Justification of the design parameters of the combined device

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Abstract. This article analyzes the theoretical and practical aspects of the process of drying food products, in particular medicinal plants. Since drying is a complex technological process based on heat and mass transfer, a combination of infrared radiation and convective airflow is proposed to increase its energy efficiency. The article substantiates the design of the drying unit, optimal operating parameters, and mathematical models. Recommended thermal regimes for drying quality and preservation of bioactive substances in the product are also described.
Keywords : Drying process, convective drying, infrared radiation, medicinal plants, heat and mass transfer, energy efficiency, drying unit, optimal parameters.

I. Introduction

Drying is a complex heat and mass transfer technological process, which in most cases should not only preserve a number of properties of the product, but also improve these properties. Drying also contributes to the long-term storage of the product, i.e., its preservation. In the food industry, convective drying is often used. In this case, the heated air contacts the material, releasing its heat and absorbing the material's moisture [1,2].

Various dryers are used in the food industry, and various materials are dried. Dryers are classified according to various characteristics [3].

Let's consider various dryers used in the food industry. The following table classifies the types of dryers.

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Classification symbol	Type of dryer
1. Operating mode	Intermittent and continuous operation
2. Method of heat transfer	Conductive, radiative, convective, high-frequency
3. Type of drying agent	Air, using furnace gases, using heated steam
4. Pressure of the drying chamber	Atmosphere, vacuum, deep vacuum
5. Drying process option	Normal process, with intermediate heating of air in the chamber
6. Drying agent circulation	With natural and artificial circulation
7. Construction	Chamber, shaft, belt, drum, tube, corridor, spray, etc.
8. Direction of material and drying agent flow	Reverse-flow, forward-flow, cross-flow

The drying process plays a large role in various sectors of the national economy. In the CIS countries, more than 3 million tons of fuel are used annually for the drying process. In the food industry, drying is one of the main processes and is used in almost all industries[4].

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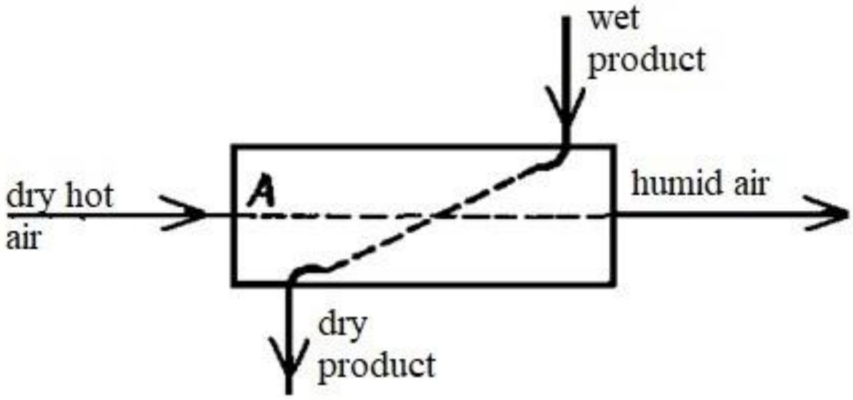

Figure 1. Principal scheme of drying.

II. SIGNIFICANCE OF THE SYSTEM

Humidity concentration

Usually, moisture is unevenly distributed in the body. Therefore, the average moisture concentration of the material or the moisture concentration in any part of it is determined.

Material moisture content is understood as the amount of moisture calculated as a percentage of the material's mass:

$$W = \frac{m_{нам}}{m} \qquad (1)$$

where: m_{nam} – mass of water, kg; m – mass of material, kg.

