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Article

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ANALYSIS OF INTENSIFICATION OF ZEOLITE DRYING ON A VIBRATING CONVEYOR DRYER WITH INFRARED EMITTERS

The object of the research is the drying process of zeolite. The work is dedicated to analyzing an effective method for intensifying the drying process of zeolite while preserving its structural integrity. For the given task, it was necessary to choose a promising drying method with minimized heat loss and preservation of the quality indicators of zeolite. Zeolite has a wide range of applications, including soil improvement, mineral fertilizer for plant growth, dietary supplement for animal feed, air, and water purification. The crucial process for obtaining high-quality natural zeolite is the drying process. In its natural state, zeolite contains moisture, and an excess of it can deteriorate its consumer properties. Therefore, considering the best and most efficient method of zeolite drying is a promising task today.

There is no available data on drying zeolite using radiation methods in the literature. Typically, this material is dried in rotary dryers. However, this drying method often results in a significant percentage of zeolite being crushed into dust. Many industries require a granular structure for zeolite. With radiation drying, this drawback is absent or the percentage of crushed zeolite into dust is minimal.

The main methods of drying zeolite have been examined, revealing a fact that indicates an incorrect approach to the drying process. Factors influencing the deterioration of zeolite's quality during drying have been analyzed. These factors have several drawbacks that affect the final product, namely: crushing zeolite into powder, overdrying, which affects its quality and poses a general scientific problem. The drawbacks of drying zeolite using the main methods have been identified.

The authors have developed a dryer design that minimizes the deterioration of the mentioned qualitative characteristics of zeolite, addressing an important scientific and technical challenge of creating an efficient and environmentally friendly method of zeolite drying using infrared radiation energy and the development of appropriate equipment. The proposed dryer has suggested applications in various fields.

Keywords: *zeolite drying, dryer, heat losses, radiation drying, infrared radiation, granular material.*

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1. Introduction

Zeolites are a group of minerals widely used in various industries, including construction, animal husbandry, poultry farming, aquaculture, agriculture, and water purification, among others. The presence of natural zeolite deposits in Ukraine requires processing to obtain the necessary parameters for the final product. In addition to the chemical composition, the size fractions and final dryness are crucial factors. Zeolite cannot be used as an adsorbent without drying. Therefore, it is important to achieve the required parameters of zeolite as a final product with minimal costs.

The size fractions of zeolite are achieved through grinding or comminution. However, during this process, zeolite dust is also generated, which is a less valuable byproduct. It is therefore relevant to minimize the formation of dust during grinding and subsequent stages, including transportation and drying. Drying zeolite is a time-consuming and energy-intensive process.

One of the major global challenges facing humanity is the excessive use of energy resources. Therefore, there is a need for implementing energy-saving and energy-efficient technologies by intensifying existing processes, including zeolite drying. It is well-known that drying is required for over 200,000 different products in the chemical industry alone, with more than 80 % of them being dispersed materials. Approximately 15 % of the fuel and electricity produced is used for drying purposes [1]. Statistics show that the energy intensity of technological processes in Ukraine is 3–5 times higher compared to more developed countries worldwide. In most cases, the energy consumption for drying processes is approximately 2.5–3 times higher than the energy required to convert moisture into steam, indicating the imperfection of current drying methods and technologies [1].

Zeolite drying is a lengthy and energy-intensive process that can result in the formation of a significant amount of zeolite dust, reducing the yield of high-quality product. Therefore, it is advisable to analyze existing methods of zeolite drying and propose a method that preserves the quality of the final product while minimizing dust formation. Additionally, a dryer design should be proposed to implement this drying method. To reduce the drying time and overall energy consumption, methods for intensifying the proposed dryer design need to be established.

Since pulverized zeolite is a granular material with sufficient hardness, convective and contact drying methods are commonly used. Drum dryers, belt dryers, turbine dryers, and fluidized bed dryers are employed for this purpose. Less common methods include radiation drying and high-frequency current drying.

Each of these methods has its advantages and disadvantages. To achieve better economic efficiency and reduce energy consumption, it may be beneficial to combine these methods [2].

In zeolite production, drying in drum dryers is the most commonly used method [3].

