Coefficient of Viscosity, Surface Tension and Volume Flow Rate of Normal Human Blood

[1]Mohammed Abdul Razack Maniyar and [2]Dr. Mohd Khalid Mubashir Uz Zafar

[1]Ph.D Research Scholar, Department of Physics, Dravidian University, Kuppam, India
[2]Associate Professor, Maulana Azad National Urdu University, Hyderabad, India
Email – [1]abdulmaniyar@yahoo.co.in, [2]mkmzafar@gmail.com

Abstract: *Parameters like Coefficient of Viscosity, Surface Tension and Volume Flow Rate of normal human blood can be studied using the capillary viscometer. A Capillary tube is used which has a capillary bore radius of 0.05 cm. Different human blood samples of groups 'A', 'B', 'AB' and 'O' are taken and the viscosity, Surface Tension and Volume Flow Rate is determined. The captured output values are taken as input parameters to the software written code in Computer 'C' language. It can be observed that there is no change in Surface Tension of blood irrespective of blood groups. Whereas, the Coefficient of Viscosity is minimum in the 'A' blood group and maximum in 'O' group. And the Volume flow rate is reciprocal of viscosity in behaviour.*

Key Words: *Normal Human Blood, Capillary Viscometer, Rheological data.*

1. INTRODUCTION:

The most striking feature of the blood, to sustain the life processes, is *hemodynamics* or *hemorheology*. Hemorheology can be regarded as a branch of biomechanics related with the vessels and dynamics of blood under mechanical forces. The important parameters involved in hemodynamic are Coefficient of viscosity, Dynamic surface tension and Volume flow rate. In view of this, extensive research is being done in the field of hemodynamics.

2. LITERATURE REVIEW:

Well and Edward reported the influence of the velocity gradient upon blood viscosity, obtaining rheological characteristics of liquids. In this viscometer, the liquid placed between two coaxial cylinders rotating relatively to each other was subjected to homogeneous slip. The spherical bottom of the coaxial cylinder introduces error in viscosity measurement, due to which the rheological curves of highly viscous liquids could not be obtained. The use of bel-l type coaxial cylinder in the RV-8 viscometer of the existing design was recommended. This simple constructional change diminished the edge effects and allows the measurement on the highly viscous liquids of the order, greater than 10^5 poise. [1]

Bhattachary and Majumdar modified Ostwald viscometer. This type of viscometer is very convenient for measuring viscosity of a liquid at a fixed temperature. [2]

Dormandy in his paper examined the concepts and problems involved in studying the viscosity of a non-Newtonian fluid. Methods of measuring the viscosity of blood were described and proposals were put forwarded for the design of a clinical blood viscometer. [3]

Breaves and Joseph forwarded the rotating rod viscometer. It was shown that measurements of the free surface near rods rotating in STP and also near polyacrylamide were accurately reproducible and were in agreement with the theory of rod climbing. Results were presented, that establish the theory and experiment as a viscometer for determining the values of certain constants that arise in the theory of shear flow. [4]

Voinov and Trapeznikov studied a disc viscometer of the cup-and-disc type under the conditions where the bulk liquid entertained by the surface layer, which could have significant effect on the results of the surface viscosity measurements. [5]

Bowit described a cheaply constructed viscometer with a plastic syringe and hypodermic needle, which was helpful in measuring viscosity of various liquids. [6]

Shankland and Dunlop introduced some correction for capillary viscometers at 20° C and 1atm. Results obtained with an extremely simple viscometer indicated that the changes in flow time due to the slip and kinetic energy corrections cancelled one another. In order to evaluate the slip correction factor, the kinetic energy correction should be as small as possible, which can be achieved by increased length of capillary. [7]

Kango and Bro developed a capillary viscometer with an electrode and associated circuit to observe the passage of meniscus through the viscometer. The viscometer was kept inside a sealed aluminum container to minimize the pressure differential. [8]

