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Determination of Kinetic Regularities of the Process of Drying Perlite by Radiation Method

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Abstract. The actual methods of perlite drying are established. The radiation method of perlite drying is offered. A description of an experimental installation for drying perlite by the radiation method is given. The kinetic regularities of this method are established. Graphical dependences of moisture content on drying time, perlite surface temperature on drying time, and drying speed of perlite on drying time are described. The influence of the initial moisture content of perlite, the value of the heat flux density from the infrared emitter, the thickness of the perlite layer, and the value of the perlite fraction were determined. The analysis on the resulted graphic dependences is made. A drying installation with a combined drying method is proposed. The general conclusions concerning the expediency of a radiation method of drying perlite are made.

Keywords: perlite drying, drying time, radiation drying method, infrared radiation, drying curves.

1 Introduction

Perlite is a rock of volcanic origin used in agriculture, metallurgy, medicine, energy, construction, and other industries.

Perlite by chemical composition is a natural structure of oxides [1]. Depending on the grain size, expanded perlite is divided into the following fractions: fine sand, coarse sand, fine gravel, and coarse gravel.

Bulk materials, including perlite, are dried in drum dryers, in dryers with fluidized beds, vibrating, radiation dryers, and others. However, the most common methods of drying perlite are drying in drum dryers and fluidized bed machines. However, with such drying, there is a large percentage of dusty perlite. Moreover, dust formation can degrade the quality of the final product and complicate cleaning gaseous emissions. Therefore, there is a need to modernize the existing equipment and search for new methods and techniques of drying, which will consume less energy and preserve the granular structure of perlite.

Expanded perlite has found the greatest application. It is obtained by holding in furnaces at certain temperatures [2]. The unique microstructure of expanded perlite has a positive effect on its properties. Expanded perlite is lightweight and is an extremely low bulk density material. Also, expanded perlite has a low thermal conductivity [3]. It has high heat and sound insulation properties and fire resistance, it is inorganic, chemically inert, and its properties are unchanged over time [4].

A promising method of drying bulk materials is the radiation method. After all, this method does not require active movement of the material and reduces the likelihood of abrasion of the material into dust. Because for intensification of radiation drying a slight blowing and mixing of the bulk material is enough.

It is obvious that the expediency of drying the material by radiation method depends primarily on the ability of the material to absorb infrared radiation and the lack of resistance on the surface of the material for the diffusion of moisture into the environment.

Since there is no data in the literature on the drying of perlite by radiation method, it is advisable to conduct appropriate experimental studies.

Therefore, the aim of the study is to determine the kinetic patterns and basic parameters of the process of drying perlite by radiation method.

The object of research is the process of drying perlite by radiation method.

The subject of the research is the kinetic regularities of the process of drying perlite by radiation method and determination of the main process parameters necessary for intensification of the drying process.

2 Literature Review

To achieve the required final dryness of perlite, it must be dried. One of the most common methods of drying perlite is drying with a hot gaseous coolant, in particular in a fluidized bed. Therefore, in the literature, there is usually information on the drying of perlite by this method [5].

Scientists have also considered less common methods of drying perlite, for example, using microwaves [6]. However, the kinetic patterns of perlite by the radiation method were not detected.

The radiation method of drying the material is quite common and in some cases is highly effective. Thus, in particular, the radiation drying method is suitable for drying such fibrous materials as paper [7], as well as granular bulk materials, such as zeolite [8]. Therefore, it is expedient to study the kinetic regularities of drying perlite by the radiation method to determine the effectiveness of this method.

The preliminary mathematical modeling of the perlite drying process by the radiation method was described by the authors in the article [9].

3 Research Methodology

3.1 Experimental installation

To study the process of drying perlite by radiation method, an experimental installation was used, shown in Figure 1. This installation allows obtaining sufficient accuracy the results of drying materials by radiation method [10].

