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DETERMINATION OF THE VISCOSITY OF LOCAL HONEY BY FALLING-SPHERE VISCOMETER

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Abstract

In this study, a falling-sphere viscometer was used to measure the viscosity of local honey by determining the elapsed time of free-fall of ball-bearings traveling a specific distance through the liquid honey with the terminal velocity. Average moisture content of the honey was measured using vacuum pump drying at a pressure of 10^7 N/m^2 for six hours. The viscosity of the local honey was calculated using Stoke's law. The coefficient of viscosity of the sample at 29 ^oC was found to be 1.913 ± 0.002 Pas at an average moisture content of 18.93%, while the Reynold's number was 0.055. The analysis in this study could be used to determine the purity of honey.

Keywords: Viscosity, terminal velocity, Stoke's law, honey

1. INTRODUCTION

Viscosity is the quantity that describes a fluid's resistance to flow. Both liquids and gases are fluids. Viscosity is a property arising from collisions between neighbouring particles in a fluid that are moving at different velocities. The S.I unit of viscosity is the Pascal Second (Pas), however, its most common unit is the dyne second per square centimeter (dynes/cm^2) which is given the name poise (P) after the French physiologist, Jean Poiseuille (1799-1869). Ten Poise equal one pascal second. (10p=1pas).

There are actually two quantities that are called viscosity. Dynamic viscosity is the ratio of the shearing stress to the velocity gradient in a fluid. It is sometime called absolute viscosity or simple viscosity or just viscosity to distinguish it from the other quantity called kinematic viscosity which is the ratio of the dynamic viscosity of a fluid to its density. The S.I Unit of Kinematic viscosity is the square meter per second (m^2/s) which has no special name. Its more common unity is the square centimeter per second (cm^2/s) which is given the name stokes (st) after the Irish Mathematician and physicist George Stokes (1819-1903)(1cm^2/s = 1st)

The falling-sphere viscometer is regarded as being one of the earliest, simplest and most accurate types of viscometer by means of determining the low shear rate of liquids with numerous applications in the testing of petroleum products, food and beverage products and pharmaceuticals [1]. It works simply by determining the elapsed time of free-fall of a sphere travelling a known distance in the fluid with the terminal (constant) velocity at a specified temperature, where this time is directly related to the fluid viscosity. In other words, the more viscous a fluid, the more time the sphere takes to travel the distance.

The fluid which viscosity was determined in this work is local honey while the spheres were small ball-bearings used in motorcycles and bikes. Honey is a sweet food made by bees foraging nectar from flowers. The variety produced by honey bees (the genus Apis) is the one most commonly referred to, as it is the type of honey collected by most beekeepers and consumed by people.

2. PURPOSE OF THE STUDY

The main aim of this work is to determine the coefficient of viscosity of local honey and the objectives are:

i. To calculate the terminal velocities of steel ball-bearings falling through the local honey.
ii. To calculate the related Reynold's number and,
iii. To determine the validity of stokes' law in this experiment
iv.

3. SIGNIFICANCE OF THE STUDY

This method is suitable for determining the viscosity of viscous liquids and the viscosity of a liquid is needed for:

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i. many fluid mechanics problems,
ii. designing piping systems,
iii. It can be used in fields as diverse as food sciences and baking,
iv. It helps in determining Reynold's Number**.**

4. THEORY

Now consider the sphere falling (figure 1) vertically under gravity in a viscous fluid (honey in this case) . Three forces act on it:

i. Its weight, W, acting downwards = $\frac{4}{3}\pi r^3 pg$
ii. The upthrust, U, due to the weight of fluid displaced, acting upwards = $\frac{4}{3}\pi r^3 \sigma g$, and
iii. The viscous drag, F, acting upwards = $6\pi\eta r V_t$ (Stokes' law)

Where: p is the density of the falling sphere
σ is the density of the fluid (local honey)
V_t is the terminal or constant velocity attained by the sphere
r is the radius of the falling sphere
g is the acceleration due to gravity
η is the coefficient of viscosity of the local honey

The resultant downward force is (W-U-F) and causes the sphere to accelerate until its velocity become steady and so the viscous drag reaches values such that

W-U-F = 0 (1)

The sphere then continues to fall with a constant velocity, known as its terminal or settling velocity (V_t) [2]
Also, if steady conditions still hold when the terminal velocity (V_t) is reached, then by Stokes' law:

F= $6\pi\eta r V_t$ (2)

