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SUBSTITUTION OF TECHNOLOGICAL PARAMETERS OF INFRARED VIBRATION DRYING

The search for resource-efficient and environmentally friendly technologies and technical solutions in the field of food production should be carried out by creating and improving new analytical approaches and constructive solutions, which will contribute to the development of the industry not only within the state, but also at the international level. Rational use of production capacities of processing enterprises is traditionally accompanied by a high level of their mechanization.

Drying is one of the most common technological processes in the processing and food industry, in particular during the preservation of raw materials. Further development of drying technologies is aimed at reducing energy consumption in the process of moisture removal, improving the quality of finished products, creating highly efficient universal equipment and ensuring environmental safety of drying production.

When studying various physical phenomena in the process of vibration drying, two research methods are used, which allow obtaining quantitative patterns. The first method uses experimental research of specific properties of a single phenomenon, the second - proceeds from the theoretical study of this problem. The advantage of the experimental research method is the reliability of the results obtained.

The paper analyzes literary sources and substantiates the need and possibility of creating new designs of dryers using infrared effects on the product and vibrational oscillations of the working container to intensify the drying process. The proposed design solution of an experimental laboratory drying plant for drying granular and granular materials in a vibrating fluidized bed allows identifying patterns of changes in the parameters of the drying process, obtaining data for process optimization and for developing a methodology for engineering calculation of devices for infrared drying in a fluidized bed.

Keywords: *grain, drying, convective drying, vibratory dryer, vibration, vibrating fluidized bed.*

Problem statement. Grain mass as an object of storage and further processing is characterized by significant structural heterogeneity and dynamic variability of its properties over time. Such features are due to the course of various physical, physicochemical and biological processes that occur in individual components of the grain mass and affect its general condition.

One of the determining parameters that forms the physicochemical properties of grain is its moisture content. It is the moisture content that largely determines the temperature regime of the grain mass, the degree of its freshness, the intensity of respiratory processes, as well as the preservation of quality indicators during storage. Exceeding the permissible moisture content leads to the activation of microbiological processes, self-heating and deterioration of the consumer and technological properties of grain.

In this regard, the grain drying process has acquired special importance as one of the key technological operations aimed not only at ensuring its reliable storage, but also at improving the quality and stability of the properties of grain products.

The technological process of grain drying is focused both on achieving the desired end results —

obtaining the required amount of grain with high quality indicators and compliance with environmental requirements — and on the rational use of all types of resources, in particular material and energy, which is an important factor in increasing the economic efficiency of production [1].

The results of numerous scientific studies indicate that the use of vibration is an effective means of significantly intensifying the drying process. Vibration contributes to improving heat and mass transfer, uniform distribution of the material in the working space of the dryer and reducing internal and external diffusion resistances, which has a positive effect on the duration and efficiency of the process.

In this regard, there is a need for further deepening scientific research aimed at creating and substantiating rational design and technological parameters, as well as optimal operating modes of vibration drying units. Of particular relevance is the determination of such drying conditions under which maximum intensification of the process is achieved while maintaining the quality indicators of the product.

Thus, the search for effective ways to increase the intensity of drying without deteriorating the physicochemical and consumer properties of the material is an important and relevant direction of modern scientific research in the field of drying technologies [2].

Analysis of recent research and publications. The grain drying process is aimed at achieving two main goals: reducing the moisture content of the grain mass to a level below the critical level, which ensures its reliable and long-term storage, as well as improving the quality indicators of the grain. Comprehensive scientific research in this area, together with the practical experience of leading manufacturers of technological equipment, has confirmed the effectiveness and feasibility of applying vibration to the grain mass during the drying process.

The use of vibration during drying provides a number of significant advantages. In particular, intensive mixing of material particles contributes to the equalization of the temperature field throughout the volume of the drying apparatus, which prevents local overheating of the grain. Constant renewal of the heat and moisture exchange surface provides more intensive moisture removal and a reduction in the duration of the drying process. As a result, an increase in uniformity and overall quality of drying is achieved.

In addition, the vibration mode of operation of dryers allows you to reduce the coolant supply rate and reduce specific energy consumption, which is an important factor in increasing the energy efficiency of the technological process. A significant advantage is also the possibility of combining several technological operations within one continuous process, in particular, transportation and drying, granulation and drying, shell formation and drying, fractionation and drying [3].

