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A3_6 Newton's Blood

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Abstract

We have explored the change in force that would be required within the blood vessels of the body if blood were not a shear-thinning liquid but Newtonian or shear-thickening. We found that for a Newtonian blood, the force would need to be 7.1 times the magnitude of actual blood, and for shear-thickening it would need to be 50.1 times as great.

Introduction

One way in which fluids can be grouped is by the properties of their viscosity. Those that have time independent viscosity can be broken down into three further groups: Newtonian; shear thinning and shear thickening. Of these, blood is shear thinning. [1] This means that under a shear force, the viscosity appears to decrease, where with shear thickening it would appear to increase. For Newtonian fluids, the viscosity is not affected by any shear forces. This property is necessary for survival as it means that blood can flow with little resistance through our veins and arteries. Despite this, the heart does enormous work continuously pumping blood all around our bodies. In this paper we explore the effects that would result from our blood instead being a Newtonian fluid or a shear thickening fluid, while keeping all other factors the same.

Theory

The viscosity of fluids that have time independent viscosity can be modelled using the power law equation, [2]

$$\eta = K\gamma^{n-1}, \quad (1)$$

where η is viscosity, K is a constant, γ is shear force and n is the behaviour index. The behaviour index is a value determined by the type of fluid. For shear thinning $0 < n < 1$, for Newtonian $n = 1$ and for shear thickening $n > 1$. In order to calculate viscosity for fluids that do not exist, we use the shear thinning results to determine K . The independent variable is the behaviour index and the dependent is viscosity in this model. This is why K could be calculated, as all other variables were considered to be unchanged. Viscosity for blood at normal temperatures is around 3.5×10^{-3} Pas. To determine shear force the equation

$$\gamma = \frac{v}{h} \quad (2)$$

can be used [4]. Typically this is calculated with parallel plates separated by the fluid, where h is the separation of the plates and v is the velocity of the top plate with respect to the bottom. In the case specific to the blood vessels, h is their diameter and v is the velocity of the blood.

It is difficult to calculate answers for these precisely, as the human body is inhomogeneous, and made up of many pathways that all have greatly varying velocities and diameters of blood vessels. Hence, for simplicity, it has been assumed that the human body is mostly made of arteries, arterioles, elastic veins and muscular veins[3]. An average was taken for the diameters of these and was found to be 6.5×10^{-3} m [3].

The average velocity of the blood in these blood vessels was taken as 0.32ms^{-1} [5]. Hence, γ was found to be 49.23s^{-1} . As $0 < n < 1$ for a shear thinning liquid, we used the average value of $n = 0.5$ as the flow behaviour index. Putting these into Eq. (1) gives an answer $K = 0.025$. This value can be substituted into Eq. (1), changing the value of $n = 1$ for the Newtonian fluid and $n = 1.5$ for the shear thickening fluid, for symmetry with the shear thinning. This produced results of $\eta_N = 0.025$ Pa s and $\eta_{STick} = 0.175$ Pa s respectively where η_N is the viscosity for Newtonian blood and η_{STick} is the viscosity for shear thickening blood.

Discussion

We can use a rearrangement of Newton's Law of Viscosity

$$F = \eta A \gamma \quad (3)$$

to determine the factor by which the force would be larger for the other types of fluid, where F is the force, and A is the area of blood vessel in which the measurement is taken (the area of the top plate). As we are considering all other variables to remain the same, we can see that $F \propto \eta$.

From this, we can determine the relative magnitudes of force that would have to be delivered through the blood vessels in order to keep blood flow the same within the body. These are given respectively for Newtonian and shear thickening fluids below.

$$\frac{\eta_N}{\eta_{SThin}} = 7.1 \quad (4)$$

$$\frac{\eta_{STick}}{\eta_{SThin}} = 50.1 \quad (5)$$

where η_{SThin} is the viscosity of shear thinning blood. As can be seen, Newtonian fluids would require 7.1 times as much force and shear thickening fluids would require 50.1 times as much force as actual blood.

Conclusions

In this paper, we have shown that blood would require much more force to pump around the body if it were not shear thinning, meaning that your heart would need to work 7.1 times or 50.1 times as hard. We made a few assumptions in order to calculate this such as assuming that all of the blood vessels are arteries, arterioles, elastic veins and muscular veins. Further work could be done on investigating how the values calculated change when capillaries and other thin vessels are taken into consideration.

References

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