ABSTRACT

of dissertation for the degree of Doctor of Philosophy (PhD)
in the specialty 6D072400 – Production machines and equipment

Janabayev Dauren Zhumagalievich

Development and Calculation of the Process of Filtration Drying of Fibrous Structure Materials.

Relevance of the dissertation research. It is known that the process of removing moisture from the material is accompanied by a violation of its connection with the material, which consumes a significant amount of energy. During the drying of raw cotton, it is important to choose the optimal drying mode, because if the drying parameters are not appropriate, there is a breakage of the fiber, a decrease in its length, which reduces the quality of the fiber.

One of the high-intensity methods for removing both free and bound moisture is filtration drying. This is due to the fact that during filtration drying, the heat agent is filtered through the porous structure of the wet material. During filtration drying, the actual velocity of the heat agent relative to the layer elements is significantly higher than in the case of drying by any other methods. The large surface of heat and mass transfer and the speed of the heat agent in the pores and channels of the stationary layer of wet material provide high coefficients of heat and mass transfer and, accordingly, the intensity of filtration drying.

At the same time, the total energy consumption for the filtration drying process consists of pressure losses in the stationary layer and heating of the heat agent (air) to a given temperature. Given the above, it is important to establish the dependence of pressure losses in a stationary layer of wet cotton fiber on the fictitious filtration rate of the heat agent, as an important factor determining the intensity and economic efficiency of filtration drying.

Therefore, the use of the filtration method for drying raw cotton and experimental, theoretical studies of hydrodynamics, reducing energy costs, preserving the original quality of raw cotton is an urgent task in the processing of cotton and is of great importance for the development of the cotton cluster of the Republic of Kazakhstan.

The subject of research was hydrodynamic regularities, the kinetics of the drying process, and heat and mass transfer during filtration drying of raw cotton.

The purpose of the work: to develop the scientific basis for the process of filtration drying of fibrous materials, to create scientifically based methods for their calculation and design, and to test the results obtained in experimental industrial conditions with implementation in industry**.**

Scientific novelty of the research:

- based on a certain geometric shape of raw cotton fibers and hydrodynamic regularities of filtration of the heat agent through a stationary layer of irregular fibrous particles, the phenomenon of "shrinkage" under the pressure of the head of

the heat agent is established and equations are obtained for calculating the surface, initial and current specific surfaces of cotton fibers and the equivalent diameter of pores and channels;

- based on the Darcy-Weisbach dependence, a formula for calculating the hydraulic resistance of a porous stationary layer is derived and equations for calculating the hydraulic resistance coefficient are obtained that take into account the surface, initial and current specific surfaces, and the equivalent diameter of the pores and channels of raw cotton fibers;
- calculated dependences of the layer porosity on the fictitious speed of the heat agent, the coefficient of hydraulic resistance of cotton fibers, and the Euler number on the Reynolds number are obtained based on generalization of experimental and theoretical data of the power function;
- the periods of full and partial saturation of the heat agent are established based on the study of the laws of filtration of the heat agent through a stationary layer of raw cotton and the mechanism of filtration drying is justified;
- the regularities of the kinetics of filtration drying of raw cotton fibers in a stationary layer are studied, and the minimum layer height at which the heat agent is completely saturated with moisture is calculated, and its dependence on the filtration rate of the heat agent is determined;
- based on the similarity theory, the criterion dependences of the Nusselt and Sherwood numbers are proposed for determining the heat transfer coefficients from the heat agent to the layer of dry raw cotton fibers and the heat and mass transfer coefficients from the heat agent to the wet layer of raw cotton during filtration drying.

The theoretical significance of the study lies in the fact that on the basis of theoretical and experimental studies of the regularities of filtration drying, the methodology for calculating the filtration drying plant for drying fibrous materials is scientifically justified**.**

Practical value. The design of a filtration drying plant has been developed and a method for drying raw cotton has been proposed.

