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ANALYSIS OF THE RESEARCH RESULTS OF THE ZEOLITE DRYING PROCESS

Об'єктом дослідження є процес сушіння цеоліту радіаційним способом. В якості дослідних зразків використано сипучий цеоліт двох фракцій (0–1 мм та 0–5 мм). Сушіння відбувалось за товщини шару цеоліту, рівній 3 та 5 мм. За джерело теплової енергії використано електричний інфрачервоний випромінювач керамічного типу з номінальною електричною потужністю 1 кВт. Встановлено вплив величини фракцій цеоліту, товщини шару цеоліту під час сушіння, а також густини теплового потоку на кінетику процесу сушіння. Визначено чисельні значення часу сушіння цеоліту в різних періодах сушіння. Згідно аналізу результатів дослідження сушіння цеоліту радіаційним способом встановлено, що кінетичні закономірності цього процесу подібні процесу сушіння капілярно-пористих тіл. Тривалість періодів сушіння залежить від густини теплового потоку і зменшується зі збільшенням густини теплового потоку. А збільшення величини фракцій цеоліту інтенсифікує процес сушіння в періодах прогріву та першому періоді сушіння, проте не впливає на швидкість сушіння в другому періоді. Також визначений вплив параметрів процесу сушіння на вологовміст в кінці першого періоду. Температура цеоліту в першому періоді сушіння не є постійною, а збільшується. Це свідчить про надлишок теплової енергії, що подається в цей період. Аналіз результатів дослідження також показав, що час сушіння цеоліту фракції 0–5 мм менший, ніж фракції 0–1 мм. Тому доцільно сушити цеоліт фракції 0–5 мм та, в разі необхідності, додатково подрібнювати вже після процесу сушіння. Це дозволить зменшити енерговитрати та час виробництва цеоліту в цілому. Отримані криві сушіння цеоліту дають змогу прогнозувати характер протікання процесу та можуть бути використані для проектування сушильних установок.

Ключові слова: сушіння цеоліту, час сушіння, радіаційний спосіб сушіння, інфрачервоне випромінювання, криві сушіння.

1. Introduction

Zeolite is a common material used in the agricultural sector, food, chemical and petrochemical industries, medicine, construction, etc. [1]. And the prospects for the use of zeolite, in particular in the food industry, are favorable [2]. Zeolite can be attributed to the group of capillary-porous mineral materials. However, it is not known, the characteristic kinetic laws governing the drying of a zeolite by a radiation method using typical curves of drying capillary-porous bodies. Indeed, in the literature, as a rule, convective and contact methods for drying a zeolite are described [3]. Although it is possible to meet in relation to non-standard methods of drying zeolite, for example, using microwave energy [4]. Mathematical models of the process of drying sorbents by the above methods of drying, including zeolite, are available in the literature [5–7]. It is possible to find a description of the drying processes of various materials in the dryer using sorbents [8–10]. However, there are no kinetic patterns of zeolite drying using infrared radiation energy (radiation drying method) and recommendations for this process. So, the *object of research* is the process of drying the zeolite by the radiation method. And the *aim of research* is determination of the kinetic laws of zeolite drying process by radiation.

2. Methods of research

Experimental studies of the zeolite drying process were performed on a computerized unit [11]. It allows to continuously measure the mass change of the sample during the drying process. The measurement results with

a frequency of 3 Hz were transferred to a computer for registration and further processing. According to the source of thermal energy, an electric infrared emitter of ceramic type with a nominal electric power of 1 kW was used. To reduce heat losses from the radiator to the environment, a reflector was installed above the radiator.

For the study, samples of a hydrated zeolite fraction of 0–1 mm with an initial moisture content of about 30 % were used. The zeolite particles were enclosed by a dense layer 1 mm high on a metal substrate mounted on an electronic scale under the working surface of an infrared emitter.

3. Research results and discussion

Curves of zeolite drying are constructed at different heat flux densities q , W/m² (Fig. 1), the shape of which is characteristic of capillary-porous bodies, for example, paper [12]. And the zeolite itself does not significantly affect the kinetic regularities of the process of drying paper as filler [13].

The initial moisture content u_0 of the zeolite, the moisture content at the beginning u_1 and at the end u_{1k} of the warm-up time period τ_w and τ_{1k} , drying time τ_Σ to humidity $w=2$ % and drying rate in the first period N according to Fig. 1 are given in Table 1.

The rectilinear portions of the drying curves (the first drying period) reflect the evaporation of surface moisture and moisture from large capillaries. The speeds of these processes are constant. With increasing heat flux density, the evaporation rate increases proportionally, and the drying time decreases.

