Impact of Inclined Embolism on the Flow of Jeffrey Fluid in a Capillary

C. H. Badarinarayana
Department of Mathematics
CSTS Governament Kalasaa, Jangareddy Gude, West Godavari District, Andhra Pradesh, India

P. Devaki*
Department of Mathematics
SRM Institute of Science and Technology, Ramapuram, Chennai, Tamilnadu, India

Abstract- **Influence of inclination and embolism on the flow of Jeffrey fluid in a tube. Closed from solutions are obtained from the governing equations of the fluid flow. Stream function, velocity and flux are derived from equations governing the flow phenomenon. Effect of Jeffrey parameter, inclination, stenosis length, stenosis height is observed on stream function, velocity, and flux. Interesting observations are made through graphical representation. These findings create interest among young researchers to develop new research in the field of biofluid flows with embolis**m.

Keywords – Embolism, Inclination, Jeffrey Fluid, Stream Function, Flux.

I. INTRODUCTION

In recent days transplantation of organs in human body is quite common. There are many reasons for arteries getting damaged, most cases are due to existing food habits formation of fatty plaque in blood vessels is a major issue. Apart from this due to accidents which is increasing day-by-day artery/vines/ capillary's get damaged. Based on these circumstances replacement of artery/vines/ vessels is well acceptable fact. Transplantation is done in two major ways: one is to replace artery/vines/ vessels from other body parts of patient, and other is to replace the damaged artery/vines/ vessels by artificial organs. If the damaged artery is replaced from patient's other body parts, then there is a chance of arteriosclerosis and some post-surgical complications. To avoid these complications, it is preferred to go for artificial organ replacement.

Researchers developed artificial organs and tested on animals for three months and it got succeeded. Usage of artificial organs is done from past 10 years. There are three different types of artificial organs produced: i) Fully automated, ii) Semi-automated and iii) hand worked. Every work has its own advantages and disadvantages. It is found and confirmed by the research institutes that there are few differences in original human organ and artificial organ in which two major points are flux of blood flow and blood clotting. Blood clotting is the most important point to be concentrated as it affects human body very badly. Based on these facts study biofluid flow in circular tubes in the presence of stenosis is required in deeper. Literature survey of past works done in this field of biofluids reveal the fact that research is not concentrated on few parameters like wavelength of the tube, inertial forces, viscous forces etc. in the presence of embolism in a tube.

Maruthi and Prabhakar [1] worked on flow of Nano fluid in a non-uniform artery under the influence of numerous stenosis and permeability. Some interesting observations are noted on shear stress and stream function under the impact of nano particle, temperature, permeability. A practical investigation on the severity of stenosis on flow of blood flow is done by Aliabar et al. [2]. Velocity is noted to be more with 40 percent of stenosis and radius of the cross section of the artery will be reduced with the increase in stenosis size. Woorak [3] concentrated on kinetic energy and its fluctuation on the bio fluid flow with vulnerable stenosis in vessels. Sriyab [4] noticed that if the geometry of the stenosis should be cosine and bell shaped to get higher flow rate and higher skin friction, respectively. Nano fluid flow in an artery with constriction was studied by Devaki et al. [5]. In this paper concentration was given to different shapes of the nano particles and stenosis effect on fluid flow. Jeffrey fluid is one among the simplest models of non-Newtonian fluids in the filed of fluid mechanics.

There are several research works done on the flow of Jeffrey fluids in tubes and channels in the presence of stenosis and in the absence of stenosis. Devaki et al. [6] focused on two fluid models with Jeffrey fluid as one of the fluids passing through a tube. The impact of volume of the blood is given more attention in this paper. The blood is modelled as immiscible fluids by considering Bingham fluid in core region and Jeffrey fluid in peripheral region was depicted by Badari et al. [7]. Ramesh Babu and Savita [8] study the effect of the multiple stenoses on the flow of Jeffrey fluid through an artery with some boundary conditions. Closed form solutions are derived from the governing equations. Expressions for velocity, flux and volumetric flow is obtained in terms of the other parameters. Several authors [9-11] focused on stenosis effect on biofluid flows in either tubes or in channels with interesting outputs.

Inclination of a tube or channel is also one of the major points to be concentrated in fluid flows. Usually in living organism's arteries or capillaries need not be in a properly defined position. In this point of view there are many studies carried out in point of inclination. Abudakar and Adeoye [12] concentrated on an inclined artery under the influence of mild stenosis. The governing equations of the fluid flow were solved using the method of differential transform with the help of Mathematica software. Immiscible fluid flows were noticed by Maklakov and Kayumov [13], in which the interphase of immiscible fluid is taken perpendicular to the tube wall. Experimental work on the turbulent flow of fluids in an inclined tubed with heat transfer was observed by Akeel et al. [14]. Authors [15-17] studied on various non-Newtonian fluid flows in tubes or cannel with inclination effect.

