UDC 676.04.02
DOI: https://dx.doi.org/10.20535/2521-1943.2018.83.143021

Probation results of the original swirling drying apparatus for paste products

V. Marchevskii ● Y. Grobovenko

Igor Sikorsky Kyiv Polytechnic Institute, Kyiv, Ukraine

Received: 03 September 2018 / Accepted: 28 September 2018

Abstract. *The purpose of this work is substantiating the technology of drying finely divided paste products and to offer the construction of a vortex dryer, to make the original apparatus and to determine the conditions under which the process of drying the titanium dioxide paste in the vortex flow of the heat carrier occurs, and the resulting dried product fits the technical and consumer requirements.*
In the article the method and the original drying vortex apparatus for drying of paste-like products and obtaining finely divided powders, the characteristics of which comply with generally accepted requirements and standards are proposed. As a result of the theoretical, simulation and experimental studies of the operation of the installation, optimal modes and operating conditions have been determined which provide the necessary hydrodynamic modes of the heat carrier movement and the high speed of the processes of drying and drying of the product. The resulting final product, a finely divided titanium dioxide powder, meets all mechanical and consumer standards.
The experimental, static and dynamic methods for determining the gas phase pressure differences, the kinetics of the grinding, drying and drying of fine-dispersed products and the optical method for investigating photo samples of the finished product TiO_2 are used in the work.
The design of the drying apparatus can be used to obtain fine particles and pigments from paste-like products, by intensive grinding and drying, in food, light, pharmaceutical, pulp and paper and other industries.

Keywords: *drying process, drying apparatus, vortex flow, coolant, dispersion, powder, dryness.*

Introduction

The process of drying fine paste is a technological process that consists of a combination of heat transfer processes of heat and mass. When choosing the optimal drying and rational design of the dryer, it is necessary to provide the conditions necessary for obtaining the technological properties of the material, which require industry standards. The rational method of heat treatment and the most suitable design of drying apparatus are established only for a particular material or group of materials having similar physical and chemical properties. In this paper, as a material for the study of drying processes, is paste of TiO_2 titanium dioxide.

An important scientific problem is reducing the cost of heat energy in the drying process, which consumes up to 25% of world energy production [1]. An insufficiently solved problem is the reduction of energy costs and the intensification of drying in the production of finely divided powders, in particular titanium dioxide. The market demand for titanium dioxide is increasing. Major consumers of TiO_2 titanium dioxide are paint and varnish, metallurgy, paper, pharmaceuticals and other industries where it is used as filler. Titanium dioxide is also used as filler for the manufacture of various plastic masses and products, and for the production of high-quality paper.

In the technology of titanium dioxide production, the process of drying paste of TiO_2 is the most energy-intensive and limiting process. One of the main indicators of finished products is the low residual moisture of fine powder. It should be no more than 0.3%. To obtain such a value of residual moisture in conventional drying machines, the temperature of the waste heat carrier at the exit of the dryer increases, this leads to significant costs of thermal energy. It is necessary to destroy agglomerates, withstand a narrow range of moisture content, to separate the particles in geometric sizes (remove dust particles), to clean the coolant. Therefore, the study of the process of drying paste of titanium dioxide and the development of new high-efficient and energy-saving equipment for obtaining a TiO_2 product with high given mechanical and consumer properties is an actual task.

✉ Y. Grobovenko
bars909@mail.ru

Analysis of scientific works

The choice of the most appropriate type of apparatus for drying a fine particle of titanium dioxide is based on the analysis of a large number of various factors that influence the drying process, such as:

- characteristics of paste as an object of drying;
- productivity of the device;
- technological requirements for drying, taking into account all the processes necessary for obtaining high-quality products;
- requirements of environmental and industrial sanitation;
- energy and economic requirements.

The analysis of literature [1, 4, 5-8] showed that at present, the choice of optimal and expedient type of drying apparatus for fine disperses paste is a complex task of the system analysis of processes and apparatuses of chemical technology. Almost such a choice is made on the basis of a quantitative or qualitative assessment of the conformity of known types of apparatus to the properties of the paste. Important properties are:

- the value of the specific surface, the size and volume of the pores, which determine together the diffusion resistance of the internal mass transfer;
- thermal properties that determine the thermal resistance during drying;
- the forms of moisture communication with the material, which determine the energy that needs to be spent on drying and affect the heat transfer mechanism;
- hydraulic properties.

