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BASIC PATTERNS OF MOISTURE ABSORPTION DURING THE HYDROTHERMAL TREATMENT OF FIBROUS AND DISPERSED MATERIALS WITH THE PERIODIC HEAT AND MOISTURE SUPPLY

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The paper presents an analysis of moisture absorption during the oscillated hydrothermal treatment of fibrous and dispersed materials, which is performed on the basis of kinetic laws for vegetable raw materials and an increase in the utilization rate of the coolant energy potential considering the energetic and exergetic methods of thermodynamic analysis. As a result, the author developed a continuously acting toroidal apparatus with a periodic combined moisture and heat treatment in order to ensure the energy-effective processes of moisture absorption.

One of the directions aimed at the intensification of moisture absorption processes during the hydrothermal treatment (hydration, moisturization, washing, impregnation, etc.) of bulk materials includes the application of oscillated heat and moisture supply to produce high-quality finished products with assigned properties [1, 2].

The influence of an oscillated heat and moisture supply on the process of the hydrothermal treatment of raw materials is specified by the intensity of periodic supply of external flows and their interaction with the particles of a bulk material [1–5].

The periodic pulse mode of supplying a liquid coolant during the hydrothermal treatment with various intensities can be used to ensure the periodic action of heat on particles, decrease the coolant flow rate, and exclude the overmoisturization of a particle surface. All the above contributes to better heat- and mass exchange, shorter treatment duration, as well as an increase in the effectiveness of using the energy potential of a coolant and the quality of a finished product [2].

The present study is aimed at a description of the laws governing the moisture absorption during the oscillated hydrothermal treatment of fibrous and dispersed capillary-porous colloidal materials, as well as the development of continuously acting technological equipment with periodic heat and moisture supply for the energy-effective processes of moisture absorption.

This can be achieved by the results of studying the kinetic patterns of moisture absorption and drying, as well as the thermal and exergetic analysis of determining the degree of the thermodynamic effectiveness for the control surfaces of technological processes on the basis of the second law of thermodynamics [1–7]. In this case, basic requirements include an increase in the thermal efficiency of moisture absorption, drying, and interconnected processes, as well as a decrease in power consumption and shorter treatment duration, while continuing to ensure the high quality of finished products.

In the process of studying the hydrothermal treatment, it is necessary to examine the intensity of the heat and moisture action, as well as its influence on the process of moisture absorption by a material.

The following assumptions were made for the process of moisture absorption during the hydrothermal treatment of fibrous and dispersed materials:

– the filtration of the coolant proceeds one-dimensionally over the height of a layer h;
– there is a local thermal equilibrium in the treated medium, i.e., $\mathrm{grad}T|_V = 0$ and $\mathrm{grad}P|_V = 0$ for the layer volume V;

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– heat losses are absent;
– the instantaneous flow rate of the fluid and coolant at the entrance into the layer is constant.

In order to examine the process, the method of a sequential change of steady states is used, according to which nonstationary moisture absorption is the totality of instantaneous steady processes with continuously changing in time characteristics [2].

Let us consider that the intensity of fluid spraying shows the specific amount of a fluid per unit time and unit area of the moisturized surface of a gas distribution plate

$$i_2 = \frac{G_2}{S} = \left(\frac{g_2}{\tau_0'} \cdot f \cdot \tau_0\right) \Big/ S, \tag{1}$$

where G_2 – fluid flow rate during τ_0 time of a hydrothermal treatment, kg/s; S – area of the moisturized surface of a gas distribution plate, m^2; g_2 – quantity of the fluid sprayed during the period $(\tau_0' + \tau_0'')$, kg/period; τ_0', τ_0'' – duration of the coolant and fluid supply, s; f – frequency of fluid spraying, Hz, $f = 1/(\tau_0' + \tau_0'') = k/\tau_0$.

Taking into account the specific load on a gas distribution plate $q = G_1/S$

$$i_2 = (1/\tau_0') \cdot (G_2/G_1) \cdot q, \tag{2}$$

where G_1 – quantity of raw materials, kg; indices 1 and 2 denote solid and fluid phases, respectively.

The value of G_2/G_1 comprises a specific flow rate of a fluid per unit mass of a treated product. If the same quantity of a fluid accounts per unit of a treated material during the hydrothermal treatment, then G_2/G_1 = const.

Consequently, the intensity of periodic fluid spraying at G_2 = const is the function of the value inversely proportional to the duration of spraying during one period $1/\tau'$.

Thus, the intensity of fluid spraying at at constant quantity per unit mass of a material in the process of hydrothermal treatment is determined by the duration of supplying fluid during one period.

The relation $(\tau_0' + \tau_0'')/\tau_0'$ represents the value reciprocal of the duty cycle. If we designate the duty cycle of fluid spraying during the heat and moisture treatment as $s = \tau_0'/(\tau_0' + \tau_0'')$, than

$$s = \frac{\tau_0'}{1/f} = f \cdot \tau_0'. \tag{3}$$

Let us designate the value of moisturizing the unit area of the gas distribution plate during the time τ_0 of the heat and moisture treatment

$$j = G_2/S \tag{4}$$

Then, taking into account expression (4)

$$i_2 = (1/\tau 2_0) \cdot j = (j/S) \cdot f. \tag{5}$$

Consequently, in the process of the hydrothermal treatment with a periodic heat and moisture supply, the intensity of oscillated finely dispersed spraying of a fluid is directly proportional to the product of the moisturization per unit area of the gas distribution plate and frequency of fluid supply and inversely proportional to the duty cycle of the fluid supply.

