Two Layered Model of Blood Flow through Composite Stenosed Artery in Porous Medium under the Effect of Applied Magnetic Field

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Abstract— **The present paper deals with a two-layered mathematical model for blood flow through stenotic tube in porous medium under the effect of an applied magnetic field. In this mathematical model, the blood is considered as Newtonian fluid of variable viscosity in the central region and plasma fluid which is considered as Newtonian fluid of constant viscosity in the peripheral region of the stenotic tube. In this model, the flow is assumed to be steady, laminar, incompressible and unidirectional, and expressions are obtained for axial velocities, flow rate and wall stresses. The governing equations representing the flow in central and peripheral layer are solved for the velocities of fluid, flow rate, shear stress by using Shooting method. It is observed that the fluid's velocity and flow rate were reduced when the magnetic field was introduced as well as when its intensity was increased. While wall shear stress increases with the increase in Hartmann number as well as Reynolds number. Effect of permeability constant on shear stress and on velocity are also studied graphically.**

Keywords— **Stenosis vessel, two-layered model, blood flow, Newtonian fluid, peripheral layer, magnetic field, shear stress.**

I. INTRODUCTION

It is known that stenosis is a dangerous disease and is caused due to the abnormal growth in the lumen of the arterial wall. The actual reason for the development of this abnormal growth along the walls of artery is not clear but many researchers have pointed that the cause of this problem is transport of low density lipoproteins (LDL) molecules to walls of artery, which leads to formation of plaques and restricts the blood flow. Since the wall of artery is a porous connective tissue and deposition of LDL causes intimal thickening which makes it more stiffened and obstructs the natural flow of blood [1], [2]. An artery which is affected by this abnormal growth can lead to serious consequences such as blockage of the artery, stroke and many other arterial diseases. It has been realized that various hydrodynamic effects (e.g. pressure distribution and wall shear etc.) play important role in the development and progression of this disease [3]. Thus the study of blood flow through stenotic arterial region plays an important role in the diagnostic and fundamental understanding of cardiovascular diseases under different flow conditions [4-9].

In the existing literature many researchers have studied blood flow through stenosed artery under the influence of external forces considering blood as Newtonian or non-Newtonian fluid [10]. The idea of electromagnetic field in medical research was firstly given by Kolin [11] and later Krchevskii et al. [12] discussed the possibility of regulating the movement of blood in human system by applying magnetic field. Sanyal et al. [13] have studied pulsatile blood flow through an inclined circular tube under periodic body acceleration considering magnetic effect, taking blood as a couple stress fluids. Suri and Suri [14] have studied the effects of static transverse magnetic field on the stenosed bifurcated model of artery. They have observed that application of magnetic field reduces the strength of stenosis at the apex of bifurcation, shear stress and increases the velocity of blood flow. Haldar and Ghosh [15] discussed the effects of magnetic field on the blood flow with variable viscosity through stenosed tube and obtained analytic expressions for velocity, flow rate and shear stress, and were discussed graphically. Haldar and Andersson [16] studied two-layered model of blood flow through stenosed arteries under the effect of magnetic field. In this model the central layer is represented by Casson fluid flow.

Ponalagusamy [17] has taken two-layered model of blood flow with variable thickness of peripheral layer and obtained expressions of slip velocity, core viscosity and thickness of peripheral layer. Chakravarty et al. [18] have taken two-layered model of blood flow in tapered flexible stenosed artery. The central layer is represented by Casson fluid and peripheral layer, free from cells, is a form of Newtonian fluid. Ponalagusamy et al.[19] also discussed about a two-layered model of blood flow through stenosed arteries, considering the core-region of blood as a non-Newtonian fluid obeying the law of Casson model and the peripheral layer of plasma as a Newtonian fluid. Joshi et al. [20] have investigated the two-layered model of blood flow through composite stenosed artery and explained the results of resistance to flow and wall shear stress graphically. Sankar et al.

[21] have discussed the two-layered blood flow through a composite stenosis in the presence of a magnetic field and studied the magnetic effect, wall shear stress and flow rate graphically in presence of the parameters obtained. A two-phase model of blood flow through a composite stenosis in the presence of a peripheral-layer is studied by Srivastav et al. [22] and they explained flow resistance and wall shear stress graphically.

Biswas and Barbhuiya [23] studied the effects of the stenosis on the axial velocity, flow rate and wall shear stress for Newtonian fluid through a tapered artery in a two-layered blood flow with velocity slip at the interface. Sharma et al. [24] discussed the role of heat transfer in blood flow through stenotic artery and numerically investigated the Navier-Stokes equations and energy equations using finite difference scheme. Bali and Awasthi [25] analysed the effect of magnetic field, height of stenosis, parameter determine the shape of profile on velocity, volumetric flow rate and shear stress through multiple stenosed artery.

