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NUMERICAL SIMULATION OF BLOOD FLOW WITH SODIUM ALGINATE (SA) NANO PARTICLES IN STENOSED HUMAN ARTERIES IN THE PRESENCE OF BODY ACCELERATION

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ABSTRACT

Numerical simulation of blood flow with sodium alginate nano particles in stenosed human arteries in the presence of body acceleration is obtained. Effect of sodium alginate (SA) nano particles in the presence of body acceleration is observed on velocity, flow rate and resistive impedance to blood flow in stenosed human artery. The governing equations are discretized by explicit finite difference scheme. The discretized equations are the simulated using MATLAB. Velocity, flow rate and impedance to flow are observed to be influenced in the presence of both nano particles as well as body acceleration. The joint effect of nano particles and body acceleration is also observed. Resistance to flow is observed to be less in the presence of nano particles. This nano particle drug delivery may be useful for patients having cardiovascular diseases.

Key words: Nano fluid, stenosed artery, body acceleration, sodium alginate nano particles

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1. INTRODUCTION

Nano particle drug delivery is rapidly developing tool for treating various diseases. Nanomedicine is the science where materials in the nanoscale range are delivered to targeted part in controlled manner. Nowadays, nanotechnology is useful for enhancing efficacy of

natural bioactive compounds. Atheroclerosis is the most common disease that affects the cardio-vascular vessel. The disease developed due to deposition of fatty material inside an artery which leads to the blood flow disorder. Reduction in the space of the lumen of artery due to deposition of fatty material is called stenosis. Stenosis causes cardiovascular disorders which is cause of deaths of so many people worldwide. Therefore study of blood flow through stenosed region in the presence of nano particles is an important area of research.

P. Ghosh et al [1] studied role of Gold nano particles in drug delivery applications. Effects of nanoparticles and slip on blood as Jeffrey fluid through tapered artery with mild stenosis was studied by S. U. Rahman et al [2].Influence of parameters namely Brownian diffusion coefficient, thermospheric diffusion parameter, Grashof number and material constant of Jeffrey fluid on variation in velocity, temperature and concentration was studied.

R. Ellahi et al [3] studied blood flow of Jeffrey fluid in a catherized tapered artery in the presence of nanoparticles. They used homotopy perturbation method for solving nonlinear coupled equations of nano fluid model. They calculated expressions for velocity profile, impedance and pressure rise. Convection effects of heat transfer with catheter are also studied. S. Nadeem et al (2016) [4] discussed stenosis hemodynamics in the presence of nano particles as well as magnetic field. They used copper and silver nano particles as drug carrier. Analytic solution of fluid temperature, axially induced magnetic field, velocity and current density distribution is obtained. They also compared effectiveness of silver nano particles over copper nanoparticles. Transport characteristics of non-spherical gold nanoparticle as a drug delivery agent suspended in the blood flowing through an irregular shape stenosed artery in the presence of magnetic field was studied by Changdar et al [5]. They observed that the non-spherical coefficient in the presence of magnetic field plays important role in effective drug delivery.

A. Ahmed [6] studied arterial flow of copper nanoparticles in catheterised arteries in the presence of overlapping stenosis. They solved the governing equations using perturbation approximation to compute velocity, resistance to flow and wall shear stress distribution of nano fluid. Jamil D. F et al [7] studied effect of magnetite(Fe_3O_4), Titanium oxide (TiO_2) and copper (Cu) nanoparticles on unsteady blood flow through stenosed arteries in the presence of periodic body acceleration. They modelled blood as non-Newtonian Bingham plastic fluid. Ponalagusamy R. [8] et al studied blood flow through porous arterial stenosis in the presence of periodic body acceleration and magnetic field. They modelled blood as Herschel–Bulkley fluid. They observed effect of power law index, Hartmann number on wall shear stress and flow resistance.

Effect of sodium alginate (SA) nano particles on velocity, flow rate and resistive impedance to blood flow in stenosed human artery in the presence of body acceleration is not yet studied. Therefore we have attempted to study nano particle drug delivery in blood flow experiencing body acceleration. This study may be useful in the development of medical treatments to cardiovascular patients and for diagnostics purpose.

