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IMPROVING THE CONTROL SYSTEM FOR THE DRYING PROCESS OF BULK MATERIALS IN CONVECTIVE DRYERS

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Annotation
This article examines the moisture content of bulk materials, drying methods and devices used in the manufacturing industry. Among them, studies have been carried out on the convective drying method and the main technological parameters of this process, which are widely used in the food, chemical, construction, fuel and energy and light industries. As a result of the research, the problems of taking into account the influence of atmospheric air on energy efficiency and optimal process control in convective dryers, as well as ensuring that the drying process is carried out according to established technological standards, were solved.

Keywords: humidity of bulk materials, drying process, convective drying methods, increasing energy efficiency during drying, optimal control.

The technological process of drying is the removal of liquid (most often water moisture, less often other liquids, for example, volatile organic solvents) from substances and materials by thermal methods. Drying is carried out by evaporating the liquid and removing the resulting vapors when heat is supplied to the material being dried, most often with the help of so-called drying agents (heated air, flue gases and their mixtures with air, inert gases, superheated steam).

Wet bodies are subjected to drying: solid colloidal, granular, powdery, lump, granular, sheet, woven and others (this group of dried materials is the most common); pasty; liquid suspensions, emulsions, solutions [1].

The purpose of the technological drying process, widely used in the production of the fuel and energy complex, agriculture, chemical, food, textile and light industries and other sectors of the national economy, is to improve the quality of substances and materials, prepare them for processing, use, transportation and storage. This process is often the last technological operation before the release of the finished product. In this case, the liquid is first removed by cheaper mechanical methods, and finally by thermal methods [2].

In large-tonnage industries with a capacity of 1 to 500 tons per hour of dried bulk material, continuous convective dryers are most widely used due to their relative simplicity and cost-effectiveness compared to dryers based on other drying methods.

Convective dryers for drying bulk (granular) materials are structurally divided into shaft-type dryers, pneumatic tube dryers, drum dryers, aero fountain dryers, with a fluidized and vibro-fluidized bed.

The proposed developments for controlling the drying process are mainly aimed at reducing energy costs during its implementation, which are a determining factor in the final price of the product. The main drying agent ingredient in most convection dryers is atmospheric air. It is characterized by dynamically changing temperature, humidity and atmospheric pressure, which necessitates their periodic measurement. During the period June-July the air temperature θ_a fluctuates within $35 \div 45^{\circ}$C.

This is the season of ripening of bulk materials. The change in relative air humidity is within 30 ÷ 80 % and accordingly moisture content Y_a within 0,006 ÷ 0,021 kg/kg.

In convective dryers, parameters such as temperature, speed and humidity of the drying agent are controlled [3]. Atmospheric air is used as a dehumidifier. The proposed drying process control controls the temperature and speed of the drying agent taking into account the current temperature and humidity of the atmospheric air. The limit values at which these controlled variables change are: temperature $\theta = 20 \div 90^{\circ}$C and speed $v = 0{,}2 \div 3$ m/s.

In the proposed control, a complex criterion is selected as an indicator of its effectiveness, taking into account energy consumption, process duration and the specified quality of the finished product at variable values of atmospheric air (temperature and humidity).

Determination of energy consumption while maximizing the potential of atmospheric air. Basically, when controlling drying processes, the kinetics of the process and very rarely the energy consumption for drying are controlled. The collected data on the process in real convective dryers show that the specific heat consumption depends on many factors and even for the same product varies widely - 1600 ÷ 14000 kJ/kg on kg evaporated water. The control criteria must take into account energy costs, determined mainly by the heat costs for the implementation of the process [4].

The energy efficiency of the process of removing moisture from a product is mainly assessed by the energy costs for its implementation. The required energy to implement the process is determined by the equation:

$$J_E = \int \alpha \dot{m}_a (c_{p,a} + c_{p,v}\ \ Y_a) \cdot (\theta - \theta_a) dt,\ \text{kWh} \tag{1}$$

where α- weight coefficient; $\dot{m}_a$- mass air flow,kg/s; $c_{p,a}$- specific heat capacity of dry air 1,005 kgJ/kg °C; $c_{p,v}$- specific heat capacity of water vapor 1,863 kgJ/kg °C; Y_a- humidity of atmospheric air,kg/kg; θ_a- ambient air temperature, °C; θ- temperature of the drying agent, °C; t_d- drying time,h.

Mass air flow $\dot{m}_a$ defined as:

$$\dot{m}_a = S \cdot v \cdot \rho, \tag{2}$$

where S forest area, m^2; v- speed of the drying agent, m/s; ρ- density of humid/exhaust air,kg/m^3.

$$J_E = \int S \cdot v \cdot \rho (c_{p,a} + c_{p,v}\ \ Y_a) \cdot (\theta - \theta_a) dt, \tag{3}$$

The values given in table 1 characterize the change in air parameters in the temperature range $\theta = 0 \div 100$ °C. Drying processes are carried out at temperatures 40 ÷ 90°C. With these values, table 1 shows that the density of the leaving drying agent ρ decreases with increasing temperature.

