INFLUENCE OF CONTACT MASS EXCHANGE ON THE PROCESS OF DEHYDRATION IN A VACUUM

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The influence of contact mass exchange on the process of dehydration of a material in a vacuum is analyzed. Ways of intensifying the drying of thermolabile materials are indicated.

One possible way of intensifying the process of dehydrating materials in a vacuum is the application of sorbents, but there is insufficient information on this method in previously published papers [1, 2].

The aim of this paper is the study of the basic laws governing the process of dehydrating moist capillary-porous materials in contact with sorbents under vacuum conditions.

The experiments are carried out in a laboratory vacuum device described in [4] when the environment has the following external parameters: overall pressure of vapor–gas mixture, 1-0.9 mm Hg; ambient temperature, 20-22°C.

The moist material (red brick with a 30% initial moisture content) is taken in the form of a layer of granules with a mean equivalent diameter of 1.5 mm. The dimensions of the layer ($l/h = 10$) make it possible to minimize the adverse influence of the resistance of the dried layer on the transfer of heat and substance and also to increase the exchange surface [1-3]. A granulated synthetic zeolite CaA with a mean particle size of 1 mm is used as the sorbent.

The schematic representation of the process used for the experimental solution of the problem as stated is given in Fig. 1.

Modification I of the scheme: sublimation from the pure surface of the moist material; modification II: the sorbent layer is located on a layer of the material being sublimated; modification III: the layer of material to be sublimated is confined between sorbent layers; modification IV: alternating layers of sorbent and moist material.

When all the modifications are designed and constructed a cassette–cylindrical ring assembly, interconnected by a lug and socket system (Fig. 1a), is used. The base of the cassettes is a polycaprolactam grille. The cell size of the cassette bases is selected to be less than 1 mm in order to prevent the mixing of sorbent and moist material particles.

A number of problems can be resolved by using this model: a) the creation of direct contact between the moist material and the sorbent; b) the feasibility of changing the layer structure by varying the sequence of layers and their number and thickness; c) the creation of a directional univariate flow of water vapor; d) the feasibility of measuring the basic parameters governing the kinetics of sublimational dehydration (moisture content, pressure, temperature) layer by layer.

Figure 2 represents the curves characterizing the kinetics of material dehydration for all the modifications and the kinetics of moisture sorption by the zeolite. The influence of contact mass exchange on the intensity of the dehydration process is assessed from the nature of the curves.

The shape of the curve in the first case (Fig. 2a) shows that a variation in the rate of moisture loss is observed only in the first phase of the process (subfreezing and surface-moisture-elimination phase), after

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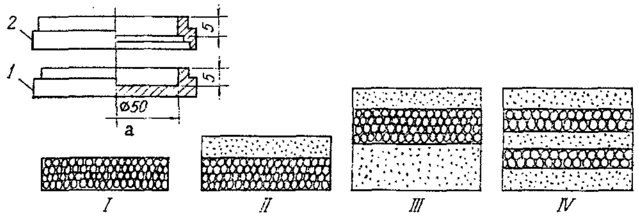

Fig. 1. Diagram of process. I, II, III, and IV) modifications [a) set of cassettes: 1) cassette-tray, 2) intermediate].