Rathee and Singh [1] have taken a two-layered model of blood flow through composite stenosed artery in porous medium under the effect of magnetic field and explained the results of pressure gradient and wall shear stress graphically. They considered the two-layered model of blood flow through composite stenosed blood vessel. The blood flowing in central layer is considered to be Newtonian fluid with variable viscosity. The viscosity of blood varying according to Einstein relation. The peripheral region of the vessel comprises of plasma layer whose flow is considered as Newtonian and of constant viscosity. Considering the above situation, an attempt is made in this analysis to study the flow of blood through a composite artery in presence of stenosis with no slip condition in presence of an externally applied inclined magnetic field in a two-layered blood flow model.
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II. FORMULATION OF THE PROBLEM

A. Flow Geometry
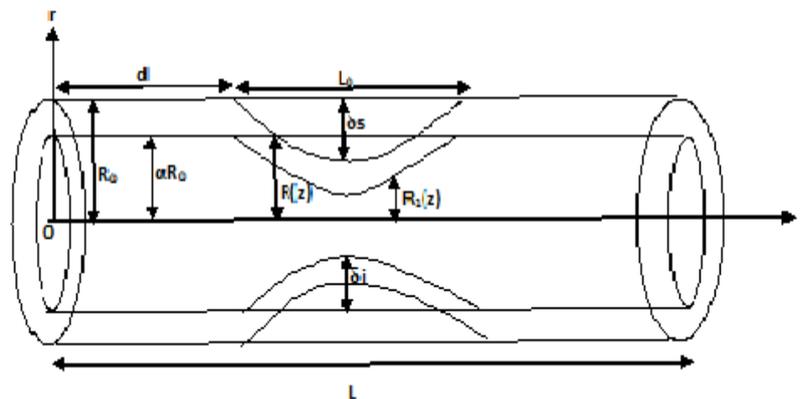
The geometry of composite stenosed artery is-

Fig 1. Flow geometry of the stenosed artery.

$$R_1(z) = \begin{cases} \alpha R_0 - \frac{2\delta_i}{L_0}(z - d), & d \leq z \leq d + \frac{L_0}{2} \\ \alpha R_0 - \frac{\delta_i}{2}\left\{1 + \cos\frac{2\pi}{L_0}\left(z - d - \frac{L_0}{2}\right)\right\}, & d + \frac{L_0}{2} \leq z \leq z + L_0 \\ \alpha R_0, & otherwise \end{cases} \qquad (1)$$

$$R(z) = \begin{cases} R_0 - \frac{2\delta_s}{L_0}(z - d), & d \leq z \leq d + \frac{L_0}{2} \\ R_0 - \frac{\delta_s}{2}\left\{1 + \cos\frac{2\pi}{L_0}\left(z - d - \frac{L_0}{2}\right)\right\}, & d + \frac{L_0}{2} \leq z \leq z + L_0 \\ R_0, & otherwise \end{cases} \qquad (2)$$

where $R_1(z)$ and $R(z)$ are respectively the radii of central layer and stenotic tube with peripheral layer and R_0 is the radius of unobstructed blood vessel. L_0 is length of stenosis, d is the position of stenosis, δ_s is the height of stenosis, δ_i is the maximum bulging of the interface at $z = d + \frac{L_0}{2}$, α is the ratio of radius of central layer and radius of unobstructed artery.

B. Flow Analysis and co-ordinate system

We consider a steady, incompressible and fully developed flow of blood through two layered model of composite stenosed artery under the influence of an externally applied uniform magnetic field. The blood is assumed to be axially symmetric (i.e. $v_r = 0, v_\theta = 0$, flow in z- direction only). The blood in central layer of blood vessel is a suspension of erythrocytes and is considered as Newtonian fluid with variable viscosity which varies according to Einstein relation. The peripheral layer is filled with plasma fluid and is considered Newtonian fluid of constant viscosity.

A uniform magnetic field of strength B_0 is applied in the direction making an angle 'θ' to r-direction. It induces another magnetic field $\bar{B}$ along the line of motion. Hence the component of velocity and magnetic field distribution are $(0,0,\bar{w}(\bar{r}))$ and $(B_0\lambda, 0, \bar{B}(\bar{r}) + B_0\sqrt{1 - \lambda^2})$.

The viscosity of blood in central layer is allowed to vary according to the Einstein relation-

$$\bar{\mu}_c = \mu_p\left[1 + \beta\bar{h}(\bar{r})\right] \qquad (3)$$

where $\bar{\mu}_c$ is the viscosity of central layer, μ_p is the viscosity of plasma (constant), $\bar{h}(\bar{r})$ is hematocrit and β is constant.

Hematocrit is described by the relation $\bar{h}(\bar{r}) = h_m\left[1 - \left(\frac{\bar{r}}{R_0}\right)^3\right] \qquad (4)$

where h_m is maximum hematocrit of blood.

Substituting the value of $\bar{h}(\bar{r})$ from equation (4) in equation (3), we get

$$\bar{\mu}_c = \mu_p\left[a - k\left(\frac{\bar{r}}{R_0}\right)^3\right] \qquad (5)$$

where $a = 1 + k$ and $k = \beta h_m$

Under the above assumptions, the governing equations (Navier Stokes equations of motion) for the flow in central and peripheral layer for the present problem, are given by-

$$\bar{\mu}_c\left[\frac{\partial^2\bar{w}_c}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial\bar{w}_c}{\partial\bar{r}}\right] + \left(\frac{\partial\bar{\mu}_c}{\partial\bar{r}}\right)\left(\frac{\partial\bar{w}_c}{\partial\bar{r}}\right) - \sigma_e^c\bar{w}_cB_0^2\lambda^2 - \frac{\partial\bar{p}}{\partial\bar{z}} = 0 \qquad (6)$$

and $\mu_p\left[\frac{\partial^2\bar{w}_p}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial\bar{w}_p}{\partial\bar{r}}\right] - \frac{\mu_0}{K}\bar{w}_p - \sigma_e^p\bar{w}_pB_0^2\lambda^2 - \frac{\partial\bar{p}}{\partial\bar{z}} = 0 \qquad (7)$

where K is permeability constant, $\frac{\partial\bar{p}}{\partial\bar{z}}$ is pressure gradient, $\bar{w}_c$ and $\bar{w}_p$ are the velocities of fluid, σ_e^c and σ_e^p are electrical conductivities of central and peripheral layers respectively.