2. GOVERNING EQUATIONS

The segment of stenosed artery of length L is considered as cylindrical tube containing Newtonian fluid representing the flowing blood. The geometry of the stenosis is presented in figure 1. The flow is assumed to be laminar, unsteady, two dimensional and axisymmetric. The mathematical model can be expressed by conservation of mass, momentum and temperature from S. Nadeem et al [9],

$$\frac{\partial u}{\partial r} + \frac{u}{r} + \frac{\partial w}{\partial z} = 0 \qquad (1)$$

$$\rho_{nf}\left(\frac{\partial u}{\partial t} + u\,\frac{\partial u}{\partial r} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial r} + \left(\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r} - \frac{u^2}{r^2} + \frac{\partial^2 u}{\partial z^2}\right) \quad (2)$$

$$\rho_{nf}\left(\frac{\partial w}{\partial t} + u\,\frac{\partial w}{\partial r} + w\frac{\partial w}{\partial z}\right) = -\frac{\partial p}{\partial z} + \mu_{nf}\left(\frac{\partial^2 w}{\partial r^2} + \frac{1}{r}\frac{\partial w}{\partial r} + \frac{\partial^2 w}{\partial z^2}\right) + g(\rho\gamma)_{nf}(T - T_1) + B(t) \quad (3)$$

$$\left(\frac{\partial T}{\partial t} + u\,\frac{\partial T}{\partial r} + w\frac{\partial T}{\partial z}\right) = \left(\frac{k_{nf}}{(\rho C_p)_{nf}}\right)\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{Q_0}{(\rho C_p)_{nf}} \quad (4)$$

Where r and z are radial and axial directions respectively. u and w are radial and axial velocities respectively. μ_{nf}, ρ_{nf}, k_{nf} and γ_f are viscosity, density thermal conductivity, coefficient of thermal expansion of nano fluids. T is temperature of fluid, Q_0 is constant of heat absorption or heat generation. $\frac{\partial p}{\partial z}$ is pressure gradient which is given by S. Chakravarty et al [10] as $-\frac{\partial p}{\partial z} = A_0 + A_1 \cos \omega t$, where A_0 is contant amplitude and A_1 is amplitude of pulsatile component which results into systolic and diastolic pressure. Body acceleration term B(t) is given by P. K. Mandal et al [11] as

$B(t) = a_0 \cos(\omega_b t + \psi)$

a_0 is amplitude, ω_b is frequency and ψ is phase difference.

The dynamic viscosity μ_{nf} of the nano fluid is given as [9]

$$\mu_{nf} = \frac{\mu_f}{(1-\emptyset)^{2.5}}$$

Where $\emptyset$ is volume fraction of nano particles inserted.

Physical values of blood and nano particle are given by Akbar Zaman et al [12] and M. Hatami et al [13]

Parameters	Blood	Sodium alginate(SA)
C_p(J/KgK)	3594	4175
ρ (Kg/m^3)	1063	989
γ (1/K)	0.18	0.16
K (W/mK)	0.492	0.6376

3. THE GEOMETRY OF STENOSIS

Iqbal M. A. et al [14] described the time dependent geometry of the stenosis as

$$R(z,t) = a_1(t)\left\{a - \frac{\tau_m}{2}[1 + \cos\{\pi(z - l_1)/l_0\}]\right\} \quad \ldots\ldots d < z < d + 2l_0$$
$$= a a_1(t) \quad \ldots\ldots \text{Otherwise}$$

Where $a_1(t) = 1 + K_R \cos(\omega t - \psi)$ in which ω is angular frequency, ψ is the phase difference and K_R is a constant. l_1 is the centre of the stenosis, l_o is the half length of the stenosis region, τ_m is the maximum height of the stenosis and a is the radius of artery in non stenotic region. Arterial segment of length 3cm is considered for study.