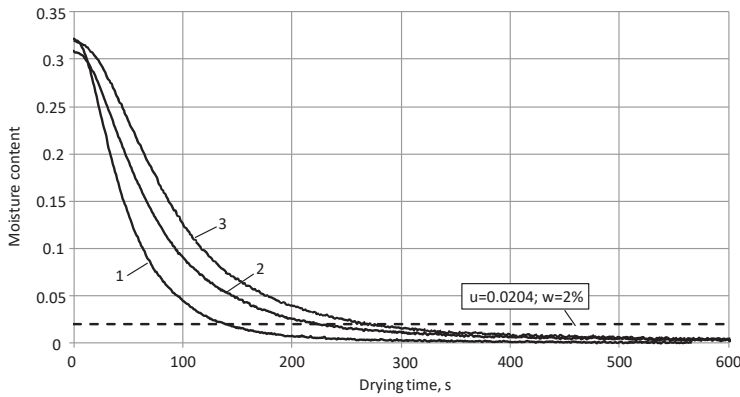


Fig. 1. Dependence of the moisture content on the zeolite drying time (fraction 0–1 mm) with different density of heat fluxes: 1 – $q \approx 21 \text{ kW/m}^2$; 2 – $q = 18 \text{ kW/m}^2$; 3 – $q = 14 \text{ kW/m}^2$

Indicators of zeolite drying according to Fig. 1

$q, \text{ kW/m}^2$	u_0	u_1	u_{1k}	$\tau_w, \text{ s}$	$\tau_{1k}, \text{ s}$	$\tau_{\Sigma}, \text{ s (} w=2\% \text{)}$	$t_{\text{max}}, \text{ }^\circ\text{C}$	$N, \text{ s}^{-1}$
14	0.2	0.3	0.15	22	88	264	240	0.0024
18	0.31	0.29	0.15	16	67	207	310	0.003
21	0.32	0.3	0.15	12	46	131	456	0.0047

Table 1

The duration of the second period, in which moisture from microcapillaries and adsorption-bound water evaporates, also decreases with increasing heat flux density. To a final moisture content of 2 %, zeolite lasts up to 264 s.

However, the duration of drying to the equilibrium moisture content is more than 500 s.

The presence of the kinetic regularities of the zeolite drying process will allow to more accurately determine the required drying time for calculating the drying unit, which can reduce the energy consumption for drying.

Analysis of the distribution of the drying process in the first and second periods shows that the second period is a longer and slower process.

A significant increase in the drying rate in the second period is observed with a maximum increase in the density of the heat flux. And the maximum temperature of the zeolite is reached at the end of drying and also increases with increasing heat flux density.

It is also determined that the moisture content at the end of the first period and, accordingly, at the beginning of the second one is constant, does not depend on the density of the heat flow and is 0.15 kg/kg.

Studies of zeolite drying with a fractional composition of 0–1 mm and 0–5 mm with a height of 3 and 5 mm layers and heat flux density $q=21 \text{ kW/m}^2$ are performed.

The obtained drying curves for zeolite are shown in Fig. 2.

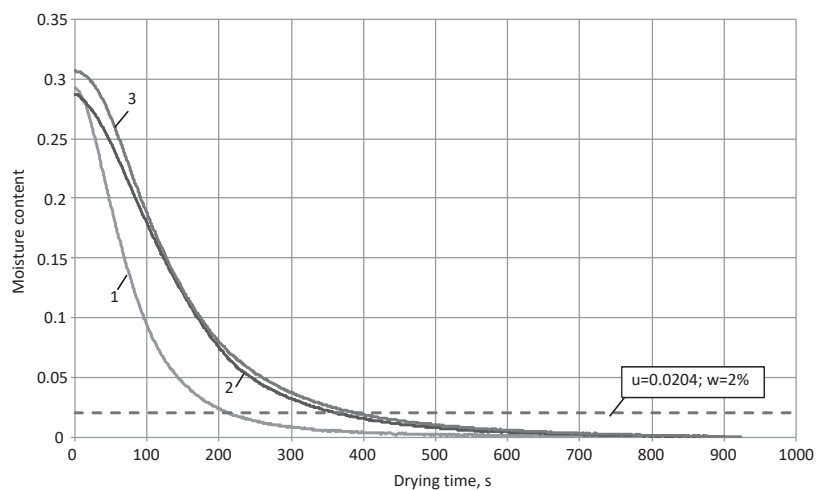


Fig. 2. Dependence of the moisture content of the zeolite layers on the drying time at a heat flux density of 21 kW/m^2 in the range of 0–1000 s: 1 – fraction 0–1 mm, layer height 3 mm; 2 – fraction 0–1 mm, layer height 5 mm; 3 – fraction 0–5 mm, layer height 5 mm

