SOME DRYING CHARACTERISTICS OF GRANULATED SUGAR IN AN EXTERNALLY HEATED PNEUMATIC DRYING TUBE

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Relations derived from an experimental study of the drying of granulated sugar in a pneumatic drying tube with external heating make it possible to determine the necessary height of the tube.

Research shows that high-quality granulated sugar intended for silo storage should have a uniform granulometric composition (crystal size not less than 0.3 mm), the final moisture content should be low ($W = 0.03–0.05\%$), and the final temperature should not exceed 20–22° C.

Present industrial dryers do not satisfy these requirements. Hence the need for more effective drying methods that will ensure a high-quality finished product.

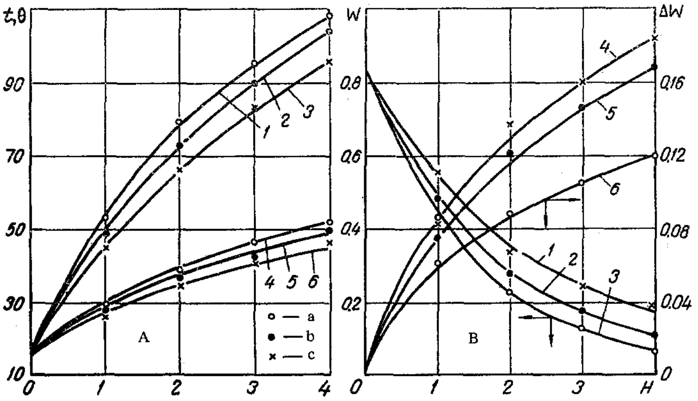
In relation to granulated sugar, drying tubes with external heating possess the following advantages:

1. Possibility of operation at high solids concentrations, since the amount of heat supplied is not limited by the amount of drying agent, whose flow rate need be no more than necessary to ensure reliable pneumatic transportation of the material. This results in economies due to the reduced entrainment of dust.
2. High rate of heat transfer from the heated surface to the two-phase flow determined by the considerable reduction in thermal resistance due to artifically induced boundary layer turbulence and the high volume heat capacity of the two-phase flow.
3. Contact between the high-temperature drying agent and the high-humidity material may lead to a product improved color characteristics. Granulated sugar is a heat-sensitive material whose moisture content is determined chiefly by the moisture present at the surface of the crystals in the form of a thin film of saturated solution. Heat causes decomposition of sucrose in the sucrose-water system with the formation of colored substances, whose rate of formation increases with increase in temperature [5]. At the same temperature the sucrose decomposes more rapidly in dilute than in concentrated solutions.

At the beginning of the drying process in a pneumatic drying tube with external heating, when the concentration of the solution enveloping the crystal surface is relatively low, the material is in contact with cooler drying agent. The temperature of the heat transfer agent is lowest at the beginning of the drying process and increases along the tube when, as moisture is evaporated and the temperature of the material rises, the solution at the crystal surface becomes more concentrated.

The apparatus used in the experiments operated as follows: from the feed hopper the starting material enters the stainless-steel working chamber 25 mm in diameter and 4 m tall, is entrained by the ascending flow of heat transfer agent, and is carried upward, absorbing heat from the hot chamber walls. It then enters a cyclone, where the granulated sugar is separated from the drying agent, which is discharged into the atmosphere, while the sugar runs into the dried-product hopper. Before coming into contact with the moist material, the drying agent can be heated to the required temperature in a horizontal section equipped with an independent heating coil.

The working chamber had four sections, each 1 m long and fitted with an independent heating coil connected to the power supply system across an RNO-250-5 transformer. The sectional construction of the working



A) Variation of temperature (°C) of drying agent (1, 2, 3) and material (4, 5, 6), B) moisture content (%) of material (1, 2, 3) and amount (kg/hr) of evaporated moisture (4, 5, 6) over height of drying tube ($\mu = 0.64$ kg/kg; $t_W = 130°$ C; $W_1 = 0.89\%$; $t_1 = \theta_1 = 15°$ C): a) $v\rho = 13.5$ kg/m^2·sec; b) 17.5; c) 26.8.

chamber and rheostat voltage regulation made it possible to keep the temperature of the heating surface constant and uniform and to study the variation of the moisture content and temperature of the material over the height of the tube. In the case of preheated starting material the feed hopper was also heated electrically, the voltage at the terminals of the heating coil being regulated with a laboratory autotransformer. The apparatus was equipped with all the necessary control and measuring instruments. The granulated sugar used in the experiments had a mean particle size $d_{av} = 0.865$ mm.

The experimental results were correlated in the form of curves representing the variation of drying agent temperature and material moisture content over the height of the tube. (The data on three experiments are presented in the figure.) These curves were constructed by successively carrying out experiments with a variable working section height at fixed values of the process parameters in each series of experiments.

A mathematical analysis of the curves yielded the following equations for the drying agent temperature and material moisture content over the height of the tube:

$$t = t_w - (t_w - t_1)\exp(-AH), \tag{1}$$

$$u = u_{eq} + (u_1 - u_{eq})\exp(-BH), \tag{2}$$

where A and B are empirical coefficients reflecting the effect of the external conditions on the heat and mass transfer processes and the drying properties of the material.