Determining the full set of these properties is a complex and bulky task that requires a lot of experimental work. Therefore, in order to expedite the choice of the most appropriate type of dryer, in this work it was decided to assess the existing modern drying equipment for the conformity of the dried product.

After a preliminary assessment of existing drying equipment, many of the presented vehicles preferred a group of dry-cleaners such as "fluidized bed" (FB). This is the most promising group of devices for fine-grained materials [4, 8], since they only allow to provide heat and mass transfer to each individual unit capable of aggregation. This group includes units: boiling bed (BB) and passing boiling bed (PBB);

- «Flush» type;
- fountain bed and aero fountain bed;
- vibroboiling bed (VBB);
- swirling bed (SB);
- pneumatic transport (PT);
- with twisted streams (TS);
- with counterclockwise twisted streams (CTS).

The selected list of drying appliances should be supplemented with devices with an organized fluidized bed (OFB) and pneumatic helix driers (PHD) [5], as well as combined plants of various types.

Problems of intensification of heat and mass transfer in drying apparatuses for dispersed materials, as well as elimination of the removal of non-material material or reduction of the retour and some other problems characterizing the quality of the chosen drying method and design of the dryer, are determined by the hydrodynamic regime. Hydrodynamics of vortex flows, as well as physical and mathematical simulation of the fine-dispersed drying process, have been studied in detail and widely presented in the literature [2, 3, 7-10].

Experimental installation

In order to achieve the prescribed requirements for a dried titanium dioxide powder, a specially designed methodology for carrying out the experiment was used.

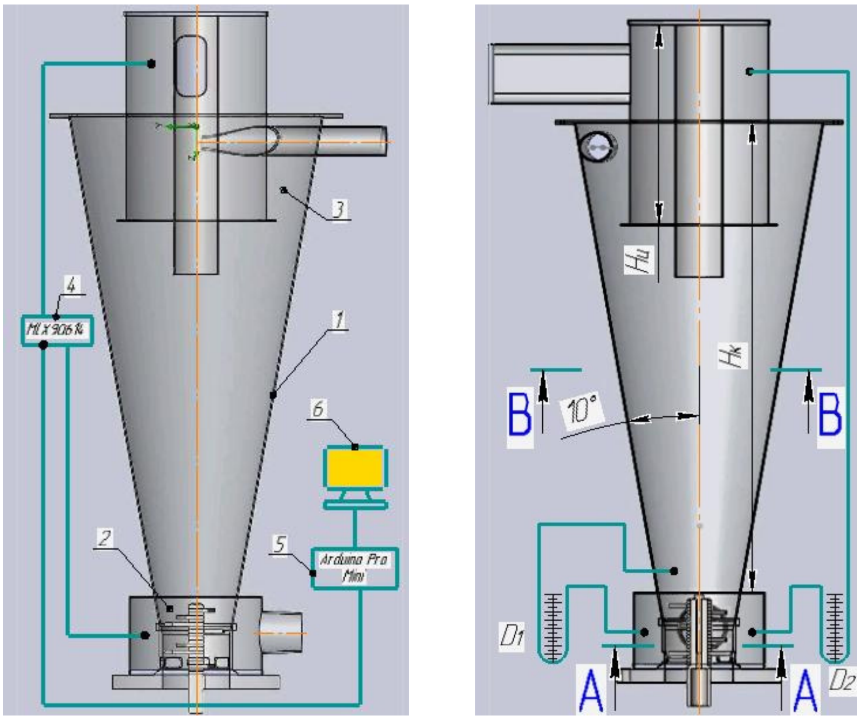
The study of the drying process of fine titanium dioxide paste in vortex fluxes of the coolant was carried out on a pilot installation with the dimensions of the vortex drying conical chamber A × B × H = 0,1 × 0,4 × 0,7 m. The vortex chamber of the drying apparatus in the lower part is equipped with a dispersant for grinding agglomerates of paste [Patent of Ukraine No. 108688, IPC F26B 17/10 (2006.01)]. Also, the authors of the article developed a method for drying paste-like materials, on which the design of a dryer was implemented [Patent of Ukraine No. 107089 of the IPC F26B 17/10 (2006.01)].