Belyakov et al introduced an automatic rotating disc viscometer with torsional null balance, which was set by a servomotor. Starter position was sensed by an autotransformer, which supplied the motor control signal. The servomotor drive voltage was recorded as a direct indication of viscosity. [9]

Fisch et al reported acoustic viscometer technique. A transducer in the shape of tuning fork was cut from an X-cut quartz plate and was employed as a four-terminal device. The mechanical resonance response of the element was examined directly and was easily related to the shear viscosity of the fluid sample. This method was particularly suitable for relative viscosity measurements. [10]

Heckenbach and Muscheknautz calculated the error in measuring the viscosity with rotating cylinder viscometer, because the cylinders were not exactly coaxial. [11]

Shiba et al introduced the measuring principle for the annular viscometer on the basis of Newtonian laws of motion and viscosity. Three types of viscometers were constructed. The viscosity, the pressure difference and volumetric flow rate were measured in the case of the fixed tube type. While force and volumetric flow rate were measured in the case of movable outer tube and movable inner tube type. The advantage of the annular viscometer over the capillary viscometer is that the kinetic energy corrections and end corrections are not needed. [12]

Everage and Ballman described an extensional flow capillary rheometer, which had been evaluated, for the measurement of extensional (flow viscosity properties) of wide range of materials over a broad range of extensional rates. However, because of the difficulty of imposing a purely extensional deformation on a fluid material, very few experimental measurements of extensional viscosity have been obtained in well-defined kinematic conditions. [13]

Bate and Grande used Casson equation to compare results for whole blood, anticoagulated with (a) heparin and (b) trisodiumcitrate, obtained from cone plate and capillary viscometers over the shear range 15 to 230 s^{-1}. Significant differences were found between the two anticoagulants for the slopes and intercepts of plots obtained from these instruments. These differences were discussed together with the effect on viscosity coefficient in the shear range. [14]

Heuser studied the secondary effects in cone and plate viscometers. In this, the viscometers were used to study the influence of shear stress on the blood damage in low viscosity suspending media. In the high-speed rotation, centrifugal force of one plate of the instrument could no longer be neglected and the influence of this on the flow condition within the shearing region exists. There was a good agreement between theoretical and experimental pressure distributions for Newtonian fluids, but the experimental results for blood showed marked deviation from Newtonian behavior. The rate of hemolysis depends distinctly on the gap width. The force acting on the erythrocytes produces a shift in concentration in radial direction, which is detected by the measurement of the hematocrit values and calculated by the balance of forces. [15]

Einfeldt studied the surface tension effects in capillary viscometers of Ubbelonhde type-I. The exact theoretical calculations of the surface tension effect in capillary viscometers of Ubbelohde type with spherical fluid reservoir was given and the numerical treatment with a large computer was described. In the volume range 5 cm^3 to 70 cm^3 it was possible to compensate the total surface tension effects. [16]

Ravey et al developed a new type of couette apparatus and studied transient rheology of some Newtonian fluids. In the experiment the transient motions of rotor were studied for Newtonian fluids and some applications were described for non-Newtonian fluids. [17]

Priel developed an automatic Ubbelohde type viscometer with accuracy 0.1 ppm. It was shown that using a differential photodiode, flow time of the order of 1000 s could be measured with an accuracy of ±100 µs. [18]

Van Vliet et al (1981) described a simple constant stress viscometer without bearing. The rotating part consisted of a ferromagnetic disc, which was floated on the liquid. It was driven and centered by a fast-rotating magnetic field. The shear stress varied continuously between $5x10^{-5}$ and 0.5 pa by changing the distance between the disc and the rotating magnet. [19]

Garcia modified the earlier version of the falling cylinder of viscometer, such that the falling cylinder could have large length to diameter ratios, so as to reduce the end effects. [20]