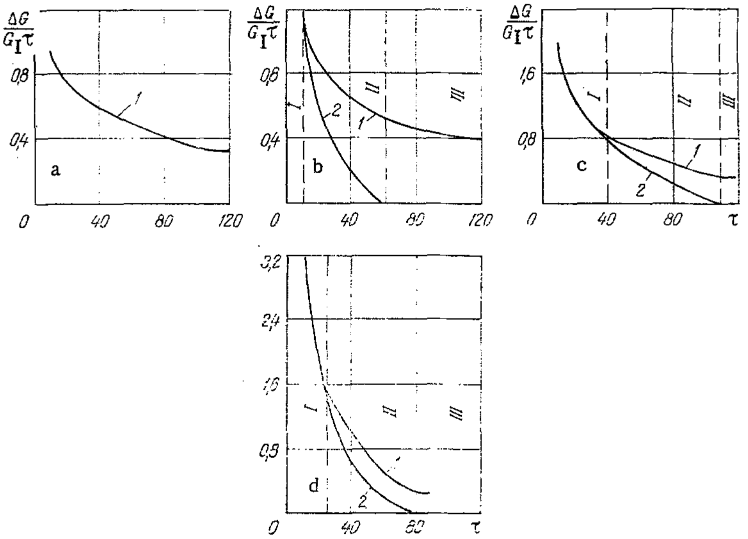

Fig. 2. Kinetics of material dehydration and moisture sorption by a zeolite: a) modification I; b) modification II; c) modification III; and d) modification IV. 1) Curves of material dehydration; 2) curves of zeolite sorption (I, II, and III – phases). $\Delta G/G_{I\tau}$, %/min; τ, min.

which the drying proceeds at a constant rate provided that the thickness of the layer is commensurate with particle size.

The mechanism of heat and mass transfer in the layer of frozen material (internal problem) will be analogous in all four modifications, but there are significant differences in the nature of the material–environment interaction (external problem).

In the first case (modification I in Fig. 1) the molecules are diffused through a layer of gas on the surface of the material. In II-IV the vapor molecules are absorbed as they move by the sorbent layer, which is in direct contact with the surface being sublimated.

According to the theory of [5, 6], the sorption of water vapor by a zeolite under vacuum conditions begins with a surface process – adsorption – proceeding at a very high rate. The volumetric sorption – absorption – process proceeds in parallel. This is a diffusive process, the rate of which is, of course, low. As the sorbent surface becomes saturated, the influence of the adsorption is weakened, the role of the volumetric absorption grows, and a partial filtration of the vapor through the sorbent layer is observed [7]. When the sorbent is totally saturated the moisture is eliminated from the material being sublimated by the filtration and subsequent desublimation of the vapor.

The variation in the rate of moisture absorption by the zeolite is illustrated by the $\bar{u}_s = f(\tau)$ curves in Fig. 3, the nature of which confirms the sorption mechanism described above. The asymptotic approximation of the curves to the line *a*b, corresponding to the limiting saturation of the zeolite, indicates that its dynamic activity is constant, but the limiting saturation time is directly proportional to the layer thickness. Thus, for a 10 mm layer thickness the saturation time is 60 min, for 20 mm it is 120, and for 30 mm it is 180. The

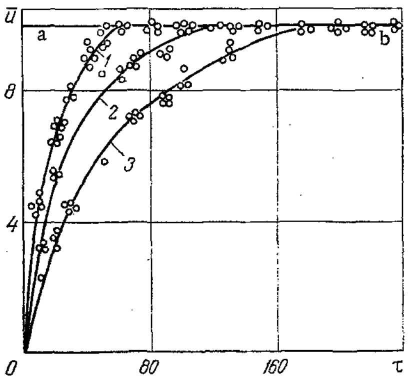

Fig. 3

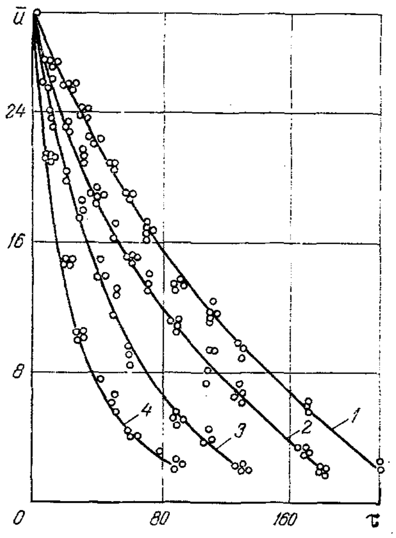

Fig. 4

Fig. 3. Variation in absorptivity of zeolite in time: 1) sorbent layer thickness: 10 mm; 2) 20 mm; 3) 30 mm. $\bar{u}$, %; τ, min.