The magnetic induction equation in axial direction for the flow in central and peripheral layer are given by-

$$\lambda B_0\left[\frac{\partial\bar{w}_c}{\partial\bar{r}} + \frac{\bar{w}_c}{\bar{r}}\right] + \eta_m\left[\frac{\partial^2 B(\bar{r})}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial B(\bar{r})}{\partial\bar{r}}\right] = 0 \qquad (8)$$

$$\lambda B_0\left[\frac{\partial\bar{w}_p}{\partial\bar{r}} + \frac{\bar{w}_p}{\bar{r}}\right] + \eta_m\left[\frac{\partial^2 B(\bar{r})}{\partial\bar{r}^2} + \frac{1}{\bar{r}}\frac{\partial B(\bar{r})}{\partial\bar{r}}\right] = 0 \qquad (9)$$

C. Boundary conditions

The boundary conditions are

$$\frac{\partial \bar{w}_c}{\partial \bar{r}} = 0 \, , \bar{B}(\bar{r}) = b_0 \text{ at } \bar{r} = 0$$

$$\bar{w}_p = 0, \, \bar{B}(\bar{r}) = b_s \text{ at } \bar{r} = \bar{R}(\bar{z})$$

$$\bar{w}_c = \bar{w}_p, \, \bar{\tau}_c = \bar{\tau}_p, \, \bar{B}(\bar{r}) = b_1 \text{ at } \bar{r} = \bar{R}_1(\bar{z})$$

(10)

III. SOLUTION PROCEDURE

Introducing the following non-dimensional scheme-

$$r = \frac{\bar{r}}{R_0}, z = \frac{\bar{z}}{R_0}, R(z) = \frac{R(\bar{z})}{R_0}, R_1(z) = \frac{R_1(\bar{z})}{R_0}, \, p = \frac{\bar{p}}{\rho \bar{w}_0^2}, w_c = \frac{\bar{w}_c}{\bar{w}_0}, \, w_p = \frac{\bar{w}_p}{\bar{w}_0},$$

$$\mu_c = \frac{\bar{\mu}_c}{\bar{\mu}_0}, B(r) = \frac{B(\bar{r})}{B_0}, \tau_c = \frac{\bar{\tau}_c}{\bar{\tau}_0}, \, \tau_p = \frac{\bar{\tau}_p}{\bar{\tau}_0}, \bar{\tau}_0 = \frac{C R_0^2}{2}, \, \bar{w}_0 = \frac{C R_0^2}{4\bar{\mu}_0} .$$

The equations (5) to (9) becomes-

$$\mu_c = (a - k r^3) \qquad (10)$$

$$\mu_c \left[\frac{\partial^2 w_c}{\partial r^2} + \frac{1}{r} \frac{\partial w_c}{\partial r} \right] + \left(\frac{\partial \mu_c}{\partial r} \right) \left(\frac{\partial w_c}{\partial r} \right) - \lambda^2 M_1^2 w_c - Re \frac{\partial p}{\partial z} = 0 \quad (11)$$

$$\frac{\partial^2 w_p}{\partial r^2} + \frac{1}{r} \frac{\partial w_p}{\partial r} - R_0^2 \frac{w_p}{K} - \lambda^2 M_2^2 w_p - Re \frac{\partial p}{\partial z} = 0 \qquad (12)$$

$$\lambda R_m \left[\frac{\partial w_c}{\partial r} + \frac{w_c}{r} \right] + \left[\frac{\partial^2 B}{\partial r^2} + \frac{1}{r} \frac{\partial B}{\partial r} \right] = 0 \qquad (13)$$

$$\lambda R_m \left[\frac{\partial w_p}{\partial r} + \frac{w_p}{r} \right] + \left[\frac{\partial^2 B}{\partial r^2} + \frac{1}{r} \frac{\partial B}{\partial r} \right] = 0 \qquad (14)$$

where $M_1^2 = \frac{\sigma_e^c}{\bar{\mu}_0} \bar{B}_0^2 \bar{R}_0^2$ (Hartmann number for central layer)

$\qquad M_2^2 = \frac{\sigma_e^p}{\bar{\mu}_0} \bar{B}_0^2 \bar{R}_0^2$ (Hartmann number for central layer)

$\qquad Re = \frac{\rho \bar{R}_0 \bar{w}_0}{\bar{\mu}_0}$ (Reynolds number).

$\qquad R_m = \frac{\bar{w}_0 \bar{R}_0}{\eta_m}$ (Magnetic Reynolds number)

As $w = w(r)$ i.e. axial velocity is a function of 'r' only and the pressure gradient is the function of 'z' only i.e. $p = p(z)$, which causes the motion of the flow in the z-direction only, therefore $\frac{\partial p}{\partial z}$ can be written as $\frac{\partial p}{\partial z} = \frac{dp}{dz}$.

