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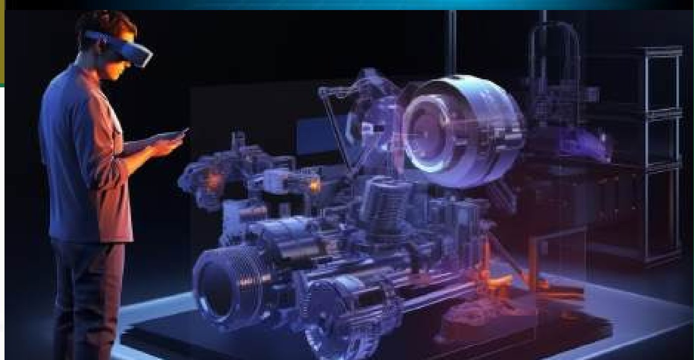

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“ZAMONAVIY IQTISODIYOTDA YUQORI MUHANDISLIK TEXNOLODIYALARINI ILMIY-AMALIY JORIY ETISH INNOVATSION TARAQQIYOT POYDEVORI”

MAVZUSIDAGI ILMIY MAQOLALAR TO‘PLAMI

OPTIMIZING THE EFFICIENT TRANSPORT OF MASS FROM ALTERNATIVE ENERGY SOURCES AND THE PROCESS OF HEAT AND MASS EXCHANGE DURING THE PROCESSING OF SPICES

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Abstract: The scientific research illustrates that the change in humidity over the entire surface of the material placed on each shelf of the drying chamber has analyzed. The drying rate substantiated depending on the trajectory of the coolant flow and the geometric arrangement of the mesh shelves. A drying device has developed that ensures uniform removal of moisture from the surface of the product due to the arrangement of mesh hearths relative to each other, as well as due to the formation of spherical holes on both sides of the shelves. The optimal configuration of the outlet nozzles has proposed, which ensures the continuous removal of moist air released from the product composition per unit of time. Based on the studies carried out, the diffusion coefficient for the air-water vapor system was determined. The calculations have carried out on a stationary field of the coolant velocity in the working zone of the dryer and non-stationary conditions of heat and moisture transfer.

Key words: heat and mass transfer, drying, moisture, drying agent, diffusion, temperature, agricultural raw materials, convection.

Annotatsiya: Ilmiy tadqiqotlar shuni ko'rsatadiki, quritish kamerasining har bir tokchasiga joylashtirilgan materialning butun yuzasi bo'ylab namlikning o'zgarishi tahlil qilingan. Quritish tezligi sovutish suvi oqimining traektoriyasiga va to'r tokchalarining geometrik joylashishiga qarab asoslanadi. To'rli o'choqlarning bir-biriga nisbatan joylashishi, shuningdek, javonlarning har ikki tomonida sharsimon teshiklar hosil bo'lishi tufayli mahsulot yuzasidan namlikni bir xilda olib tashlashni ta'minlaydigan quritish moslamasi ishlab chiqilgan. Chiqish nozullarining optimal konfiguratsiyasi taklif qilingan, bu vaqt birligida mahsulot tarkibidan chiqadigan nam havoni doimiy ravishda olib tashlashni ta'minlaydi. O'tkazilgan tadqiqotlar asosida havo-suv bug'lari tizimi uchun diffuziya koeffitsienti aniqlandi. Hisob-kitoblar quritgichning ish zonasidagi sovutish suvi tezligining statsionar maydonida va issiqlik va namlikning statsionar bo'lmagan sharoitlarida amalga oshirildi.

Kalit so'zlar: issiqliq va massa uzatish, quritish, namlik, quritish agenti, diffuziya, harorat, qishloq xo'jaligi xom ashyosi, konveksiya.

