PAPER • OPEN ACCESS

Determination of Newtonian fluid viscosity and design constants of a rotary viscometer

To cite this article: I P Kondrashov *et al* 2020 *J. Phys.: Conf. Ser.* **1515** 042058

Determination of Newtonian fluid viscosity and design constants of a rotary viscometer

I P Kondrashov[1], P L Pavlova[2] and P M Kondrashov[2]

[1]AO «OKB ZENIT», 660118, 22 Alekseeva Street, Krasnoyarsk, Russia
[2]Siberian Federal University, 660041, Krasnoyarsk, 79, Svobodny Avenu, Russia

[2]E-mail: pkondrashov@sfu-kras.ru

Abstract. In this paper the problem of determining the viscosity coefficient of a Newtonian liquid for the development of a rotary viscometer considered. The least squares method is proposed to be used for processing the measurement results. Conversion factors of electric sensor readings are proposed. The calibration instrument is designed to calculate the conversion coefficient of the torsional moment to current of the sensor. The proposed formulas are useful for developing an algorithm for calculating a rotary viscometer with more accurate processing of measurement results.

Properties liquids and gases are the main inputs for the oil and gas industry. One of these parameters is the viscosity which is necessary for the construction, operation and development of oil and gas fields [1, 2]. Technical and economic parameters of production depend on the accuracy of liquid viscosity measurement.

The Newton's rheological model [3, 4, 5] is:

$$\tau = \mu \frac{\mathrm{d}U}{\mathrm{dr}}, \quad (1)$$

where τ – tangent shear stress; μ – the viscosity (dynamic viscosity) in the Newton model; $\frac{\mathrm{d}U}{\mathrm{d}r}$ – velocity gradient in the direction perpendicular to the fluid velocity.

It is generally accepted [6,7,8] that the fluid's velocity varies according to the linear law in the gap between the measuring cylinders of the rotary viscometer and the numerical value of its derivative doesn't depend on the distance to the rotating cylinder surface (figure 1):

$$\frac{\mathrm{d}U}{\mathrm{d}r} = const = \frac{U}{\delta}, \quad (2)$$

where U – linear velocity on the rotating cylinder surface; δ – the gap between walls of rotating and measuring cylinders.

The rotation velocity is used to calculate the derivative of velocity. It is measured in modern instruments with almost any given accuracy. Its measurement is much more accurate than the amount of torsional moment on the measuring cylinder. The tangent shear stress is calculated from the torsional moment.

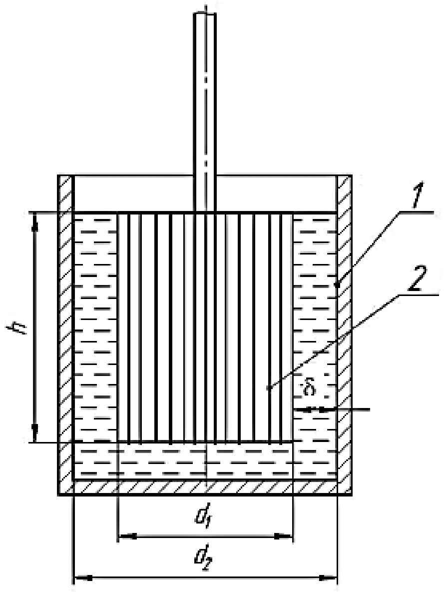

Figure 1. The cylinders of the rotational viscometer: 1 – internal surface of the rotating cylinder (outer); 2 – measuring (internal) cylinder.

Therefore the error of the rotation velocity measuring is usually ignored and only takes into account the variation of the values of ω (figure 2) relative to a straight line according to the formula (1).

At present the selected point's method (nodes of approximation) is used to determine of the dynamic viscosity coefficient. This method is simple and obvious but it has a more coarse accuracy of measurement.

The least squares method is proposed to be used for the algorithm development to the processing viscosity measurement results [2]. It will improve the accuracy of the viscometer measurement.

