Study on Measuring the Viscosity of Lubricating Oil by Viscometer Based on Hele-Shaw Principle

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Abstract: In order to explore the method of accurately measuring the viscosity value of oil samples using the viscometer based on Hele-Shaw principle, three different measurement methods are designed in the laboratory, and the statistical characteristics of the measured values are compared, in order to get the best measurement method. The results show that the oil sample to be measured is placed in the magnetic field formed by the magnet, and the oil sample can be sucked from the same distance from the magnet. The viscosity value of the sample can be measured accurately.

1. Introduction
Viscosity is an important indicator of lubricating oil and has an important impact on the performance of the lubricating oil [1]. If the viscosity is too small, it is difficult to form a solid oil film, and then can not achieve the role of reducing friction. However If the viscosity is too large, it will cause the equipment to start difficult, and also makes the oil can not be cycle normally among the equipment, resulting in equipment lubrication failure finally [2]. Therefore, the choice of the correct viscosity of lubricating oil is of great importance to the normal use of the equipment. At the same time, in the oil monitoring process, viscosity is often the test items. In the laboratory, when measured the viscosity of lubricants, the viscometer is often used which is based on the principle of Hele-Shaw, but in the actual use of the process found that the measurement method has a great influence of the result when measuring the viscosity of the lubricating oil.

In this paper, by comparing the results of different ways of using the viscosity measurement, to find the best way to use the viscometer based on Hele-Shaw principle when measuring the viscosity of lubricant viscosity, and ensure the accuracy of measurement of lubricating oil viscosity, provide guidance and method for laboratory use of this type of viscometer to measure viscosity.

2. Experimental equipment
A viscometer based on the Hele-Shaw principle, ordinary droppers, processed droppers (Fig.1), a magnet, an experimental oil sample, a non-woven fabric, etc.

3. Experimental method
Method 1. The sample viscosity is measured directly by viscometer. First, wipe the measuring board of the viscometer with a non-woven fabric. Then drain the sample to be measured with a dropper and drop two drops of oil into the instrument vertically.

Attention please: In order to keep the accuracy of measurement results, attention should be paid to
measurements:

(1) When the sample is measured, the first data is discarded as there hasn’t formed an effective and uniform oil film in the sample detection area before the first time’s measurement.

(2) In order to prevent the effect of the initial velocity of the sample on the experimental results, the height of the dropper from the instrument should be the same as when the sample is dropped, and the sample is naturally dropped.

**Method 2.** Shake the sample before the measurement, and then use the method 1 to measure the sample viscosity value;

**Method 3.** When measuring the magnetic force of the sample, it is found that the lubricant sample has weak magnetic properties. Therefore, use a magnet to assist in viscosity measurements. The specific method is as follows. First put the oil sample bottle on the magnet do without shaking the sample, and then use the treated straw to suck the sample from the same position at the bottom, which is shown as fig. 2. Finally use the method 1 to measure the viscosity value.

![Figure 1. Treated dropper](image1)

![Figure 2. Draw oil samples using method 3](image2)

4. Analysis of the experimental results

When measuring two groups of oil samples using the method 1, it is found that the maximum value of the data standard deviation has reached 7.83, and the relative value compared to the average value of viscosity is as high as 7.79%, showing that it has no value to do using method 1 [3], as the method 1 can not effectively measure the viscosity of the lubricating oil and the viscosity data measured is shown in tab. 1.

| Number Times | 1     | 2     | 3     | 4     | 5     | 6     | Average Value | Standard Deviation | Relative value of standard deviation |
|--------------|-------|-------|-------|-------|-------|-------|---------------|-------------------|------------------------------------|
| #1           | 103.8 | 114.8 | 108.9 | 99.1  | 104.9 | 98.6  | 105.0         | 6.12              | 5.83 %                             |
| #2           | 108.0 | 101.2 | 98.6  | 110.8 | 90.9  | 93.5  | 100.5         | 7.83              | 7.79 %                             |

4.1. Gross error elimination

For methods 2 and 3, the relative values of the standard deviations of the viscosity values are less than 2% and have practical engineering value. (The values of viscosity measured by method 2 and method 3 are A and B respectively). The gross error of the data is eliminated. Because of the small sample value, the gross error is eliminated by using the Grabus quasi[4].

