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The study of changes in the thermodynamic parameters of moist air in solar-drying installations

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ABSTRACT: The work studied the thermodynamic parameters of a drying agent (moist air) in solar drying installations. The effect of the thermal and humidity state of the drying agent on the kinetics of drying the fruits is shown. Studies were carried out to determine the operational parameters of drying and the characteristics of the drying agent. The main goal of computational research is to study the boundary layer of the fetal surface, to identify the nature of the mutual influence of heat and mass transfer during drying.

An equation is obtained that relates the drying rate of fruits (during the first drying period) with the heat and mass transfer parameters of the drying agent inside the chamber in the stationary drying mode. To control the humidity in the drying chamber, automation elements were used.

KEY WORDS: drying, recirculation, dryer, air humidity, heat transfer and mass transfer, drying speed, air enthalpy, steam concentration, drying agent.

I.INTRODUCTION

In wet air technology, one has to deal with the calculation of fuel combustion processes, air conditioning systems, and especially when calculating the drying processes that occur in drying plants. In engineering practice, for the development and design of effective solar drying systems, it is necessary to have data on the temperature and humidity conditions in the whole installation based on mathematical modeling of the occurring heat and mass transfer processes. Also, for working out the drying regimes of fruits in solar dryers, it is important to accurately determine the temperature and humidity parameters of the drying agent in the drying chamber and the duration of drying of the products.

II.LITERATURE REVIEW

To increase the efficiency in thermal and, including, in solar drying plants, the recirculation mode is used during the drying process. In this mode, the spent drying agent is returned to the drying chamber. The use of recirculation accelerates the intensification of the drying process and helps to improve the quality of products.

If in the initial stage of drying (the first drying period) moisture is not removed in a timely manner, then this leads to air saturation with moisture. Continuous removal of moisture leads to large heat losses and a decrease in temperature and drying intensity.

III.METHODS AND MATERIALS.

For the rational implementation of this measure and automatic control of the drying process, it is necessary to know the drying potential of the drying agent, its thermodynamic state, and also the degree of saturation of the steam-air mixture inside the chamber, since the moisture-saturated drying agent negatively affects the intensification of the drying process. As you know, in the drying season in Uzbekistan, the average daily humidity does not exceed 15 ÷ 20%. This indicates that the exhaust air in the drying chamber has sufficient drying potential and can be reused as a drying agent. The aim of this work is to study the changes in the thermodynamic state of moist air and its effect on the drying rate of fruits in the recirculation mode.

IV.ANALYSIS

Wet air, used as a drying agent for drying and heat treatment of various materials in heat and mass transfer apparatuses, is a mechanical mixture of dry air and water vapor. At a pressure close to atmospheric, moist air can be considered an ideal gas, to which the Dalton law and the Clapeyron-Mendeleev equation of state are applicable.

To study the thermodynamic parameters of the drying agent, we consider some characteristics of the state of moist air. The main parameters of humid air include moisture content, relative humidity and enthalpy of air, vapor concentration, etc.

It is very convenient to determine the parameters of humid air, as well as solve practical problems associated with drying various products, using the Id diagram. To determine the parameters of moist air from the Id diagram, two of them must be set, then it is easy to find all other parameters from them.

The degree of saturation of moist air is characterized by the moisture content of the air, which is determined by the formula:

$$d = \frac{\mu_n}{\mu_в}\left(\frac{\varphi P_{нас}}{P-\varphi P_{нас}}\right) = 0,622\frac{\varphi P_{нас}}{P-\varphi P_{нас}} \qquad (1)$$

where μп and μв are the molecular masses of steam and air, φ is the relative humidity of the air, P is the total pressure of the vapor-air mixture, and $P_{нас}$ is the pressure of saturated steam at a given temperature. The enthalpy of moist air is one of the main parameters and is widely used in the calculation of drying plants. The enthalpy of moist air refers to one kg of dry air in a steam-air mixture and is determined as the sum of the enthalpies of dry air and water vapor, i.e.

$$I = i_B + di_n \qquad (1.1)$$

It is known that at any temperature, air can contain only a strictly defined maximum possible amount of moisture. For example, at a temperature of 0^{0C} in 1 m3 of air contains not more than 4.8 g of water, and at a temperature of 30^0C the water content rises to 30.4 g.