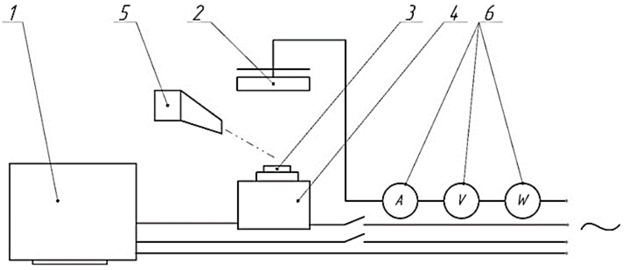

Figure 1 – Scheme of the experimental installation for drying perlite by radiation method: 1 – personal computer (PC); 2 – infrared emitter; 3 – platforms for placing perlite; 4 – electronic scales; 5 – pyrometer; 6 – wattmeter, ammeter, voltmeter

The experimental installation consists of scales that can measure the current weight of the perlite test specimens at a resolution of 1 mg. Mass values with a frequency of 3 times per second are sent to the computer with the ability to record them. Subsequently, the data were processed using Excel software.

The surface temperature of perlite was measured non-contact with a pyrometer. The measurement accuracy – 1 °C.

An electric ceramic infrared emitter was used as a heater. The rated electric power of the heater is 1 kW.

An ammeter and a voltmeter were used to determine the current and voltage. With the help of the obtained values, the actual value of the electric power of the infrared emitter was obtained.

A reflector is installed on the reverse side to reduce heat loss from the infrared emitter to the environment.

Experimental samples of perlite during the experiment were placed on the vapor-permeable surface of the platforms, which was located on the scales.

3.2 The method of the experiment

Perlite of Ukrainian origin of three different factions was used as experimental samples. The average particle sizes of perlite by fractions were 0.4 mm, 0.7 mm, and 1.3 mm.

Before the experiment, perlite was kept for some time in desiccators. This made it possible to saturate the perlite with moisture to obtain a constant value of moisture content.

Perlite was placed on the vapor-permeable surface evenly without additional sealing.

Before drying, the infrared emitter was kept on until it was fully heated. The final surface temperature of the emitter became constant. Due to this, the heat flow from the surface of the radiator was stabilized.

The change in the magnitude of the heat flux from the infrared emitter to the surface of perlite occurred due to the change in the distance between them. In all cases, the area of the emitter significantly exceeded the area of the prototypes. The values of the heat flux density from the radiator to the perlite surface were about 4 kW/m², 7 kW/m², and 14 kW/m².

The main parameters of the environment were determined using a thermometer and hygrometer.

Before the experiment, the following values were recorded: ambient temperature and humidity, the temperature of the working surface of the infrared emitter, current, and voltage of the electrical network to which the emitter is connected.

During the experiment, the following current values were recorded: perlite mass, perlite surface temperature, time.

The experiments were performed before the onset of a constant value of the perlite mass for some time.

To determine the effect of a particular parameter on perlite's drying kinetics, all other process parameters remained constant.

4 Results

4.1 Experimental kinetic regularities of perlite drying by radiation method

The generalized results of the experimental researches are presented in the form of graphic dependences of moisture content of perlite on drying time $u = f(\tau)$ (drying curves), the surface temperature of perlite from drying time $t = f(\tau)$, and drying speed on moisture content $du/d\tau = f(u)$.

The kinetic regularities of the process of drying perlite by radiation method at different heat flux densities are obtained. The corresponding drying curves are shown in Figure 2.

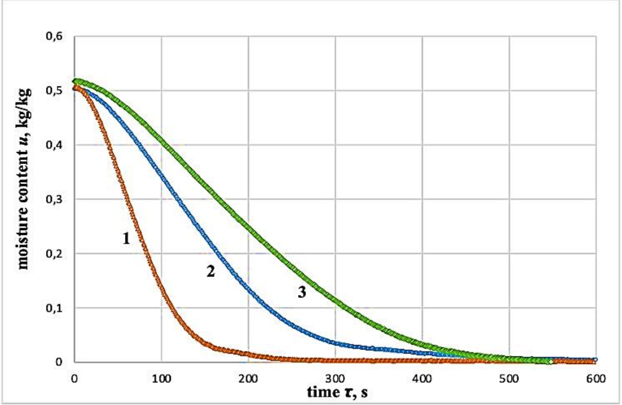

Figure 2 – Graphic dependence of the moisture content of perlite on the drying time at different heat flux densities: 1 – 14 kW/m^2; 2 – 7 kW/m^2; 3 – 4 kW/m^2

The obtained perlite drying curves are similar to the typical drying curves of capillary-porous bodies.

