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IMPROVEMENT OF EQUIPMENT IN ORDER TO INTENSIFY THE PROCESS OF DRYING DISPERSED FOOD PRODUCTS

S. Sabadash
PhD, Associate Professor*
E-mail: s.v.sabadash@ukr.net
M. Savchenko-Pererva
PhD, Associate Professor*
E-mail: marina.savchenko-pererva@snau.edu.ua
O. Radchuk
PhD, Associate Professor*
E-mail: oleg.radchuk@snau.edu.ua
L. Rozhkova
PhD, Associate Professor*
E-mail: rozhkova_lg@ukr.net
A. Zahorulko
PhD, Senior Lecturer
Department of Processes, Devices and Automation of Food Production
Kharkiv State University of Food Technology and Trade
Klochkivska str., 333, Kharkiv, Ukraine, 61051
E-mail: zagorulkoAN@hduht.edu.ua
*Department of Engineering Technology of Food Production
Sumy National Agrarian University
H. Kondratieva str., 160, Sumy, Ukraine, 40021

Одним з найбільш розповсюджених і досліджених процесів у харчовій промисловості є процес сушіння, він становить завершальну стадію технологічних схем і визначає якість готового продукту. Встановлено, що завдяки ефективному використанню об'єму сушарки та збільшенню поверхні фазового контакту інтенсифікувався процес сушіння та зменшилася собівартість висушеного продукту. Визначено, що збільшування відносної швидкості дисперсної і газової фази в свою чергу збільшувало рушійну силу процесу сушіння і зменшувало витрату теплоносія на сушіння. З'ясовано, що при застосуванні інертного носія збільшувалася відносна швидкість поверхні фазового контакту.

Проведено теоретичні та експериментальні дослідження, які дозволили одержати емпіричні співвідношення, необхідні для інженерного розрахунку конструктивних особливостей сушарки із псевдозрідженим шаром інертного носія для сушіння дисперсних харчових продуктів. Основні особливості установки для сушіння дисперсних харчових продуктів полягають в наступному. По-перше, у верхній частині камери був розміщений пристрій для уловлення продукту, який запобігав винесенню разом із частинками інертного носія. По-друге, використання фторопластової крихти дало змогу інтенсифікувати процес сушіння внаслідок збільшення поверхні тепломасообміну. По-третє, використання вентилятора і калорифера дозволяло отримати сухе гаряче повітря необхідної температури, запобігаючи потемнінню продукту.

Під час розробки сушильної установки було встановлено основні вимоги забезпечення рівномірного сушіння в усьому об'ємі сушильної камери при високих техніко-економічних показниках: мінімальних габаритах та мінімальних витратах матеріалів на побудову сушарки, мінімальних витратах теплоти та електроенергії на висушування одного кілограма сировини, простому обслуговуванні, зменшення вартості ремонту обладнання. невисокі затрати на виробництво, простота і надійність експлуатації.

Під час порівняння розрахунків за показником енергоефективності встановлено, що енергоефективність розробленої моделі сушарки вища на 0,25 % у порівнянні з типовою моделлю сушарки

Ключові слова: сушіння, псевдозріджений шар, дисперсні харчові продукти, калорифер, технологічна схема, тепломасообмін

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1. Introduction

According to reference [1], the processes related to drying account for 25 % of the national energy consumption by industrialized countries; in the food and processing industry – up to 30 %. Paper [2] indicates that the drum-type convective dryers are characterized by specific energy consumption of 4,000–9,000 kJ/kg of evaporated moisture; in this case, most losses accounted for the used drying agent (up to 40 %). In this regard, the issue on rational use of energy can be resolved in two basic ways:

– development of new, and improvement of existing, drying techniques;

– development of new technological procedures for the process of dehydration.

Choosing an energy efficient drying technique, as well as energy savings, have been increasingly relevant in recent years. Fig. 1 shows the comparison of various drying techniques in terms of their energy consumption [3].

