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DETERMINATION OF THE SORPTION CAPACITY OF NEEDLE-PUNCH MATERIAL

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The method of determining the sorption capacity of a material is selected as a function of the shape of the samples and conditions of runoff of excess liquid. The maximum height of runoff of liquid from the sample must not exceed 5 cm. The sorption capacity is a function of the size of the cross section of the capillaries in the space between the fibre tufts and in the bulk of the tufts.

The sorption capacity of needle-punch material is an important functional characteristic that affects the effectiveness of cleaning measures. However, the use of different methods of determining the sorption capacity of fibre materials makes it difficult to compare the experimental results. The time of holding the samples in the liquid and removing the excess liquid are common conditions of conducting the experiment. Determining the effect of the sample size on removal of excess liquid is of practical interest.

We investigated samples of needle-punch materials made of polyester fibre with a linear density of 0.33 tex according to TU 6-13-0204077-95-91. Materials of different surface and bulk density (Table 1) were fabricated by a mechanical method of forming the fibre web and by varying the needle-punching density. The structural characteristics of the materials were determined according to GOST 15902.1-80.

In determining the sorption capacity, a stack of seven rectangular samples of known weight was placed in a vessel with M-8V machine oil. For the same area of the samples of 0.032 m^2, the height was varied from 0.01 to 0.32 m. After holding for 2 h, which was sufficient to attain equilibrium sorption, the stack of samples was removed from the vessel and the top and bottom samples were discarded. During removal of the excess liquid, each sample was individually weighed in the vertical position and held until it had totally drained. The samples were then placed in a hermetically sealed polymer container of know weight and weighed. Using a polymer container excluded losses of liquid during movement and weighing of the sample.

The problem posed here requires substantiating the parameter for comparing the sorption capacity of needle-punch materials of different structure (see Table 1) that affects sorption of liquid. A parameter calculated from the equation below has traditionally been used to estimate the sorption capacity of a material

$$G = \frac{m_2 - m_1}{m_1}, \quad (1)$$

where G is the sorption capacity, kg/kg; m_1 and m_2 are the mass of the sample before and after absorption of the oil, kg.

Use of this parameter is limited by its dependence on the bulk density of the material [1], which is complex in shape. A model is proposed in [2] which establishes the dependence between the volume of sorbed liquid (V_l, m^3) and the specific pore volume (V_m, $m^3 \cdot m^{-2} \cdot kg$), calculated as the real pore volume per unit of sample area and weight [2]. The equation for the model is

$$V_e = k_Q V_m m S_Q, \quad (2)$$

where k_Q is the dimensionality factor; m is the weight of the material, kg; S_Q is the area of the material, m^2.

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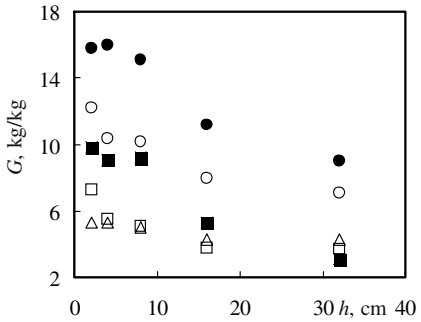

Fig. 1.

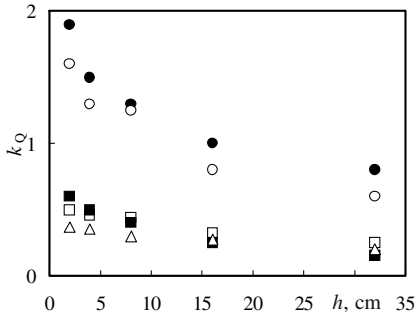

Fig. 2.

Fig. 1. Sorption capacity of samples of needle-punch material 1 (●), 2 (○), 3 (■), 4 (□) and processed 5 (△) as a function of the liquid runoff height.

Fig. 2. Coefficient k_Q of samples of needle-punch materials 1 (●), 2 (○), 3 (■), 4 (□) and processed 5 (△) as a function of the liquid runoff height.

