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The dehydrator parameters for convective drying of food products

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Abstract When developing dehydration processes, special attention should be paid to the latest achievements in the field of equipment for drying agricultural products, as well as energy-saving processes used in this area. The article presents the parameters of the drying cabinet operation obtained by the authors and data on the time and efficiency of drying products of the agro-industrial complex. The material in the article may be of interest to specialists involved in drying food products, as well as to those designing and developing systems for drying. The research focuses on a RAWMID drying cabinet and samples of the extra class bananas. The research was carried out at the "Scientific and Educational Center of Refrigeration, Cryogenic Equipment, and Technology" of Kemerovo State University. The research resulted in thermograms of temperature changes in the working volume of the drying cabinet, as well identifying the temperature and mass of the dried product. The velocity field in the working volume of the dehydrator was also determined, which was found out to have a significant degree of unevenness. The results make it possible to significantly optimize the drying process, as well as to obtain a dried product of a more stable quality.

1 Introduction

Drying is one of the most common methods of preserving food products as it allows to increase their shelf life by removing water, which is the main source of microorganisms development and rotting [1]. In addition, drying can be used to manufacture new food products, such as dried fruits, vegetables, mushrooms, spices, and herbs, which have a longer shelf life and can be used in cooking and food production.

Drying processes are widely used in the food industry to dehydrate animal products, such as meat, fish, dairy products, etc. Dehydration increases the shelf life of products and preserves their nutritional properties. In addition, drying is an important stage in the production of some new food products, such as breakfast cereals, fast food, etc. [2].

Drying is an energetic process of removing moisture from raw materials. Raw fruits and vegetables dried to a lower moisture have a longer shelf life, but must be packed in moisture-proof containers. The drying process in the food industry can be divided into two

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stages. The first stage is heating the product, then free moisture evaporates from the intercellular spaces between its surface and the free zone [3-5]. As moisture evaporates from the surface, it moves from the center to the periphery. At this time, it is important that the drying temperature keeps up with the rate of evaporation of water from the surface and the rate of moisture transfer from the inner layers. Otherwise, a crust may form on the surface of the drying object preventing dehydration, and moisture from deeper layers can cause a change in sensory properties and the destruction of biologically active substances.

In the second period, the bound moisture evaporates. The drying temperature should be increased since the evaporation rate from the surface decreases, whereas the temperature inside the product increases during this phase [5-8].

Convective drying is widely used in technological processing of agricultural products. Drying is a rather time-consuming and energy-intensive operation. Currently, there are a large number of ways to dry food raw materials, and they mainly differ in the way the moisture is removed from the product. Drying chambers have different operating modes, thus an important requirement for them is a uniform temperature distribution in the volume. This is necessary to stabilize the spatial and temporal characteristics of the drying chamber and ensure synchronous drying of products or materials distributed in the working volume. The geometric characteristics of the drying chamber may make it impossible to evenly distribute the drying agent in the working volume [9-10]. This is especially true in the case of convective drying, when air is forced to move inside the volume. The spatial formalization of the temperature field in the working volume of the drying chamber helps design the technological process to ensure the uniform drying of products distributed inside the working volume even without a uniform temperature distribution in the drying unit.

Convective drying is the most common drying method and is used both for industrial and domestic purposes. The main difference and advantage from other types of dryers is the simplicity of design and the transfer of heat to the dried object by means of the energy of the heated drying agent: air or a vapor-gas mixture [11-15].

2 The purpose of the work

The purpose of this study was to determine the technological features of the RAWMID Modern RMD-10 dehydrator and to study drying with changing temperature in the object.

3 Research objectives

To explore the parameters of the drying cabinet and the food drying process, the following tasks were set:

- to determine the geometric and technological parameters of the dehydrator;
- to study the temperature field in the working volume of the dehydrator under different operating temperature conditions;
- to study the velocity field in the working volume of the dehydrator;
- to determine the drying efficiency, namely, the change of temperature inside the product and of its mass during drying.

4 Materials, equipment, and methods

The RAWMID Modern RMD-10 dehydrator used for research has a number of features, such as: a wide temperature setting range (from 35 °C to 70 °C with a temperature change step of 5 °C) to preserve all useful substances in dried fruits; uniform distribution of the drying agent throughout the chamber volume to achieve a uniform process drying.

The air is taken in through the ventilation window by a fan in the rear wall, and the air is let out by slit-like holes at the top of the dehydrator and one rectangular hole on the left side of the front door (Fig. 1). The electric heating elements are located behind the fan impeller to ensure uniform heating of the incoming air. The drying technology used in this apparatus and its design based on the above factors may not provide uniform heating and air distribution, which largely determines the drying process.