In some cases, it is convenient to take the ratio of moisture content to the absolute dry mass of the substance. In this case, the moisture content in the material is:

$$\xi = \frac{m_{нам}}{m_{нам} - m_{нам}} \qquad (2)$$

When a wet material is dried convectively, moisture moves from the center of the material to the surface. There, the material is washed with a drying agent (air, furnace gases). Such movement of moisture is mainly a diffusion process, and the source of the driving force is the difference in moisture concentrations in different parts of the material. But this process, as we will see later, is complicated by the influence of external heat. Initially, moisture movement is considered only as a result of the difference in moisture concentrations. Since the process under consideration is diffusive, we can write the moisture permeability equation similarly to Fourier's equation as follows:

$$m_W = \_K_W F\left(\frac{dc}{dx}\right)\cdot\tau, \qquad (3)$$

where: m_W - the amount of moisture passing through the F phase during τ-time; $\frac{dc}{dx}$ - moisture concentration gradient; K_W - coefficient depending on the nature of the dependence of moisture on the material and the nature of the material.

The material drying process consists of three stages:

- moisture movement from inside the drying material to the outside;
- foam formation;
- the release of vapor from the material surface into the surrounding air.

We discussed the first of these stages above and saw that this process is complex. Moisture evaporates both inside and on the surface of the material. The vapor formed inside the material shifts towards the surrounding environment - it diffuses. This process has three stages and proceeds as follows.

An air-vapor boundary layer forms on the surface of the drying wet material. This layer is in equilibrium with the material's moisture; ultimately, at the material's temperature, this layer becomes saturated. The driving force of moisture diffusion on the surface of the boundary layer is the partial pressure difference, i.e.:

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$$\Delta P = P_H - P_B \qquad (4)$$

where: - partial pressure of water vapor in the boundary vapor layer; $P_в$ - partial pressure of water vapor in the environment.

Diffused vapor amount:

$$m = B\left(p_н + p_в\right) \cdot F \cdot \tau \qquad (5)$$

where: V - evaporation coefficient; F - surface area of evaporation.

III. METHODOLOGY

The amount of vapor passing from the material to the environment through the boundary layer is necessarily equal to the amount of vapor formed inside the material and entering the boundary layer. The drying rate can be limited by the intensity of these processes and depends on the material properties and the drying cake. The drying line is obtained by observing the changes in the material mass during the drying process.

The graph of the drying process (line) is drawn as a relationship between material moisture w and time τ. Material moisture is transferred to mass, and time to coordinates in minutes or hours. Figure 2 shows the drying graph of a colloidal capillary porous material.

