A Study On Viscoelasticity Of Human Blood

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ABSTRACT

The concept of viscosity is commonly used to characterize a material, but it is not adequate to describe the mechanical behavior of a substance, particularly non-Newtonian fluids. several other rheological properties which relate the relations between the stress and strain rate tensors under different flow conditions, such as oscillatory shear, or extensional flow can be described the mechanical behavior of non-Newtonian fluids like Blood.

Viscoelasticity is a rheological phenomenon that describes the flow properties of complex fluids like blood. Viscoelastic materials have interesting properties. They exhibit both viscous behavior as well as elasticity. The viscosity and elasticity of blood are direct indicators of how these parameters affect the ability of the blood to flow under the shear conditions imposed by the pulsatility of the circulation.

The present study aims at 1.)To measure velocity of blood for different flow rates in a capillary tube, which is achieved by allowing the blood to flow in a capillary tube of different radii and 2) To measure ultrasonic velocity and absorption in blood at different frequencies. The data is presented and findings and conclusions are drawn from this data.

Key Words: viscosity, Elasticity, Viscoelasticity, Flow rate, Ultrasonic velocity, Absorption

1. INTRODUCTION

For describing the dynamics of blood flow, the viscoelastic parameters such as viscosity and elasticity, should be obtained from the measurements under oscillatory shear flow. The viscosity is an assessment of the rate of energy dissipation due to cell deformation and sliding, while elasticity is an assessment of the elastic storage of energy primarily due to kinetic deformability of the red blood cells. Early investigations conceptualized blood as a viscous fluid, assuming that the viscosity controls its flow properties. But blood is not a fluid in the ordinary sense; it is a fluidized suspension of elastic cells. In 1972, G. B. Thurston was the first to measure the viscoelastic properties that control the pulsatile flow of blood. The viscoelasticity reflects the cumulative effects of many blood parameters such as plasma viscosity, red blood cell deformability, aggregation, and hematocrit.

Viscoelasticity is a rheological phenomenon that describes the flow properties of complex fluids like blood. There are two components to the viscoelasticity, the viscosity and the elasticity. The viscosity and elasticity of blood are direct indicators of how these parameters affect the ability of the blood to flow under the shear conditions imposed by the pulsatility of the circulation.

For this study, the viscosity is measured for different flow rates in a capillary tube of different radii and the Ultrasonic Interferometer with multiple frequencies is used to find out the ultrasonic velocity of blood. By knowing the density of blood, elastic constant and acoustic parameters like coefficient of absorption, modulus of elasticity and loss modulus are determined for different frequencies to understand the viscoelastic behavior of blood,

2. MATERIALS AND METHODS

In this study an open-end capillary viscometer is used and the theory is developed on the basis of Poiseuille's theory for the dynamics of a liquid column in an open capillary tube. No external pressure is applied on the liquid column. The pressure at the two ends of the capillary tube is the atmospheric pressure.

The simple capillary viscometric technique which is employed in this study is used to measure both viscosity and volume flow rate. The blood samples were collected in siliconized bottles with EDTA anticoagulant in the powder form.

3. RESULTS AND DISCUSSION

Table.1 indicates the data on coefficient of viscosity of water. Four capillary tubes of different radii i.e. 0.029cm, 0.040cm, 0.045cm and 0.055cm were taken to find out the coefficient of viscosity of water. Five samples of water were taken for different capillary tubes and found the viscosity. It is found that there is no change in the coefficient of viscosity of water with different radii of capillary tubes.

Table 1: Data on coefficient of Viscosity of Water

CT=Capillary Tube; CT1= 0.029cm; CT2= 0.040cm; CT3= 0.045cm; CT5= 0.055cm

Sample Code	Viscosity, η (poise)			
	CT1	CT2	CT3	CT4
W1	0.012	0.012	0.012	0.012
W2	0.012	0.012	0.012	0.012
W3	0.013	0.013	0.013	0.013
W4	0.013	0.013	0.013	0.013
W5	0.012	0.012	0.012	0.012

Mean: 0.012 Mean: 0.012 Mean:0.012 Mean: 0.012

S.D= ±0.0005 S.D= ± 0.0005 S.D= ±0.0005 S.D= ± 0.0005

Table 2 shows the data on coefficient of viscosity of human blood. The fresh samples of blood were collected and found the viscosity for four different radii of capillary tubes as above. It is observed from the table that as the radius of the capillary tube increases, the coefficient of viscosity also increases.