Taking the measurement data of # 1 sample as an example, the average value of the sample is: \( \bar{x} = 40.40 \) cSt, the standard deviation is \( s = 0.626 \), and \( G_1 = 1.12 \), \( G_6 = 1.44 \), and we can get that the \( G_0 \)
= 1.822 as n = 6 through the Grabus value table. Then, \( G_1 < G_0, G_6 < G_0 \), so there is no coarse error, the group of data does not need to be coarse error rejection.

Eliminate the gross errors of the remaining data in turn, and the average and standard deviations and the relative percentages of standard deviations are recalculated and showed in Tab. 2 and Tab. 3.

Table. 2 Viscosity values (40℃) of group A samples

| Numbers | Viscosity Times | 1 | 2 | 3 | 4 | 5 | 6 | Average value /X | Standard deviation/s | Relative value of standard deviation ( %) |
|--------|----------------|---|---|---|---|---|---|-----------------|----------------------|---------------------------------------|
| 1      | 90.9           | 90.0 | 89.7 | 93.5 | 91.6 | 92.6 | 91.4 | 1.46 | 1.60                 |
| 2      | 104.2          | 103.1 | 104.5 | 102.8 | 101.4 | 101.2 | 102.9 | 1.37 | 1.33                 |
| 3      | 99.6           | 98.6 | 101.0 | 98.9 | 97.5 | 97.9 | 98.9 | 1.25 | 1.26                 |
| 4      | 103.3          | 103.8 | 102.8 | 103.8 | 104.2 | 104.0 | 103.7 | 0.51 | 0.49                 |
| 5      | 103.8          | 101.5 | 100.1 | 98.7 | 100.8 | 99.1 | 100.7 | 1.86 | 1.85                 |
| 6      | 100.0          | 102.8 | 101.2 | 100.5 | 101.7 | 100.7 | 101.2 | 1.00 | 0.98                 |
| 7      | 105.4          | 103.5 | 104.5 | 103.8 | 102.1 | 102.6 | 103.7 | 1.20 | 1.16                 |
| 8      | 99.8           | 100.3 | 99.1 | 98.2 | 100.5 | 99.6 | 100.5 | 0.95 | 0.95                 |
| 9      | 103.3          | 100.5 | 103.1 | 101.0 | 101.9 | 102.4 | 102.0 | 1.12 | 1.10                 |
| 10     | 105.9          | 108.7 | 105.2 | 107.0 | 105.4 | 107.5 | 106.6 | 1.37 | 1.28                 |

Table. 3 Viscosity values (40℃) of group B samples

| Numbers | Viscosity Times | 1 | 2 | 3 | 4 | 5 | 6 | Average value /X | Standard deviation/s | Relative value of standard deviation ( %) |
|--------|----------------|---|---|---|---|---|---|-----------------|----------------------|---------------------------------------|
| 1      | 110.3          | 110.8 | 109.6 | 111.5 | 111.2 | 109.6 | 110.5 | 0.80 | 0.73                 |
| 2      | 110.8          | 109.8 | 110.5 | 111.9 | 110.3 | 109.8 | 110.5 | 0.78 | 0.71                 |
| 3      | 111.7          | 111.9 | 111.2 | 111.5 | 111.2 | 112.2 | 111.6 | 0.38 | 0.34                 |
| 4      | 112.7          | 112.2 | 111.0 | 112.7 | 110.5 | 110.5 | 111.6 | 1.01 | 0.91                 |
| 5      | 110.8          | 112.2 | 112.2 | 112.9 | 111.5 | 110.8 | 111.7 | 0.85 | 0.76                 |
| 6      | 113.4          | 111.9 | 111.7 | 112.9 | 111.9 | 111.5 | 112.2 | 0.73 | 0.65                 |
| 7      | 112.2          | 112.2 | 112.2 | 112.1 | 112.4 | 112.2 | 112.2 | 0.17 | 0.15                 |
| 8      | 115.2          | 112.9 | 113.4 | 115.0 | 113.8 | 112.9 | 113.9 | 1.03 | 0.90                 |
| 9      | 116.2          | 118.3 | 117.3 | 118.7 | 118.0 | 116.2 | 117.4 | 1.09 | 0.93                 |
| 10     | 125.3          | 125.0 | 125.3 | 124.8 | 125.3 | 125.1 | 125.1 | 0.21 | 0.17                 |

4.2. Data significance test

Since the average and standard deviations of each measurement data are known, the t distribution [5] is used to test the samples. Below, take the sample #1 and #2 in the A data set as an example and calculate.