The design of drum dryers is versatile as it allows for working with highly moist and contaminated materials. However, the intense movement of the material in the dryers results in significant friction between zeolite particles and the walls of the drum as well as between the particles themselves. This leads to substantial zeolite dust formation. However, due to the intense hot gas airflow, the surfaces of the zeolite particles undergo rapid evaporation, followed by the removal of vapor from the drying zone. This ensures a sufficiently high drying intensity.

Another common method of zeolite drying is through pseudo-fluidized bed drying. Pseudo-fluidized bed dryers are suitable for drying materials in a gas environment with moderate temperatures (200–300 °C) or high temperatures (1000 °C) [2]. Increasing the temperature of the gas heat carrier intensifies the drying process, but its feasibility needs to be carefully considered.

The advantage of zeolite drying in a pseudo-fluidized bed lies in the ability to control the temperature of the heat carrier and achieve high process intensity. However, there may be thermal losses associated with the heat carrier and significant abrasion of zeolite particles due to constant friction between particles and the internal surface of the dryer. This can lead to changes in the material's quality properties, increased dust formation, and reduced overall efficiency of the dryer [4].

To reduce the wear of zeolite particles during drying, conveyor radiation dryers can be used. In other words, radiation drying can be considered a promising method for drying zeolite, particularly due to the low generation of dust particles during this process.

Infrared radiation used during radiation drying has the ability to penetrate through the surface of wet zeolite. It is then converted into thermal energy, which, through conductivity, penetrates into deeper layers of the material [2]. However, the intensity of the drying process by radiation may be insufficient due to the accumulation of water vapor above the surface of the zeolite and the limited contact area between the zeolite and the radiation [2]. This is because during drying, the material is positioned in a layer on a supporting surface, and only its top surface is directed towards the infrared radiation source. Therefore, heating and moisture removal become more challenging for the internal layers.

There are additional heat losses from infrared radiation sources as well. This is because not all of the electrical energy supplied to the infrared radiators is converted into heat. When gas burners are used, there are losses due to the combustion of natural gas and the heating of the radiation surface [5].

Another source of heat loss is the backside of the infrared radiators, which is not directed towards the zeolite.

Scientists are striving to improve the intensity and uniformity of drying for granular materials with the desired drying quality by employing a constructive arrangement of the infrared radiation source with a reflective screen (reflector) positioned above the conveyor belt [6, 7]. They propose a reflective screen in the form of a convex arc-shaped or tubular (spiral) surface. However, this does not address the low intensity of the drying process due to the stationary placement of the material relative to the conveyor belt on which it is situated.

To address this issue, the authors of the paper [8] propose an improved design of a belt dryer. It incorporates a deformed conveying element that creates vibrations in the belt carrying the material. This mixing action ensures the zeolite particles are constantly in motion, renewing the surface exposed to infrared radiation absorption. This leads to faster heating and improved moisture removal from deeper layers of the zeolite. However, due to the lack of hot air circulation, the drying intensity may still be insufficient.

Additionally, to enhance hydraulic resistance and steam generation within the material, new elements and connections are proposed, including a rarefaction chamber [9]. This creates a pressure gradient, improving the overall quality of the material by ensuring uniform drying. However, these additional elements result in high energy consumption. Moreover, steam accumulation on top poses challenges for effective steam removal.

There are belt dryers available that dry zeolite by hot air convection [10]. In this drying method, zeolite experiences minimal wear, but it remains almost stationary, resulting in low intensity.

Therefore, it can be concluded that the most common methods for drying zeolite are drum dryers and pseudo-fluidized bed dryers. These methods provide a relatively intense drying process, but they are associated with a significant generation of dust particles (wear of zeolite particles), which is a negative aspect.

Minimizing dust generation during drying can be achieved by using a belt dryer. However, the drying intensity for zeolite may be lower. Increasing the thermal load from infrared radiators can lead to higher heat losses and a decrease in the thermal efficiency of the drying system.

Therefore, there is a need for modernizing existing designs of belt dryers to minimize zeolite dust generation, reduce heat losses, and intensify the drying process.

It can be hypothesized that combining infrared radiation and hot air convection in a belt dryer would enhance the efficiency of zeolite drying and decrease heat losses.