Table 1 Temperature change in air parameters

Temperature θ, °C	Density ρ, kg/m^3,	Specific heat capacity/thermal capacity$c_{p,a}$, kJ/kg °C	Thermal conductivity λ, W/m °C	Kinematic viscosity v_a. m^2/s $* 10^{-6}$	Expansion factor 1/^{0}C $* 10^{-3}$
0	1,293	1.005	0.0243	13.30	3.67
20	1.205	1.005	0.0257	15.11	3.43
40	1.127	1.005	0.0271	16.97	3.20
60	1.067	1.009	0.0285	18.90	3.00
80	1000	1.009	0.0299	20.94	2.83
100	0.946	1.009	0.0314	23.06	2.68

After substituting into formula (3) the area of leeches of the experimental dryer and the density of moist air at 80 °C for the mass flow is obtained:

$$J_E = \int 0.81v(1.005 + 1.863Y_a) \cdot (\theta - \theta_a)dt, \quad (4)$$

where optimization is based on variables θ and v with the corresponding atmospheric air parameters θ_a and Y_a.

Analysis (4) shows the dependence of energy consumption on the operating parameters of the drying process - temperature and speed of the drying agent. Considering dependence (4) at constant values of atmospheric air characteristics - temperature, moisture content, relative humidity and atmospheric pressure, a more significant dependence of the required energy on the speed of the drying agent is observed -v, respectively, the amount of air relative to the temperature change -θ. Or, to put it simply, maintaining a higher temperature of an agent with a larger amount of it (due to the high speed of its movement) requires greater energy consumption. Table 2 shows the analytically calculated values of the required energy per hour under the following conditions: at the end of June and beginning of July, when bulk materials ripen, the average ambient temperature is $\theta_a \approx 25^{\circ}C$, humidity -$Y_a \approx$ 0,0088 kg/kg. Forest area 1 m^2 and their load is permissible 15 kg/m².

Table 2. Required energy in kWh for drying at given parameters of the drying agent and fixed temperature and humidity of the atmospheric air.

θ/v	0.5	0.75	1.0	1.25	1.5	1.75	2.0	ρ, kg/m^3	Y_a,kg/kg	θ_a, °C;
50	0.806	1.209	1.612	2,016	2.419	2.822	3.225	1.095	0.0088	25
55	0.953	1.430	1.907	2,383	2860	3.337	3.813	1079	0.0088	25
60	1.100	1650	2200	2750	3300	3850	4399	1.067	0.0088	25
65	1.238	1.857	2.476	3.095	3,714	4.333	4.953	1.051	0.0088	25
70	1369	2.054	2,738	3.423	4.107	4.792	5.476	1.033	0.0088	25
75	1498	2,246	2995	3,744	4.493	5.242	5990	1.017	0.0088	25
80	1620	2.430	3.240	4050	4859	5669	6.479	1000	0.0088	25

The experimental results also showed a strong dependence of energy consumption on mode parameters. Therefore, it is necessary during the drying process depending on the temperature θ_a and humidity Y_a atmospheric air so that the temperature θ and speed v desiccant are determined to obtain a minimum J_E.

Excessive heating of ambient air used as desiccant with high instantaneous moisture content will result in excessive energy losses. In the presence of high relative air humidity, it is advisable to use a larger amount of drying agent and, accordingly, a higher blowing speed rather than heating it. It is also appropriate to have higher agent rates at the beginning of the drying cycle and higher temperatures and lower rates at the end to help remove moisture from the interior of the raw material [5].

All these prerequisites are specified as limiting conditions in the control algorithm used.

Determination of moisture separation. The intensity of the drying process is determined by the drying rate, which is the amount of moisture evaporated per unit time from the total body weight. The drying speed depends on the mode parameters, the dimensions and thermophysical characteristics of the material and other indicators:

$$-\frac{\mathrm{dMR}}{\mathrm{dt}} = f(M_t, \theta, \phi, v, t\varphi x, l1, l2, l3, ...) \quad (6)$$

$$t = \int \frac{\mathrm{dMR}}{f(M_t,\theta,\phi,v,t\varphi x,l1,l2,l3,....)} \quad (7)$$

or having generalized drying kinetic curves, it is possible to easily determine the moisture content of the material at any point in the process. To achieve a high drying speed, it is necessary to look for mode parameters during the drying process at which there is a minimum value of moisture separation, relative to the average moisture content of the material -$\bar{M}$. In addition, to obtain a high quality finished product, it is necessary not to exceed the maximum permissible temperature of the drying agent. This defines the objective function in process control:

$$\underset{\min}{J_U} = \bar{M} - M_e, \text{ at } \theta \leq \theta_{\text{per}}, (8)$$

