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Determination of Viscosity of Liquids

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ABSTRACT

Viscosity of fluid plays an important roles in fluid characterization, fluid transfer and quality control. This study aim at determination of viscosity of two Newtonian fluids (Glycerine and Engine oil) using falling sphere viscometer. In this method, two steels balls (small and big steels balls) and two Newtonian fluids (Glycerine and Engine oil) were used to analysed the results of the study. The density of both fluids, density of both steels balls, acceleration due to gravity, radius of the steel balls and the velocity of both steels balls are essential in the determination of the dynamic and the kinematic viscosity of both fluids. The density of each steel balls was calculated using the formula, density=mass/volume, the mass of each balls was determined with the aids of a weighing balance and the volume of each steel balls was determined using the formula, $V=\pi r^3$, where r is the radius of the balls which is half of the diameter. The diameters of each steels balls was determined using a vernier caliper. The density of the fluids was also determined using the relation, density=mass/volume. The mass and the volume of each fluid were also determined using the weighing balance and a graduated measuring cylinders respectively. The velocity of each steel ball was calculated using the formula, velocity= distance travel by the steel ball through their respective fluid columns per unit travelled time. The acceleration due to gravity is $9.8 m/s^2$. The results of the study show that the Glycerine is more viscous with viscosity of 14.572 and 33.265poise than the Engine oil with viscosity of 7.24 and 18.629poise. The Reynolds numbers were also computed and were found to be less than unity which shows the validity of the experimental results. This method of viscosity measurement is only suitable for Newtonian fluids.

Keywords : Newtonian Fluids, Dynamic Viscosity, Kinematic Viscosity, Falling Sphere Viscometer, Reynolds Number, Fluid Velocity, Density, Steel Ball.

I. INTRODUCTION

All liquids possess viscosity as their fundamental characteristic properties (Viswanah, Prasad, Dutt, & Rani, 2007, p.1). Liquid that flows possess an internal resistance which opposes the flow of liquid (Viswanah et at, 2007, p.1). The measure of this resistance to the flow of liquid which measure the fluid frictional properties is called viscosity or referred to as the frag force (Viswanah et at, 2007, p.1). Temperature and pressure are function of viscosity which varies with the viscosity of liquid and gas and thereby affecting it in various forms (Viswanah et at, 2007, p.1).
Viscosity are of two types, these includes: Dynamic (Absolute) viscosity and the kinematic viscosity (Viswanah et at , 2007, p.1).

The force per unit area needed to move a layer of fluid over the other is called shear stress (τ=F/A), (Perry, Green &Maloney, 1997, p.6-4). When a fluid moves through a plate, it established a linear velocity profile within the fluid in the plate owing to the condition of no slip, the fluid in contact with the lower plate is at zero velocity and that in contact with the upper plate is at the plate velocity (Perry et al, 1997, p.6-4). In this case the shear rate is the velocity gradient ($\gamma^{\cdot}$ = du/dy), (Perry et al, 1997, p.6-4).

Shear stress per unit shear rate is called viscosity ($\mu = \frac{\tau}{\gamma^{\cdot}}$), (Perry, Green &Maloney, 1997, p.6-4). Kinematic viscosity is the ratio of the fluid viscosity to the fluid density (Viswanah et at, 2007, p.1). The S.I unit of viscosity are poise, Pa.s(pascal second) or kg/(m.s), (Perry et al, 1997,p.6-4).

Reynolds number is a dimensionless parameter that described fluids behavior as either laminar, transitional or turbulent, it is expressed as Re = $\frac{\rho v d}{\mu}$ (v is the kinematic viscosity) , where Re called the Reynolds number (Nakayama, & Boucher, 1999, p.46). Laminar flow is a flow in which there is no disturbance between the fluid layers. For an unsteady flow, the flow is smooth streamlines with a smooth fluid velocity components varying with and position (Perry et al, 1997, p.6-6). In turbulent flow, the fluid velocity component display chaotic fluctuation with respect to time and position, hence there is no smooth streamlines (Perry et al, 1997, p.6-6).

Fluid that obeys the newton law of viscosity is called a Newtonian fluid that is viscosity remain constant irrespective of the applied shear at constant temperature, fluids includes water, mineral oil, and engine oil etc. (Peters, Newtonian, 2015, para.1). In non- Newtonian fluid, the viscosity is not constant that is it changes, examples of these fluids are Dilatant, pseudo plastic, Rehopectics and thixotropic, Peters (non-Newtonian, 2015, para.4).

Viscosity can be determined by the following methods: falling sphere viscometer, consistometer, capillary viscometer etc. (Elert, 2018, viscosity, para.17-18).

The falling sphere viscometer is the most suitable and simplest method of measuring the viscosity of a Newtonian fluids among the aforementioned methods. In this method, the principle of Newton law of motion under the influence of a force on a falling sphere is utilized to reach the final velocity (Yuan & Ben, 2008, measurement of viscosity, para.1).