The purpose of the research is to increase the efficiency of the drying process by scientifically substantiating the design and technological parameters of the vibration dryer.

Presentation of the main material. One of the promising methods of drying bulk materials is drying in a vibro-fluidized (pseudo-fluidized) layer, the implementation of which is possible using vibration dryers of various design types. This method of drying provides intensive heat and mass exchange between the coolant and the material. At the same time, given the significant duration of drying of certain types of materials, the most appropriate are drying units based on vibration conveyors. Their use allows, in comparison with other types of dryers, to significantly increase the time of residence of the material within one unit and to ensure a more uniform drying process.

Despite the obvious advantages of vibration infrared drying units, the choice of a rational fluidization mode requires experimental confirmation. For this purpose, a series of comparative experiments were conducted on a laboratory batch plant, the schematic diagram of which is shown in Figure 1.

The laboratory plant consists of the following main components: a drying chamber 1 with a perforated tray that performs the function of a gas distribution grid 11; infrared emitters 2; a fan 3; a vibration drive 4; as well as a complex of control and measuring equipment for recording process parameters. The drying chamber 1 is connected to a cylindrical pipe 5, which is driven into oscillatory motion in a vertical plane by a vibration drive 4 through a system of rods 6. The design of the plant provides for the possibility of adjusting the amplitude of oscillations in the range from 0 to 10 mm.

The vibration frequency of the vibration drive was changed using a thyristor voltage regulator and a laboratory autotransformer (LATRA) 14 in the range from 0 to 50 Hz, which corresponds to 0–3000 rpm.

A cylindrical drying chamber with a diameter of 100 mm is equipped with a viewing window made of heat-resistant glass, which allows you to visually observe the drying process. The material under study is loaded directly into the chamber, which is fixed to the nozzle 5 using a clamp 7. The nozzle is mounted on a frame using vibration mounts 8 and connected to an air duct 9, through which air from the fan 3 is supplied to the drying chamber using a flexible connecting sleeve 10.

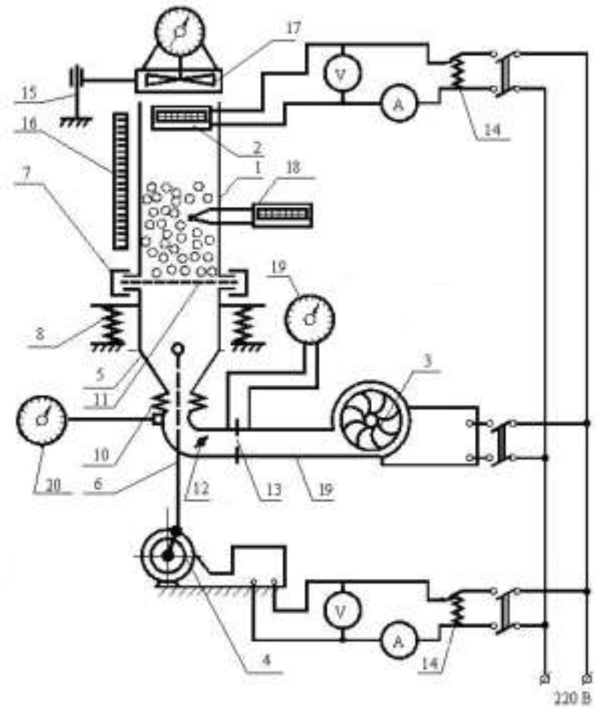

Fig. 1. Schematic diagram of an experimental laboratory drying unit: 1 drying chamber; 2 - infrared emitter; 3 - fan; 4 - vibration drive; 5 - cylindrical pipe; 6 - vibration drive rod; 7 - clamp; 8 - vibration mounts; 9 - air duct; 10 - connecting sleeve; 11 - gas distribution grille; 12 - regulating damper; 13 - diaphragm; 14 - LATR; 15 - anemometer holder; 16 - ruler; 17 - anemometer; 18 - thermocouple; 19 - micromanometer; 20 - differential micromanometer.

Due to the combined action of the vibration drive 4 and the air flow created by the fan 3, a state of fluidization of the product layer is formed in the drying chamber. This provides a significant intensification of the drying process, improvement of heat and mass transfer conditions, as well as uniform heating of the material throughout the volume of the drying chamber. Heating of the studied product was carried out by irradiation with infrared emitters 2 with a fixed power of 100, 200 and 300 W.