Many researchers studied so far concentrated on non-Newtonian fluid flow in a tube in the presence of stenosis. Present paper is concentrating on the flow of Jeffrey fluid in a circular tube with mild stenosis and inclination. The fluid flow is observed through graphs for velocity and flux under the influence of physical parameters.

II. Mathematical Formulation and Solution

Consider the steady flow of a Jeffery fluid through a tube with non-uniform cross section and with two embolisms. We consider the cylindrical polar co-ordinate system (r, z, ɵ) so that z – coincides with the center line of the channel. The embolism is mild and axially symmetric.

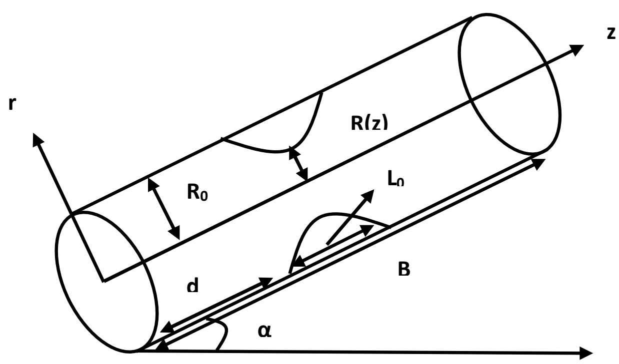

Figure.1. Flow pattern in the stenotic artery

The basic equation governing the flow is

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{r}{1+\lambda_1}\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial \psi}{\partial r}\right)\right)=\frac{1}{\mu}\frac{\partial p}{\partial z}-\rho g\sin\alpha \tag{1}$$

where λ_1 is Jeffery parameter, p is pressure, μ is viscosity of the fluid, R_0 is the radius of the tube.

The boundary conditions are

$$\psi=0,\ \frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial \psi}{\partial r}\right)=0 \quad \text{when} \quad r=0 \tag{2}$$

$$\frac{1}{r}\frac{\partial \psi}{\partial r}=0 \quad \text{when} \quad r=R(z) \tag{3}$$

Introducing the following non – dimensional variables

$$\bar{r}=\frac{r}{R_0},\ \ \bar{p}=\frac{pR_0^2}{\mu UB},\ \ \bar{w}=\frac{w}{U},$$
$$\bar{z}=\frac{z}{B},\ \bar{R}(z)=\frac{R(z)}{R_0},\ \bar{\psi}=\frac{\psi}{UR_0^2} \tag{4}$$

The non-dimensional radius of the tube is taken as

$$R(z)=\begin{cases}1 & \text{, in normal artery}\\ 1-\dfrac{\delta}{2R_0}\left[1+\cos 2\pi z\right], & d\le z\le d+L_0\end{cases} \tag{5}$$

Non dimensional governing equations after dropping bars

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{r}{1+\lambda_1}\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial\psi}{\partial r}\right)\right)=\frac{\partial p}{\partial z}-F \quad , \quad F=\frac{R_0^2\rho g\sin\alpha}{U} \tag{6}$$

The non - dimensional boundary conditions are

$$\psi=0,\ \frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial\psi}{\partial r}\right)=0 \quad \text{when} \quad r=0 \tag{7}$$

$$\frac{1}{r}\frac{\partial\psi}{\partial r}=0 \quad \text{when} \quad r=R(z) \tag{8}$$

Solving equation (6) by applying boundary conditions (7) and (8) the stream function and axial velocity can be obtained as

$$\psi=\left(\frac{\partial p}{\partial z}-F\right)\frac{1+\lambda_1}{4}\frac{r^2}{4}\left(2R^2(z)-r^2\right) \tag{9}$$

$$w=\left(\frac{\partial p}{\partial z}-F\right)\frac{1+\lambda_1}{4}\left(R^2(z)-r^2\right) \tag{10}$$

The volumetric flow rate is obtained as

$$Q=\left(\frac{\partial p}{\partial z}-F\right)\frac{(1+\lambda_1)}{16}R^4 \tag{11}$$

III. Results And Discussions

Effect of inclination and stenosis on the flow of non-Newtonian Jeffrey fluid in an artery is studied in this chapter. Influences of various physical parameters on velocity, flux and stream function are graphically observed.

