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ME 476 C Section: 3

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Analytical Analysis: Fluid Properties

Introduction

This project relates directly to issues of health that faces our society, specifically that of ways to treat aneurysm in the brain. Currently there are a few ways to treat aneurysms, the best options that are being utilized involve in-vitro methods, which is when a tube is inserted into a blood vessel usually in the leg and is then fed using a catheter to the brain or the source of the aneurysm. This in-vitro method is better than the other method that are used, which involve cutting into a person's skull or neck to treat the aneurysm, which can be dangerous to the patient if there are in poor health. While using this in-vitro method can be much safer since a leg incision is usually not too dangerous to the patients' health. This project in which our team is involved is how to test these in-vitro methods using a model to see if the device being tested is a viable method that can be used on human patients, without having patients be tested and risk their wellbeing.

Abstract

To further understand the forces that are involved within our model an analysis of the fluid properties of blood was done, and compared with a wide variety of other fluids to see if similar properties of blood could be reflected in another fluid. The two properties that were important to understand as to identify the correct fluid to use for this model is the density and viscosity of the fluid. Two fluids were narrowed down, Carboxymethyl Cellulose (CMC) (1% Wt.) which was the closest approximation to the same viscosity of blood with a viscosity of 3.8025*10^-3 (Pa*s) [1] to blood which has a viscosity of 3.5375*10^-3 (Pa*s) [2], both of the viscosities of these fluids are non-Newtonian, exhibiting shear thinning. The other fluid that was chosen as an option is powdered milk due to it having a similar density and viscosity to blood with a viscosity of 2*10^-3 (Pa*s) [3] and a density of 1029 (kg/m^3) [4], with blood having a density of 1060 (Kg/m^3) [5].

Results and Discussion

Table 1:Fluid properties

Types of Fluid	Density (Kg/m^3)	Dynamic Viscosity (Pa*s)	Relative error of density against human blood	Relative error of viscosity against human blood
Water	998 [7]	.001002 [8]	5.84906%	71.6749%
Bovine Blood (Cow)	1045.9 [9]	.003 [9]	1.33019%	15.1943%
Glycerol Mixture (22% Wt.)	1052.9 [10]	.001240 [10]	0.669811%	64.947%
Homogenized Milk @ 20 C	1033.0 [4]	.002 [3]	2.54717%	43.4629%
CMC (1% Wt.)	1000.4 [6]	.003002 [1]	5.28113%	15.1378%
Human Blood at Circle of Willis	1060 [5]	.0035375 [2]	None	None

Due to the fluid properties of blood it was important to understand the shear rate going on in the circle of Willis since the majority aneurysms occur in this area of the brain.

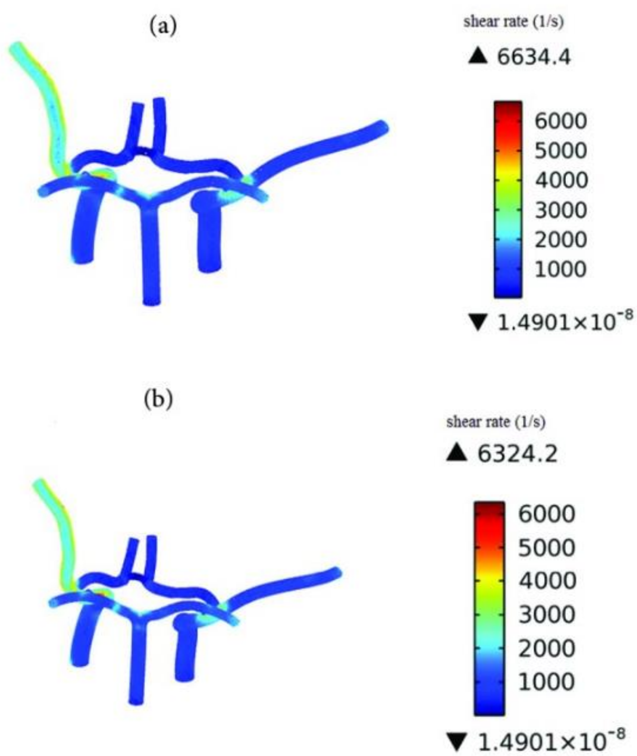

Figure 1:Shear rate in Circle of Willis [11]

From (fig. 1) it can be shown that the min shear rate that occurs is 1.4901*10^-8 (s^{-1}) in the Circle of Willis, which with bloods properties of shear thinning for this low shear rate would give the highest viscosity and provide the highest shear forces on the walls of the blood vessel. Along with that in (fig. 1) through sources that were found, the fluid was treated as a Newtonian and non-Newtonian fluid and in steady state in two separate cases, it stated that treating the fluid as Newtonian or non-Newtonian the shear rate was close enough that the blood flow through the Circle of Willis could be treated as a Newtonian fluid for steady state conditions. Using this data, it can be concluded that it is a safe assumption to use Newtonian fluid to represent bloods non-Newtonian properties within the model if steady state conditions are met within the system.