The temperature inside the product particles was measured using chromel-copel thermocouples 18 with a wire diameter of 0.2 mm, which allowed obtaining reliable data on the temperature fields in the volume of the material. To determine the pressure losses in the drying chamber and in the material layer, micromanometers 20 were used. The flow rate of the drying agent was controlled by an anemometer 17 of the ASO-3

The method of conducting experimental studies of the drying process provided for preliminary adjustment of the installation to a given operating mode. Before starting the experiments, the infrared emitters were warmed up to the operating state, the required air supply speed was set and the vibration parameters were set. Achieving a stable mode was determined by the stability of the main technological parameters. "Hot" thermocouple junctions located at points with different relative coordinates were introduced into the samples of the studied material.

Experimental experiments on drying were carried out in the following sequence. The prepared material was pre-weighed, loaded into the drying chamber and the height of the stationary layer was determined. During the drying process, measurements were made of the air supply speed, the height of the fluidized bed, the pressure under and above the product layer, the air temperature before and after the layer, the temperature of individual material particles in the central part and near the surface, the parameters of the vibration effect, and the air flow rate.

The duration of the treatment was recorded with a stopwatch and additionally controlled using a diagram tape of a high-speed potentiometer KSP-4. The operating air speed in the drying chamber was selected from the condition of ensuring uniform fluidization of the wet product throughout the volume of the layer. After the specified time interval, the installation was turned off, and the entire sample of material was unloaded from the chamber into boxes with a predetermined mass for further determination of humidity.

The following experiments were carried out with other values of the drying duration while all other process parameters remained unchanged. To increase the reliability of the results obtained, each experiment was repeated at least 3–5 times, after which the results were averaged. Separate series of experiments were performed without stopping the drying process, with periodic sampling of the material at given intervals.

The obtained experimental data were systematized and summarized in tabular form. Based on these data, graphical dependencies were constructed, their mathematical processing was performed in order to establish patterns and relationships between the studied parameters, and the absolute and relative errors of the conducted experimental studies were also determined.

The main tasks of experimental research on a laboratory drying unit were:

- determination of the hydrodynamic characteristics of the studied material;
- establishment of regularities in the drying process of bulk materials;
- obtaining data necessary for optimization of the technological process;
- obtaining initial information for the development of a methodology for engineering calculation of devices for infrared drying in a fluidized bed.

To determine the optimal parameters of the vibration dryer, a series of experiments were conducted in which the influence of the degree of loading of the container on the kinetics of drying sunflower seeds was studied. The experiments were performed at a loading of 67%, 50% and 33% of the container volume, with an air velocity of 1.2 m/s, initial raw material humidity W = 19%, a distance from the infrared emitter to the product layer of 40 mm and a heat flux density of the emitter of 5 and 3.64 kW/m².

Analysis of the experimental results showed that with an increase in the degree of loading of the container, the drying process is significantly prolonged. This is explained by the fact that a greater thickness of the material layer increases the resistance to heat exchange, reduces the intensity of fluidization and slows down the penetration of heat into the deeper layers of the product. As a result, the heating of the grain mass occurs more slowly, and the humidity in the central parts of the layer decreases not simultaneously with the surface ones.

The density of the heat flux of the infrared emitter also plays an important role in the drying speed. An increase in the heat flux increases the intensity of the radiation heating of the material, which contributes to the acceleration of moisture evaporation and reduces the total duration of drying. It must be taken into account that an excessive increase in the heat flux can lead to local overheating of the surface layers of the product, which negatively affects its quality.

Thus, optimization of the drying process in infrared vibration dryers involves a comprehensive approach that takes into account the relationship between the degree of loading, heat flow intensity, air velocity and vibration parameters. A rational combination of these factors allows for uniform heating of the grain mass, reducing energy costs and increasing the efficiency of the drying process.

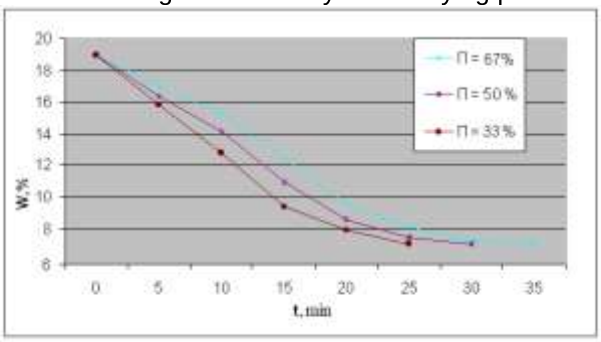

Fig. 2. Kinetics of the sunflower seed drying process at a distance from the IR emitter to the product layer of 40 mm and a heat flux density of the IR emitter of 5 kW/m.

