https://www.proconference.org/index.php/gec/article/view/gec41-00-026
DOI: 10.30890/2709-1783.2025-41-00-026

UDC 621.355.9

FEATURES OF DRYING ZEOLITE 13X IN A MICROWAVE FIELD

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Abstract. *It has been proven that zeolites currently have a wide range of applications due to their large pore surface area; zeolites for thermochemical heat storage are of particular interest due to their ability to provide high energy density. It is known that for the multiple use of zeolites, it is necessary to carry out energy-efficient and rapid regeneration, which is based on the desorption process. It has been determined that for the regeneration of zeolites, microwave heating has a number of advantages over convective and conductive heating. The methodology for conducting the experiment and the experimental setup for studying the drying of zeolite 13X, the particles of which had different shapes (cylindrical and spherical), in a microwave field are described. The results of calculating the amount of heat for moisture evaporation and heating of the test sample, which determine the useful heat flow, are presented. Data on the efficiency of converting microwave energy into thermal energy are provided; this efficiency is defined as the ratio of the useful heat flow to the output power of the magnetron. The importance of rational formation of the zeolite layer to increase the energy efficiency of the dehydration process has been determined.*

Key words: *energy efficiency, microwave heating, drying, heat, zeolites.*

Introduction.

The interest in zeolite preparation is driven by their wide range of applications. The scope of zeolite use is very broad: catalysis, adsorption, and biomedicine, due to their properties such as accessible void space and large pore surface area [1]. Zeolites for thermochemical heat storage are of particular interest because of their ability to provide high energy density. This is based on processes of one of two types: reversible reactions and sorption. Due to the ability of sorption systems to store thermal energy at ambient temperature indefinitely without heat loss, thermochemical heat storage has become a widely researched technology for seasonal low-temperature energy storage (for household applications).

The regeneration of zeolites is the most critical stage determining the efficiency of the entire process involving adsorption. The problem of fast and effective desorption is crucial for the efficiency of adsorption reactors [2]. Microwave heating in the drying process leads to heating only the zeolite containing adsorbed water, without heating the surrounding air [3, 4]. However, the regeneration of zeolits during microwave drying is insufficiently studied, particularly regarding the energy effect of the interaction between the microwave field and the material under study. This is a problem that prevents their industrial implementation in a number of specific fields, particularly in thermochemical heat storage technologies.

The aim of this work is to determine the efficiency of microwave drying of a dense layer of zeolite 13X with different grain shapes based on a comparative analysis of the efficiency of converting the energy of the microwave electromagnetic field into the internal energy of the material. To achieve this research goal, experimental studies on the drying kinetics of a zeolite layer with cylindrical grain shape ($13X_c$) and spherical grain shape ($13X_s$) were conducted. Based on thermal calculations, a comparison of the intensity of moisture content and temperature change was performed, an analysis of the redistribution of heat flows for material heating and moisture evaporation during drying was carried out, and the influence of layer thickness on the efficiency of converting microwave energy into thermal energy was determined.

In recent years, a growing interest in zeolite heat accumulators and corresponding zeolite materials has been noted [5]. Zeolite heat accumulators are chemical storage systems that promise to achieve an energy density of 150–200 $kWh \cdot m^{-3}$ with practically no energy loss over a season [6, 7]. The results of a study on heat-accumulating zeolite and an evaluation of key parameters, obtained based on experimental results with NaY without a binder, are presented in work [7].

The regeneration of zeolites is the most critical stage determining the efficiency of their multiple use, which is defined by the quality of their regeneration process. To achieve this, it is necessary to solve the problem of fast and effective desorption. Microwave heating, which has numerous advantages compared to convective heating, can be used for the regeneration of zeolites—for example, direct and volumetric heating of the irradiated material, as well as selective heating [8]. It is noted [9] that the application of microwave heating allows the process to be conducted much faster, cleaner, and with lower energy intensity compared to traditional methods. The results of [10] confirm that microwave heating does not degrade the adsorption properties of zeolites, as subsequent tests showed perfect reproducibility of adsorption and desorption results.

Analysis of the provided literature data shows that the application of microwave heating for zeolite drying possesses significant advantages compared to convective and conductive methods. However, there is a lack of experimental data on drying kinetics and the redistribution of heat flows during microwave processing for zeolites that are recognized as rational in thermochemical heat storage technologies.

Main text.

Experimental research was conducted on a laboratory setup, the schematic of which is presented in [11]. To ensure uniform heating of the material, it was moved within the volume of the working chamber by placing the processed material on a rotating platform.