Fig. 1. RAWMID Modern RMD-10 Dehydrator.

To determine the temperature field, chromel-copel thermoelectric converters were used, permanently installed in the working volume of the dehydrator (Fig. 2).

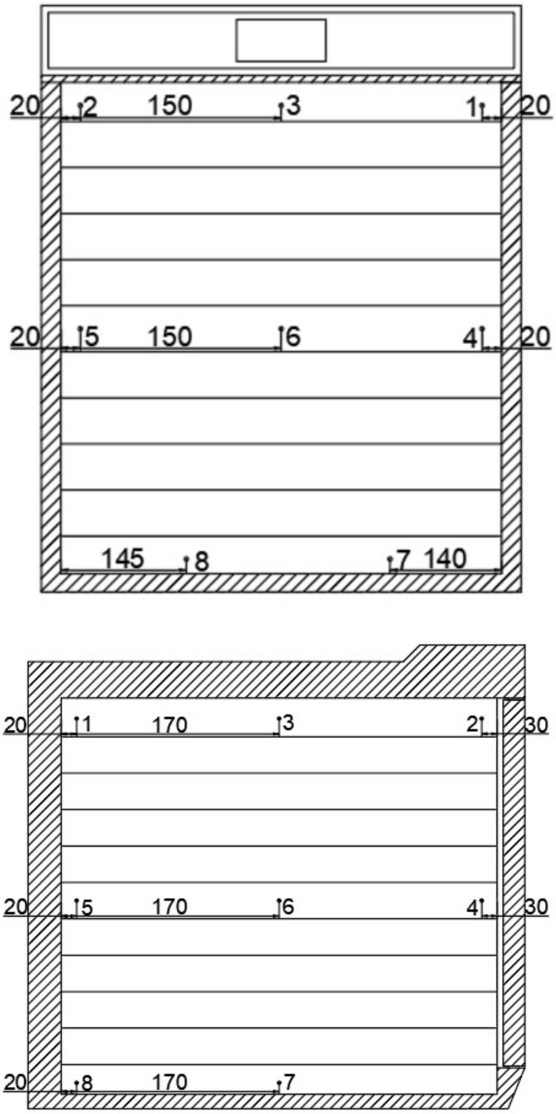


Fig. 2. Location of thermocouples along the working volume of the dehydrator chamber.

The measuring complex also included an eight-channel PID regulator TRM148, an interface converter AC-4, as well as a personal computer with the specialized software OWEN Process Manager.

For the experiment, chromel-copel thermoelectric converters were installed throughout the entire working volume of the dehydrator (Fig. 2). After that, temperature control is carried out by means of thermoelectric converters; the received data are recorded into the computer memory until the drying cabinet reaches the set temperature regime of 50 °C. After the dehydrator enters the stationary mode of operation, it is switched off until the temperature in the working volume equalizes with the ambient temperature. Then the studies were repeated at other specified temperature conditions in the working volume of

the dehydrator. In total, 3 temperature modes of the dehydrator were examined, i.e. 50 °C, 60 °C, and 70 °C.

Based on the readings from thermocouples, the temperature in different parts of the chamber is plotted against the time of the experiment (Fig. 6). The graph shows the temperature lines in the drying chamber, namely: in the center, along the upper and lower corners of the chamber, the rear and front walls to take the medium-volume temperature.

The next step to study the operation of the drying unit was to investigate the parameters of the air velocity [15].

To conduct the experiment, a measuring complex was used. It included a RELEON winged anemometer for taking air velocity readings during measurements, a computer with the RELEON LITE program installed to receive and record readings from the anemometer, a Mathcad program for processing the data obtained and constructing graphical matrices of air velocities.

To conduct the experiment, a system was made for fixing and positioning the anemometer in one position and taking measurements with the dehydrator lid closed. After fixation, an anemometer was placed at various points of the drying chamber to obtain volumetric values of air velocity. The air velocity is measured along two coordinate axes, namely along the Z axis (Fig. 3) at a distance of 5, 10, 15, 20, 25, and 30 cm from the rear wall of the chamber in which the fan with electric heating elements is located directly and along the Y axis (Fig. 4) at a distance of 6, 12, 18, 24, 30, and 36 cm from the floor of the dehydrator in the upward direction. All data are recorded, after which the transition to the next mode of operation takes place.

