

# A Coaxial Cylinder Type Rotational Viscometer- Design and Optimization

Md Rasedul Islam, Md Mahbubur Rahman, Shamim Ahmed and Mihir Ranjan Halder

**Abstract**—The history of viscosity measurements is outspread and is believed to date back to when people began measuring the viscosities of engine oils with the advent of the automobile industry [1]. A rotational viscometer is one which can be used to measure viscosity at different temperature. In this treatise, a coaxial cylinder type rotational viscometer (CCTRV) has been designed, constructed and compared with existing one in order to obtain more accurate data of viscosity of any liquid. Actually, a CCTRV is such a type in which 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. The temperature of the sample is maintained by a temperature controlling bath (TCB). The materials need to fabricate this CCTRV were locally available what results a minimization of cost to obtain it. It has been tried to design and construct it with low cost. However, end effects is a difficulty when design of a CCTRV is taking place. Many scientist developed empirical equation for compensating it. But in the present design, it was eschewed due to having insignificant gaps in the bottom of the CCTRV. Finally, absolute viscosity of different liquid has been measured with the constructed viscometer and made a comparison with a saybolt viscometer and a correction coefficient has been provided.

**Index Terms**—Viscosity, Rotational viscometer, CCTRV, TCB, inner Cylinder, torque, viscous effect, end effect, saybolt viscometer.

## 1 INTRODUCTION

Viscometer is a device by which the viscosity of fluids is measured. A coaxial cylindrical rotational viscometer is such a type which works on the principle that a solid (inner) cylinder is rotated inside a hollow cylinder which contains test sample of liquid [1]. The torque experienced by the solid cylinder due to viscous effect of the test sample is measured and hence viscosity can be calculated. Some of the advantages are: measurements under steady state conditions, multiple measurement with the same sample at different shear rates, continuous measurement on materials whose properties may be function of temperature and small or no variation in the rate of shear within the sample during a measurement, the rate of shear is constant, so both Newtonian and non-Newtonian fluids can be tested. By rotating the spindle or inner cylinder at different speeds, shear dependent behavior can be analyzed, permitting analysis of time-dependent fluids, easy operation, stable performance, easy maintenance, applicable to measure the viscosity of various fluids such as engine oil, water, kerosene, petroleum oil, paint, printing ink [3].

The measurement of fluid viscosity is very important in chemistry, chemical industry, and many types of manufacturing practices. The viscosity of a substance determines how it should be handled and stored. It has wide applications in var-

ious types of industries such as automobile, forming of polymers, manufacturing of varnishes, cosmetics, certain food products, various suspensions etc. For example, in automobile industries the viscosity of lubricant is of great importance in ensuring that the lubricant can provide the correct film thickness in different parts such as crankshaft, main bearings, engine cylinder, gearboxes, axles, differential etc. to ensure that metal components do not rub against each other and create component wear. If a lubricant's target viscosity level changes abnormally as a result of use, then the lubricant's ability to provide protection to a machine's components will become compromised and the machine will be at risk of breakdown in service. Oil analysis offers a detailed understanding of a machine's internal condition without the need to pull the machine from service to undergo a strip-down. Regular oil analysis should be conducted by Maintenance Engineering teams on a periodic basis in order to ensure plant and production reliability. 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, due to the listed reasons below:

- Unavailability in the local market.
- High cost for the importation.
- Use of local technology and skills for the construction of the device.

Apart from lubrication, it is necessary to reduce rub among different component in various types of machinery and that is why measurement of viscosity is necessary.

## 2 HISTORICAL BACKGROUND

After the Newton's law of viscosity, several approach has been made to construct the viscometer personally but commercial

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versions of rotational viscometers were introduced in the early decades of the twentieth century, there were always both controlled-stress and controlled-rate instruments in the market. The earliest commercial controlled-strain viscometer is that due to McMichael (1915; 1918). The instrument was manufactured by Eimer and Amend of New York, USA, and it incorporated a 60-mm diameter disc, 5-mm thick suspended in a rotating cup, or various cylinders, driven at 20 rpm, as shown in Figure-2.1. Viscosity was usually quoted in Mac-Michael degrees read from the graduations on the disc for measuring the twist on the torsion wire. The instrument had good temperature control, and worked efficiently for viscosities in the 0.05-250 Pa.s range. Many improvements were made to the original design, particularly by extending the speed range to 10-38 rpm, giving a shear rate range of around 1~10 s<sup>-1</sup>, with a measured shear stress up to about 300 Pa [1]. The contemporary commercial controlled stress equivalent wears the Searle and Stormer instruments as shown in Figure-2.2. The Searle instruments were commercialized in 1912 by Pye Company of Cambridge, England and Stormer's design was also commercialized in 1909 by Arthur H. Thomas of Philadelphia. One obvious result of these two kinds of instrument meant that flow curves were plotted in two ways. Either with the shear rate or the shear stress plotted along the x- axis as the controlling factor, or else the shear rate. Then on the y-axis, the resulting shear stress or the shear rate were plotted. The prevalence of stress-controlled machines meant that most early flow curves had the stress plotted along the x-axis [2]. The next steps in the development of viscometers in general moved beyond these instruments, and are reviewed by many viscometer manufacturers. A huge development of rotary viscometer has been carried out by Brookfield Company. At present rotary viscometer is enriched with many features such as digital display, temperature control bath, different speed regulation etc. In this project, a CCTRV has been made which is capable to measure viscosity of liquid using developed equation.