Аннотация: В научных исследованиях показано, что проанализировано изменение влажности по всей поверхности материала, размещенного на каждой полке сушильной камеры. Обоснована скорость сушки в зависимости от траектории движения потока теплоносителя и геометрического расположения сетчатых полок. Разработано сушильное устройство, обеспечивающее равномерное удаление влаги с поверхности продукта за счет расположения сетчатых подов относительно друг друга, а также за счет образования сферических отверстий с обеих сторон полок. Предложена оптимальная конфигурация выходных патрубков, обеспечивающая непрерывный отвод влажного воздуха, выделяющегося из состава продукта, за единицу времени. На основании проведенных исследований определен коэффициент диффузии для системы воздух-водяной пар. Расчеты проведены при стационарном поле скорости теплоносителя в рабочей зоне сушилки и нестационарных условиях тепловлагообмена.

Ключевые слова: тепломассоперенос, сушка, влага, сушильный агент, диффузия, температура, сельскохозяйственное сырье, конвекция.

INTRODUCTION

At present, the increase in the cost of energy consumed in the field of complex processing of agricultural raw materials and food products requires a new approach to improve the efficiency of existing devices and create energy and resource-saving equipment and technologies. The most energy-intensive processing of agricultural products is thermal and mass transfer, as well as the process of drying and safe storage of finished products. In industrialized countries, the drying process consumes 25% of energy, and in the food and raw materials industry - up to 30%. [1]. An analysis of modern technologies shows that convective drying devices are most widely used in the food industry. In these devices, 4000–9000 kJ of energy has consumed to evaporate 1 kg of moisture [2]. In particular, 20-30% of energy costs accounted for by the release of the drying agent into the atmosphere, part of the energy has spent to heat the drying agent to the required temperature in the drying chamber.

From this point of view, the improvement of drying technology achieved by modernizing traditional schemes and developing fundamentally new technologies for dehydrating products with a significant reduction in energy costs. The general scientific and technical idea of the development has expressed in the use of the principles of targeted delivery of forced energy to the product and its elements. In addition, in the utilization of the heat leaving with the drying agent and its uniform distribution over the entire surface of the product, placed on mesh pallets in the drying chamber. The development of technology should follow the path of a directed, selective supply of energy to those elements of raw materials that minimally exposed to energy impact. Particular attention paid to the capillary-porous structures of the product.

MATERIALS AND RESEARCH METHODOLOGY

The direction and speed of the flow of the drying agent is one of the main factors that ensure uniform release of moisture over the entire surface of the products located in each shelf of the drying chamber. It has known that the drying rate depends on the trajectory of the airflow and the geometric arrangement of the mesh shelves. In addition, in many cases, because of improper supply of the drying agent, waterlogging of the raw materials located in the lower mesh shelves occurs. Therefore, it is necessary to ensure the flow of the drying agent in such a way as to prevent the removal of its moisture through the product. To do this, it is desirable to ensure the optimal location of the mesh shelves in the drying chamber.

The analyzes show that the change in the amount of moisture released per unit time from raw materials placed on the upper, middle and lower mesh trays of the drying chamber depends on the geometric arrangement of the mesh shelves and the circulation of the coolant flow. From this point of view, the principle of mathematical modeling used in order to develop the optimal design of the dryer, which makes it possible to accelerate the release of moisture from the composition of the product, and to determine the influencing parameters. Accordingly, an optimal geometric arrangement of mating pallets placed in relation to each other developed in order to improve the uniform release of moisture from the surface of the product and the level of circulation of the drying agent. The optimal variant of the geometric arrangement of heating elements in the drying chamber experimentally and theoretically investigated.

To improve the intensity of heat and mass transfer, the acceptable location of the grid shelves and heating elements inside the dryer, the following prerequisites adopted:

- a more efficient mechanism for arranging mesh shelves from each other in the drying chamber has been developed;

- to improve the circulation of the drying agent, the optimal geometric configuration of the mesh shelves was developed separately;

- for uniform removal of moisture from the object under study, the type of heating elements was chosen, and their wavelength during the heating of the product and the absorption of water molecules, as well as their location in the drying chamber;

- to remove the spent drying agent, there is a cone-shaped opening with self-rotating outlet nozzles on top of the unit;

- to model the flows of the drying agent, the Navier-Stokes equations were used in the formulation for the laminar flow of a wet drying agent. The average speed in the inlet section was set to 2.1 m/s.

