stenosis in the existence of magnetic field. Blood is categorized as generalized Power –law fluid and let (r, θ, z) be the co-ordinates of a material point in the cylindrical polar coordinate system. Here z axis is taken as the axis of the artery. r is in radial direction and θ is circumferential direction.

The geometrical representation of the multiple stenosed artery as follows

$$R(z) = \begin{cases} 1 - A\left\{ L_0^{n-1}(z-d) - (z-d)^n \right\} & for \quad d \le z \le d + L_0 \\ 1 & for \quad else \end{cases} \tag{1}$$

Here $R(z)$ is treated as radius of the normal artery, the shape defining parameter of the stenosis n>2 is in the stenotic region, L_0 is the length of the stenosis, d shows its locality then A is given by

$$A = \frac{\delta n^{\frac{n}{(n-1)}}}{R_o L_o^n (n-1)} \tag{2}$$

Here δ signifies extreme height of the stenosis at,

$$z = d + \frac{L_o}{n^{1/(n-1)}} \tag{3}$$

By using Maxwell's relations

The current density J is stated by

$$J = \sigma(E + \mathrm{V} \times B) \tag{4}$$

Where σ, E, V and B are electrical conductivity, electric field intensity vector velocity and magnetic flux intensity respectively.

The Navier Stokes equalities of blood flow with Lorentz's force is

$$\rho\left(\frac{\partial V}{\partial t} + \mathrm{V}.\nabla\, \mathrm{V}\right) = J \times B - \nabla \mathrm{p} + \mu \nabla^2\, \mathrm{V} \tag{5}$$

Under the assumptions the governing equations may be written in the cylindrical coordinates system as

$$\frac{\partial u}{\partial z} + \frac{v}{r} + \frac{\partial v}{\partial r} = 0 \tag{6}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial z} + v\frac{\partial u}{\partial r} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - \frac{1}{\rho}\left[\frac{1}{r}\frac{\partial}{\partial r}(r\,\tau_{rz}) - \frac{\partial}{\partial z}(\tau_{zz})\right] - \frac{\sigma B_o^2}{\rho\left(1+m^2\right)}(u - mv) \tag{7}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial z}+v\frac{\partial v}{\partial r}=-\frac{1}{\rho}\frac{\partial p}{\partial r}-\frac{1}{\rho}\left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rr})+\frac{\partial}{\partial z}(\tau_{rz})\right]-\frac{\sigma B_o^2}{\rho\left(1+m^2\right)}(v+mu) \qquad (8)$$

In case of two dimensional motion the relationship between the shear stress and shear rate is given by

$$\tau=-m\left[\left|\sqrt{\frac{1}{2}(\dot{\gamma}\dot{\gamma})}\right|^{n-1}\right]\gamma \qquad (9)$$

With $\frac{1}{2}(\dot{\gamma}\dot{\gamma})=2\left\{\left(\frac{\partial v}{\partial r}\right)^2+\left(\frac{v}{r}\right)^2+\left(\frac{\partial u}{\partial r}\right)^2\right\}+\left(\frac{\partial v}{\partial z}+\frac{\partial u}{\partial r}\right)^2$ (10)

At this point τ symbolizes the stress tensor, $\dot{\gamma}$ the symmetricity rate of deformation tensor, m is the electrical conductivity and n is the electrical conductivity.

Now the corresponding reliability and performance factors of fluid

$$\tau_{zz}=-2\left\{m\left|\left[\left(\frac{\partial v}{\partial r}\right)^2+\left(\frac{v}{r}\right)^2+\left(\frac{\partial u}{\partial z}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial u}{\partial r}\right)^2\right]^{1/2}\right|^{n-1}\right\}\left(\frac{\partial u}{\partial z}\right) \qquad (11)$$

$$\tau_{rz}=-\left\{m\left|\left[\left(\frac{\partial v}{\partial r}\right)^2+\left(\frac{v}{r}\right)^2+\left(\frac{\partial u}{\partial z}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial u}{\partial r}\right)^2\right]^{1/2}\right|^{n-1}\right\}\left(\frac{\partial u}{\partial r}+\frac{\partial v}{\partial z}\right) \qquad (12)$$