### 3. Design

There are three general categories for rotational viscometer based on their design configuration 1. Coaxial-Cylinder Viscometer 2. Cone and Plate Viscometer 3. Coni-Cylinder Viscometer. The major disadvantages of first and second type are the involvement of complexity of construction and more friction. In this project, CCTRV in which inner cylinder is rotating and outer cylinder remains stationary. The schematic diagram of this one is shown in Fig. 1.

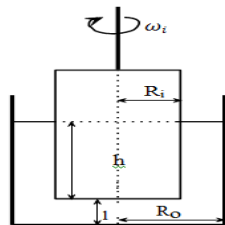


Figure-2.6 Schematic diagram of a CCTRV

#### 3.1 Design Equations

With the help of Newton's law of viscosity and torque

produced by inner cylinder, an equation for viscosity measurement of a sample has been developed

$$\mu = \frac{T \times 60}{4\pi^2 N_i h} \left( \frac{1}{R_i^2} - \frac{1}{R_i R_o} \right)$$

Where, T is torque offered by the test sample, R<sub>i</sub>, R<sub>o</sub> are radii of inner and outer cylinder respectively, N<sub>i</sub> is rpm of the inner cylinder and h is height of inner cylinder filled up by the liquid. The Equation for 'T' is

$$T = T_L - T_{NL}$$

$$T_{NL} = \frac{60 P_m}{2\pi N_{NL}}$$

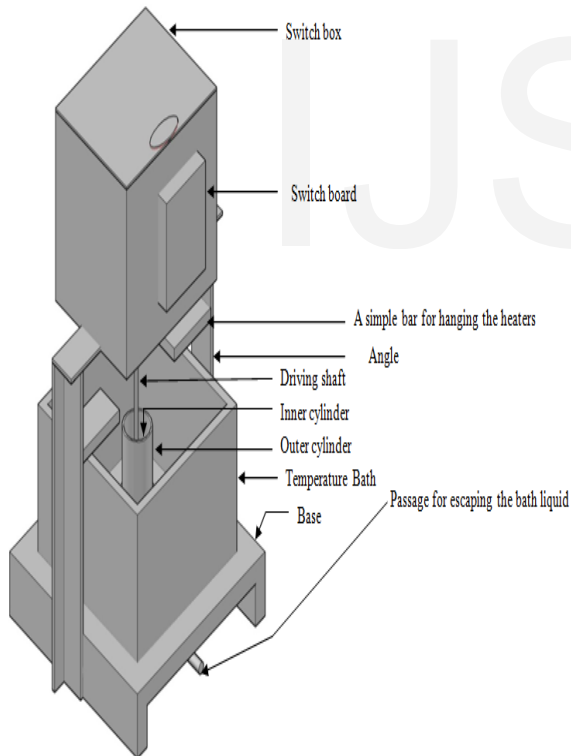
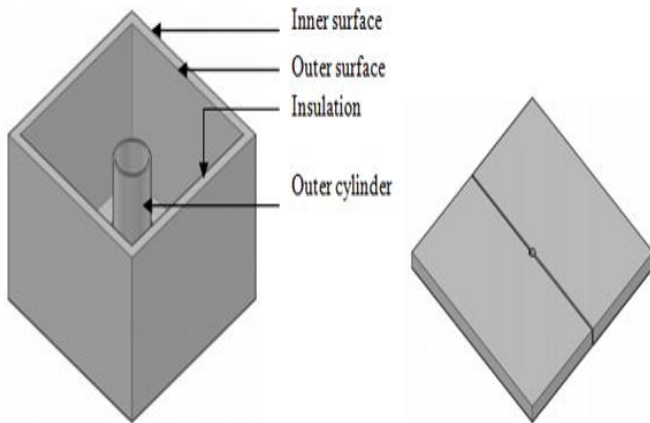
$$T_L = \frac{60 P_m}{2\pi N_L}$$

Where, T<sub>L</sub>, T<sub>NL</sub> and N<sub>L</sub>, N<sub>NL</sub> are speed torque of the motor shaft at load and no-load respectively. P<sub>m</sub> is power required for motor shaft.

