A STUDY DRAG REDUCTION IN BLOOD FLOWS THROUGH A STENOTIC ARTERY OF SMALL DIAMETER

CHAPTER VII

7.1 INTRODUCTION

During the flow of any fluid there is always some resistance to flow during the flow process. Sometime this resistance is very high and some time it is present but can be negligible or it is not of much importance to measure it or reduce it. This resistance is known as the drag forces. This greater resistance always require more energy to transport fluid because this force reduces power required for pumping fluid in any process. So, our main concern to all engineering process is to reduce these forces [Virk (1971); Savena (1964)] either by suitable design and by the addition of some foreign materials known as the drag reducing agents. It is convenient to separate the total drag forces into two components:

(1) Skin friction drag force

(2) Pressure drag force.

The skin friction drag force is due to the viscous shear stress and pressure drag force is due to the normal shear stress. The skin friction drag is due to the viscous shear stress and pressure drag force is due to the normal shear stress. The skin friction drag is most important component of drag forces and in some situation, it is very effective component. The drag reduction [savins (1964)] can result a number of benefits in various situations, for example;

(1) We can reduce power consumption of a vehicle or to transport fluid from one place to another through a pipeline.

2) It results in reduction of friction in conduit [Tandon et. al. (1978)] in turn the power required for the pumping liquids.

(3) This drag reduction can result in lighter structure.

(4) The use drag reduction agents can improve the preformance of hydraulic machinery.

(5) It reduces pressure on heart in blood transport in blood vessels.

The earliest work published in the open literature on drag reduction by means of very dilute polymer solutions appear to have been is that of Toms (1949). In late 40's Toms was investigating the mechanical degradation of high polymeric solution in pipe flows. It is found that a solution of polymethyl methacrylate in monochlorobenzene required a lover pressure gradient than the solvent alone to produce the same flow rate. In late 50's the work is done in oil industry [Casson (1959); Ousterhout and Hall (1960); Hele-show (1987)] had noticed that when certain gums were sand-water mixture employed in oil well-techniques, the friction was decreased. was decreased. The experiment of the oil well with guar gum [Dever and Harbour (1962)] and in particular the contributions of Previtt and Crawford (1963) of the western research company, led to the Navy exploration of drag reducing effects for possible military application.

One of the first identification by some researchers Elperin et. al. (1966) spectacular “Drag reducing” ability of polyeotheylene oxide is most important effective friction reducing material known.

In human body presence of stenosis is one or more of the major vessels supplying blood to the brain can lead to cerebral accident [Eklof and Schwartz (1970)]. The drag thus increased due to the stenosis is reduced by a dilution process in medical practice known as Hemodilution in which only saline water is injected intravenously to dilute the blood and thus the drag is reduced. This naturally reduces the pressure on heart. In human body the stenosis is generally observed in the arterial Granches. Various mechanism like coupling between the growth of stenosis and the blood flow abnormal cellular growth etc. play an important role in gradual development of stenosis the presence of stenosis in circulatory system leads to hypertensive diseases.

Human circulatory system is very complex and it is very difficult to incorporate all physical and biological factors such as taperness, branching pulsatality, distensibility and the characteristics of biofluids. Neglecting taperness and pulsatality in comparison to rigid walled stenosis is reasonably good approximation to study the localised flow characteristics as considered by Tandon et al. (1976).

In this chapter, Casson fluid model is used to study the drag reduction phenomena in blood flows through straight and stenotic tubes. Assuming a mild stenosis inside the rube with central core region surrounded by the suspension of blood cells described by Casson's fluid with very thin peripheral layer as a true representation of blood given below

$$\bar{r}^{\frac{1}{2}} = \bar{r}_0^{\frac{1}{2}} + \mu^{\frac{1}{2}} \left[-\frac{d\bar{u}}{d\bar{r}}\right]^{\frac{1}{2}} \qquad \text{if } \bar{r} \geq r_0 \qquad (7.1)$$

$$\frac{d\bar{u}}{d\bar{r}} = 0 \qquad \text{if } r < r_0 \qquad (7.2)$$

where r_0 is yield stress and μ denotes viscosity coefficient.

7.2 FORMULATION OF THE PROBLEM

Considering a problem of drag reduction in blood flow through a tube of uniform diameter having symmetrical stenosis. The radius of such an artery is described by:

$$\bar{R} = R_0 - \bar{\varepsilon}\left(1 + \cos\frac{2\pi}{L_0}\left(\bar{z} - \frac{L_0}{2}\right)\right) \qquad (7.3)$$

where L_0 is the length of stenosis, $\bar{\varepsilon}$ is the maximum height of stenosis such that $\bar{\varepsilon} \ll 1$. R_0 is the unobstructed radius of the vessel. The stenosis developes right from the entry cross-section.

The governing equations of motion and continuity are:

$$0 = -\frac{\partial p}{\partial z} + \frac{1}{\bar{r}}\frac{\partial}{\partial \bar{r}}(\bar{r}\bar{r}) \qquad (7.4)$$

$$\frac{d\bar{p}}{d\bar{r}} = 0 \qquad (7.5)$$

$$\frac{\partial \bar{u}_c}{a\, z} + \frac{\partial}{\partial \bar{r}} (\bar{r}\, \bar{u}_c) = 0$$

Where $\bar{r}$ is the shear stress defined by the equation (7.1).