Einfeldt and Schmezler reported the theory of capillary viscometers taking into account of surface tension effects. They calculated numerically this dependence in the case of Ostwald-Rankine and Ubbelohde type viscometers. In the case of Ubbelohde viscometers with suspended level, it was possible to make the surface tension errors lower than 0.01% by the suitable choice of the radius of curvature of the suspended level. [21]

Ross et al presented a brief review on the better-known classes of viscosity behaviour of fluid and described the viscosity measurements with Ferranti-Shirlley cone and plate viscometer. [22]

James and Marriott modified oscillating sphere magnetic micro rheometer, capable of measuring visco elastic properties of biological secretions. Linking the rheometer to the frequency response analyzer facilitated data acquisition. [23]

Mazza and Washbow described a semi-automatic viscometer, which incorporated a microprocessor system, and opto-electronics were used to detect the flow of fluid through the capillary, the flow time being displayed as a timer with an accuracy of 0.01 s. [24]

Hanks presented the solution of the equations of motion for a non-Newtonian fluid of Casson model in rotational Couette viscometer. Proper equations for fluid in rotational Couette viscometer were presented. Suitable equations were also proposed for determining the rheological parameters, based on the data obtained from commercial viscometers. [25]

Raihani and Stoltz devised a new type of viscometer comprising a vertical cylinder, containing the fluid to be tested, and an inner hollow cylinder floating in the fluid and filled with magnetic liquid. The magnetic liquid and inner cylinder were set in motion by applying a rotating magnetic field. Torque was balanced by the stresses in the fluid and the inertia of the rotating cylinder. The viscometer could be used to study transient flow in Newtonian fluids and blood suspensions. [26]

Stoltz et al devised a new erythrometer capable of determining both red blood cell filterability and plasma viscosity. In the case of filterability measurements, a suspension of washed red blood cells was filtered at a study flow rate through a 3 or 5 µm pore diameter membrane. [27]

Isogal et al developed an op-rheometer system, as new device for the analysis of viscosity and viscoelasticity of blood at low shear rates (0.2 to 40 Sec.). This system consisted of a mechanical unit, as control unit (console), a data processing unit and a printer. [28]

Jung et al developed a capillary tube viscometer for the measurement of plasma viscosity. Errors in measurement were due to insufficient cleaning of residual cleaning solution. To avoid this polyurethane tube were used which can be replaced before each measurement. [29]

Elliott devised a viscometer using a microprocessor as the control and timing unit. [30]

McMillan et al modified Couette viscometer, adding a computer controlled stepping motor and a second digital voltmeter. The latter was used to determine the angular position of the sensing system. Blood viscoelasticity was observed to fall substantially with the increase in shear rate. [31]

Monshausen and Matrai presented a comparative study on the rotational instruments in the case of blood viscosity. Three rotational viscometers for blood viscometry were compared at moderate and high shear. [32]

Izuchi and Nishibata develop a rolling ball viscometer for the use under high pressure up to 1 Gpa. It was proved that the calibration coefficient of the viscometer depends on its inclination angle and that this dependence varies with the diameter ratio of ball and tube. The accuracy of viscosity measurement was estimated to be ± 0.9%. [33]

Santra et al developed a differential viscometer to measure small differences in viscosity of two liquids using the principle of the well-known rotating cylinder viscometer. [34]

Litt et al gave the theory and design of disposable clinical blood viscometer which could produce viscosity measurements over a wide range of shear rates in a single rapid determination. The design was based upon the time varying flow of blood through a capillary. The flow was driven by the pressure in a fixed volume air chamber and transmitted to the sample through a complaint membrane. A suitable transducer measured the time varying pressure in the air chamber. The instantaneous shear stress of the blood in the capillary was proportional to the air pressure, while the instantaneous shear rate was proportional to the pressure time derivative. [35]

Sutira et al described a programmable computer controlled cone plate viscometer capable of acceleration or deceleration through a step change in speed in less than 0.7s. The speed of the rotating cone is controlled by a microcomputer, which can be programmed to generate speed versus time ramp functions of variable slope. The viscometer was used to carry out a series of preliminary studies in which platelet-rich plasma was subjected to continuous and pulsatile shear stress at 37°C. [36]