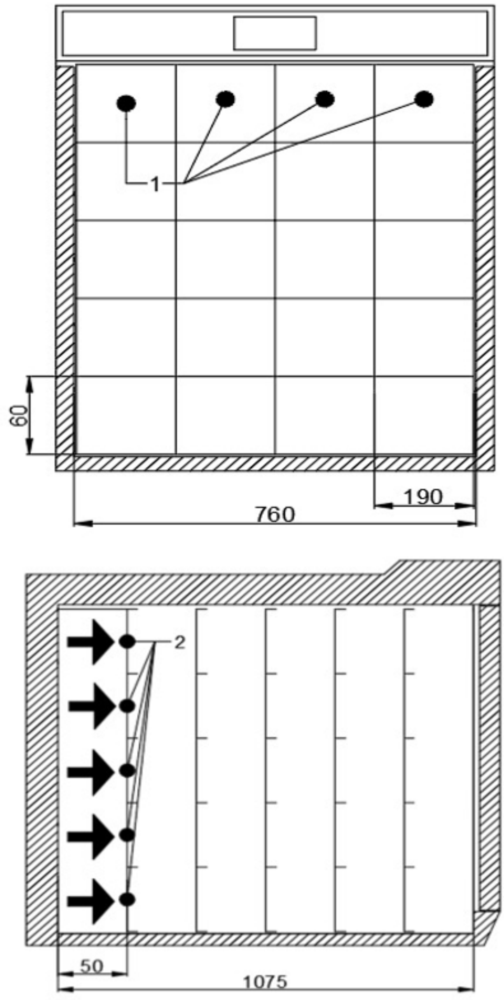


Fig. 3. Anemometer layout when measuring the air velocity in the working volume of the dehydrator along the Z axis:

1 – location of the anemometer, the front view;

2 – location of the anemometer, the side view.

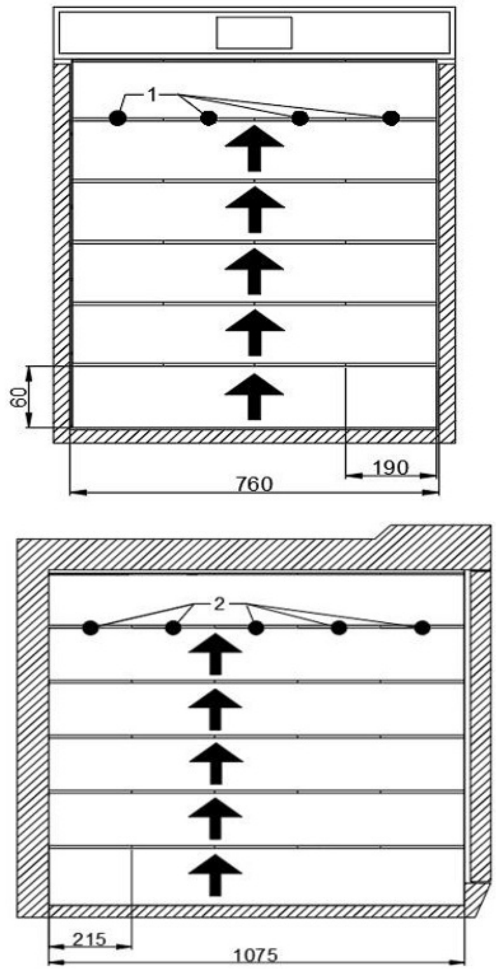


Fig. 4. Anemometer layout when measuring the air velocity in the working volume of the dehydrator along the Y axis:

1 – location of the anemometer, the front view;

2 – location of the anemometer, the side view.

The plan of the experiment in the final part of study is based on the methodology described in the literature [3, 12]. To do this, it was necessary to determine the change in temperature and mass of the drying object.

After we determined the temperature change in the empty dehydrator, our next step was to determine the temperature in the fruit at different positions of the thermocouples and different operating modes of the drying cabinet.

Bananas (botanical berries) selected for the drying process are an elongated, edible fruit. Bananas grow large, up to 250 grams each, and there are up to 7 berries in a bunch. They have a rich yellow color, a dense rind, an elongated and curved shape with soft flesh. With proper care, the fruits stay firmly on the tree. Sometimes the yellow surface of bananas includes brown spots – they appear during long storage, which means that the banana is spoiled. The flesh of bananas is light yellow, juicy, and sweet. What are the benefits and

how many calories are in a ripe banana? Banana pulp is very rich in starch, and it also has a low sugar content and a very large amount of vitamins. The calorie content of these bananas is quite high — 94.5 kcal per 100 grams.