Materials

As a drying material, a thyrotrophic, fine-dispersed TiO_2 titanium dioxide paste w = 55% and a density of ρ = 2173 kg/m^3 were used which, when applied mechanically, reduced its viscosity and increased fluidity. This feature of the paste allows you to feed it into the drying chamber with an increased dryness of up to 80% and will not clog up the feeder-dispenser of the installation.

Measuring complex

The difference in pressure for the dispersion zone and the drying zone was continuously measured by two diffusers D_1 and D_2, the temperature and humidity of the vortex fluxes of the heat carrier and titanium dioxide particles by a computerized system in the application of humidity and temperature sensors MLX90614 at a frequency of 63 measurements per second (63 Hz), under connected to your computer with Arduino Pro Mini. The diagram of the arrangement of devices and sensors for data loss and differential meters is shown in Fig. 1.



a *b*

Fig. 1. Scheme of a computerized system for measuring the difference in pressure, temperature and humidity in the experimental installation of a drying machine
a – Diagram of placement of sensors for measuring the temperature and humidity of the coolant;
b – Diagram of placement of difemometers for measuring of changes in coolant pressures; 1 – vortex drying chamber; 2 – dispersant for titanium dioxide; 3 – final drying zone; 4 – sensor for measuring temperature and humidity; 5 – microcontroller Arduino Pro Mini; 6 – Computer for visualization and data storage

Theoretical studies of trajectories and hydrodynamics of vortex flows of a drying agent in a developed drying chamber

First of all, it is necessary to know the distribution of gas flow between continuous gas and fine material for the development of methods for calculating heat and mass transfer processes when drying fine-grained pastes and the creation of appropriate equipment with two-phase media. These tasks form the basis for describing the behavior of two-phase environments, namely vortex flows, and therefore cause great interest in these problems. However, satisfactory quantitative patterns that adequately reflect the aerodynamic and hydrodynamic characteristics of vortex flows are still rare in the literature.

In this paper, the original design of a drying apparatus (Figure 2) is considered for the production of a fine powder of titanium dioxide.

Two-phase vertical streams arise in the drying chamber, in which a process of drying of a wet product - a finely divided paste of TiO_2 - occurs. As a coolant the heated dry air is used at a temperature of 90 - 120°C. These flows at each stage play an important role in addition to the heat and mass transfer processes, as well as the displacement of solid dispersion over the respective zones of the drying chamber A, B, C, D (Figure 2).

In the first zone A, the dispersion of the fine material is added with the addition of dried powder and drying of the surface moisture. In the second wall zone B, the separation of the solid fraction occurs due to the centrifugal force that rejects the heavy particles on the cone-shaped surface of the drying chamber, which are transferred again to the dispersion zone A. Then the dried fine material is moved to the drying zone C, after which it enters the outlet pipe and withdrawn from the drying chamber.

The main flow of the drying agent to the bottom of the drying chamber 4 in the amount of W_1, m^3/s, is fed through the nozzle 1 to the diffuser 2, which distributes the heat carrier flows and directs them to the dispersant 3, where the flows are swirled in the vortex stream in the direction of rotation of the knives. Simultaneously, in the upper part of the drying chamber tangentially, through the nozzle 5, a drying agent amounting to W_2, m^3/s, is added to the pre-drying of the finely divided particles of the material.

The total cost of the drying agent can be written, taking into account the dimension of m^3/s, in the form:

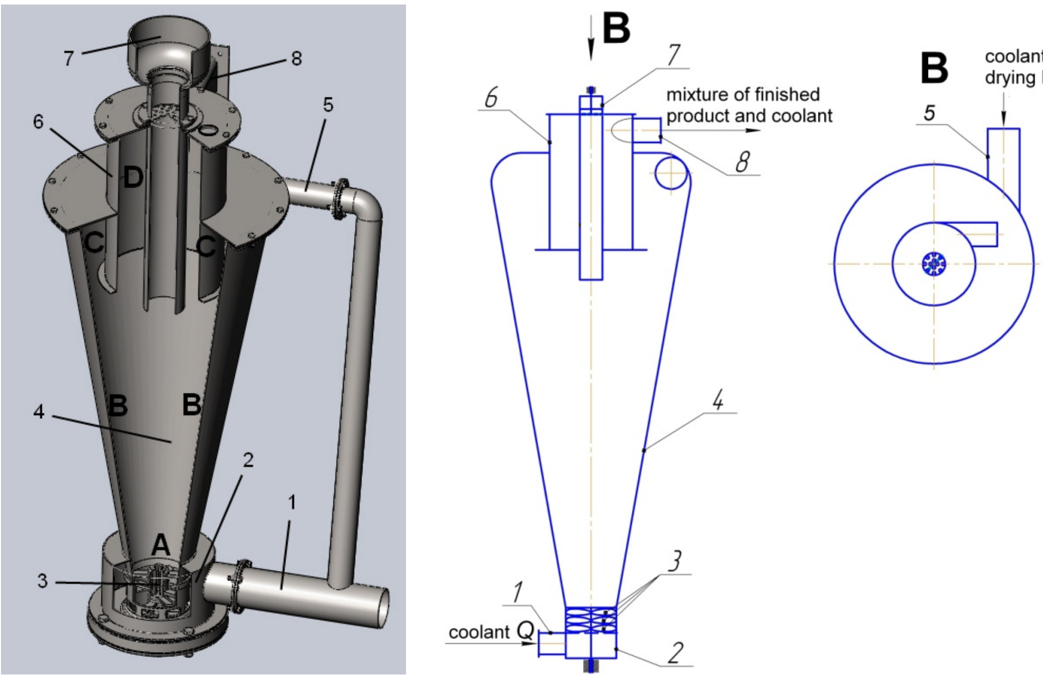


Fig. 2. Scheme of the original drying apparatus for obtaining fine dispersions
1 – main supply pipe for the drying agent; 2 – diffuser; 3 – dispersant; 4 – cone-shaped drying chamber; 5 – nozzle for final drying agent drying; 6 – separation cylinder; 7 – system for supply wet dispersions; 8 – outlet pipe; A – dispersion zone; B – fractional separation zone; C – final drying zone

$$W=W_1+W_2,\ W=k\cdot W,$$

where k – the ratio of the amount of drying agent to drying the fine particles of the material. The coefficient k to determine the required amount of drying agent for drying is determined from the material and thermal balance.

The moist material is fed into the middle of the drying chamber 4 by means of the supply system 7. As a result, two streams are found in the drying chamber and a total swirling vortex flow of the drying agent and the particles of the moist material (Figure 3-5) is formed, from which it is evident that as a result of twisting two streams in one direction, they do not destroy each other, and encountering in the middle zone of the camera in plane S, unite and deduced from the drying chamber. Placement of the plane S will depend on the cost of the drying agent W_1 and W_2, m^3/s.

