Development of vibration viscometer for industry purpose and experience of its practical

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Abstract. Modern viscometers are devices widely presented on the market. The main advantages of viscometers are automation, increased accuracy, and speed of measurements. That's why it is important to know about the measurement of vibrational viscosity, methods for measuring vibrational viscosity and formulas for their calculation. As well as the next views which should be considered are devices for measuring vibrational viscosity and ways to improve them. The similarities and differences between viscosity measuring instruments also help to widen the outlook on the topic. A theoretical review of methods and technical means for measuring the viscosity of liquids was carried out to achieve this goal. In conclusion, we can say that vibratory viscous measuring equipment based on a new design and measurement method is promising.

1 Introduction

Determination of the viscosity value is of key importance in all areas of the oil industry. For example, when transporting oil and oil products, viscosity is one of the main indicators of the quality of the pumped oil. Also, this indicator is considered when planning the optimal operating modes of oil pumping stations, particularly oil pumping units. Therefore, operational control of such a parameter as viscosity is required. To carry out operational control, devices capable of providing this task are required; such devices are viscometers (viscosity converters).

The advantages of the self-oscillating method for measuring viscosity are disclosed in several works [1]. This method, based on measuring the amplitude of harmonic self-oscillations, provides the highest theoretically possible sensitivity of an oscillating probe in terms of viscosity, achieved due to the automatic maintenance of the probe's resonant mode.

2 Literature review

The level of development of the problem. In modern oil and gas extraction and refining plants and chemical and pharmaceutical plants, many scientists have been engaged in scientific research on viscosities for measuring the viscosity and viscosity of liquids.

Theoretical and methodological foundations of the study of the theory of viscosity of
liquids in the technical literature in the XV-XVII centuries I. Newton, B. Pascal, G. Galilei, E. Torricelli, full members of the St. Petersburg Academy D. Bernoulli, L. Euler, M.V Lomonosov, D. Poleni, A. Shezi, P. Dubua, D. Venturi, O. Reynolds, and others. The 19th and 20th centuries were the most advanced periods in the science of measuring the viscosity of liquids. Well-known researchers of this period are F. Forhgeimer, M. Weber, Prandtl, M.A. Velikanov, B.A. Bakhmetov, N.N. Pavlovsky, N.M. Vernadsky, Rebok, Cox and others.

The research of local scientists and its impact on modernization in modern conditions has developed significantly since the 90s of the twentieth century. As major contributors to the study of fluid viscosity problems, H.A. Rakhmatulin, O.M. Arifjanov, Q.T. Raximov, A.K. Khodjiev, et al. The authors consider this problem from different positions and propose their new conclusions.

3 Methods

The method is ideally suited for automatic measurements since it does not require adjustments during the operation of the device. With fluctuations in the resonant frequency of the probe, due to the influence of extraneous factors, the oscillator automatically tunes to this frequency, and the amplitude of self-oscillations remains sufficient but stable. It is also not very sensitive to the phase instability of the elements of the self-excitation ring [2].

The use of steady harmonic oscillations of the probe is preferable to the mode of free oscillations and other unsteady modes due to the absence of aperiodic transient processes of the probe [3], which reduce the measurement accuracy.

For these reasons, the method has been implemented in several designs of viscometers [4].

Along with significant advantages, the self-oscillatory method also has some disadvantages.

The sensitivity of the device to viscous damping is characterized by the following value [5] $C_A$

$$C_A = \frac{\partial A}{\partial D} = -\frac{1}{(x+D+xD)^2} \frac{\partial}{\partial D} \left( \frac{1+D}{x+D+xD} \right)$$

(1)

where $A$ is the amplitude of self-oscillations, normalized by the limiting amplitude at a frequency tending to zero; $D$ is the factor of viscous damping (1). $x$ is the tangent of the mechanical loss angle of the elastic suspension of the probe.

Figure 1 shows the dependence of $C_A$ on $D$ for various values of $x$, from which it can be seen that the sensitivity of the $C_A$ calculation method with decreasing $x$ and its maximum value is equal to $x$-2. The sensitivity drops sharply with increasing damping factor, especially at small values of $D$. 
Fig. 1. Dependence of the sensitivity $C_A$ of the self-oscillatory method and the sensitivity $C_F$ of the compensation self-oscillatory method on the damping coefficient for different values of $x$.

Since the method applies to relatively high-quality factors of the probe, $x$ "1 and $D$ "1 should be taken. In this case, as can be seen from figure 1, high sensitivity of the probe to viscous damping is achieved.

The error in determining the viscosity is [6]

$$\frac{\Delta \eta}{\eta} = \eta \left(1 + \frac{1}{D}\right)(x + D + xD) \frac{\Delta A}{A} \tag{2}$$

where $\frac{\Delta A}{A}$ is the relative error in measuring the amplitude of self-oscillations, $N_d$ is the error factor of the measurement method.

It can be seen from figure 2 that to reduce the determination error [7]

Fig. 2. The error coefficient of determining viscosity for ordinary and compensatory caroler methods as the function $D$ and $x$. 

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Viscosity should aim to reduce probe loss. Unfortunately, with a decrease, the non-uniformity of sensitivity over the range of measured viscosity values increases. This change can be several orders of magnitude, which forces the measurement range to be divided into subranges and prevents the creation of wide-range viscometers. The scale of the device is inverse (i.e., as the viscosity increases, the amplitude of self-oscillations decreases) and non-linear [8].

