ABSTRACT

Of the dissertation for the degree of Doctor of Philosophy PhD on 6D072400 – "Technological machines and equipment"

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Hydrodynamics and heat and mass transfer during filtration drying of crushed wood

The purpose of the dissertation research: to develop the theoretical foundations of hydrodynamics, kinetics and dynamics of heat and mass transfer processes of filtration drying of crushed cotton stalks, their experimental confirmation and, based on the scientific results obtained, to create a methodology, calculation procedure and recommendations for the design of a filtration drying plant, as well as testing in production conditions with introduction into industry.

Research objectives:

- determination of physico-chemical characteristics, fractional composition of a polydisperse mixture of crushed cotton stalks, porosity, density and determination of particle shape;
- experimental study of the hydraulic resistance of the porous structure of a layer of crushed cotton stalks under the influence of a thermal agent and obtaining a calculated functional dependence of the Euler number on the Reynolds number, determination of experimental coefficients of the modified Ergun equation;
- experimental study of the kinetics of filtration drying of crushed cotton stalks with changes in the speed, temperature of the heat agent and the height of the layer;
- obtaining dependencies for calculating the time to reach critical humidity and drying time with partial and full saturation of the thermal agent, as well as determining the total filtration drying time;
- study of the processes of heat and mass transfer between a thermal agent and dry and wet crushed cotton stalks during filtration drying and generalization of the results of experimental studies in dimensionless form;
- development of a methodology and calculation procedure for a filtration drying plant for drying crushed cotton stalks based on the results obtained, as well as recommendations for operation and design;
- testing of research results in experimental industrial conditions and implementation in industry.

Research methods: methods of sieve analysis and electron microscopy to determine the granulometric composition and structural structure, modern methods of physical and mathematical modeling to obtain experimental data on hydrodynamics, a model of ideal displacement for calculating kinetic parameters, thermophysical modeling to study heat and mass transfer, numerical and analytical methods for solving differential equations, application software packages for processing and generalization the results of experimental studies.

The main provisions (proven scientific hypotheses and other conclusions that are new knowledge) submitted for defense:

- the design of a filtration plant for drying crushed cotton stalks;

- the results of the study of hydraulic resistance during filtration of a thermal agent through a stationary layer of crushed cotton stalks, experimental coefficients of the modified Ergun equation, as well as the obtained functional dependence in the form of dimensionless Euler and Reynolds complexes;

- the established periods of full and partial saturation of the thermal agent, as well as the obtained dependence for determining the value of the kinetic coefficient “n” for crushed cotton stalks;

- dependences for calculating the time to reach critical humidity and drying time at partial and full saturation of the thermal agent, calculation equation for determining the total filtration drying time of crushed cotton stalks from initial to final moisture content;

-equations for determining the heat transfer coefficient depending on the speed of movement of the heat agent through the dry layer and the coefficients of heat and mass transfer through the wet layer of crushed cotton stalks during filtration drying;

-methodology and procedure for calculation, design and operation of industrial filtration drying plants for drying crushed cotton stalks.

Description of the main results of the study.

Using a multipurpose scanning electron microscope, the physicochemical characteristics, fractional composition, porosity, bulk and true density were determined, the geometric shapes of crushed cotton stalks were established.

During laboratory studies of the filtration drying plant, graphical dependences and calculation equations of hydraulic resistance, drying time in the periods of partial and full saturation of the heat agent with moisture, mass and heat exchange parameters during filtration of the heat agent through a layer of crushed cotton stalks were obtained.

Taking into account that the coefficient of hydraulic resistance λ1 is a function of the Reynolds number, for calculation it is presented in the form of a two-term equation that takes into account friction losses and local resistance losses:

$$\Delta\mathrm{P} = \mathrm{A} \cdot \frac{\mu \cdot \mathrm{a}^2}{32 \cdot \varepsilon^3} \cdot \mathrm{H_e} \cdot \upsilon_0 + \mathrm{B} \cdot \frac{\rho \cdot \mathrm{a}}{8 \cdot \varepsilon^3} \cdot \mathrm{H_e} \cdot \upsilon_0^2, \quad (1)$$

where A and B are experimental coefficients; μ is the coefficient of dynamic viscosity of the gas flow, Па·с; a is the effective specific surface area of the stationary layer of crushed material, $м^2/м^3$ ε is the proportion of voids per unit volume of the stationary layer of crushed material, $м^3/м^3$; υ_0 is the fictitious gas filtration rate, м/с; H_e is the equivalent length of the channels through which the gas flow moves, м; ρ is the density of the gas flow, $кг/м^3$;

