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RESULTS OF DETERMINATION OF BITUMEN MOVEMENT MODES AT DIFFERENT TEMPERATURES

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Abstract: The article presents the results of determining the modes of bitumen movement at various temperatures, the results of reducing the viscosity of construction bitumen grade BNSHK-1 depending on the process temperature, and the results of determining the main parameters of the hydrodynamics of the mixing process (the angular velocity of the mixer is 31.4 rad/s).

Keywords: hydrodynamics, bitumen, mixer, angular velocity, motion mode, Reynolds, laminar mode, turbulent mode.

Introduction. Laminar flow is typical for bitumen at low speeds and high viscosities. Heat exchange is slowed down, heat transfer is carried out mainly due to thermal conductivity, temperature heterogeneity occurs, and longer heat exchange surfaces are required [1].

Transient and turbulent modes. The internal mixing speeds increase. The heat transfer coefficient increases significantly. The uniformity of heating and temperature stability are improved. Overheating or local stagnation may decrease. The transition to a more intensive mode (turbulence) improves heat transfer, especially for viscous media [2].

The classification of liquid or gas flow modes in pipes or channels is based on the Reynolds number (Re), a dimensionless quantity that characterizes the ratio between inertial and viscous forces in the flow [3].

The laminar flow mode is Re <2320; in this mode of motion, the flow is ordered and layered. The liquid particles move parallel to each other. Laminar flow is typical for viscous liquids at low speeds. The transition mode is Re ≈ 2300-10000, the flow is unstable: it can fluctuate between laminar and turbulent. The slightest disturbance can lead to a complete transition to turbulence. In this range, the mode is difficult to predict, depending on geometry, roughness, vibrations, etc. The turbulent flow mode is Re

>10000, the flow is chaotic, with many vortices and pulsations. Inertial forces prevail over viscous ones. It is typical for gases and water in large pipes at high speeds [4].

Bitumen is a viscous non–Newtonian liquid, and its flow behavior may differ from water or air. Nevertheless, the Reynolds number is still used for an approximate estimation of the flow regime [5].

The laminar regime is Re < 100 – 500 (for bitumen!), the movement is very slow, layered, viscous forces dominate. This flow is typical when transporting bitumen in pipes without heating or at very low speeds. The flow is steady, without eddies. The transition mode is Re ≈ 500 – 1500, the flow can fluctuate between laminar and turbulent. Temperature, pump pulsations, and pipe roughness play an important role in this range. The turbulent regime is Re > 1500-2000 (*for bitumen, this is turbulence),* the flow is chaotic, with vortices and mixing [6].

The mode of movement and the flow rate are influenced by the viscosity and density of the raw materials. The viscosity of the bitumen obtained was measured using a UB-1 vacuum viscometer according to GOST 32060- 2013. The process temperature is 70 ° C, and the volume of construction bitumen for the experiment is 50 ml each [7].

The temperatures of the bitumen obtained were increased from 20 ° C to 180 °C. We filled the viscometer with construction bitumen, avoiding the formation of air bubbles. A special syringe was used for careful filling. The viscometer was placed in an upright position. They removed the plug and started the timer when the bitumen started flowing. The time required to drain 50 ml of bitumen was measured. A vacuum was created on the viscometer, usually up to 300 mmHg (40,000 Pa). Bitumen flows through the capillary of the viscometer under the action of vacuum. The time it takes for bitumen to pass through a certain volume of the capillary was recorded with a stopwatch [8].

The dynamic viscosity was calculated using this formula:

where, η is the dynamic viscosity in Pascals-seconds (Pa·s); K is the calibration coefficient of the viscometer (indicated in the device passport); t is the time of bitumen expiration through the capillary in seconds [9].

The viscosities of building bitumen were determined at various temperatures from 60 °C to 180 °C. The results are shown in Table 1.

Table 1. The results of reducing the viscosity of construction bitumen grade BNSHK-1 depending on the temperature of the process.

No.	Product temperature, °C	Dynamic viscosity, Pa·s	Density, g/cm³	Kinematic viscosity, mm²/s
1	60	458	1,05	436
2	80	444	1,03	432
3	100	424	0,99	428
4	120	408	0,96	425
5	140	391	0,93	421
6	160	372	0,89	418
7	180	353	0,85	415

Tab. 1 shows that the obtained construction bitumen BNSHK-1 at 60° C has a dynamic viscosity of 458 Pa ·s. At a temperature of 80°C, the dynamic viscosity of the obtained BNSHK-1 bitumen has a coefficient of 444 Pa ·s. With a further increase in the product temperature to 120°C, the dynamic viscosity decreases to 408 Pa·s. An increase in the product temperature to 180°C leads to a decrease in the dynamic viscosity to 353 Pa·s. Temperature has the same effect on the density and viscosity of bitumen BNSHK-2.

The density indicator is of great importance in determining the hydrodynamics, i.e. the flow mode. The density allows you to evaluate the quality of bitumen and its compliance with standards. This is important to ensure the durability and reliability of the building material. It helps to determine the density index in calculating the volumes and masses of materials needed for the use of construction bitumen, as well as for the modification process [10-11].