Owing to the roles play by the viscosity of fluids in the design of pipelines and quality control, this study aim at the determination of viscosity of two Newtonian fluids which are Engine oil and Glycerin and also to compare their performance in products classifications. The viscosity of liquids plays an important role in the areas of fluids characterization for products quality and efficiency, and in pipeline design, pump and other products. The need arises to exploit the most simplest and suitable method of determination of liquids viscosity. This makes it possible to carry out this study.

II. METHODS AND MATERIAL

Materials are : Two steel balls (a small and a big ball), Newtonian fluids (Glycerin and Engine oil), graduated measuring cylinders, a meter rule, a stopwatch, a venier calippers , micro screw gauge, digit weighing balance , and a calculator.

Method :

1. The methods are as follows:
   - The diamters of the steel balls were made in such way that were not greater than half of the diameter of the graduated cylinder, so that they can easily pass into the cylinder.

- The graduated cylinder used in this experiment was a tansparent plastic graduated container that allowed easy measurement of liquids volume.
- A stopwatch was used for timing the travel intervals of the balls through the liquids columns
- The liquids (Glycerin and Engine oil) used were clear enough to see the steel balls as the balls were dropped through the liquids columns.

2. The density of each steels balls was calculated. Both density of the balls (big and small ball) and that of the liquids (Glycerin and Engine oil) are needed for determination of viscosity of the liquids. Density of a substance or an object is the mass per unit volume. The density of the steels balls and the liquids were obtained by.

- The mass of each steel ball was measured by placing the ball on a weighing balance and the mass of the steel ball was recorded in grams (g).
- Since the balls are spherical in shapes, the volume of each ball was determined by using the formula $V= (4/3) \times \pi \times r^3$, where V is volume, π is the constant 3.14, and r is the radius of the sphere.
- The volume can also be measured displacing water in a graduated cylinder. Record the initial water level, place the ball in the water, and record the new water level. Subtract the initial from the new water level. This number equals the volume of your sphere in milliliters (mL).
- The density of the small ball and that of the big steel ball were determined using the density formula: mass per unit volume.

3. Density of each liquids (Glycerine and Engine oil) was determined by using the same density formula as shown in the following steps:

- The mass of the Glycerine liquid was measured by weighing an empty graduated cylinder. Then the Glycerine was Poured into the graduated cylinder and then weighed again. The mass of the empty cylinder was subtracted from that of the cylinder containing Glycerin this gives the mass of the Glycerine in grams (g). The same procedure was followed to measure the mass of the Engine oil.
- To find the volume of the liquids, the Glycerin and the Engine oil were separately poured into their respective graduated measuring cylinders. The cylinders were calibrated in milliliters (mL) and the capacity of each cylinders is 30mL which gives the volume of the liquid.
- The density of the Glycerine and that of the Engine oil were determined using the density formula: mass per unit volume.

4. The graduated cylinder was filled with the Glycerine and 30mL of the Glycerine was measured. Then, two positions were marked on the cylinder, one at the top and the other at the bottom of the cylinder. The Glycerine was carefully poured into the graduated cylinder and filled to it capacity.

- The measuring cylinder is $30cm^3$ capacity, the top of the cylinder was marked at 6.5cm from the top of the liquid and the bottom of the cylinder was also marked at 6.5cm from the bottom of the graduated cylinder.
- The top and bottom marks were measured by placing a meter rule between the two marked points and the interval was measured to be 17cm.
- The whole of the procedure 4 was repeated to obtain the volume of Engine oil.

5. The time taken for each steels balls to travel between the two marked points on the cylinders that were filled with the respective fluids was recorded by using a stop watch. The whole of step 5 above was repeated three times for accuracy and the average travelled time taken of each steel ball was determined.

6. The velocity of each steels ball was determined by the relation, velocity=distance traveled per unit time.
   - Owing to the fact that both steels balls traveled the same distance of 17cm, the traveled time taken of each steel ball rolling through their respective fluid columns were determined using the stop watch. Therefore, velocity of each steel ball was calculated.

7. The dynamic viscosity of the Glycerine and that of the Engine oil were calculated using the formula, viscosity = $[2(p_s-p_l)ga^2]/9v$,where p_s is the density of the ball which was determined for both the small and the big ball, p_l is the density of the liquid which was determined for both the Glycerine and the Engine oil, g is acceleration due to gravity (a fixed value of 9.8 m/s^2), a is the radius of the sphere which was determined for the small and the big balls obtained from their respective diameters the using vernier caliper, radius is half of the diameter , and v is the velocity of the steel ball which was determined for both steel balls. The kinematic viscosity of the fluids were determined by the relation, kinematic viscosity=dynamic viscosity/fluid density.