4. BOUNDARY CONDITIONS

The velocities at the inlet and outlet of an arterial segment of finite length are taken as Sarifuddin et al [15] and S. Nadeem [9]

$$u(r,z,t) = 0 \text{ and } , w(r,z,t) = \frac{5}{3}\left(1 - \left(\frac{r}{R(z,t)}\right)^3\right) \text{ at z = 0} \quad (5)$$

$$\frac{\partial w(r,z,t)}{\partial z} = 0 = \frac{\partial u(r,z,t)}{\partial z} \text{ at z = L} \quad (6)$$

It is assumed that initially radial and axial velocity both are zero. That is when system is at rest there is no flow through artery

i.e. $u(r,z,0) = 0, w(r,z,0) = 0, T(r,z,0) = 0$ (7)

Axially, there is no radial flow, therefore the radial velocity is zero, the axial velocity gradient of the blood and temperature gradient may be assumed to be equal to zero. This may be stated as

$$\frac{\partial w}{\partial r} = 0, u(r,z,t) = 0, \frac{\partial T}{\partial r} = 0 \text{ on r = 0} \quad (8)$$

On the artery wall the axial velocity is zero due to no slip condition, temperature of the fluid is zero and radial velocity is rate of change in shape of the stenosis, which can be written as

$$w(r,z,t) = 0, u(r,z,t) = \frac{\partial R}{\partial t}, T(r,z,t) = 0 \text{ on r = R (z, t)} \quad (9)$$

5. NUMERICAL METHOD AND IMPLEMENTATION

Equations (3), (4) along with boundary conditions (5) - (9) take following form after introducing radial co-ordinate transformation, $x = \frac{r}{R\,(z,t)}$

$$\frac{\partial w}{\partial t} = \frac{1}{R}\left[x\left(w\frac{\partial R}{\partial z} + \frac{\partial R}{\partial t}\right) - u\right]\frac{\partial w}{\partial x} - w\frac{\partial w}{\partial z} + \frac{\mu_{nf}}{\rho_{nf}R^2}\left(\frac{\partial^2 w}{\partial x^2} + \frac{1}{x}\frac{\partial w}{\partial x}\right) - \frac{1}{\rho_{nf}}\frac{\partial p}{\partial z} + g(\gamma)_{nf}(T - T_1) + B(t) \quad (10)$$

$$\frac{\partial T}{\partial t} = \frac{1}{R}\left[x\left(T\frac{\partial R}{\partial z} + \frac{\partial R}{\partial t}\right) - u\right]\frac{\partial T}{\partial x} - T\frac{\partial T}{\partial z} + \left(\frac{k_{nf}}{(\rho C_p)_{nf}}\right)\frac{1}{R^2}\left(\frac{\partial^2 T}{\partial x^2} + \frac{1}{x}\frac{\partial T}{\partial x}\right) + \frac{Q_0}{(\rho C_p)_{nf}} \quad (11)$$

$$u(x,z,t) = 0 \text{ and } , w(x,z,t) = \frac{5}{3}(1 - x^3) \text{ at z = 0} \quad (12)$$

$$\frac{\partial w(x,z,t)}{\partial z} = 0 = \frac{\partial u(x,z,t)}{\partial z} \text{ at z = L} \quad (13)$$

$$u(x,z,0) = 0, w(x,z,0) = 0 \quad , T(x,z,0) = 0 \quad (14)$$

$$\frac{\partial w}{\partial x} = 0, u(x,z,t) = 0, \frac{\partial T}{\partial x} = 0 \text{ on x = 0} \quad (15)$$

$$w(x,z,t) = 0, u(x,z,t) = \frac{\partial R}{\partial t}, T(x,z,t) = 0 \text{ on x = 1} \quad (16)$$

Solving equation (10) and (11) using finite difference approximations in which central differences have been used.

$$\frac{\partial w}{\partial x} = \frac{w_{i,j+1}^k - w_{i,j-1}^k}{2\Delta x}$$

$$\frac{\partial w}{\partial z} = \frac{w_{i+1,j}^k - w_{i-1,j}^k}{2\Delta z}$$

$$\frac{\partial w}{\partial t} = \frac{w_{i,j}^{k+1} - w_{i,j}^k}{\Delta t}$$

$\frac{\partial^2 w}{\partial x^2} = \frac{w_{i,j+1}^k - 2w_{i,j}^k + w_{i,j-1}^k}{(\Delta x)^2}$

Where $x_j = (j-1)\Delta x, \quad z_i = (i-1)\Delta z$ and $t_k = (k-1)\Delta t$.