Habib and Gruner designed a simple low cost automatic opto electronic meniscus sensor for a capillary tube viscometer with a timing resolution 0.01 s. The sensor with a timing designed for the use with critical composite binary liquids, which undergo a change in fluid opacity as a function of temperature. The sensor works over the temperature range 65° to 150°C. [37]

Ravey et al employed a new type Couette viscometer to non-Newtonian blood suspensions in order to observe the influence of both the aggregation and deformation of red blood cells (RBC) with different concentration of fibrinogen and dextron on the viscosity of blood. [38]

Wanderlich et al evaluated a newly developed GRLDA-viscometer. A two-point laser Doppler anemometer was used to determine velocity gradient. Measuring additionally the pressure drop in channel flow allows one, to use this instrument as a viscometer. [39]

Shimanouchi and Imai reported a simple automatic timing device for the capillary flow type viscometers. The same device could be adopted for the small volume, inclined, falling-ball viscometer. [40]

Chmiel et al discussed a sinusoidal oscillating capillary rheometry. The determination of different parameters, to characterize blood sample e.g., visco-elastic phase angle, aggregation index, hematocrit and plasma viscosity, were described. [41]

Maini and Kokal described the design and principle of operation of a new capillary unsteady-state pulse viscometer for measuring the viscosity of fluids at high pressures and elevated temperature. [42]

Kadim and Abdul Karim introduced the theory and design of a simple digital meter, which measures the flow rate of viscous fluid. The measurements were based on Poiseuille relation. [43]

Goncalves presented the results of an experimental study of surface tension effects in kinematic capillary viscometers. The results were deduced from a comparison with measurements obtained with Ostwald

viscometer in which surface tension effects are negligibly small. It was shown that surface tension effects in suspended level viscometers were sensitive to the shape of the capillary exit. [44]

Kurano designed and constructed a falling sphere viscometer, which was capable of measuring absolute viscosity of reference liquids upto 500 Mpa with an error less than ±0.5%. The falling time of the sphere could be automatically determined using two laser beams through the windows on the high-pressure vessel of the viscometer. [45]

Ashwini Kumar et al investigated the influence of ultrasonic standing waves on viscosity and dynamic surface tension of human blood by employing capillary viscometer technique. Blood samples are irradiated with ultrasonic standing waves at an interval of 15 min up to 2 hours using ultrasonic interferometer. [46]

3. MATERIALS AND METHODS:

3.1 Description of capillary viscometer

The viscometer is nothing but a simple capillary tube. The main experimental part is to measure flow time for a fixed distance, of the liquid column of particular length in a vertically held open capillary tube. This can be done manually using a stopwatch. On the other hand, for the accuracy and sophistication, photo-sensors can be used.

In the present investigation fibre optic system, comprises of a LED as source and photodiode as detector, has been used to measure the velocity of liquid column in a capillary tube. The viscometer is shown in (Fig. 1.) An apparatus is constructed, which can hold a capillary tube of length 30 cm and inner radius of 0.05 cm. The capillary tube is passed through a thick carbon tube such that exactly fits into it. 'A' and 'B' are the two holes drilled along the direction perpendicular to the axis of the carbon tube at its mid-point. The ends of two optical fibres are fixed in the two holes 'A' and 'B' and they face each other in such a way that their axes lie along the same straight line. The other ends of the optical fibres are connected to a LED and a photodiode.

Fig. 1. Capillary Viscometer

The optical fibre connected to LED, transmits the light from the LED and is referred as Transmitting fibre. The fibre, which is connected to photodiode, receives the light and hence called Receiving fibre. The output electrical signal of the photodiode is amplified by an amplifier and is fed to the chart recorder in order to record and store the signal (Fig. 2).