The boundary and matching conditions are:

$$\frac{\partial u}{\partial \bar{r}} = 0 \text{ at } \bar{r} = 0$$
$$\bar{u} = 0 \text{ at } \bar{r} = \bar{R} \quad (7.7)$$
$$\bar{p} = P \text{ at } \bar{z} = 0$$
$$\bar{p} = \bar{p}_L \text{ at } \bar{z} = L_0$$

To solve the above system of equations along with suitable matching and boundary conditions the following non-dimensional quantities are introduced by

$$\bar{r} = zL_{0^F} \quad \bar{\delta} = \delta R_{0^F} \quad \bar{L} = L\, L_{0^F} \quad \bar{r} = r\, L_{0^F}$$
$$\bar{r} = rr_{0\,F} \quad \bar{u} = uU_0 \,,\; \bar{P} = \frac{u_0}{r_0}\, p_{0^F}$$
$$\bar{P}_L = P_L \frac{PU_O}{r_O}.$$

The equation (6.3) takes the form

$$R = 1 - \delta(1 + \cos 2\pi(z - L/2)) \quad (7.8)$$

and the governing equations of motion and continuity are:

$$0 = -\frac{\partial p}{\partial z} + \frac{1}{r}\frac{\partial}{\partial r}(r\,r) \quad (7.9)$$

$$\frac{d_p}{dr} = 0 \quad (7.10)$$

$$\frac{\partial u_c}{\partial z} + \frac{\partial}{\partial r}(r\, u_c) = 0 \quad (7.11)$$

To solve above system of the equations, the suitable boundary and condition in non-dimensional form are as follows:

$$
\begin{array}{lll}
\frac{\partial u}{\partial r} = 0 & \text{at} & r = 0 \\
u = 0 & \text{at} & r = 1 \\
P = P_0 & \text{at} & z = 0 \\
P = P_L & \text{at} & z = 1
\end{array}
\qquad (7.12)
$$

SOLUTION OF THE PROBLEM

Solving for u from equations (7.1) and (7.2) using the boundary condition given in (7.12) we have

$$>_u = -\frac{1}{4}\frac{dD}{dz}[R^2 - r^2 - \frac{8}{3} R_0^{\frac{1}{2}} (R^{\frac{3}{2}} - r^{\frac{3}{2}}) + 2R_c(R - r)]$$

for $R_C \leq r \leq R$ (7.13)

$$<_u = -\frac{1}{4\mu}[\frac{dp}{dz}\{R^2 - R_c^2 - \frac{8}{3} R_0^{\frac{1}{2}} (R^{\frac{3}{2}} - R_0^{\frac{3}{2}}) + 2R_0(R - R_C)\}]$$

$0 \leq r \leq R_C$ (7.14)

Here R_C is the radius of the plug-flow region, defined by

$$r_0 = -\frac{\phi}{cz}\frac{R_0}{2} \qquad (7.15)$$

This drag is calculated from the formula:

Drag = 2 volume X $\frac{\partial p}{\partial z}$ /wetted area X < U >^{2}

where

$$\langle U\rangle = 2\pi \int_0^{R_c} u_c r dr + \int_{Rc}^{R} u r dr\} \qquad (7.17)$$

Thus, the drag in present case is given by

Therefore, D_c = drag for Casson's fluid = $\frac{1}{U_{C^2}}$

D_V Drag for viscous fluid is = $\frac{1}{U_{v^2}}$

For viscous fluid the average velocity is given by

$$u = -\frac{\partial p}{\partial z}\left(\frac{R^3}{30\ \mu_o}\right) \quad (7.18)$$

Thus, the percentage drag reduction in reference to that for viscous fluid is given by

$$\left(\frac{D_V - D_c}{D_V}\right) \times 100 \quad (7.19)$$

RESULTS AND DISCUSSION

Figure 7.1 presents the variation of drag in viscous and Casson's fluid representing blood in natural and diseased arteries for various values of the viscosity and growth of stenosis. It may be observed that as the stenosis progresses, the drag increases in both the cases but the drag in Casson's

fluid is smaller than that in viscous fluid. One may conclude that, in blood, there is an inbuilt mechanism of reducing the drag. Further, increase in drag due to the development of stenosis decreases with increasing values of viscosity of the Casson's fluid. In medical practice, the effects of hypertensive diseases can be lowered by increasing the Casson's viscosity.

Figure 3 depicts the variation in the percentage drag reduction with the viscosity of the viscous fluid. One may conclude from the figure that with the decreasing values of viscosity, it decreases. It also describes that for a particular value of viscosity it first starts increasing upto some distance and after attaining a peak value at the throat it decreases.

From figure 7.4, it is clear that the percentage drag reduction increases from entry upto the throat and after attaining maximum values it starts decreasing. It depicts that with the decreasing values of core thickness it decreases. One may obviously conclude that the percentage drag reduction decreases with increasing effects of

Non-newtonian characteristics. Figure 7.5 depicts the variation of the drag reduction with the increasing thickness of the stenosis. It decreases with the increasing value of the thickness of the stenosis.

The viscosity of the fluid is adjusted to about 30% by adding drag reducing agent in human plasma which is required for sick and injured persons, which would reduce the drag in order to maintain continuous flow in body. It is also good for person having weak heart.

CONCLUDING REMARKS

We conclude that Casson's fluid model is true representation of blood as it possess inbuilt properties of drag reducing agent.