TABLE 1. Structural Characteristics and Porosity Parameters of Needle-Punch and Calendered Materials

Sample No.	Needle-punching method	F, kg/m^2	$d\cdot10^3$, m	ρ, kg/m^3	V_m, m^3/(m^2·kg)
1	Needle-punching	0.140	1.2	116.7	0.24
2		0.192	1.5	128.0	0.22
3		0.353	2.2	160.5	0.17
4		0.463	3.2	144.5	0.19
5	Calendering	0.388	1.4	226.8	0.09

Notation: F — surface density; d — thickness; ρ — bulk density.

The dimensionality factor has a dual physical meaning. On one hand, it reflects the sorption capacity of the material with a single value of the weight and area. On the other hand, if m = const and S = const, which is fulfilled with the method of conducting the experiment, this factor will reflect the degree of filling of the pore volume by the liquid, which derives from the following transformation of EQ. (2):

$$k_Q = V_e/V_m.$$

The sorption capacity, expressed by different methods, as a function of the sample height is shown in Figs. 1 and 2. A calendered sample of high bulk density, not attained in needle-punching, was used to increase the number of experimental points.

The sorption capacity and the decrease in it when the height of liquid runoff from the sample increases are a function of the bulk density of the material. The maximum sorption capacity is attained when samples of minimum bulk density are used (samples No. 1 and 2 in Table 1). An increase in the bulk density decreases the sorption capacity. At the same time, the effect of the bulk density on the sorption capacity is a function of the method of expressing it (see Figs. 1 and 2).

In using parameter G for evaluating the sorption capacity, an increase in the bulk density of samples of equal height causes it to monotonically decrease. Deviation of the experimental points from the calculated curve, different for different sample bulk densities, is also observed. When coefficient k_Q is used to estimate the sorption capacity, the materials investigated are divided into two groups within which the sorption capacity is almost independent of the bulk density. Excluding the dependence of k_Q on the structural characteristics of the material ensures its effective use for estimating the effect of the liquid runoff height on the sorption capacity.

Quantity $k_Q > 1$ for the group of materials with the maximum sorption capacity indicates that the oil is sorbed when their volume increases (Fig. 2). The increase in volume, characteristic of materials of relatively low bulk density, affects determination of the thickness by the deformation method of measurement for a load of 20 kPa. Compression of the material in measuring the thickness decreases the calculated volume of the sample, which is absent in determining it for material of high bulk density. At the same time, the possibility of an increase in the volume of the layers of sorbed liquid as a result of the effect of the disjoining pressure and an increase in the mobility of the fibres when the friction between them decreases and relaxation processes accelerate.

The capillary model of porosity is considered optimum for describing sorption of liquids by fibrous material [3]. According to this model, the dependence of runoff of liquid on the capillary height, or its capacity to remain in the capillary under its own weight, is determined by the size of the capillary cross section. Formation of capillaries during needle-punching is due to uneven distribution of the fibre packing density. When the fibres are caught by the needle barbs, tufts are formed with a high packing density. The capillaries in the bulk of the tufts have small cross sections. The fibres between tufts are a significant distance apart, which ensures formation of capillaries with an increased cross section. Calendering can affect the fibre packing density in and between tufts.

Increasing the liquid runoff height (h) from 1 to 5 cm for material with the maximum sorption capacity sharply reduces it. The subsequent curve of the sorption capacity as a function of the increase in the runoff height to $h = 15$ cm is almost linear. The linear shape of the curve of the sorption capacity as a function of the runoff height is characteristic of material with minimum bulk density up to a sample height of 15 cm. At $h > 15$ cm, a further increase almost does not decrease the sorption capacity of materials of different structure.

The data obtained can be used to evaluate the distribution of capillary cross sections and use it in needle-punching and processing. When the liquid column height increases, runoff takes place from larger capillaries and primarily from capillaries located between fibre tufts. The shape of the curve of k_Q as a function of h shows the uneven distribution of capillary cross sections. Large capillaries can be distinguished for material of low bulk density, where significant extraction of liquid takes place with a small increase in the runoff height. The second group of capillaries has similar cross section sizes which are much smaller than the size of the capillaries in the first group. The third group of capillaries ensures retention of the liquid regardless of the runoff height, and we can hypothesize that these capillaries are located in the bulk of the fibre tufts. Needle-punching and processing significantly affect the decrease in the number of capillaries from the first and second groups, resulting in a decrease in the sorption capacity of these materials.

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