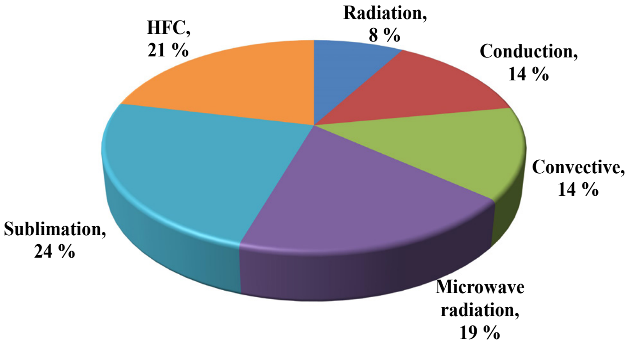

Fig. 1. Comparison of specific energy consumption by different drying techniques

Given these data, specific energy consumption is not the lowest at convective drying, but this technique has a series of advantages, such as:

– high productivity;
– simple organization of the process;
– no complexity in operation and equipment.

Thus, it is a relevant task to devise new, and to modernize existing, drying techniques. That is why this study addresses drying in the pseudo-liquefied layer of an inert carrier, which has not been applied up to now for drying the pomace of walnut kernels because of the process complexity.

2. Literature review and problem statement

Paper [4] reports results of research into dehydrating disperse foods during industrial production. It shows that scientists are forced to search for, and apply, increasingly modern and economically viable drying techniques. The issue of finding and choosing the energy-saving drying equipment requires additional investigation. Research into drying involves the processes of moisture removal from a food material, as a result of simultaneous heat and mass exchange processes [5].

Based on the research results, the authors established that most food products have a high moisture content, which is exceeds 80 %. This indicator makes food unstable to damage, requiring additional scientific investigation. This very approach was used in [6], whereby the result of dehydration of food products is a possibility to store them in stable and safe states. The study showed that reducing the activity of moisture had led to a significant increase in the shelf life of dried foods. The research reported in work [7] also established two basic conditions for improving the drying technology:

– bringing the drying kinetics in balance conformity;
– balanced hydrodynamic and thermodynamic conditions of the drying process to changes in the condition and properties of the dried material.

The above studies suggest that the time over which a material resides in the drying apparatus should not be less than the time required for drying to a predetermined humidity. It was also found that the compliance of the external environment parameters, according to the second condition, provides for the wet transfer mechanism, as well as the kinetic drying process. This also eliminates the possibility of spoiling a product during drying. In addition to these conditions, when choosing a drying technique and the process equipment, one should be guided by the following principles:

– low cost of the process stages;
– safety of drying;
– ensuring the process technology [8].

Another effective way to reduce the cost of a dried product is intensification of the drying process through the effective use of a drying chamber. The intensification of the drying process is associated in work [9] with an increase in the phase contact surface. By increasing the relative speed of the dispersed and gaseous phases, the authors increase the driving force of the drying process and reduce the heat-carrier consumption for drying. In addition, one of the common drying techniques for dispersed materials is drying in the pseudo-liquefied layer of an inert carrier, which is widely used in various industries. Such a method can significantly accelerate the process of drying food products [10]; however, achieving optimum energy consumption requires additional research into establishing ratios of structural elements in dryers with a pseudo-liquefied layer.

Patterns in the drying of walnut kernel pomace in a pseudo-liquefied layer are determined by the simultaneous progress of several physical phenomena related to transfer of heat and mass: heat exchange between the surface of a material and the environment, evaporation of moisture from the surface of a material into the environment (mass release), the movement of heat within the material (heat transfer), the movement of moisture within the material (mass transfer).

All this allows us to argue that up to now the maximum efficiency of drying products at minimum energy costs has not been demonstrated. That underlies further search for the optimum parameters and the type of drying equipment. Thus, this work addresses the construction of empirical correlations among design features of dryers with a pseudo-liquefied layer of inert carrier and the establishment of efficiency indicators.

3. The aim and objectives of the study

The aim of this study is to improve dryers with the pseudo-liquefied layer of an inert carrier based on establishing correlations among their design features.

To achieve the set aim, the following tasks have been solved:

– to design an experimental installation for the process of drying the dispersed food products;
– to investigate dependences between the drier's efficiency and the temperature of a material in the process of its dehydration;
– to explore energy efficiency of the proposed dryer model with a pseudo-liquefied layer of inert carrier.

