Fabrication and Testing of Viscosity Measuring Instrument (Viscometer)

A. B. Hassan, M. S. Abolarin, A. Nasir, and S. G. Mshelia

Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria
nasrabdulk@yahoo.com

Abstract

This paper presents the fabrication and testing of a simple and portable viscometer for the measurement of bulk viscosity of different Newtonian fluids. It is aimed at making available the instrument in local markets and consequently reducing or eliminating the prohibitive cost of importation. The method employed is the use of a D.C motor to rotate a disc having holes for infra-red light to pass through and fall on a photo-diode thus undergoing amplification and this signal being translated on a moving-coil meter as a deflection. The motor speed is kept constant but varies with changes in viscosity of the fluid during stirring, which alter signals being read on the meter. The faster is revolution per minute of the disc, the less the deflection on the meter and vise-versa. From the results of tests conducted on various sample fluids using data on standard Newtonian fluids as reliable guide the efficiency of the viscometer was 76.5%.

Keywords

Development, Testing, viscometer, Measurement, Amplification

Introduction

The paper presents the fabrication and testing of a simple and portable viscometer for the measurement of bulk viscosity. Viscosity is an internal property of fluid that offers resistance to flow or it is the measure of the internal friction of a fluid. This friction becomes apparent when a layer of fluid is made to move in relation to another layer. The greater the friction, the greater the amount of force required to cause this movement which is called shear. For better comprehension one needs to realize that viscosity is the ratio of the shear force applied to the amount of resulting deformation. The deformation of the fluid is expressed as the rate of shear. Hence, viscosity can be deduced to being relationship between shearing stress and rate of shear:

$$\text{Viscosity } \mu = \text{shear stress/rate of shear} \quad (1)$$

$$\text{Shear stress} = \text{Force/Area} \quad (2)$$

In other words the shear stress can be increased or decreased by either changing the velocity of the liquid (acceleration), or the pipe size:

$$\text{Shear rate} = \text{Velocity/Film thickness} \quad (3)$$

Water, dilute suspensions, aqueous solutions and emulsions are simple cases where the shearing stress is directly proportional to the rate of shear. The proportionality constant is called the viscosity coefficient of the liquid. Liquids or fluids with such direct proportion are called Newtonian fluids (source: www.research-equipment.com).

It is therefore obvious that viscosity sensing, measurement and the determination of fluids for various practical applications are essential in many fluid processes.

The interest to design and fabricate a simple viscometer that could be used in the measurement of viscosity of different fluids came to mind, due to the under listed reasons:

- Scarcity of the instrument from the local markets;
- The prohibitive cost of importation;
- Use of local technology and skills for the construction of the device.

The viscometer was designed and fabricated; it employs well known principle of rotational spindle in the sample fluid, it is easy to setup for and therefore does not require enormous amount of operator skills.

Design Analysis

The concept of the design has two features:

1. Engineering features and design approach – creation (concept) of a complete set of

assembly and detailed drawings for each and every part used in the design. Each detail drawing specifies all the dimensions, the material specifications and production processes necessary to make a part in conformity with existing principles and theories;

2. Prototype test model (Principal features) – from these drawings a prototype test model is constructed for physical testing, with its principal features as:
   - Fat base and frame which supports the whole weight of the viscometer mechanism;
   - Complete assembly of the components of the mechanism;
   - D.C. voltage regulator power supply;
   - Instrument unit / Analogue display meter;
   - Other features consist of the following: Glass stirrer, Cables (leads), 600ml Beaker, Sample fluids.

Mode of Operation

The motor rotates a disc having holes for light from a Light Emitting Diode (LED) to fall on a photo-diode thus undergoing amplification and this signal is then transmitted to a moving-coil meter as a deflection. The speed of rotation indicates the way signals are sent thus affecting the meter deflection. If the faster the speed of rotation of the disc, then the less the deflection on the meter and vice-versa.

Comparative Analysis

The viscometer constructed employs the well-known principle of rotational viscometers used in most laboratories [1, 2].

They measure viscosity by sensing the torque required to rotate a spindle at a constant speed while immersed in the sample fluid. The torque is proportional to the viscous drag on the immersed spindle and thus to the viscosity of the fluid. Typical examples are the *Brookfield Digital Viscometer* and the *Z80 Controlled Viscometer Project* [3, 4].