$\Delta x, \Delta z$, are increments in radial, axial directions respectively.

$$w_{i,j}^{k+1} = w_{i,j}^k + \Delta t \left\{ \frac{-1}{\rho_{nf}} \left(\frac{\partial p}{\partial z}\right)^{k+1} - w_{i,j}^k \left(\frac{w_{i+1,j}^k - w_{i-1,j}^k}{2\Delta z}\right) + \left(\frac{x_j}{R_i^k} w_{i,j}^k \left(\frac{\partial R}{\partial z}\right)_i^k + \frac{x_j}{R_i^k}\left(\frac{\partial R}{\partial t}\right)_i^k - \frac{u_{i,j}^k}{R_i^k}\right)\left(\frac{w_{i,j+1}^k - w_{i,j-1}^k}{2\Delta x}\right) + \frac{\mu_{nf}}{\rho_{nf}(R_i^k)^2}\left[\frac{w_{i,j+1}^k - 2w_{i,j}^k + w_{i,j-1}^k}{(\Delta x)^2} + \frac{1}{x_j}\left(\frac{w_{i,j+1}^k - w_{i,j-1}^k}{2\Delta x}\right)\right] + g(\gamma)_{nf}(T - T_1) + B(t)\right\} \quad (17)$$

$$T_{i,j}^{k+1} = T_{i,j}^k + \Delta t \left\{ T_{i,j}^k \left(\frac{T_{i+1,j}^k - T_{i-1,j}^k}{2\Delta z}\right) + \left(\frac{x_j}{R_i^k} T_{i,j}^k \left(\frac{\partial R}{\partial z}\right)_i^k + \frac{x_j}{R_i^k}\left(\frac{\partial R}{\partial t}\right)_i^k - \frac{u_{i,j}^k}{R_i^k}\right)\left(\frac{T_{i,j+1}^k - T_{i,j-1}^k}{2\Delta x}\right) + \left(\frac{k_{nf}}{(\rho C_p)_{nf}}\right)\frac{1}{R_i^k}\left[\frac{T_{i,j+1}^k - 2T_{i,j}^k + T_{i,j-1}^k}{(\Delta x)^2} + \frac{1}{x_j}\left(\frac{T_{i,j+1}^k - T_{i,j-1}^k}{2\Delta x}\right)\right] + \frac{Q_0}{(\rho C_p)_{nf}}\right\} \quad (18)$$

MATLAB simulation is used to solve equations (17) and (18) with boundary conditions (12)-(16). Flow rate and resistance to flow can be computed using

$$Q_i^k = 2\pi\left(R_i^k\right)^2 \int_0^1 x_j w_{i,j}^k \, dx_j \quad (19)$$

Resistance to flow (Resistive Impedance) is calculated using

$$X_i^k = \frac{\left|L\left(\frac{\partial p}{\partial z}\right)^k\right|}{Q_i^k} \quad (20)$$

6. RESULT

For numerical calculations following data have been used.

d = 6 mm, $l_0 = 7.5\,mm,\ l_1 = 5mm,\ L = 30\,mm, a = 0.8\,mm, \tau_m = 0.2a, A_0 = 100\,Kg\,m^{-2}s^{-2}, A_1 = 0.2A_0$.

Variation of axial velocity in radial direction at z = 1.45 cm is presented in figure 1. Axial velocity in stenosed artery in the absence and presence of nano fluid with body acceleration is described. 7 percent sodium alginate nano particles ($\emptyset\ (phi) = 0.07$) are inserted. After insertion of nano particles, velocity is observed to be increased. Also velocity decreases in radial direction and becomes zero at the wall. In figure 2 flow rate distribution over the length of the artery is described. In the presence of nano particles, flow rate is more in comparison with flow in the absence of nano particles.