$$\tau_{rr}=-2\left\{m\left|\left[\left(\frac{\partial v}{\partial r}\right)^2+\left(\frac{v}{r}\right)^2+\left(\frac{\partial u}{\partial z}\right)^2+\left(\frac{\partial v}{\partial z}+\frac{\partial u}{\partial r}\right)^2\right]^{1/2}\right|^{n-1}\right\}\left(\frac{\partial v}{\partial r}\right) \qquad (13)$$

Now we assume that $u(r,z,t)$ be the axial and $v(r,z,t)$ be the radial velocity components respectively, p,ρ be the electrical conductivity pressure and the blood density respectively. $\partial p/\partial z$ stand-in equation (5), is established by

$$-\frac{\partial p}{\partial z}=a_0+a_1\cos\omega t\,,t>0. \qquad (14)$$

Here eq. (14) is known as pressure gradient, a_0 , a_1 are constant amplitude of the pressure gradient and amplitude of pulsatile factor respectively for given rise to systolic and diastolic pressure:
$\omega=2\pi f_p$,

Here $f_p$is frequency of pulse

Boundary conditions

On the symmetrical axis, the normal factor of the velocity, the axial velocity gradient and the shear stress disappear. These conditions may be indicated scientifically as
$v(r,z,t)=\frac{\partial u(r,z,t)}{\partial r}=0$ and $\tau_{rz}=0$ at $r=0$ (15)(a)

Limit conditions of velocity at arterial wall are given by:
$v(r,z,t)=\frac{\partial R}{\partial t}$ and $u(r,z,t)=0$ at $r=R(z,t)$ (15)(b)

It is presumed that while the system is on relaxation, no flow takes place
$v(r,z,t)=u(r,z,t)=0$ and at $t=0$ (15)(c)

Method of Solution

In the arterial lumen the blood behavior is as a homogeneous Newtonian fluid. Make known to a radial coordinate transformation $\left[x=\frac{r}{R(z,t)}\right]$, the Navier –Stokes equations and the equation of continuity that directs the unsteady nonlinear fully developed flow of blood may be transcribed in non-dimension form as

Using this transformation, equation (6-8) and (9-13) together with boundary conditions (15) (a, b, c) takes the following form

$$\frac{1}{r}\frac{\partial v}{\partial x}+\frac{v}{xR}+\frac{\partial u}{\partial z}-\frac{x}{R}\frac{\partial u}{\partial x}\frac{\partial R}{\partial z}=0 \tag{16}$$

$$\frac{\partial u}{\partial t}=\left[\frac{x}{R}\frac{\partial R}{\partial t}-\frac{v}{R}+u\frac{x}{R}\frac{\partial R}{\partial z}\right]\frac{\partial u}{\partial x}-u\frac{\partial u}{\partial z}-\frac{1}{\rho}\frac{\partial \rho}{\partial z}-\frac{1}{\rho}\left[\frac{1}{xR}\tau_{xz}+\frac{1}{R}\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{zz}}{\partial z}-\frac{x}{R}\frac{\partial \tau_{xz}}{\partial x}\frac{\partial R}{\partial z}\right]-M_1 u \tag{17}$$

Where $M_1=\frac{M}{1+m_1^2}$ and $M=\frac{\sigma B^2}{\rho}$

Normal stress

$$\tau_{zz}=-2\left\{m\left|\left[\left(\frac{1}{R}\frac{\partial v}{\partial x}\right)^2+\left(\frac{v}{xR}\right)^2+\left(\frac{\partial u}{\partial z}-\frac{x}{R}\frac{\partial R}{\partial z}\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}-\frac{x}{R}\frac{\partial R}{\partial z}\frac{\partial v}{\partial X}+\frac{1}{r}\frac{\partial u}{\partial x}\right)^2\right]^{1/2}\right|^{n-1}\right\}\left(\frac{\partial u}{\partial z}-\frac{x}{R}\frac{\partial R}{\partial z}\frac{\partial u}{\partial x}\right) \tag{18}$$

