

## HEAT- AND MASS TRANSFER IN THE PROCESSES OF DRYING AND IN DISPERSE MEDIA

### DETERMINATION OF THE KINETIC CURVES OF DRYING OF BLOCKS OF ADSORBENTS-DESSICANTS WITH DIFFERENT CROSS SECTIONS OF CHANNELS AND OF A GRANULATED ADSORBENT ON A CHANGE IN THE FLOW VELOCITY

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*The kinetics of convective drying (regeneration) of different types of adsorbents-dessicants with different geometric parameters has been studied. It is shown that adsorbents of a "channel" (cellular) type have a long constant-rate stage of drying, whereas a granulated polydisperse adsorbent is mainly dried at a variable rate. Adsorbents having a maximum water yielding capacity have been revealed. It has been established that the velocity of a drying gas flow substantially influences the process of moisture extraction from all types of adsorbents. In order to describe the kinetic curves of the given phenomenon, a model of a relaxation kinetic equation that quite satisfactorily describes the kinetics of drying of the adsorbents studied was used.*

**Keywords:** adsorbent-dessicant, convective drying, relaxation equation of drying.

**Urgency of the Problem.** The process of air dessication is one of the key stages of various technological processes, the quality and rate of realization of which greatly determine the quality and self-cost of the final product. However, it should be noted that this process is one of the most costly stages of treatment. In many respects this is connected with the fact that apparatuses (reactors) traditionally used for air dessication and adsorbent regeneration are usually constructionally cumbersome and expensive, with the process of drying (regeneration) of an adsorbent in them being extremely energy-consuming and possessing a low specific productivity, since it is based on an increase in temperature. Taking into account the diversity of the spheres of application of the process of drying, as well as its costs, the problem of creation of highly efficient drying facilities with the application of novel methods of organization and activation of the given phenomenon for large air flows is an urgent scientific-technical problem and presents practical interest.

**Types of Adsorbents.** In the work, we investigated the kinetics of convective drying of several types of adsorbents-dessicants, the external view of the specimens of which is given in Fig. 1. They differ in dimensions and shape of the channels through which the drying air flows. These are specially prepared blocks of cellular structure from an aluminosilicate mass of the following composition: 50% clay, 37% alumina oxide, 13% magnesium oxide with the dimensions of the cell  $2.5 \times 2.5$  and  $4 \times 4$  mm, as well as alumina oxide in the form of granules of diameter 1–3 mm. All of the specimens were provided by the Institute of Catalysis, Siberian Branch of the Russian Academy of Sciences.

By the order of their arrangement in Fig. 1 we will call them adsorbents No. 1–No. 4. The ratios of the total cross-sectional area of channels to the total cross-sectional area of these specimens are respectively equal to 0.47, 0.31, and 0.36; the last adsorbent was granulated and had a loose porosity in experiments.

**Statement of the Experiment.** The setup used for convective drying consists of a fan with an ohmic heating element. In order to control the air flow, a thermocouple was used. The velocity of the heated air was also measured.

The adsorbents of all types, which had been preliminarily and temporarily ( $\sim 0.5$  min) soaked in water, were subjected to convective drying by a heated air at different flow velocities. After the soaking, the moisture content of

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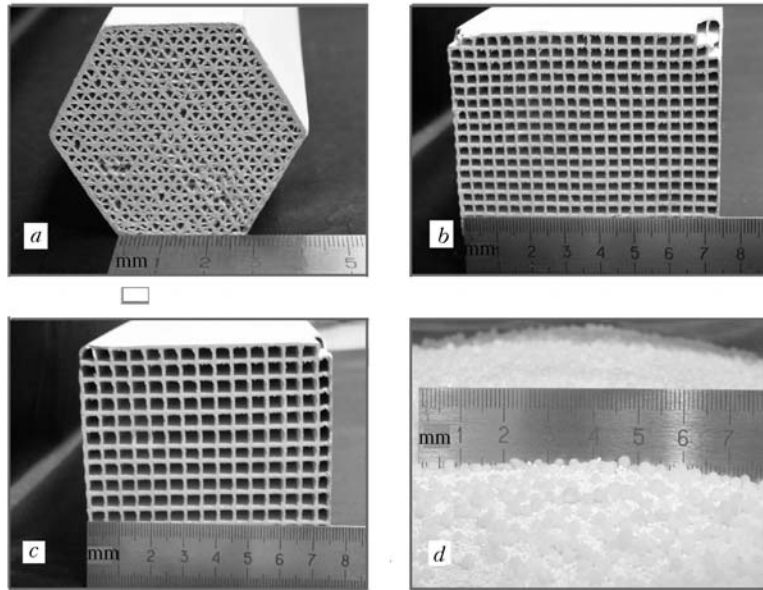


Fig. 1. Adsorbents No. 1 (a), No. 2 (b), No. 3 (c), and No. 4 (d).