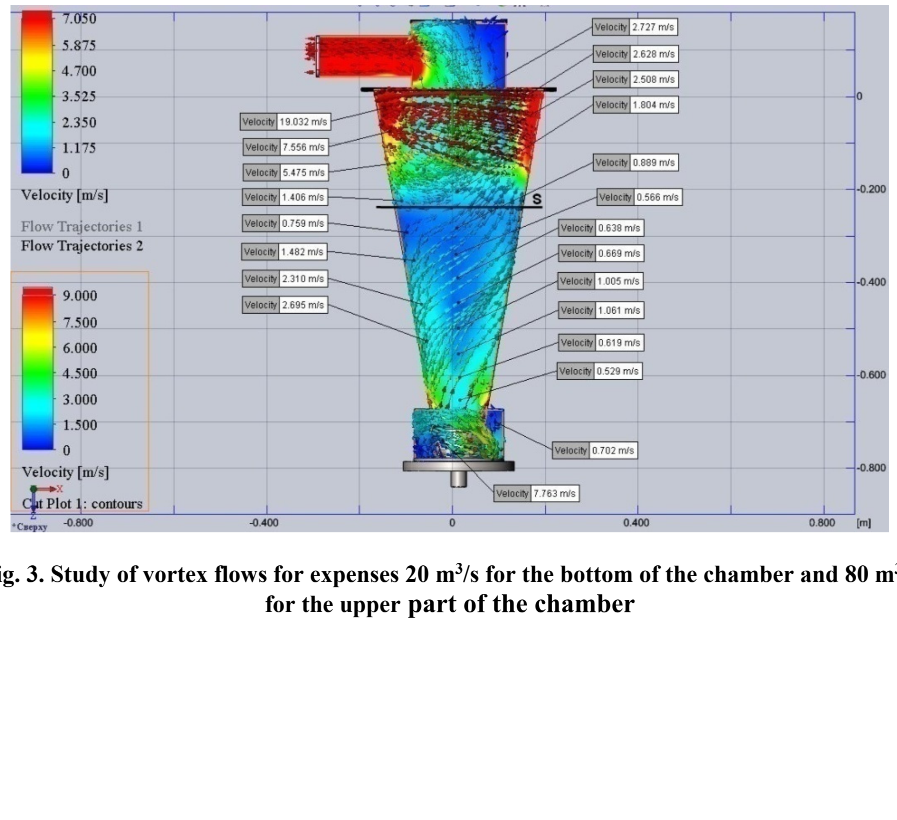


Fig. 3. Study of vortex flows for expenses 20 m³/s for the bottom of the chamber and 80 m³/s for the upper part of the chamber

Using the Solid Works design and Flow Simulation a 3D model of the dryer was designed and the velocity and pressure velocity fields of the vortex fluxes of the coolant were studied. By setting different combinations of charges of the drying agent at the inlet of branch pipes 1 and 5, one can determine the nature of the movements of the drying agent in the cell of the apparatus. The following cost values were used:

1. Entrance pipe 1 – 20 m^3/s, entrance pipe 5 – 80 m^3/s (figure 3);
2. Entrance pipe1 – 20 m^3/s, entrance pipe 5 – 120 m^3/s (figure 4);
3. Entrance pipe1 – 20 m^3/s, entrance pipe 5 – 150 m^3/s (figure 5);

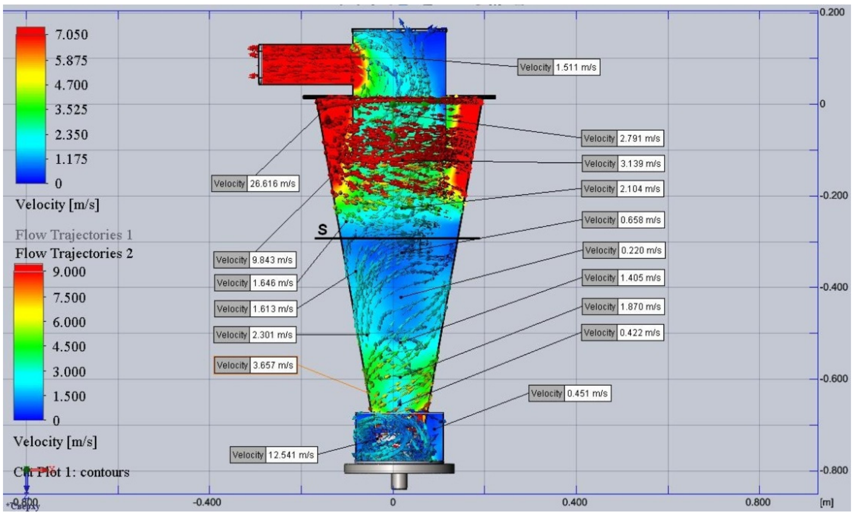


Fig. 4. Survey of vortex flows for expenses 20 m³/s for the bottom of the chamber and 120 m³/s for the upper part of the chamber

As can be seen from figures 3 and 4, the vortex flows of the coolant are twisted in one direction and occur in the middle part of the vortex chamber and inhibit each other. It is in this zone that the separation of already dried fine particles of titanium dioxide from moist paste conglomerate takes place.