Where $\bar{M}$- average moisture content of the material, kg/kg; M_e– equilibrium humidity, kg/kg.
To determine the average moisture content of the material during the drying process, models are used, table. 3, describing the kinetic drying curves for various bulk materials. In the experiments performed, a modified Page model was used. Average material moisture $\bar{M}$ during the drying process at initial humidity M_o=5.25kg/kg and equilibrium humidity M_e=0.22 kg/kg is defined as:

$$\bar{M} = (5.25 - 0.22)\exp(-(\mathrm{kt})^n) + 0.22 \quad (9)$$

where are the parameters k and n the modified Page model, depending on the values of the desiccant, is:

$$k = 1.5919 * 10^{-5} + 6.9358 * 10^{-5}\theta - \frac{0.0019}{v} + \frac{4.0082*10^{-4}}{v^2},$$

$$n = 1.6543.v^{0.6681}e^{\frac{-24.6037}{\theta}} + \frac{4.1787}{e^v} + \frac{0.5008}{v} - 0.7915$$

If the goal is to achieve a high drying speed, then it is necessary to determine the temperature during the drying process θ and speed v drying agent so as to obtain a minimum J_U under the limiting condition $\theta \leq \theta_{\text{per}}$.
By choosing adequate models that describe the kinetic drying curves, the maximum duration of the process can be determined. In this way, the user can schedule a point in time to start/start the drying process. Examples of duration calculations are given in table 3. Final value of moisture separation MR equals 0, but for correct calculations the minimum values should be taken MR $\approx$ 0.001

Table 3 Calculation of the duration of the drying process

№	Model	Name	Duration, td
1	$\mathrm{MR} = \exp(-\mathrm{kt})$	Newton	$t = -\frac{1}{k}\ln\mathrm{MR}$
2	$\mathrm{MR} = \exp(-\mathrm{kt}^n)$	Page	$t = \sqrt[n]{-\frac{1}{k}\ln\mathrm{MR}}$
3	$\mathrm{MR} = \exp(-\mathrm{kt})^n$	Modified I Page	$t = -\frac{1}{k}\sqrt[n]{\ln\mathrm{MR}}$
4	$\mathrm{MR} = \mathrm{aexp}(-\mathrm{kt})$	Henderson and Paibis	$\mathrm{t} = -\frac{1}{\mathrm{k}}\ln\frac{\mathrm{MR}}{\mathrm{a}}$
5	$\mathrm{MR} = \mathrm{aexp}(-\mathrm{kt}) + \mathrm{c}$	Logarithmic	$\mathrm{t} = -\frac{1}{\mathrm{k}}\ln(\frac{\mathrm{MR}-\mathrm{c}}{\mathrm{a}})$

In the proposed convective processing of bulk materials, the main attention is paid to its production in the process of controlling energy consumption, process costs and determining the quality of the finished product under variable atmospheric air speed (i.e. temperature, humidity, etc.). When the drying process is automatically monitored and controlled, the kinetics of the process and the amount of energy spent on cleaning are rarely kept under control. The data obtained from the process of convective dryers show that the specific heat consumption depends on many powers and can vary greatly even for the same product. For this reason, energy can be added to energy saving and optimal process control based on the proposed method.

REFERENCES

1. Antipov S.T.Warm-and mass transfer during convective drying in a moving layer of product//Modernization of existing and development of new types of equipment for the food industry: Sat. scientific tr./Voronezh. state technol. acad. – Voronezh, 2003. – Issue. 13. pp. 6-9.
2. Md. Raisul Islam, J. C. Ho, A. S. Mujumdar. Convective Drying with Time-Varying Heat Input: Simulation Results. Drying Technology, vol. 21, No. 7, 2003, pp.1333-1356.
3. Natareyev, OS Teploperenos v protsesse konvektivnoy sushki vlajnogo materiala / OS Natareyev, NR Kokina, SV Natareyev // Izv. vuzov “Ximiya i ximich. technology". – T. 58, No. 2. – 2015. – s. 67 – 72.
4. Egamberganov DI Current state of automation process of convection drying of bulk materials. // International journal of discoveries and innovations in applied sciences. Vol 3. Issue 10. 2023. 41-46.
5. AN Yusupbekov, DI Egamberganov.Development of a system for drying grain products by adapting a microcontroller.VII International Scientific and Practical Conference “Scientific advances and innovative approaches”, November 02-03, 2023. ISBN 978-92-44513-74-3 DOIhttps://doi.org/10.5281/zenodo.10079827. P. 247-251.