Fig. 4. Variation in moisture content of material in drying process [1) modification I; 2) II; 3) III); 4) IV]. $\bar{u}$, %; τ, min.

TABLE 1. Mean Intensity of Material Dehydration. $(\Delta G/G_I)/\Delta\tau_{\text{phase}}$, %/min

Scheme modifications	Phases		
	1	2	3
II	1,40	0,72	0,42
III	1,25	1,09	0,36
IV	1,65	1,35	0,23

sorption rate is thus dependent on the saturation conditions, which in the case in question are governed by the layer thickness.

A conclusion about the expediency of using thin sorbent layers to increase the intensity of the drying process suggests itself. The use of three layers of sorbent each 10 mm thick instead of one layer 30 mm thick reduces by a factor of three the time taken to eliminate the same amount of moisture as a result of increasing the active contact surface.

Three characteristic dehydration phases can be distinguished by an analysis of the curves in Fig. 2. In the first phase the material dehydration and sorbent moistening curves are observed to coincide – the transfer of moisture proceeds exclusively by contact moisture exchange. In this case the surface and volumetric sorption proceed simultaneously with the influence of adsorption predominating.

The divergence of the curves in the second section (phase) shows that the contact mass exchange (sorption) is being accompanied by the penetration of vapor molecules through the zeolite (filtration). The practical conclusion of the sorption gives rise to a constant rate of moisture elimination by filtration – phase III.

The numerical values of the mean intensity of material dehydration during the course of one year are presented in Table 1.

As can be seen from Table 1 the most intensive dehydration for modifications II-IV is in phase I when the absorptivity of the sorbent is maximal. Nevertheless, the rate of dehydration is influenced by the constructional design. In fact, the role of the absorption is extended by an increase in the amount of sorbent due to the layer thickness in modification III which causes a reduction in dehydration intensity in the first phase compared with modification II. The process is intensified by a multiple-layer structure with the same amount of sorbent (modification IV) by the increase in active exchange surface.

The intensification of the sublimational dehydration process by the use of sorbents can be evaluated quantitatively from the variation in time in the moisture content of the material–drying curves in Fig. 4.

The time taken to dry a moist brick to a given moisture content (2%) is 220 min (modification I). When the sorbent is placed on the surface to be sublimated (modification II) the duration of the dehydration is cut by 18% ($\tau = 180$ min). The dehydration time is affected significantly by the organization of the layer structure: modification III $\tau = 130$ min and modification IV 90 min, i.e., the duration of drying is reduced by 40% and 60%, respectively.

Thus, the duration of dehydration in a vacuum is shortened considerably by the use of sorbents in direct contact with the material and by the correct organization of the sorbent–material layer structure.

This kind of contact mass exchange takes on especial significance for the low-temperature drying of highly thermolabile materials. In particular, for a number of products of biological origin a 10-15° increase in temperature causes the sudden inactivation of ferments and denaturation of cellular albumin. In this case the cost of sorbents and their requirement for periodical regeneration is of secondary importance compared with the quality of the material being dried.

NOTATION

G_I, ΔG, initial amount of moisture and loss of moisture in specimen; τ, $\Delta\tau_{\text{phase}}$, time and phase time; $\bar{u}_m$, $\bar{u}_s$, mean moisture contents of material and sorbent; l, h, length and thickness of layer, respectively.

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ANALYTIC INVESTIGATION OF HEAT AND MASS TRANSFER UNDER VARIED DRYING CONDITIONS

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Formulas are obtained for heat and mass flows at the boundary of the semispace during the second drying period with the temperature and mass-transfer potential remaining constant at that boundary.

In a number of engineering processes the basis is provided by heat and mass transfer (drying, conditioning, rectification, etc.). In the present article an analytic investigation is carried out of heat and mass transfer during the process of drying under varied conditions.

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