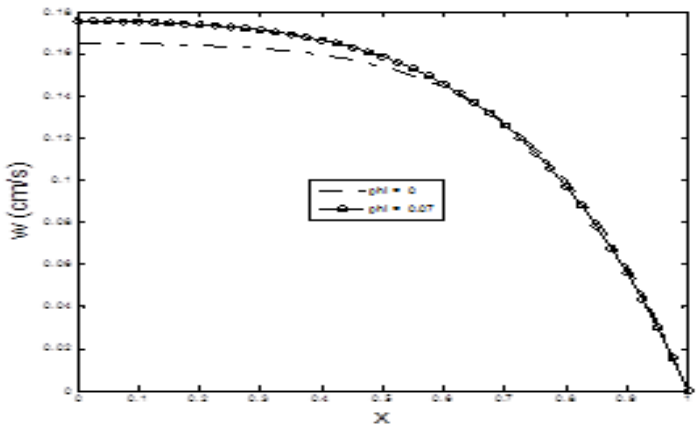

Figure 1. Variation of axial velocity in radial direction at z=1.5 cm

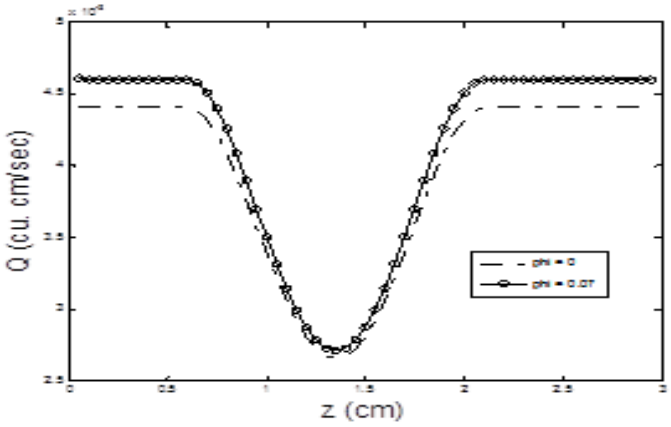

Figure 2. Flow rate distribution in axial direction

In figure 3, resistive impedance over the length of the artery is presented. It is oberved that in the presence of nano particles, resistive impedance is less as compared to resistive impedance in the absence of nano particles. Axial variation of axial velocity is presented in figutre 4. It is observed to follow shape of the stenosis. In the presence of nano particles axial velocity is more than axial velocity in normal blood flow.

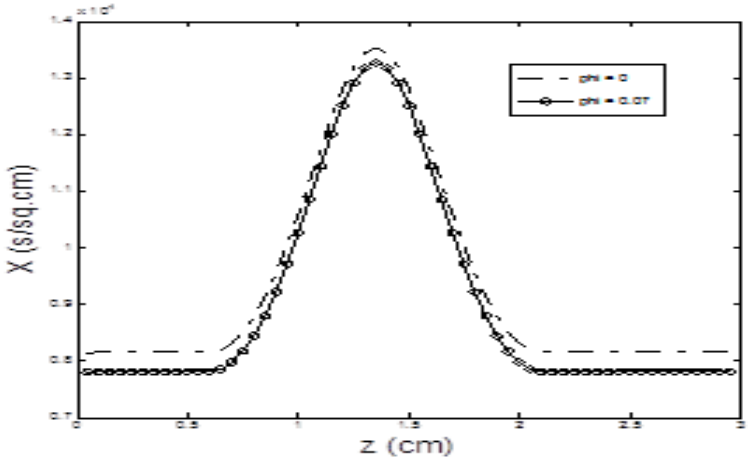

Figure 3. Resistance to flow (Impedance) distribution over length of artery

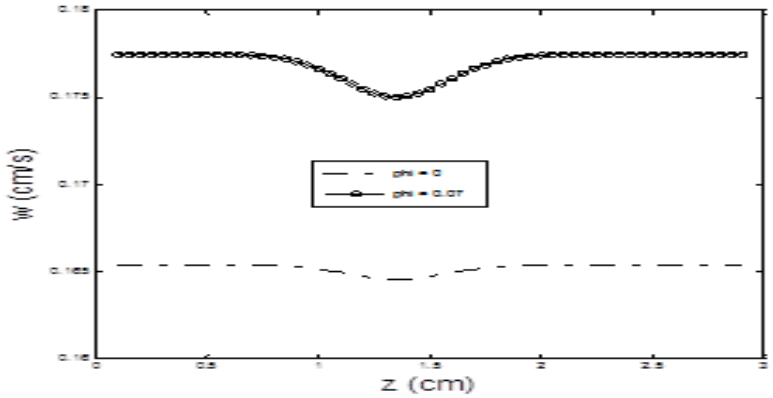

Figure 4. Axial variation of axial velocity

Figure 5 is comparison of radial velocity in the presence and in the absence of body acceleration. In the presence of body acceleration, velocity is observed to be increased. The combine effect of nano particles and body acceleration term influences the flow velocity. Comparison of flow rate in the presence and in the absence of body acceleration is presented in figure 6. It is observed that flow rate is increasing when an individual is experiencing body acceleration.