Also we take $C = -\frac{dp}{dz}$

So the equations from (11) to (14) reduces to the ordinary differential equations as-

$$\mu_c \left[\frac{d^2 w_c}{dr^2} + \frac{1}{r} \frac{d w_c}{dr} \right] + \left(\frac{d \mu_c}{dr} \right) \left(\frac{d w_c}{dr} \right) - \lambda^2 M_1^2 w_c - Re \frac{dp}{dz} = 0 \quad (15)$$

$$\frac{d^2 w_p}{dr^2} + \frac{1}{r} \frac{d w_p}{dr} - R_0^2 \frac{w_p}{K} - \lambda^2 M_2^2 w_p - Re \frac{dp}{dz} = 0 \qquad (16)$$

$$\lambda R_m \left[\frac{d w_c}{dr} + \frac{w_c}{r} \right] + \left[\frac{d^2 B}{dr^2} + \frac{1}{r} \frac{dB}{dr} \right] = 0 \qquad (17)$$

$$\lambda R_m \left[\frac{d w_p}{dr} + \frac{w_p}{r} \right] + \left[\frac{d^2 B}{dr^2} + \frac{1}{r} \frac{dB}{dr} \right] = 0 \qquad (18)$$

The boundary conditions (10) (in dimensionless form) are reduces to the form-

$$\frac{d w_c}{dr} = 0, B = b_0' \text{ at } r = 0$$

$$w_p = 0, B = b_s' \text{ at } r = R(z)$$

$$w_c = w_p, \, \tau_c = \tau_p, \, B = b_1' \text{ at } r = R_1(z)$$

(19)

The total flow rate $\overline{Q}(\bar{z})$ is determined as-

$$\overline{Q} = \overline{Q}_c + \overline{Q}_p$$

where $\overline{Q}_c$ and $\overline{Q}_p$ are flow rates corresponding to core and peripheral layers respectively, given by-

$$\overline{Q}_c = 2\pi \int_0^{\overline{R}_1/\overline{R}_0} \overline{rw}_c \, d\overline{r} \quad \text{and} \quad \overline{Q}_p = 2\pi \int_{\overline{R}_1/\overline{R}_0}^{\overline{R}/\overline{R}_0} \overline{rw}_p \, d\overline{r}$$

The dimensionless volumetric flow rate $Q(z)$ is given by the formula

$$Q = 4\left[\int_0^{R_1(z)} rw_c \, dr + \int_{R_1(z)}^{R(z)} rw_p \, dr \right] \tag{20}$$

where $Q = \dfrac{\overline{Q}(\overline{z})}{\overline{Q}_0}$ and $\overline{Q}_0 = \dfrac{\pi \overline{C} R_0^4}{8\overline{\mu}_2}$.

The wall shear stresses of the flow at the vessel wall and the interface of the fluid is given by

$$\overline{\tau}_{\overline{R}(\overline{z})}\big/_{\overline{R}_0} = \left(-\mu_p \frac{\partial \overline{w}_p}{\partial \overline{r}}\right)_{\overline{r}=\overline{R}(\overline{z})} \quad \text{and} \quad \overline{\tau}_{\overline{R}_1(\overline{z})}\big/_{\overline{R}_0} = \left(-\overline{\mu}_c \frac{\partial \overline{w}_c}{\partial \overline{r}}\right)_{\overline{r}=\overline{R}_1(\overline{z})}$$

The dimensionless form of the wall shear stresses of the fluid are

$$\tau_{R(z)} = \left(-\frac{1}{2}\frac{\partial w_p}{\partial r}\right)_{r=R(z)} \quad \text{(at the vessel wall)}$$

$$\tau_{R_1(z)} = \left(-\frac{1}{2}\mu_c \frac{\partial w_c}{\partial r}\right)_{r=R_1(z)} \quad \text{(at the interface)} \tag{21}$$

where $\tau_{R(z)} = \dfrac{\overline{\tau}_{\overline{R}(\overline{z})}}{\overline{\tau}_0}$, $\tau_{R_1(z)} = \dfrac{\overline{\tau}_{\overline{R}_1(\overline{z})}}{\overline{\tau}_0}$ and $\overline{\tau}_0 = \dfrac{CR_0}{2}$

The equations (15) to (18) for velocities of the flow are solved numerically using Shooting method. Similarly the volumetric flow rate and wall shear stresses are also evaluated numerically with the help of that method for various parameters from equations (20) and (21) respectively.

IV. RESULTS AND DISCUSSION

.The problem under consideration is a two layered model of blood flow in composite stenosed artery under the effect of applied magnetic field through porous medium. It reduces to a boundary value problem given by the equations (15) to (18). This problem is solved numerically using Shooting method. Numerical calculations have been done for various combinations of parameters i.e. the magnetic parameters (Hartmann numbers M_1 and M_2), Reynolds number Re, Magnetic Reynolds number Rm, Permeability constant K. The axial velocity profiles, flow rate and wall shear stresses are computed for the various parameters.