Figures (2-5) represents change in velocity with respect to radius under the influence of parameters. In the model specified the stenosis is started from $z=4$ and it is noticed from figure (2) that velocity increases with respect to radius as z increases. This is because of the presence of stenosis, which slowdown the flow phenomenon. Figure (3) shows the variation of stenosis length on the velocity with respect to radius. It is observed that as the length of the stenosis increases there is a decrease in velocity. As the angle of inclination increases the speed of the fluid flow is increasing, which is depicted in figure (4). The non-Newtonian behavior is included in this chapter through Jeffrey parameter. From figure (5) it can be understood that as Jeffrey parameter increase the velocity is increasing.

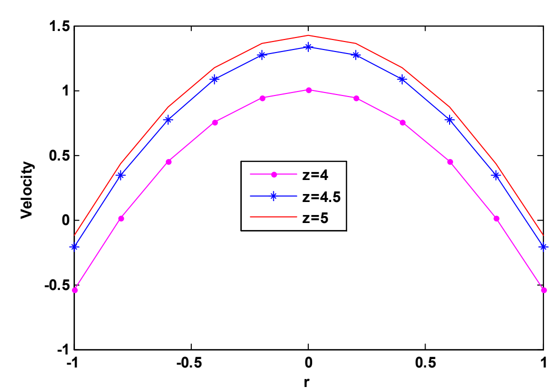

Figure 2: Velocity profiles at different z values

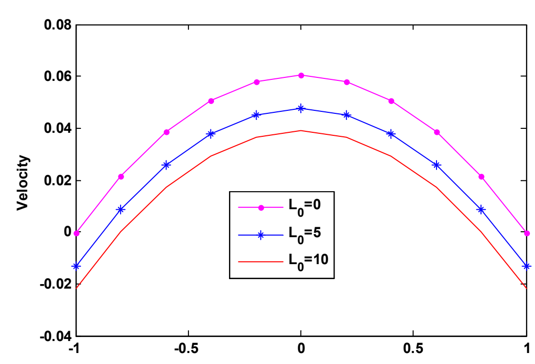

Figure 3: Velocity profiles for different stenosis lengths.

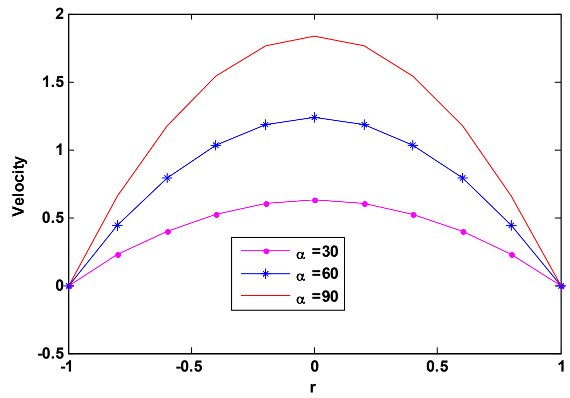

Figure 4: Velocity profiles for different angle of inclinations.

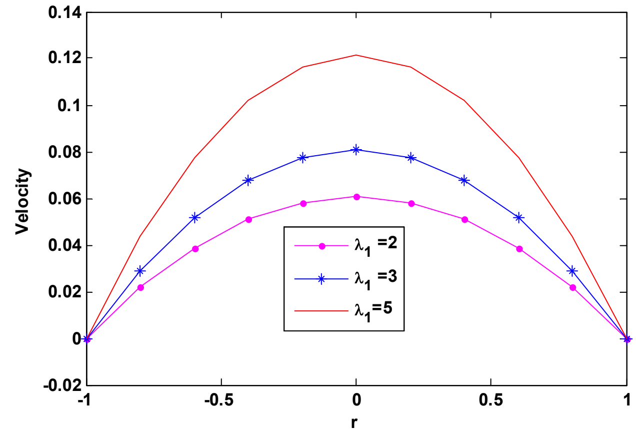

Figure 5: Velocity profiles for different values of Jeffrey parameter.

Impacts of various parameters on the flux are spotted in figures (6-9). Figure (6) says that flux of the fluid increases with increase in Jeffrey parameter. For increasing values in length of the stenosis, there is different flow pattern observed in the Jeffrey fluid, which can be spotted through figure (7). By figure (8), it is noticed that flow per unit area for a non-Newtonian Jeffery fluid decrease with the increase in angle of inclination. This is because as the direction of the tube is changed as per the angle of inclination the flow must undergo certain pressure, which reduces flow phenomenon. Figure (9) shows the change in flux with respect to the length of the tube for different values of stenosis height.

