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IMPROVING THE METHOD OF MEASUREMENT OF VISCOUS PILOID SUBSTANCES

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The use ultrasonic method of measuring viscosity for piloid substance control, namely the method of measuring the viscosity of a substance with the piezoelectric transducers was suggested in the article. To do this, the transducer is placed in the tested material and the viscosity is measured by exciting it free oscillations and determining the viscosity number of these oscillations above a fixed level. To extend the range of measurement devices were developed the containing ultrasound hubs.
Keywords: *viscosity, the viscometer, piezoelectric, ultrasonic horn, mud, piloids.*

СОВЕРШЕНСТВОВАНИЕ МЕТОДА ИЗМЕРЕНИЯ ПАРАМЕТРОВ ВЯЗКИХ ПЕЛОИДНЫХ ВЕЩЕСТВ

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В статье предложено применять ультразвуковой метод измерения вязкости для контроля пелоидных веществ, а именно метод измерения вязкости вещества с помощью пьезоэлектрических преобразователей. Для этого преобразователь помещают в исследуемое вещество и измеряют вязкость путем возбуждения в нем свободных колебаний и определяют вязкость по числу этих колебаний, превышающих фиксированный уровень. Для расширения диапазона измерений разработаны устройства, содержащие ультразвуковые концентраторы.
Ключевые слова: *вязкость, вискозиметр, пьезоэлемент, ультразвуковой концентратор, грязелечение, пелоиды.*

Introduction. Mud therapy is called pilotherapy from the Greek. pilos – silt, clay, therapio – treatment. Mud therapy is one of the oldest methods of treatment using natural remedies. As a kind of treatment mud was firstly used in Ancient Egypt, Ancient Rome, India and other countries. In Ukraine mud therapy has been applied since the XIII century using the mud from Crimean lakes. Therapeutic muds are used in spa resorts, as well as in physiotherapy in hospitals in Ukraine as a kind of out resort mud therapy [1].

Therapeutic muds or piloids – substances produced in natural conditions under the influence of geological processes. They are used for medicinal purposes in the form of baths and local applications.

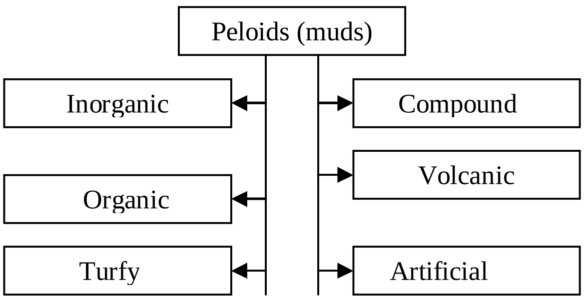

Fig. 1. International Mud Classification

Therapeutic mud – complex physical and chemical dynamic system consisting of three interrelated components of mud solution (liquid part), the coarse-dispersion (skeleton) and fine (colloidal complex).

Piloids belong to special class of fluids called viscoplastic fluids (VPF). The therapeutic mud composition, temperature, density and humidity, mechanical strength or other external impact applied to piloid before or during treatment have an influence on the strength of its structure.

It is well known, [2] the connection between applied force and intensity of the motion caused by the matter is characterized by the dynamic viscosity coefficient (Pa). If the dynamic viscosity coefficient does not depend on driving conditions of a substance and is determined only by its composition and temperature, such substance is called Newtonian. Newtonian substances include water, lake brine, significantly dilute mud solutions [3].

The current of viscoplastic fluids, including therapeutic muds obeys different laws. Viscoplastic fluids (VPF) are structured. It is characterized by the values of normal and shear stresses' limits. When exceeding, the structure [4]:

1) destroys;

2) viscoplastic liquid starts to leak in the force direction;

3) a layer of material detaches from the walls of the apparatus;

4) the adhesion between the particles of any fluid is broken.

There is a need for controlling the viscosity of mud applications. Now a significant amount of viscometers is proposed, this is due to a variety of tasks of viscometry and difference of the properties investigated fluids and plastic bodies. However, not all of them are suitable for measuring the piloids viscosity. The disadvantages are the inability to measure the viscosity of highly viscous materials (capillary viscometer), the accumulation dissipate heat in a deformable substance (rotational viscometer) and the complexity of design and method of measurement.