It is established that with increasing the heat flux density, the drying rate of perlite increases, in particular in the heating period and the first period (constant speed period). As a result, the drying time of perlite is reduced. This is due to the increase in the amount of heat released in the volume of perlite. However, the decrease in the time the material reaches equilibrium is not proportional to the increase in heat flux density. In the second period of perlite drying, the intensity of heat supply does not limit the drying rate. This confirms the statement about the inexpediency of overdrying the material. Also, at the end of drying the perlite, it may be advisable to reduce the heat flux or conduct a periodic supply of heat energy.

According to the obtained experimental data, a graphical dependence of the drying rate on the moisture content is constructed (Figure 3).

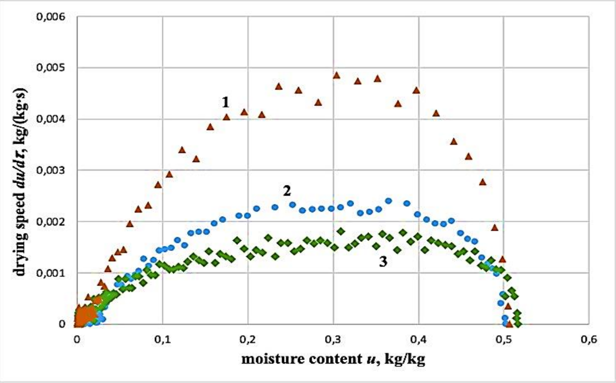

Figure 3 – Graphic dependence of the drying rate of perlite on the moisture content of perlite at different heat flux densities: 1 – 14 kW/m^2; 2 – 7 kW/m^2; 3 – 4 kW/m^2

According to Figure 3, the acceleration of drying during the heating period is more intense at a higher heat flux density. This is due to the faster heating of the material to the temperature of a wet-bulb thermometer.

Also, this graphical dependence confirms the above conclusions on the drying curves.

Graphical dependences of perlite surface temperature at the heat flux density change are constructed (Figure 4).

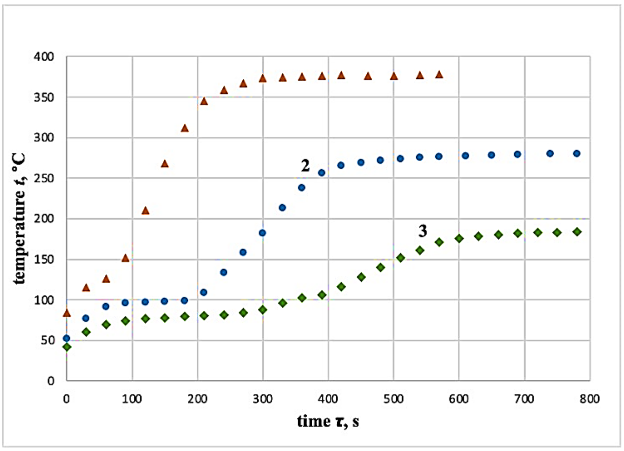

Figure 4 – Graphic dependence of the surface temperature of perlite on the drying time of perlite at different heat flux densities: 1 – 14 kW/m^2; 2 – 7 kW/m^2; 3 – 4 kW/m^2

According to the obtained data with increasing heat flux, the intensity of temperature increase increases during the heating period, the first drying period. In the second period of perlite drying, the intensity of temperature rise occurs until the moisture content of perlite approaches the equilibrium value.

Also, with increasing the heat flux density, the temperature of the first drying period and the equilibrium temperature of perlite increase.

At small values of heat density (4 kW/m² and 8 kW/m²) flow, the surface temperature of perlite in the first drying period is close to constant. However, when the heat flux density increases to 14 kW/m², an increase in temperature can be observed in the first period of perlite drying. This indicates that under such conditions, the drying rate is not limited by the rate of supply of heat to the perlite.

The influence of the initial moisture content of perlite on the drying kinetics was also established.

Figure 5 shows the graphical dependence of the moisture content of perlite on the drying time.