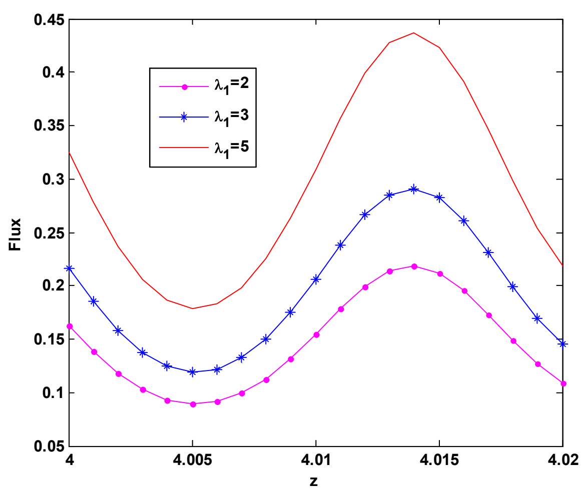

Figure 6: Flux for different values of Jeffrey parameter

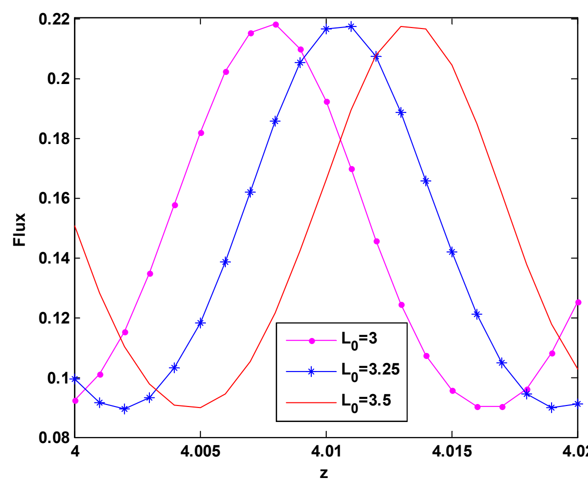

Figure 7: Flux with v for different stenosis lengths.

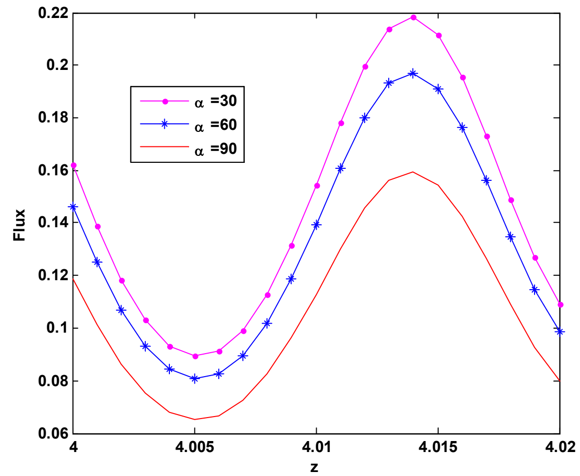

Figure 8: Flux with z for different values of angle of inclination.

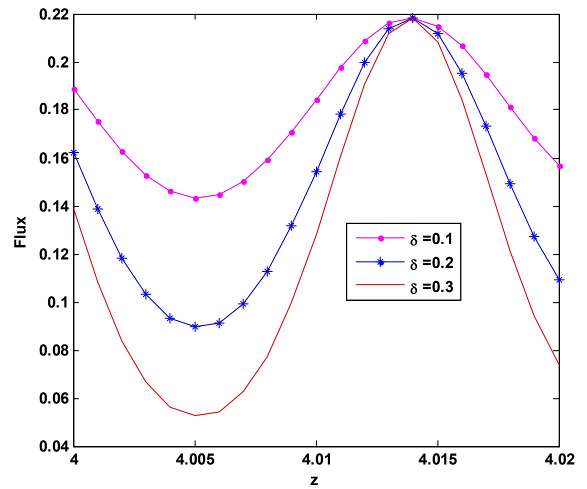

Figure 9: Flux with z for different values of stenosis height.

IV.CONCLUSION

Influence of stenosis and angle of inclination on non-Newtonian Jeffrey fluid is concentrated in this chapter. Stream function, velocity and flux are obtained by solving governing equations analytically. Change of many physical parameters on stream function, velocity and flux are exposed graphically through MATLAB software. Some of the findings are as below.

1. As the Jeffrey parameter increases, there is an increase in flow as well as in velocity of the fluid.
2. Increase in the values of angle of inclination finds increment in velocity and decrement in flux of Jeffrey fluid.
3. Velocity of the fluid decreases with the increase in length of the stenosis.
4. Flux of the fluid decreases with increment in height of the stenosis.

