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STABILIZATION OF THE SPEED OF PUMPING-OUT THE CHAMBER IN THE DYNAMIC THERMOVACUUM METHOD OF HYDROMETRY OF LOOSE MATERIALS

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Analysis is made of the effect of the parameters of the elements of the vacuum system and the temperature of the water vapor on the speed of pumping-out the chamber of a dynamic thermovacuum hydrometer. To stabilize the speed of pumping-out the chamber it is suggested that a diaphragm be mounted; an expression for calculation of the diaphragm cross section is given.

One of the main shortcomings of the existing dynamic thermovacuum method (DTV method) of hydrometry of loose materials is the dependence of the informative parameter that characterizes the speed of moisture desorption on the speed of pumping-out the vacuum chamber [1, 2].

To conduct DTV measurements, use in made of a vacuum system that consists of three elements: a vacuum chamber, connection lines, and a vacuum pump. The speed S_0 of pumping-out the vacuum chamber with the analyzed sample of a moist loose material is determined by the speed of vacuum-pump operation S_p and the conductivity of the connection lines U:

$$S_0 = \frac{US_p}{U + S_p} . \quad (1)$$

It is seen from (1) that speed of chamber pumping-out can be considered constant during a measurement if

$$U >> S_p , \quad S_p = \text{const} \quad (2)$$

or

$$U << S_p , \quad U = \text{const} . \quad (3)$$

In the case of (2), the speed of chamber pumping-out is determined only by the speed of vacuum-pump operation, which, for DTV measurements, must satisfy the following requirements: must evacuate the water vapor, must produce a pressure in the chamber that is lower than the pressure of saturated water vapor at 0°C, must provide a constant speed of operation for a pressure variation in the intake connection pipe in the range of working pressures (in the range of pressures of saturated water vapor at temperatures of 0 to 20°C).

Mechanical vacuum pumps with an oil seal equipped with gas-ballast devices satisfy the above requirements [3, 4]. Plate-rotor mechanical pumps with a low speed of operation (up to $5 \cdot 10^{-3}$ m^3/sec according to State Standard 14707-77) can be used in DTV measurements employing vacuum chambers of small volumes (less than $2 \cdot 10^{-4}$ m^3).

To determine the conductivity of the connection lines, we introduce the parameter Z:

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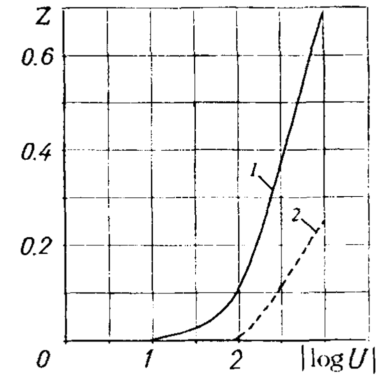

Fig. 1. Dependence of the parameter Z on the conductivity of the connection lines for different values of the speed of pumping-out: 1) 1 liter/sec; 2) 5.

$$Z = \frac{\partial S_0}{\partial U} = \left(1 + \frac{U}{S_p}\right)^{-2}. \tag{4}$$

To satisfy condition (2), the conductivity of the connection lines in using pumps with a speed of operation of $5 \cdot 10^{-3}$ m^3/sec (2NVR-5DM) or 10^{-3} m^3/sec (3NVR-1DM) must be higher than 10^{-1} m^3/sec (see Fig. 1).

Rubber vacuum pipelines, whose transmissivity is determined by their geometric dimensions and the temperature and pressure of the water vapor, are used as connection lines in DTV measurements. Since the length of the pipelines is limited to 2 m, a transmissivity higher than 10^{-1} m^3/sec is provided by choosing the corresponding diameter according to technical specifications TU 38-105881-75.

In the case of (3), the speed of chamber pumping-out is determined by the conductivity of the connection lines (the pipeline). The modes of gas flow in the pipeline are differentiated by the Knudsen number Kn = λ/D. In pumping-out the water vapor at $D > 7 \cdot 10^{-4}$ m, we have Kn < 10^{-2}; consequently, the flow mode is viscous. The conductivity of the pipeline is found using the formula [3]

$$U = \frac{\pi D^4 (p_0 + p_p)}{4.352 \cdot 10^{-5} T^{1.116} l}. \tag{5}$$

The pressure of the water vapor in the vacuum chamber depends on its temperature.

As is seen from (5), the conductivity of the pipeline is constant if the temperature of the pumped water vapor changes little during the measurement, which is observed only in evacuation of materials with a low moisture content (up to 0.01) [2]. At a high moisture content (higher than 0.05) the temperature of some materials changes by 10° or more. By the data of calculations, in a system with the parameters of the elements $S_p = 10^{-3}$ m^3/sec, $D = 8 \cdot 10^{-3}$ m, and l = 1.5 m the speed of pumping-out S_0 changes by 15% as the temperature of the water vapor changes from 20 to 0°C.

Thus, during a measurement the condition S_0 = const is met only in the case of (2).

However, during operation of the pump, S_p may vary (wear of the plates, deterioration of the properties of the oil as a sealer, etc.), thus leading to a change in S_0, a decrease in the accuracy of measurements, and the need to re-calibrate the hydrometer (the same occurs in replacement of the pump). To eliminate the effect of a change in S_p on S_0, it was suggested a diaphragm be mounted in front of the connection pipeline; the cross section of the diaphragm F is calculated from the condition of a critical pressure drop τ

$$\frac{208.22T}{S_p^2} F^2 + \frac{6.28 \cdot 10^{-4} T^{1.616} l}{\pi D^4 p_0^2} F - \tau^2 = 0. \tag{6}$$

In this case, the velocity of gas flow through the diaphragm becomes constant and equal to the velocity of sound [3]. The speed of chamber pumping-out is found using the formula

$$S_0 = 14.43F\sqrt{T}\,. \tag{7}$$

For a vacuum system with the parameters of the elements $S_p = 10^{-3}$ m^3/sec, $D = 8\cdot10^{-3}$ m, and $l = 1.5$ m, the value of F calculated by (6) is $1.5\cdot10^{-6}$ m^2. When such a diaphragm is mounted, a change in S_p of 50% does not affect S_0, and a decrease in the temperature of the water vapor from 20 to 0°C leads to a decrease in S_0 of only 3.5%.

NOTATION

S_0, speed of chamber pumping-out, m^3/sec; S_p, speed of pump operation, m^3/sec; U, conductivity of the connection lines, m^3/sec; Kn, Knudsen number; λ, mean free path of the gas molecules, m; D, diameter of the pipeline, m; T, absolute temperature of the water vapor, K; p_0, p_p, pressure of the water vapor in the chamber and at the intake connection pipe of the pump, Pa; l, length of the pipeline, m; τ, critical ratio of pressures; F, cross section of the diagram, m^2.

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