To determine the experimental coefficients A and B, equations (1) should be reduced to a linear form relative to the fictitious filtration rate of the gas stream and presented as

$$\frac{\Delta\mathrm{P}}{\mathrm{H} \cdot \upsilon_0} = \mathrm{A}^* + \mathrm{B}^* \cdot \upsilon_0 , \quad (2)$$

Where $\mathrm{A}^* = \mathrm{A} \cdot \frac{\mu \cdot \mathrm{a}^2}{32 \cdot \varepsilon^3}$ and $\mathrm{B}^* = \mathrm{B} \cdot \frac{\rho \cdot \mathrm{a}}{8 \cdot \varepsilon^3} \cdot \upsilon_0$

The experimental coefficients of equation (2) for cotton stems were determined experimentally under experimental conditions:

$$\frac{\Delta\mathrm{P}}{\mathrm{H} \cdot \upsilon_0} = 9800 + 15000 \cdot \upsilon_0 \quad (3)$$

To obtain the calculated dependences in the form of dimensionless complexes, the experimental results were presented in the form of a functional dependence of the Euler number on the Reynolds number and a geometric simplex. Approximation of experimental data by a power function allowed us to determine the Reynolds number index and the experimental coefficient A:

$$\mathrm{Eu} = 105 \cdot \mathrm{Re}_e^{-0,4} \cdot \frac{\mathrm{H_e}}{\mathrm{d_e}}. \qquad (4)$$

This dependence is valid for the value of the Reynolds number 40≪Re≪180. It is shown that the maximum relative error does not exceed 8%.

Analysis of the results of studies of drying kinetics show that the critical moisture content of crushed cotton stems depends both on the temperature and filtration rate of the thermal agent and the height of the stationary layer. The periods of full and partial saturation of the heat agent with moisture have been established. The dependence for determining the value of the kinetic coefficient “n” for crushed cotton stems is obtained:

$$\eta = 3,3 \cdot 10^{-4} \cdot t^{0,54} \cdot v_0^{2.8}. \qquad (5)$$

Taking into account the dependence (5), an equation is obtained for calculating the time to reach the critical moisture content, which makes it possible to predict the intensity of filtration drying of crushed cotton stalks during the period of complete saturation of the thermal agent with moisture and is valid until the crushed cotton stalks reach the critical moisture content $w_{кр}^c$:

$$\frac{w^c}{w_0^c} = 1 - 3,3 \cdot 10^{-4} \cdot t^{0,54} \cdot v_0^{2.8} \cdot e^{-20,74 \cdot H}, \qquad (6)$$

taking into account equation (6), an equation is obtained for calculating the time for the crushed cotton stems to reach critical humidity:

$$\tau_I = \frac{(w^c - w_{kp}{}^c)}{w_0^c \cdot 3,3 \cdot 10^{-4} \cdot t^{0,54} \cdot v_0^{2.8} \cdot \tau \cdot e^{-20,74 \cdot H}}, \qquad (7)$$

and to calculate the drying time in the period of partial saturation of the heat agent with moisture, the dependence is obtained:

$$\tau_{II} = \frac{1}{\chi \cdot N} \cdot (1 + ln\chi(w^c - w_k^c)) = \\ = \frac{1}{(1,1 \cdot w_0^c \cdot 3,3 \cdot 10^{-4} \cdot t^{0,54} \cdot v_0^{2.8} \cdot \tau \cdot e^{-20,74 \cdot H})} \times (1 + ln(1,1 \cdot N \cdot (w^c - w_k^c))). \qquad (8)$$

the filtration drying time of crushed cotton stalks can be calculated as the sum of dependencies (7) and (8).

$$\tau = \tau_I + \tau_{II} = \frac{(w_0^c - w_k p^c)}{(w_0^c \cdot A \cdot t^n \cdot v_0^m e^{-a \cdot H}} + \frac{1}{\chi \cdot N} \cdot (1 + ln\chi(w^c - w_{kp}{}^c)). \qquad (9)$$

where, w^c, $w_p{}^c$, $w_{кр}{}^c$ are, respectively, the current, equilibrium critical values of the moisture content of the material; kg H_2O⁄ kg dry.mat.; **τ** is the drying time, c; “η” and “a” are kinetic coefficients; *N* is the drying rate during the period of complete saturation of the thermal agent with moisture, kg H_2O⁄ kg dry.mat.; χ - relative drying coefficient, kg H_2O⁄kg dry.mat.

