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Fabrication and Validation of Rotational Viscometer

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Abstract: An efficient rotational viscometer capable of determining viscosity of Non-Newtonian fluids has been developed and the design of this viscometer is described in detail in this paper. The Equations to find the viscosity of fluids is described in this paper. Viscosity of a Non-Newtonian fluid (ketchup) is found. The instrument is calibrated using standard fluids and a correction coefficient is obtained. An efficient method to find the viscosity of Non-Newtonian fluids is introduce in this paper.
Keywords: Rotational Viscometer; Ketchup; Viscosity

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I. INTRODUCTION

This paper reviews the theory of co-axial concentric rotational viscometer. Viscosity is one of the important properties that must be dealt with in many liquid flow problems. Efficient method are developed for measuring the viscosity of liquids. These methods generally have been developed around Newton's law of viscosity and it's assumptions that viscosity is independent of rate of shear. The viscosity of Newtonian fluids are easy to calculate as there are many instruments which provide direct value of viscosity. The viscosity of Non Newtonian fluids is difficult to determine as the shear rate is not proportional to the strain rate i.e. they do not follow newton's law of viscosity. In nature the fluids found are mainly non Newtonian fluids and therefore it becomes very essential to find their viscosity.

The interest to design and fabricate a rotational viscometer with locally available materials that could be used in the measurement of viscosity of different fluids were due to the listed reasons below:

1) Unavailability in the local market.
2) High cost for the instrument.

A coaxial cylindrical rotational viscometer works on the principle that a solid (inner) cylinder is rotated inside a hollow cylinder which contains test sample of liquid. The torque experienced by the solid cylinder due to viscous effect of the test sample is measured and hence viscosity can be calculated. Rotational viscometers measure the amount of torque needed to rotate an object moving through fluid at a known RPM. Using the measured torque, RPM, and dimensions of the device, the viscosity can be calculated [2]. To find the viscosity of the fluids one must obtain torque-angular velocity data.

By rotating the spindle or inner cylinder at different speeds, shear dependent behavior can be analyzed, which are applicable to measure the viscosity of various fluids such as engine oil, water, kerosene, petroleum oil, paint, printing ink.

II. METHODOLOGY

A. Equation

An equation for viscosity measurement for a sample has been developed.

Viscosity = (Shear stress)/ (shear rate)

Shear stress = force/ (area in contact with fluid)

The torque is offered by curved surface area and the base circular area of inner cylinder.

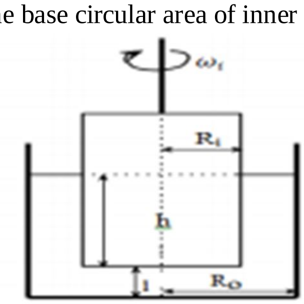

Figure 1 Rotational viscometer

Torque offered by curved surface $\square_1 = \frac{2\pi R_i^3 \mu H \omega}{R_o - R_i}$

Torque offered by flat surface $\square_2 = \frac{\pi \mu \omega R_i^5}{5(R_o - R_i)}$

$$\mu = \frac{\square_{total}}{\pi \omega R_i^3 \left(\frac{2H}{R_o - R_i} + \frac{R_i^2}{H}\right)}$$

Where

$\square_{total}$ = torque offered by the test sample (N.m)

$= \square_1 + \square_2$

R_i, R_o = radii of inner and outer cylinder respectively (m)

ω = Angular velocity of the inner cylinder (rad/sec)

H = height of inner cylinder filled up by the liquid (m)

For Non-Newtonian fluids there are some modifications.
Torque 1 = rotation without fluid
Torque 2 = rotation with fluid
Resisting Torque = Torque 1 – Torque 2
This Resisting torque is used in the equation to find viscosity

$$\mu = \frac{\square_{Res}}{\pi \omega R_i^3 \left(\frac{2H}{R_o - R_i} + \frac{R_i^2}{H}\right)}$$

B. Design of the components

The main parts of a co-axial concentric rotational viscometer are an outer cylinder (hollow), an inner cylinder (solid) and a motor. The other parts are a base and a driving shaft for inner cylinder. The diameter of the inner cylinder is 50mm and the height is 20 mm. Due to its low inertia, wider temperature range and non-reactivity with the tested liquid aluminum is chosen for inner cylinder. In case of outer cylinder, stainless steel is selected as the material for the outer cylinder.

C. Design parameters

There are three general categories for rotational viscometer based on their design configuration 1.Coaxial-Cylinder Viscometer. Cone and Plate Viscometer 3. Conic-Cylinder Viscometer. The major disadvantages of third and second type are the involvement of complexity of construction and more friction. In this project the inner cylinder is rotating and outer cylinder remains stationary. The gap between the inner cylinder and Outer cylinder plays an important role for obtaining torque. More accurate measurements are obtained if the gap between the inner cylinder and outer cylinder is reduced. In our instrument there is a gap of 50 mm between the outer and inner cylinder [2]. The length of the shaft should be small to avoid off-axial rotation of the cylinder. For proper rotation of the cylinder along its axis a bearing was fixed at half length of the shaft.