Shear Stress

$$\tau_{xz}=-2\left\{m\left|\left[\left(\frac{1}{R}\frac{\partial v}{\partial x}\right)^2+\left(\frac{v}{xR}\right)^2+\left(\frac{\partial u}{\partial z}-\frac{x}{R}\frac{\partial R}{\partial z}\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial z}-\frac{X}{R}\frac{\partial R}{\partial z}\frac{\partial v}{\partial x}+\frac{1}{r}\frac{\partial u}{\partial x}\right)^2\right]^{1/2}\right|^{n-1}\right\}\left(\frac{1}{R}\frac{\partial u}{\partial z}+\frac{\partial v}{\partial z}-\frac{x}{R}\frac{\partial R}{\partial z}\frac{\partial u}{\partial x}\right) \tag{19}$$

Where n is fluid behavioral index parameter. Transform the boundary conditions then we get:

$v\,(x,z,t)=\frac{\partial u(x,z,t)}{\partial r}=0$ and $\tau_{xz}=0$ when x=0 (20)(a)

$v(x,z,t)=\frac{\partial R}{\partial t}$ and $u(x,z,t)=0$ when x=1 and (20)(b)

$v(x,z,t)=u(x,z,t)=0$ at t=0 (20)(c)

So as to get the radial velocity component $v(x,z,t)$, we contemplate the equation (6) as follows

$$x\frac{\partial v}{\partial x}+xR\frac{\partial u}{\partial z}-x^2\frac{\partial u}{\partial X}\frac{\partial R}{\partial z}=0 \tag{21}$$

Now, within the limits $0\rightarrow x$ integrate equation (21) in respect of x then we have

$$u(x,z,t)=x\left[\frac{\partial R}{\partial z}u-\frac{\partial R}{\partial t}(2-x^2)\right] \tag{22}$$

The rate of flow can be calculated by

$$Q=\int_0^R 2\pi\, r\, dr \tag{23}$$

The flow resistance can be evaluated from $\lambda=\frac{\partial p}{\partial z}/Q$ (24)

The wall shear stress is defined as $\tau_{xy}=\mu\left(\frac{\partial u}{\partial x}+\frac{\partial u}{\partial z}\right)$ (25)

Finite difference approximation

Discretize the axial velocity $v_z(x,z,t)$ as $v_z(x_j,z_i,\,t_k)$ or $(v_z)_{i,j}^k$

We state

$x_j=j.\Delta x$ *and* $z_i=i.\Delta z$ where $x_N=1.0$ $i=0,1,2,\dots M, j=0,1,2,\dots N$

By finite difference technique solve eq. (14) on the basis of central difference approximation intended for all the spatial derivatives in the succeeding style

$$\frac{\partial u}{\partial x}=\frac{u_{i,j+1}^k-u_{i,j-1}^k}{2\Delta x}=u_{fx}, \tag{26}$$

$$\frac{\partial u}{\partial z}=\frac{u_{i+1,j}^k-u_{i-1,j}^k}{2\Delta z}=u_{fz} \tag{27}$$

While the time derivative in (14) is similar to

$$\frac{\partial v}{\partial t}=\frac{v_{i,j}^{k+1}-v_{i,j}^k}{2\Delta t} \tag{28}$$

Related expression can also be achieved for u,τ_{xz} and τ_{zz}. Here $v(x,z,t)$ is discretized to $v(x_j,z_i,t_k)$ and turn into $w_{i,j}^k$, here we express $x_j=(j-1)\Delta x,(j=1,2,\dots N+1)$ like that $x_{(N+1)}=1.0, z_i=(i-1)\Delta z,(i=1,2,\dots M+1)$

and $t_k = (k-1)\Delta t, (k = 1,2 \ldots)$ for whole section of artery in study. Δx is the additions in the radial and Δz is the addition in axial direction and Δt is the small addition in time.