Energy was supplied to the working chamber, of rectangular cross-section (306x201x322 mm), via a waveguide from a magnetron with a generation frequency of 2.45 GHz and a power of 800 W. The design of the microwave (MW) chamber allowed for simultaneous air blowing over the material layer along with the supply of MW energy. The test material was placed in the experimental cell and processed in the microwave chamber. At 30-second intervals, the current mass of the zeolite was determined gravimetrically, and the amount of evaporated moisture and the moisture content of the zeolite were calculated. Temperature measurements were taken using an ACCTA AT-280 multimeter, the probe of which was placed directly within the zeolite layer immediately after the magnetron was turned off. The error in determining the average integral moisture content was ±2.7%, and the average layer temperature was ±3.5%. The studies were performed on zeolite 13X with particles of different shapes: cylindrical ($13X_c$) and spherical ($13X_s$).

The amount of heat used for moisture evaporation and heating of the test sample (useful heat flow, Q_{use}) is determined by the following dependence:

$$Q_{use} = \left(\Delta m_i \cdot r + m_i \cdot c_{w.i} \cdot \Delta t\right) / \tau_i, \text{ Вт} \qquad (1)$$

where r is the specific heat of vaporization, J/kg; $c_{w.i}$ is the heat capacity of the wet material, J/(kg·K); τ_i is the duration of the i-th processing interval; Δt is the change in zeolite temperature.

The efficiency (η) of the process of converting microwave energy into thermal energy, defined as the ratio of the useful heat flow to the magnetron's output power (P), allows for assessing the effectiveness of microwave energy utilization:

$$\eta = \frac{Q_{use}}{P}\ \%, \quad (2)$$

The results of calculating the efficiency of converting microwave energy into thermal energy during the drying of zeolite 13X in a microwave field are presented in Table 1.

Table 1 – Efficiency of the process of converting microwave energy into thermal energy during the drying of zeolite 13X in a microwave field.

Time τ, c	30	60	90	120	150	180
Efficiency $13X_c$	0,25	0,46	0,33	0,25	0,21	0,24
Efficiency $13X_s$	0,33	0,24	0,36	0,29	0,31	0,38

The average efficiency of converting microwave energy into thermal energy for the zeolite $13X_s$ layer was 31%. The relatively low efficiency is due to the small layer thickness of δ=5 mm. The average efficiency for the zeolite $13X_c$ layer was 30%. The layer thickness, as for the $13X_s$ zeolite, was also δ=5 mm.

Subsequently, experiments were conducted with a zeolite layer of the same mass (100 g) but with a greater thickness of δ=22 mm by using an experimental cell with a smaller diameter. It was found that the efficiency increased to 50%, i.e., by a factor of 1.7. This indicates the importance of rational layer formation that creates conditions for the free exit of moisture during the drying process. Excessive increase in layer thickness leads to a deterioration of the drying process due to hindered moisture removal from the layer; therefore, it is necessary to determine the optimal layer thickness, taking into account its dielectric characteristics.

The results of calculating the heat distribution expended on water evaporation and heating of $13X_s$ and $13X_c$ zeolites weighing 100 g at specified time intervals during microwave drying are presented in Table 2. The heat consumption for water evaporation from the zeolite layer is determined by the first term in equation (1), and the heat consumption for heating is determined by the second term.

Table 2 – Calculation results of the heat distribution expended on water evaporation and heating of 100 g zeolites $13X_s$ and $13X_c$ at specified time intervals during microwave drying.

Time τ, c		30	60	90	120	150
Heat of zeolite heating, J	$13X_s$	5609	3402	1777	2459	2814
	$13X_c$	3725	11234	1154	1596	1010
Heat of water evaporation, J	$13X_s$	2260	2260	6780	4520	2340
	$13X_c$	2260	4520	4520	4520	2340

Analysis of the calculations shows that at the beginning of the drying process, a larger fraction of the energy from the magnetron is spent on heating the zeolites, and a smaller one on moisture evaporation. At $\tau \geq 90$ s, the heat consumption for evaporation increases significantly.

It was found that the efficiency for $13X_s$ and $13X_c$ is practically the same, leading to the conclusion that the grain shape does not affect the drying intensity.

Summary and conclusions.

1. With a layer thickness of $13X_s$ and $13X_c$ zeolites of δ=5 mm and a mass of 100 g, the average efficiency of converting microwave energy into thermal energy is 30%. When the layer thickness was increased to δ=22 mm, the efficiency increased to 50%, i.e., by a factor of 1.7. This indicates the importance of rational layer formation that creates conditions for the free release of moisture during the drying process.

2. Excessive increase in layer thickness leads to a deterioration of the drying process due to the hindered release of moisture from the layer. Therefore, it is necessary to determine the optimal layer thickness, taking into account its dielectric characteristics.

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Scientific adviser: Doctor of Technical Sciences, prof. Boshkova I.L