The analysis of recent modifications to zeolite drying systems has revealed that excessive wear of zeolite particles is their major drawback. To reduce this negative phenomenon, a belt dryer with infrared radiation can be utilized. Therefore, it is advisable to minimize zeolite dust generation and decrease heat losses during drying through the development of a new or the modernization of an existing belt dryer.

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The aim of research is to introduce the authors' proposed improved design of a belt dryer for zeolite drying. Its implementation aims to minimize the degree of zeolite wear and reduce heat losses in the drying system through the rational utilization of heat sources. This objective is based on an analysis of contemporary designs of bulk material dryers.

2. Materials and Methods

The object of research is the process of zeolite drying. *The subject of research* is the technological processes of zeolite drying. A theoretical investigation was conducted to identify the advantages and disadvantages of the existing drying systems used for zeolite and other bulk materials. A literature review was conducted to explore methods for improving the existing drying apparatus. This allows for an increase in the drying intensity and improvement in the quality of dried zeolite, particularly by minimizing its wear into dust particles.

3. Results and Discussion

Based on the analysis of modern and relevant dryers for bulk materials, it has been determined that to reduce the dust formation of zeolite, it is advisable to use a continuous-action conveyor belt dryer. However, it is necessary to increase the drying intensity of zeolite and reduce the heat losses to the environment from infrared radiators.

The dryer proposed by the authors is shown in Fig. 1. It combines radiation and convective drying methods.

Bulk zeolite is fed onto a mesh belt conveyor, which has the ability to accumulate heat. This facilitates faster heating of the zeolite as it is loaded onto the conveyor at the beginning of the dryer.

The main source of heat is infrared radiators installed above the belt conveyor and directed towards it. To reduce heat losses from radiation on the reverse side of the infrared radiators, a reflective screen, called a reflector, is installed above them. There is a gap between the reflector and the back side of the radiators. This gap creates a channel for the passage of the gaseous heat carrier – air, which is supplied by a fan.

The air, passing over the hot surface of the back side of the radiators, gets heated and exits the channel through the gaps between the radiators onto the surface of the zeolite layer. This contributes to the intensification of drying by increasing the thermal load on the zeolite. Additionally, the hot air flow removes the water vapor above the zeolite surface, which is generated during the drying process through moisture evaporation. Reducing the moisture content in the drying zone further enhances this process.

The hot air, together with moisture, moves against the direction of the zeolite belt. This increases the agitation of the vapor above the zeolite surface and enhances its mixing with the air stream, improving its removal from the dryer's environment.

In addition to increasing the drying intensity, the supply of the gaseous heat carrier also reduces heat losses to the surrounding environment. This is because the thermal load on the reflector decreases, resulting in reduced heating and heat transfer to the surrounding environment.

After exiting the drying zone, the air can be partially recirculated back into the system. This means that partial recirculation of the used heat carrier, which has a higher temperature than fresh air, can be implemented. However, in order to reduce the moisture level in the used heat carrier, it is necessary to partially replenish it with fresh air. The partial return of the used heat carrier helps increase the thermal efficiency of the system. To accelerate the heating of the zeolite and improve moisture removal from the inner layers to the outside, the belt conveyor is connected to a vibration device. This induces oscillatory motion of the zeolite particles, promoting their mixing. This reduces the likelihood of particle agglomeration and compaction, thereby decreasing the overall porosity of the layer. Additionally, the oscillatory motion causes the particles to roll and change their surface orientation, making them more susceptible to the influence of infrared radiation. Moreover, the particles from the bottom layer of the zeolite move upwards, while the hotter particles from the top move downwards, contributing to better heat distribution within the layer.

As a result, there is a more intense transfer of heat and expulsion of generated vapor from within the zeolite layer.

Since the particle bed of zeolite has sufficient porosity, a portion of the hot air passes through it and the perforated belt of the conveyor. It is then removed from the drying zone through exhaust channels. This blowing of hot heat carrier through the zeolite particles inside the layer enhances heating and moisture removal from the inner layers to the outside.