Table 2: Data on coefficient of Viscosity of Human Blood

Sample Code	Viscosity, η (poise)			
	CT1	CT2	CT3	CT4
HB1	0.02427	0.02663	0.02889	0.03927
HB2	0.02126	0.02399	0.03393	0.0434
HB3	0.02184	0.02308	0.03009	0.04825
HB4	0.02663	0.03055	0.03505	0.04849
HB5	0.02951	0.03062	0.03551	0.05101
HB6	0.02569	0.039	0.03924	0.04541
HB7	0.02569	0.02926	0.03414	0.04732
HB8	0.02539	0.02968	0.03414	0.04014
HB9	0.03765	0.03405	0.04045	0.04243
HB10	0.02951	0.03582	0.03984	0.04043
HB11	0.03368	0.03516	0.03804	0.04227
HB12	0.02968	0.03057	0.0364	0.03889
HB13	0.02473	0.03595	0.03677	0.04611
HB14	0.02299	0.02971	0.03553	0.04237
HB15	0.02698	0.02873	0.03286	0.04732
HB16	0.02299	0.02846	0.03553	0.0479
mean	0.027	0.031	0.035	0.044
S.D=±	0.0044	0.0044	0.0032	0.0038

Table 3 shows the data on volume flow rate of water. For five samples of water four different radii of capillary tubes were taken to find out the volume flow rate. It is observed from the given table that the flow is continuous when the length is infinite.

Table 3: Data on Volume flow rate of water

Sample Code	Volume flow rate, Q (cm3 sec-1)			
	CT1	CT2	CT3	CT4
W1	0.035	0.06757	0.08552	0.12775
W2	0.033	0.06406	0.08107	0.12111
W3	0.031	0.06029	0.076302	0.113982
W4	0.035	0.066819	0.084568	0.126335
W5	0.032	0.061041	0.077255	0.115406
Mean	0.034	0.064	0.081	0.121
S.D= ±	0.0017	0.0033	0.0042	0.0062

Table 4. gives the data on volume flow rate of human blood. Here also four capillaries with different radii were used respectively for different samples of blood and the flow rate was found. It is seen clearly from the table that the flow rate increases with the increases of the radii of capillary tubes.

Table 4.: Data on Volume flow rate of Human Blood

Sample Code	Volume flow rate, Q (cm^3 sec^{-1})			
	CT1	CT2	CT3	CT4
HB1	0.01188	0.03918	0.05786	0.06498
HB2	0.01188	0.03173	0.04955	0.06082
HB3	0.0132	0.04521	0.0561	0.07844
HB4	0.01082	0.03416	0.04768	0.07693
HB5	0.01293	0.0371	0.05086	0.07313
HB6	0.01199	0.04069	0.04924	0.08216
HB7	0.01122	0.03567	0.04896	0.07883
HB8	0.01135	0.035	0.04896	0.06319
HB9	0.01165	0.03064	0.04133	0.06174
HB10	0.00977	0.0305	0.04433	0.06174
HB11	0.01101	0.0331	0.04289	0.0617
HB12	0.01147	0.03516	0.04942	0.07313
HB13	0.01103	0.0331	0.04673	0.06648
HB14	0.01154	0.0376	0.04705	0.07123
HB15	0.01158	0.0301	0.04005	0.07218
HB16	0.01154	0.03667	0.04705	0.07788
Mean	0.012	0.035	0.048	0.070
S.D= ±	0.0008	0.0041	0.0047	0.0073

Table 5 shows the data on acoustic and elastic parameters of water. The parameters include ultrasonic velocity, absorption coefficient, modulus of elasticity and loss modulus. All these parameters are calculated at different frequency ranges.