Although it is still undetermined if steady state conditions will be met when conducting this experiment due to issues involving which pump will be used for testing the model. If a programmable pump is used this assumption will not be valid due to steady state conditions not being met, but if a simple pump is used, that provides steady state conditions, then this assumption can be used and Newtonian fluid can be used to represent blood within the system.

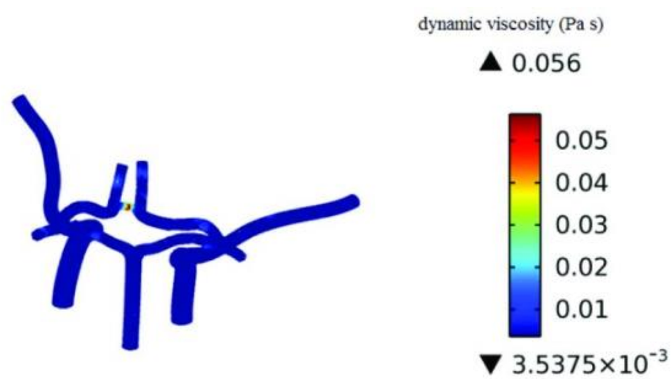

Figure 2:Dynamic Viscosity in Circle of Willis [11]

The dynamic viscosities that are present within the Circle of Willis range from a value of 3.5375*10^-3 (Pa*s) to .056 (Pa*s) as seen in (fig. 2). Since the majority of the dynamic viscosities are at the lower end of the range, 3.5375*10^-3 (Pa*s) was used as the goal for the dynamic viscosities within the system.

Unlike the other fluids that were found CMC is a non-Newtonian fluid that exhibits thixotropic behavior and has a different shear stress depending on the shear rate of the fluid. So the following table's properties were used and plugged into (Eq.1) to get the dynamic viscosity. The shear rate that was used for this calculation was the lowest shear rate found on the Circle of Willis (fig. 1), because that would yield the highest shear stress that would be possible in an actual human brain vessel. The values were randomly plugged in to achieve closest properties to that of blood, the results of this can be seen in (table 1).

Table 2:CMC properties [1]

CMC (%)	λ_c (s)	n (−)	μ_0 (Pa s)	μ_∞ (Pa s)
0.2	0.010	0.67	0.019	0.001
0.4	0.016	0.65	0.045	0.001
0.8	0.060	0.60	0.230	0.002
1.0	0.088	0.61	0.530	0.003
1.5	0.172	0.64	1.970	0.020
2.0	0.287	0.66	6.355	0.024
2.5	0.530	0.69	21	0.038
3.0	0.865	0.69	48	0.040
4.0	1.026	0.68	70	0.040
5.0	1.804	0.67	200	0.045
6.0	3.459	0.67	700	0.060

$$\frac{\mu - \mu_\infty}{\mu_0 - \mu_\infty} = \frac{1}{1 + \left(\lambda_c \cdot \dot{\gamma}\right)^n}$$

[1]

μ- Dynamic viscosity (Pa*s)

μ_o-Zero shear rate (Pa*s)

μ_∞-Infinite shear rate (Pa*s)

$\dot{\gamma}$-Critical shear rate (s^{-1})

λ_c – Time constant (s)

η-Degree of dependency

Narrowing choices

While bovine and human blood provides very similar properties to that of human blood, it is not the easiest fluid to implement within the system. This arise from the fact that blood is a biological material and would require that the experiment be sterile and would cause issue when repeating the experiment, due to the need for repeatedly sterilizing and cleaning of the system.

Glycerol mixture and water on the other hand do not require the need of sterilization since they are both non-biological materials, but both of them have a high error when comparing their densities and viscosities. Due to both of these factors they are excluded from being used in the system due to the error being too high and other better fluids that could be used.

Conclusion

Powdered milk was chosen as a Newtonian fluid that could best represent blood, since its density and viscosity are very close to that of blood and its non-biological and would allow for repeatability. Also depending on the type of pump is used if it is a steady state or a transient state pump this type of fluid would be able to approximate the stresses within the Circle of Willis since in steady state systems a Newtonian fluid can be used, from the reasons shown above.

The other option is to use the CMC fluid since it will allow for repeatability as it is non-biological, its properties are the closest to that of blood compared to any of the other non-biological fluid, and it is non-Newtonian, which is the same as blood. If a transient state pump is used than the CMC fluid should be used since it will be able to change its viscosity similarly to that of blood when the shear rate is changed, since it is thixotropic.

References

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