From the t distribution test formula, we can be obtained that the degrees of freedom \( v \approx 10 \), then the experimental statistics is \( t = 34.45 \). Select the confidence of 95%, check t distribution table and we can get the critical value of ‘t’ is that \( t = \pm 1.812 \).

Since the obtained t value is within the range determined by the critical value, that is, at a confidence level of 95%, there is a significant difference between the two sets of data, so it can be determined that the viscometer based on the Hele-Shaw principle can clearly distinguish the two oil samples.
The data of any two sets of data in group A and group B are analyzed statistically, and #4 and #7, #5 and #6 in group A data as well as #1 and #2, #3 and #4, #4 and #5, #6 and #7 in group B data have no significant difference.

4.3. Data fitting test
The average value of the data measured by the two methods is tested by data fitting, and the curve is shown in fig. 3.

**Figure. 3** The viscosity value fitting curve of group A group B

What we can see from the Fig. 3 are as follows.

① The viscosity of the method three shows an increasing trend. The viscosity of the sample measured by the method two shows great fluctuation.

② According to the data fitting, the value of viscosity fitting curve of the samples measured by method 3 is $y = 0.1205x^3 - 2.1043x^2 + 11.258x + 83.703$ and the $R^2 = 0.981$ when the #2, #4 and #6 was removed as they can not to be distinguish through this viscositor, the $R^2 = 0.997$; The viscosity fitting curve of the samples measured by method 2 is $y = 0.1205x^3 - 2.1043x^2 + 11.258x + 83.703$ and $R^2 = 0.716$, when removed the #4 and #6, $R^2 = 0.709$.

As the sample to be measured in the experiment are got through heating the oil, and the heating time increase from #1 to #10, as the lubricating oil oxidation reaction occurs only, no fuel or water dilution that will decrease the oil viscosity. In the process of oxidation, lubricating oil will decompose and a series of chemical reactions such as polymerization will lead to the gradual deepening of the color of lubricating oil and the gradual increase of sediment, which will gradually increase the viscosity of lubricating oil [6-8]. Therefore, the viscosity of lubricating oil in theory should show a tendency of increase.

The percentage of the relative value of the standard deviation compared to the lubricating oil obtained by the method 2 is basically above 1%, while the percentage value of the method 3 is less than 1%. At the same time, it can be seen from the data fitting curve that the measured viscosity of the method 2 is very violent and does not accord with the theoretical situation, and it is not conducive to the study of laboratory data, too. On the contrary, the viscosity value of the method 3 has a significant increasing trend as the theoretical situation. And then the data fitting result of measuring viscosity value by method 3 is much higher than that of method 2.

4.4. Accuracy test
To test the accuracy of the two methods, the new oils and standard oils who have known viscosity were measured using methods 2 and 3 respectively, and the result are shown in tab. 4.

**Table. 4.** The viscosity of the new oil and standard oil through the two methods unit: cSt
| Samples Number | 1   | 2   | 3   | 4   | 5   | 6   | Average value | True value | Error value |
|----------------|-----|-----|-----|-----|-----|-----|--------------|------------|------------|
| Method 2       |     |     |     |     |     |     |              |            |            |
| standard oil   | 83.4| 86.2| 82.5| 85.5| 85.8| 84.4| 84.6         | 88.1       | 4.1%       |
| new oil        | 103.1| 107.5| 105.4| 107.0| 104.5| 103.5| 105.2        | 115.4      | 8.8%       |
| Method 3       |     |     |     |     |     |     |              |            |            |
| standard oil   | 88.3| 88.8| 89.3| 89.0| 88.8| 88.8| 88.9         | 88.1       | 0.9%       |
| new oil        | 115.7| 114.1| 113.6| 115.0| 112.7| 114.1| 114.2        | 115.4      | 1.1%       |

Through the tab.4, we can see that when measuring the standard oil and new oil using the two methods, the error value of method 3 compared to the true value is much less than the method 2.

To sum up, the method 3 is more accurate and reliable than the method 2.

5. Conclusion

1) Shake the sample before testing the sample, and the result has a greater error, because the bubble generated during the shake will affect the accuracy of measurement.

2) The lubricating oil sample to be measured is placed in the magnetic field formed by the magnet, and the oil sample is drawn from the same distance from the magnet, so that the viscosity value of the sample can be accurately measured.

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