

HEATING RATE IN A DENSE BED OF WET GRANULAR MATERIAL

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Measurements are reported on the heat transfer in a bed of wet granular material during drying.

Heat and mass transfer within a material during drying are coupled processes; usually, the coupling is expressed as a relationship between the temperature and the water content (the dimensionless temperature coefficient of drying B) or as a relation between the heat consumed in raising the temperature of the material and in evaporating the water (the R_b number). The dimensionless drying coefficient also allows us to relate the mean temperature \bar{t} of the body to the mean water content \bar{u} [1].

The effects of working parameters on B and R_b have been examined in experiments over wide ranges in temperature and drying-agent speed.

We used granulated potato starch, in which the drying is an intermediate stage in the production of powdered potato [2], on which very little research has been done.

The initial material is prepared in accordance with the technological specification [3]; the paste is granulated by means of a pressure sieve with holes of diameter 0.005 m. The initial water content is 74–77%, and the drying is performed to a final water content of 45–50% [2]. The temperature t_d of the drying agent was varied over the range 70–130°C by steps of 10°C, while the speed V_d was varied over the range 0.6–1.4 m/sec by steps of 0.2 m/sec. The drying was performed in a dense layer of thickness 0.03 m.

The temperature was measured at three points: at 0.005 m from the bottom, in the center of the layer, and at 0.005 m from the top; Chromel–Copel thermocouples were used with wire diameters of 0.2 mm, which worked into an ÉPP-09M automatic potentiometer, class 0.5.

Figure 1 shows the mean temperature of the layer as a function of time (a) and the amount of water removed (b), in each case for several different temperatures of the drying agent.

The curves are clearly nonmonotonic; the initial mean temperature after heat treatment is 54–57°C at the start of drying.

The negative internal heat source initially causes the temperature to fall, but subsequently the latter rises again.

The time corresponding to the minimum shifts initially as the drying temperature is raised; in each particular case, that time represents 40–44% of the total drying time.

Figure 1 shows that the minimum in each case corresponds to the same water content:

$$\bar{u}' = 1.90 \pm 0.03 \text{ kg/kg.}$$

The speed of the drying agent has a similar effect on the course of the curves and the position of the minimum.

For convenience in surveying the data on B and R_b , the entire range of water contents (from \bar{u}_0 to \bar{u}_f) is split up into two ranges: from \bar{u}_0 to \bar{u}' and from the latter to \bar{u}_f .

The following relationships apply [1] for R_b and B for a colloid with capillary pores:

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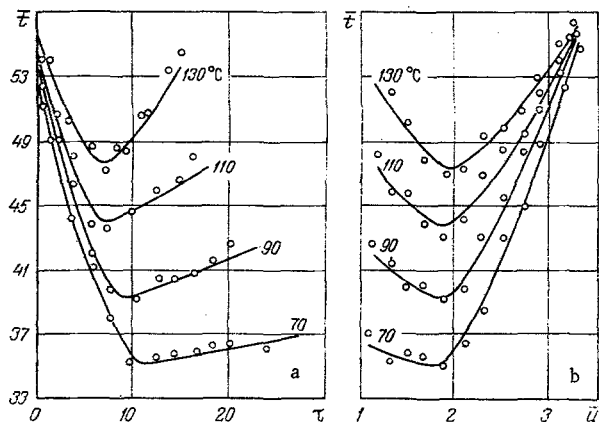


Fig. 1

Fig. 1. Mean temperature \bar{t} ($^{\circ}\text{C}$) of material for various temperatures of the drying agent as a function of: a) time τ (min); b) water content \bar{u} (kg/kg).

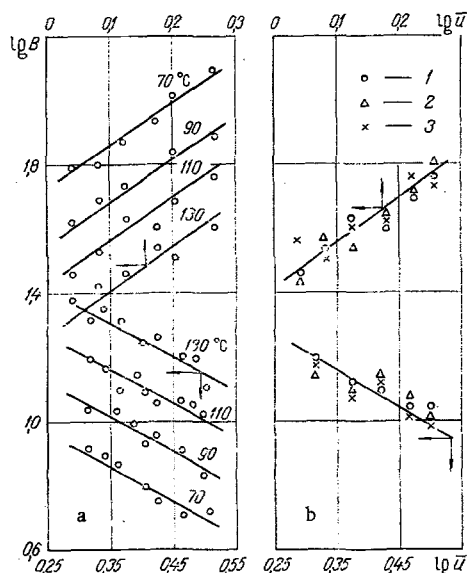


Fig. 2

Fig. 2. Dimensionless temperature coefficient B as a function of water content for: a) four temperatures of the drying agent; b) speeds v (m/sec) of the drying agent: 1) 0.6; 2) 1; 3) 1.4.

$$Rb = a\bar{u}^m, \quad (1)$$

$$B = c\bar{u}^n. \quad (2)$$

The measurements for use in (1) and (2) were processed separately for each of the ranges in water content.