It has known that moisture is contained in the dried product in the form of vapor and liquid, and the following condition is observed:

$$К_l + К_п = 1 \quad (1)$$

where $К_l$ - coefficient of saturation of the capillary pores of the product with the liquid phase;

$К_p$ - saturation coefficient of capillary pores in steam.

In this case, the saturation coefficient of the capillary pores of the product with the liquid phase has determined by the formula:

$$К_l = \frac{c_l \cdot M_l}{\rho_l \cdot \varepsilon} \quad (2)$$

where c_l - moisture concentration in the product, mol/m³;

M_l - molar mass of water, kg/mol;

ρ_l - density of water, kg/m³;

ε - product porosity.

The movement of heat flows through the dryer has described by the equation:

$$\rho \cdot c_\rho \cdot \frac{\partial T}{\partial \tau} + \rho \cdot c_\rho \cdot \vartheta \cdot \nabla T + \nabla q = \sum Q_h \quad (3)$$

where c_ρ - heat capacity of the medium, J/(kg °C);

ϑ - velocity of drying agent, m/s;

$q = -k\nabla T$ - heat flux density, W/m²;

k - coefficient of thermal conductivity, W/(m °C);

$\sum Q_h$ - total intensity of heat release, W/m³;

T - temperature, °C.

Transportation of the released moisture from the material along the mesh shelves has implemented according to the equation:

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (-D_i \nabla c_i) + \vartheta \cdot \nabla c_i = 0 \quad (4)$$

where c_i - concentration i- substance, mol/m³;

D - diffusion coefficient i- substance, m²/s.

C In order to develop and implement the optimal variant of the drying system for agricultural products, the modeling of drying equipment was carried out in two stages. To obtain the necessary data of the object under study, according to equations (2) and (3), calculations of the stationary field of heat consumption in the working zone of the dryer and non-stationary conditions of heat and moisture transfer performed.

In the working area of the drying chamber, the process of drying products carried out on mesh pallets of the same geometric size and area, successively converging with each other. The degree of saturation of the heat carrier with moisture and the patterns of changes in moisture content in the product studied. Despite the release of moisture from the product, located on the bottom 1-5 trays of the dryer, there was a partial re-moistening of the product (Fig. 1).

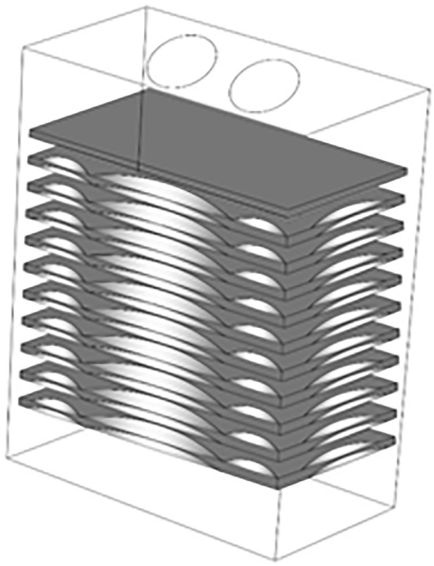

Figure.1. View of the distribution fields of moisture saturation in each of the trays of the existing drying chamber (the location of the trays is clearly one under the other) [3].

As can be seen from Figure 1, during the first 50-70 minutes of the drying process, a uniform release of moisture from the product has not ensured. The main release of moisture comes from the product located in the center of the pallets. From the product located at the edges of the pallet, moisture does not practically released. In addition, the product located on the upper pallet has waterlogged due to the released moisture from the underlying products. To eliminate this drawback, improve the circulation of the drying agent, accelerate the release of moisture from the surface of the product from each pallet, an improved model of the drying apparatus was developed.