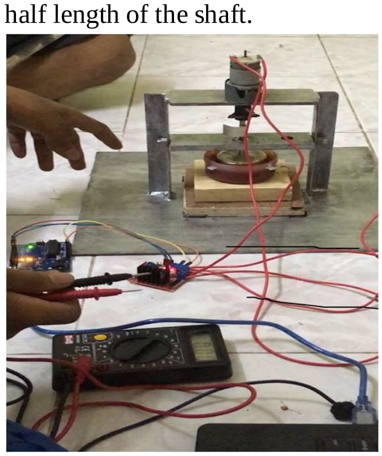

Figure 2 Actual Model

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The list of electronic components used are-
DC motor - 150rpm, 12 V.
Microprocessor - Arduino Uno.
Motor Driver - L298.
Battery - 12V.
Multimeter.

D. Calibration

Water was the first fluid tested in order to gage the accuracy of the viscometer. However, water proved to be unusable due to its low viscosity and thus not generating a readable torque. For this application to get any usable data, medium to high viscosity fluids had to be used [2].

Table 1 Standard fluids with their Viscosity

Water	0.0091 poise
SAE 30	650 cp
Kerosene	0.0164 poise

The viscosity of SAE 30 was measured at room temperature and the motor was rotated initially at some rpm.The obtained value was compared with the standard value and a correction factor was obtained.
Torque 1 = rotation without fluid
Torque 2 = rotation with fluid
Resisting Torque = Torque 1 – Torque 2

Table 2 Readings for SAE30

Rpm	Torque 1	Torque 2	Resisting Torque	μ(Pa-s)
76	0.02106	0.02192	0.00086	0.6622
96	0.02200	0.02219	0.00019	0.8890
108	0.02281	0.02423	0.00142	07694
114	0.02223	0.02386	0.00163	0.8599
120	0.02255	0.02382	0.00127	0.6186
129	0.02256	0.02371	0.00115	0.5208

Average viscosity is μ = 0.719 Pa-s = 719 cp
Therefore; Correction factor (C_d) = 0.91
It was observed that the correction factor gave approximately similar value of viscosity as the standard value at different temperatures. Then the motor was rotated at different rpm and the readings were noted. Similar measurements were carried out for kerosene and a correction factor was obtained. This correction factor was similar to the correction factor obtained by experimenting with SAE 30.

III. RESULTS

Once the calibration was complete the testing of viscosity was started. Ketchup (Maggi) was selected as our non-Newtonian fluid. For Ketchup the result table is

Table 3 Result table for Ketchup.

Rpm	Resisting Torque	μ*C_d (Pa-s)
105	0.082565	41.93
127	0.07762	32.5962
142	0.071914	27.01
153	0.07414	25.844
162	0.073148	24.0826
165	0.07213	23.3157

For 105 rpm the viscosity of the ketchup at room temperature is found out to be 41.93 Pa-s.
The viscosity of Ketchup for the highest value of Rpm was found out to be 23.3157 Pa-s
The Graph of Viscosity of the ketchup at different angular velocity is plotted and is shown in figure 3.

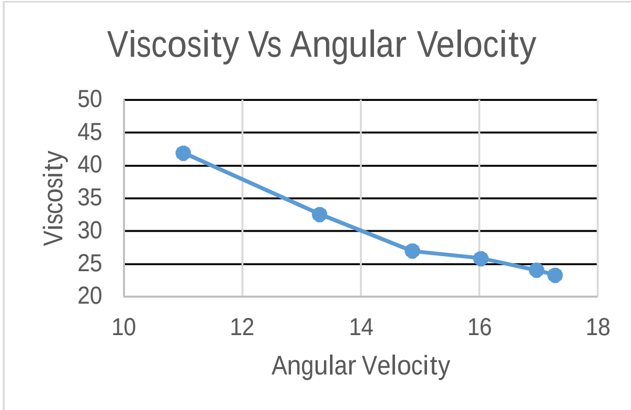

Figure 3 Graph of result for Ketchup

IV. CONCLUSION

From the table and graph it is clear that the viscosity of non-newtonian fluids like ketchup can be measured.
Shear thinning can be seen from the above graph i.e. the viscosity increases with the shear strain rate. The ketchup has a tendency to show shear thinning [3]. Thus the viscometer correctly shows the physics of fluid flow of ketchup.
Thus the viscometer successfully measures viscosity of fluids.

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