Table 5: Data on Acoustic and elastic parameters of Water

Sample Code	Frequency, υ (MHz)	Ultra sonic Velocity m/sec	Absorption co-efficient, α (cm^{-1})	Modulus of Elasticity ($\times 10^{11}$) dyne/cm^2	Loss modulus, ($\times 10^8$)
W1	1	1457	0.016	0.217	0.158
	2	1463	0.015	0.219	0.077
	3	1470	0.014	0.221	0.048
	5	1477	0.013	0.223	0.0271
	10	1483	0.012	0.224	0.0127

Table 6 gives the data on acoustic and elastic parameters of normal human blood. The parameters such as ultrasonic velocity, absorption coefficient, modulus of elasticity and loss modulus were calculated for normal blood samples at different frequency ranges.

Table 6: Data on Acoustic and elastic parameters of normal human blood

Sample Code	Frequency, υ (MHz)	Ultra sonic Velocity, m/s	Absorption co-efficient, α (cm^{-1})	Modulus of Elasticity, $M^1 \times 10^{11 dyne/cm2}$	Loss Modulus, M^{11} (×108)
HB_1	1	1517	0.027	0.243	0.318
	2	1651	0.025	0.288	0.188

	3	1703	0.022	0.306	0.122
	5	1764	0.020	0.329	0.0739
	10	1920	0.018	0.389	0.0429
HB2	1	1589	0.025	0.254	0.335
	2	1635	0.020	0.283	0.147
	3	1698	0.017	0.305	0.0935
	5	1793	0.015	0.340	0.058
	10	1938	0.013	0.397	0.318
HB3	1	1602	0.031	0.273	0.430
	2	1686	0.026	0.302	0.210
	3	1701	0.023	0.308	0.128
	5	1862	0.020	0.368	0.0875
	10	1886	0.017	0.378	0.0384

Sample Code	**Frequency, υ (MHz)**	**Ultra sonic Velocity, m/s**	**Absorption co-efficient, α (cm^{-1})**	**Modulus of Elasticity, $M^1 \times 10^{11 dyne/cm2)}$**	**Loss Modulus, M^{11} (×108)**
HB4	1	1522	0.031	0.246	0.369
	2	1640	0.028	0.285	0.208
	3	1649	0.025	0.289	0.126
	5	1735	0.023	0.320	0.0810
	10	1881	0.021	0.375	0.0472
HB5	1	1547	0.029	0.255	0.362
	2	1560	0.024	0.259	0.153
	3	1586	0.022	0.268	0.099
	5	1698	0.021	0.307	0.069
	10	1715	0.018	0.313	0.031

4. CONCLUSIONS

In the present investigation, it is observed that the coefficient of viscosity of blood and its constituents increases nonlinearly with increase of radius of capillary tube. But in the case of water, the coefficient of viscosity remains constant. As it is known, in Newtonian fluids the viscosity is independent of resistance and the stress, strain relation is linear , where as in a non Newtonian fluids viscosity increases non linearly with the radius of a capillary tube. The volume flow rate of blood and its constituents also increases with the increase of radius. It is interesting to know that the coefficient of viscosity and volume flow rate both are proportionally increasing with the radius. In other words, it can be stated that the coefficient of viscosity increases as the flow rate increases. But this is not true in the case of Newtonian fluids. Hence, one can consider the fluid (blood) as viscoelastic, when viscosity increases with the increase of radius of the tube (blood vessel).

In ultrasonic investigations, the ultrasonic velocity is determined for water for different frequency ranges of 1MHz, 2MHz, 3MHz, 5MHz and 10Mhz. The velocity does not depend on frequency and it is almost same for all the frequencies. The ultrasonic velocity of normal and diseased blood also determined for different frequency ranges. But, here, the velocity depends on frequency and it increase nonlinearly as frequency of ultrasound increases.

The coefficient of absorption decreases with the increase of frequency. Elastic moduli are also determined for normal and diseased human blood and its constituents. The modulus of elasticity increases with the increase of frequency and the loss modulus decreases.

Hence the blood ,as a rule, can be considered as viscoelastic, when modulus of elasticity increases and loss modulus decreases with increase of frequency of ultrasound.

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