The Pegasus Review: UCF Undergraduate Research Journal (URJ)

Volume 12 | Issue 1 Article 6

2020

Mimicking Blood Rheology for More Accurate Modeling in Benchtop Research

Lindsey Webb
University of Central Florida, lindseywebb@knights.ucf.edu

Vol. 12.1: 28-34

URJ

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

Published
August 5th, 2020

Mimicking Blood Rheology for More Accurate Modeling in Benchtop Research

By: Lindsey Webb
Faculty Mentor: Alain Kasab
UCF Department of Mechanical and Aerospace Engineering

ABSTRACT: Because blood is challenging to use as a working fluid in a laboratory setting due to health and safety concerns, a blood analogue would be useful to perform benchtop experiments. Viscosity is an important fluid property for modeling and experiments, especially because blood is a shear thinning fluid; therefore, it has a decreasing viscosity with higher shear rates. This project seeks to create a blood-mimicking fluid for benchtop laboratory use. Numerous fluids with different combinations of water, glycerin, salt, and xanthan gum (XG) were created to mimic blood viscosity at different hematocrit levels. Four additional solutions were also created from the previously mentioned solutions by adding 0.5% by mass salt. The solutions were compared with blood at the equivalent hematocrit (EH) and with previous tests. Three different EHs were tested and all produced results similar to blood viscosities. The solutions were also able to mimic the shear thinning behavior of blood at different EHs. The fluids with 0.075% XG, 50% water, and 50% glycerin were better representative of blood than the fluids with 0.075% XG, 60% water and 40% glycerin. However, no difference in viscosity was found between the fluids with and without salt. These results show that the proposed mixtures can closely mimic blood viscosities at different hematocrit levels.

KEYWORDS: Viscosity; viscoelasticity; hematocrit; bench top; xanthan gum; shear thinning

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

12.1: 28-34

INTRODUCTION

To confirm Computational Fluid Dynamics (CFD) analysis, benchtop experiments are needed with a fluid that mimics blood and its viscoelastic properties. Ultimately, the goal of such research is to use this blood surrogate fluid in Left Ventricular Assist Device (LVAD) benchtop flow loop experiments aimed at tailoring the outflow graft conduit implantation to reduce stroke. It is challenging to use blood as a working fluid in a laboratory setting because of health and safety concerns. Other issues stemming from the use of blood include its tendency to clot and become unusable, its opacity, its high cost, the difficulty of storing it, and its inability to be reused. Therefore, a blood analogue would be useful to perform benchtop experiments. Viscosity is an important property of fluids for modeling and experiments. Blood is a non-Newtonian fluid, which means its viscosity changes with imposed shear stress. Shear stress causes slippage of fluid layers, which deforms the fluid element. Blood is a shear thinning fluid, so it has a decreasing viscosity with higher shear rates.

Figure 1 shows shear rate versus viscosity for water and for human blood. Power-law, Casson, and H-B in Figure 1 refer to the different models of viscosity of a shear thinning fluid. Note that the human blood shear rate has a logarithmic scale. [1] Figure 1 shows how the viscosity of blood decreases as shear rate increases, while the viscosity of water does not change with changing shear rates. At room temperature, water has a viscosity of 1 cP (one centipoise, equivalent to one millipascal-second (mPa)), and at higher temperatures, viscosity decreases. At 37oC, blood viscosity is around 3 cP to 4 cP.

Xanthan gum is a readily available food additive that can be acquired over the counter. It is used as a thickening agent. Xanthan gum has been previously used with a mixture of water and glycerin to produce a shear thinning fluid which behaves as a blood analogue. [2] Another advantage to using water, glycerin, and xanthan gum is the ability to change the equivalent hematocrit, a volume percentage of red blood cells in blood, by manipulating the relative amounts of xanthan gum to glycerin and water. Many patients with cardiac issues, especially those with LVADs, take blood thinners and have lower levels of hematocrit, resulting in lower blood viscosities. [3] This fact is important because different blood viscosities affect blood flow and other properties. Further, there is a natural range for levels of hematocrit within humans: 40-54% for men and 36-48% for women. [4] Changes in levels of hematocrit change the viscosity of blood and therefore can change the outcome of benchtop experiments. When blood is under high shear conditions, the red blood cells are well mixed and blood viscosity decreases to a typical value of 3 cP for a normal 40-50 Hematocrit range. [5] When blood is under low shear rates (below 100/s) conditions, the red blood cells align into structures called Rouleaux, and blood viscosity increases. [5] Blood is also opaque, so in order to examine the particles in the flow in the benchtop flow-loop, the fluid needs to be transparent. A solution of water, glycerin, and xanthan gum fulfills this requirement.