4. Materials and methods to study the equipment for intensifying a drying process

The drying of dispersed food products in a dryer with the pseudo-liquefied layer of an inert carrier is a complex technological and physical process, due to the simultaneous grinding and milling of particles of the dried product [11].

The material that we used in the research is the pomace of walnut kernels. To provide for the rational use of methods for transporting and storing walnut kernel pomace, we examined the dispersed composition of the product by the method of microscopic determination.

Analytical, theoretical, and experimental methods of research into the drying process were applied in our study, as well as a statistical method of experimental planning. In addition, results from measurements of technological indicators of the drying process in a dryer with the pseudo-liquefied layer of an inert carrier were treated using the method of computer processing.

To investigate the process of drying the walnut kernel pomace in the pseudo-liquefied layer of an inert carrier and to solve the set tasks, we have designed and fabricated an experimental installation.

5. Experimental installation for the drying process of dispersed food products

Based on the results from laboratory studies, we have designed an experimental industrial installation for drying the dispersed food products. The drying process in it is enabled in the following way: drying of the sprayed material in a direct flow with the gaseous heat-carrier and final drying at the surface of the inert materials that are in a state of fluidization.

Our theoretical and experimental studies have made it possible to derive empirical correlations, necessary for engineering calculation of design features of a dryer with the pseudo-liquefied layer of an inert carrier for drying paste-like dispersed products. The installation for drying is characterized by the following features:

– the upper part of the chamber hosts a device to capture a product, thereby preventing the outflow of an inert carrier along with particles;

– using fluoroplastic crumbs makes it possible to intensify the drying process as a result of the increased heat-and-mass exchange surface;

– the application of a fan and a heater makes it possible to obtain a dry hot air of the required temperature, thereby preventing darkening of the product.

When designing a drying plant, the main requirements were as follows: low costs for production, simplicity and reliability in operation, low energy consumption for a drying process. The initial data employed to design and construct a drying plant are given in Table 1.

Table 1

Initial data to design and construct a drying installation

1	Raw material	Walnut kernel pomace
2	Dryer's productivity in terms of wet material, kg/s	0.45
3	Loading raw materials and product discharge	Automated
4	Drying mode control	Automated
5	Control of heater	Automated, electronic
6	Number of people to operate	3–5

According to the initial data, we selected a drying installation of continuous action with an electric heater.

A technique to supply heat to a product – convection, a heat-carrier – air.

Fig. 2 shows the structure of the designed drying chamber.

Schematic of the designed drying installation is shown in Fig. 3.

The drying installation consists of cylindrical-conical chamber 1, gas distribution grille 2, which is placed at the bottom of the chamber.

Inlet nozzle 3 is connected to electric heater 4 to heat the air fed into chamber 1 by pressure fan 5. The top of chamber 1 hosts a nozzle to introduce a product into chamber 6 with a dispenser. Outlet nozzle 7 is connected to DCSF 8. The bottom part where a dry product is collected, hosts a conical shutter along the axis of the unit. The shutter is pressed against the bottom hole of ASFP 8 through a screw with a spring.

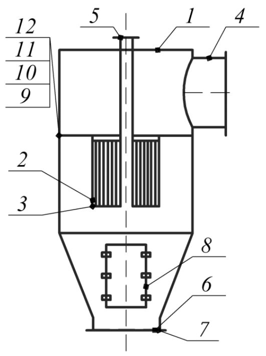

Fig. 2. Cross-section of the cylindrical-conical chamber of the drier with a pseudo-liquefied layer of the inert carrier: 1 — drying chamber; 2 — product capturing device; 3 — openings; 4 — outlet nozzle; 5 — inlet nozzle; 6 — gas distribution grille; 7 — inlet for heat-carrier; 8 — hatch; 9 — bolts; 10 — nuts; 11 — sealing; 12 — gasket