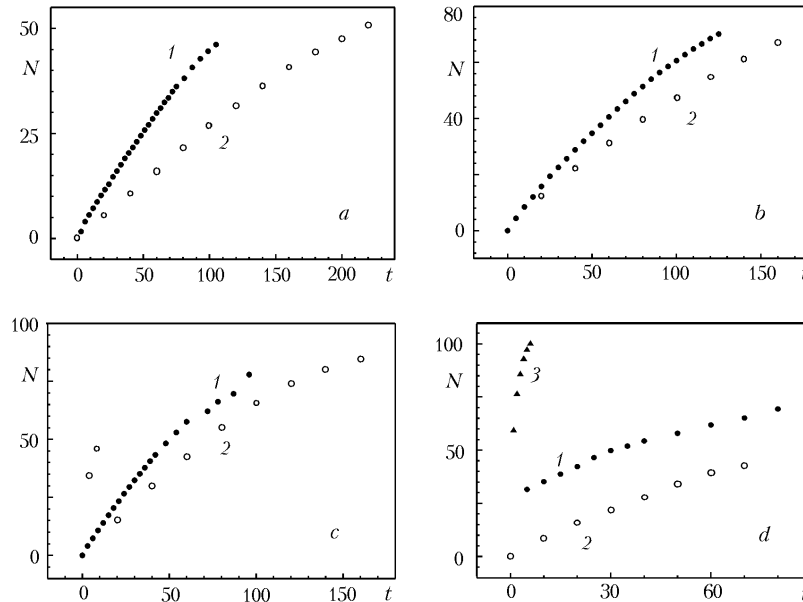


Fig. 2. Amount of extracted water as a function of time for adsorbents No. 1 (a), No. 2 (b), No. 3 (c), and No. 4 (d): 1)  $v = 1$  m/sec; 2) 0.5; 3) 24.  $N$ , %;  $t$ , min.

the specimens, depending on their type, was from 23 to 33%. The air temperature amounted to  $35^{\circ}\text{C}$ , and the flow velocity was equal to 0.5 and 1 m/sec and, in some experiments, to 24 m/sec. Since in the experiments we employed a gravimetric method of studying the kinetics of drying, the specimens were weighed in definite intervals of time, and the mass of extracted water was determined. Preliminarily we also determined the weight of water initially absorbed by the specimens.

**Influence of Flow Velocity.** The results of experiments are presented in Figs. 2–4. It is seen from Fig. 2a that for specimen No. 1 the quantity of extracted water increases by 80% at the hundredth minute of drying on a two-fold increase in the convective flow velocity. As is seen, an increase in the amount of adsorbed water with the flow velocity is also observed for all the remaining types of adsorbents (Fig. 2b–d).

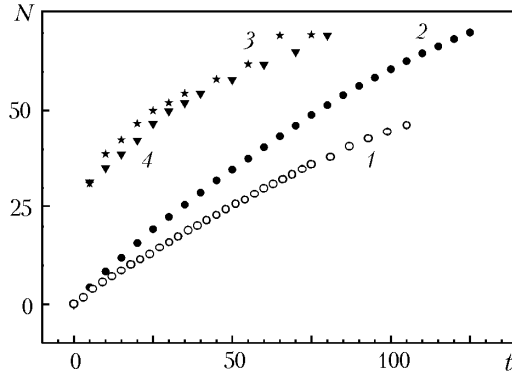


Fig. 3. Kinetic curves of drying of different types of adsorbents at the convective flow velocity  $v = 1$  m/sec: 1) adsorbent No. 1; 2) No. 2; 3) No. 3; 4) No. 4.  $N$ , %;  $t$ , min.

We carried out special experiments with the granulated adsorbent (No. 4) at a convective flow velocity of  $v = 24$  m/sec and a temperature close to the conditions of the experiment at a small velocity. It turned out that when the velocity changed from 0.5 to 24 m/sec, and the amount of extracted water increased 20 times in 7 min of drying (Fig. 2d). Below we will consider in more detail the reasons for this phenomenon.

Comparative data on the kinetics of drying of all types of adsorbents are given in Fig. 3. It turned out that adsorbent No. 3 has a maximum rate of drying, No. 4 is close to it, and No. 1 has the lowest rate.

**Analysis of Results.** As is seen from the kinetic dependences, the rate of drying of the majority of adsorbents maintains a constant value for a considerable portion of time. This means that the so-called first stage of drying is realized, when the rate is determined in the main by the processes proceeding on the surface of the material being dried [1]. For the adsorbents considered, this fact seems to be natural, since the channels have thin walls and a well-developed microsurface.