The hydrothermal treatment process was investigated at atmospheric pressure with an oscillated supply of coolant and sprayed fluid flows under various hydrodynamic modes of the layer of a vegetable raw material, which is a capillary-porous colloidal material, taking into account the qualitative transformation of its components and an increase in the moisturization rate [2–4].

According to an experimental study of moisture absorption and removal under various modes of supplying fluid and coolant flows, a combined process with periodic moisture and heat action on particles can be proposed based on the kinetic patterns of treating a dispersed raw material [2, 3].

Following a warm-up period, subsequent stages of raw material treatment and multistage drying were carried out at pulse modes of coolant supply. The layer was permeated at the gas distribution plate with an upward flow of a coolant; a thermal action mode was used with step-changing of velocity and temperature [1–3].

As a result of studies concerning the hydrothermal treatment of vegetable raw materials, including drying, it was noted that the periodic mode of the fluid and coolant supply can provide periodic exposure of bulk material particles to moisture and heat, as well as reduce coolant consumption and overmoisturization of the particle surface. In addition, this

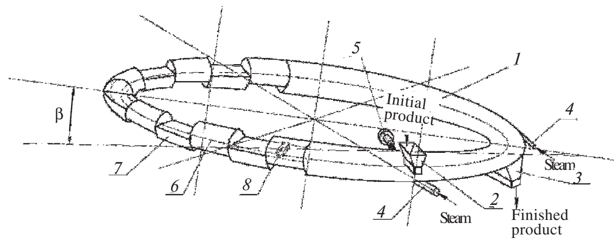

Fig. 1.

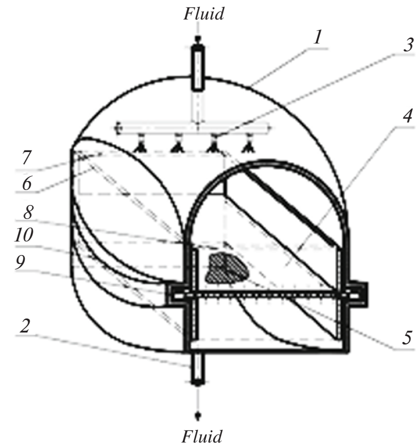

Fig. 2.

Fig. 1. Scheme of the toroidal apparatus: *1* – housing; *2* – loading bin; *3* – unloading bin; *4* – conduits; *5* – adjustable drive; *6, 7* – upper and lower sectors, respectively; *8* – sections.

Fig. 2. General view of the hydrothermal treatment module: *1* – toroidal housing; *2* – circulation conduit of the fluid supply circuit; *3* – moisturizers; *4* – sectional working chamber; *5* – frame with sieve bottom; *6* – side walls; *7, 8* – rear and front partitions, respectively; *9* – ball wheel supports; *10* – guides.

mode contributes to a better heat and mass exchange due to intensive renewal of the interphase surface, reduces the treatment duration, as well as increasing the potential efficiency of coolant energy use and the quality of finished products [2, 3, 6].

The proposed design of a combined toroidal continuous-action apparatus for hydrothermal treatment can be used in chemical, food, pharmaceutical, and other industries for providing the processes of moisturization, hydration, and drying of fibrous and dispersed materials.

The toroidal closed-cycle continuous action apparatus comprises a housing *1*, loading *2* and unloading *3* bins, conduits *4* (or steam pipelines, depending on the type of raw materials), and an adjustable drive *5* (Fig. 1). A distinctive feature of the design involves the toroidal shape of the housing located in a plane inclined towards the side of unloading finished products. The housing is provided with alternating upper *6* and lower *7* sectors with cut-outs. This housing is divided by partitions into several alternating moisturization and drying chambers including sections *8* installed in guides with the possibility of moving on rollers inside the toroidal surface of the housing.

The sections, which have a rectangular cross-section, can be displaced along a helical line. Following alternating sectors *6* and *7*, the housing assumes a cylindrical section, where, depending on the type of products, it is possible to cure the product to bring it to a finished state, as well as to dry it, if necessary, by using steam and concentrated energy flows.

The toroidal apparatus can include separate modules for treating raw materials. The module of a hydrothermal treatment of bulk materials provides for spraying the solution and saturation with a fluid. In the absence of a sprayed fluid supply, it can be used for drying of raw materials (Fig. 2). The module is made in the form of a sectional working chamber and has a toroidal housing *1*. The housing is equipped with a circulation conduit *2* of a fluid supply circuit with a heat exchanger, a pump, and moisturizers *3* for supplying the fluid medium (solution).

The sectional working chamber *4* consists of a frame with a sieve bottom *5*, side walls *6*, rear *7* and front *8* partitions, as well as ball wheel supports *9*. The rear partition *7* has an arched visor in the upper part, which covers from above the front partition *8* of the subsequent sectional chamber. The sectional working chamber *4* is located in the guides *10* with the possibility of a displacement inside the toroidal surface of the housing using ball wheel supports *9* (Fig. 1). The sectional working chamber *4* is equipped with shock-absorbing bumpers fixed on axes and rigidly connected to partitions *7* (Fig. 2).

On the basis of experimental hydrothermal treatment studies, methods were developed to combine moisture and heat action along with proposed equipment designs and compiled algorithms for controlling technological processes depending on the treated object [8–13]. Based on the results of the analysis performed by the "Rospatent"

Federal Service for Intellectual Property, the method for automatic control of the moisture and heat treatment of dispersed materials using a periodic combined convective-HF energy supply was included in a list of 100 best inventions 2018 [14].

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