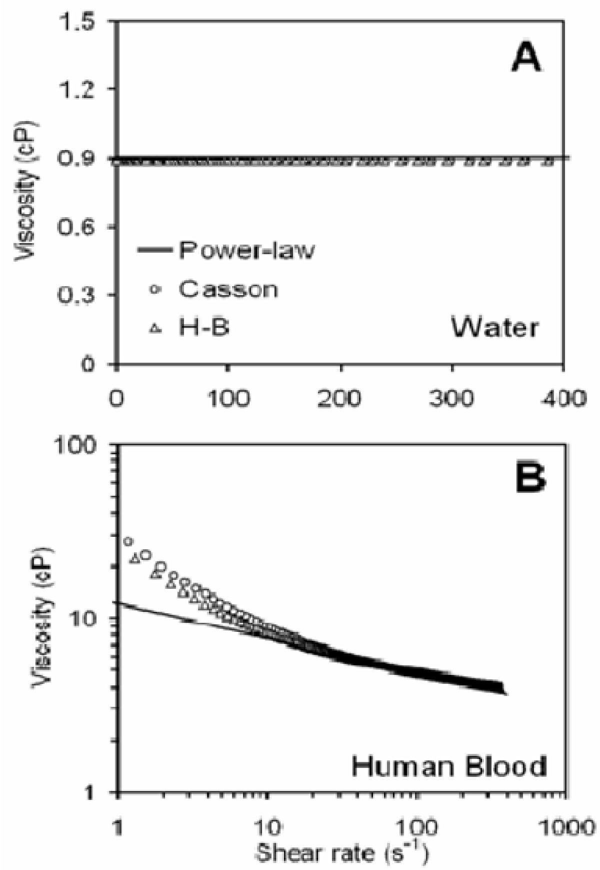

Figure 1. Shear Rate vs Viscosity for Water and Human Bloood

Because water is polar and glycerin is slightly polar, adding salt to a mixture with both of those ingredients could increase the intermolecular bonds between the molecules. When salts dissolve, they form dissociated ions. These ions can form strong ion-dipole intermolecular bonds with the solvent. Strong intermolecular bonds make it hard for the fluid molecules to flow over each other,

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL
URJ
12.1: 28-34

thereby increasing the fluid viscosity.

The ultimate goal of this research is to conduct benchtop studies of LVADs to help determine placement, function, and risk for maximum efficacy and safety due to blood's limiting factors. Blood is dangerous, opaque, prone to spoiling, and difficult to obtain. Further, blood has unique shearing qualities that make it very difficult to work with. Accordingly, the main goal of the study is to improve the effectiveness of the non-Newtonian fluid for use to aid in further studies.

METHODS

This research was conducted at the Applied and Computational Biofluids Laboratory at the University of Central Florida.

The first objective of this research was to design a fluid with water, glycerin, and xanthan gum, one with salt and another without salt, to mimic the shear thinning property of blood at different hematocrit levels. Since the amount of xanthan gum is very small, an analytical balance was used. To mix the water, glycerin, xanthan gum, and salt together, an immersion blender was used. Because xanthan gum clumps rapidly, many cooking websites recommend using an immersion blender. A cone/plate rheometer was used to measure the viscosity at various shear rates. To use the rheometer, 0.5mL of the fluid to be tested was placed in the cup and attached to the rheometer. The fluid was then heated to 25˚C with a device which heats and circulates water around the rheometer to heat the tested fluid. Once the fluid reached 25˚C, the rheometer was turned on and the tests began. The data were obtained from 10-90 torque percent, the range over which the rheometer is accurate. For this reason, the exact ranges of shear rate to be tested could not be reliably determined beforehand, as these figures are dependent on the test fluid. Torque percent is the amount of torque resistance measured by immersing the rotating spindle in a fluid. The data were obtained starting from the top of the range, at 90 torque percent, and moving down to 10 torque percent.

The second objective of this research was to determine the effect of salt on the viscosity of the fluids. There were eight fluids with differing amounts of xanthan gum, water, glycerin and salt with three different amounts of xanthan gum. The researcher changed the percent by weight of each of these for each of the different solutions. This process models different levels of hematocrit, as benchtop study with the LVADs should model between 20% and 50% hematocrit.

The rheometer used was the Wells-Brookfield Cone/Plate Rheometer (see Figure 2). In this rheometer, the cone is rotated, and the rotation is resisted with a beryllium copper spring. The shear stress is calculated from the twist of the spring, and the shear rate is calculated based on the angular speed and dimensions of the cone.