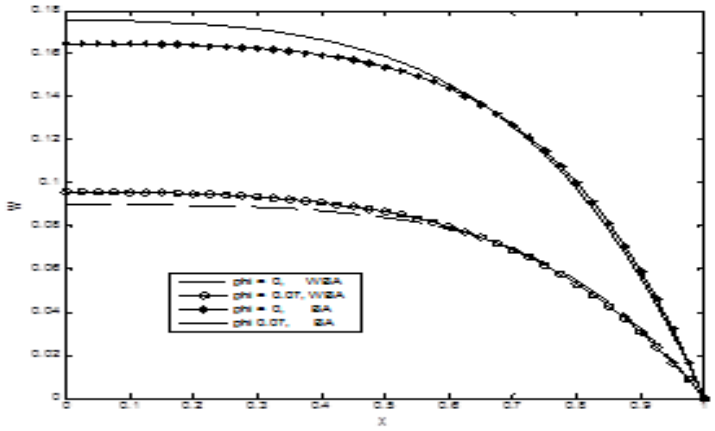

Figure 5 Radial variation of axial velocity without (WBA) and with body acceleration (BA)

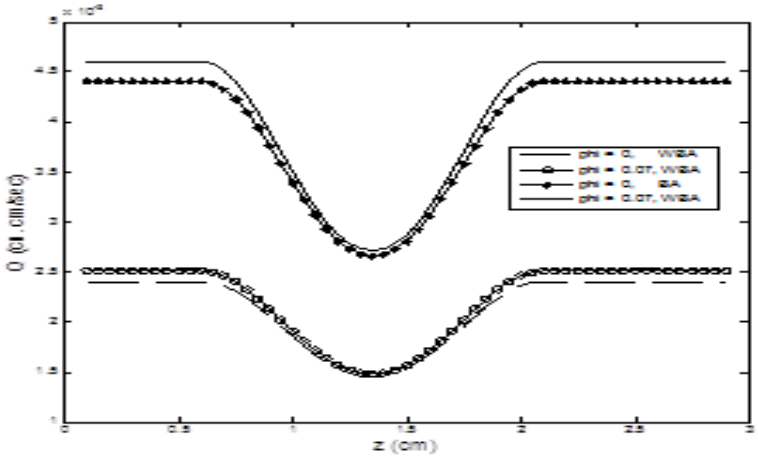

Figure 6. Flow rate distribution in axial direction without (WBA) and with body acceleration (BA)

Figure 7 is distribution of resistance to flow with nano particles in the presence and in the absence of body acceleration. The joint effect of insertion of nano particles as well as body acceleration term is found to be more beneficial. There is less resistance to flow when nano particles are inserted in normal flow. When we observe joint effect of both these factors, resistance is notably less.

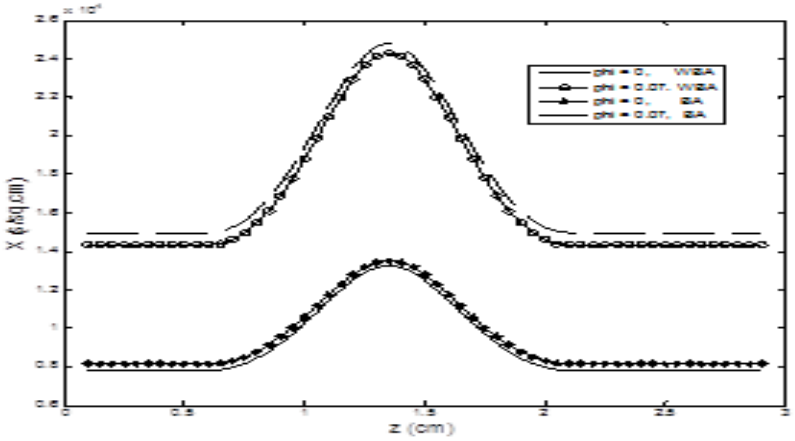

Figure 7 Distribution of resistance to flow over length of artery without (WBA) and with body acceleration (BA)

7. CONCLUSION

This study is useful in the development of medical treatments to cardiovascular patients and for diagnostics purpose. The increase of axial velocity and flow rate in constricted region experiencing body acceleration in the presence of nano particles may be useful for treating patients having cardiovascular diseases. The joint effect of nano particles and body acceleration will be more helpful as it offers less resistance to flow inside the stenosed region.

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