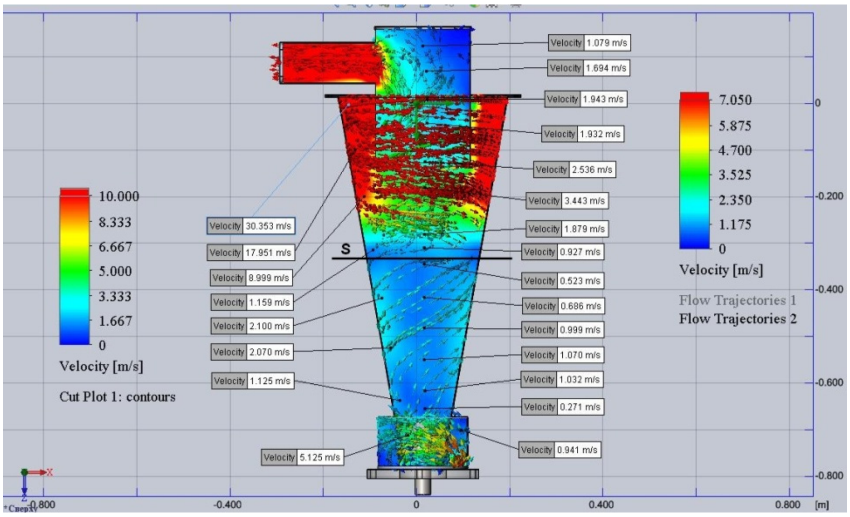


Fig. 5. Surface flow studies for costs 20 m³/s for the lower part of the chamber and 150 m³/s for the upper part of the chamber

As can be seen from the distribution diagram of the flows, the speed of the drying agent is divided into two components: axial and tangential. The axial speed is centered on the drying chamber, and which transports the finely divided particles of the material from the grinding zone to the drying zone and removes from the chamber. The tangential velocity of the gas phase is concentrated on the periphery of the drying chamber and separates the particles of the material and increases the heat transfer efficiency between the particles and the coolant due to the turbulence of the common two-phase flow and the increase of the Re number. The tangential velocity of the vortex stream decreases as a result of decreasing the radius of the drying chamber. The swirling coefficient of vortex flows is the ratio of tangential velocity to the axial and is 5.5 ... 7.0 for this drying configuration.

The suspended particulate material is raised by vortex flows to the upper part of the drying chamber 4. In this case, the agglomerated powder particles are transferred to the peripheral layer due to centrifugal forces in which the lower part of the drying chamber moves through the vortex flow of the superheated coolant supplied through the inlet pipe 9. As a result the grinding and drying of the fine powder is carried out and removed from the drying chamber through the outlet 8.

The finished product as a titanium dioxide powder must conform to the following technical requirements according to GOST 9808-84 (table 1) [4]:

Table 1

Basic technical requirements for titanium dioxide powder

№	Param	Value
1	Ultimate dryness, %	no less than 99,5
2	Dispersion, мкм	no more than 12 - 15
3	Mass fraction of titanium dioxide, %	no less than 98
4	Mass fraction of volatile substances, %	no more than 0,5
5	Mass fraction of water-soluble substances, %	no more than 0,4
6	pH of aqueous solution	6,5 – 8,0
7	Coverage, г/м^2	no more than 40
8	Linen, conditional units	no less than 95
9	Mass fraction of iron compounds in terms of Fe_2O_3, %	no more than 0,02
10	Mass fraction of phosphorus compounds in terms of P_2O_5, %	no more than 0,05

The obtained samples of the finished product of titanium dioxide were examined under a microscope and photo materials were obtained (Fig. 6), on the basis of which the distribution of the content of particles of a certain size from the particle size was obtained (Fig. 7).

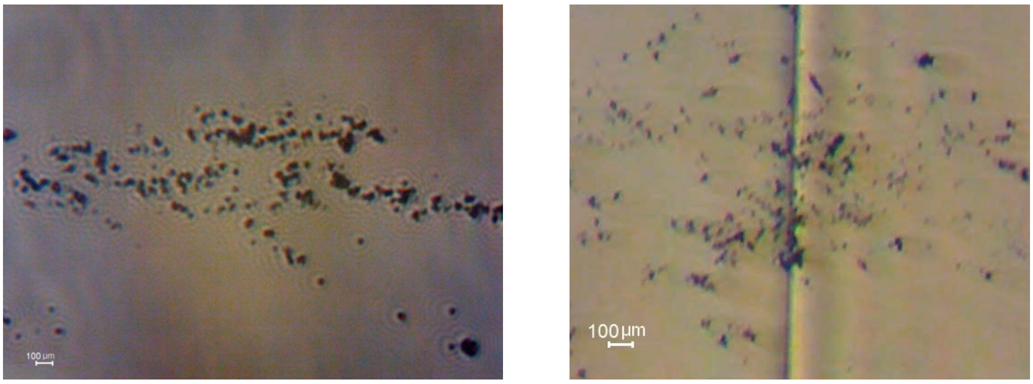


Fig. 6. Photographs of finely divided particles of titanium dioxide resulting from the drying of paste in an original dry-type apparatus of the vortex type