Hence, making substitutions into equation (1), we have :

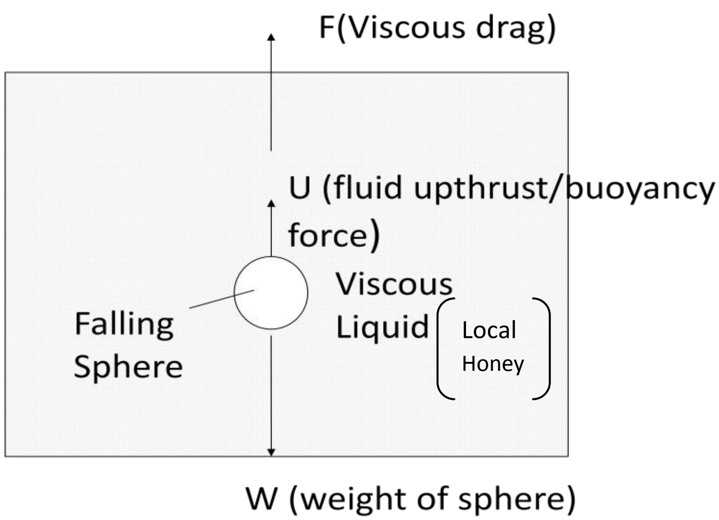

Figure 1: Forces on object falling through viscous liquid (the local honey)

$$\frac{4}{3}\pi r^3 \rho g - \frac{4}{3}\pi r^3 \sigma g - 6\pi\eta r V_t = 0$$

Thus; $V_t = \frac{2r^2(\rho-\sigma)g}{9\eta}$ (3)

Equation (3) is valid at steady flow

From hydrodynamical considerations, it was shown by Stokes that when a sphere falls under gravity through a fluid of **infinite extent**, ultimately it moves with a constant velocity, called the terminal velocity[3] given by Equation (3):

In practice, this experiment was performed in a liquid of total depth, H, taken in a cylinder of inner radius, R. This finite depth and radius of the liquid seem to call for a correction in the formula [3,4,5]

For finite radius, R, it was shown by Faxen and Bason that the observed terminal velocity (V_t) should be multiplied by a

factor $\left(1+\frac{2.4r}{R}\right)$ to take into account the finite lateral extension of the liquid.
Again, for the finite depth H, the corresponding multiplying factor is $\left(1+\frac{3.3r}{H}\right)$.
These corrections are known as Ladenburg corrections [3]. Thus the corrected value of the terminal velocity (V_t) will be:

$$\therefore V_t = \frac{2r^2(\rho-\sigma)g}{\left(1+\frac{2.4r}{R}\right)\left(1+\frac{3.3r}{H}\right)9\,\eta} \quad (4)$$

The value of V_t may be determined from the time t(s), required by a sphere in moving a known distance**, x,** in the liquid with the terminal velocity.
Thus from equation [4], the coefficient of viscosity will be:

$$\eta = \frac{2}{9}\frac{r^2 g(\rho-\sigma)}{Vt\left(1+\frac{2.4r}{R}\right)\left(1+\frac{3.3r}{H}\right)} \quad (5)$$

The terms are as defined earlier.

5. FACTORS AFFECTING VISCOSITY

i. Viscosity is first and foremost a function of material; water, gases, pastes, gels, emulsions, butter margarine, molten glass are different materials with different coefficients of viscosity.
ii. Viscosity varies with temperature: Experiment shows that the coefficient of viscosity of a liquid usually decreases rapidly with temperature rise [2].
iii. The viscosity of honey is affected greatly by both temperature and water content. The higher the water percentage, the easier honey flows.