Consuming Eq. no. (25) and (26), Eq. (14) possibly be converted into the subsequent difference equation

$$u_{i,j}^{k+1} = u_{i,j}^{k} + \Delta t\left[-\frac{1}{\rho}\left(\frac{\partial p}{\partial z}\right)^{k+1} + \left\{\frac{x_j}{R_i^k}\left(\frac{\partial R}{\partial t}\right)_i^k - \frac{u_{i,j}^k}{R_i^k} + \frac{x_j}{R_i^k}\left(\frac{\partial R}{\partial z}\right)_i^k u_{i,j}^k\right\}\left(u_{fx}\right)_{i,j}^k - u_{i,j}^k\left(w_{fx}\right)_{i,j}^k - \frac{1}{\rho}\left\{\frac{1}{x_j R_i^k}\left(\tau_{xz}\right)_{i,j}^k + \frac{1}{R_i^k}\left[\left(\tau_{xz}\right)_{fx}\right]_{i,j}^k - \left[\left(\tau_{xz}\right)_{fz}\right]_{i,j}^k + \frac{x_j}{R_i^k}\left(\frac{\partial R}{\partial z}\right)_i^k\left[\left(\tau_{xz}\right)_{fx}\right]_{i,j}^k\right\}\right] \tag{29}$$

Even though Eq. no (16) and (17) have their discretized form as:

$$(\tau_{zz})_{i,j}^k = -2\left\{m\left|\left[\left(\frac{1}{R_i^k}\left(u_{fx}\right)_{i,j}^k\right)^2 + \left(\frac{u_{i,j}^k}{x_j R_i^k}\right)^2 + \left(\left(u_{fx}\right)_{i,j}^k - \frac{x_j}{R_i^k}\left(\frac{\partial R}{\partial z}\right)_i^k\left(u_{fx}\right)_{i,j}^k + \frac{1}{R_i^k}\left(u_{fx}\right)_{i,j}^k\right)^2\right]^{1/2}\right|^{n-1}\right\}\left[\left(u_{fz}\right)_{i,j}^k - \frac{x_j}{R_i^k}\left(\frac{\partial R}{\partial z}\right)_i^k\left(u_{fx}\right)_{i,j}^k\right] \tag{30}$$

$$(\tau_{xz})_{i,j}^k = -\{\ldots\ldots\}\left[\left(u_{fz}\right)_{i,j}^k - \frac{x_j}{R_i^k}\left(\frac{\partial R}{\partial z}\right)_i^k\left(u_{fx}\right)_{i,j}^k + \frac{1}{R_i^k}\left(v_{fx}\right)_{i,j}^k\right] \tag{31}$$

As well the recommended eq. (18) and eq. (20) have finite difference illustrations as

$$0, v_{i,1}^k = v_{i,2}^k, (\tau_{xz})_{i,1}^k = 0 \tag{32}$$

$$v_{j,N+1} = 0, u_{i,N+1}^k = \left(\frac{\partial R}{\partial t}\right)_i^k \tag{33}$$

$$u_{i,j}^1 = 0 = v_{i,j}^1 \tag{34}$$

$$Q_i^k = 2\pi\left(R_i^k\right)^2\int_0^2 x\left(u\right)_{i,j}^k dx_j \tag{35}$$

$$\lambda_i^k = \frac{\left(\frac{\partial p}{\partial z}\right)^k}{Q_i^k} \tag{36}$$

Numerical outcomes and discussions

To perceive the measureable possessions of the Hartmann's number H, the Hall parameter m, for the tenacity of scientific calculations of the anticipated extents for foremost physiological importance, the subsequent parameter values have been use ;

$$a = 0.7mm, \quad \Delta x = 0.025, \quad \tau_m = 0.4a, a_1 = 0.2A_0, b = 0.2, L = 50mm,$$
$$L_0 = 18mm, d = 20mm, \mu = 0.035P,$$
$$n = 0.639, \rho = 1.06\times10^3 kg\times m^{-3}, A_0 = 100kg\times m^{-2}s^{-2}, m = 0.1735\ P,,$$
$$\Delta z = 0.1, f_p = 1.2Hz$$