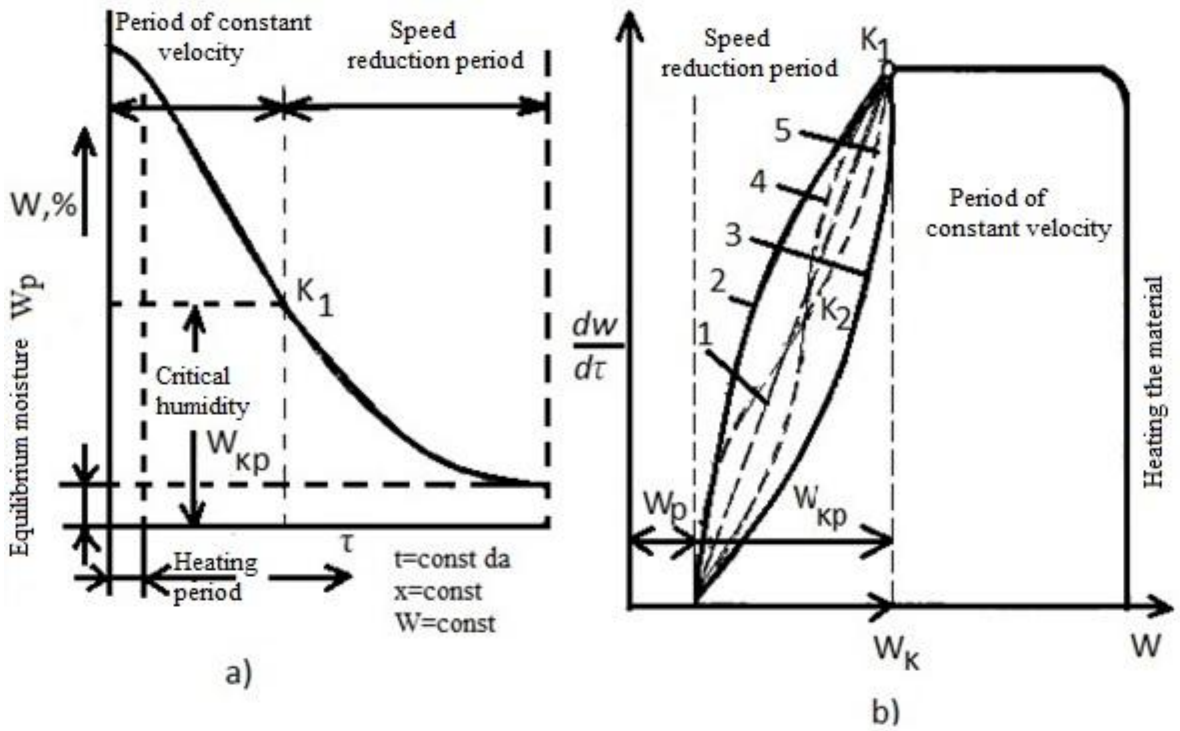

Figure 2. Graph of the drying process: a) drying rate of the colloidal capillary-porous product; b) drying rate line

At the beginning of the drying process, over a certain period of time, the drying curve has the shape of a curve, which is the heating time of the material. Then the drying rate is constant and consists of a straight line. At point K_1, the character of the drying curve changes at a certain material moisture content. The curve becomes increasingly curved and has an asymmetrical character, approaching the equilibrium moisture content (W_P) in the established drying regime. In the next, second period, the drying rate continuously decreases.

Based on the results of morphological analysis for the selection of a rational drying method and a mathematical model of heat and mass transfer during cyclic IR heating with stimulating cold blowing of the drying material, we substantiate the main design elements of the developed drying device for plant medicinal raw materials[5].

Basic requirements for the drying unit

The device for drying rosehip must meet the following requirements:

1. Rapid and efficient moisture removal - evaporation of internal moisture by infrared heating and its removal by convective airflow.

2. Maximum thermal efficiency - ensuring energy saving.

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3. Maintaining product quality - bioactive substances, color, taste, and smell should not be spoiled.

4. Uniformity of the drying process - each part of the product must be dried evenly.

Based on the results of morphological analysis of the choice of a rational drying method and a mathematical model of heat and mass transfer during periodic infrared heating of the drying material with stimulating cold air, we substantiate the main structural elements of the developed drying unit for plant medicinal raw materials.

We will consider this issue from the point of view of choosing the type of infrared heaters, determining their location relative to the material being dried, supplying cold air to the material and blowing it with heated air, loading the material being dried into a container, as well as the general structure of the drying cabinet.

The device should consist of a series of drying modules, be reliable in operation, maximally automated in control, and ensure high quality of material drying with energy-saving indicators.

In order to familiarize ourselves with the thermal characteristics of the dryer, energy balances were compiled for each of its elements.

When compiling the energy balance equations, we accept the following assumptions:

- We assume that the heat capacities of the air, light-transmitting, and insulating layer are small and do not take them into account;
- We assume that the temperature gradient along the thickness of the light-transmitting glass or polyethylene layer is absent;
- The device is designed with maximum airtightness and therefore no air leakage;
- We assume that the decrease in product volume during the drying period is insignificant.