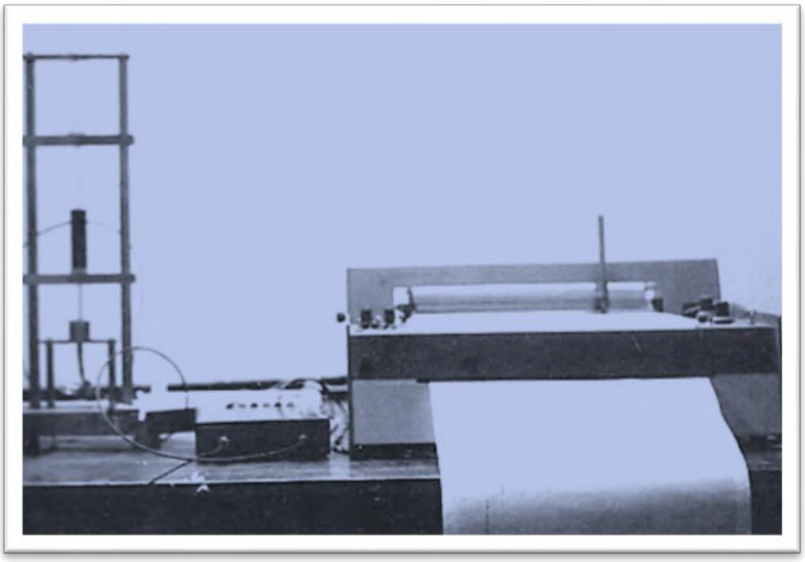


Fig. 2. Viscometer setup

4. EXPERIMENTAL PROCEDURE:

A capillary tube of length 30 cm and radius 0.05 cm is held vertically in the specially designed apparatus for this purpose. Blood sample was sucked into the capillary tube by means of a rubber tube attached to one of the ends of capillary tube, through a pinchcock. The length of the blood sample taken in the capillary tube ranges from 2 to 8 cm. The pinchcock arrangement controls the flow of blood column. The vertical clamping of the capillary tube with sample will set the blood column into one-dimensional motion.

At the beginning of the experiment, the lower surface of the blood column of length 'L' was set above A and B. The receiving fibre receives the light from transmitting fibre, after passing through the capillary tube along its cross section. Then the photodiode receives the maximum light and the chart recorder records maximum voltage. This is indicated by the line AB in the chart paper (Fig. 3.).

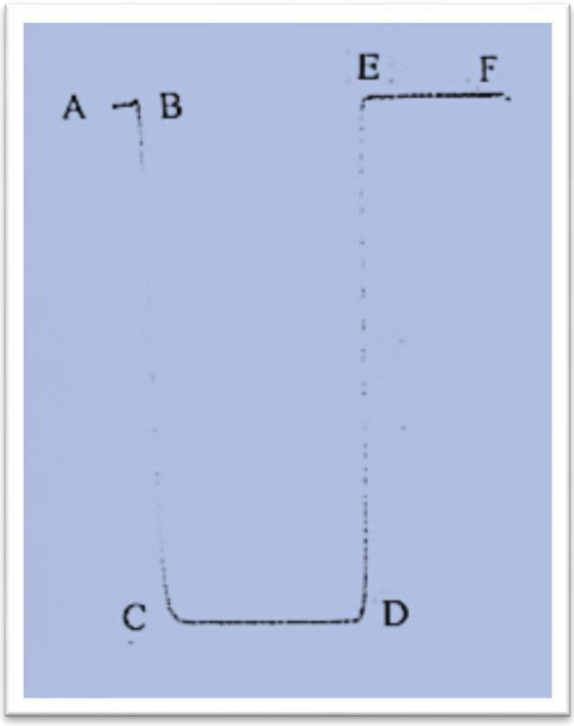


Fig. 3. Viscograph of human blood

Chart speed: 32 cm/min; Voltage sensitivity: 4 mV/cm

The moment of the lower surface of the blood column is at A and B, the light is obstructed, the output voltage of the photodiode becomes minimum or zero, which is reflected in the chart recorder i.e., the voltage, comes down from B to C. This continues until the whole blood column passes A and B. The CD in the chart indicates the fall in voltage. Once the upper surface of the blood column crosses A and B, again the light is received by the receiving fibre and the chart recorder shows the maximum voltage, indicated by E and it continues, shown by the line EF in the chart. The distance traveled by the blood column is its length 'L' that crosses A and B in time t. The time 't' is calculated by measuring the length (l) of CD and knowing the chart speed S.