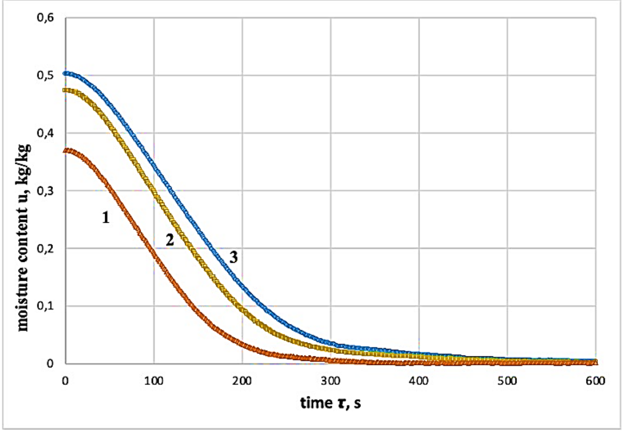

Figure 5 – Graphical dependence of the moisture content of perlite on the drying time at different initial moisture content: 1 – 0,37 kg/kg; 2 – 0,47 kg/kg; 3 – 0,5 kg/kg

The drying curves of perlite in the heating period and the first drying period are parallel. This indicates that the drying rate of perlite does not depend on the initial moisture content.

With the increasing value of the initial moisture content, the amount of moisture in the material increases. This increases the drying time of perlite. However, in the second period of drying perlite, a phenomenon is observed when for perlite with lower moisture content, the drying time decreases disproportionately. This is due to the removal of adsorption-bound moisture.

Graphical dependences of the drying rate on the moisture content with changes in the initial moisture content are shown in Figure 6.

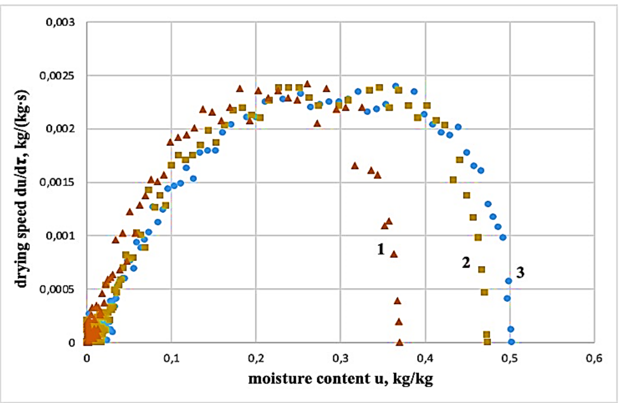

Figure 6 – Graphic dependence of the drying rate of perlite on the moisture content of perlite at different initial moisture content: 1 – 0.37 kg/kg; 2 – 0.47 kg/kg; 3 – 0.50 kg/kg

The obtained graphical dependencies (Figure 6) are parallel between the heating and the first drying periods. This indicates the exact nature of the drying process in these periods.

Graphical dependences of perlite surface temperature on drying time at different initial moisture content are constructed (Figure 7).

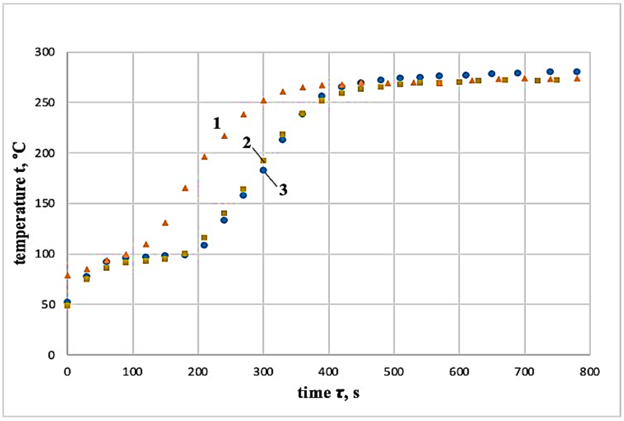

Figure 7 – Graphical dependence of the drying rate of perlite on the moisture content of perlite at different initial moisture content: 1 – 0.37 kg/kg; 2 – 0.47 kg/kg; 3 – 0.50 kg/kg

The influence of the initial moisture content on the temperature by drying periods and the intensity of temperature rise was not detected. Thus, the temperature of the first drying period and the equilibrium temperature of perlite are the same for different initial moisture content. And the graphical dependences at the beginning of the second period of perlite drying are parallel.

The influence of the thickness of the perlite layer on the kinetic regularities of its drying was also established.

Graphical dependences of the moisture content of perlite on the drying time for different thicknesses of the perlite layer are shown in Figure 8.

