Lesson №7. Capillary viscometer method for Determination of liquid viscosity.

Theory.

The viscosity of biological fluids (blood, lymph, liquor, etc.) depends on the physiological state of the body and changes with pathology. Thus, an increase in blood viscosity occurs in ischemic heart disease, myocardial infarction, hypertension, diabetes and other diseases. Knowing the blood viscosity allows you to assess the degree of stress on the patient's cardiovascular system. The determination of viscosity is important and is widely used in medicine:

- in clinical diagnostics: measurement of blood viscosity using viscometers, assessment of erythrocyte sedimentation rate (ESR) (also take into account the aggregation of red blood cells);
- in forensic medicine (use the dependence of blood viscosity on age and gender);
- in medical research: the viscosity (microviscosity) of the cell's cytoplasm is determined. It depends on the structure of its constituent biopolymers and subcellular formations, on the period of the cell cycle, on the temperature, and on the intensity of various external influences (for example, radiation exposure).

The ability of real liquids to resist the movement of bodies in them or their own flow due to the forces of intermolecular interaction is called internal friction or fluid viscosity. This phenomenon can be observed in the case of fluid movement between two solid plates, when the upper plate moves uniformly parallel to the lower fixed plate (Fig. 1).
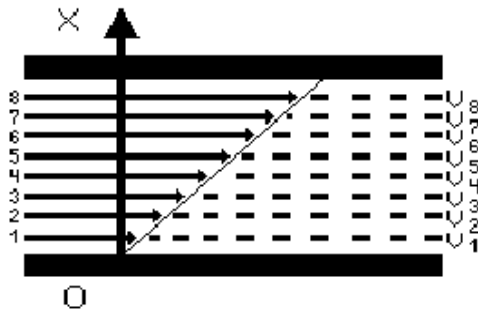

Fig. 1. Diagram of velocities of fluid layers, obeying the Newton equation.

Due to the intermolecular interaction, the upper layer of the liquid will have a velocity equal to the velocity of the upper plate of the V, and the lowest layer will be stationary ($\omega=0$). Intermediate layers due to the internal friction force (between them) will have intermediate velocity values ($0 < y < V$). If the change in the velocity of the layers with distance is linear, then the value of the internal friction force F_{fr} is determined by the Newton equation:

$$F_{fr} = \eta \frac{d\upsilon}{dx} S \qquad (1)$$

η - **the coefficient of internal friction or dynamic viscosity**

$\dfrac{d\upsilon}{dx}$ - **velocity gradient**

S - the contact area between layers

[η]=Pa·s in the SI system
[η]= 1puaz (P) in the GHS system
1 PA·s=10 P

Graphically, this flow of fluid is shown in Fig. 1. Such fluids are called **Newtonian**. The viscosity coefficient of such media depends on their nature, temperature (it decreases with increasing temperature), and pressure at low temperatures. Newtonian liquids include water, low-molecular organic compounds, and true melts of metals and their salts.

If the liquid has a complex structure and contains large molecules (for example, solutions of polymers, proteins), they have an increased viscosity, since, in addition to overcoming the noted force of intermolecular interaction, the work of external forces is also spent on the destruction of spatial structures, aggregates created by groups of molecules. The flow of such liquids does not obey Newton's formula, and liquids are called **non-Newtonian** or **structurally viscous**.

In particular, blood, which is a suspension of shaped elements in a protein solution-plasma, belongs to non-Newtonian fluids. However, in some cases, the blood viscosity coefficient is taken as a constant value, getting its approximate values.

Often, when studying the viscosity of a liquid, the flow curve is determined - the dependence of the shear stress $\tau = F/S$ on the velocity gradient (Fig. 2).

For a Newtonian fluid (1), the graph starts from the origin and increases linearly with increasing velocity gradient. Indeed, according to the formula (1):

$$\frac{F_{\text{тр}}}{S} = \eta \frac{d\upsilon}{dx}$$
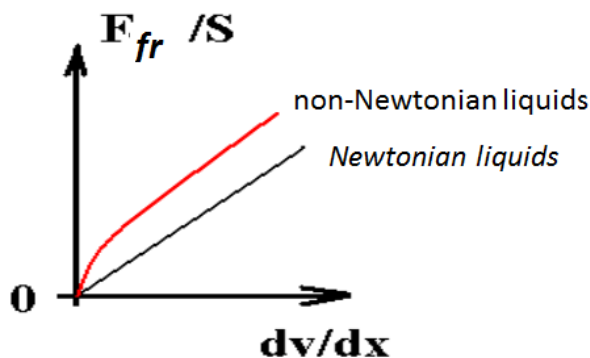

Fig. 2. Dependence of the shear stress τ on the velocity gradient for Newtonian (1) and non-Newtonian (2) fluids.