Drying bananas is also reasonable, as well as drying any fruits and vegetables. It significantly increases the shelf life of the product, without losing nutrients and vitamins, it also considerably reduces the cost of transporting bananas. In addition, dried bananas or banana chips are a food product with a fairly wide range of possible applications in food technology.

Bananas corresponding to GOST R 51603-2000 of the extra class were used in the research. The fruits had the following geometric characteristics: the largest cross-sectional diameter of 3-4 cm, the minimal length of 20 cm, and bunches from 4 to 8 pieces. The next step is to peel bananas and cut the product into slices of 5 mm with a kitchen slicer, after which the resulting slices were placed on pallets and alternately placed in the dehydrator. To obtain the data, 8 thermocouples were used, 7 of which were in the product and one outside the product. The layout of the thermocouples is shown in Figure 5.

The final stage of studying the convective method of drying food products based on the material [16] was the change in the mass of the product during the drying process. The graphs are shown below in Figure 9. At this stage, the mass of the product was measured every 30 minutes.

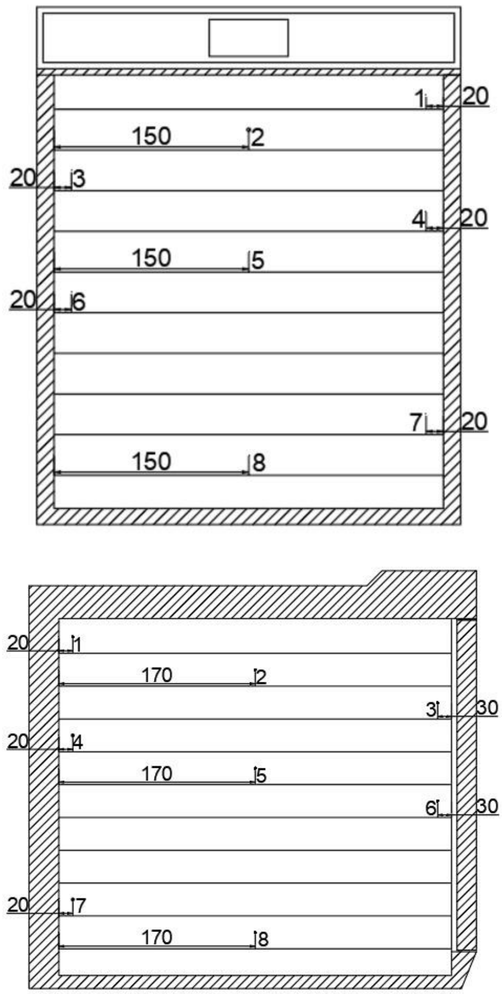
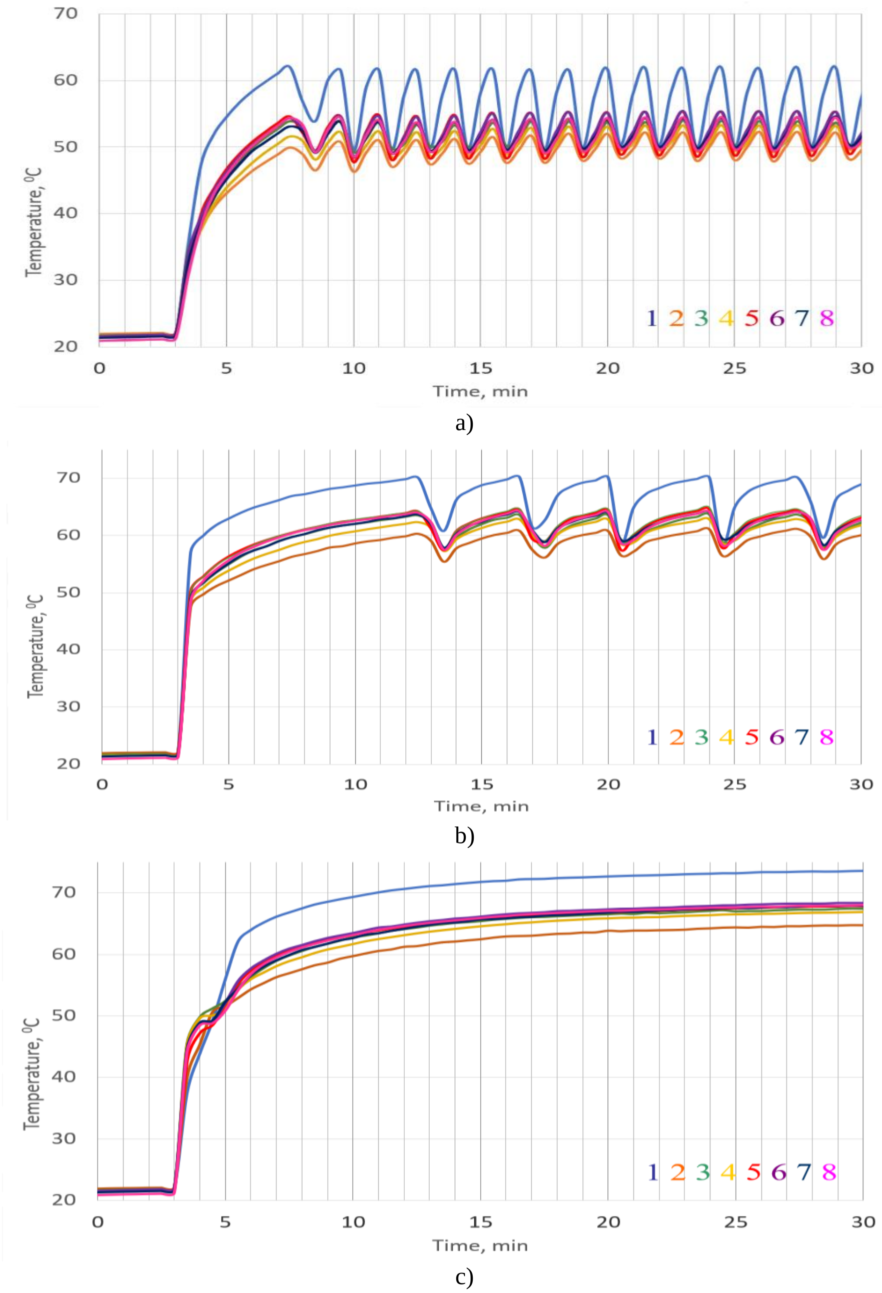