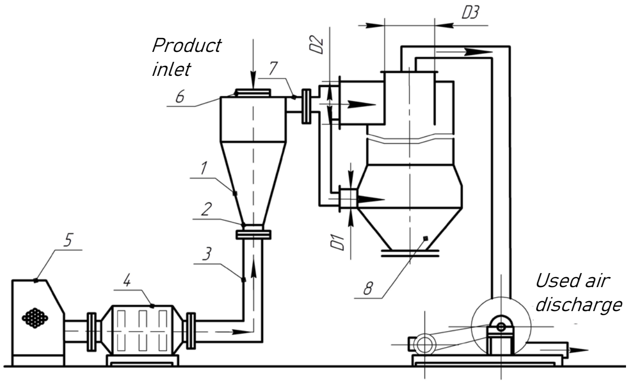

Fig. 3. Schematic of experimental installation: 1 — drying chamber; 2 — gas distribution grille; 3 — inlet nozzle; 4 — heater; 5 — fan; 6 — nozzle to introduce a product into the chamber; 7 — product release nozzle; 8 — device with counter-swirling flows (DCSF)

The installation for drying food products operates in the following way: heated air is fed to drying chamber 1 through distribution grille 2 by heater 4 and fan 5, which brings the inert carrier to the fluidization state, under which the carrier particles intensively move relative to each other. The particles of the carrier receive, through the nozzle, a paste-like product, which envelopes fluoroplastic crumbs with a thin film. Under the action of the heated air, the film dries and crushes to the fine-dispersed particles of the product. Then the spent air, along with the product, enters the swirler, from which the resulting mass enters the capacity for a dry product.

The proposed technical solution was tested at an experimental bench with a standard design of a dryer at productivity 55–60 m^3/h with the air heated, at the inlet, to a temperature of 110...150 °C, and, at the outlet, to 52...60 °C. The drying chamber's volume was 1.7 liters, its diameter – 0.12 m, the body height – 0.14 m. The distribution grille was made in the form of a mesh of 0.001×0.001 m. The grille's diameter was 0.05 m.

DCSF to capture a product has a diameter of the primary flow D_1=0.45 m, a diameter of the vortex swirler D_2=0.9 m, a diameter of the dust hole D_3=0.6 m. A dusty gas can enter the body, at the same time, through the central axial inlet and the tangential inlet of the gas flux. The secondary flow, which is fed through the swirler with a hole diameter D_1, moves from the top of the body downwards. In the course of its movement, it gradually blends with the near-axial flow, which moves from the bottom upwards through the swirler with a hole diameter D_2 [12].

Thus, the use of the installation for drying paste-like materials, due to cooling a product in the bunker, makes it possible to obtain a better product, which can be applied in agriculture and food production.

Based on the selected rational regimes, we calculated, by using empirical and standard equations of heat and mass balance, basic technical characteristics for the installation for drying a product in the pseudo-liquefied layer of an inert media. The main characteristics for the installation are given in Table 2.

Table 2

Basic characteristics of the installation for drying walnut kernel pomace

Characteristic	Characteristic value
Dryer productivity in terms of wet material, kg/h	1,980
Productivity in terms of evaporated moisture	1,000
Heat consumption, W	$35 \cdot 10^4$
Air consumption, kg air/kg moisture	32
Consumption of heat for evaporating 1 kg of moisture, kJ	3,070

Having compared the data on specific consumption of heat for evaporating 1 kg of moisture under different drying techniques, given in Table 3, we argue that drying a dispersed product by the devised technique could bring down the typical specific consumption of heat. It should be noted that the designed dryer executes a complete process of drying the product, that is, the actual drying and trapping of the product in the device with counter-swirling flows.

Table 3

Consumption of heat for evaporating 1 kg of moisture

Product drying technique	Consumption of heat for evaporating 1 kg of moisture, kJ
Drum-type dryer	4,976
Chamber dryer	7,952
Belt dryer	5,281
Devised technique	4,080

Thus, we have designed an energy-efficient installation for drying dispersed products in the pseudo-liquefied layer of an inert carrier with a capacity of 1,980 kg/h for a wet material and a heat consumption of 4,080 kJ.