If the dispersion value D is minimal that the coefficient is considered to be selected correctly:

$$D \to \min . \tag{3}$$

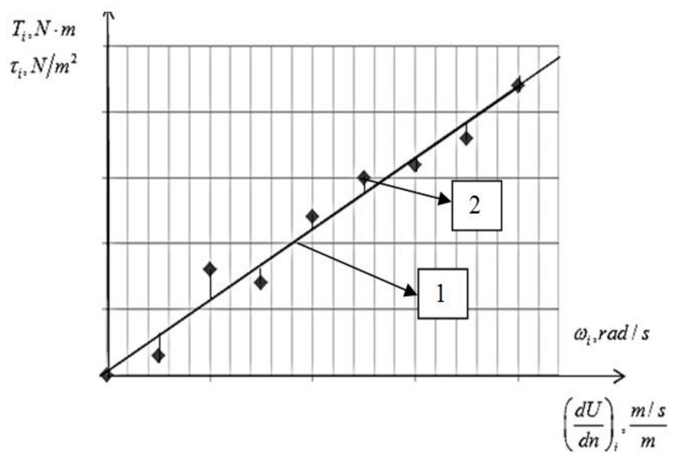

Figure 2. Example of an algorithm for measuring rotation velocity in a rotary viscometer: 1 – the line according of the model; 2 – the result of measuring

The condition (3) is met when the first derivative of the variance is zero and the second is greater than zero [2]:

$$\begin{cases} \dfrac{\partial D}{\partial \mu} = 0 \\ \dfrac{\partial^2 D}{\partial \mu} > 0 \end{cases}. \tag{4}$$

In this case the dispersion is the sum of the squares of the deviations of the measurement results from the line (1):

$$D = \sum_{i=1}^{i=n} \left[\tau_i - \mu \cdot \left(\frac{\mathrm{d}U}{\mathrm{d}r} \right)_i \right]^2. \tag{5}$$

where n – number of points on the graph (figure 3) from the measurements.

The derivative of dispersion is placed in the upper equation (4):

$$\sum_{i=n}^{i=n} 2 \cdot \left[-\left(\frac{\mathrm{d}U}{\mathrm{d}r} \right)_i \right] \cdot \left[\tau_i - \mu \cdot \left(\frac{\mathrm{d}U}{\mathrm{d}r} \right)_i \right] = 0. \tag{6}$$

Where

$$\mu = \frac{\sum_{i=1}^{i=r} \left(\frac{\mathrm{d}U}{\mathrm{d}r} \right)_i \cdot \tau_i}{\sum \left(\frac{\mathrm{d}U}{\mathrm{d}r} \right)_i^2}. \tag{7}$$

It is necessary to set experimentally values τ_i and $\left(\frac{\mathrm{d}U}{\mathrm{d}r} \right)$ in the rotary viscometer for calculating the viscosity according to the formula (7). These values can only be obtained from indirect readings of the instrument. There values can be derived from indirect measurements.

Sensors with electrical output should be used to use ensure of modern computer technology and technology in determining of the liquid rheological characteristics. Both values can be measured by electrical sensors with an electrical current at the output in the viscometer. In this case, the sensor, based on the readings we get $\left(\frac{\mathrm{d}U}{\mathrm{d}r} \right)_i$, shows the number of revolutions per minute n_i at the output. The torsional moment sensor generates an electric current that increases with the torsional moment.

As a result of together measurement we obtain experimental values I_i and n_i :

$$I_i = f(n_i). \tag{8}$$

The translation coefficient of the "independent variable" in Newtonian liquids is determined using the formula:

$$\left(\frac{\mathrm{d}U}{\mathrm{d}r} \right)_i = \frac{U_i}{\delta} = \frac{\pi d_2}{\delta} \cdot n_i, \tag{9}$$

where d_2 is the inner diameter of the rotating (outer) cylinder.

As a result we get a coefficient that depends on the design parameters of the rotary viscometer

$$c_1 = \frac{\pi d_2}{\delta}. \tag{10}$$

The conversion coefficient of the variable current to torsional moment on the measuring cylinder of the device can be determined using the calibration instrument (figure 3).