6. METHODOLOGY

The experiment was set up as shown in figure 2. The inner diameter of the cylinder was measured by a Vernier Calliper at different places, and the mean diameter and hence the radius (R) was determined.
Diameters (2r) of the ball-bearings were measured by means of a screw-guage at two different places to determine the mean diameter and hence the radius (r) was determined.
The distance between the two timing marks on the glass cylinder was measured and found to be 7.00cm. The cylinder was filled with the local honey and sometime was allowed so that it might be in temperature equilibrium with the surroundings. The thermometer was placed in the liquid and after stirring it for a while, its temperature was recorded as 29.00^0C.
The balls of similar diameters in each group were first wetted with the honey and then with the help of a spatula, one ball after another was gently dropped on the liquid surface and the time it took each ball in crossing the timing marks was noted by a stop watch. From these timings, the terminal velocity (V_t) was obtained. The procedure was repeated fro the balls in other groups. The liquid honey level was several centimeters above the top timing mark so that the ball had time to reach its terminal velocity before the timing began. Thus it was ensured that the ball had reached its terminal velocity before it reached the first timing mark.
Density(σ) of the local honey used was determined by a specific gravity bottle method as $1.411gcm^{-3}$ while the means density of the steel ball-bearings was $7.000gcm^{-3}$. The radius (R) of the cylinder equals 4.74cm whereas the height (H) of the liquid in the cylinder was 23.30cm.
The average moisture content of the honey was determined using vacuum pump drying at 10^7Nm^{-2} pressure for six hours at the Department of Food Sciences and Technology Obafemi Awolowo University, Ile-Ife.
Reynold's number (Re) was calculated using the equation (6) below [6]:

$$Re = \frac{\sigma V_t d_s}{\eta} \quad (6)$$

Where d_s is the mean diameter of the ball-bearings. The calculated value of the Reynold's number is approximately equalt to 0.055. Reynold's number is useful in the study of the stability of fluid flow and since it was much less than one, Stoke's law is valid for determining the equation for viscosity.

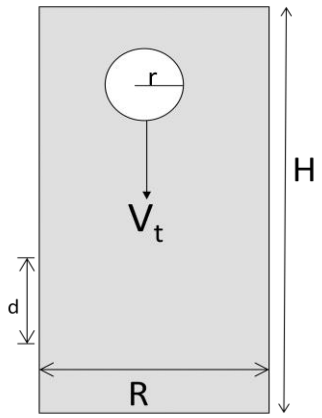

Figure 2: Experimental set-up

7.1 RESULTS AND DISCUSSION

The diameters and hence the mean raddi of the different steel ball-hearings used is has shown in Table 1. The mean diameters of the ball-bearings range between 2.33mm and 4.73mm.

TABLE 1: DIAMETERS AND MEAN RADII OF THE BALL-BEARINGS

Group of balls	Diameters (mm) at 2 places									
	1^{st} ball		2^{nd} ball		3^{rd} ball		4^{th} ball		Mean (Average) Diameter (mm)	Mean (Average) radius(mm)
	d_1	d_2	d_1	d_2	d_1	d_2	d_1	d_2		
A	2.34	2.35	2.29	2.32	2.31	2.41	2.29	2.30	2.330±0.038	1.165±0.019
B	2.84	2.99	2.88	2.87	2.76	2.76	3.00	2.91	2.880±0.085	1.440±0.043
C	3.24	3.22	3.16	3.13	3.20	3.24	3.20	3.20	3.200±0.036	1.600±0.018
D	3.49	3.48	3.42	3.38	3.23	3.35	3.27	3.27	3.360±0.093	1.680±0.047
E	4.52	4.47	4.46	4.48	4.49	4.47	4.46	4.48	4.480±0.018	2.240±0.009
F	4.91	4.70	4.72	4.76	4.70	4.72	4.68	4.68	4.730±0.070	2.366±0.035

Table 2. Illustrates the time of falling of each group of balls through the timing distance and their terminal velocities. It was observed that as the radius of the balls increases down the different groups, the time of fall reduces, thus, the velocity increases down the group. This means that balls of smaller diameter moved slowly through the liquid (that is takes longer time), whereas balls of larger diameter moved quickly or faster through the honey (i.e takes shorter time)

TABLE 2: TIME OF FALL OF EACH GROUP OF BALLS AND THE TERMINAL VELOCITY

Group of balls	Mean radius of balls: r/(mm)	Time of fall t(s)							
		t_1(s)	t_2(s)	t_3(s)	t_4(s)	t_5(s)	t_6(s)	Mean t(s)	Terminal Velocity of all $V_t = \frac{L}{t} (\frac{cm}{s})$
A	1.165±0.019	5.11	5.04	5.06	4.94	5.32	5.06	5.088±0.116	1.376
B	1.440±0.043	3.74	3.96	3.94	4.06	4.22	4.41	4.055±0.214	1.726
C	1.600±0.018	3.58	3.46	3.61	3.38	3.39	3.70	3.520±0.118	1.989
D	1.680±0.047	3.72	3.60	4.02	4.15	-	-	3.873±0.222	1.808
E	2.240±0.009	2.65	2.70	2.33	2.50	2.69	2.56	2.572±0.129	2.722
F	2.366±0.035	2.64	2.50	1.99	2.11	2.11	1.97	2.220±0.256	3.153

The density (σ) of the local honey by specific gravity bottle method was 1.411 gcm^{-3} while the density of the ball-bearings was 26.79gm^{-3}. The radius, R, of the cylinder equals 4.7cm whereas the height (H) of the liquid in the cylinder equals 23.30cm. Distance between the two timing marks on the cylinder was 7.00cm and the temperature of the honey was 29.00^{0}C.