Fig. 5. Location of thermocouples in the drying chamber with the product.

5 Results and discussions

At the first stage, the temperature distribution in the working volume of the dehydrator without the product was studied. After measurements, the thermograms shown in Figure 6 were plotted according to the data obtained.



a)

b)

c)

Fig. 6. Dependence of the air temperature in the chamber on the drying time:

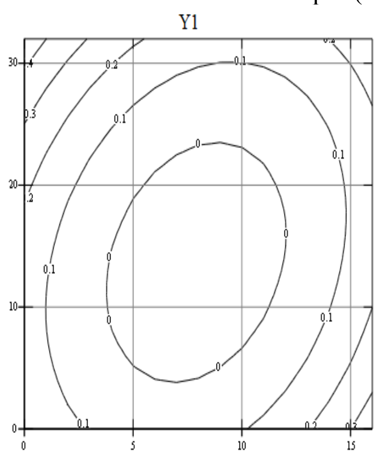
a – at 50 °C; b – at 60 °C; c – at 70 °C

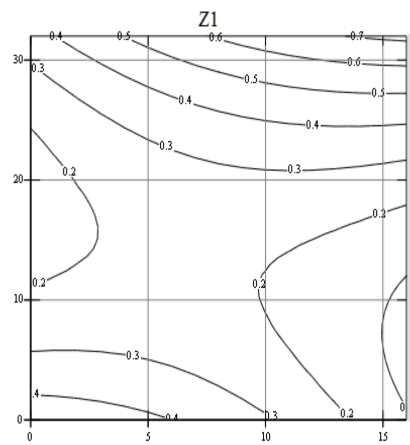
The obtained graphs clearly show that the temperature remained unchanged for the first 3 minutes of the dehydrator operation. After 6 minutes from the start of measurements, the temperature reached its maximum, which allows to conclude that the maximum temperature differs from the set temperature by an average of 5 °C. Then a sharp drop in temperature is noticeable, indicating that the heating elements are switched off. The fan runs without heating for 30 seconds, after which the heating element turns on and then the

cycle repeats. The studies were carried out for temperatures of 50, 60 and 70 °C. The graphs are shown in Figure 6. For 50 °C and 60 °C, the graphs have no special differences, and at 70 °C, no temperature drops were observed, which can be explained by the operation of the dehydrator at a constant heating of its heating elements. The thermocouples were calibrated to detect measurement errors, and all deviations were taken into account when plotting the graphs.