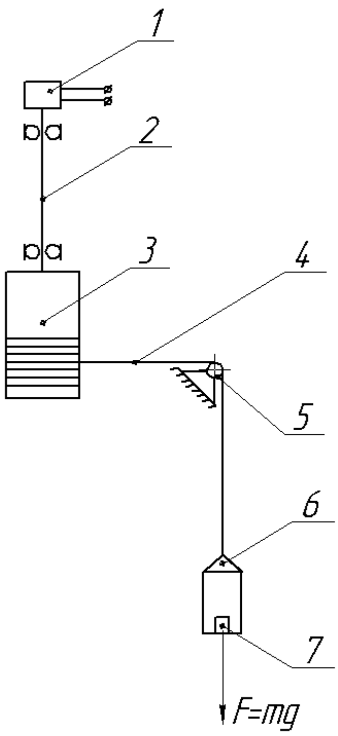

Figure 3. Scheme of the calibration instrument: 1 – torque sensor; 2 – shaft of the measuring cylinder; 3 – measuring (internal) cylinder of the rotary viscometer; 4 – nylon thread with a diameter from 0.1 to 0.3 mm; 5 – roller; 6 – suspension; 7 – graduated load

The torsional moment of the calibration instrument is determined by suspending various loads by weight m_j. Sensor detects the respective torsional moments and currents.

Therefore,

$$T_j = m_j g \cdot \frac{d_1}{2}. \tag{11}$$

$$T_j = c_j \cdot I_j. \tag{12}$$

Calculate the average value of the translation coefficient:

$$c_2 = \frac{\sum_{j=1}^{j=u} c_j}{u}, \tag{13}$$

where u is the number of dimensions.

Therefore the torsional moment of the rotary viscometer is equal to:

$$T_i = c_2 \cdot I_i. \tag{14}$$

The translation coefficient P of the torsional moment into the tangent shear stress is determined using the formula:

$$T_i = F_i \cdot \frac{d_1}{2} = \tau_i S \frac{d_1}{2} = \tau_i \pi \frac{d_1^2}{2} h. \quad (15)$$

where S – the area of the side surface of the measuring (internal) cylinder; h – the height of the measuring (internal) cylinder.

$$\tau_i = \frac{2}{\pi d_1^2 h} \cdot T_i. \quad (16)$$

Therefore,

$$P = \frac{2}{\pi d_1^2 h}. \quad (17)$$

Using the proposed calculations is possible to develop a rotary viscometer for determining the viscosity coefficient of Newtonian liquids. The least squares method is proposed to be used for processing measurement results which it will improve the accuracy of calculations.

References

[1] Wang G, Pu X-L 2011 Rheology of High-Density Drilling Fluids: Wall Slip During Viscosity Measurement *Petroleum Science and Technology* **29** 2321-8
[2] Rabia H 1985 *Oilwell Drilling Engineering: Principles and Practice* (Heidelberg: Springer Netherlands)
[3] Matveyenko V N, Kirsanov E A 2011 Viscosity and Structure of Disperse Systems *University Chemistry Bulletin* **66** 199-8
[4] Korganova O G, Kuznetsov V A 2012 Rotary Viscometer *Samara State Technical University Press* **4** 55-1
[5] Esteves R, Onukwuba N and Dikici B 2016 Determination of Surfactant Solution Viscosities with a Rotational Viscometer *Undergraduate Research Journal* **2** 12-9
[6] Hassan A B, Abolarin M S, Nasir A and Mshelia S G 2006 Fabrication and Testing of Viscosity Measuring Instrument *Leonardo Electronic Journal of Practices and Technologies* **8** 49-9
[7] Blanco A, Negro C, Fuente E and Tijero J 2007 Rotor Selection for a Searle-Type Device to Study the Rheology of Paper Pulp Suspensions *Chemical Engineering and Processing* **46(1)** 37-4
[8] Detler M F, Krivorotov A V , Nedoluzhko A I and Parubets A Yu 2017 Determination of rheological characteristics of technical liquids by rotational gyroscopic viscosimeters *Engineering journal of Don* **2**