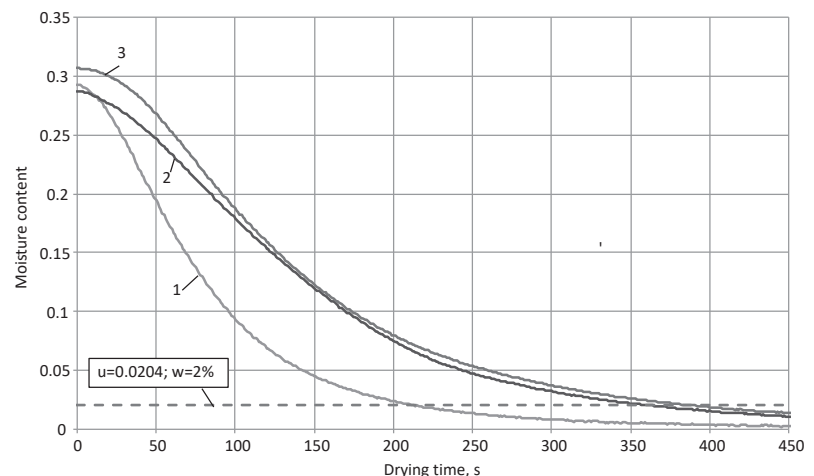


Fig. 3. Dependence of the moisture content of the zeolite layers on the drying time in the range of 0–450 s at a heat flux density of 21 kW/m^2 : 1 – fraction 0–1 mm, layer height 3 mm; 2 – fraction 0–1 mm, layer height 5 mm; 3 – fraction 0–5 mm, layer height 5 mm

For detailed analysis, similar drying curves of zeolite in the range of 0–450 s are shown in Fig. 3.

Indicators of zeolite drying at constant heat flux density and various fractions d and heights of the layer h according to Fig. 3 are given in Table 2.

From the Table 2 it is shown that the drying rate of zeolite along the same layer thickness and heat flux density increases with increasing particle size of the fraction. This can be explained by the increase in porosity of crushed zeolite. Also, an increase in speed in the first drying period reduces its duration. It is established that the value of zeolite fractions per drying rate in the second period does not follow.

The obtained data show that the moisture content at the end of the first drying period is constant both when the heat flux density changes and when the layer thickness changes.

However, this moisture content increases with an increase in the fraction.

It is also established that the zeolite drying time depends on the thickness of its layer. Thus, during the drying of a zeolite of the same fraction and heat flux density with increasing layer thickness, the drying rate decreases, and the duration of each drying period increases.

The dependence of the zeolite temperature of various fractions and layer thickness on the drying time is important for the choice of drying modes, which is shown in Fig. 4.

Indicators of zeolite drying according to Fig. 3

q , kW/m ²	d , mm	h , mm	u_0	u_1	u_{1k}	τ_{wr} , s	τ_{1kr} , s	τ_{Σ} , s ($w=2\%$)	t_{max} , °C	N , s ⁻¹
21	0–1	3	0.29	0.25	0.15	22	71	212	415	0.0025
21	0–1	5	0.29	0.25	0.15	46	125	360	431	0.0013
21	0–5	5	0.31	0.27	0.17	48	112	388	438	0.0016

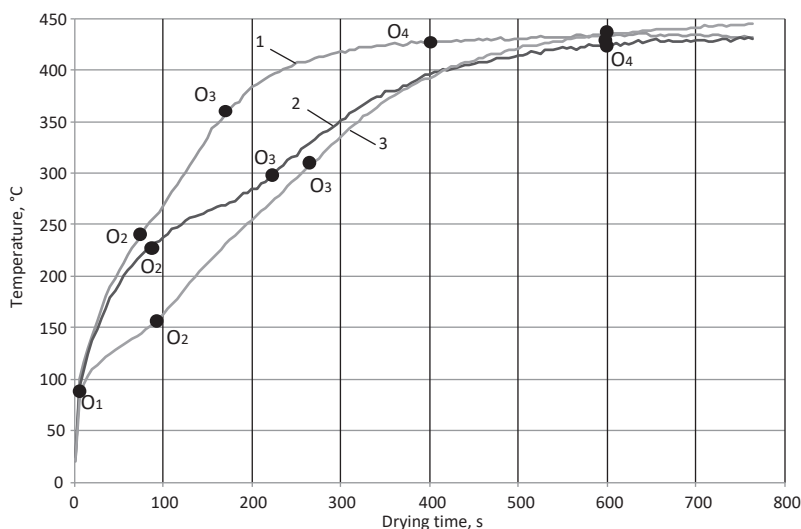


Fig. 4. Dependence of the temperature of the zeolite surface on the drying time:
1 – fraction 0–1 mm, layer height 3 mm; 2 – fraction 0–1 mm, layer height 5 mm;
3 – fraction 0–5 mm, layer height 5 mm

From the graphs in Fig. 4 it is possible to show that all layers of the fraction are heated very quickly to a temperature of 90 °C (O_1), after which evaporation of surface moisture begins and the temperature growth rate decreases to the deflection points of the O_2 curves. From the O_2 points to the O_3 points, the evaporation of moisture from large and small capillaries and the heating of the layers, as well as a decrease in the amount of heat due to a decrease in the temperature difference between the radiating surface and the absorbing surface of the layer are carried out. From the inflection points of O_3 and to O_4 , evaporation of adsorption-bound and, partially, chemically bound water to almost complete dehydration takes place. An increase in temperature in the first drying period indicates that the evaporation rate in this period is not limited by the rate of heat supply.

4. Conclusions

The kinetic laws of the drying process of a zeolite of various fractions by a radiation method at various densities of heat fluxes are established. The important parameters of the drying process are determined and a fraction of 0–5 mm is chosen as the most promising for drying.

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