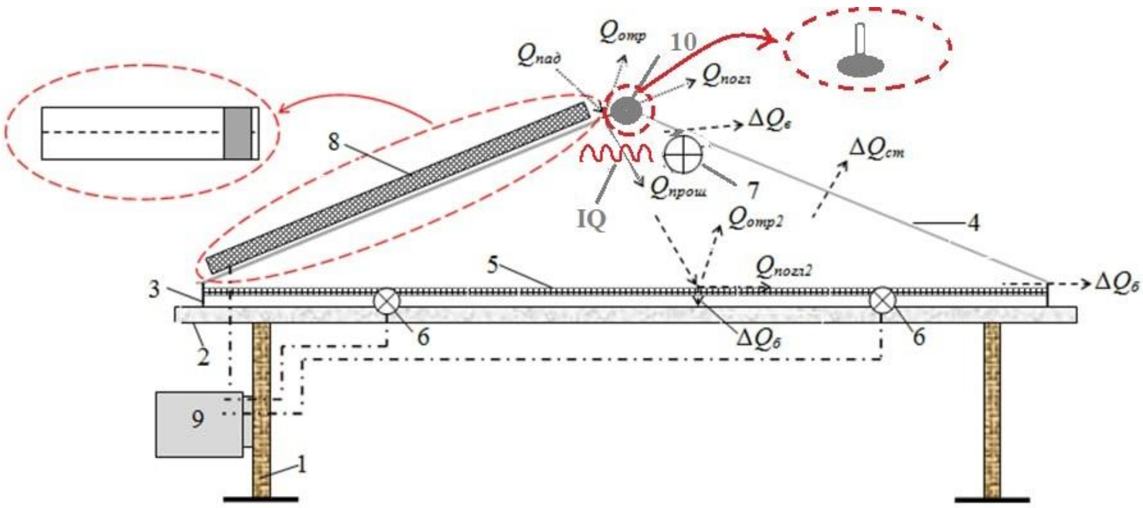

Figure 3. Principal diagram of a tunnel-type solar dryer.

1-drying column; 2-insulation layer made of sandwich panel; 3-insulation layer made of iron; 4 - light-transmitting layer (made of glass or polyethylene); 5-grid-shaped base; 6-ventilators; 7-aperture for releasing moist air; 8-solar panel; 9-system for accumulating solar energy and performing the process; 10 - IR lamp.

IV. EXPERIMENTAL RESULTS

Determination of the design parameters of the drying unit

Infrared heating system parameters

- Infrared wavelength: 2-10 micrometers (medium and far IR range).
- Infrared heating temperature: 50-70°C (optimal for storing vitamins and bioactive substances).

Proper distribution of infrared radiation contributes to uniform evaporation of moisture inside the product.

Parameters of the convective drying system

1. Air temperature: 40-60°C (to prevent damage to the thin crust).
2. Air velocity: 1.5 - 3.5 m/s (air flow should be evenly distributed).
3. Moisture removal rate: The fan power is selected appropriately for effective moisture removal of 50-70%.

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Proper adjustment of the convective system, combined with infrared heating, accelerates the drying process.

Selection of optimal drying conditions

The optimal drying process consists of a combination of infrared radiation and convective heat flow:

Stage	Infrared heating temperature	Convective air temperature	Air velocity	Drying time
Step 1 (Quick heating)	60-70°C	50-55°C	3.0-3.5 m/s	15-20 min
Stage 2 (main drying)	50-60°C	40-50°C	2.5-3.0 m/s	2-3 soat
Stage 3 (soft drying)	40-50°C	35-40°C	1.5-2.5 m/s	1-2 soat

Such a combination helps to maintain product quality and save energy.

Optimal operating modes of the drying unit

1. The combination of infrared + convective drying provides an energy-saving and high-quality drying result.
2. Infrared rays help evaporate moisture from inside the product.
3. Convective hot air quickly removes evaporated moisture.
4. The optimal drying temperature should be 50-60°C, as high temperatures can spoil bioactive substances.

V. Conclusion And Future Work

Drying is an important technological stage in the food and pharmaceutical industries, which allows for long-term storage of the product and preservation of its quality indicators. Based on the scientific approaches presented in the article, a drying unit based on a combination of infrared and convective energy was designed for medicinal plants. The proposed device design is aimed at increasing thermal efficiency, maintaining product quality, energy saving, and ensuring the uniformity of the drying process. Based on the energy balance and mathematical modeling, optimal drying modes were determined, and important recommendations for practical use were given. This approach allows for high-quality and efficient drying of medicinal plants.

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