This viscometer is close in mechanism with the Z80 viscometer but has a number of components different thereby simplifying the process of measurement:

http://www.can-am.net/practicalcourse/brookfield_knowledge_test.htm

The essential innovation in the design is the use of single rotating disc with four (4) equidistance spaced holes in alignment with both LED and photo-transistor to sense electrical signals instead of torque; and the signals converted to measurement on a calibrated moving-coil meter.

Unavailability of the instrument in local markets and the exorbitant cost associated with importation are the major constraints. In comparison to importations of viscometers, the cost of producing this viscometer is less [5, 6]. This prototype can be greatly improved upon when precision / skilled machinist and standard materials / machines are used [7, 8].

Performance Test

After the construction the viscometer was subjected to performance test. The D.C motor, rotating disc, pillars, chuck and the stirrer were continuously adjusted to reduce / eliminate effect of noise, vibration and wobbling of the machine. To ascertain its reliability and durability, it was subjected to one hour (60 minutes) test runs at intervals. The test runs were adjudged satisfactory and thereby put in to use to test the values of the standard Newtonian fluids.

Procedures to Set-Up the Viscometer Constructed

1. Level the viscometer;
2. Put spindle onto the viscometer and screw up the spindle onto the chuck (right handed threaded screws);
3. Pour the sample fluid into the 900ml beaker;
4. Lower the viscometer (using adjustable nub behind the stand) into the fluid until the notch on the spindle shaft is just below the fluid surface;
5. Turn ON the viscometer (powering both motor & components) from AC/DC Adaptor;
6. Observe the analogue meter deflection;
7. After 60 sec. (when reading is steady), read the prevailing meter deflection and record;
8. Turn OFF the viscometer;
9. Raise the spindle until the viscometer clears the top of the beaker;
10. Pour the content of the beaker into the sink/container and clean the beaker/spindle for next use;