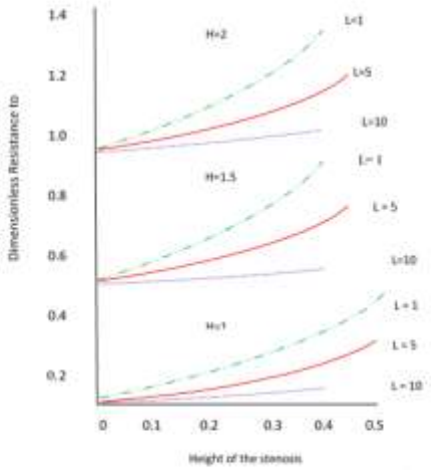

Fig1: Variation of thedimensionless resistance to flow with height of the stenosis for different values of *H*

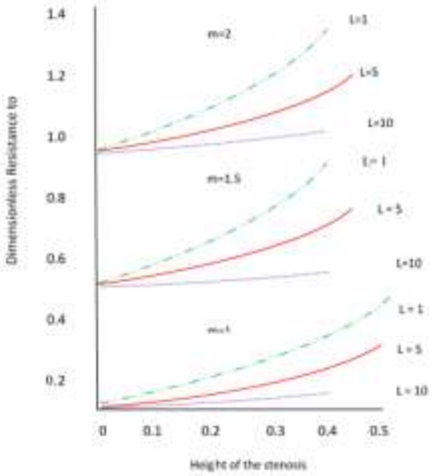

Fig.2: Variation of the dimensionless resistance to flow with height of the stenosis for different values of m.

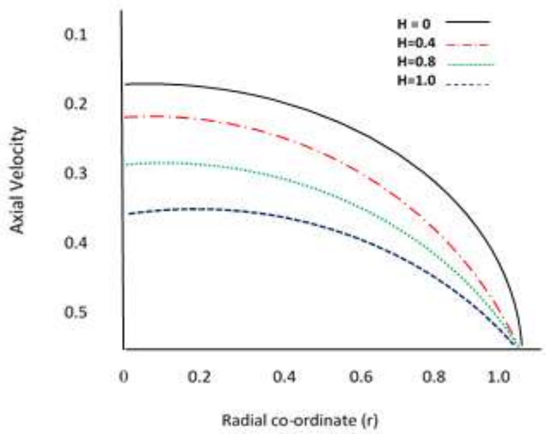

Fig.3: Variation of axial velocity profile with radial co-ordinate (r) for different values of H.

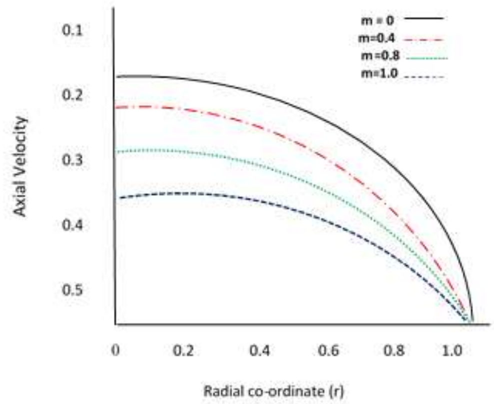

Fig.4: Variation of axial velocity profile with radial co-ordinate (r) for different values of m.