Numerical results are shown graphically by using the following parameter values- $\alpha = 0.9$, $L_0 = 1.8$, d = .2, δi =.1, δs =.15, C=.51, R_0=1, R_1=.01, Re=10, k=2. Values of Hartmann number, M_1=1,2,3,4; M_2=3,4,5,6; Reynolds number Re=1,2,3,4,5,6,7,8,9; Magnetic Reynolds number Rm=.5,1,1.5,2,2.5,3 and Permeability constant K=.2,.5,1 are used in this analysis. It has been observed that the effect of the parameters on the velocity field, flow rate as well as wall shear stress is very prominent.

In figure 2, axial velocity profiles for both central layer (w_c) and peripheral layer (w_p) are studied for different values of the magnetic parameters (Hartmann numbers M_1 and M_2). It is seen that as the Hartmann numbers increases, the velocity of the fluid decreases in both the layers of the flow. It can also be seen that in the absence of the external magnetic field (M=0), the fluid's velocity is higher than in its presence (M > 0). Therefore, the presence of an external magnetic field reduces blood's velocity and as the intensity of the magnetic field is increased, it is further reduced [21]. This occurs due to the opposing Lorentz's force that is introduced when the magnetic field is applied. Hence, magnetic field can be used to control blood flow. Also it is observed that fluid velocity is almost constant as radial distance increases from the axis of the tube and near the wall it decreases i.e. in the peripheral layer fluid velocity decreases with the increase of radial distance 'r'.

From figure 3, we have seen the axial velocity profiles for different values of permeability constant K. It is observed that increase of permeability constant K, yields the rise of fluid velocity. Effect of Reynolds number Re on velocity profile is shown in figure 4. It is noticed that as the Reynolds number increases, fluid velocity is also increases. The velocity is seen to be almost constant as we move along the radial distance from the axis of the tube and near the wall (i.e. in the peripheral region) it decreases.

In figure 5, the magnetic field strength for different values of magnetic Reynolds number Rm are observed. As the values of Rm increases, the strength of the magnetic field is also increases. So with the variation Rm ,the magnetic field effect as well as the blood flow in the tube can be controlled.

Variation of flow rate Q with Reynolds numbers for different values of Hartmann numbers are discussed in figure 6. It is seen that as the Hartmann numbers increases, the flow rate decreases. Also for a fixed pair of values of Hartmann numbers, it is noticed that with the increase in the values of Reynolds number, the flow rate increases.

In figure 7, flow rate Q against axial distance for different values of Hartmann numbers are studied. It is seen that for a fixed pair of values of Hartmann numbers, the flow rate is maximum in the initiation of the stenosis (d=.2) and it reduces to minimum at the stenosis throat (d=1.1) and again it goes on increasing and become maximum at the end of the stenosis. Also it observed that the flow rate is higher in the absence of the magnetic field than in its presence. As the intensity of the magnetic field increases, (i.e. M_1 and M_2 increases) the flow rate decreases.

Figure 8 describes the combined behavior of the ratio of radius of central layer to the radius of unobstructed artery (α), magnetic field and porosity. The increase in the value of α results in decrease of thickness of peripheral layer, hence it is reported that decrease in thickness of peripheral layer causes increase in flow rate under the effect of magnetic field.

Figure 9 describes the variation of shear stress at the wall with magnetic field (M_2) for different values of Reynolds number Re. As the Reynolds number increases wall shear stress also increases with the increase in magnetic field intensity. The figure 10 shows the variations of shear stress with stenosis height for different values of Hartmann numbers M_1 and M_2. It is seen that for fixed value of stenosis height, shear stress rises with rise in the values of Hartmann numbers. Also as the stenosis height δs, increases the shear stress on the wall increases in the presence of the magnetic field. Therefore, the larger the stenosis gets, the greater force is exerted on the wall. Thus exposure to an external magnetic field increases the shear stress at the stenosis and as the intensity increases the shear stress is further increased which may lead to plaque rupture [21].

The variations of shear stress with stenosis height δs for different values of permeability constant K is shown in figure 11. It is noticed that for fixed value of stenosis height, the shear stress rises with the rise in the values of permeability constant K which leads to more and more deposition of LDL molecules along the walls of artery and ultimately forms the arteriosclerotic plaques and retards the blood flow.

V. CONCLUSIONS

In the present analysis, we consider a two-layered model of blood flow in the presence of an applied magnetic field. The blood flowing in central layer is considered to be Newtonian fluid with variable viscosity and the periphery region of the vessel comprises of plasma layer whose flow is considered as Newtonian and of constant viscosity. The fluid velocity, flow rate and wall shear stress are examined numerically. From the above discussions the following observations have been made:

1. Hartmann number retards the fluid velocity. The fluid velocity decreases as the magnetic field is introduced and as its intensity is increased.
2. Reynolds number accelerates the fluid velocity.
3. Fluid velocity increases with the increase in values of permeability constant.
4. Magnetic Reynolds number enhance the magnetic field strength.
5. Flow rate increases with the increase of Reynolds number and decreases with the increase of magnetic field intensity.
6. Flow rate is maximum at the initiation of the stenosis and minimum at the throat of the stenosis.
7. The presence of peripheral layer causes reduction in flow characteristics of the blood flow in stenosed artery under the effect of magnetic field through porous medium.
8. Wall shear stress shows higher values with the increase of Reynolds number and it also increases with the increase of the values of the magnetic parameter.
9. Wall shear stress increases with the increase of the stenotic height.
10. The rise in shear stress at the walls of stenosed artery with increase in the value of permeability constant, results in increase of net uptake of LDL along the walls of blood vessel leads to formation of stenosis.
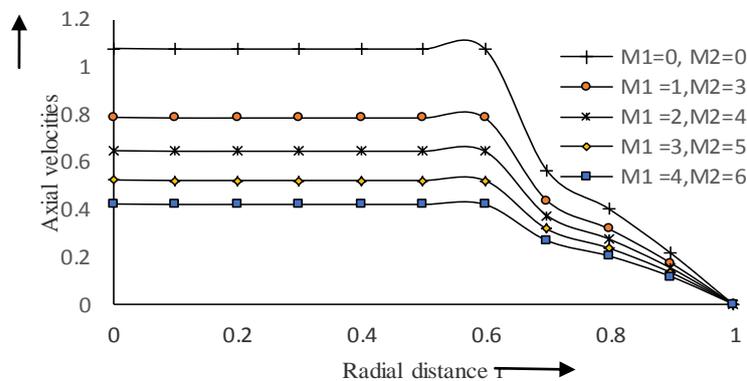

Fig 2. Variation of axial velocities for different values of Hartmann numbers M_1 and M_2 at Re=10.
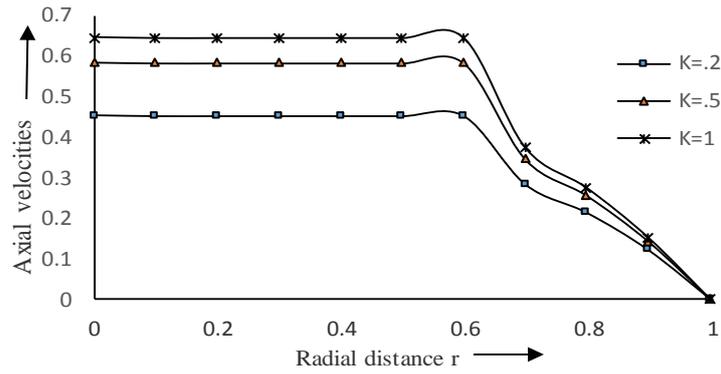
Fig 3. Variation of axial velocities for different values of Permeability Constant K at Re=10
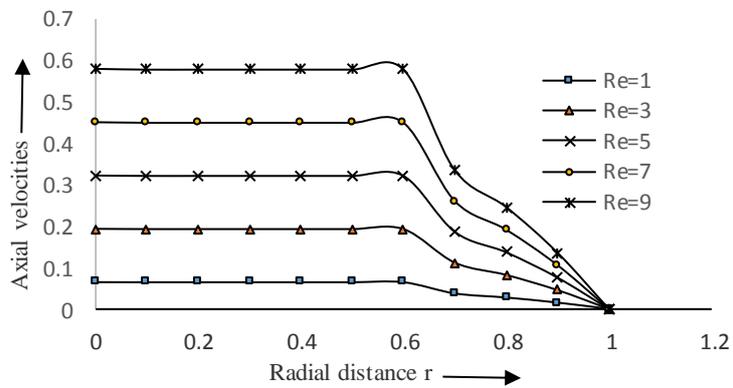

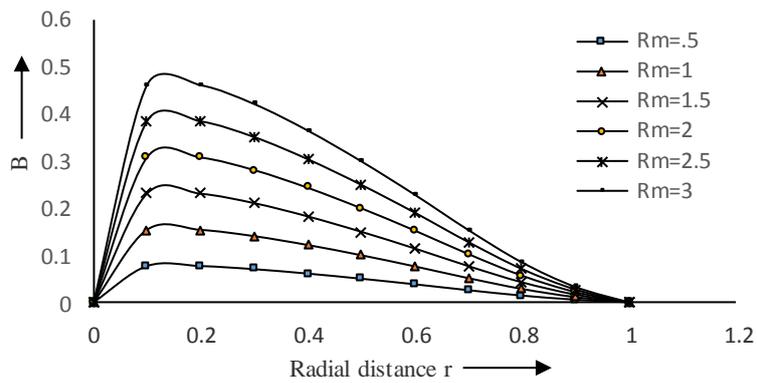Fig 4. Variation of axial velocities for different values of Reynolds number Re.

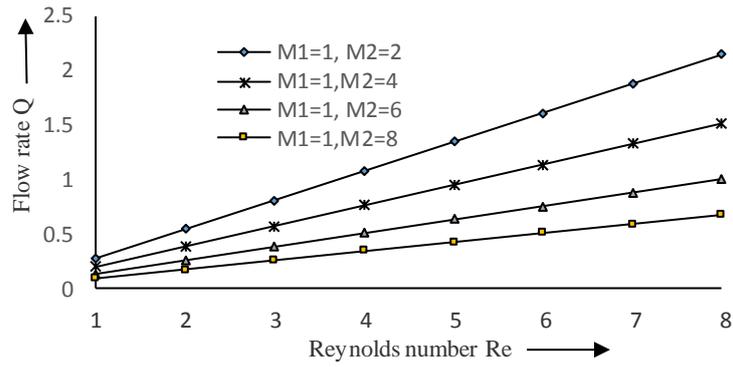Fig 5. Variation of magnetic field strength for different values of Magnetic Reynolds number Rm.