The convective flow velocity exerts a substantial influence on the process of drying. This is due to its effect on the coefficient of heat transfer from a heated air to an adsorbent. It is known, for example, that in the drying of wood the dependence of the Nusselt number on the Reynolds number has the form [2]

$$Nu = 0.072Re^{0.8}. \quad (1)$$

According to Eq. (1), on a twofold increase in the flow velocity the coefficient of heat transfer and, together with it, the rate of drying (in the period of its constant value) increase 1.74 times. From the results of the present work it follows that the rate of drying (estimated by a change in the moisture content within 100 min) of specimen No. 1 increases by a factor of 1.67 (Fig. 4a). For adsorbents No. 2 and No. 3 this increase amounts to 1.44 (Fig. 4b) and 1.46, which is close to the dependence on the Reynolds number to the power 0.5. The rate of drying of granulated adsorbent No. 4 changes 2.08 times, i.e., there is almost a linear dependence.

Other conditions being equal, the geometric characteristics of the specimens also exhibit an appreciable effect on the rate of drying (see Fig. 3). The best one to release moisture is specimen No. 3, which has channels with maximum cross section. Specimen No. 1 with the least cross section of the channels fared worse. This is attributed to the decrease in the average velocity of flow in the channels due to the influence of the boundary layers on the walls. In this case the effective cross section of the channel decreases.

As is shown in [3], the kinetic curves of drying can be quite satisfactorily described by the solution of the linear kinetic relaxation-type equation:

$$\frac{dW}{dt} = -\frac{W - W_e}{\tau}. \quad (2)$$

Figure 4 compares the solutions of Eq. (2) with the experimental data obtained. One can see a quite satisfactory agreement at relaxation times within the range 35.2–640.9 min.

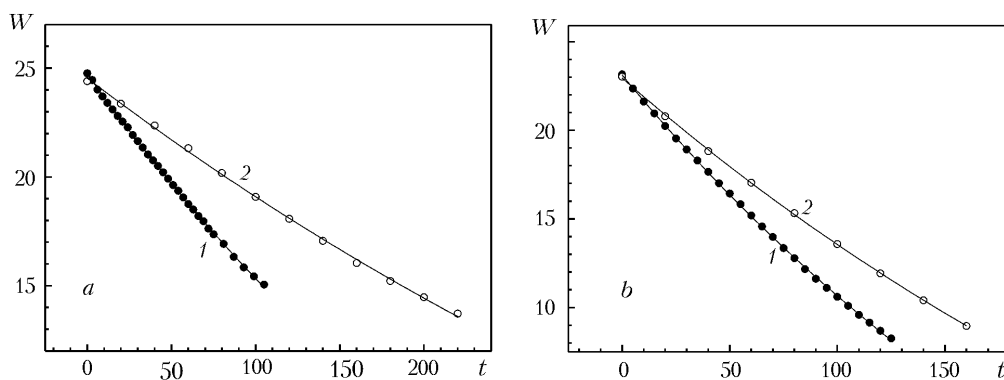


Fig. 4. Comparison of experimental results (points) of the dependence of moisture content on time with the solution of the kinetic relaxation-type equation (curves) for adsorbents No. 1 (a), No. 2 (b): 1)  $v = 1$  m/sec; 2) 0.5.  $W$ , %;  $t$ , min.

## CONCLUSIONS

1. The rate of drying of the blocks depends substantially on their internal structure: block No. 3 with maximal cross-sectional area of the channels is dried more rapidly, whereas hexahedral block No. 1 is dried more slowly. The granulated sorbent has a comparatively high rate of drying close to that for block No. 3.
2. "Channel"-type sorbents have a well-expressed constant-rate stage of drying.
3. The rate of drying of all types of specimens depends substantially on the velocity of convective air flow.
4. Experimental data on the kinetics of drying of all types of adsorbents are rather well described by the solution of a linear kinetic equation with various characteristic times of relaxation from 35.2 to 640.9 min.

## NOTATION

$N$ , relative amount of extracted moisture equal to the ratio of the weight of the water extracted from a specimen to the initial weight of the water absorbed, %;  $Nu$ , Nusselt number;  $Re$ , Reynolds number;  $t$ , time of drying, sec;  $v$ , convective flow velocity, m/sec;  $W$ , moisture content of the specimens equal to the ratio of the weight of water in a specimen to the general weight, %;  $W_e$ , equilibrium (with the medium) moisture content of specimens, %;  $\tau$ , time of relaxation of the process of drying, sec. Subscript: e, equilibrium.

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