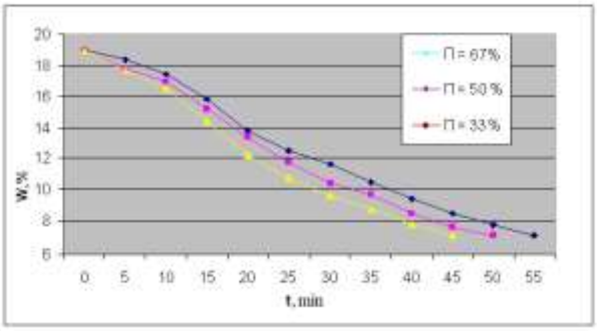

Figure 3 – Kinetics of the sunflower seed drying process at a distance from the IR emitter to the product layer of 40 mm and a heat flux density of the IR emitter of 3.64 kW/m.

The initial moisture content of sunflower seeds significantly affects the kinetics of the drying process and determines the duration of the treatment. To study this effect, experiments were conducted on a vibration dryer with the following parameters: the distance from the infrared emitter to the product layer is 40 mm, the heat flux density of the IR emitter is 5 kW/m², the container loading is 67%, 50% and 33%, the initial moisture content of the grain is W = 19%, 23% and 25%, the air velocity is 1.2 m/s (Fig. 4–6).

Analysis of the results showed that with a decrease in the initial moisture content of the grain, the drying rate increases significantly. This is explained by the fact that a lower moisture content in the product reduces the total mass of water that needs to be removed, and also reduces the intensity of the intralayer diffusion resistance. As a result, the heat flux entering the material increases the grain temperature more effectively, and moisture evaporation occurs faster, which shortens the duration of the drying process.

The loading of the container also plays an important role in the drying speed. Increasing the height of the grain layer with a higher loading increases the resistance to air movement and slows down the fluidization process. This leads to a slowdown in the heating of the middle of the layer and an extension of the drying time, especially for grain with high initial moisture. On the contrary, a smaller loading provides more uniform fluidization, better aeration and faster moisture removal.

The density of the heat flux of the IR emitter is the third key factor. An increase in the heat flux contributes to a faster heating of the surface and inner layers of the grain, which increases the rate of moisture evaporation. However, an excessive increase in the heat flux can cause local overheating of the surface layers and, as a result, a decrease in product quality, so the parameters of the thermal effect must be selected optimally.

Thus, the analysis of the graphs (Fig. 4–6) showed that the maximum drying rate is achieved with a combination of low initial product moisture content, optimal container loading and a sufficiently high heat flux density of the IR emitter. The rational combination of these parameters allows you to reduce the drying time, ensure uniform heating of the grain mass and maintain high product quality.

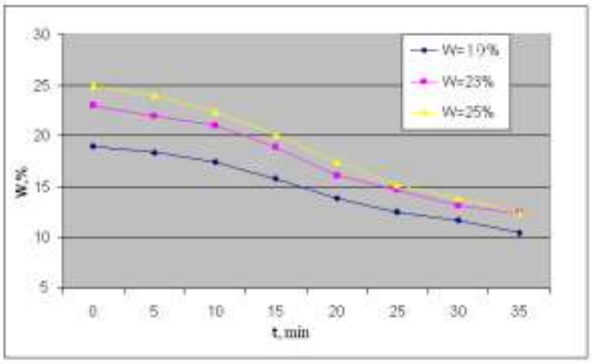

Fig. 4. Kinetics of the sunflower seed drying process at a distance from the IR emitter to the product layer of 40 mm, an IR emitter heat flux density of 5 kW/m, and a container load of 67%

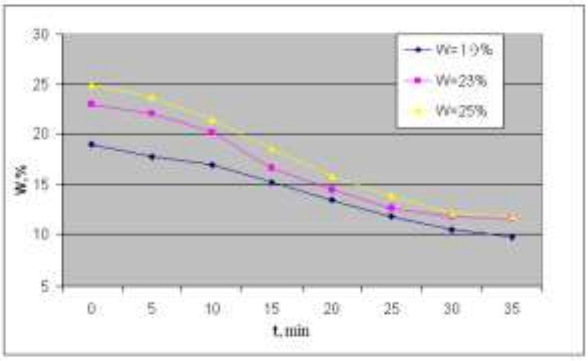

Fig. 5. Kinetics of the sunflower seed drying process at a distance from the IR emitter to the product layer of 40 mm, an IR emitter heat flux density of 5 kW/m, and a container load of 50%

