DESICCATION KINETICS OF A THIN LAYER OF PELLETIZED MATERIAL

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Results are shown of an experimental study concerned with the kinetics of heating and drying in thin layers of wet-pressed food mix. The equation of the desiccation curve is derivėd by the two ranges method, and an approximate temperature curve is derived by the method in [6].

Much attention has been recently paid to the desiccation of pelletized materials, especially of wet-pressed food mixes [1-3]. For expediency, a study of this process should begin under the simplest conditions in a thin layer, where every pellet is well exposed to the stream of drying agent and where the conditions of heat and mass transfer may thus be regarded the same all around its surface.

In the next step of such a study, one considers clusters of pellets and the effect of individual pellets on one another during the desiccation process.

In this study the authors used pellets of wet-pressed food mix with an initial moisture content 25-28% and a final moisture content not above 14.5% (according to [4]). The pellets were cylindrical in shape (4.5-5.0 mm in diameter and 15-18 mm long). The food mix had been prepared according to the recipes in [5].

The desiccation process was studied at various velocities of the heat carrier V (2.3, 3.3, and 4.3 m/sec), referred to the free section of the desiccation chamber, and at various temperatures of the drying agent T_d (333, 348, 363, and 393°K).

In all tests we measured the temperature at the center of a pellet as well as the temperature of the drying agent in the active chamber, with Chromel—Copel thermocouples (wire diameter 0.1 mm) through a 6-point automatically switching model PS1-08 electronic potentiometer. The thermocouples had been precalibrated for these tests. An axial hole 0.2 mm in diameter was then drilled into a pellet with a special tool. Into this hole was placed the thermocouple bead (the bead diameter was also 0.2 mm), whereupon the thermocouple wires were tightly pasted along the hole wall with the same material of which the pellet was made. A pellet with the thermocouple inside was then held above a perforated mesh by means of a glass tube inside which the thermocouple wires had been carefully insulated.

The tests were performed in an apparatus shown schematically in Fig. 1.

The apparatus consisted of a desiccation chamber 1, a perforated mesh 2 (active section area 5-6%), and air-supply diffuser 3, an electric radiator 4, a fan 5, and a suction pipe 6.

TABLE 1

T_d, K	A	B	$k_1 \cdot 10^3$, 1/sec	$k_2 \cdot 10^3$, 1/sec	$a \cdot 10^2$	m
333	0,75	0,25	0,467	4,33	0,68	—0,18
348	0,78	0,22	0,817	5,5	1,3	—0,16
363	1,0	0	1,83	∞	2,0	—0,19
378	1,0	0	2,83	∞	2,6	—0,19
393	1,0	0	4,5	∞	3,2	—0,19

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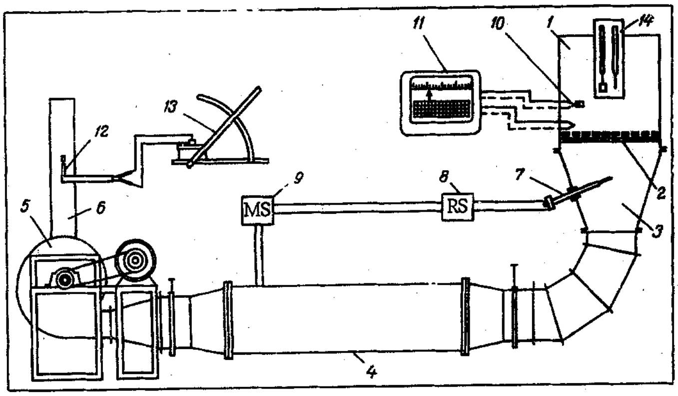

Fig. 1. Schematic diagram of the test apparatus: 1) dessication chamber; 2) perforated mesh; 3) air-supply diffuser; 4) electric radiator; 5) fan; 6) suction pipe; 7) contact thermometer; 8) relay system; 9) magnetic starter; 10) thermocouple; 11) model PSI-08 potentiometer; 12) Pitot—Prandtl tube; 13) model MMN-240 microammeter; 14) psychrometer.