Fig 6. Variation of Volumetric flow rate Q with Reynolds number Re for different values of Hartmann number M2.
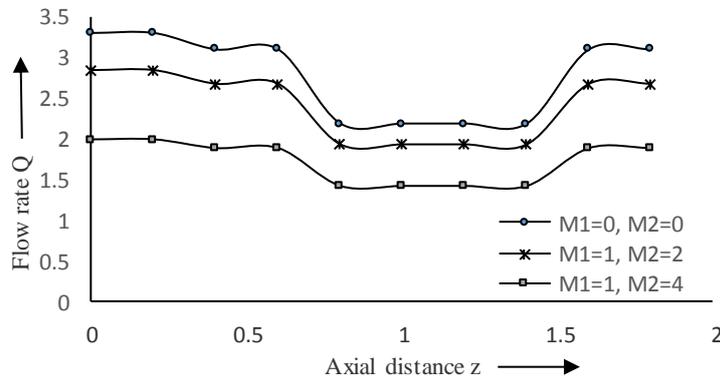

Fig 7. Variation of Volumetric flow rate Q against axial distance with different values of Hartmann numbers.
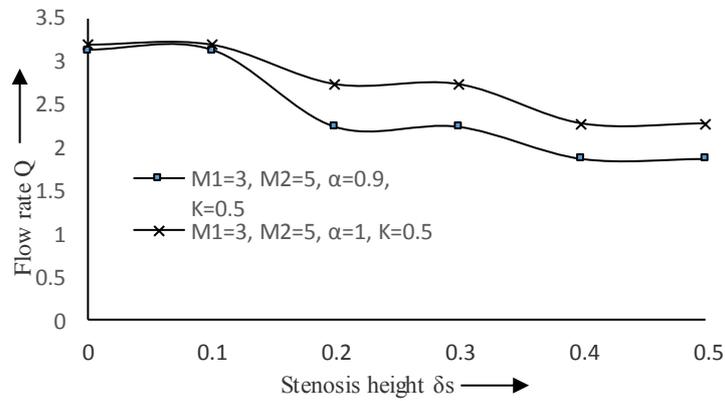
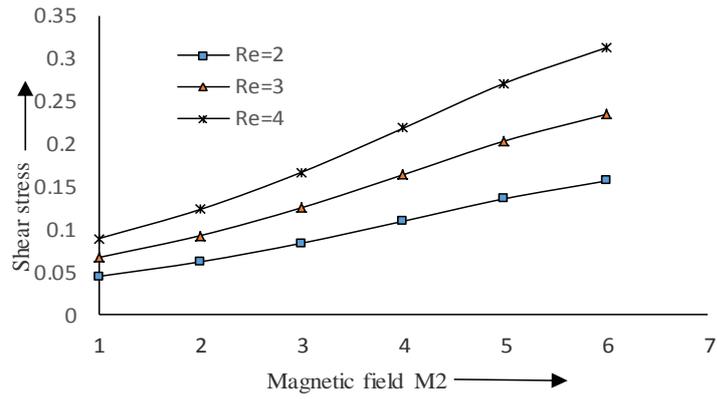Fig 8. Variation of Volumetric flow rate Q against stenosis height δs with different values of α.

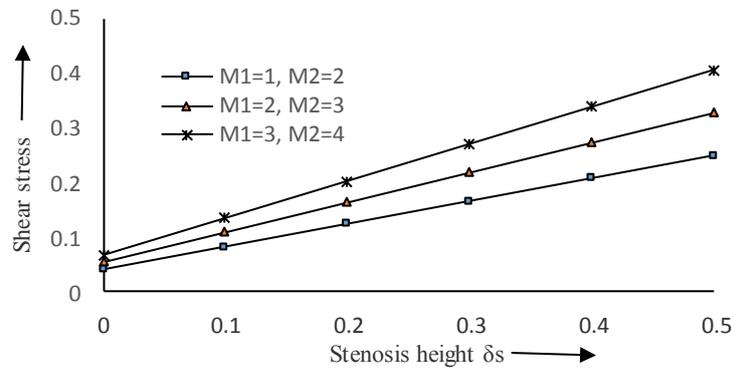Fig 9. Variation of Shear stress with magnetic field for different values of Reynolds number Re.

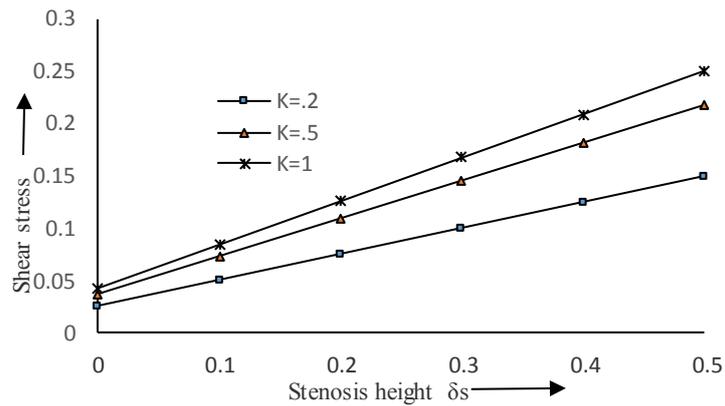Fig 10. Variation of Shear stress with stenosis height δs for different values of Hartmann numbers.