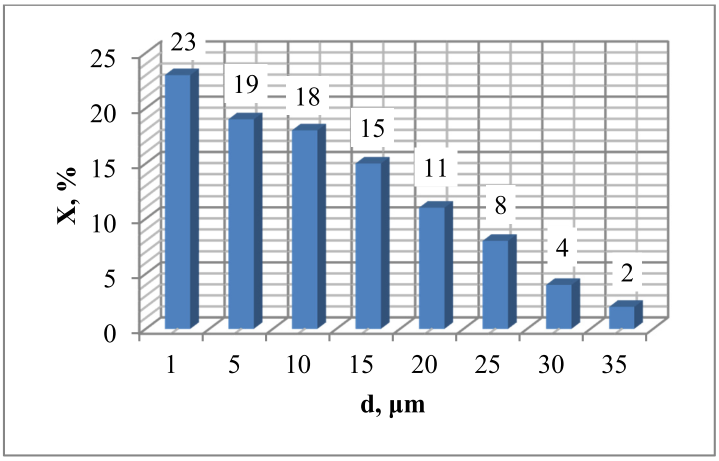


Fig. 7. Distribution of particles of a certain size from particle size

As can be seen from Figure 7, that 75% of the dispersed composition of the product is within 1-15 microns, which meets the requirements of GOST. The remaining 25% of the product will be crushed on the jet mills.

Advantages of the proposed drying machine:

1. Possibility to supply moist material with moisture content less than 40% in the drying chamber.
2. Reducing the resistance forces acting on the knives of the rotor and, accordingly, reducing the power of their drive.

The advantages mentioned above allow significantly reducing energy costs and increasing the time of drying of paste-like materials and concentrating their feeding clearly into a drying shaft through a feeder-dispenser placed on the top lid of the drying apparatus.

Conclusions

1. The method of drying of paste-like products in vortex fluxes of heat carrier is grounded.
2. A new design of a vortex device for drying of finely divided paste is proposed.
3. The conditions and modes of the drying process are determined, which provide an increase in the drying rate and a decrease in the energy consumption of the drying process.
4. The finished product fits all the necessary mechanical and consumer requirements.

Результати випробування оригінального вихрового сушильного апарату для пастоподібних продуктів

В.М. Марчевський, Я.В. Гробовенко

Анотація. *Метою даної роботи полягає в необхідності обґрунтувати технологію сушіння тонкодисперсних пастоподібних продуктів та запропонувати конструкцію сушильного апарата вихрового типу, виготовити оригінальний апарат та визначити умови при яких відбувається процес сушіння пасти діоксиду титану у вихрових потоках теплоносія, а отриманий висушений продукт відповідає технічним та споживчим вимогам.*

В статті запропоновано спосіб і оригінальний сушильний апарат вихрового типу для сушіння пастоподібних продуктів та отримання дрібнодисперсних порошків, характеристики яких відповідають загальноприйнятим вимогам і стандартам. В результаті проведених теоретичних, імітаційних та експериментальних досліджень роботи установки визначено оптимальні режими та умови роботи, які забезпечують необхідні гідродинамічні режими руху теплоносія та високу швидкість процесів сушіння і досушування продукту. Отриманий кінцевий продукт – тонкодисперсний порошок діоксиду титану, відповідає всім механічним та споживчим нормам.

В роботі застосовано експериментальні, статичні і динамічні методи для визначення перепадів тиску газової фази, кінетики процесів подрібнення, сушіння та досушування тонкодисперсних продуктів та оптичний метод дослідження фото зразків готового продукту TiO_2.

Розроблена конструкція сушильного апарату може бути застосована для отримання тонкодисперсних порошків і пігментів із пастоподібних продуктів, шляхом інтенсивного подрібнення та сушіння, в харчовій, легкій, фармацевтичній, целюлозно-паперовій та інших галузях промисловості.