The velocity of the air stream was measured with a Pitot—Prandtl tube inside the suction pipe. The readings were recorded through a model MMN-240 microammeter. Prior to the experiment, this Pitot—Prandtl tube had been calibrated against a standard gage. The relative humidity of the air inside the desiccator chamber was measured with a psychrometer consisting of a dry-bulb and a wet-bulb thermometer.

The temperature of the drying agent was set and held constant by means of a control system consisting of a thermometer 7, a relay 8, and a magnetic starter 9.

The error of measurement was estimated and found not to exceed ±1-2%.

All tests were performed with pellets of the same batch. The pellets were placed on the perforated mesh in amounts of 100 g. The material was spread on the mesh in a single layer so that the pellets did not touch one another.

The variation of the moisture content in pellets with time is shown in Fig. 2a for various velocities of the drying agent. According to an analysis of the test data, the desiccation proceeded here in the decreasing-rate mode. The test values follow the same trend (Fig. 2a) within the 2.3-4.3 m/sec range of velocities of the drying agent. It has also been established that, while the velocity of the drying agent at a constant temperature of 363°K varied, the temperature at the center of a pellet remained also constant (Fig. 2b). The effect of the temperature of the drying agent on the desiccation process is indicated in Fig. 3a and its effect on the temperature at the center of a pellet is indicated in Fig. 3b.

It would be worthwhile to use here the results of the theoretical estimate made by A. V. Lykov [6], subsequently refined by A. I. Ol'shanskii [7], and P. S. Kuts [8], regarding the desiccation kinetics and the pellet temperature as a function of the moisture content.

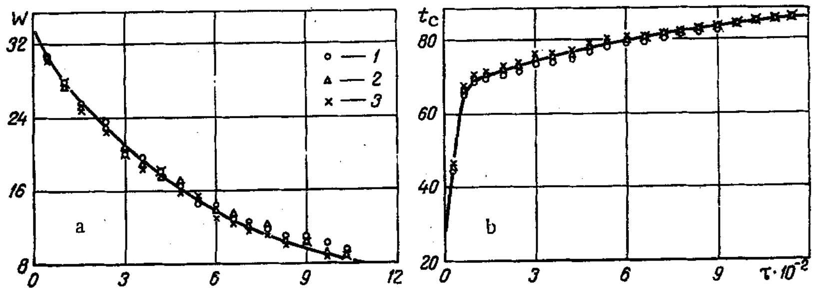

Fig. 2. a) Moisture content in a wet-pressed food mix (W, %) and b) temperature at the center of a pellet (t_c, °C), as functions of time (τ, sec), at various air velocities V: 1) 2.3 m/sec; 2) 3.3 m/sec; 3) 4.3 m/sec; T_d = 363°K, φ = 15.3%.

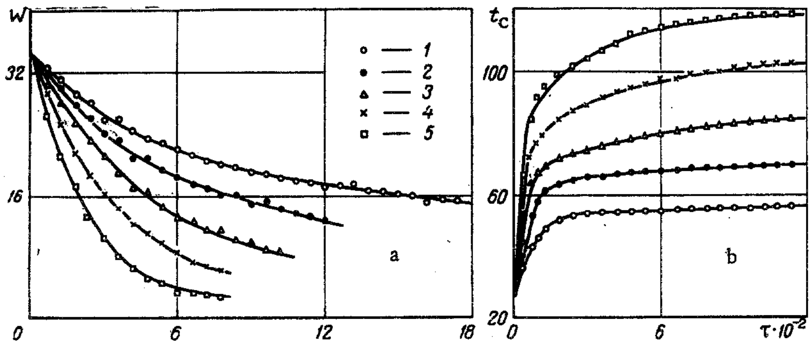

Fig. 3. a) Desiccation curves for pellets (W, %) and b) heating curves for the center of a pellet (t_c, °C) of wet-pressed food mix at various air temperatures T_d: 1) 333°K at φ = 25.3%; 2) 348°K at φ = 18.9%; 3) 363°K at φ = 15.3%; 4) 378°K at φ = 12.7%; 5) 393°K at φ = 8.5%; air velocity V = 3.3 m/sec.

