CALCULATION OF THE DRYING OF A DISPERSE POLYFRACTIONAL SYSTEM

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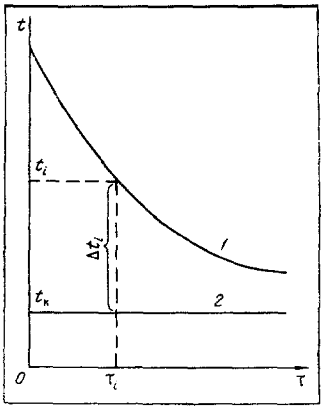
A method is presented for the calculation of the time required to dry disperse polyfractional ceramic suspensions with a high initial content of the solid phase.

In addition to the processes of heat and mass transfer, the general solution for the problem of the evaporation of a disperse polyfractional system of drops must take into consideration such processes as the dispersion of the material, its distribution in the gas flow, and the joint motion of the material and the hot gases. A general solution is presently impossible, not only because of the mathematical difficulties, but also because of the fact that the mechanism responsible for certain of the phenomena responsible for the actual drying process is unclear. For an analysis of the experimental data and for the generalization of the latter it is extremely important to have analytical solutions for the problem of the evaporation of a polyfractional system of drops, with these problems formulated in the simplest manner.



Temperature change in gases and material as a function of time: 1) temperature of gas medium; 2) temperature of material.

The literature contains several references devoted to this problem. Of greatest interest among these is the work of Marshall [1], in which the method of successive approximations is used to calculate the time required for the evaporation of a cloud of water droplets of a specified granulometric composition, in the assumption that Nu = 2.

In considering the drying drops in suspension, we must bear in mind that the final diameter of the dried particle is governed by the content of the solid phase in the suspended drop.

Studies conducted at the Institute of Gasses of the UkrSSR Academy of Sciences into the drying of solitary drops of ceramic suspensions used in the manufacture of structural ceramics have demonstrated that the diameter of a drop in the drying process varies insignificantly. For an initial moisture content of 50% in the suspension, the change in the drop diameter is approximately 10%. Moreover, it has been established that the drying process occurs primarily during a period of constant velocity, and that the temperature of the drop in the suspension varies only slightly, depending on the temperature of the ambient medium.

Considering the above, let us consider the process of heat and mass transfer between a polyfractional system of drops in a ceramic suspension and high-temperature gases. It is assumed in the formulation of the problem that the distribution of the particles has been specified in advance on the basis of size; the particles have been uniformly distributed through the volume of the gas; at each instant of time the gas temperature is uniform through the entire volume and it is equal to t_i at the initial instant of time. The time variation of the gas and material temperature is shown schematically in the figure.

To simplify the calculations, we assume the particle diameter D and the drop temperature t_d to be constant throughout the entire drying process: D = const; t_d = const. We assume that the heat and mass transfer for the small drops is subject to the equation Nu = 2.

The disperse material is conditionally divided into n fractions on the basis of particle size. The particle diameters in each fraction are assumed to be identical. The calculation of the drying is carried out in stages, as each fraction is completely dried.

Data for the Calculation of the Drying of a Ceramic Suspension of Specified Granulometric Composition

i	D_i, μm	M_i	$\Delta\varphi^i_{av}$	t_i, °C	t_{i+1}, °C	Δt_i, °C	λ_i, kcal/m · hr · deg	τ_i, sec	The moisture content of the various moisture compositions					
									I	II	III	IV	V	VI
1	50	0.08	0.08	1000	860	860	0.047	0.007	0	0	0	0	0	0
2	100	0.12	0.20	860	650	755	0.044	0.034	0.375	0	0	0	0	0
3	150	0.20	0.335	650	415	532	0.039	0.105	0.450	0.283	0	0	0	0
4	200	0.25	0.425	415	260	338	0.034	0.28	0.469	0.375	0.215	0	0	0
5	250	0.20	0.477	260	170	215	0.031	0.68	0.48	0.42	0.32	0.18	0	0
6	300	0.15	0.500	170	130	150	0.029	1.41	0.491	0.449	0.379	0.28	0.15	0

At the instant τ_i, when the very smallest particle (the first fraction) has not yet dried out, we can write for each of the fractions of the material

$$M_i \Delta \varphi_i R = \alpha_i F_i \Delta t \tau_i. \tag{1}$$

Having substituted the values of F_i and α_i into Eq. (1), after simple transformations, we obtain

$$\tau_i = \frac{R \rho D_i^2 \Delta\varphi_i}{12 \lambda \Delta t}. \tag{2}$$

We write Eq. (1) for the first and any other fraction of the material at the instant of time τ_i, and we compare the values of $\Delta\varphi$:

$$\Delta \varphi_i = \Delta \varphi_1 \frac{D_1^2}{D_i^2}. \tag{3}$$

The fraction $\Delta\varphi_{av}$ of the moisture removed from all of the material during τ_i will be equal to

$$\Delta \varphi_{av} = \sum_{i=1}^{n} M_i \Delta \varphi_i. \tag{4}$$

At the instant at which the k-th fraction is completely dried, the fraction of the moisture removed from the material will be

$$\Delta \varphi_{av}^k = \varphi_0 \left[\sum_{i=1}^{k} M_i + D_k^2 \sum_{i=k+1}^{n} \frac{M_i}{D_i^2} \right]. \tag{5}$$

The process of drying a polyfractional material is treated in sequence, as each of the fractions dries out. We rewrite Eq. (2) in the following form for the i-th fraction:

$$\Delta \tau_i = \frac{R \rho D_i^2 \varphi_i}{12 \lambda_i \Delta t_i}. \tag{6}$$

Here $\Delta\tau_i$ is the time required for the complete drying of the i-th fraction, after the (i−1)-th fraction has dried out.