Therefore, t =l /s

The velocity v of the blood column of length L is calculated as

$$v = L / t$$

Here,

l = length of CD in the chart
s = speed of chart recorder
L = length of blood column
t = time of flow of blood column to travel a distance 'L'.

Velocity of blood column was calculated for its different lengths. A plot was drawn between L^{-1} on X-axis and v on Y-axis. The plot is a straight line with a negative slope and y-intercept. Viscosity and surface tension were calculated from the intercept and slope of the straight line, respectively, knowing the radius of capillary tube R and angle of contact (θ) of the sample with the capillary wall. Hence, radius of the capillary tube R was measured using a traveling microscope of LC 0.001cm. The angle of contact was measured by keeping a circular scale marked in degrees behind the capillary tube and viewing the meniscus of the sample through traveling microscope. It is not possible to measure angle of contact very accurately and hence it is approximated to 30^{o} for the blood. A computer program was written in 'C' language, for the computation of viscosity and surface tension. The experimental parameters, length of sample column 'L' and flow time 't' can directly be fed to obtain viscosity and surface tension at a stretch.

The expressions for coefficient of viscosity (η) and surface tension (T) are:

$$\eta = (R^2 \rho g) / (8 v_o)$$

$$T = (4\eta \tan \alpha) / (R \cos\theta)$$

Volumetric flow rate (Q) is calculated using the relation

$$Q = v_o \pi R^2$$

Where, v_o= velocity of blood column obtained from the Y-intercept of the plot between L^{-1}on X-axis and velocity v on Y-axis.
R = Inner radius of the capillary tube.

5. RESULTS AND DISCUSSION:

Table1 presents hemodynamical data on human blood of healthy donors. The hemodynamical parameters studied are characteristic velocity, volume flow rate, coefficient of viscosity and surface tension. The radius of the capillary tube and angle of contact are kept constant.

Table 1 - Data on Coefficient of viscosity of normal human blood of group 'A'.

Blood Group	Coefficient of viscosity, η (poise)	Surface Tension, T (dyne/cm)	Volume Flow Rate, Q ($cm^3.sec^{-1}$)
A1	0.041	65.84	0.312
A2	0.038	63.31	0.336
A3	0.039	56.04	0.328
A4	0.045	62.31	0.284
A5	0.033	57.94	0.242
Mean	0.039	61.09	0.300
SD	±0.004	±4.01	±0.038

Table 2 - Data on Coefficient of viscosity of normal human blood of group 'B'.

Blood Group	Coefficient of viscosity, η(poise)	Surface Tension, T (dyne/cm)	Volume Flow Rate, Q ($cm^3.sec^{-1}$)
B1	0.042	59.67	0.304
B2	0.041	55.11	0.312
B3	0.046	59.65	0.278
B4	0.049	60.13	0.261
B5	0.027	67.80	0.291
Mean	0.041	60.47	0.289
SD	±0.008	±4.58	±0.020

Table 3 - Data on Coefficient of viscosity of normal human blood of group 'AB'.

Blood Group	Coefficient of viscosity, η(poise)	Surface Tension, T (dyne/cm)	Volume Flow Rate, Q ($cm^3.sec^{-1}$)
AB1	0.054	60.77	0.237
AB2	0.045	60.11	0.284
AB3	0.033	58.37	0.387
AB4	0.046	65.35	0.278
AB5	0.037	63.99	0.234
Mean	0.043	61.72	0.284
SD	±0.008	±2.87	±0.062

Table 4 - Data on Coefficient of viscosity of normal human blood of group 'O'.