The aim of this work is to use the ultrasonic method for measuring the viscosity [5] of piloid substances.

Methods for measuring the viscosity of fluids can be divided into three groups [5]:

1. Methods based on measurements of shear stress, which supports constant rate of deformation under uniform shear.

2. Methods based on the measurement of average speed of the current flow in the flow of given shape or the velocity of steady motion (falling) of a solid of some form in the infinite viscous medium.

3. Methods based on the measurement of the speed of unsteady movements: observation of the amplitude decay of the periodic oscillations or the decrease of the rate in aperiodic motion occurring as a result of conversion of kinetic energy into heat due to internal friction of the medium.

The classical absolute methods are capillary method, rotating cylinder method, the falling ball method. In severe cases, when distribution of the velocity or law movement, for example, of a rigid body in a viscous medium, can not be derived analytically from the general hydrodynamics laws of a viscous medium, the absolute viscosity measurements are not possible.

2 types of devices belong to the 1st group:

- Less than perfect, in which the largest amount of deformation is limited by size of the device;

- Improved methods with unlimited quantity of deformation, allowing to observe the long determination of the fixed shear rate, for example, in case of highly viscous and elastic (structured) liquids (polymers and their concentrated solutions - gels). Such instruments are based on the relative rotation of coaxial cylinders with radii r_1 и r_2 and gap between them $\Delta r = (r_2 - r_1) << r_1$ full of the viscous medium.

Group 2:

- Rotational viscometers, which have gaps of arbitrary width, in contrast to the devices from the 1st group; in case of truly viscous (Newtonian) liquids.

- Viscometers based on viscous medium current in long and narrow tubes (capillaries) of constant circular cross-section. They are usually used for accurate measurements of the Newtonian fluids' viscosity;

- Viscometers based on measuring the velocity of a steady motion of a solid ball in the viscous medium under the influence of constant external force, in the simplest case - the force of gravity.

Devices of the third group have more complex theory, or do not serve for absolute measurements of viscosity.

The authors propose us to measure the viscosity of a substance with piezoelectric transducers. This transducer is placed into testing substance and the viscosity is measured by excitation free oscillations in it and the viscosity is determined by the number of oscillations exceeding fixed level. [6].

Under pulsed excitation of a piezoelectric transducer there are waves with natural frequency, damped exponentially with a damping coefficient δ:

$$d = \frac{R_1}{2L}, \quad (1)$$

The attenuation of these oscillations depends on the losses in the piezoelectric element and on viscous friction (viscosity) of a substance. At constant value of the internal friction of the piezoceramic *(R_1)* [6] the oscillation damping depends only on the viscosity R_2.

Logarithmic decrement Δ [7] is equal to:

$$\Delta = e^{-d\mathrm{T}} = e^{-\frac{R}{2Lf_p}}, \quad (2)$$

where f_p – pulse repetition frequency, $f_p = \frac{1}{\mathrm{T}}$; $R = R_1 + R_2$; L – equivalent inductance of a piezoelectric element;

Number of free oscillations N_0 from the initial amplitude A to the amplitude a can be determined from the expression:

$$e^{-\frac{RN_0}{2Lf_p}} = \frac{1}{a}$$

After simple transformations, we'll obtain:

$$N_0 = \frac{2Lf_p \ln a}{R}.$$

The number of oscillations per second:

$$N = f_{сл} f_p \frac{2L}{R_2 + R_1} \ln a, \quad (3)$$

where f_{pr} – pulse repetition frequency; f_r – resonant frequency of a piezoelectric element; L – equivalent inductance.

It follows that we can judge the viscosity by the number of oscillations *N*.