Figure 2. Cone/Plate Rheometer Used

RESULTS

Xanthan 0.075%

A xanthan percentage of 0.075% produces results equivalent to those of someone who has a high (79%) hematocrit (see Table 1). This hematocrit level could be from someone who is blood doping, which is the process of adding blood, which they had previously taken out, through an IV back into their bloodstream. This process results in a higher amount of red blood cells in the blood, increasing oxygen carrying capacity for longer, more arduous exercise. These results for viscosity show there were no significant difference between the obtained results and literature values for blood. [2] The 0.5% by mass salt made no difference in viscosity.

Xanthan .0075%

A xanthan percentage of 0.0075% produces results equivalent to those of someone who is has low (20%)

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

12.1: 28-34

hematocrit (see Figure 3). The low hematocrit level could be caused by taking blood thinners, which is a common treatment for LVAD patients. There is no significant difference between the obtained values of viscosity and literature values for blood. However, these results were closer to the literature values for blood than another similar xanthan mixture found in the literature. [2] Again, the 0.5% by mass of salt made no difference in viscosity.

Xanthan .04%

A xanthan percentage of 0.04% produces results equivalent to those of someone with normal (46%) hematocrit levels (see Figure 4). There is no significant difference between the obtained viscosity results and literature values for blood. [2] As with the previous results, the 0.5% by mass of salt made no difference in viscosity.

	Xanthan Gum	Water	Glycerin	Salt	Equivalent Hematocrit
1	.075%	60%	40%	.5%	79%
2	.075%	60%	40%	0%	79%
3	.075%	50%	50%	.5%	79%
4	.075%	50%	50%	0%	79%
5	.0075%	60%	40%	.5%	20%
6	.0075%	60%	40%	0%	20%
7	.04%	60%	40%	.5%	46%
8	.04%	60%	40%	0%	46%

Table 1. Percent by mass of all 8 of the tested fluids.