6. Results of studying the dependence of a dryer performance on the temperature of a material during its dehydration

Establishing a dependence between the performance of a dryer and the temperature of a material during its dehydration is one of the relevant tasks when studying a food drying process in the pseudo-liquefied layer of an inert media. From Fig. 4, we observed that the specific performance of the dryer in terms of evaporated moisture is directly proportional to the temperature of the drying agent, that is, increasing the air temperature at the inlet to the drying chamber increases the performance of the dryer, reaching its maximum value at productivity ΔW=150 kg moisture/m^3 hour. Thus, it has been established that the optimum temperature for drying dispersed foods in the pseudo-liquefied layer of an inert carrier is 130 °C. At this temperature, the maximum performance of the drier is attained in terms of evaporated moisture. If one increases the temperature of a drying agent, it would lead to deterioration in product quality and to an increase in energy consumption. The resulting curve indicates that the temperature is the most meaningful factor that affects the performance of the dryer.

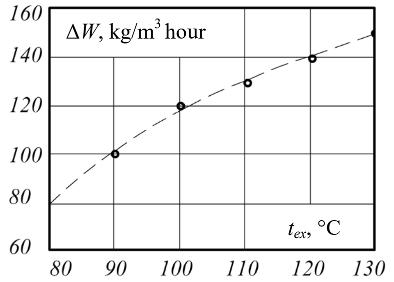

Fig. 4. Dependence of dryer performance (ΔW) on air temperature at the inlet to the chamber (t_{ex}) at ω_{in}=45 %, ω_{fin}=10 %

Fig. 5 shows interrelation between specific performance of the dryer and the initial moisture content of a material (ω_{in}) at different temperatures. These data characterize a degree of decrease in the dryer performance depending on the initial mass fraction of moisture in a product. The lower the mass share of moisture in a product, the lower the performance of the dryer for evaporating this moisture. The experiment error is 2 %.

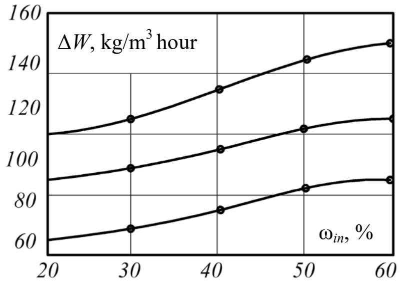

Fig. 5. Dependence of dryer performance (ΔW) on the initial moisture content in a product at ω_{in}=10 %; 1 – 90 °C; 2 – 110 °C; 3 – 130 °C

The practically important generalized dependence

$$\Delta W = f(\omega_{in}, \omega_{ex}, t_{ex}), \tag{1}$$

was studied with the use of statistical methods for experiment planning [13].

Our calculations have established that the factor, which affects most the performance of a dryer in terms of evaporated moisture, is the initial temperature and moisture content of a material. Temperature at the inlet to the chamber and the resulting humidity of the material also exert significant influence.

The temperature mode of drying, which enables obtaining a product with the resulting moisture content of up to 10 %, is as follows:

– at the inlet to the chamber – 100...130 °C;

– at the outlet from the chamber – 40...60 °C.

7. Studying the energy efficiency in the process of drying dispersed products in a dryer with the pseudo-liquefied layer of an inert carrier

The issue of energy efficiency of the drying process is extremely relevant [14]. By conducting an analytical study of the process of drying dispersed materials, we have devised ways for improved efficiency of driers in the pseudo-liquefied layer of an inert carrier (Fig. 6).

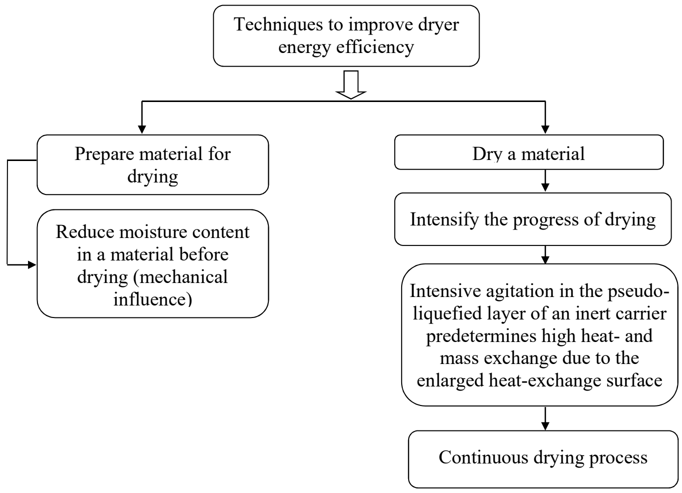

Fig. 6. Ways to improve energy efficiency of dryers in the pseudo-liquefied layer of an inert media