Therefore, the dynamic viscosity index of a Newtonian fluid is a constant and does not depend on the velocity gradient.

For a non-Newtonian fluid (2), the graph starts from a certain value τ_0 (the limiting shear stress) and increases non-linearly with increasing velocity gradient. That is, the dynamic viscosity index of a non-Newtonian fluid depends on the velocity gradient. For such liquids, the viscosity coefficient also depends on the flow mode and pressure. Their viscosity is characterized by a so-called conditional viscosity coefficient, which depends on the conditions of the liquid flow.

The coefficient of internal friction of solutions of viscous liquids depends on their concentration. As the concentration of such liquids increases, the viscosity increases.

Units of measurement of the viscosity coefficient in SI - (N·s / m^2) (PA·s) (Pascal .second), in the GHS system – (DIN·s / cm^2) (P) (poise). The relationship between these values is 1 PA·s = 10 P. In practice, the relative viscosity от R$_{el}$ is often used, determining the ratio of the viscosity coefficient of the test liquid to the viscosity coefficient of water η$_o$. under the same conditions (at t = 200C and η$_o$ ≈1 SP).

Viscosity measurement is of great practical importance for medicine. The relative blood viscosity is normally 4.2-6. In pathologies, it can decrease to 2-3 (with anemia) or increase to 15-20 (with polycytamia), which affects the rate of erythrocyte sedimentation (ESR). Blood viscosity is different in men (4.3-5.9) and women (3.9-4.9), it changes with age, which is important for forensic research. Relative viscosity of blood serum-1,4-1,7, plasma-1,5-1,8. Blood viscosity depends on the concentration of red blood cells and plasma proteins, as well as their composition, the size of blood cells, and the elasticity of red blood cell membranes.

Stationary motion of liquids is *laminar*. In laminar flow, different layers of liquid flow without mixing, parallel to each other. When a laminar flow of liquid through a pipe of constant cross-section increases the velocity of the layers from the periphery to the center (Fig. 3).
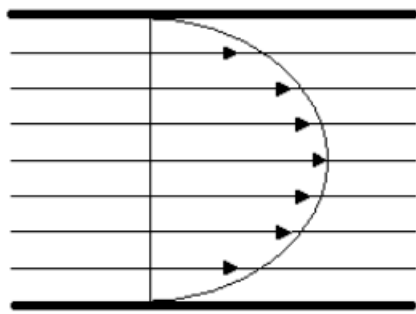

Fig. 3. Laminar flow of liquid in the pipe.

The maximum speed will be along the pipe axis, and the minimum speed (almost equal to 0) will be for the wall layers. Therefore, the difference between the velocities of two adjacent layers has the greatest value at the walls of the pipe, and the minimum value is in the center. If you connect the ends of the velocity vectors of the layers with a smooth curve, you will get a parabola.

An increase in the flow rate of a viscous liquid due to pressure inhomogeneity along the cross section of the pipe creates swirls, and the movement becomes eddy or turbulent. With a turbulent flow, the particle velocities in each place continuously and chaotically change, the movement is non-stationary, accompanied by noise.

The nature of the flow of a liquid through a pipe is determined by the Reynolds number:

$$Re = \frac{\rho V D}{\eta}$$

Density of fluid

Velocity of fluid

Diameter of pipe

Reynolds Number

Dynamic Viscosity of fluid

If the Reynolds number is greater than a certain critical number, then the fluid movement will be turbulent. For example, for smooth cylindrical tubes, Re = 2300, and for blood vessels, normally Re = 2000.