ANALYSIS AND RESULTS

The Bukhara Engineering Technological Institute is developing a scientific direction in the theory and technology of drying, based on the concept of targeted energy delivery to the material being dried. This lies in the fact that, in the heating zone, IR emitters with a wavelength of 0.7-1.1 microns used in a pulsed mode, and in the drying zone, IR emitters with a wavelength of 2.8 microns are used to continuously remove moisture. In addition, for uniform removal of moisture over the entire surface of the dried product, optimal circulation of the drying agent ensured with the arrangement of mesh shelves in the drying chamber. A more acceptable configuration of mesh shelves has developed for the normal passage of the drying agent between the shelves. There are 12 pallets in the drying chamber. A zigzag mechanism for guiding the movement of the heat carrier has implemented to increase the range of the heat carrier over the entire surface of the pallets, as well as to accelerate the release of moisture from the product. In addition, the pallets are staggered, and on the side that attached to the base, there are hemispherical holes. This, in turn, allows the coolant to move at the same speed between the pallets. In addition, to create a uniform temperature over the entire surface of the dried product, the heating elements were located perpendicular to the base (Fig. 2). In our opinion, such a design will lead to a faster equalization of the temperature field inside the dryer, as well as over the entire surface of the dried product. In addition, in this design, an acceleration mechanism provided to remove the released moist air from the dryer. At the same time, a cone-shaped self-rotating outlet pipes installed on the top of the drying chamber, which ensure the continuous removal of moist air. Based on the conducted studies, the change in the moisture content of the product within 1-1.5 hours in the controlled and offered 1-3 trays of the drying device studied. During the first 50 minutes the moisture content of the product on the first tray changed by 18%, within 70 minutes the moisture content of the product on the second tray changed by 21% and within 90 minutes the moisture content of the product on the third tray changed by 25%. As you can see, there is a discrepancy between the compared options, both in the drying time and in its uniformity. Also in the drying chamber, with staggered pallets and zigzag movement of the drying agent, almost the same amount of moisture released from the surface of the product from all pallets, and the same distribution area of the drying agent achieved throughout the entire volume of the drying chamber.

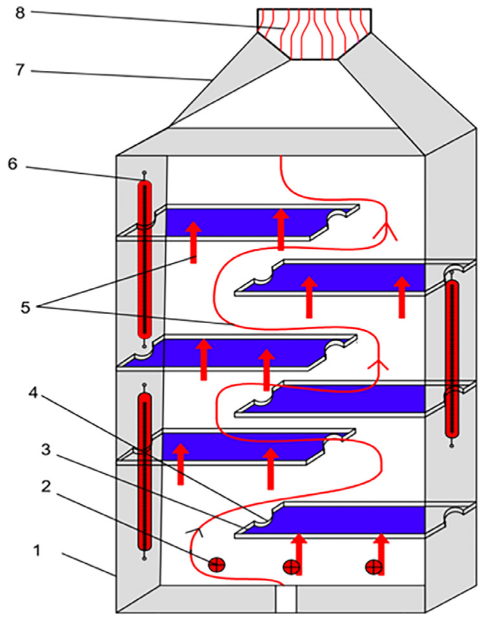

Figure 2. Geometric model of the modernized drying chamber.

(The arrangement of mesh shelves is zigzag in a checkerboard pattern)

1-body, 2, 6-IR emitters, 3-mesh hearth, 4-polyspherical holes, 5-direction of airflow through the layer of material and between mesh shelves, 7-tapered top compartment, 8-self-rotating outlet.