The moisture content φ_i for this instant is easily determined from (3), since we know that the initial moisture content of the material is equal to φ_0:

$$\varphi_i = \varphi_0 \left(1 - \frac{D_{i-1}^2}{D_i^2} \right). \tag{7}$$

Let us substitute the value of φ_i into Eq. (6):

$$\Delta \tau_i = \frac{\varphi_0 R \rho (D_i^2 - D_{i-1}^2)}{12 \lambda_i \Delta t_i}. \tag{8}$$

We will subject each of the material fractions to similar considerations. The total time required for the drying of the n-th fraction is

$$\tau_n = \frac{R \rho \varphi_0}{12} \sum_{i=1}^{n} \frac{D_i^2 - D_{i-1}^2}{\lambda_i \Delta t_i}. \tag{9}$$

The values of λ_i are taken for the average temperature of the vapor-gas film. The values of the initial (t_i) and final (t_{i+1}) temperature for the gas medium for each time interval are determined from the heat-balance equation of the system from the formula

$$t_{i+1} = t_i - \frac{R' M_m}{c M_g} \Delta \varphi_{av}^i. \tag{10}$$

Here c is the gravimetric specific heat of the gas; M_g and M_m denote the mass of the gases and of the material; R' is the specific heat of vapor formation with consideration given to the loss of heat to the ambient medium, to the heat expended on the heating of the material and on the water vapor, referred to 1 kg of evaporated moisture.

In determining the average gas temperature for each time interval for a large number of intervals, we can use the mean arithmetic law of temperature averaging.

Thus the calculation of the time required for the drying of a polyfractional material with a high content of the solid phase reduces to the division of the material into fractions. We then determine the values of the mean losses in moisture content by all of the material after each of the fractions has been dried out. For a given value of M_g/M_m, we calculate the mean temperature of the gas for each drying-time interval. On the basis of the temperature for the gas medium, we find the values of λ_i and Δt_i for the intervals. The total drying time of any given fraction is determined from formula (9).

The data of typical calculations carried out for the drying of a ceramic suspension with specified granulometric composition are given in the table. It was assumed in the calculation that

$$\frac{M_g}{M_m} = 1.5 \text{ kg/kg}, \quad c = 0.28 \text{ kcal/kg} \cdot \text{deg},$$

$$t_d = 70^\circ \text{C}, \quad \rho = 1400 \text{ kg/m}^3, \quad t_i = 1000^\circ \text{C},$$

$$R' = 730 \text{ kcal/kg} \quad \varphi_0 = 0.5.$$

The total time required for the drying of a polyfractional system of drops is 1.41 sec. The calculation of the evaporation of a monofractional system of drops exhibiting diameters of 300 μm, for the same initial data, yields a result of 1.25 sec. The average temperature difference between the gas and the material for a monofractional system was assumed to be a logarithmic mean.

The increase in the time required for the drying of a polyfractional material can be explained by the differing intensity needed for the drying of drops of various diameters: small drops dry out more rapidly, markedly lowering the gas temperature, as a result of which the conditions for the drying of large drops are impaired.

In applying this method to calculate the drying of a material in spray dryers, we have to determine the average temperature difference between the gas and the material, bearing in mind the unique features involved in the execution of the process.

Analysis of the operation of drum spray dryers shows that the large recirculation flows in the drying chamber virtually even out the gas temperature throughout the entire volume (2). Equation (10) is not suitable in this event. For a uniform gas temperature t_g in a drum dryer we can write: $\lambda_i = \text{const}$, $\Delta t_i = t_g - t_d = \text{const}$.

The determination of the drying duration for the material on the basis of formula (9) then coincides with the time calculated for the drying of the very largest drops. The small fractions have no effect on the drying process for the large drops in this case.

In dryers which operate without recirculation flows, we find substantial gas-temperature gradients running vertically. Here it is best to use Eq. (10), which can be refined with a correction factor for the distribution of the gas velocities through the cross section of the dryer.

NOTATION

M is the weight fraction; R is the specific heat of evaporation; $\Delta\varphi$ is the loss of moisture; α is the heat transfer coefficient; Δt is the mean temperature difference between the gas and the material at τ_i; F is the particle surface; τ is the drying time; i is the ordinal fraction number; ρ is the suspension density; λ is the thermal conductivity of the medium.

REFERENCES

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