Free from these shortcomings is the compensatory self-oscillating method for measuring viscosity proposed by the authors [9], the essence of which is that the amplitude of self-oscillations of the probe is maintained constant by a corresponding change in the amplitude of the excitation force used to determine the viscosity.

Setting the amplitude of self-oscillations constant from (1), we obtain an expression for the amplitude of the exciting force in the form:

$$F = A \cdot \frac{x + \frac{D}{1 + D}}{1 + D} = \left( x + \frac{D}{1 + D} \right) \cdot A$$  \hspace{1cm} (3)

where the $A$ — a given amplitude of the trolley of the probe [10]. Figure 3 shows Graduating curves for conventional and compensatory self-oscillating methods. The amplitude of the exciting force with accuracy to constant terms does not depend on its own losses of the $x$ probe, and its dependence on $D$ is close to linear. The sensitivity of the compensation method does not change much when changing $D$ from 0 to 0.1, which makes it possible to develop widely-band viscometers. The main measurement error for the compensation method is equal to the error of the conventional autocolors method and is set by the formula (2). Therefore, with compensation measurements, one should strive to increase the probe quality [11].

Figure 4a shows a block diagram of a compensation self-oscillatory viscometer for general industrial purposes VVN-3 (low-frequency vibration viscometer).

**Fig. 3.** Calibration dependencies for conventional and compensation self-oscillatory methods.
The viscosity sensor 1 with its exciting converter 2 and the receiving converter 3 is connected to the output and entrance of the amplifying path of the self-excitation ring and serves the role of the feedback link. The Ring of self-excitation also contains a phasorrier 4, which provides the optimal phase of the phase in the Ring of self-excitation, in which the smallest phase instability of the amplitude exciting $1 - 10^{-1} \cdot A\ (x = 10^{-2}),\ 2 - 10^{-2} \cdot A\ (x = 10^{-2}),\ 3 - 10^{-3} \cdot A\ (x = 10^{-3}),\ 4 - \left(\frac{10F}{A} + \text{const}\right)$—with any values forces (2); Empire-limiter 5, practically excluding the effect of instability of the ring amplification on the testimony of the device; strip filter 6, highlighting the first harmonic of the output voltage of the enhancer amplifier and providing a purely harmonic regime of oscillations of the probe; The output coordinating cascade 7 and the controlled attenuator 8, which regulates the amplitude of the exciting voltage supplied to the exciting converter of 2 viscosity sensors, and therefore the amplitude of the force exciting the probe [12].

The controlled attenuator 8 is kinematically connected to the axis of the automatic indicating and recording potentiometer 9, the input of which is fed a signal from the output of the comparator 10, which forms the difference between two constant voltages arriving at its inputs. The harmonic signal from the receiving transducer 3 of the viscosity sensor 1 is fed to the detector 12, and through the cathode follower, 11 is fed to one of the inputs of the comparator device 10. The voltage from the stabilized reference voltage source 13 is applied to its second input, if the amplitude of self-oscillations of the probe is equal to a certain value due to the magnitude of the reference voltage. Otherwise, the automatic potentiometer 9 changes the amplitude of the exciting force probe until self-oscillations amplitude reaches a predetermined value [13]. Thus, automatic maintenance of a constant amplitude of self-oscillations is ensured by changing the amplitude of the exciting force probe. The circuit of the device allows by very simple means - by selecting the elements of the controlled attenuator and the value of the second voltage - to change the division value of the device while maintaining an almost linear scale. This makes it possible to obtain either a wide survey range of measurements or to stretch the scale in the vicinity of any selected viscosity value. The latter circumstance is very important for the control of many production processes; it ensures the wide versatility of the device and the possibility of its general industrial application. The vibration explosion-proof viscosity sensor of the VVN-3 device (figure 4B) is an improved modification of the sensors of the VVN-1 and VVN-2 viscometers. It is conveniently built into pipelines and tanks and has small dimensions. Probe 1, integral to the membrane, performs rotational vibrations around the point of elastic suspension in the drawing plane. An excitatory 2 and a receiving 3 electromagnetic transducer are placed in the viscosity sensor housing [14].

Figure 5 shows the calibration curves obtained using the same viscosity sensor with conventional and self-compensating self-oscillatory circuits.
Fig. 4A. Functional diagram of the compensation self-oscillating viscometer VVN-3.

1 is viscosity sensor, 2,3 are exciting and receiving electromechanical converters, 4 id phase shifter, 5 is limiting amplifier, 6 is filter, 7 is amplifier output stage, 8 is controlled attenuator, 9 is automatic potentiometer, 10 is comparator, 11 is cathode follower, 12 is detector, 13 is reference voltage source.

Fig. 4b. Viscosity sensor of VVN-3 viscometer. 1 is probe, 2,3 are exciting and receiving electromagnetic transducers, 4 is elastic suspension.

The VVN-3 device has passed state acceptance tests and is being implemented in several industries [15].

4 Results and Discussion

The main error of the device is ± 4% of the measurement limits; the measurement limits can vary in a wide range from $1 \cdot 10^{-3}$ to 30 PUAZ and higher.
Concluding remarks

In conclusion, various methods and ways are used to measure and calculate vibrational viscosity. Research on viscometers shows their importance in modern life by facilitating many important tasks. The qualities inherent in the compensatory self-oscillating method ensure its wide practical application in industry and scientific research.

References