APPROXIMATE METHOD OF CALCULATING THE KINETICS OF CONVECTIVE DRYING OF FLAT MATERIALS

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An approximate method of calculating the kinetics of convective drying of flat materials in the period of a decreasing drying rate is presented.

The artificial drying of materials has now obtained wide application in industry. It is hard to find a factory where the goods, products, or materials have not been subject to drying at least once in the course of their technological processing. Also, the development of drying technology has been inseparably connected with the development of the scientifically based methods of engineering calculation of drying processes.

Thus, not only the tasks of the search for new, more efficient drying methods and the creation of highly productive installations but also those of the development of new engineering methods of calculation and their coordination with the kinetics of the drying process stand before the technology of drying.

An engineering method of calculating the kinetics of the convective drying of flat materials in the period of a decreasing drying rate is proposed in the present report on the basis of the works of A. V. Lykov and his students [1-7].

The intensity of heat exchange in the period of a decreasing drying rate can be found from the fundamental equation of drying kinetics

$$q(\tau) = \rho_0 r R_v \frac{d\bar{u}}{d\tau} (1 + \mathrm{Rb}), \tag{1}$$

and the intensity of moisture exchange can be found from the equation

$$j = \frac{q(\tau)}{r}. \tag{2}$$

To determine the intensity of heat exchange in the period of a decreasing drying rate it is necessary to know the dependence between the Rebinder number Rb and the moisture content $\bar{u}$ of the substance. For a majority of capillary-porous materials this dependence can be expressed (according to our experiments [2, 3, 7]) by the empirical equations

TABLE 1. Constants χ' and n in Eq. (5)

Material	Drying conditions			χ', 1/%	n
	t_1, °C	φ, %	v_1,m/sec		
Wood (pine)	90—150	5	3—25	0,005	1,1
Clay	90—150	5	3—25	0,045	1,2
Felt	90—150	5	3—26	0,007	1,1
Asbestos	90—150	5	3—25	0,0355	1,12

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TABLE 2. Values of the Constants A, n, m, and a in Eqs. (3), (6), and (8)

Material	δ, mm	Drying conditions			A	n	m	a
		t, °C	φ, %	v, m/sec				
Porous ceramic	5—10	90—150	5	3—10	0,5	20	35	$3{,}9 \cdot 10^{-3} T_m - 1$
Asbestos	4—12	9—150	5	3—25	0,5	15	22	$6{,}5 \cdot 10^{-3} T_m - 1{,}55$
Sole leather	4,5	40—60	15	3—5	0,5	8,5	7,5	$12{,}3 \cdot 10^{-3} T_m - 3{,}6$
Wool felt	8—18	90—150	5	3—25	0,1	6	12	$2{,}84 \cdot 10^{-3} T_m - 0{,}65$
Felt	4	50	24—74	0,5	0,1	10	12	$0{,}32 - 0{,}32\,\varphi$
Wood (pine)	10—50	90—150	5	3—25	0,025	—3	—2	$0{,}215 \cdot 10^{-3} T_m - 0{,}04$
Cardboard	4,5	90—130	5	3—25	0,025	—3,5	—1,9	$0{,}415 \cdot 10^{-3} T_m - 0{,}1$
Carrot	10	90	5	3—10	0,00465	—0,44		
Entobacterin	8	60—70	10—20	0,5—3	0,00465	—4,5		

$$\mathrm{Rb} = A \exp[-n(\bar{u} - u_e)], \tag{3}$$

$$\mathrm{Rb} = A(\bar{u} - u_e)^n, \tag{4}$$

where A and n are constants determined from experiment.

The use of the number Rb for calculating the drying kinetics has proved very convenient and considerably simplifies the calculations because the Rebinder number does not depend on the operating parameters in a wide interval of their variation [2, 3, 7].

To determine the drying rate in the second period we will use the equation

$$-\frac{dW}{d\tau} = \chi' N (W - W_e)^n. \tag{5}$$

The relative drying coefficient χ' and the constant n are determined experimentally from the curves of the drying rate.

An analysis of experimental data on the drying of a whole series of capillary-porous moist materials showed that the constants χ' and n entering into Eq. (5) do not depend on the operating parameters or on the thickness of the material in a wide range of their variation, the drying-rate curve being described accurately enough by Eq. (5).

The values of the constants χ' and n in Eq. (5) for certain materials are given in Table 1.

To calculate the temperature of the material in the period of a decreasing drying rate one must know the value of the relative temperature coefficient B of the drying. For a number of capillary-porous materials the dependence $B = f(\bar{u})$ can be represented by the equations

$$B = a \exp[-m(\bar{u} - u_e)], \tag{6}$$

$$B = a(\bar{u} - u_e)^m. \tag{7}$$

The constant m in Eqs. (6) and (7) does not depend on the drying conditions and is determined only by the type of material, while the value of a is a linear function of the temperature:

$$a = KT_m - P. \tag{8}$$

The values of the constants in Eqs. (3), (6), and (8) determined from experiment are presented in Table 2 for a whole series of capillary-porous colloidal materials.