#### 3.2 Design of the components

The main parts of the designed CCTRV are an outer cylinder (hollow), an inner cylinder (solid), a motor and a temperature controlling bath (TCB). The other parts are a base, a driving shaft for inner cylinder and a thermometer. In this project, the diameter of the inner cylinder was assumed as 3 cm. Generally height is to be taken as twice the diameter [10]. Due to low inertia, wider temperature range and non-reactivity with the tested liquid, aluminum was chosen for inner cylinder. In this project, highest rpm has been taken 300 rpm for the more assurance of flow in the gap between two cylinder walls would remain linear (i.e. velocity profile in the passage between two cylinder walls would be linear) and to avoid vibration[5]. In case of outer cylinder, it should be bear in mind that the diameter of outer cylinder should be such that the flow between two cylinders should not be critical or turbulent. By examining critical Reynold's number of a sample for the variation of gap between two cylinders retaining that the flow does not break [4], the ratio D<sub>i</sub> / D<sub>o</sub> = 0.50 has been obtained. GI sheet is selected as the material of the outer cylinder since it has high thermal conductivity and its numerical value is 18 W/mK. For motor specification, total torque (0.28 Nm) has been estimated from the inertia of driving shaft, inner cylinder and test sample. Then a dc motor with minimum capacity of 8.79 Watt (Standard: 25W) and 6-12V is needed. TCB is a device for regulating the temperature of anything subjected to heat, by surrounding the vessel containing it with another vessel containing liquid which can be kept at a desired temperature. It is generally used to maintain desired temperature. It consists of a means for heating and a vessel which contain the liquid to heat the desired fluid. The vessel of the desired fluid is inside the bath and bath liquid is heated and then heated liquid transfer heat to the desired fluid whose temperature is to be maintained [11]. In order to design the dimension of temperature bath, we will look upon what amount of test sample of liquid will be heated. Generally the volume of bath liquid will be ten times larger than the liquid whose temperature would be maintained and its shape is rectangular. For TCB design,

volume (19×19×10 cm) and material whose heat transfer capacity is low has been preferred. In this project, 1 cm thickness of insulation of galss wool (0.04 W/mk) was used. Two heaters each having capacity of 500W, are used in control temperature bath. Each heater operates at 220-240V. The material of driving shaft has been chosen as brass since it needs light weight resulting low torque requirement for motor.



### 3.3 End Effects

The main concern with the coaxial cylinder viscometer is the end effects. The equation for measuring viscosity of sample liquid has been derived without considering the end effects. End effects are the resistances offered by the test sample at the base and top of the inner cylinder. End effect at the top may be avoided by ensuring that the wetted height will not be higher than the height of the inner cylinder. Several scien-

tists have been working to determine end effect. In this section, various approaches for end effect at the base will be discussed. Lindsley and Fisher found that the end effect is negligible in the range of 1 to 150 poise, but the viscosity must be corrected when it is below 1 poise [7]. Lindsley and Fisher, and Highgate and Whorlow suggested that modification of the design may not be adequate to account for the end effects. Therefore experimental measurements and theoretical analysis were proposed by a number of researchers to correct the viscosity for end effects [7][8].

Kobayashi provided end corrections for several combinations of bob (inner cylinders) and cup (outer cylinder) design. For rotating bob viscometer system, the end correction appears to increase for Reynolds numbers above 10, even for low viscosity. A conical end of the inner cylinder and a wide gap between the inner and outer cylinder give a larger end correction. But wide gap between inner and outer cylinder tends to break linearity of velocity potential in the gap [9].

In this project, end effect will be compensated by carrying out experiment of different sample. Finally a correction coefficient will be provided which will take into account end effect and other instrumental error.

### 4 DATA

Then viscosity of three liquid; water, diesel and kerosene, has been measured with the constructed CCTRV and compared with existing Saybolt Viscometer. The data are presented below

TABLE-1: VISCOSITY MEASURED BY SAYBOLT VISCOMETER AND CCTRV

Temperature (°C)	Viscosity for Water ( $\times 10^{-3}$ Pa.s)		Viscosity for Diesel ( $\times 10^{-3}$ Pa.s)		Viscosity for Kerosene ( $\times 10^{-3}$ Pa.s)	
	Saybolt	CCRTV	Saybolt	CCRTV	Saybolt	CCRTV
35	0.723	0.8505	4.15	4.770	1.95	2.24
40	0.656	0.669	4.04	4.253	1.766	1.839
45	0.599	0.576	3.8	3.486	1.583	1.508
50	0.549	0.458	3.68	2.992	1.4	1.157
55	0.506	0.395	3.05	2.421	1.32	1.039
60	0.469	0.339	2.20	1.606	1.24	0.873
65	0.436	0.290	1.95	1.309	1.16	0.758
70	0.406	0.248	1.60	1.003	1.08	0.679
75	0.380	0.221	1.43	0.836	1	0.575
80	0.357	0.196	1.22	0.656	0.98	0.541