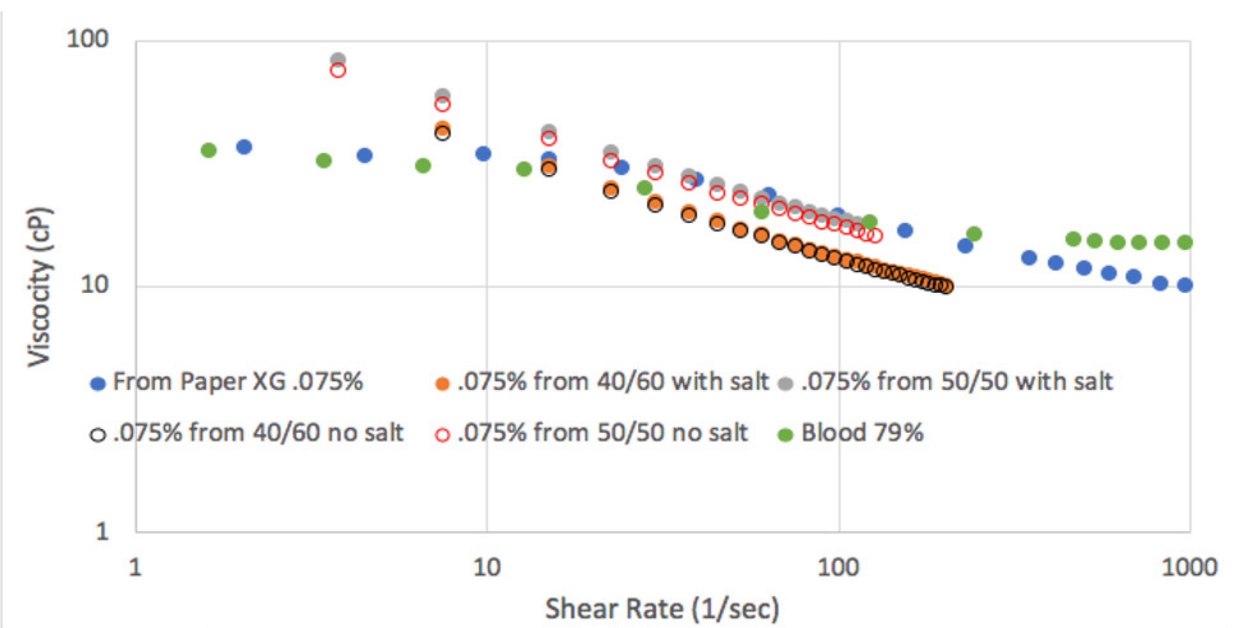

Figure 3. 0.075% Xanthan Gum

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

12.1: 28-34

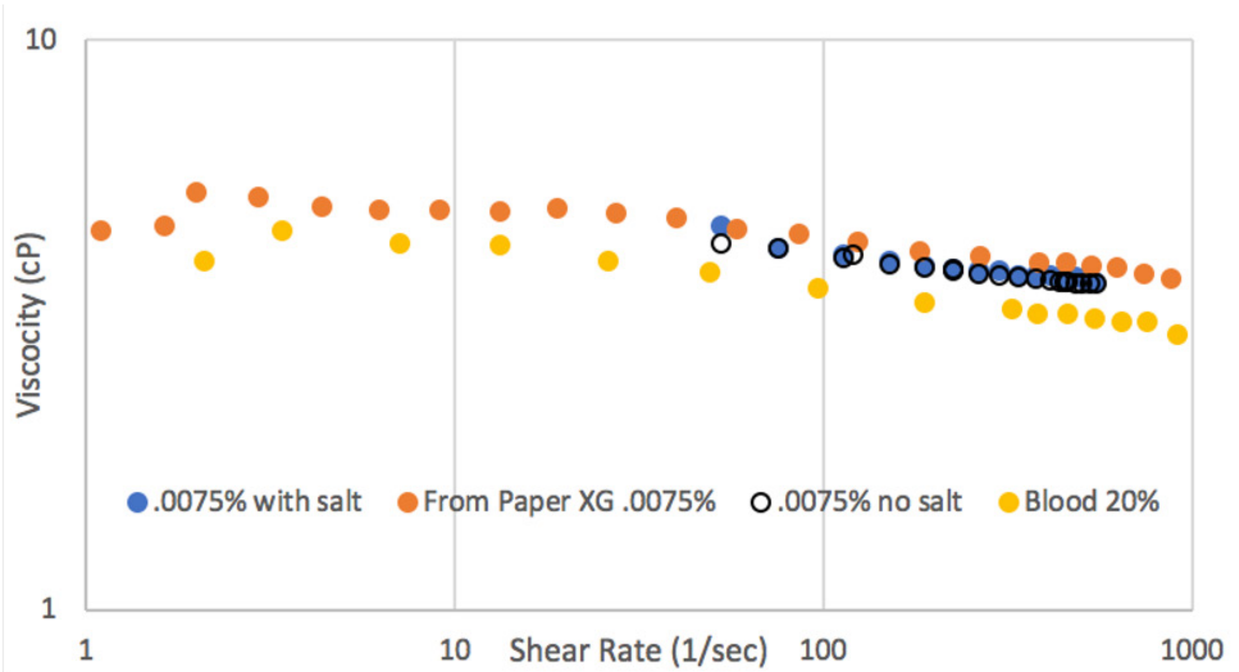

Figure 4. 0.0075% Xanthan Gum

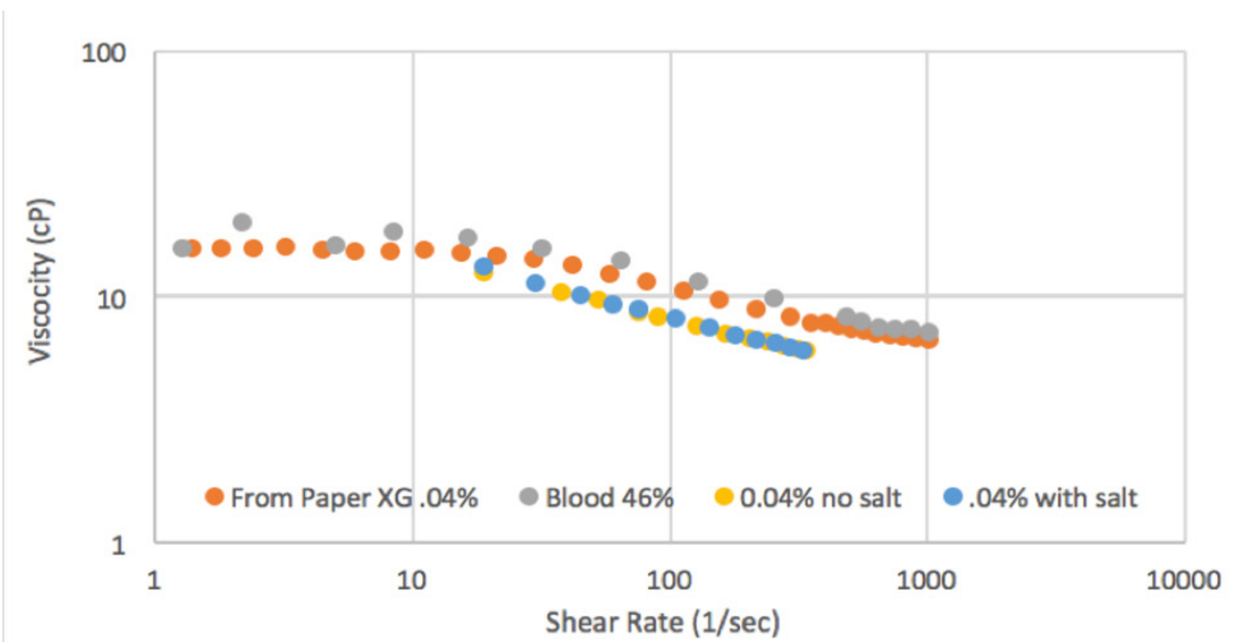

Figure 5. 0.04% Xanthan Gum

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

12.1: 28-34

DISCUSSION

These results show that it is feasible to mimic the shear properties of blood at different equivalent percent hematocrits. This method is a safe, cost-effective alternative to blood for benchtop flow loop experiments. Because only three equivalent hematocrits were tested, more experiments need to be performed to establish the correct amounts of xanthan gum, water, and glycerin for different normal levels of hematocrit and low levels of hematocrit, which are the most relevant to the LVAD patient population. The fluids with 0.075% XG, 50% water, and 50% glycerin were more representative of blood than the fluids with 0.075% XG, 60% water and 40% glycerin. A larger proportion of the more viscous glycerin is needed to increase the viscosity of the fluid to match the high equivalent hematocrit.

Adding salt did not affect the viscosity of the fluids. This result was unexpected, as salt should increase the intermolecular bonds in the fluids. Since salt is ionic and water is polar, adding the salt to the fluid would cause the ion-dipole intermolecular bonds to form. Ion-dipole intermolecular bonds are strong intermolecular bonds. This intermolecular interaction would make it more difficult for the molecules to flow over one another and make the fluid more viscous. It is possible that there was not enough salt to make a difference in viscosity.

This study also used tap water in its mixture. This was because tap water will be used for the future benchtop experiments. It is unknown if the ions in the tap water affected the results and deionized or distilled water would have had lower viscosities. In the future, distilled water may be a better choice to see if salt affects the outcome.