Determining the density of bitumen for the modification process has several key meanings: Knowing the density of bitumen helps to choose the right proportions of modifiers (for example, waste from worn tires, packaging products, polymers) to achieve the necessary properties of the final product. Deviations from the norm of the density index may cause problems during the modification process. When modifying bitumen, it is important to take into account its density in order to adjust the temperature correctly to ensure uniformity and mixing efficiency. Knowing the density helps in calculating the cost of raw materials and in determining the required volume of bitumen for various construction projects. Thus, determining the density of the obtained bitumen is an important step for successful modification, affecting the final properties and quality of the modified bitumen.

The density of the bitumen obtained was determined by a pycnometer according to GOST 32183-2013. This standard is identical to the ASTM D 70-09 standard "Standard Method for determining the density of semi-solid Bituminous materials (pycnometric method)" ["Standard test method for density of semi-solid bituminous materials (pycnometer method)", IDT].

For the experiments, a glass pycnometer consisting of a cylindrical vessel with a stopper diameter of 24 mm was used. The height of the concave part in the center of the plug is 12.0 mm. The capacity of the stoppered pycnometer is 26 cm^3 and has a mass of 40 g. The sample was carefully heated, stirring to prevent local overheating, to a liquid state so that it could be poured. The sample was heated to 60°C. A sufficient amount of bitumen was poured into a clean, dry, heated pycnometer. A pycnometer with the resulting bitumen was cooled to room temperature for 40 minutes and weighed together with a stopper with an accuracy of 0.001g.

A pycnometer was placed in a glass and left for 30 minutes. Dried and weighed. We denote the mass of the pycnometer with a sample of material and water by the letter D.

The relative density was calculated:

$$\rho_{относителная} = \frac{C - A}{\text{B - C - D - C}}$$

where, C is the mass of a pycnometer filled with construction bitumen, g;
A is the mass of the pycnometer with a plug, g;
B is the mass of a pycnometer filled with water, g;
D is the mass of the pycnometer with bitumen and water, g;

$$\rho = \rho_{отн.} \cdot W_m$$

where, $W_т$ is the density of water extracted from the oil sludge at the test temperature.

Experiments were conducted at temperatures from 20°C to 180°C. As the temperature increased, the density of the obtained bitumen decreased from 1.05 g/cm³ to 0.89 g/cm³.

Calculation based on agitator parameters and viscosity. Hydrodynamic formulas for mixing devices can be used.

Linear speed on the agitator blades:

$$\vartheta = \omega \cdot r = 31{,}4 \cdot 0{,}6 = 18{,}84 \text{ rad/s};$$

"ω" is the angular velocity of the agitator (rad/s); r is the radius of rotation of the blade (m).

This velocity shows the velocity of the fluid moving near the blade.

The average flow rate in the agitator depends on the type of agitator (vane, turbine, propeller, etc.), the number of revolutions and the viscosity of bitumen. A 6-blade agitator was used here.

Reynolds number for viscous liquids:

$$Re = \frac{\rho n D^2}{\mu} = \frac{1050 \cdot 400 \cdot 1{,}2^2}{458} = 1320$$

where, ϱ is the density of bitumen (kg/m³), n is the rotation speed (rpm), D is the diameter of the mixer (m), and μ is the dynamic viscosity of bitumen (Pa·s).

$$\omega = \frac{2\pi n}{60} = \frac{2 \cdot 3{,}14 \cdot 300}{60} = 31{,}4 \frac{\text{rad}}{\text{s}}$$

Table 2. The results of determining the main parameters of the hydrodynamics of the mixing process (the angular velocity of the mixer is 31.4 rad/s)

No.	Product temperature, °C	Dynamic viscosity, Pa·s	Density, g/sm³	Reynolds
1	60	458	1,05	1320
2	80	444	1,03	1336
3	100	424	0,99	1345
4	120	408	0,96	1355
5	140	391	0,93	1370
6	160	372	0,89	1378
7	180	353	0,85	1387

From the table 2 it can be seen that the temperature effect has a noticeable effect on the viscosity of the product. With an increase in temperature from 60°C to 180°C, there is a steady tendency to decrease the dynamic viscosity from 458 Pa·s to 353 Pa·s. This is due to the liquefaction of bitumen material, which is typical for viscous petroleum products when heated. The density of the product also decreases with increasing temperature, from 1.05 g/cm3 at 60°C to 0.85 g/cm³ at 180°C. This reflects the thermal expansion of the substance, leading to a decrease in specific gravity. The Reynolds number shows a moderate increase as the temperature increases, which is associated with a decrease in viscosity and density. The values vary from 1320 to 1387, which indicates a laminar or transient flow regime characteristic of highly viscous media at relatively low speeds.

Thus, as the product temperature increases from 60°C to 180°C, there is a consistent decrease in all three parameters - dynamic viscosity, density and kinematic viscosity. Increasing the temperature helps to reduce the viscosity and density of the product, improving its fluidity and facilitating the pumping and processing processes. At the same time, the value of the Reynolds number increases from 1320 to 1387, reflecting an increase in flow turbulence due to a decrease in viscosity and density at higher temperatures. This means that as the temperature increases, the hydrodynamic characteristics of the product increase, which can help improve mixing and transport processes.

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