INFRARED DRYER WITH MODERN CONVECTION-VACUUM TECHNOLOGY FOR DRYING VEGETABLE PRODUCTS

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Abstract: *In this article, the drying of plant products utilizing infrared light, convection, and reduced pressure is the subject of investigation. Due to efficiency optimization and energy consumption reduction, the drying process for food products is still significant today. Apples, bell peppers, and bananas are among the products used in the experimental study that is being presented. The cut's thickness ranges from 5 to 10 mm. Observations demonstrate that employing the specified drying plant is entirely practical when parameters and drying modes are optimized.*

Key words: *drying, infrared radiation, reduced pressure, convection, dried products, experimental setup.*

Drying is a real technique for processing goods with both animal and vegetable origins while preserving their useful and nutritive qualities. Fruits, vegetables, herbs, and meat can all be preserved by drying, which also reduces the weight and volume of the raw materials that have been treated. In most cases, organic solvents also evaporate when items are dried, ensuring the elimination of the liquid component, which is often based on water [1].

There are many different drying techniques, and they all work by moving internal moisture to the surrounding area through various mechanical and physical processes. The primary restriction in such processes is the rate at which moisture is lost from the product's internal structure to its surface, as well as changes in the environment's aggregation state, transformation into a gaseous state, and composition of the air mixture close to the product. Quantity, form, and energy of the link between moisture and the substance all affect how this transfer occurs [2, 3].The objective of this study is to determine the optimal parameters and modes of an experimental drying plant to preserve valuable substances in the product and extend the shelf life of raw materials.

The drying parameters and modes were established through experiments conducted on bananas, apples, and peppers. The following method was employed:

The drying product underwent initial preparation, including washing and removal of damaged (rotten) parts from the main portion [4].

Fruits were cut into the following dimensions: bananas - circular slices with a thickness of 7-10 mm; apples - circular slices with a thickness of 5-8 mm; peppers - rings with a thickness of 5-10 mm.

Several samples of the dried product were weighed and their relative humidity measured to determine the average values of these parameters.

A measured portion of the test product with a mass (m) was loaded into the drying chamber.

The automated drying process was initiated based on predetermined parameters of time, temperature, and intra-chamber pressure, with the parameters adjusted for each type of product.

After completion of the process, the dried product was removed from the chamber and allowed to cool to room temperature.

A sample of the dried product underwent repeated measurement of mass and relative humidity before being sent for analysis of its qualitative characteristics as a dried raw material [5, 6].

The measurement and regulation of drying parameters were automated during the operation of the installation. The physicochemical analysis of the dried products utilized laboratory methods in accordance with GOST (GOST R 8.633-2007 - Infrared Thermogravimetric Method for Moisture Content Determination) for each specific raw material. The obtained data was further subjected to statistical processing.

To facilitate an efficient drying process, a chamber-type batch dryer was designed and constructed. It operated based on infrared heating of the product under reduced intra-chamber pressure, coupled with blowing of the processed raw materials. A constant reduced pressure of approximately 0.5 atm was automatically maintained within the chamber. The chamber was equipped with cylindrical incandescent lamps, functioning as infrared heating sources, with a coil temperature of 2500 °C and an electric power of 800 watts. The chamber walls, made of 3 mm thick stainless steel, featured reflectors to minimize heat loss.

Fresh air entered the chamber through an automatically regulated intake valve located at the bottom. The air traversed the entire volume of the heated chamber, passing through the product tray grid and three confusers positioned at the upper part of the chamber. Subsequently, the dry air, saturated with evaporated moisture, was directed to a vacuum water ring pump, which filtered the chamber mixture and produced dry, purified, hot air. During continuous operation, the heated air remained within the system without escaping into the environment. The air intake valve closed automatically, increasing the temperature of the blow-off for the wet product, thus accelerating the drying process. Fans were installed near the chamber walls to ensure forced air circulation within the sealed chamber, with a total volume flow of 100 m3/hour. The experiments investigated the weight loss of the drying product, temperature variations inside the chamber, and relative humidity of the chamber air.

The measuring range for mass was from 0 to 2000 g, temperature from 0 °C to 100 °C, and relative air humidity from 1% to 95%. The resolution was set at 0.1 g, 0.1 °C, and 0.1% respectively, with measurement errors of ±0.5 g for mass, ±1.5 °C for temperature, and 2% for humidity. Experimental data were recorded in the computer memory at intervals of 5 seconds [10].

Compared to similar dryers, the installation offered several advantages. It enabled one-time processing of the product with infrared rays under reduced pressure, resulting in lower drying temperatures. Additionally, the convection of air flows inside the drying chamber facilitated rapid removal of moist air from the product's surface. The drying process of any plant or animal-based product could be fully automated using pre-calculated and programmable parameters [11]. It should be emphasized that the automation of the drying process ensured superior quality of the dried product and precise measurement of weight, humidity, temperature, and pressure within the drying chamber [12].

Figure 1 depicts the general view of a combined chamber-type drying apparatus designed for intermittent operation, incorporating reduced intra-chamber pressure and blowing of the product to be dried.

Throughout the research, samples of plant materials were placed on a tray covered with a Teflon mesh to prevent burning. The temperature and duration required for vegetable raw materials to reach an acceptable moisture content for consumption were calculated at the initial stages of drying [12].

The relative humidity of the air and the exhaust time from the vacuum chamber are reduced to 33%. However, after activating the infrared lamp, the humidity increases to allow the smoke vapor to dry on the product's surface, reaching 78% of its initial condition before gradually decreasing. This decrease occurs due to the removal of molecules in the air and the lower vapor density of the water-soluble pump, coupled with an increase in air temperature [13].

During the drying process, the temperature of the remaining air in the chamber rises from 20°C to 55°C.

The drying period was divided into 11 stages, with each stage having its own intensity of infrared lamp heating. This periodic variation in infrared lamp intensity is necessary to effectively dry the product.

Based on preliminary results, it can be concluded that the best results are achieved when the product has a thickness of 5 mm during drying. However, a thickness of 10 mm yields the least desirable outcome. This is because thicker products make it more difficult for moisture from the inner part of the product to reach the surface, resulting in a significant portion of moisture remaining inside. Moreover, it was visually observed that when banana slices were cut with a thickness of 10 mm, a crust formed on the surface, hindering the penetration of moisture and causing the banana to begin "cooking."

Table 1

Displays the relative weight loss of different products after drying and its correlation with the thickness of the product.

Thickness, mm	Product	Weight up to, gr	Weight after, gr	Потеря веса, %
5	Pepper	79,84	23,43	Weight loss, %
	Apple	116,7	35	70,01
	Banana	51,7	17,57	66,02
10	Pepper	96,47	96,47	52,6
	Apple	84,12	54,1	35,69
	Banana	79,86	57,5	28,00

Conclusion

Initial experiments have demonstrated enhanced drying efficiency through the combination of infrared radiation and convection methods, utilizing reduced intra-chamber pressure.

Future research should focus on conducting a comprehensive full-factorial experiment. This experiment will consider variable factors such as pressure, infrared lamp radiation intensity, and air flow rate, while measuring response functions such as energy consumption and the quantitative preservation of valuable substances in the product.

The most significant impact was observed when drying the product with a thickness of 5 mm, while the least favorable results were obtained with a product thickness of 10 mm. For instance, the weight of the pepper decreased from 79.84 grams to 23.43 grams, representing a weight loss of 70.65%.

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