The coefficient of heat transfer from the heat agent to the dry particles of crushed cotton stalks at different speeds of movement of the heat agent was calculated according to the dependence:

$$Nu = 0.35 \cdot Re_e^{0.88} \cdot Pr^{0.33}, \qquad (10)$$

where: $Nu = \frac{\alpha \cdot d_e}{\lambda}$ is the Nusselt criterion; $Re_e = \frac{v \cdot d_e}{\nu}$ is the Reynolds criterion; $Pr = \frac{\nu}{a}$ is the Prandtl criterion; λ is the thermal conductivity coefficient of the thermal agent, Вт/м·К; v-is the actual filtration rate of the thermal agent, м/с; ν - is the kinematic viscosity coefficient of the thermal agent, $м^2$/с; α - is the thermal conductivity coefficient of the thermal agent, $м^2/с$.

The dependence for determining the heat transfer coefficient from the heat agent to the wet particles of crushed cotton stalks has the form:

$$Nu = 0{,}061 \cdot \mathrm{Re}_e^{0{,}65} \cdot \mathrm{Pr}^{0{,}33}. \qquad (11)$$

The dependence for determining the mass transfer coefficient in a thin layer of crushed cotton stems taking into account the geometric parameters of the layer and the apparatus is presented as:

$$Sh = 0{,}061 \cdot \mathrm{Re}_e^{0{,}65} \cdot Sc^{0{,}33} \qquad (12)$$

The above dependences (11) and (12) allow us to determine the coefficients of heat transfer and mass transfer during filtration drying in a stationary layer of crushed cotton stalks within a wide range of changes in the Reynolds number ($10 \le Re \le 100$) and predict the costs of thermal energy for the implementation of the filtration drying process and, accordingly, the operating costs at the design stage of the filtration drying plant. The maximum value of the relative error does not exceed 9%.

Engineering and technical solutions are proposed for the development of a filtration drying plant for drying crushed cotton stalks in the production of composite chipboard, which are implemented in the LLP "Cotton Processing Plant Myrzakent". These solutions involve replacing the drum drying unit with a filtration drying unit, for which a patent of the Republic of Kazakhstan for a utility model has been obtained.

The device is distinguished by the design of the plate and the lid of the drying chamber with differential perforation with a decrease in the live section in the direction of movement of the dried material. The coolant distribution system is located directly in the drying chamber located with a decreasing step in the direction of movement of the dried material.

The proposed engineering solutions make it possible to create the same hydraulic resistance along the entire dilution chamber and reduce the material consumption of the installation. The placement of the coolant distribution system directly in the drying chamber ensures uniform drying of the material, eliminating its overheating, which will reduce operating costs and increase the efficiency of the process.

Based on the obtained equations and known dependencies in the field of heat and mass transfer, a methodology and procedure for calculating the hydraulic resistance, kinetic parameters, heat and mass transfer of a filtration drying plant has been developed, which was transferred to the Myrzakent Cotton Processing Plant LLP for calculating and upgrading the drying plant.

Recommendations on the design and operation of industrial samples of devices for drying processes have been developed and an analysis of the technical characteristics of the proposed filtration plant has been carried out with the calculation of material and operational costs.

Substantiation of the novelty and importance of the results obtained. The novelty of the proposed equations for calculating hydraulic resistance, calculated dependencies in the form of dimensionless complexes (functional dependence of the Euler criterion on the Reynolds criterion and geometric simplex, mass transfer and heat transfer coefficients in the criterion form), dependence for determining the value of the kinetic coefficient, equations for calculating the time to reach critical moisture content, is justified by the fact that they take into account the laws of motion, temperature thermal agent and layer height, granulometric composition, porosity, bulk and true density, the established geometric shapes of crushed cotton stalks, as well as the design parameters of the installation, for which there is a patent of the Republic of Kazakhstan for a utility model, are obtained on the basis of known laws of hydrodynamics and heat and mass transfer. The importance of the obtained equations lies in the fact that they form the basis of the engineering methodology and calculation procedure and allow calculating the technological parameters of the filtration drying plant.

Compliance with the directions of scientific development or state programs. The work was carried out in accordance with the research direction of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan on the priority "Sustainable development of the agro-industrial complex and safety of agricultural products", in the specialized scientific direction "Processing and storage of agricultural products and raw materials".

Description of the doctoral student's contribution to the preparation of each publication. 10 articles have been published on the topic of the dissertation. The total contribution of a doctoral student is 55-60%. The contribution to the articles is represented by such components as conducting experimental studies, processing the results in the form of tabular values and graphical dependencies, obtaining computational equations.