The desiccation kinetics during the period of decreasing rate can be represented formally by various methods [6, 7, 9, 10]. Most accurate is the two ranges method of calculating the desiccation curve [7, 9], a further extension of the Lykov method. The gist of this method is to replace the desiccation curve by two exponential functions. The period of decreasing rate is divided into two ranges. Within each of them the desiccation rate varies proportionally to the excess moisture content. The second critical point is the border point between both ranges. As a result, one obtains two independent equations applicable to various limiting levels of excess moisture content.

We have used the two ranges method for expressing the desiccation curve analytically. The test results pertaining to the desiccation kinetics were approximated by the expression

$$\frac{W - W_e}{W_0 - W_e} = A \exp(-k_1\tau) + B \exp(-k_2\tau). \tag{1}$$

A comparison between theoretical and test data has yielded a satisfactory agreement in values of the constants, as shown in Table 1.

Pelletized food mix contains vitamins, antibiotics, medications, growth stimulants, and other heat sensitive ingredients. For this reason, determining the temperature of such a material as a function of the moisture content during desiccation is very important for the design of technological processes in this industry.

The calculation of the temperature curve here was checked by the method in [6], with the aid of an equation relating the mean temperature of a body to its mean moisture content:

$$\frac{t_d - \bar{t}}{T_d} = \frac{a(\bar{u} - u_e)^{m+1}}{(m + 1)\bar{u}_0}. \tag{2}$$

As a result, we have obtained the following linear relation between coefficient a and the temperature:

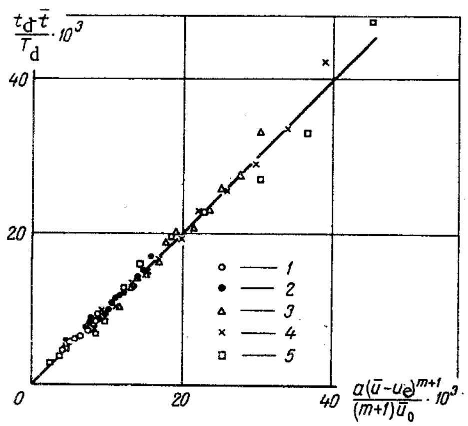

Fig. 4. Relation between $(t_d - \bar{t})/T_d$ and $(a(\bar{u} - u_e)^{m+1})/((m + 1)\bar{u}_0)$ during desiccation of wet-pressed food mix pellets, at various air temperatures T_d: 1) 333°K and φ = 25.3%; 2) 348°K and φ = 18.9%; 3) 363°K and φ = 15.3%; 4) 378°K and φ = 12.7%; 5) 393°K and φ = 8.5%; air velocity V = 3.3 m/sec.

$$a = 4.2 \cdot 10^{-4} T_d - 13.3 \cdot 10^{-2}. \quad (3)$$

This result is shown in Fig. 4, the numerical values of coefficients a and m appearing in Table 1.

Our study of wet-pressed food mix has yielded approximate equations for the desiccation time and for the temperature curve under most favorable hydrodynamic conditions.

NOTATION

V	is the velocity of the drying agent, referred to the free section area of the desiccator chamber, m/sec;
T_d	is the temperature of the drying agent, °K;
W	is the instantaneous moisture content in the material, %;
W_0	is the initial moisture content in the material, %;
W_e	is the equilibrium moisture content in the material, %;
A, B, a, m	are dimensionless constants;
k_1, k_2	are constants, sec^{-1};
τ	is the time, sec;
t_d	is the temperature of the drying agent, °C;
$\bar{t}$	is the mean-integral temperature of the material, °C;
$\bar{u}$	is the mean instantaneous moisture content in the material, kg/kg;
$\bar{u}_0$	is the mean initial moisture content in the material, kg/kg;
u_e	is the equilibrium moisture content in the material, kg/kg;
t_c	is the temperature at the center of a pellet, °C;
φ	is the relative humidity of air, %.

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