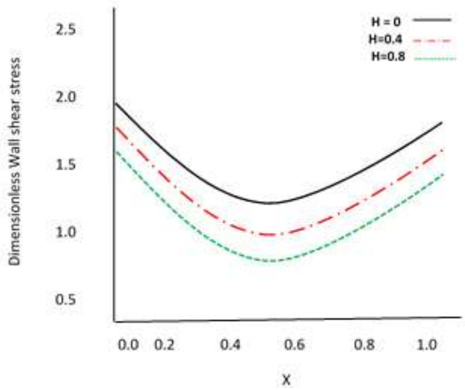

Fig: 5: Variation of the dimensionless shearing stress at the stenosis throat for different values of Hartmann number H

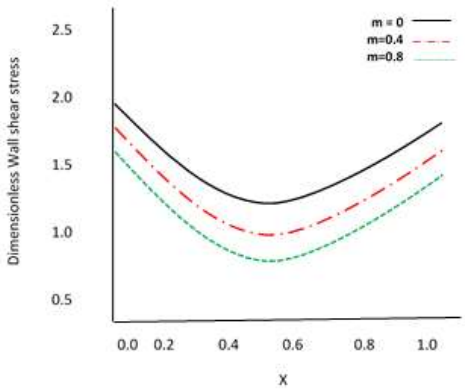

Fig: 6: Variation of the dimensionless shearing stress at the stenosis throat for different values of Hartmann number H

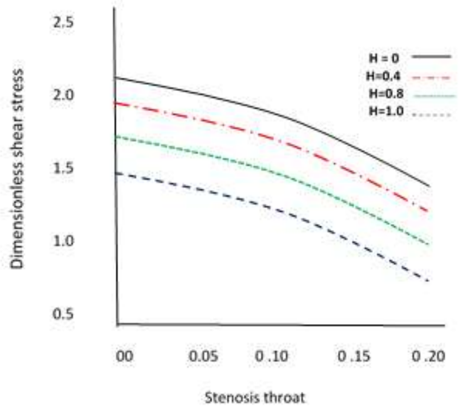

Fig.7: Variation of the dimensionless shearing stress at the stenosis throat for different values of Hartmann number H

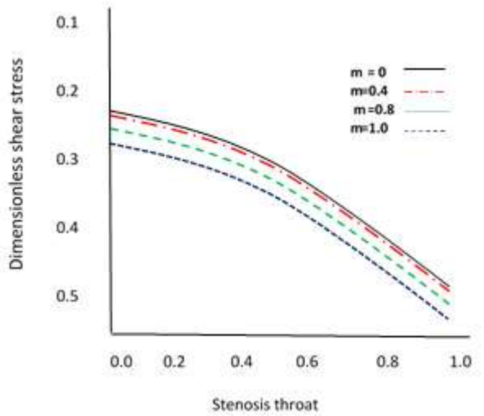

Fig.8: Variation of the dimensionless shearing stress at the stenosis throat for different values of Hartmann number m

RESULTS AND CONCLUSION

Figure 1-2 show the variation of the dimensionless resistance to flow λ with stenosis height δ with the Hartmann's number H and the Hall parameter m. Here we perceive that resistance to flow λ increases as the Hartmann's number H rises with stenosis size δ, and declines as the Hall parameter m rises with stenotic length L. The shape parameter n, achieves its extreme in the symmetric stenosis case $n = 2$.

Figure 3 shows as the Hartmann's number rises, the velocity of the fluid declines and It can also be realized that if external magnetic field is not present over there i.e. $M = 0$ the velocity of fluid is greater than in its occurrence ($M \neq 0$). Therefore, the occurrence of an exterior magnetic field shrinks velocity of the blood as the strength of the magnetic field is increased.

Figure4 shows the Hall parameter influence on the velocity profile. Here the velocity increases as Hall parameter increases. It means that wall shear stress also shakes if there is an external magnetic field exist. From

Figure 5-6, perceived that as Hartmann's number H rises the wall shear stress rises. The wall shear stress is greater in the existence of the magnetic field in comparison than in its nonexistence. Thus in the existence of exterior magnetic field a superior force to be applied on the vessel wall. As the strength of the field increases the force also rises. We notice that the wall shear stress distribution τ increases if the shape parameter n, increases.

Figure 7-8 show at the throat, the wall shear stress sharing and its' values are in an inverse proportion with admiration to Hartmann's number and Hall parameter.

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