Ключові слова: *процес сушіння, сушильний апарат, вихровий потік, теплоносій, дисперсний, порошок, сухість.*

Результаты испытания оригинального вихревого сушильного аппарата для пастообразных продуктов

В.Н. Марчевский, Я.В. Гробовенко

Аннотация. *Цель данной работы заключается в необходимости обосновать технологию сушки тонкодисперсных пастообразных продуктов и предложить конструкцию сушильного аппарата вихревого типа, изготовить оригинальный аппарат и определить условия, при которых происходит процесс сушки пасты диоксида титана в вихревых потоках теплоносителя, а полученный высушенный продукт соответствует техническим и потребительским требованиям.*

В статье предложен способ и оригинальный сушильный аппарат вихревого типа для сушки пастообразных продуктов и получения мелкодисперсных порошков, характеристики которых соответствуют общепринятым требованиям и стандартам. В результате проведенных теоретических, имитационных и экспериментальных исследований работы установки определены оптимальные режимы и условия работы, обеспечивающие необходимые гидродинамические режимы движения теплоносителя и высокую скорость процессов сушки и досушивания продукта. Полученный конечный продукт – мелкодисперсный порошок диоксида титана, соответствует всем механическим и потребительским нормам.

В работе применены экспериментальные, статические и динамические методы для определения перепадов давления газовой фазы, кинетики процессов измельчения, сушки и досушивания тонкодисперсных продуктов и оптический метод исследования фото образцов готового продукта TiO_2.
Разработанная конструкция сушильного аппарата может быть применена для получения тонкодисперсных порошков и пигментов с пастообразных продуктов, путем интенсивного измельчения и сушки в пищевой, легкой, фармацевтической, целлюлозно-бумажной и других отраслях промышленности.

Ключевые слова: *процесс сушки, сушильный аппарат, вихревой поток, теплоноситель, дисперсный порошок, сухость.*

References

1. Гробовенко Я. В. Kinetics of drying the titanium dioxide paste in the vortex dryer / Я. В. Гробовенко, В. М. Марчевський. // Ukrainian Food Journal. – 2018. – №7. – С. 311–323, DOI: 10.24263/2304- 974X-2018-7-2-14
2. Costa I. Analysis of regime transitions and flow instabilities in vertical conveying if coarse particles using different solids feeding systems / I. Costa, M. Ferreira, J. Freire. // The Canadian Journal of Chemical Engineering. – 2004. – №3. – С. 48–59.
3. Гробовенко Я. В. Моделювання процесу сушіння дрібнодисперсних частинок TiO_2 в потоці сушильного агенту / Я. В. Гробовенко, В. М. Марчевський. // Вісник Національного технічного університету України "КПІ", Хімічна інженерія, технологія та ресурсозбереження. – 2017. – №1. – С. 78–81.
4. Гробовенко Я. В. Аеродинаміка вихрових потоків сушильного агенту в сушильній камері / Я. В. Гробовенко, В. М. Марчевський. // Вісник Житомирського технологічного університету, серія "Технічні науки". – 2018. – №1. – С. 22–25.
5. Гробовенко Я. В. Процес сушіння пасти діоксиду титану у вихровому сушильному апараті / Я. В. Гробовенко, В. М. Марчевський. // Науковий журнал “Smart and young”. – 2016. – №11. – С. 55–58.
6. Дмитриев В. Конвективная сушка полидисперсных материалов в аппаратах закрученного взвешеного слоя / В. Дмитриев. // Вестник Тамбовского госудорственного университета. – 2013. – №3. – С. 602–614.
7. Adamiec J. Drying of waste sludges in a fluidized bed dryer with a mixer / Adamiec. // Drying Technology. – 2002. – №20. – С. 839–844. https://doi.org/10.1081/DRT-120003766
8. Mechanically agitated fluidized bed drying of cohesive particles at low air velocity / [R. Bait, S. Pawar, A. Banerjee та ін.]. // Drying Technology. – 2011. – №29. – С. 808–815. https://doi.org/10.1080/07373937.2010.541574
9. Drying kinetics of palm oil frond particles in an agitated fluidized bed dryer / I.Puspasari, M. Talib, W. Daud, S. Tasirin. // Drying Technology. – 2012. – №30. – С. 619–628. https://doi.org/10.1080/07373937.2012.654873
10. Drying of low rank coals: A review of fluidized bed technologies / [S. Chongdian, J. Wu, Y. Wang та ін.]. // Drying Technology. – 2015. – №33. – С. 277–284. https://doi.org/10.1080/07373937.2014.952382