Of practical interest is the question: what is the maximum amount of moisture in the air in the drying chamber in the recirculation mode? Of course, we could estimate the moisture content based on some of the above data (at 0^0C, the maximum moisture content of air is 4.8 g / m3, etc.), but in the literature there is a ready-made formula for calculating this value:

$$\rho_s(T) = 4,46.10^{8,615\frac{T-273}{T}}\ г/м^3 \qquad (2)$$

where T is the air temperature. Indeed, a temperature of about 50-70^0C is maintained in the helio-drying chamber. Therefore, the maximum content of saturated water vapor in the chamber at 60^0C is

$$\rho_s(T) = 4,46.10^{8,615\frac{T-273}{T}} \approx 130,1г/м^3.$$

The state of humid air, if its temperature is up to 50 ° C, it is enough to determine the formula of Sprung. According to this formula, based on the psychomotor, you can calculate the partial pressure of water vapor in the air:

$$P_n = P^1{}_{нас} - 6,78(t_n - t_m)\ \frac{P}{10270} \qquad (3)$$

where P_n is the partial pressure of the vapor contained in the air, $P^1{}_{нас}$ is the saturated vapor pressure at the temperature of the wet thermometer.

In engineering calculations, the Sprung formula is called the psychometric formula and is written in a different form:

$$P_n = P^1{}_{нас} - A(t\ - t^1{}_m)\ P \qquad (4)$$

where $P^1_{нас}$ is the saturated vapor pressure at the temperature of the wet thermometer, $(t-t^{1м})$ is the temperature difference between dry and wet thermometers, P is the barometric pressure, and is the coefficient depending on a number of factors, of which the air speed is the main. At speed $v \geq 0{,}5\frac{м}{c}$;

$$A = 0{,}00001\ (65 + \frac{6{,}75}{v}) \qquad (5)$$

Consider the influence of the thermal state of the drying agent on the kinetics of drying products. The hot air entering the dryer comes in contact with the surface of the wet product and heat-mass transfer begins between them. At the interface between the surface of the material and the environment, the equation of the balance of the mass of moisture takes place

$$j_n = \alpha_\mu(\mu_n - \mu_c) = -a_м \rho_0(\Delta u + \delta \Delta t),$$

$\alpha_p -$ moisture exchange coefficient

$j_n -$ evaporation rate.

Under isothermal conditions, as well as at small temperature differences in the boundary layer of moist air, the difference in chemical potentials $(\mu_ò - \mu_ñ)$ can be replaced by the difference in partial vapor pressures

$$(p_ò - p_ñ) \text{ т.е. } j = \alpha_\mu(p_n - p_c) \qquad (6)$$

Formula (6) is known as the Dalton formula. Dalton's formula is approximate and reflects the interaction of a wet body with the environment. It is applicable only for the stationary drying process (evaporation of a liquid from a free surface in the period of a constant drying rate).

V.DISCUSSION

The authors developed a combined solar-thermal dryer for drying fruits. In the chamber of this dryer, it is possible to use the recirculation process of the drying agent. The recirculation of the drying agent is carried out in a sealed drying chamber. In this drying mode, the moisture content of the air inside the chamber gradually increases in the first drying period. After reaching the set value of air humidity, the moisture controller automatically turns on the top fan to discharge the spent drying agent into the atmosphere. Further, with a decrease in the air humidity in the chamber to a certain value, the fan turns off and the process repeats by the signal of the moisture regulator.