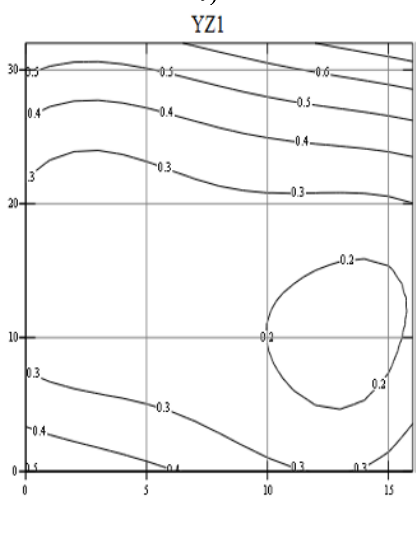
The thermograms of the temperature distribution in the working volume of the dehydrator shown in Figure 6 indicate, in general, a fairly uniform temperature field in the drying unit. The unevenness of the temperature sensor readings was within 4÷5 °C for thermocouples 2÷8. Only thermocouple 1, located in the stagnant zone (in the front right upper corner), was out of the readings of other thermocouples on average by 7 °C upwards. Thus, for a uniform drying process, it is necessary to ÷swap the trays one, two, or three times during the duration of the process (6-12 hours).

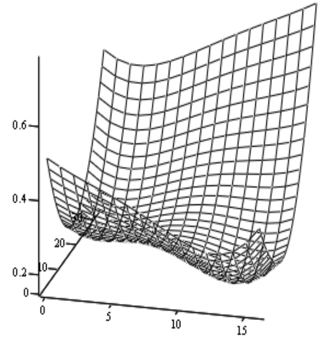
Obtained experimentally air velocities in the given coordinates of the working volume of the drying chamber were processed in the Mathcad program and volume fields of air distribution velocities linked to the coordinate system of the working volume of the chamber were obtained at the output (Fig. 7) [15].





a) b)





c) d)

Fig. 7. Velocity fields in the dehydrator at a distance of 5 cm from the rear wall:

a) velocity fields whose vectors are directed along the Y axis at a distance of 6 cm from the floor of the dehydrator in the upward direction (up);

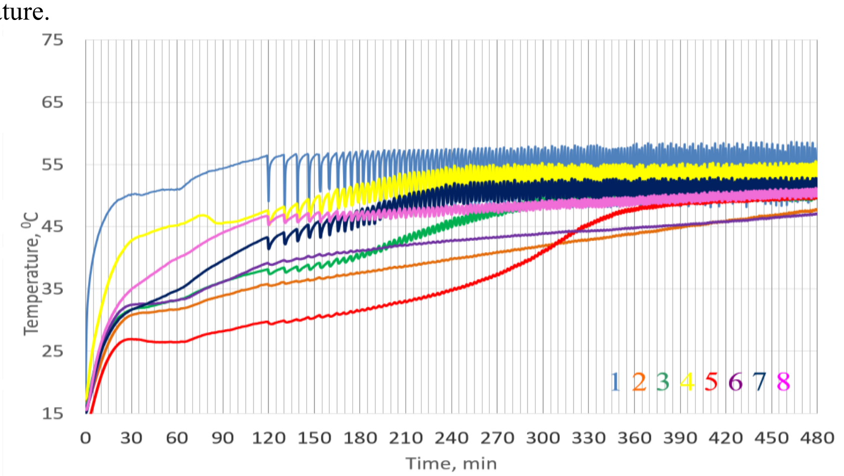
b) velocity fields whose vectors are directed along the Z axis at a distance of 5 cm from the rear wall in the direction of the dehydrator door (along the fan axis);

c) the total velocity field whose vectors are in Y-Z coordinates depicted in 2D form;

d) 3D projection of the velocity field whose vectors are in Y-Z coordinates depicted in 3D.

Based on the readings taken from the thermocouples, we plotted the graph of dependence (Fig. 8) of the temperature inside the product on the drying time. Seven thermocouples were placed in the center of the product to take the average volume temperature, and one thermocouple measured inside the chamber to determine the dependence of temperature changes inside the product and directly in the chamber itself.

After the end of drying, at a temperature of 50 °C, the data on temperature change were obtained. The graph below (Figure 8) clearly shows that the temperature outside the product differs from the temperature inside the product, this can be seen by the thermocouple 1, which is located in the upper right corner of the chamber (stagnant zone). Over time, the temperature in the product continues to rise until the dehydrator reaches the operating temperature mode, at which the heating elements are briefly switched off, approximately 120 minutes into the study. Then the cycle is repeated at intervals of 10 minutes, while the temperature in the product continues to rise, approaching the set drying temperature.