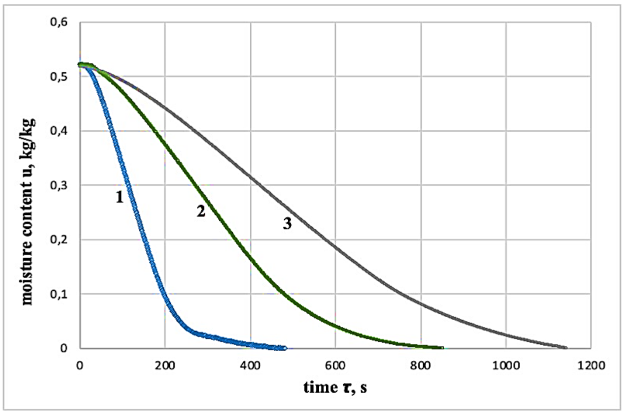

Figure 8 – Graphical dependence of the moisture content of perlite on the drying time at different thicknesses of the perlite layer: 1 – 1.5 mm; 2 – 3.0 mm; 3 – 5.5 mm

As the thickness of the perlite layer increases, the amount of moisture in it increases. The distance for the passage of moisture from the lower layers of perlite to the surface and hydraulic resistance also increases. And at the same heat flux density, its share concerning the total mass of perlite decreases. All this leads to a decrease in the intensity of moisture removal from perlite (drying rate) and, accordingly, increases perlite's heating and drying time.

The drying curves confirm this in Figure 8 and the dependence of the drying rate on the moisture content (Figure 9). Obviously, with increasing the layer of perlite, the drying rate decreases, particularly in the heating periods and the first period. Accordingly, as the thickness of the perlite layer increases, the total drying time increases.

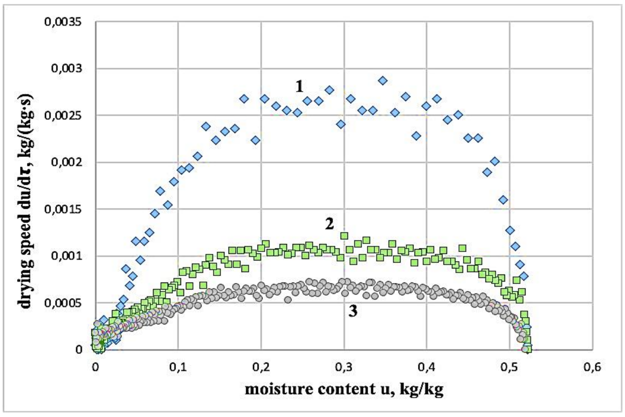

Figure 9 – Graphical dependence of the drying rate of perlite on the moisture content at different thicknesses of the perlite layer: 1 – 1.5 mm; 2 – 3.0 mm; 3 – 5.5 mm

As the thickness of the perlite layer increases, a slight increase in the temperature of the first drying period can be observed (Figure 10).

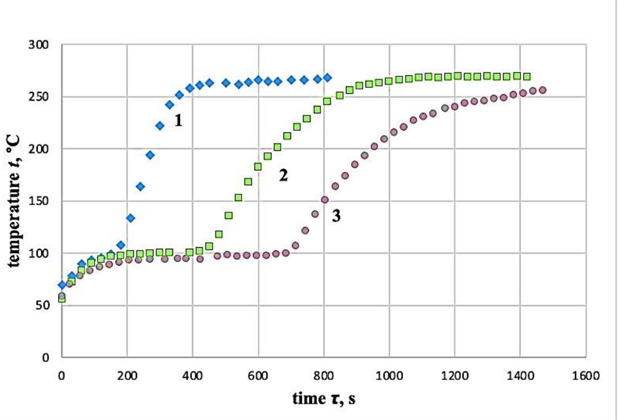

Figure 10 – Graphic dependence of the temperature of the perlite surface on the drying time for different thicknesses of the perlite layer: 1 – 1.5 mm; 2 – 3.0 mm; 3 – 5.5 mm

Also, an increase in the thickness of the perlite layer leads to a lower intensity of temperature rise at the beginning of the second drying period. This can be caused by faster heating of the inner layers of perlite at its insignificant thickness. This leads to a decrease in the thermal gradient and, accordingly, the amount of heat transferred into the material by thermal conductivity.