The results obtained in a dryer with a zigzag direction of the drying agent, with a staggered arrangement of mesh trays and a conical self-rotating outlet nozzle, were compared with the results of a control sample. In the proposed dryer with a zigzag direction of the coolant on 1-3 trays, the following results obtained on the change in product moisture per unit time. During the first 60 minutes of the drying process, the moisture content of the product on the first tray changed by 26%, on the second tray - 27%, on the third tray - 29%. Over 90 minutes, the change in moisture content of the product on the first, second and third trays was almost the same and averaged 42.5 percent. The difference in speeds of the drying agent at the inlet and outlet of the dryer was 0.3 m/s [6].

This means that the best option is to arrange mesh shelves in a checkerboard pattern and ensure the movement of the drying agent with a zigzag channel, which confirms our idea.

Thus, the presence of a zigzag channel and the arrangement of the hearths in a checkerboard pattern makes it possible to increase the blowing of the material with a coolant by 0.9-1.2 times. Another positive side of the zigzag channel is that moisture removed gradually from top to bottom.

Next, a drying plant investigated, in which mesh shelves with holes on both sides installed in a hemispherical shape. Another variant of one of the operating modes of the considered drying chamber was to intensify the drying process by supplying additional energy in the first period. At the same time, an IR heater installed under the first shelf to heat the incoming air to the required temperature.

The process of moisture displacement, which takes place in the main areas of the drying chamber, is considered. It has known that moisture in the air is steam, while in a porous body, in addition to steam, moisture presented in the form of a free liquid, which is not bound to the material. This is according to the classification of P.A. Ribender is called adsorption moisture, which is held on the surface of the material. Moisture transfer is associated with convection and diffusion. Then the moisture transfer in the air part of the drying chamber can be described by the following equation:

$$M_{п}\rho_{вв}\frac{\partial \frac{C_{п}}{\rho_{вв}}}{\partial t} + M_{п}\rho_{вв}\vartheta_{воз}\nabla\left(\frac{C_{п}}{\rho_{вв}}\right) + \nabla g_{Д} = G \qquad (5)$$

where ρ_{ma} – density of moist air, kg/m^3;
ϑ_a – air speed, m/s;
M_m – molar mass of water vapor, kg/mol;
C_v – water vapor concentration, mol/m^3;
G – moisture absorption, kg/(m^3 s);
g_d – diffusive vapor flow, kg/(m^{2}s).
Diffusion steam flow:

$$g_d = -M_m \cdot \rho_{ma} \cdot D \cdot \nabla C_v \qquad (6)$$

where D - diffusion coefficient of vapor in air, $D = 2.6 \cdot 10^{-5}$ m^2/s [3]
Water vapor concentration:

$$Cv = \varphi_0 \cdot c_s \qquad (7)$$

where φ_0 - relative humidity, %;
c_s - saturated steam concentration;

$$C_s = \frac{P_{нп}}{RT} \qquad (8)$$

where P_s - saturated steam pressure, Pa;
R - gas constant, R=8,31J/(mol^{0}C);
T- air temperature, ^{0}C.

Evaporation rate of water from the free surface:

$$W/(\tau \cdot F) = c(H\text{-}h)/B \qquad (9)$$

where W - the amount of evaporated moisture from the material located in 12 mesh shelves, kg;
τ - duration of evaporation, hour;
F - evaporation surface, m^2;
c - evaporation rate;

H- the vapor pressure in the boundary layer of the evaporating liquid is equal to the partial pressure of saturated vapor, Pa;

h - partial vapor pressure in the surrounding air, Pa;

B- total barometric pressure, Pa.

Evaporation rate of water:

$$c = a\sqrt{\vartheta\rho} \qquad (10)$$

where a - coefficient;

ϑρ - mass air velocity, kg/(m²).