Empirical relation (2) indicates that the drying process takes place in the falling rate stage. As Luikov points out [1], the rate of moisture evaporation from the surface of a material is analogous to the evaporation of liquid from a free surface and, in accordance with Dalton's law, is determined by the difference between the vapor pressure at the surface of the material P_m and the partial vapor pressure in the ambient medium P_p:

$$\frac{dW}{d\tau} = KS(P_m - P_p).$$

In the case of granulated sugar, the moisture is evaporated from the surface of a saturated solution. As the product is dried, the concentration of the solution enveloping the crystals increases, and, in accordance with Raoult's law, the vapor pressure over the solution surface decreases with a consequent continuous decrease in drying rate. This is confirmed by the temperature curves (figure, A).

The following quantitative relations were obtained for the coefficients A and B:

$$A = (1.235 - 0.008E_1)(v\rho)^{-0.47}\mu^{-0.25}. \tag{3}$$

$$B = 0.0115(v\rho)^{-0.85}\mu^{-0.25}d_{av}^{-0.15}E_1^{0.08}t_w. \tag{4}$$

The process parameters were varied over the following ranges: $0.2 \le \mu \le 4$ kg/kg; $9 \le \nu\rho \le 27$ kg/m^2 · sec; $70 \le t_w \le 140°$ C; $0.5 \le d_{av} \le 2.5$ mm; $4 \le E_1 \le 46°$ C; $11\,000 \le \mathrm{Re} \le 34\,600$.

In designing sugar drying tubes with external heating it is necessary to know the coefficient of heat transfer from the surface to the two-phase flow. The results obtained for low solids concentrations ($\mu < 5$ kg/kg) are often contradictory. Accordingly, additional experiments were performed using the same apparatus as already described.

In calculating the heat transfer coefficient it is possible to neglect the radiative and contact components [2–4] (the heating surface temperature did not exceed 140° C). The value of α_w was determined from the following expression:

$$\alpha_w = \frac{Q \ln \dfrac{t_w - t_1}{t_w - t_2}}{F(t_2 - t_1)}, \tag{5}$$

where

$$Q = c\,L(t_2 - t_1) + $$
$$+ G_{d.m}(c_{d.m} + u_2)(\theta_2 - \theta_1) + G_{d.m}r(u_1 - u_2).$$

An analysis of the experimental data showed that the heat transfer rate depends chiefly on the velocity of the drying agent and the solids concentration. The following quantitative relations were obtained:

$$\mathrm{Nu} = 0.084\,\mathrm{Re}^{0.643}\exp(0.102\mu),$$
$$0.2 \leqslant \mu \leqslant 0.9 \text{ kg/kg}; \tag{6}$$

$$\mathrm{Nu} = 0.084\,\mathrm{Re}^{0.643}\exp(0.124\mu),$$
$$0.9 < \mu \leqslant 4 \text{ kg/kg}. \tag{7}$$

Empirical relations (3), (4), (6), and (7) make it possible to determine the height of the drying tube with allowance for heating of the material to the maximum permissible temperature [6].

An analysis of the fractional composition and external appearance of the dried product indicates that drying in a pneumatic drying tube with external heating does not result in any abrasion of the crystals or changes in the color of the material; the crystals preserved their original sparkle and sharp edges. Granulated sugar, dried under optimum processing conditions, fully satisfies the requirements of the relevant State Standard.

NOTATION

t_1, t, and t_2 denote the initial, variable, and final temperatures of the drying agent; t_w is the temperature of the heating surface; H is the height of the drying tube; u_1, u_{eq}, and u denote the initial, equilibrium, and variable moisture contents of the material; S is the evaporation surface; K is the evaporation coefficient; $dW/d\tau$ is the drying rate; $v\rho$ is the mass velocity of the drying agent; μ is the solids concentration; $E_1 = t_1 - t_{wet}$ is the drying potential; t_{wet} is the wet-bulb temperature; d_{av} is the average particle size; α_w is the coefficient of heat transfer from the heating surface to the two-phase flow; F is the heating surface of the drying tube; c_a is the specific heat of the air; L is the hourly flow rate of the drying agent; $G_{d.m}$ is the output of the apparatus with respect to dry material; $c_{d.m}$ is the specific heat of dry material; r is the heat of vaporization; $Nu = \alpha_w d_t/\lambda_m$ is the Nusselt number; $Re = vd_t/\nu_m$ is the Reynolds number; d_t is the diameter of the drying tube; λ_m and ν_m denote the thermal conductivity and kinematic viscosity; θ_2 and θ_1 denote the final and initial temperatures of the material.

REFERENCES

1. A. V. Luikov, Drying Theory [in Russian], Gosénergoizdat, Moscow-Leningrad, 1950.
2. Z. R. Gorbis, Heat Transfer of Disperse Through Flows [in Russian], Moscow, 1964.
3. L. Farbar and M. Morley, Industrial and Eng. Chemistry, no. 7, 1957.
4. C. Tien, Transactions of the ASME, no. 2, series C, 1961.
5. S. Z. Ivanov, Author's abstract of Doctoral dissertation, Moscow, 1958.
6. I. L. Lyuboshits, I. F. Pikus, and N. G. Alkhanashvili, collection: Problems of Intensification of Heat and Mass Transfer in Drying and Thermal Processes [in Russian], Izd. Nauka i tekhnika, Minsk, 1967.

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