Calculation methods and recommendations for the design and operation of filtration drying plants for drying raw cotton have been developed**.**

Publications on the research topic.10 articles were published on the topic of the dissertation, including 6 articles in the proceedings of international conferences, 1 article in the publication included in the international database of scientific journals SCOPUS (percentile 29), 3 articles in journals recommended by the Committee for quality assurance in education and science of the MES RK. The materials of the articles cover the main content of the dissertation**.**

The introduction gives an assessment of the current state of the scientific problem being solved, the basis and initial data for the development of the topic, the justification for the need for research work, information about the planned scientific and technical level of development and metrological support of the dissertation, the relevance and novelty of the topic, the relationship of this work with other research works, the purpose, object and subject, research objectives, methodological base, provisions submitted for defense, practical value and testing of practical results**.**

The first section analyzes existing drying technologies and types of equipment, discusses the features of drying fiber materials and developments in the field of theory and practice of filtration drying of various materials, as well as methods for calculating them. The qualitative and quantitative requirements for raw cotton during drying are analyzed. On the basis of the analysis, the tasks of research were formulated.

The second section describes an experimental setup for studying hydrodynamic parameters, kinetics, and heat and mass transfer characteristics during filtration drying of raw cotton, and describes the design and operating principle of the filtration unit. Methods of experimental investigation of the porous structure, bulk density, total and specific surface of the fiber layer are presented. The results of the study of raw cotton using a multi-purpose scanning electron microscope are presented, which allowed us to determine the geometric characteristics of raw cotton fibers and the temperature dependences of the effective specific Isobaric heat capacity C_p, the thermal conductivity coefficient λ, and the thermal diffusivity coefficient α of raw cotton and its components.

The range of changes in the regime parameters in the conducted studies: the speed of the gas heat agent $w_г$ – 0,5÷2,5 m/s; the temperature of the heat agent ttep. $t_{теп.аг.}$= 20÷100 ^{0}C; the height of the stationary layer of raw cotton H_{ST}=0,001÷0,011 m; the drying time was 90-120 s; the mass loss of the sample during the experiment was less than 0.2%, the mass of the dried raw cotton m=0,1÷0,11kg.

The third section presents the results of studies of hydrodynamic characteristics of filtration drying of raw cotton.

Experiments have shown that when a heat agent moves through a stationary layer under the influence of a pressure drop, the equivalent diameter of the channels through which the heat agent moves, the porosity of the layer, and, accordingly, the actual speed of the heat agent change. A change in the actual filtration rate of the gas flow v leads to an increase in pressure losses in the layer ΔP, and the height of the cotton fiber layer H leads to an increase in the volume density ρ_v (analogous to the bulk density for dispersed materials). That is: $H = f(\Delta P)$; $d_e = f(\Delta P)$; $\varepsilon = f(\Delta P)$; $\rho_v = f(\Delta P)$; $\Delta P = f(v)$.. In this case, only the weight of the fiber hitch and $G_v = const$ and the outer surface of all cotton fibers $F = const$ remain constant.

Assuming that the experimental container contains N identical villi of length L_v, the outer surface of all the fibers was represented, taking into account the geometric shape, as:

$$F = 2 \cdot (\mathrm{a} + b) \cdot L_v \cdot \frac{G_v}{\rho_v \cdot a \cdot b \cdot L_v} = \frac{2 \cdot (\mathrm{a}+b) \cdot G_v}{\rho_v \cdot a \cdot b} \quad (1)$$