Overall, the developed belt conveyor dryer is suitable for drying both zeolite and other bulk materials. The economic feasibility of using such a dryer compared to others, including drum dryers and fluidized bed dryers, should be determined through calculations in each specific case. However, thanks to the provided structural solutions, apart from reducing particle wear, there is an intensification of drying and a decrease in heat losses. Additionally, there is an increased productivity in terms of the amount of moisture removed from the material per unit of time.

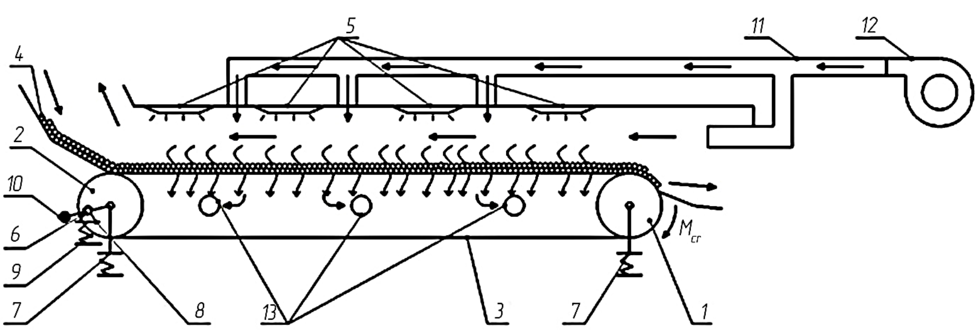

Fig. 1. Vibrating conveyor dryer with infrared radiators: 1 – leading roller; 2 – support roller; 3 – conveyor belt; 4 – zeolite; 5 – infrared emitters; 6 – eccentric shaft; 7 – support unit of the vibrator; 8 – platform; 9 – elastic element; 10 – counterweights; 11 – air duct; 12 – air blast; 13 – ventilation shaft

According to preliminary theoretical calculations [11], the increase in productivity in terms of moisture removal is estimated to be approximately 28 %. However, this needs to be confirmed through experimental testing. The calculation itself was performed by solving heat and mass transfer equations and determining the corresponding similarity numbers. The Newton-Richmann law was used to account for heat transfer from the hot gas heat carrier to the zeolite and heat losses from the system to the surrounding environment. The Stefan-Boltzmann law was utilized to consider the heat flux from infrared radiation to the surface of the zeolite, and the Burger's law was used to describe the distribution of heat within the material caused by this radiation. Additionally, the Fourier's law was applied to account for heat transfer within the zeolite due to thermal conductivity. The heat flux density from the heat sources to the zeolite varies over time, which is associated with changes in the zeolite's temperature and moisture content [11].

Currently, the existing designs of vibration conveyor dryers with infrared emitters have certain drawbacks, namely increased energy consumption due to insufficient process intensity. This results in prolonged drying times.

In the current conditions of a state of war in Ukraine, the development of science is complicated by a number of reasons, including the reduction of favorable conditions for conducting scientific research. Among the primary reasons for this are the challenges in ensuring the safety of researchers and the redistribution of funds towards more urgent needs in the country. As a result, scientists are adapting to the realities of the present in order to ensure the development of the scientific community.

In the perspective of further research, there is a need for the modernization of existing equipment and the exploration of new methods and approaches to drying that require less thermal energy and preserve the integrity of the zeolite structure.

The outcome of this work can be utilized in a facility involved in drying zeolite or other bulk materials. The theoretical research has demonstrated that this drying method is more efficient and energy-saving. A comprehensive experimental study would provide concrete values to confirm this theory.

4. Conclusions

The proposed design is a combined belt dryer with infrared emitters and the supply of gaseous heat carrier, belonging to the field of heat and mass transfer technology. This dryer can be used for drying bulk materials, including zeolite, as well as grains and seeds of agricultural crops in the food, pharmaceutical, microbiological, chemical, and other industrial sectors.

During the research, several advantages of the proposed design have been identified. The reduction of zeolite particle abrasion into dust allows for minimizing their loss into the environment with the heat carrier. Additionally, reducing thermal losses enhances the thermal efficiency of the drying system and decreases overall energy consumption in the drying process. The projected increase in zeolite drying productivity is estimated to be around 28 %, which needs to be confirmed through experimentation.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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