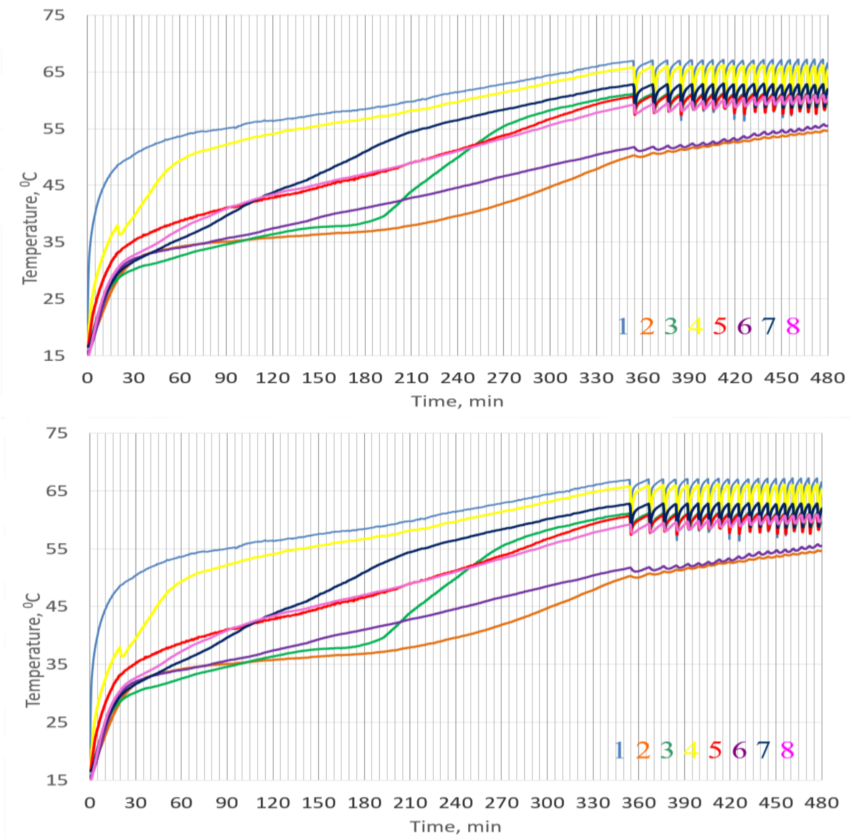


Fig. 8. Temperature changes in the product at 50 °C, 60 °C, and 70 °C

The next temperature regime was 60 °C. At the initial stage, there are no significant differences from the graph at 50 °C. The dehydrator entered the mode only after 350 minutes of drying, due to the fact that the temperature is higher and more time is needed for reaching the desired temperature in the product. Then the cycle with switching on and off the electric heating elements is repeated every 10 minutes. The graph of temperature change at 60 °C is presented above.

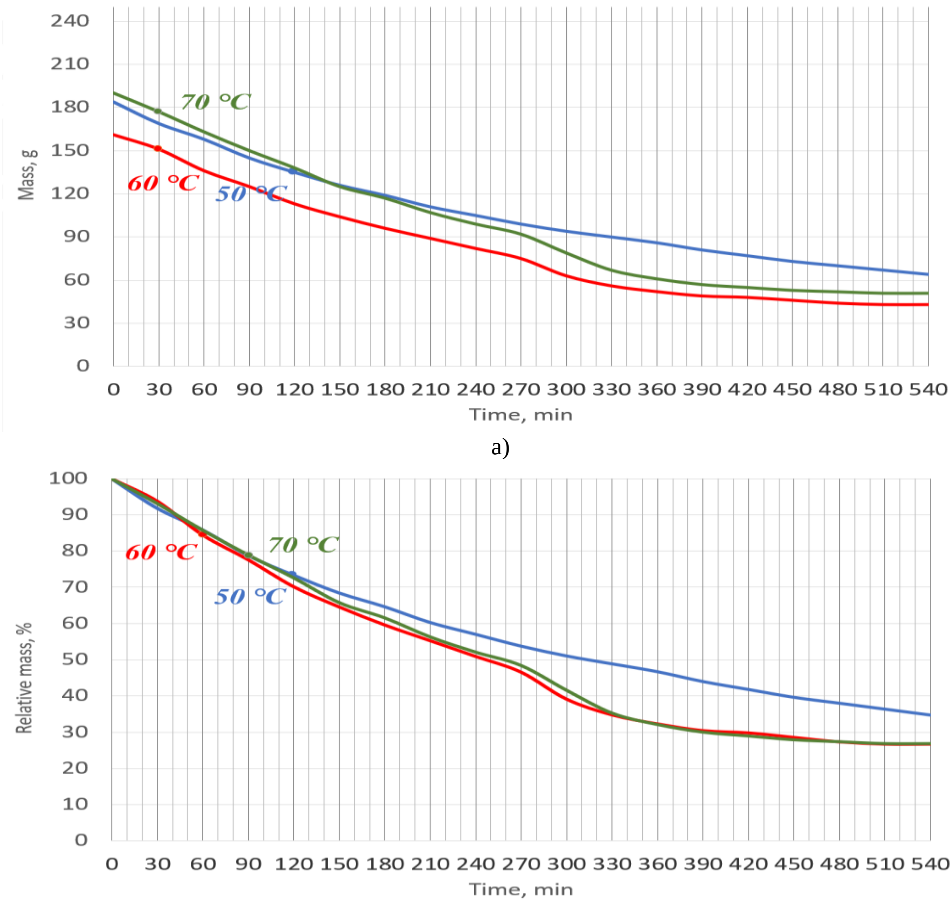
The closing mode was at 70 °C, the graph is shown in Figure 8. At this temperature, the dehydrator did not enter the operating state, and the temperature continued to rise throughout the drying process without gaining the necessary level. This can be explained by the fact that the heating elements were not turned off and the dryer was running at maximum power.