7.2. Graph of r^2 $(cm)^2$ against corrected $V_t(cms^{-1})$

Figure 3 illustrates the graph of average r^2 $(cm)^2$ against the mean corrected V_t. The graph is supposed to be straight line graph for Stoke's Law to be true [7,8]. The slope of the graph was approximately 0.015cms

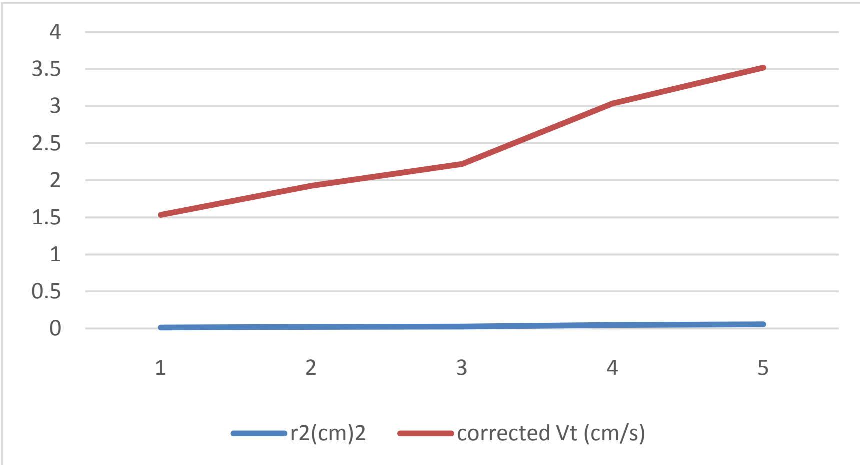

Figure 3: Graph of $r^2(cm)^2$ against V_t (cms^{-1})

7.3 Determining the coefficient of viscosity of the local honey

By substituting into equation (5) the value of the coefficient of viscosity of the local honey was obtained as:

$$\eta = \frac{0.2222 \times 0.015 \times 1000(7.8 - 1.411)}{1.0886 \times 1.0248}$$

η=19.127 poise

η=1.913 pas

8. CONCLUSION

The coefficient of viscosity of a local honey had been determined by falling-sphere viscometer method. This was achieved by measuring the time it took for steel ball-bearings to fall a certain distance through the honey. Using this time and distance, terminal velocity was calculated. Also, by using the slope from the $r^2(cm)^2$ versus V_t (cms^{-1}) graph, and the corrected Stoke's equation, the value of the coefficient of viscosity of the local honey (η) was determined to be 1.913 ± 0.002 pas at 29^{0}C and 18.93% moisture content. Reynold's number was also calculated to be 0.055 and since it was much less than 1, Stoke's law is valid for determining the equation for coefficient of viscosity.

REFERENCES

[1] Tanner R.I. (1963): End Effects in Falling-Ball Viscometry, J. Fluid Mech; 17,161-170.
[2] Duncan T. (1978): Advanced Physics Material and Mechanics, John Murray, London.
[3] Sami Kumar Ghosh (2008): A Textbook of Advanced Practical Physics New Central Book Agency Limited, Kolkata, Delhi Pune
[4] Lommatzsch T. Megharfi M., Mahe E. and Devin E., (2001): Conceptual Study of an Absolute Falling-Ball Viscometer, Metrologia, 38, 531-534.
[5] Park, N.A., IrVine T.F. (1984): The Falling Needle Viscometer; A new Technique for Viscosity Measurements, Warme-Stoffuhertragung, 18, 201-206

[6] Carl J. Schaschke (2010): High pressure Viscosity Measurement with Falling Body Type Viscometers International Review of Chemical Engineering Vol.2, N.5
[7] Anyakoha M.W. (3rd Edition) New School Physics for Senior Secondary Schools.
[8] Tyler F. (5th Edition) A Laboratory Manual of Physics