METHODS FOR MEASURING LIQUID VISCOSITY

1. Stokes Method

Used for the study of liquids with high viscosity. Experimentally, Stokes found that when the ball moves uniformly in a viscous liquid, the resistance force F_{fr} to movement is directly proportional to the velocity u, the radius of the ball R, and the viscosity coefficient of the liquid η:

$$F_{fr} = 6\pi\eta R\upsilon \tag{4}$$

Having determined the rate of immersion of the ball inside a vessel with a viscous liquid, knowing the size and density of the ball, as well as the density of the liquid RJ, find its viscosity

$$\eta = \frac{2}{9}gR^2\frac{\rho-\rho_L}{V} \tag{5}$$

2. The method of capillary viscometer

Used in the study of liquids with low viscosity. The method of measuring the viscosity coefficient with a capillary viscometer is based on measuring the flow rate of a liquid in a capillary tube (Fig. 4).
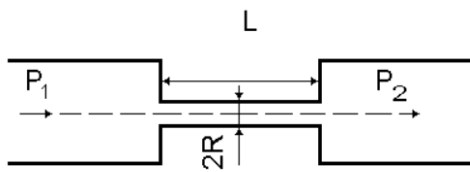

Fig. 4. The flow of liquid in the capillary tube.

The speed of liquid flow through the center of the pipe depends on the pressure difference (P_1-P_2) at the ends of the pipe, its length L, radius R, and the viscosity of the liquid:

$$\upsilon = \frac{R^2(P_1 - P_2)}{4\eta L}$$

The **Poiseuille formula** determines the dependence of the Q-volume of liquid flowing per unit time through a pipe of length L, radius R, with a pressure difference at the ends of the pipe (P1< P2), on the viscosity

$$Q = \frac{\pi R^4(P_1 - P_2)}{8\eta L}. \tag{6}$$

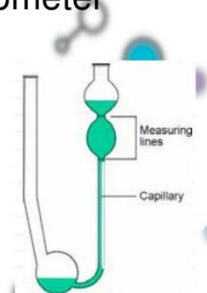The value X is called *hydraulic resistance*:

$$X = \frac{8\eta L}{\pi R^4}$$

The Poiseuille formula is valid only for laminar flow. Therefore, in order to avoid turbulent flow at normal speeds, capillary tubes are used in practice. And since it is difficult to accurately measure all the values included in it, it is most often determined by the relative viscosity coefficient, that is, the viscosity of the test liquid relative to another liquid, most often water. For this purpose, the flow time of a certain volume V of the test liquid and the flow time t of the same volume of water are measured.

Capillary viscometer method

Ostwald viscometer

- Need a small-diameter tube (capillary)
- Measure time of flow of a specific volume through the capillary
- Constant pressure drop across the capillary
- Use Poiseuille's equation to calculate viscosity
- Must be calibrated with a known material

For the test liquid:

$$V = \frac{\pi R^4 \Delta P_x}{8\eta_x L} t_x$$

For the reference liquid :
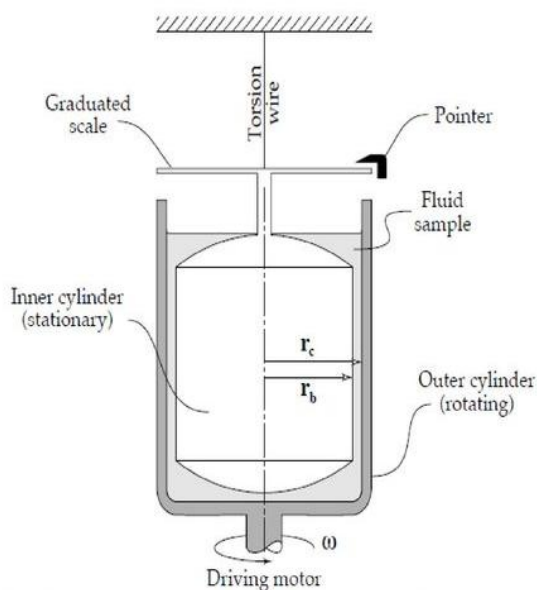
$$V = \frac{\pi R^4 \Delta P_0}{8\eta_0 L} t_0$$

$$\eta_x = \eta_0 \frac{\rho_x t_x}{\rho_0 t_0}$$

V - volume!

3. Rotary viscometer

It is used to determine the viscosity of non-Newtonian liquids. Since most biological fluids are non-Newtonian, this device is of interest for biomedical research. The viscometer consists of two coaxially positioned cylinders inserted into each other (Fig. 5).

Determine viscosity by measuring the resistance on a shaft rotating in the fluid .

They are designed to make a direct measurement of the absolute Viscosity.

The theory of operation of a rotational viscometer is based on the Couette flow model for fully developed, steady and laminar flow between two surfaces, one of which is moving.

Pointer displacement is directly proportional to fluid viscosity.

Schematic diagram of a rotating cylinder viscometer.