According to the graphs of temperature changes inside the product in Figure 8, the first step after loading is the heating of the product. At this stage, moisture is removed from the surface of the product by means of a gradually heating drying agent. On the graphs, this process lasts approximately 120 minutes from the start of drying.

At the next stage, moisture evaporates after the entire thickness of the product is heated. At this stage of drying, the associated moisture evaporates inside the product. This process is the main one and lasts throughout the drying process.

According to [5], the drying process described above can be attributed to a fairly "soft" one, since small temperatures and air velocities are created in the working volume of the unit, which was confirmed in the literature [5]. At the initial stage, the loss of moisture

content is extremely slow, during this relatively short period the temperature in all measured points of the material increases. Therefore, this stage of the drying process is called the initial stage or the heating stage of the product. After the heating stage, the moisture content of the material decreases over time according to a linear law, therefore, the drying rate will be constant. The surface temperature of the product does not change during this time and is equal to the temperature of adiabatic saturation of the air. According to the experimental data and the above figures (Fig. 8), the differences are clearly visible as the drying rate is uneven after the heating stage. The resulting patterns differ from the typical temperature curves of wet materials for surface and central edges presented in [12], this is due to the cyclic switch-off of electric heating elements when reaching a predetermined temperature regime. During the switch-off, the drying agent is cooled, and as a result, so is the product itself. The stagnant distribution zones of the drying agent also have a significant impact.



b)

Fig. 9. Changes in the mass of the product at the temperature of 50, 60, and 70 °C

a) change in the mass of the product during the convective drying process at a temperature of 50, 60 and 70 °C;

b) change in the relative mass during the convective drying process at the temperature of 50, 60, and 70 °C

During drying, the process of changing the product mass over time was investigated. Mass measurements were carried out at different temperatures, 50 °C, 60 °C, and 70 °C, with an interval of 30 minutes. At 50°, drying took 12 hours for bananas. At 60 °C and 70 °C, drying continued for 9 hours. After the end of drying, we plotted the mass change from the data obtained, which is shown in Figure 9 (a). Having transformed the obtained data, we plotted the changes in the relative mass of the product, shown in Figure 9 (b). The obtained dependencies of the banana mass change on the time of drying by the convective method show the change in the mass of the product from the time of drying. It is important to note that the experimental values of the drying time differ from the characteristics of the convective drying method given in [12] because at the beginning of drying, most of the specific energy consumption is spent on heating the structure of the drying unit and the interior space. There are also heat losses due to the leakiness of the structure.

6 Conclusion

In the course of the study, we examined the features of the dehydrator based on the method of convective drying. The results of the analysis for multiple measurements of the drying unit operation allowed to draw a number of conclusions.

1. When entering the mode, the temperature in the working volume of the dehydrator increases very intensively and noticeably exceeds the set value, after which the electric heating elements are switched off and the temperature drops below the set value. A temperature change cycle is created, resulting in a fluctuating regime of set temperatures.
2. It should be noted that the velocity field is distributed very unevenly in the working volume of the dehydrator. There are well-aerated and stagnant zones with the air speed close to zero. This affects the drying process significantly. Therefore, when the dehydrator is fully loaded, an algorithm for rearranging pallets with drying objects is necessary for uniform drying. Thus, the implementation of such algorithms will yield a product with stable characteristics and a higher quality. This approach is applicable both for small dehydrators and large drying plants.

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