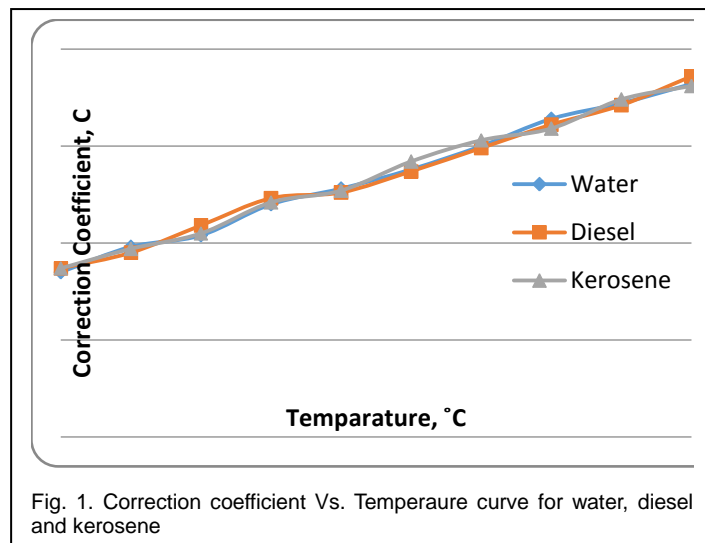
Correction coefficient which is obtained from Saybolt viscosity data divided by CCTRV data, and it is provided to improve the accuracy of the viscosity measured by the CCTRV. The

TABLE-2: CORRECTION COEFFICIENT AT DIFFERENT TEMPERATURE

Temperature (°C)	Correction coefficient, 'C'		
	Water	Diesel	Kerosene
35	0.85	0.87	0.87
40	0.98	0.95	0.97
45	1.04	1.09	1.05
50	1.20	1.23	1.21
55	1.28	1.26	1.27
60	1.38	1.37	1.42
65	1.50	1.49	1.53
70	1	1.61	1.59
75	1.72	1.71	1.74
80	1.82	1.86	1.81

correction coefficient has been obtained for different temperature as shown in Table-2 and, finally an equation for correction coefficient would be provided.

However, the value of correction coefficient for water, diesel and kerosene with the help of Table-1 is plotted against temperature, is shown in Figure-1



## 5 DISCUSSION

From the test result of water, diesel and kerosene by CCTRV and Saybolt, it is shown that there a little bit deviation of CCTRV data from Saybolt viscometer data. In order to compensate this, correction coefficient has been provided, as stated earlier. It is possible to minimize the deviation when CCTRV data is multiplied by the correction coefficient. Therefore, a means of getting value of correction coefficient is necessary for CCTRV designed and constructed according to present approach. For this, correction coefficient of water, diesel and kerosene was determined at different temperature, and plotted as shown in Fig-1. It seems that the curves are almost straight for all three liquid and at a definite temperature, values of correction coefficient differs very little. Thus an empirical equation ( $C = 0.08 + 0.0220$ ) in terms of temperature is provided to obtain the value of correction coefficient in order to refine the viscosity data and lessen error in the present CCTRV. The value obtained by CCTRV must be multiplied by the value of correction coefficient from the equation provided. However, one thing that is very important, cost should be curtailed. In this project, the material and other things required to construct it has been collected from local market. Therefore, a low cost to fabricate it was possible and it was nearly \$100. But in foreign market, much higher price is needed when a CCTRV requires to be imported.

## 6 CONCLUSION

Viscosity measurement is much important in the field of engineering e.g. automobile, powerplant, river flow, edible oil etc. In Bangladesh, there are many powerplant which is mainly based on furnace oil operated. As a result, viscosity measurement is required for its smooth maintenance and operation, resulting a necessity of viscometer. The importation cost is high, that's why an optimization was tried in this project. By this connection, the CCTRV has been designed, constructed with the local materials and technology, and compared with an existing Saybolt viscometer. The provision for the measurement of viscosity of liquids at different constant temperatures has been provided with constructed CCTRV. The performance also has also been tested. The tests are carried out for water, diesel and kerosene within the temperature range from 35°C to 80°C. From the test, an empirical equation for correction coefficient has been provided and given an instruction that The value obtained by CCTRV must be multiplied by the value of correction coefficient from the equation provided in order to improve accuracy of the viscosity data and subside error in the present CCTRV. The constructed CCTRV can be improved if Torque can be measured by adapting sensor, electronics can be applied to measure rpm of the inner cylinder, heating control system can be applied, and digital display can be introduced to obtain viscosity of the liquid directly from the display.

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