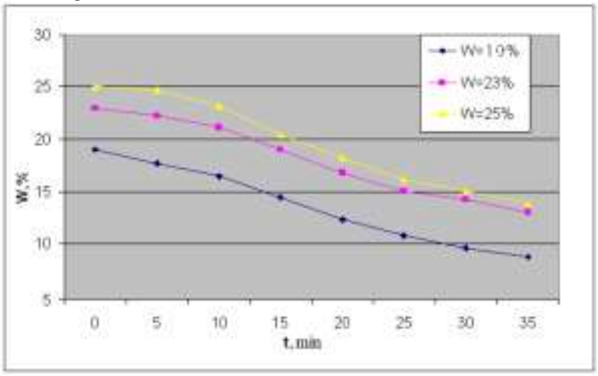

Fig. 6. Kinetics of the sunflower seed drying process at a distance from the IR emitter to the product layer of 40 mm, an IR emitter heat flux density of 5 kW/m, and a container load of 33%

Conclusions. The proposed laboratory drying plant for processing granular and granular materials in a vibrating fluidized bed has demonstrated high efficiency in conducting experimental studies. During the experiments, it allowed:

- to establish the regularities of changes in the technological parameters of the sunflower seed drying process and to assess the influence of key factors on the intensity of the process;
- to obtain reliable data for optimizing drying modes that contribute to increasing energy efficiency and uniformity of material heating;
- to form a scientifically sound basis for developing a methodology for engineering calculation of devices for infrared drying in a fluidized bed.

The design flexibility of the plant — the ability to adjust the amplitude and frequency of vibrations, air velocity and heat flux density of the IR emitter — provided a comprehensive study of the interaction of all key process factors. This allowed not only to determine the optimal parameters for increasing drying efficiency, but also to create a reliable experimental base for further scaling the technology to an industrial level, which has practical value for the food and processing industries.

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ОБҐРУНТУВАННЯ ТЕХНОЛОГІЧНИХ ПАРАМЕТРІВ ІНФРАЧЕРВОНОЇ ВІБРАЦІЙНОЇ СУШАРКИ

Пошук ресурсоефективних та екологічно чистих технологій і технічних рішень у сфері виробництва харчових продуктів має здійснюватися шляхом створення та вдосконалення нових аналітичних підходів та конструктивних рішень, що сприятиме розвитку галузі не лише в межах держави, а й на міжнародному рівні. Раціональне використання виробничих потужностей переробних підприємств традиційно супроводжується високим рівнем їх механізації.

Сушіння є одним з найпоширеніших технологічних процесів у переробній та харчовій промисловості, зокрема під час консервації сировини. Подальший розвиток технологій сушіння спрямований на зниження енерговитрат у процесі видалення вологи, підвищення якості готової продукції, створення високоефективного універсального обладнання та забезпечення екологічної безпеки сушильного виробництва.

При вивченні різних фізичних явищ у процесі вібраційного сушіння використовуються два методи дослідження, які дозволяють отримати кількісні закономірності. Перший метод використовує експериментальне дослідження специфічних властивостей окремого явища, другий – виходить з теоретичного вивчення цієї проблеми. Перевагою експериментального методу дослідження є достовірність отриманих результатів.

У статті проаналізовано літературні джерела та обґрунтовано необхідність і можливість створення нових конструкцій сушарок з використанням інфрачервоного впливу на продукт та вібраційних коливань робочої ємності для інтенсифікації процесу сушіння. Запропоноване конструктивне рішення експериментальної лабораторної сушильної установки для сушіння зернистих та гранульованих матеріалів у вібраційному псевдозрідженому шарі дозволяє виявити закономірності зміни параметрів процесу сушіння, отримати дані для оптимізації процесу та для розробки методології інженерного розрахунку пристроїв для інфрачервоного сушіння у псевдозрідженому шарі.

Ключові слова: *зерно, сушіння, конвективне сушіння, вібраційна сушарка, вібрація, вібраційний псевдозріджений шар.*

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