Experiments were also conducted to determine the effect of perlite particle size (fraction size) on the drying intensity. During the experiment, the perlite layer was made as minimal as possible.

Drying curves for different fractions are shown in Figure 11.

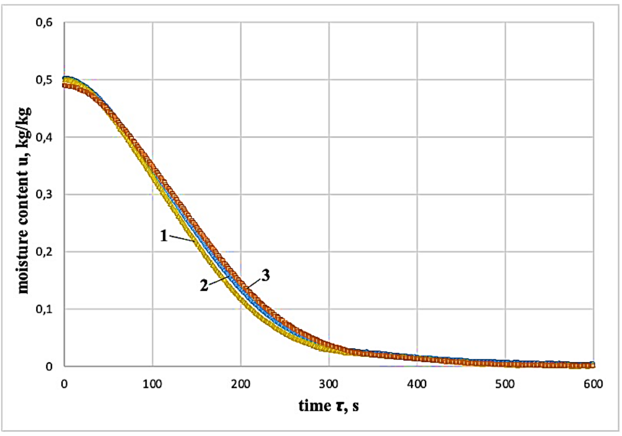

Figure 11 – Graphic dependence of the moisture content of perlite on the drying time for different fractions (particle size) and the minimum layer: 1 – fraction No. 2 (0.4 mm); 2 – fraction No. 1 (0.7 mm); 3 – fraction No. 3 (1.3 mm)

Since the fractions have different particle sizes of perlite, and the experiment was performed with the minimum possible layer of perlite, the size is effective. The layer of perlite was also different. As the perlite layer increases, as previously found, the drying rate decreases. However, as the particle size increases, the porosity will be greater. In this case, the hydraulic resistance for the passage of surface moisture from particles and vapor to the surface decreases. There is a counteraction of various factors that simultaneously affect the intensity of drying in different ways.

Figure 11 shows that the drying curves almost overlap. A slight discrepancy can be caused by both the error of the experiment and various influences of factors.

Due to the dependence of the drying rate on the moisture content, no trend was found (Figure 12).

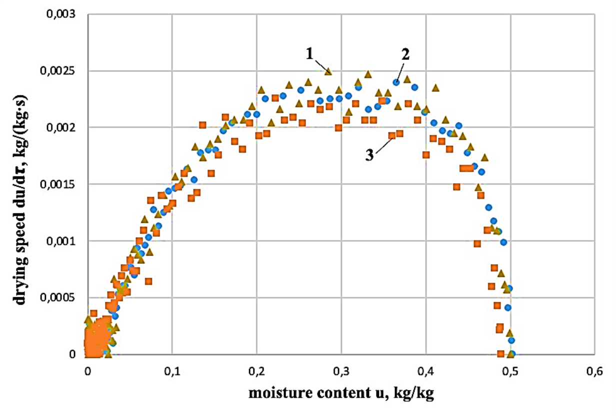

Figure 12 – Graphic dependence of the drying rate of perlite on the moisture content for different fractions (particle size) and the minimum layer: 1 – fraction No. 2 (0.4 mm); 2 – fraction No. 1 (0.7 mm); 3 – fraction No. 3 (1.3 mm)

As can be seen from Figure 13, the average speeds have almost no difference.

A similar situation is observed with the dependence of the surface temperature of perlite on the drying time (Figure 13).

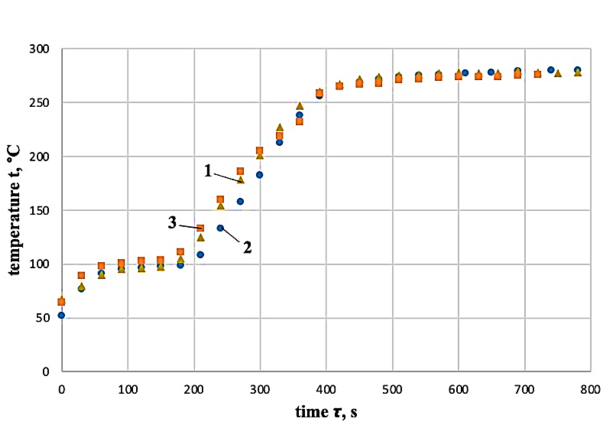

Figure 13 – Graphic dependence of the temperature of the perlite surface on the drying time for different fractions (particle size) and the minimum layer: 1 – fraction No. 2 (0.4 mm); 2 – fraction No. 1 (0.7 mm); 3 – fraction No. 3 (1.3 mm)

4.2 Design development

Based on the analysis of experimental data, the design scheme of a dryer for drying perlite was proposed (Figure 14).