To compare dryers in the pseudo-liquefied layer of an inert carrier in terms of energy efficiency, we selected a standard structure of the dryer GTZ-01 for drying dispersed materials and the proposed model of a dryer in the pseudo-liquefied layer of an inert carrier. The general form of dryers is shown in Fig. 7, 8; specifications of the dryers are given in Tables 4, 5.

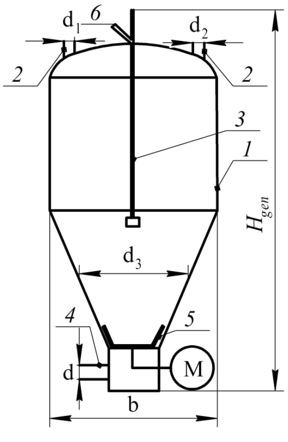

Fig. 7. Dryer in the pseudo-liquefied layer of an inert carrier GTZ-01:1 – drying chamber; 2 – nozzles for product discharge; 3 – nozzle to introduce a product to the chamber; 4 – nozzle to introduce a heat-carrier; 5 – agitator; 6 – air inlet

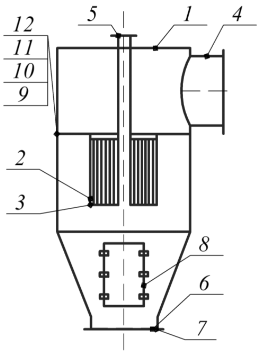

Fig. 8. The designed model of a dryer in the pseudo-liquefied layer of an inert carrier: 1 – drying chamber; 2 – product capturer; 3 – openings; 4 – outlet nozzle; 5 – inlet nozzle; 6 – gas distribution grille; 7 – inlet for a heat-carrier; 8 – hatch; 9 – bolts; 10 – nuts; 11 – sealing; 12 – gasket

Table 4

Technical characteristics of dryer GTZ-01

Performance of dryer in terms of evaporated moisture, kg/h	1,000
Mass share of moisture in a product, %:	
starting	45–75
resulting	5–8
Heat carrier temperature, °C:	
at inlet	252
at outlet	125

Table 5

Technical characteristics of the designed model of a dryer

Performance of dryer in terms of evaporated moisture, kg/h	1,000
Mass share of moisture in a product, %:	
starting	40–60
resulting	8–10
Heat carrier temperature, °C:	
at inlet	130
at outlet	50

In order to compare dryers in terms of energy efficiency at moisture removal, we employed a formula derived by scientists in [15]. To assess the efficiency of energy use during drying one should take into consideration the performance of a dryer in terms of evaporated moisture, referred to the specific energy consumption.

$$E_e = \frac{\Delta m / \Delta\tau}{Q / \Delta m}, \qquad (2)$$

where E_e is an indicator of energy efficiency, (kg/h)/(J/kg); m is the mass of moisture, removed due to drying, kg; τ is the drying time, h; Q is the full energy consumption for a process, J.

Results from our calculations are shown in Fig. 9.

The energy efficiency index under conditions of drying in the dryers of a pseudo-liquefied layer was calculated from equation (2). Comparing the energy efficiency indicators makes it clear that energy efficiency of the designed model of a dryer is much higher than that of the standard dryer, model GTZ-01. Therefore, the designed installation could be recommended for drying dispersed food products.