From a determination of the relative temperature coefficient of the drying we have

$$B = \frac{dt}{d\bar{u}} \cdot \frac{\Delta\bar{u}}{\Delta T} \quad \text{or} \quad \frac{d\bar{t}}{\Delta T} = B \frac{d\bar{u}}{\Delta\bar{u}}, \tag{9}$$

where ΔT and $\Delta\bar{u}$ are fixed values of the temperature and moisture content of the substance ($\Delta T = T$; $\Delta\bar{u} = \bar{u}_0$ or $\Delta u = \bar{u}_{cr_1}$).

Using the empirical equation (6) together with Eq. (9) we obtain an equation for calculating the average volumetric temperature of the material:

$$t = t_m - \frac{aT_m}{mu_{cr_1}} \{1 - \exp[-m(\bar{u} - u_e)]\}. \tag{10}$$

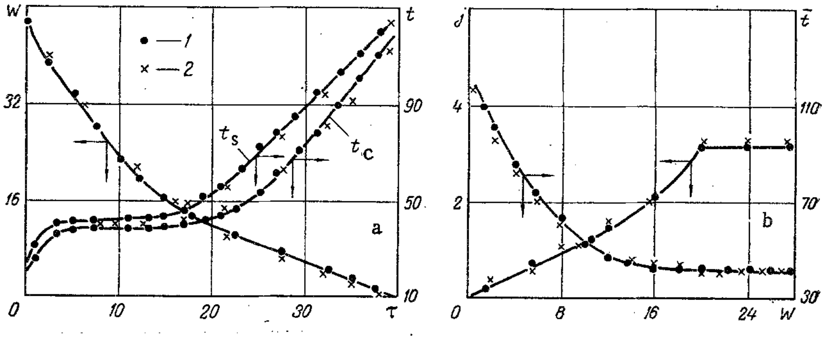

Fig. 1. Drying curve and temperature curves t = f(τ) for an asbestos plate of 120 × 80 × 6 mm (a) and curve of drying intensity and dependence between average temperature t(°C) and moisture content W (%) (b) in the course of convective drying with the conditions t_m = 120°C, v = 3 m/sec, and φ = 5% (1: experimental data; 2: calculation); τ, min; j, kg/m²·h.

The temperature at the surface of the material [4] in the course of the drying can be determined from the equation

$$T_s = T_m - N^{*0.43}(T_m - T_w). \tag{11}$$

In the period of a constant drying rate the moisture in the substance moves mainly in the form of a liquid ($\varepsilon = 0$), i.e., the temperature is the same at every point of the material and equal to the wet-bulb temperature t_w. The wet-bulb temperature can be found using Eq. (10) if the moisture content is taken as $\bar{u} \geq \bar{u}_{cr_1}$. Then

$$\bar{t} - t_w = t_m - \frac{aT_c}{m\bar{u}_{cr_1}}\{1 - \exp[-m(\bar{u}_{cr_1} - u_e)]\}. \tag{12}$$

In the period of a decreasing drying rate the temperature distribution over a cross section of the material obeys a parabolic law. Using this, the average temperature over the volume of the material is

$$\bar{t} = t_c + \Pi(t_s - t_c), \tag{13}$$

where Π is a constant numerical coefficient (for a plate Π = 1/3).

The temperature at the center of the material is determined from Eq. (13):

$$t_c = \frac{\bar{t} - \Pi t_s}{1 - \Pi}. \tag{14}$$

We can find the duration of the drying process by integrating Eq. (5). Then

$$\tau = \frac{W_0 - W_{cr_1}}{N} + \frac{(W_{cr_1} - W_e)^{1-n}}{(1-n)\chi' N}\left[1 - \left(\frac{W - W_e}{W_{cr_1} - W_e}\right)^{1-n}\right]. \tag{15}$$

Thus, the given method of calculating the drying kinetics allows one to determine all the main parameters of the process and agrees well with experiment.

A comparison of experimental data with the calculated values computed from the equations presented is given in Fig. 1a and b for an asbestos plate when it is dried under the conditions of forced convection. It is seen from the figure that the maximum error in the determination of the main characteristics of the drying kinetics (intensity of heat and moisture exchange, temperature of the material, duration of the process) does not exceed 3-5%, which is fully acceptable for approximate engineering calculations.

In conclusion, we note that the equations presented above allow one to solve problems of drying kinetics rather accurately and to considerably simplify the calculations.

NOTATION

B is the relative temperature coefficient of drying;
Rb is the Rebinder number;

$\bar{u}$	is the moisture content;
N	is the drying rate in the first period;
c	is the heat capacity of moist material;
b	is the temperature coefficient of drying;
u_e	is the equilibrium moisture content;
χ'	is the relative drying coefficient;
A, a, n, m, K, P	are the constants determined from experiment;
τ	is the duration of drying;
R_v	is the ratio of volume of the material to its surface;
r	is the specific heat of evaporation;
ρ_0	is the density of dry material;
q	is the intensity of heat exchange;
j	is the intensity of moisture exchange;
W	is the moisture of material per dry weight;
W_e	is the equilibrium moisture;
t_w	is the wet-bulb temperature;
$\bar{u}_{cr_1}$	is the first critical moisture content of material;
t_m, T_m	are the temperatures of medium;
$\bar{t}$	is the average volumetric temperature of material;
t_s, T_s	are the temperatures at surface of material;
t_c	is the temperature at center of material;
W_{cr_1}	is the first critical moisture of material;
$\Delta\bar{u}$ and ΔT	are the fixed moisture content and fixed temperature;
ε	is the phase-transformation number.

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