III. RESULTS AND DISCUSSION

The tables below present the results of the analysis. The dynamics and the kinematics viscosity of the fluids (Engine oil and Glycerine). Table 1 below shows the time taken for the steels balls to travel through their respective fluids columns. The results indicated that the small steel ball travelled faster than the big ball in their respective fluids columns. This is because the big steel ball is heavier and denser than the small steel ball which experience a high drag action on it in which the drag resists its movements through the liquids. Drag is the function of the fluid velocity and density, area and the drag coefficient. This resulted to a high velocity in the fluid columns traveled by the big steel ball, and a low velocity was observed in the fluid column travelled by the small steel ball. This shows that for a high viscous fluid the velocity is low and is high for a less viscous fluid as shown in table 2. The table shows the values of velocity, the dynamics and the kinematics viscosity of both fluids (Engine oil and Glycerine). The variation of velocity with viscosity is due to the action of the drag force acting on the steel balls rolling in the fluids as it is in the table. Since drag opposes the motion of steel ball in the fluids, the more viscous fluid (Glycerine) and the big steel ball experienced a high drag action than the less viscous fluid (Engine oil) and the small steel ball. This causes lower velocity on the big steel ball and higher velocity on the small steel ball to have lower velocity and the small steel. The viscosity of the fluids increase with decrease in the shear rate (velocity gradient).

Figure 1 shows the variation of viscosity with velocity. The viscosity varies inversely with the velocity. Figure 2 show that viscosity increases with decrease in the shear rate. That is viscosity varies inversely with shear rate.

Table 1 : Shows the average travelled time of both steels balls through the fluids columns

Engine oil		Glycerine	
$T_{big\ ball(second)}$	$T_{small\ ball(second)}$	$T_{big\ ball(second)}$	$T_{small\ ball(second)}$
6.3	4.3	12.4	9.7
6.8	4.6	13.9	10.3

6.3	4.2	12.8	9.9
Average 6.47	Average 4.37	Average 13.03	Average 9.96

Table 2 : shows the velocity, dynamics and the kinematics viscosity of the fluids (Engine oil and Glycerin)

Fluids	steel balls	Dynamic viscosity (poise)	Kinematic viscosity (stoke)	Velocity (m/s)
Engine oil	Small	7.24	3.755	0.0389
	Big	18.629	1.459	0.0263
Glycerine	Small	14.572	2.796	0.017
	Big	33.265	6.385	0.013

Table 3 : Relations of viscosity, velocity and shear rate.

Viscosity	Velocity(m/s)	Shear rate(s^{-1})	Time (s)
7.24	0.0389	0.002288	4.37
14.572	0.017	0.001	6.47
18.629	0.0263	0.001547	9.97
33.265	0.013	0.000765	13.03

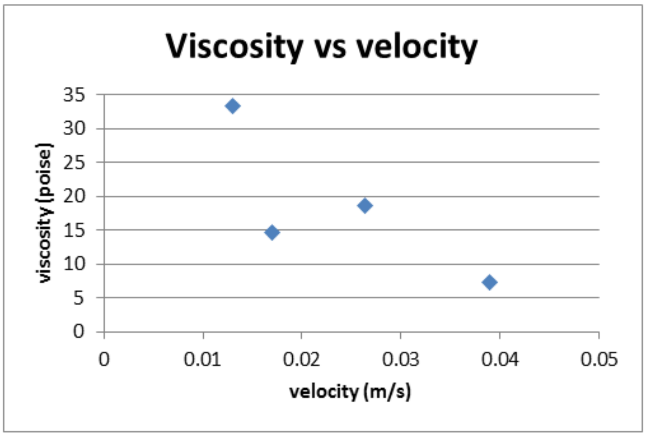

Figure 1 : variation of viscosity with velocity.

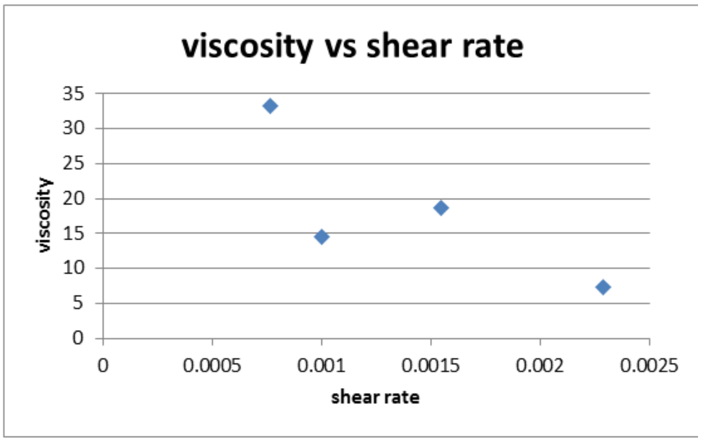

Figure 2 : variation of viscosity with shear rate

The figure 2 above shows that Newton's law of viscosity is obey that is both fluids used for this study are Newtonian fluids.

II. CONCLUSION

Viscosity of liquid is important in the design of equipment that transports fluids. Therefore, accurate determination of fluid viscosity is necessary when dealing with this equipment. The viscosity of the Glycerine and the Engine oil were determined using falling sphere viscometer. The results of the study show that the Glycerine is more viscous with viscosity of 14.572 and 33.265poise than the Engine oil with viscosity of 7.24 and 18.629poise. The Reynolds numbers of the fluids were computed and were found to be less than 1. This shows that the results of the study are within the application range for the falling sphere viscometer. The falling sphere viscometer is the easiest and suitable method for the determination of viscosity of Newtonian fluids.

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