Blood Group	Coefficient of viscosity, η(poise)	Surface Tension, T (dyne/cm)	Volume Flow Rate, Q ($cm^3.sec^{-1}$)
O1	0.049	67.33	0.261
O2	0.040	65.10	0.320
O3	0.052	58.30	0.246
O4	0.057	58.77	0.224
O5	0.035	57.68	0.236
Mean	0.047	61.44	0.257
SD	±0.009	±4.45	±0.037

Fig. 4. Compares coefficient of viscosity, surface tension and volume flow rate with respect to blood groups A, B, AB and O.

Fig. 4. 1. A comparison on viscosity of human blood of groups A, B, AB and O

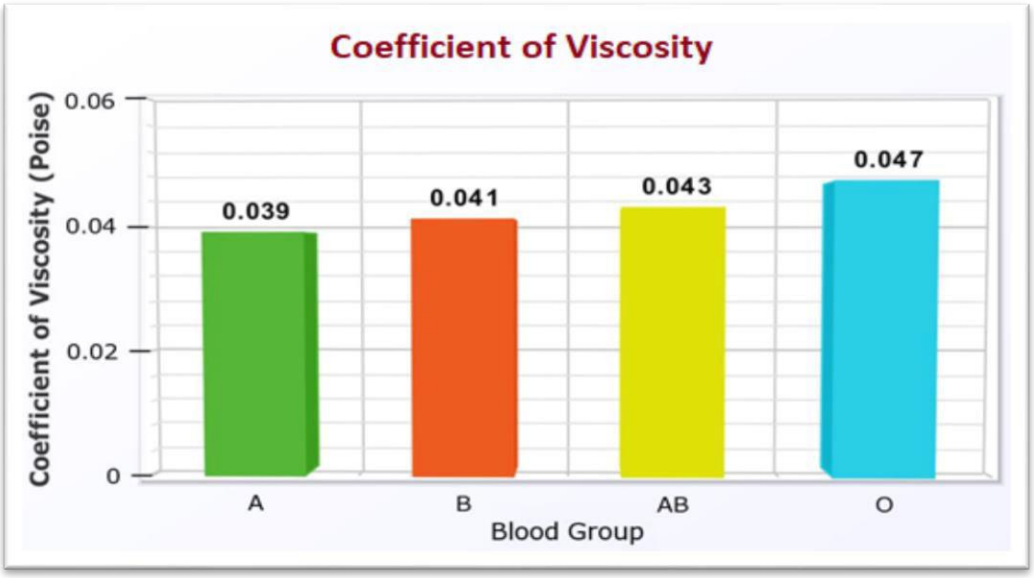


Fig. 4. 2. A comparison on surface tension of human blood of groups A, B, AB and O