Fig 11. Variation of Shear stress with stenosis height δs for different values of Permeability constant K.

REFERENCES

[1]   Rathee, R. and Singh, J. 2013. Analysis of two-layered model of blood flow through composite stenosed artery in porous medium under the effect of magnetic field. Journal of Rajasthan Academy of Physical Sciences. 12(3), 259-276.

[2]   Misra, J. C. and Shit, G. C. 2006. Blood flow through arteries in a pathological state: A theoretical study. International Journal of Engineering Science. 44,662-671.

[3]   Mukherjee, S., Sharma, R., Chandra, P., Radhakrishnamacharya, G., and Shukla, J. b. 1983. Effects of peripheral layer consistency on blood flow in arteries with non-uniform cross-section and multiple stenosis. Physiological Fluid Dynamics. Proceeding of the First International Conference on Physiological Fluid Mechanics. September 5-7, 57-61.

[4]   Shukla, J. B., Parihar R. S. and Rao, B. R. P. 1980. Effects of stenosis on non-Newtonian flow of the blood in an artery, Bulletin of Mathematical Biology, 42, 283-294.

[5]   Shukla, J. B., Parihar, R. S. and Gupta, S. P. 1980. Effects of Peripheral Layer Viscosity on Blood Flow through the Artery with Mild Stenosis, Bulletin of Mathematical Biology, 42, 797-805.

[6]   Young D. F. 1968. Effect of a Time- Dependent Stenosis on Flow through a Tube, Journal of Engineering and Industrial Transactions ASME, 90, 248-254.

[7]   Kapur, J. N. (1985). Mathematical Models in Biology and Medicine, Affiliated East-West Press, New Delhi.

[8]   Misra, J. C. and Chakravarty, S. 1986. Flow in Arteries in the Presence of Stenosis, Journal of Biomechanics, 19, 907-918.

[9]   Biswas, D. 2000. Blood Flow Models: A Comparative Study, Mittal Publications, New Delhi, India.

[10] Biswas, D. and Laskar, B. R. 2011. Influence of magnetic field and slip velocity on pulsatile blood flow through a constricted artery. International Journal of Pharmaceutical and Biomedical Research. 2(4), 227-232.

[11] Kolin, A., Proc. Soc. Exp. Biol. Med. 1963, 35, 53.

[12]Korchevskii, E. M. , Marochunik, L. S., 1965.Biophysics, 10, 411.

[13] Sanyal, D. C., Das, K. and Debnath, S. 2007. Effect of magnetic field on pulsatile blood flow through an inclined circular tube with periodic body acceleration. Journal of Physical Sciences.11, 43-56.

[14] Suri, P.K. and Suri, P. R. 1981. Effect of static magnetic field on blood flow in a branch. Indian Journal of Pure and Applied Mathematics.12 (7), 907-918.

[15] Haldar, K. and Ghosh, S. N. 1994. Effects of a magnetic field on blood flow through an indented tulie in the presence of erythrocytes. Indian Journal of Pure and Applied Mathematics. 25(3), 345-352.

[16] Halder, K. and Andersson, H.I. 1996. Two-layered model of blood flow through stenosed arteries. Acta Mechanics, 117, 221-228.

[17] Ponalagusamy, R. 2007. Blood flow through an artery with mild stenosis. A two-layered model, different shapes of stenoses and slip velocity at the wall. Journal of Applied Science. 7(7), 1071-1077.

[18] Chakravarty, S., Sarifuddin and Mandal, P. K. 2004. Unsteady flow of a two-layered blood stream past a tapered flexible artery under stenotic conditions. Comp. Methods in Appl. Math., 4(4), 391-409.

[19] Ponalagusamy, R. and Selvi, T. R. 2011. Blood flow through stenosed artery : New formula for computing peripheral plasma layer thickness. International Journal of Bio-Science and Bio-Technology. 3(1), 27-38.

[20] Joshi, P., Pathak, A. and Joshi, B.K.2009. Two-Layered Model of Blood Flow through Composite Stenosed Artery. Application and Applied Mathematics, 4(8), 343-354.

[21] Sankar, A. R., Gunakala, S. R. and Comissiong, D. M. G. 2013.Two-layered blood flow   through a composite stenosis in the presence of a magnetic field. International Journal of Application or Innovation in Engineering and Management.2 (12). 30-41.

[22] Srivastav, R. K., Ahmed, Q. S. and Khan, A. N. 2013. Two-phase model of blood flow through a composite stenosis in the presence of a peripheral layer. Journal of Multidisciplinary Scientific Research. 1(5), 39-45.

[23] Biswas, D. and Barbhuiya, B. H. 2014. Two-layered Newtonian model for blood flow through tarering asymmetric stenosed artery with velocity slip at the interface. Journal of the Indian Academy of Mathematics. 36(1), 167-185.

[24] Sharma, P. K., Ali, S. and Katiyar, V. K., Mathematical modeling of heat transfer in blood flow through stenosed artery. Journal of Applied Science Res. 7(1), 68-78.

[25] Bali, R. and Awasthi, U. 2012. A Casson fluid model for multiple stenosed artery in the presence of magnetic field. App. Math. 3, 436-441.