The initial and current specific surfaces of a conditionally stationary layer of cotton fiber, which is located in the experimental container, are determined as the ratio of the total surface to the volume:

$$S_0 = \frac{F}{S \cdot H_0} = \frac{2 \cdot (\mathrm{a}+b) \cdot G_v}{\rho_v \cdot a \cdot b \cdot S \cdot H_0}, \quad (2)$$

accordingly, we obtained the calculated formula for the current specific surface area:

$$S_{\text{тек}} = S_0 \cdot \frac{H_0}{H} = \frac{2\cdot(a+b)\cdot G_v}{\rho_v\cdot a\cdot b\cdot S\cdot H} = \frac{2\cdot(a+b)\cdot H_v\cdot S\cdot \rho_v}{\rho_v\cdot a\cdot b\cdot S\cdot H} = \frac{2\cdot(a+b)}{a\cdot b}\cdot\frac{H_v}{H} \quad (3)$$

For the equivalent diameter d_e of the pores and channels through which the coolant is filtered, taking into account (3), the equation is obtained:

$$d_e = \frac{4\cdot\varepsilon_l}{S_{\text{тек}}} = \frac{2\cdot a\cdot b\cdot\varepsilon_l}{(\mathrm{a}+b)}\cdot\frac{H}{H_v}, \quad (4)$$

To determine the pressure loss in a porous stationary layer, the well-known Darcy-Weisbach dependence was transformed, taking into account equation (4) and can be represented as:

$$\Delta P = \lambda_l\cdot\frac{H}{d_e}\cdot\frac{\rho\cdot v^2}{2} = \lambda_l\cdot\frac{H\cdot(\mathrm{a}+b)\cdot H_v}{2\cdot a\cdot b\cdot H\cdot\varepsilon_l}\cdot\frac{\rho\cdot v^2}{2} = \lambda_l\cdot\frac{(\mathrm{a}+b)\cdot H_v}{2\cdot a\cdot b\cdot\varepsilon_l}\cdot\frac{\rho\cdot v^2}{2}, \quad (5)$$

where v_0 is the fictitious filtration rate of the heat agent $v_0 = v\cdot\varepsilon_l, м/с$;

In equation (5), the formula for calculating the ξ-coefficient of hydraulic resistance of a porous layer is obtained:

$$\xi = \lambda_l\cdot\frac{(\mathrm{a}+b)\cdot H_v}{2\cdot a\cdot b\cdot\varepsilon_l}, \quad (6)$$

Approximation of the experimental data by a power function allowed us to obtain the dependence of the layer porosity ε on the fictitious velocity v_0 of the heat agent :

$$\varepsilon = \varepsilon_0\cdot v_0^{-0.025} \quad (7)$$

Generalization of experimental data on the hydrodynamics of filtration of a thermal agent through a cotton layer is presented as a dependence of the dimensionless Euler number and as a dependence of the hydraulic resistance coefficient on the Reynolds number:

$$Eu = 84\cdot 10^3\cdot Re_e^{-1.18}, \quad (8)$$

$$\xi = 16\cdot 10^4\cdot Re_e^{-1.16} \quad (9)$$

The fourth section contains the results of research of kinetic parameters and mechanism of the filtration drying of raw cotton, established that with increasing shell thermal agent begins to increase sharply the bulk density of the raw cotton, leading to significant mutual shielding of the surface, the tremendous growth in uneven filtration and the end result is to increase the drying time. This directly affects the kinetics of the filtration drying process. It is proved that the speed of filtration drying does not depend much on the height of the material layer. based on this, the minimum height at which the heat agent is completely saturated with moisture is calculated.

It has been experimentally established that during filtration drying of raw cotton fibers, a front with a height of h_{min} is formed at the beginning. At this height, the heat agent, filtering through the porous structure of the wet layer of fibrous material, gives its heat to the material, and it is saturated with moisture. If the layer height is significant and there is enough moisture, then after a while the moisture content of the heat agent reaches saturation, as a result of which its temperature decreases to the temperature of a wet thermometer. In the future, the heat agent under the influence of a pressure drop continues to filter through the porous structure of the layer, but it no longer takes part in mass transfer.