The generalized equation for the rate of evaporation of a liquid from a free surface, proposed by A.V. Lykov [4].

$$\frac{W}{\tau \cdot F} = c\frac{M \cdot D \cdot L}{R \cdot T_{п}}(H\text{-}h) \qquad (11)$$

here the evaporation coefficient c is determined by the Reynolds criterion

$$c = k \cdot R_e^n \qquad (12)$$

where $R_e = \frac{\vartheta \cdot l}{\nu}$ – Reynolds criterion; ϑ – air speed, m/s; *l* - the size of the evaporation surface in the direction of air flow, (*l*=1.8 м); L- width of the evaporation surface in the direction perpendicular to the direction of air movement, (L=0.38 м); average value of the coefficient k – for highly moist agricultural products is 480 [1].

The dependence of saturated vapor pressure on temperature expressed by the Clausius-Clapeyron equation:

$$c = k \cdot R^{\nu}\frac{dP}{dT} = \frac{\nabla H}{T(V_v - V_v)} = \frac{\nabla H}{T\,\nabla V} \qquad (13)$$

∇H – heat of vaporization, J/mol;

∇V – change in volume during the transition of 1 mol of liquid to vapor.

Mass fraction of vapors in moist air:

$$\omega_{п} = \frac{M_v \cdot \varphi_0 \cdot C_s}{\rho_{ma}} \qquad (14)$$

Diffusion coefficient for air-water vapor system, m²/h, B_0 =0, 1013 MPa [1]

$$D = 0.0754\left(\frac{T_v}{273{,}15}\right) \cdot B_0/B \qquad (15)$$

It is known that the drying of raw materials depends on the total moisture content in the product and the type of moisture bond with the material, which depends on the amount of free energy. Based on this, work was done to remove 1 mol of water at a constant temperature without changing the composition of the substance, at a given moisture content. The amount of energy to remove 1kg/mol of water from the raw material is described by the equation:

$$A = -R \cdot T \cdot \ln\varphi \qquad (16)$$

where A - binding energy of moisture, J. mol;

R- universal gas constant, J/(mol K);

T-temperature, ⁰C;

φ - relative humidity

If there is free moisture in the dried product, then A=0. When moisture is removed from the capillary cells, then the binding energy an increases. Here it is of interest to determine the specific heat capacity of the raw material, which corresponds to the amount of heat absorbed by the product when heated on 1 °C. The specific heat capacity calculated using the formula [5]:

$$c = Q/m\Delta T \qquad (17)$$

where Q - the amount of heat received by the mass of the dried material during heating, *m* - weight of the heated product,

ΔT- the difference between the temperature of the initial and final product.

Thus, in the proposed drying technology, the tasks of increasing energy efficiency, resource saving and preserving the native state of the dried product are solved. In this case, the specific energy consumption for the drying process was calculated [5]:

$$q = \frac{P}{\left(\frac{\Delta m}{\Delta \tau}\right)} \qquad (18)$$

where q - specific energy consumption for the drying process, J/kg;

P - power spent on the drying process, W;

$\frac{\Delta m}{\Delta \tau}$ - drying speed (kg using moisture/s).

In the proposed drying method, the specific energy consumption for moisture evaporation is 2.4-2.7 MJ/kg. For the mathematical description of the process, the temperature ranges of the drying agent were taken 67-73 ^{0}C, and the temperature of the dried product 58-62 ^{0}C. If we compare the energy costs for traditional drying modes, they are 1.5-1.8 times higher (3.6-5.5 MJ/kg) [2].

CONCLUSION

An original technology and installation of a dryer has developed, under the influence of infrared radiation with a wavelength of 0.7-1.1 microns in the heating zone, and 2.8 microns in the continuous drying zone. An acceptable design and mechanism for the arrangement of mesh shelves has proposed, which ensures uniform distribution of the drying agent over the entire surface of the material. For continuous removal of moist air, a cone-shaped self-rotating outlet pipe has installed in the upper part of the drying chamber. Theoretical analyzes show that the proposed method of drying under the influence of infrared radiation with the required wavelength in the heating zone and in the drying zone has a number of advantages: drying time and the native state of the dried material has preserved.

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