BASE / STAND {J} Material – Stainless steel

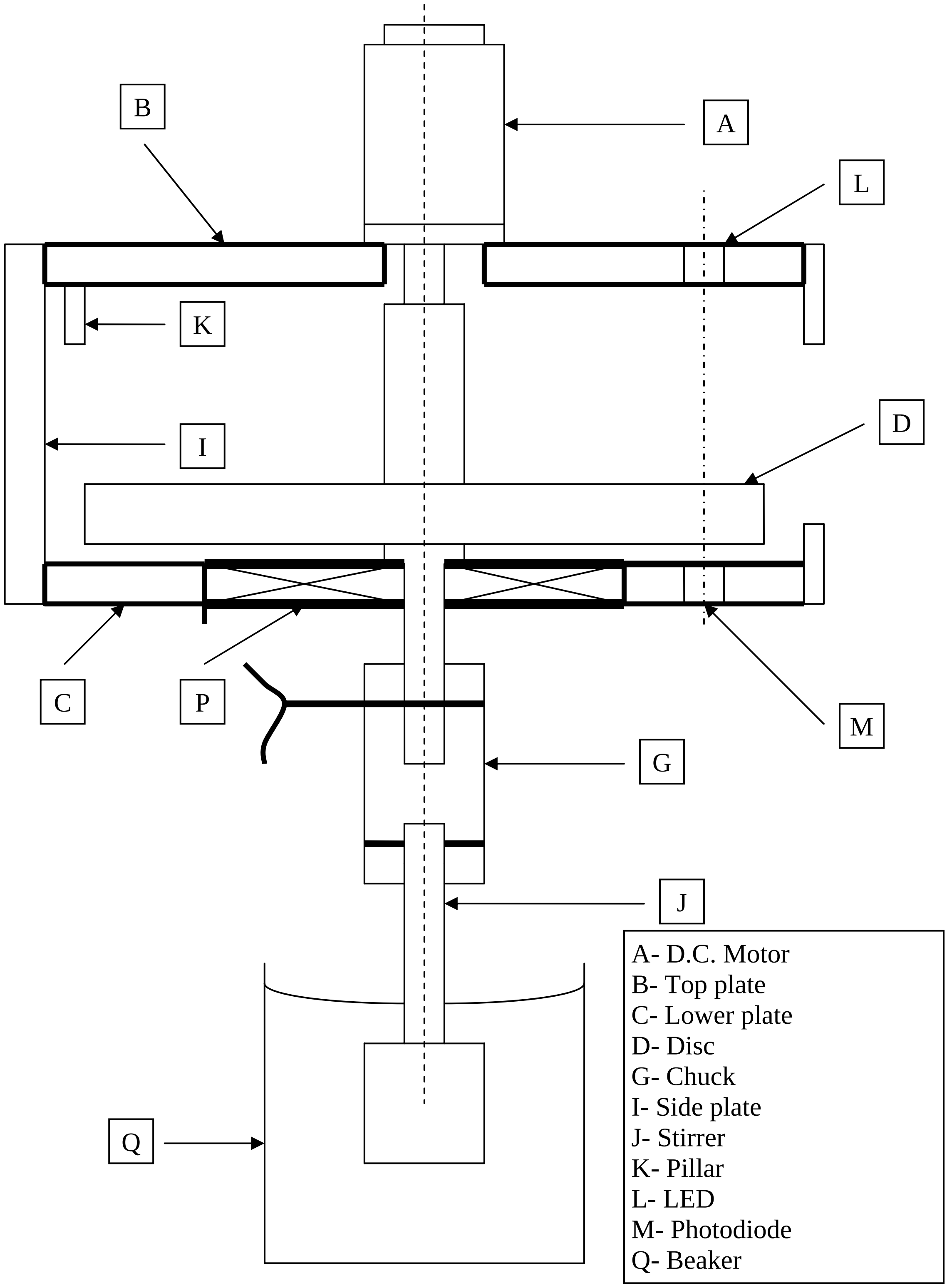

Fig. 1. Simple Viscometer Mechanism Constructed

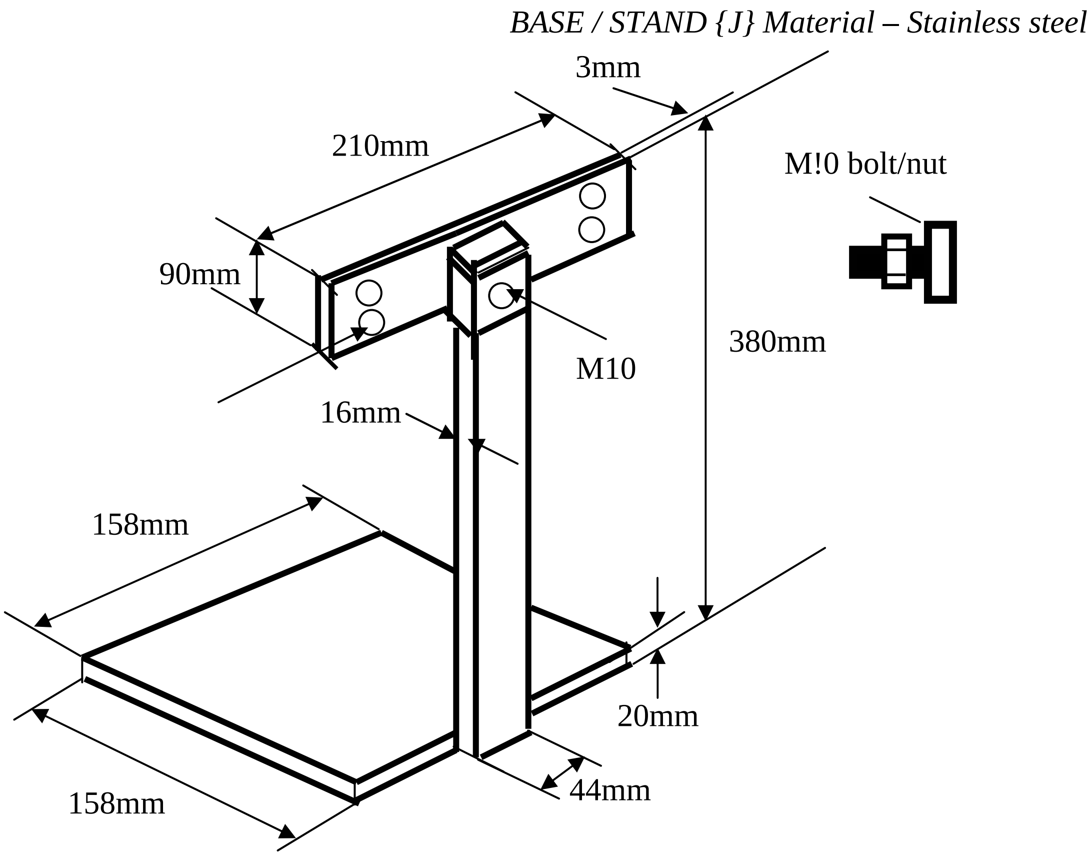

Fig. 2. Dimensions of Viscometer Stand

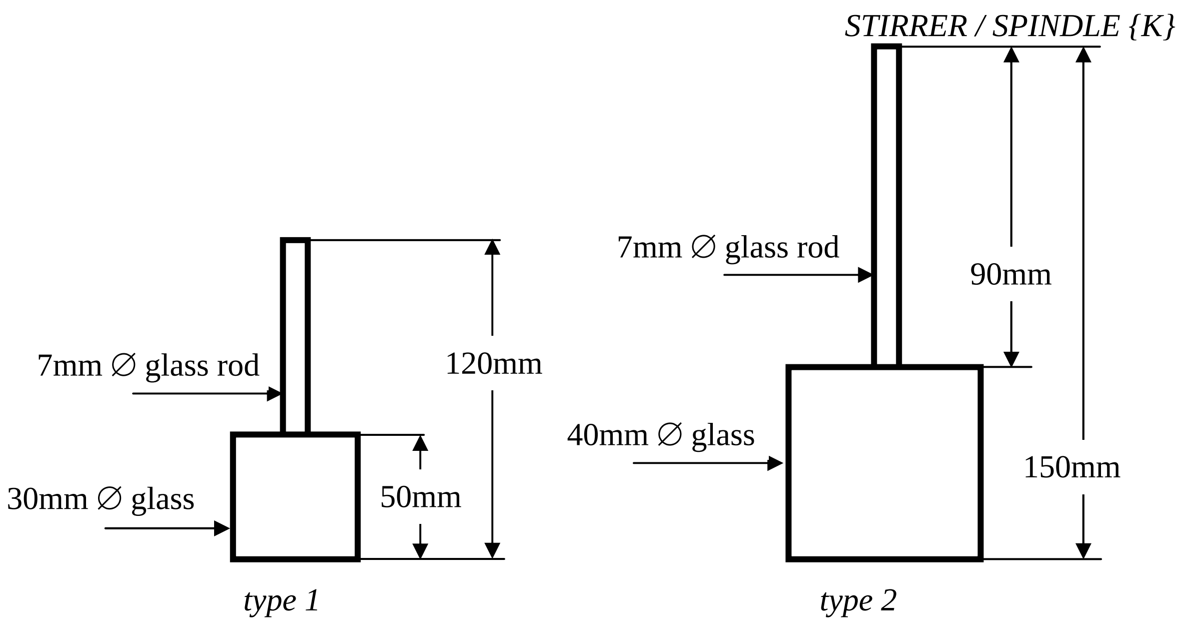

Fig. 3. Spindle

Results

Performance test to determine viscosities of different fluids was made using following test conditions: Room temperature - 32 °C; Motor speed - 120 rpm; Voltage selected - 7.5 V; Spindle size - type 1 (large).

Table 1. Performance test to determine viscometer readings for different sample fluids

Test	Types of sample fluids				
	Water at 70F	Kerosine DPK	Super duty SAE40	Gear oil EP90	Honey (thick)
1	0.2-0.9	1-1.5	2-3	3.5-4.5	6-10
2	0.1-1.0	1-1.4	2-3	3.5-4.5	6-10
3	0.1-1.0	0.8-1.4	2-3	3.5-4.5	6-10
Average	0.13-0.97	0.93-1.43	2-3	3.3-4.4	6-10
Average reading	0.55	1.18	2.50	3.85	8.00

