Measurement of Viscosity in a Vertical Falling Ball Viscometer

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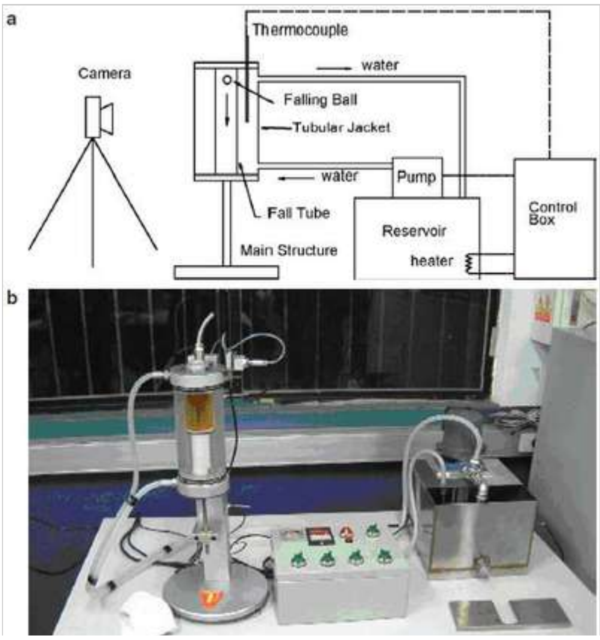
Experimental

The experimental devices were arranged as shown in *Figure 2a*, which includes the fall tube containing the liquid to be measured, a tubular jacket for thermal control, a water reservoir with a heater, a temperature control system, a pump for circulation, and a camera. The camera has four million pixels, and captures an image per 1/30 sec. The temperature control system can control the water temperature deviation to less than 0.5 °C via feedback from a sensor in the tubular jacket.

Figure 2*b* is a photograph of the entire device except for the camera. In this figure, the device on the right is the water reservoir with a heater and a pump, which connects to the tubular jacket via soft pipes. The device in the center of Figure 2*b* is the power and control box, which supplies the power to the pump and heater in the reservoir and controls the on/off of the heater to maintain a set temperature of water. The device on the left is the main structure for the falling ball. The fall tube and the tubular jacket can be inverted by rotating them together about their mounting point on the stand in order to return the ball to the starting position. On the top of the fall tube is a pin to prevent the ball from falling, and it can be released by the control on the control box. The stand is equipped with a level and feet with leveling screws for adjusting the fall tube so that it is vertical to the ground.



The experimental procedure is as follows: 1) Pour the liquid under test into the fall tube and place the ball into the tube. Then, tighten the screw on the top of the fall tube. 2) Set the measurement temperature and turn on the heater and pump. It takes at least 15 min for the tubular jacket temperature to reach the specified test temperature.

3) Rotate the fall tube 180° and fix the pin for holding the falling ball. Then, rotate it back and ready to fall ball. 4) Set up the camera to be perpendicular to the fall tube, and begin to record. 5) Release the pin for dropping the ball, and keep the camera record until the falling ball passes through the marked end line of the fall tube. 6) Record the falling time from the beginning to the end, and follow the calculation step in the above section to obtain the dynamic viscosity.

Figure 2 - a) Schematic and b) photograph of the experimental device.

Results and discussion

The present study uses an oil of SAE 30 as the sample liquid for measurement. It belongs to the CD/SF level in the classification of the American Petroleum Institute (API), and its kinetic viscosity is 111.2 cSt at 40 °C, which is equal to 0.0973 Pa·s of dynamic viscosity. The sample oil has a density of 894.4 kg/m^3 through measurement by an electrical balance with a precision of 1 mg. Moreover, the study utilizes a plastic sphere ball as the falling ball, which has a diameter of 9.756 mm, out-of-roundness of 0.09 mm, and density of 1010 kg/m^3. The experiment proceeds in a 40 °C tubular jacket temperature, with four different falling distances of 5, 10, 15, and 20 cm. Furthermore, this study was repeated 10 times for measuring the fall time in each case; the experimental results are listed in *Table 1*.