The viscosity can be considered as manifestation of internal friction of liquids during their movement, which is the result of great cohesive forces existing between the liquid molecules [8]. In the case where the contiguous layers of the liquid move at different speeds some force *F* tending to align these speeds occurs between them. This force will act slowing down at fast-moving layer, and at slowly moving bed – accelerating. Obviously, in the simplest case, the force will be directly proportional to the contact surface *S* and to the differential rate *dv/ dx*. Therefore:

$$F = h\frac{dv}{dx}S, \quad (4)$$

where h – viscosity or internal friction coefficient, characteristic for any liquid.

Since piloid substance are sufficiently viscous, there is a need to extend the range of measurements. Several devices containing in addition to ultrasonic piezoelectric transducers concentrators are developed [9, 10]. These concentrators serve for increasing the ultrasound intensity (oscillatory displacement amplitude).

There are two types of concentrators: focusing or high-frequency and low frequency or rod [11].

Focusing concentrators' action is based on focusing the sound, so there any focusing device – acoustic lenses, reflectors, etc. can be used.

Rod concentrator action is based on the increasing the amplitude of vibrational displacement of the rod particles due to the reduction of its cross-section, or density, in accordance to the law of conservation of momentum.

Rod concentrators are classified by such characteristics: shape of the longitudinal section, the cross-sectional shape (circular, wedge, etc.), number of elements with different profile of longitudinal section (simple, composite, etc.), number of series-connected resonance concentrators of half wavelength, midline form, type of concentrator oscillations (longitudinal, shear, torsion).

Rod concentrator gain [11]:

$$K = \xi_l / \xi_0,$$

where ξ_l and ξ_0 – displacement amplitudes at its narrow and wide ends.

Figure 2. Ultrasonic concentrator of torsional oscillations is used as a vibrator in viscosity control device.

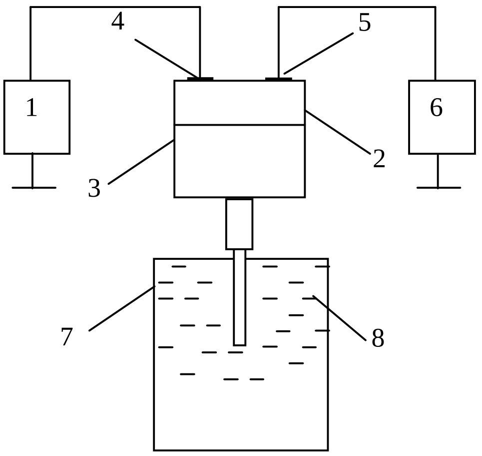

Fig. 2. Viscosity control device: 1 – piezo; 2 – torsional oscillations concentrator; 3 –sonde; 4 – hard traction; 5 – vessel; 6 – liquid; 7 – electrical oscillations generator; 8 – meter

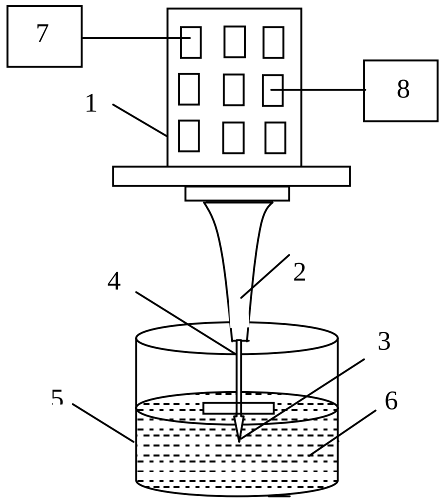

Fig. 3. Viscosity control device: 1 – electrical oscillations generator; 2 – disc piezo transformer; 3 – stepped concentrator; 4 – input electrode system; 5 – output electrode system; 6 – meter; 7 – vessel; 8 – liquid

Figure 3. A device with stepped concentrator providing the maximum transformation coefficient. This device can be used to control very viscous substances [10]. The ultrasonic concentrator allows to increase the oscillation amplitude [11]. The hollow concentrator devices with variable inner section which also serves as a vessel for the investigated material are also proposed.

Conclusions. Thus, using the ultrasonic measuring method and developed devices greatly simplify the procedure of measuring peloid substances' viscosity, to increasing the accuracy of measurement. And the application of ultrasonic concentrators allowed to extend the range of measurement.

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