Conclusion And Future Work

These results demonstrated that adding salt does not affect the viscosity of water, glycerin, and xanthan gum solutions. It was also demonstrated that the tested solutions were able to mimic the shear thinning behavior of blood at different hematocrits. The fluid with 0.075% xanthan gum, 50% water and 50% glycerin is a better representative than the fluids with 0.075% xanthan gum, 60% water and 40% glycerin because the former is closer to the literature values of blood viscosity. More work needs to be done to determine the xanthan gum, water, and glycerin amounts needed for more hematocrit values. Further, more specifics are needed for the normal range of hematocrit (40-54% for men and 36-48% for women).

THE PEGASUS REVIEW:
UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

URJ

12.1: 28-34

REFERENCES

1. S. Kim, B. Namgung, P. Ong, Y. Cho, K. Jin Chun, D. Lim, 2009, “Determination of rheological properties of whole blood with a scanning capillary-tube rheometer using constitutive models,” Journal of Mechanical Science and Technology, **23**, pp. 1718-1726.

2. K. A. Brookshier and J. M. Tarbell, 1993, “Evaluation of a Transparent Blood Analog Fluid: Aqueous Xanthan Gum/Glycerin,” Biorheology, **30** (2), pp. 107-116.

3. Ayan Sen, Joel S. Larson, Kianoush B. Kashani, Stacy L. Libricz, Bhavesh M. Patel, Pramod K. Guru, Cory M. Alwardt, Octavio Pajaro, and J. Christopher Farmer, 2016, “Mechanical circulatory assist devices: a primer for critical care and emergency physicians,” Critical Care, **20** (153), pp. 1-20.

4. Henny H. Billett, 1990, *Clinical Methods: The History, Physical, and Laboratory Examinations*, Butterworths, Boston, Chap. 151 “Hemoglobin and Hematocrit”

5. M. Anand and K.R. Rajagopal, 2004, “A Shear-Thinning Viscoelastic Fluid Model for Describing the Flow of Blood,” International Journal of Cardiovascular Medicine and Science, **4** (2), pp 59-68.