Table 1 - Measuring and calculating results of SAE 30 at 40 °C in the experiment

	Falling length (5cm)			Falling length (10cm)		
Exp. No.	time(s)	Re	μ	time(s)	Re	μ
1	1.23	3.3991	0.1044	2.40	3.5170	0.1034
2	1.17	3.7708	0.0989	2.27	3.9395	0.0976
3	1.20	3.5776	0.1016	2.33	3.7355	0.1003
4	1.17	3.7708	0.0989	2.27	3.9395	0.0976
5	1.13	4.0540	0.0952	2.23	4.0850	0.0958
6	1.23	3.3991	0.1044	2.40	3.5170	0.1034
7	1.17	3.7708	0.0989	2.30	3.8355	0.0989
8	1.20	3.5776	0.1016	2.37	3.6082	0.1020
9	1.20	3.5776	0.1016	2.37	3.6082	0.1020
10	1.20	3.5776	0.1016	2.37	3.6082	0.1020
	Falling length (15cm)			Falling length (20cm)		
Exp. No.	time(s)	Re	μ	time(s)	Re	μ
1	3.57	3.7681	0.1001	4.67	3.6869	0.1014
2	3.40	3.9268	0.0980	4.47	4.0276	0.0969
3	3.43	3.8575	0.0989	4.47	4.0276	0.0969
4	3.37	3.9979	0.0971	4.43	4.1014	0.0961
5	3.37	3.9979	0.0971	4.40	4.1581	0.0954
6	3.60	3.4977	0.1039	4.57	3.8516	0.0991
7	3.47	3.7680	0.1001	4.50	3.9735	0.0976
8	3.57	3.7681	0.1001	4.60	3.8010	0.0998
9	3.57	3.7681	0.1001	4.67	3.6869	0.1014
10	3.63	3.4395	0.1048	4.70	3.6396	0.1020

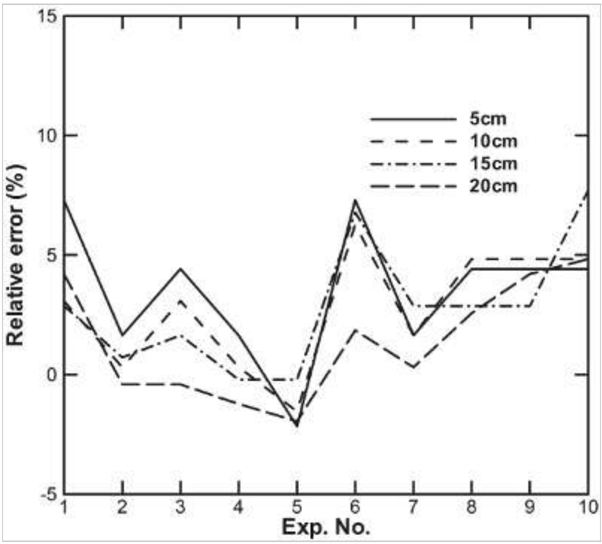


Figure 3 - Relative error of measuring dynamic viscosity to the reference value in different falling distance.

Figure 3 shows the relative error of the measuring dynamic viscosity in Table 1 to the reference value of SAE 30 oil. The continuous, dashed, dash–dotted, and long dashed line represent the error in different falling distances of 5, 10, 15, and 20 cm, respectively. In the figure, the relative error rank in descending order is continuous, dashed, dash–dotted, and long dashed line. That means the longer measuring distance can reduce the measuring error. In Figure 3, all relative errors are ±10%, and the average relative error in different falling distance is 3.9, 3.4, 2.9, and 2.2%. Therefore, this method of measuring dynamic viscosity is reliable.

This study refers to the metrology in evaluating measurements of a single measurand and expression of uncertainty to analyze the uncertainty of this experiment.[10] *Table 2* lists the mean of results; experimental standard deviation; uncertainty; and confidence internal, which are defined as follows:

Table 2 - Uncertainty and the confidence internal in this experiment

Fall Distance	$\overline{\mu}$	s	u	$\pm 4.09u$
5cm	0.10071	0.28006E-4	0.88562E-3	±0.00362
10cm	0.10030	0.26843E-4	0.84885E-3	±0.00347
15cm	0.10002	0.25890E-4	0.81900E-3	±0.00335
20cm	0.09866	0.24114E-4	0.76255E-3	±0.00312

$$\overline{\mu} = \frac{1}{n}\sum_{j=1}^{n}\mu_j \qquad (10)$$

$$s = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(\mu_j - \bar{\mu})^2} \quad (11)$$

$$u = \sqrt{\frac{1}{n(n-1)}\sum_{j=1}^{n}(\mu_j - \bar{\mu})^2} \quad (12)$$

$$\mu = \bar{\mu} \pm 4.09u \quad (13)$$

In Table 2, the uncertainty and confidence interval decrease with the increase in falling distance, and the confidence interval is ±0.0034 with a confidence level of 99.73%. This demonstrates that the error of measurement is about 6%, which is an acceptable experiment error.

Comments

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