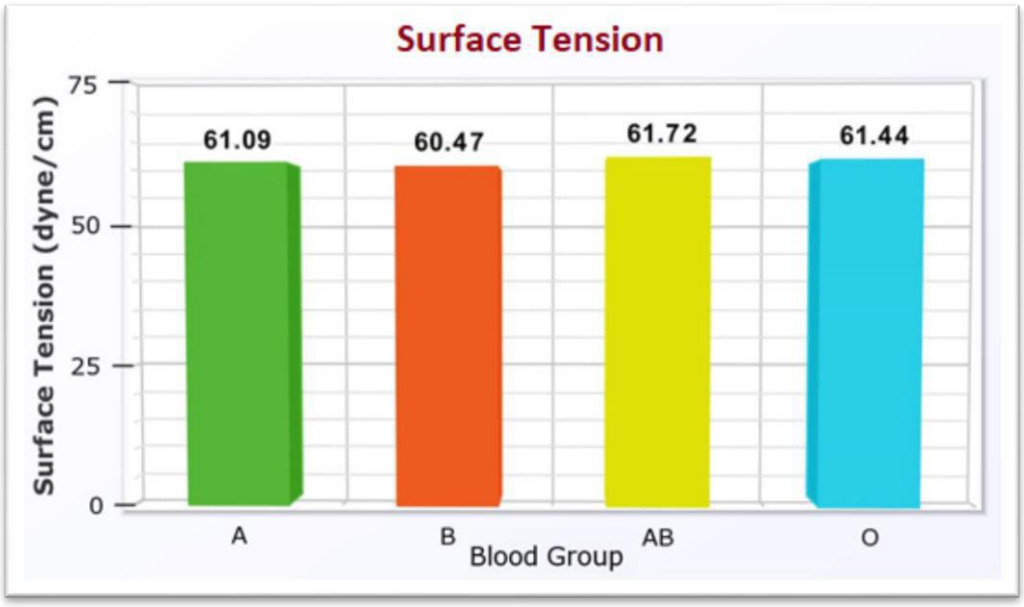
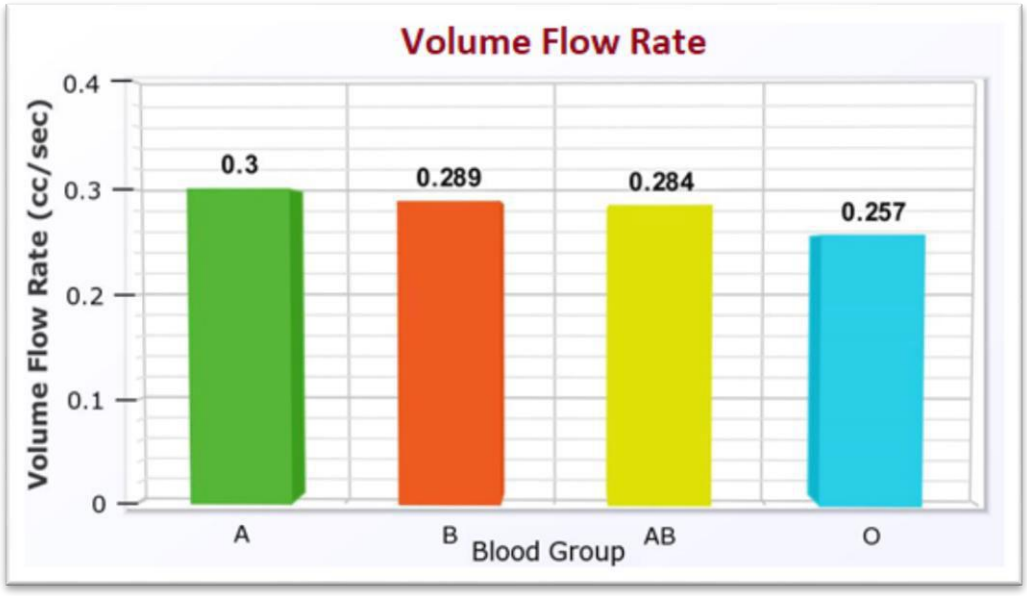


Fig. 4. 3. A comparison on volume flow rate of human blood of groups A, B, AB and O



It can be observed that viscosity is maximum in 'O' group, minimum in 'A' group and in between in the case of 'B' and 'AB' groups. But, there is no significant change in surface tension of blood irrespective of blood groups. However, volume flow rate, in behaviour, is reciprocal of viscosity. It seems blood antigens may influence viscosity and flow rate but not surface tension of human blood.

It is interesting to note that literature presents many techniques developed for the measurement of viscosity of blood as well as other biological fluids. But this technique developed at Biophysical research laboratory of Nizam College is unique in the sense it measures viscosity, surface tension and volume flow rate of biological fluids, specially blood at a stretch. Also, it is advantageous with respect to quantity of sample as it requires two to three drops of liquids mainly diseased blood. The automation in the designed viscometer with optical devices and the use of Software computer programs improves the accuracy of measurement in flow time.

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