Table 2. Factors used for conversion based on standard fluids

Standard fluid	Water at 70F	Kerosine DPK	Motor oil SAE40	Gear oil EP90	Honey (thick)
Standard reading in centipoises (Y)	1-5	10	250-500	1000-2000	2000-3000
Viscometer reading (R)	0.1-1.0	1.0-1.5	2.0-3.0	3.0-4.6	6.0-10.0
Conversion factor (X)	5	6.67	166.67	444.44	300

Table 3. Conversions of Performance Results into Standard Centipoises

Sample Fluid	Water at 70F	Kerosine DPK	Motor oil SAE40	Gear oil EP90	Honey (thick)
Standard Reading [cP] (Y)	1-5	10	250-500	1000-2000	2000-3000
Constructed viscometer Reading (R)	0.1-1.0	1.0-1.5	2.0-3.0	3.0-4.5	6.0-10.0
Conversion Factor (X)	5	6.67	166.67	444.44	300
Average reading of constructed viscometer	0.55	1.18	2.5	3.85	8
Actual reading [cP]	2.75	7.87	416.68	1711.09	2400

To determine conversion factor, the relation Standard reading equal to Viscometer reading multiplied by conversion factor can be used: $R \times X = Y$, $X = Y/R$.

Conversion factor for Kerosine: for Kerosine, $Y = 10$, $R_{max} = 1.5$, and then $X = 6.67$. Note: Maximum values for both Y and R were used to determine the conversion factors.

Discussion

Tables 1, 2 and 3 shows results of test conducted on various sample fluids. These results will help in the determination of the effectiveness and efficiency of viscometer. This provides a reliable guide in obtaining the conversion factors for the corresponding samples used. As a result low level of precision during the mechanical components/spindle, systematic error is caused by eccentric rotation and would require correction to high degree of accuracy.

As for the spindle, a double free jointed may be used to overcome the effects of eccentric rotation. Where cylindrical spindle is used, it is important to determine relationship between spindle diameter and vessel (beaker) diameter in order to quantify the edge effect that obstructs laminar flow.

Every rotational speed is changed for every spindle, the time and how many spindle revolution it takes for a stable output reading. The settling time for each revolution per minute (rpm) increment is statistically similar, indicating that the length of time to obtain stable viscosity measurement is independent of incremental rpm increase. For the purpose this test a single revolution per minute was selected.

Thus, efficiency of the Viscometer can be determined as:

Efficiency = Actual max. Meter Reading (cP) / max. Standard Reading (cP)

For the different fluids the efficiencies are:

- Water: 2.75/5 = 0.550;
- Kerosene: 7.87/10 = 0.787;
- Motor oil: 416.68/500 = 0.833;
- Gear oil: 1711/2000 = 0.855;
- Honey: 2400/3000 = 0.8000;
- Total: 3.825;
- Average: 3.825/5 = 0.765 = 76.5%.

Conclusion

The viscometer that produces output signals, which could be displayed on an analogue meter, was fabricated and designed using the concept of light emitting diode (LED). The viscometer produced was found to have performance efficiency of 76.5% and measurement can be taken within a very short period of 60 seconds.

References

[1] American Society of Heating, Refrigeration and Airconditioning Engineers Inc. (ASHRAE), *ASHRAE Handbook (1984 Systems)*, ASHRAE Publishers, p. 391, 1984.

[2] Central Machine Tool Institute Banglore, *Machine Tool Design*, McGraw-Hill, p. 676-683, 1999.

[3] Duncan T., *Advanced Physics Material and Mechanics*, John Murray, p. 61-68, 362-364, 400-401, 1973.

[4] Eugene A. A., Theodore B., *Mack's Standard Handbook for Mechanical Engineers*, McGraw-Hill, p.16-18, 31-37, 178-184, 1997.

[5] Hicks T. G., Editor P. E., *Standard Handbook of Engineering Calculations*, McGraw-Hill, p. 4-53, 1972.

[6] Higgins R. A., *Materials for the Engineering Technicians*, Hodder & Stoughton, p. 161-164, 1975.

[7] Michael N., Philip P., *Advance level physics*, Prentice-Hall, p. 277-278, 1996.

[8] Norton R. L., *Design of Machinery*, McGraw-Hill, p. 7-18, 1999.