Note that in solar dryers the temperature-humidity regime is formed during the drying of fruits. For an optimal drying process, you need to know at what value of relative air humidity it is necessary to remove the used steam-air mixture from the chamber. Therefore, to determine the operating parameters of the drying and the characteristics of the drying agent, it is necessary to conduct computational studies. The main goal of computational research is to study the boundary layer of the fetal surface, to identify the nature of the mutual influence of heat and mass transfer drying. For this, it is necessary to simulate the kinetics of fruit drying and the thermal regime of the drying chamber as a whole.

The model of this phenomenon is based on the following assumptions: firstly, heat transfer in the fetus is due to moisture transfer; secondly, moisture diffusion occurs in the layer of the fetal peel, which has a diffusion coefficient D and a thickness l.

By the first assumption:

$$j = \frac{q}{r}, \qquad D = \frac{\lambda}{C_p \rho} \qquad (7)$$

Here j is the moisture mass flux density; q is the flow of thermal energy; r-latent heat of vaporization; λ thermal conductivity coefficient; Cp is the specific heat of moisture, ρ is its density. Fure law

$$q = \lambda \frac{dT}{dn} \qquad (8)$$

Therefore, taking into account (7) and (8), the density of the moisture mass flux per unit time is:

$$j = \frac{q}{r} = \frac{C_p T}{r} D \frac{dT}{dn} \qquad (9)$$

The proportionality between the density gradient and the temperature gradient at the border with the skin of the fetus is expressed by the equation:

$$\frac{dT}{dn} = \frac{T}{\rho} \frac{d\rho}{dn} \qquad (10)$$

So, taking into account the last expression, (9) the equation takes the form:

$$j = \frac{C_p T}{r} D \frac{d\rho}{dn} \qquad (11)$$

The density on the inner surface of the fetus is equal to the density of saturated steam at a given temperature, since the equilibrium of the interfacial transition is established in micropores. Therefore, the density difference Δρ is equal to:

$$\Delta\rho = [\rho_s(T) - \rho_n] \qquad (12)$$

where ρs (T) is the density of saturated vapor. It is determined from the equation of state of an ideal gas.

$$\rho_s(T) = \frac{P_s(T).\mu}{RT} \qquad (13)$$

where $P_s(T)$ is the saturated vapor pressure. It depends on temperature and is determined by the following formula [6]:

$$P_s(T) = 610{,}8.10^{8{,}615\frac{T-273}{T}}$$

Given (12) and (13), we find the expression for the speed of drying the fruits

$$\frac{dM_\phi}{d\tau} = \frac{C_p T}{r} \frac{D}{l} S_\phi [\rho_s(T) - \rho_n] \qquad (14)$$

where S_ϕ is the total area of fruits. So, we have obtained an equation linking the drying rate of fruits with the heat and mass transfer parameters of the drying agent. The saturated vapor density – ρ_s (T) is related to the relative humidity φ by the ratio:

$$\varphi = \frac{\rho_n}{\rho_s(T)} \qquad (15)$$

Therefore, expression (14) can be written as follows:

$$\frac{dM}{dt} = \frac{C_p T}{r} \frac{D.\rho_s(T)}{l} S(1 - \varphi) \qquad (16)$$

A. THE RESULTS OBTAINED AND THEIR DISCUSSION

In the solar-thermal dryer, apples and mulberry fruits were selected for experiments. Samples of the same mass (100 g each) were dried in a dryer in different modes. Moisture of the fetus was determined by the change in the mass of the fetus during the drying time. Copper-constantan thermocouples were used to measure the air temperature inside the chamber and fruits. The heat carrier velocity at various temperature conditions of the dryer was measured with an AP-1 electronic anemometer and controlled by a blower equipped with a special electric potentiometer. The mass loss of the samples was measured by an electronic balance every hour. Based on the mass of the samples, the relative humidity of the product was calculated and a curve of fruit drying was plotted (Fig. 1).