From the mechanism of filtration drying shown by us, it is established that before reaching the mass transfer front of the perforated partition, we have a complete saturation of the heat agent with moisture vapors. When the mass transfer front reaches the perforated partition, the amount of wet material decreases, and the heat agent is only partially saturated with moisture vapors. Similarly, as in the first case, it is advisable to call this stage the period of partial saturation of the heat agent.

In the fifth section, the results of studies of heat and mass transfer in a dry and wet layer of raw cotton are presented. based on similarity theories, equations are obtained for calculating the heat transfer coefficient in a dry layer of raw cotton fibers in the criterion form**:**

$$Nu = 6{,}6 \cdot 10^{-3} \cdot \mathrm{Re}_{экв}^{1{,}17} \cdot \mathrm{Pr}^{0{,}33}, \tag{10}$$

for a wet fibrous material, the Nusselt number will have the form:

$$Nu = 4{,}5 \cdot 10^{-2} \cdot \mathrm{Re}_{e}^{0{,}1} \cdot \mathrm{Pr}^{0{,}33}, \tag{11}$$

to calculate the mass transfer coefficient the Sherwood number:

$$Sh = 4{,}5 \cdot 10^{-2} \cdot \mathrm{Re}_{e}^{0{,}1} \cdot Sc^{0{,}33} \tag{12}$$

As can be seen from equations (11) and (12), for both cases, the equation in dimensionless complexes is characterized by the same exponents of the Reynolds number, which indicates the same influence of hydrodynamics on these coefficients.

It should be noted that for a fully moistened surface, the heat and mass transfer areas are almost identical, so that the surface temperature is close to the temperature of a wet thermometer; for a partially moistened surface, the effective mass transfer area decreases with increasing surface humidity.

The results obtained make it possible to predict the values of the Nusselt and Sherwood numbers, and, accordingly, to calculate the heat transfer and mass transfer coefficients for filtration drying of raw cotton fibers with an accuracy of ±9.0% within the change in the Reynolds number ($10 \le \mathrm{Re} \le 100$). They allow you to predict the cost of thermal energy for the process of filtration drying of fibrous material, operating costs at the stage of its design, and establish the economic feasibility of using the filtration drying method.

The sixth section provides recommendations for the design and implementation of a filtration drying plant for drying raw cotton.

Design recommendations contain information about the choice of operating and design parameters.

Based on the results of the research, the design of an industrial filtration drying plant was developed, which was implemented at the Myrzakent cotton Processing plant LLP in the technological scheme of primary processing of raw cotton. At the same time, by reducing the temperature of the drying heat agent to 60^0C, the power consumption per 1 ton of processed cotton is reduced to 631.77 kWh.

In conclusion, the summary findings of the dissertation research, the assessment of the completeness of the solutions of the tasks, developed recommendations and inputs on specific use of results, evaluation of technical and economic efficiency of implementation and the scientific quality of the work performed in comparison with the best achievements in this field**.**

Convention:

a and b– are the average width and thickness of lintcotton, respectively, m; G_v - the mass of sample, kg;S – is the cross – sectional area of the experimental tank, m^2; S_0, $S_{тек}$ – initial and current specific surface area of the fiber layer, m^2/m^3; ρ_v - specific density of cotton fibers, kg/m^3;H_v – height fiber layer with a density of ρ_v, м; H– the current height of the fiber layer, depending on the pressure losses, m; ε_l – porosity layer,m^3/m^3; ΔP – pressure loss in the material layer, Πa; H – layer height,m; ρ – the density of the gas flow,kg/m^3; υ – the actual speed of the gas flow,m/s. ν – kinematic viscosity coefficient, m^2/s; $Nu = \frac{\alpha \cdot d_e}{\lambda}$ – the number Nusselt; $\mathrm{Re}_e = \frac{v \cdot d_e}{\nu}$ – Reynolds number; $Pr = \frac{\nu}{a}$ – Prandtl number; $Sh = \frac{\beta \cdot d_э}{D}$ – the number of Sherwood; $Sc = \frac{\nu}{D}$ – the number of Schmidt.