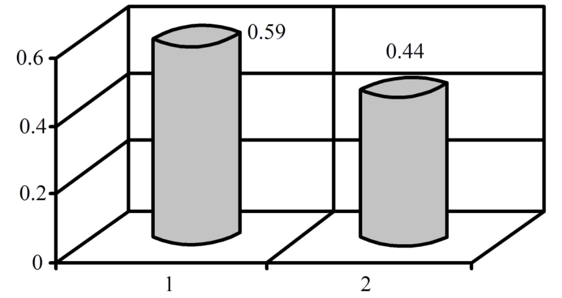

Fig. 9. Energy efficiency indicator for dryers: 1 – designed dryer in the pseudo-liquefied layer of an inert media; 2 – standard dryer, model GTZ-01

8. Discussion of results from a study into improving the installation for drying the dispersed food products

To accomplish the set task on improving the equipment to intensify the process of drying the dispersed food products, we have designed and fabricated a model of the dryer at the laboratory of Sumy National Agrarian University (Ukraine). In it, the process of drying walnut kernel pomace implied the following: drying of the spray material in a direct flow with a gaseous heat-carrier and final drying at the surface of inert materials, which were in a state of fluidization. Special features of the designed dryer are: the upper part of the chamber hosts a device for trapping a product, which prevents the outflow of inert particles along with the dried product; the use of fluoroplastic crumbs makes it possible to intensify the drying process as a result of the increased heat-and-mass exchange surface; using a fan and a heater makes it possible to obtain a dry hot air of the required temperature, thereby preventing darkening of the product.

Establishing a dependence between the performance of a dryer and the temperature of a material during its dehydration is one of the most relevant tasks when studying the drying of dispersed products in the pseudo-liquefied layer of an inert carrier. In Fig. 4, we observed that the specific performance of the drier in terms of evaporated moisture is directly proportional to the temperature of a drying agent, that is, increasing an air temperature at the inlet to the drying chamber increases the dryer performance, reaching its maximum value at performance ΔW=150 kg moisture/m^3 hour. Thus, it has been established that the optimum temperature for drying walnut kernel pomace in the pseudo-liquefied layer of an inert carrier is the temperature of 130 °C. At this temperature, the maximum dryer performance in terms of evaporated moisture is achieved. If one increases the temperature of the drying agent, it would lead to deterioration in product quality and increased energy consumption. The resulting curve indicates that temperature is the most meaningful factor that affects the dryer performance.

Fig. 5 shows the interrelation between specific performance of the dryer and the initial moisture content in a material (ω_{in}) at different temperatures. These data characterize the degree of decrease in the dryer performance depending on the initial mass fraction of moisture in the product. The lower the mass proportion of moisture in a product, the lower the performance of the dryer for this moisture evaporation.

The energy efficiency indicator under conditions of drying the pomace of walnut kernels in the dryers with a pseudo-liquefied layer was calculated from equation (2). Comparison of energy efficiency indicators of dryers has shown that energy efficiency of the designed model of a dryer is much higher than that for the standard model GTZ-01. Therefore, the designed installation could be recommended for drying walnut kernel pomace.

Thus, the devised technological line for drying the dispersed food products has the following advantages:

– we have proposed an authentic drying technique in the pseudo-liquefied layer of an inert carrier, which is based on the kinematic patterns, thereby ensuring a one hundred percent contact between a heat-carrier and the dried product and inert bodies, which makes it possible to intensify the process, to achieve the required productivity and quality of drying;

– the use of a fan and a heater makes it possible to obtain a dry hot air of the desired temperature, thereby preventing darkening of the product.

The above advantages allow us to conclude that at present this technology is the most promising; it makes it possible to receive a quality product at low capital and operating costs.

9. Conclusions

1. We have improved the drying equipment in order to intensify the drying process by studying the hydrodynamics and the process of a heat-and-mass exchange, which includes the advanced equipment for drying walnut kernel pomace and DCSF. The improved model of the drying equipment differs from a standard structure by the device to capture the product, while drying it, thereby increasing the technological process efficiency.

2. It has been established experimentally that the optimum temperature for drying the pomace of walnut kernels in the pseudo-liquefied layer of an inert carrier at the inlet to the dryer is t=130 °C, at the outlet – t=55 °C; the initial moisture content in a product prior to drying is ω_{in}=45 %, after drying – ω_{ex}=10 %. At these parameters, the maximum dryer performance is achieved in terms of evaporated moisture, ΔW=150 kg/m^3 per hour.

3. Our calculations of energy efficiency have established that the energy efficiency indicator is much higher for the designed dryer than that of a standard model, and is 0.59 versus 0.44, respectively. Thus, the drying installation can be used for drying food products.

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