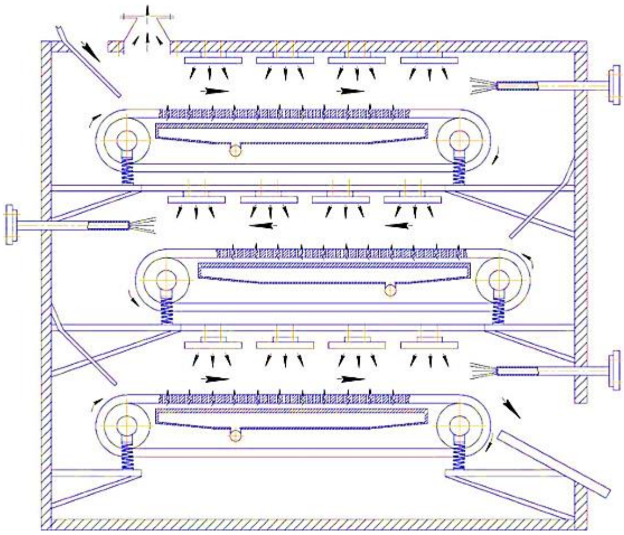

Figure 14 – The design scheme of the developed dryer

This dryer combines radiation, filtration, and convective drying methods. For additional intensification of drying due to active renewal of the drying surface, perlite vibrates during pouring and spills from belt to belt.

The dryer works as follows. Perlite enters the belt dryer with the perforated belt. Above the belt are infrared emitters aimed at it (radiation component of drying).

At the bottom of the perforated belt with perlite is fed hot gaseous coolant passing through them. Thus, filtration drying of perlite is realized.

Above the surface of the perlite, the countercurrent is blowing hot gaseous coolant. This increases the heat load on the perlite and helps to remove moist air from the drying area. This makes it possible to implement the convective component of drying.

This dryer may have a system of partial recirculation of a hot gaseous coolant to reduce heat loss.

To intensify drying, the belt dryer is mounted with a vibratory drive, which increases the oscillations of perlite and its mixing. Perlite is also mixed during pouring from one belt to another. In addition, it reduces the overall length of the dryer.

5 Conclusions

The kinetic regularities of the process of drying perlite by the radiation method are similar to the regularities of drying of capillary-porous bodies.

During the heating period, the drying rate and the temperature of the perlite surface increase. In the first period, the drying rate is constant and maximum. The temperature is also constant at low heat flux. However, with a significant increase in the heat flux, the drying process ceases to be limited by the speed of heat supply to perlite. Therefore, the excess heat is absorbed by perlite, and its temperature begins to rise.

In the second drying period, the drying rate of perlite begins to decrease sharply, and then the intensity of the decrease in moisture content decreases. At the beginning of the second period of perlite drying, the surface temperature begins to increase sharply, and then the intensity of temperature increase decreases.

At equilibrium, the value of the final moisture content and the surface temperature remains unchanged. And during the experiment, while drying, the values of temperature and moisture content can fluctuate amplitude within the error of the experiment.

The analysis of experimental data showed that in the period of heating and the first period of perlite drying, it is expedient to increase the value of heat flux to the surface of perlite. This will increase the intensity of moisture removal and reduce the drying time. However, in the second period of drying perlite, the increase in heat flux to a lesser extent affects the intensity of moisture removal. Therefore, it may be appropriate in the second drying period of perlite to reduce the heat flux or use intermittent drying.

Also, with increasing the heat flux, the temperature of perlite can increase significantly, particularly in the second drying period. This can degrade the qualitative indicators of perlite.

The obtained kinetic regularities of the process of drying perlite by radiation method make it possible to assess the nature of the process, which is necessary when choosing the method of drying and design of the drying installation.

In general, the study of drying perlite by radiation method has shown that it is effective. It has been suggested that this method of drying perlite can be intensified by combining it with active mixing of perlite and blowing hot coolant over its surface. Also promising is the study of perlite drying combining radiation and filtration drying methods.

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