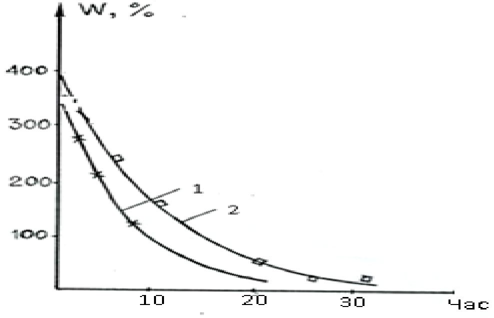

Fig. 1. Curves of kinetics of drying of fruits :. 1-apples (cut in the form of a disk 4-5mm thick), 2-mulberry. The air temperature inside the chamber is 500 C, the air velocity is v = 0.5 m / s.

From equation (16) it can be seen that the drying speed of the fruit depends on the air temperature, the diffusion coefficient of the fruit and the relative humidity. The experiments showed that the diffusion coefficient of the fetal peel is proportional to the humidity of the fetus, and is determined by the following empirical expression, which we obtained by processing the experimental data using the least square method.

$$D = D_0 e^{K\left(\frac{W}{W_0}-1\right)} \qquad (3.53)$$

where K-coefficient, the value of which depends on the type of fetus;

D_0 is the initial diffusion coefficient of the fetus. The calculation method calculated the drying speed of apples. The results were obtained at air temperatures of 40^0C and 60^0C. The graph shows that the drying speed of the fruit is inversely proportional to the relative humidity in the drying chamber. This dependence is graphically presented in Figure2.

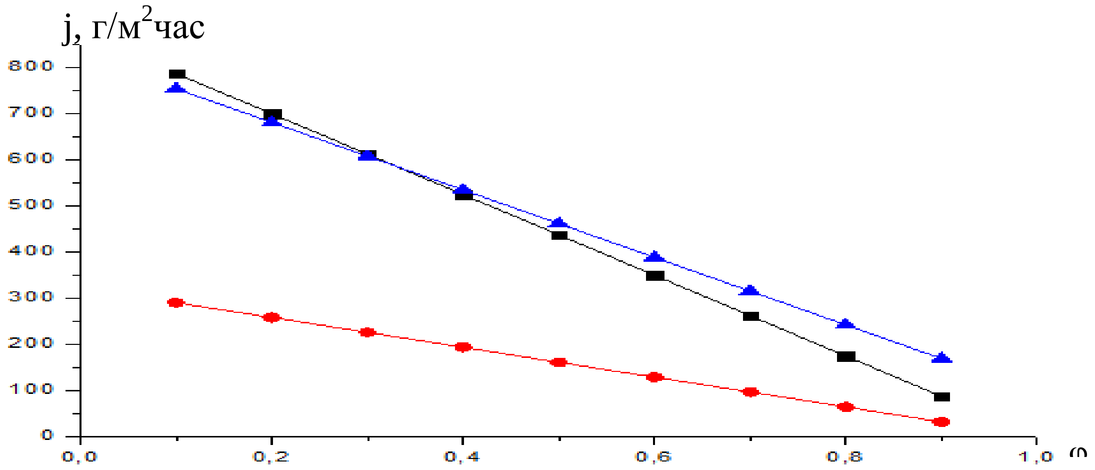

Fig. 2. The dependence of the drying speed of apples on the relative humidity in the drying chamber: 1- at T = 313K, $D^0 = 16.10^{-8}$ m^2 / s; 1^1- experiment at T = 323K, v = 0.5 m / s. 2 - T = 333K, D^0 = 16. 10^{-9} m^2 / s.

VI.CONCLUSION

Based on studies on the thermodynamic parameters of moist air in solar-drying plants, the following conclusions can be drawn: Studies have been carried out to determine the heat and mass transfer parameters of moist air at the boundary layer of the fetal surface during drying. The kinetics of fruit drying was modeled and an equation was obtained that relates the fruit drying rate to the heat and mass transfer parameters of the drying agent. The resulting equation allows us to predict the drying rate of products in solar-drying plants at any relative humidity. The drying rate of apples was calculated at air temperatures of 40^0C and 60^0C.

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