Figure 2 shows B as a function of \bar{u} for various temperatures (a) and various speeds in the drying agent (b). The following empirical relationships were derived:

$$B = (0.088 - 0.052 \cdot 10^{-2} t_d) \bar{u}^{1.05} \text{ for } \bar{u}' \leq \bar{u} \leq \bar{u}_0, \quad (3)$$

$$B = (0.052 \cdot 10^{-2} t_d - 0.019) \bar{u}^{-1.34} \text{ for } \bar{u}_f \leq \bar{u} \leq \bar{u}'. \quad (4)$$

The data on Rb were processed similarly to give the following empirical relations:

$$Rb = (0.0200 - 0.0118 \cdot 10^{-2} t_d) \bar{u}^{2.05} \text{ for } \bar{u}' \leq \bar{u} \leq \bar{u}_0, \quad (5)$$

$$Rb = (0.022 \cdot 10^{-2} t_d - 0.088) \bar{u}^{-0.64} \text{ for } \bar{u}_f \leq \bar{u} \leq \bar{u}'. \quad (6)$$

The coefficient of variation in the results from (3)-(6) does not exceed 6%.

An equation has previously been given [1] for the mean temperature of the material, which can be used with (3) and (4) to give an equation for the mean temperature of the bed:

$$\bar{t} = \bar{t}_0 - \frac{11.7 - 2.59 \cdot 10^{-2} t_d - 2.53 \cdot 10^{-2} t_d^2}{\bar{u}_0} (\bar{u}_0^{2.05} - \bar{u}^{2.05}) \quad (7)$$

for $\bar{u}' \leq \bar{u} \leq \bar{u}_0$,

$$\bar{t}' = \bar{t}_0 + \frac{15.3 \cdot 10^{-4} t_0^2 + 36.2 \cdot 10^{-2} t_d - 15.3}{\bar{u}'} (\bar{u}^{-0.34} - \bar{u}'^{-0.34}) \quad (8)$$

for $\bar{u}_f \leq \bar{u} \leq \bar{u}'$.

When (8) is used, the mean temperature of the bed (for $\bar{u} = \bar{u}'$), namely, \bar{t}_0' , is taken as the result for the temperature from (7) with $\bar{u} = \bar{u}'$.

The coefficient of variation obtained in using (7) and (8) does not exceed 7%.

NOTATION

B, dimensionless temperature coefficient; Rb, Rebinder number; \bar{t} , mean temperature of the material; t_d , temperature of drying agent; T_d , absolute temperature $T_d = t_d + 273^\circ\text{K}$; \bar{u} , mean (bulk) water content of material; u_0 , initial water content; u_f , final water content.

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CALCULATION OF HYDROCARBON-GAS SEPARATION IN A TURBULENT TUBE

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The separation of hydrocarbon gases in a turbulent tube is calculated by means of the material-balance method. The results are compared with experimental data.

At present, there are very many works on turbulent tubes used in the gas-retreatment industry. However, there are few data on the possibility of calculating the separation of hydrocarbon gases in such tubes [1-6].

The process of gas separation in a turbulent tube may be represented as follows: tangential introduction of gas through a tapering nozzle; condensation of heavy hydrocarbons at the exit from the nozzle; centrifugal separation of the resulting gas-liquid mixture to give an axial (cold) gas flow depleted in heavy hydrocarbons and an enriched (hot) gas flow at the wall.

For considerable velocities at the nozzle outlet (Mach number $0.9 < M < 1.5$) condensation is a nonequilibrium process [3]. However, if a series of assumptions is made (for example, assuming the nozzle to be sufficiently large), it is possible to proceed as for equilibrium separation of multicomponent systems using the material-balance method

$$\sum_{i=1}^n x_i' = \sum_{i=1}^n \frac{z_i}{1 + e(k_i - 1)} = 1,$$
$$\sum_{i=1}^n x_i^* = \sum_{i=1}^n \frac{k_i z_i}{1 + e(k_i - 1)} = 1.$$

The equilibrium constants k_i are determined by expressing them as a function of the convergence pressure according to the NGPA atlas. As the parameters for the calculation of the k_i , we take the measured static pressure at the outlet from the turbulent-tube nozzle and the corresponding calculated static temperature:

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