REFERENCES

[1] K. Maruthi Prasad and Prabhaker Reddy Yasa, "Flow of non-newtonian fluid through a permeable artery having non-uniform cross section with Multiple stenosis", *J. Nav. Archit. Mar. Eng.,* vol. 17, pp. 31-38, 2020.

[2] K. Aliabar, T. Davood, L. A. Abdulkareem, A. Alizadeh, Z. Majid, and Arash Karimipour, "Roll of stenosis severity, artery radius and blood fluid behavior on the flow velocity in the arteries: Application in Biomedical Engineering", *Med. Hypotheses*, vol. 144, p. 109864, 2020.

[3] C. Woorak, J. Hong Park, and J.L. Sang, "Flow induced stress on vulnerable stenosis in tandem stenosed vessels", *Phys. Fluids*, vol. 32, p. 101904, 2020.

[4] S. Sriyab, "The effect of Stenotic geometry and non-Newtonian property of blood flow through arterial stenosis", *Cardiovasc Hematol Disord Drug Targets*., vol. 20(1), pp. 16-30, 2020.

[5] P Devaki, B Venkateswarlu, S Srinivas, and S Sreenadh, MHD Peristaltic flow of a nanofluid in a constricted artery for different shapes of nanosized particles, *Nonlinear Eng*., vol. 9(1), pp. 51-59, 2019.

[6] P. Devaki, A. Subba Rao, Ram Prakash Sharma, and S. Sreenadh, "Impact of hematocrit on the flow of casson fluid in contact with Jeffrey fluid over a narrow pipe", *Indian J. Pure Appl. Phys.*, vol. 58 ,pp. 758-764, 2020.

[7] C. H. Badari Narayana, P. Devaki and S. Sreenadh, "Flow of Bingham fluid in contact with a Jeffrey fluid in a circular tube", *Int J Eng Res Man*, vol. 3(6), pp. 96-99, 2016.

[8] V. Ramesh Babu, and T. Savita, "Flow of Jeffrey fluid through an artery with multiple stenosis", *Int. J Eng. Dev. Res.*, vol. 7(2), pp. 473-477, 2019.

[9] Yasser Abuouf, Shinichi Ookawara, and Mahmoud Ahmed, "Analysis of the effect of guidewire position on stenosis diagnosis using computational fluid dynamics", *Computers in Biology and Medicine*, vol. 121, p. 103777, 2020.

[10] Puskar R. Pokhrel, Jeevan Kafle, Parameshwari Kattel, and Hari Prasad Gaire, "Analysis of blood flow through artery with mild stenosis", *J Inst Sci. Tech.*, vol. 25(2), pp. 33-38, 2020.

[11] Navid Freidoonimehr, Maziar Arjomandi, Nima Sedaghatizadeh, Rey Chin, and Anthony Zander, "Transitional turbulent flow in a stenosed coronary artery with a physiological pulsatile flow", *Int J Numer Method Biomed Eng,* vol. 36(7), 2020.

[12] J.U. Abubakar and A.D. Adeoye, "Effects of radioactive heat and magnetic field on blood flow in an inclined tapered stenosed porous artery", *Journal of Taibah University for Science*, pp. 77-86, 2019.

[13] D.V. Maklakov and I. R Kayumov, "Stratified Laminar Flows in Inclined Pipes", *Russ Math.*, vol. 63, pp. 77-82, 2019.

[14] Akeel Abdullah Mohammed, Ansam Adel Mohammed, and Luay Abdulmuttaleb Sadeq, "Heat transfer Augmentation in an Inclined Tube Using Perforated Conical Ring Inserts", *J. Mech. Eng. Res.*, vol. 43(5), pp. 204-217, 2020.

[15] T. D. Bennett, "Laminar Convection in Circular Tubes with Developing Flow", *J. Heat Transfer*., vol. 142, pp. 111803-111815, 2020.

[16] Xinyu Dong, QinchengBoi, Xiang Cheng, and Fan Yao, "Convective heat transfer performance of solar salt in an inclined circular tube", *Appl. Therm. Eng.,* vol. 178, p. 115349, 2020.

[17] Haitao Wang, Tao Tao, Xuesong Mei, Haijun Wang, and Hongfang Gu, "Experimental study on condensation heat transfer characteristics inside an inclined wave-finned flat tube of direct air-cooling system", *J. Therm. Sci.*, vol. 30, pp. 432–440, 2021.