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RELATIVE DIFFUSION RESISTANCE IN DRYING WHEAT

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An apparatus is described for examining various methods of convective drying.

Convective drying of moist grain under optimal conditions retains all the technological and other features, and sometimes can even improve them.

Proper organization of the drying requires ordered movement of the water toward the surface of the particles without excessive depth of the evaporation zone and temperatures below the upper limit [1-3].

The diffusion rate within the grain is dependent on the form of water binding, the diffusion resistance, and the working conditions.

The relative diffusion resistance can [4, 5] be determined for any instant as the ratio of the drying rate in the constant-rate period (drying at the surface) to the drying rate in the second period when the outward diffusion rate is less than the surface evaporation rate, i.e., the dry layer increases the resistance.

Drying is accompanied by molecular diffusion and by molar diffusion [6]; therefore, by diffusion here we mean the overall process.

A laboratory equipment has been built [7] that enables one to perform tests with the grain layer in various states and with the temperature and speed of the drying agent adjustable over wide ranges (Fig. 1).

If the drying curve is known (Fig. 2), then the relative diffusion resistance R can be derived from

$$R = \frac{\operatorname{tg}\alpha}{\operatorname{tg}\varkappa} = \frac{N_{\mathrm{I}}}{(dW^{c}/d\tau)_{\mathrm{II}}}. \tag{1}$$

This R indicates the reduction factor for the diffusion rate in the material relative to the rate in a layer of air at the same pressure and temperature. The drying curves and drying rate (Fig. 2) give R as a function of water content W^c (Fig. 3), which can be approximated as a power law:

$$R = \frac{A}{(W^{c} - W^{c}_{e})^{\alpha}} + \gamma. \tag{2}$$

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TABLE 1. Approximation of $R(W^c)$ by a Function of the Form of (2)

Drying method	Values of coefficients			Standard deviation, $\sqrt{\langle R-R_{exp}\rangle^2}$
	A	α	γ	
Dense bed	3,42	0,91	0,90	0,21
Fluidized bed	9,27	1,00	1,21	0,35
Pneumatic-transport mode	15,30	0,93	0,96	0,51

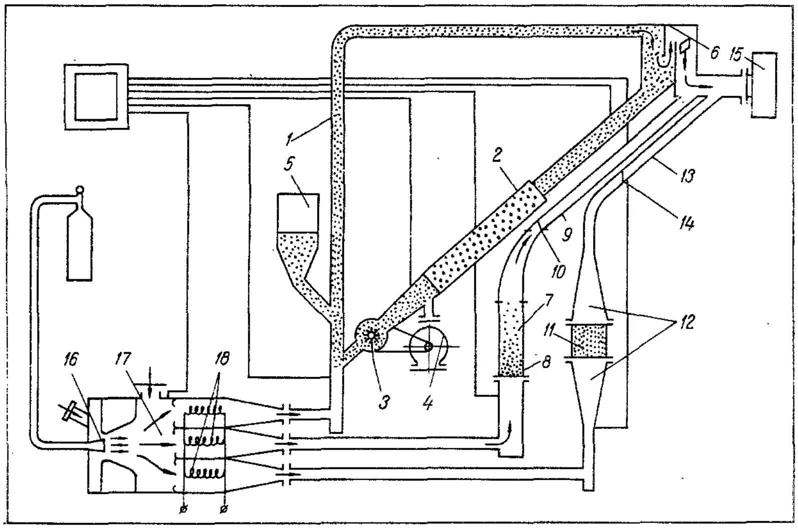

Fig. 1. The apparatus: 1) pneumatic-transport pipe; 2) intermediate-cooling section; 3) feed system; 4) electric motor; 5) bunker; 6) grain separator; 7) fluidized-bed chamber; 8) gas-distributing grid; 9 and 13) outlet pipes; 10 and 14) gate valves; 11) dense bed chamber; 12) inlet and outlet conical sections; 15) fan; 16) gas input; 17) mixing chamber; 18) electric heaters.

Table 1 gives the theoretical coefficients for (2) and the standard deviation of R from the observed value. It is clear that (2) agrees reasonably well with experiment.

It follows from (2) that R is minimal for high water contents, with $R \to \infty$ for $W_c \to W_e^c$.

The value of R increases least during pneumatic transport (curve 2 of Fig. 3) in the time up to attainment of the conditioned water content (15-16%), while the fluidized-bed and dense-bed cases give higher values (curves 1 and 3 of Fig. 3). This is due to the mode of transport of the water in the material. The drying during pneumatic transport can be split up into several stages. A small proportion of the water is lost in the first stage, mainly from the surface, which occurs in the drying tube with the drying agent at a high temperature (573°K), but where the exposure is only brief. In the second stage, most of the water is removed by contact transfer and spontaneous evaporation in the cooling zone. A major point here is that the temperature gradient within the grain reverses in the cooling zone, so the flows of heat and water coincide in direction. This facilitates outward movement of the water, and water-soluble nutrients migrate outwards also, which has advantageous effects on the grain as seeds [8].

Drying in a dense bed and (especially) in a fluidized one is accompanied by a marked increase in R as the conditioned water content is attained, since the temperature gradient then becomes considerable. In other words, thermal diffusion here constitutes an obstacle to outward movement, while producing conditions that favor evaporation within the grains, which adversely affects the quality of the dried material.

The depth of the evaporation zone gradually extends during the falling-rate period, because the mode of transport is dependent on the form of binding to the material. This stipulates that the transport of water outward from the particle depends on its form of binding with the substance. The capillary water is lost as the evaporation surface penetrates inward, while the adsorbed water is lost gradually throughout the evaporation thickness.

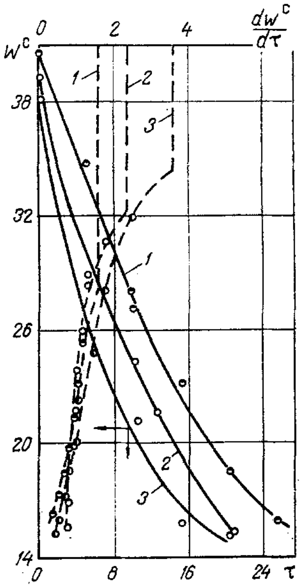

Fig. 2

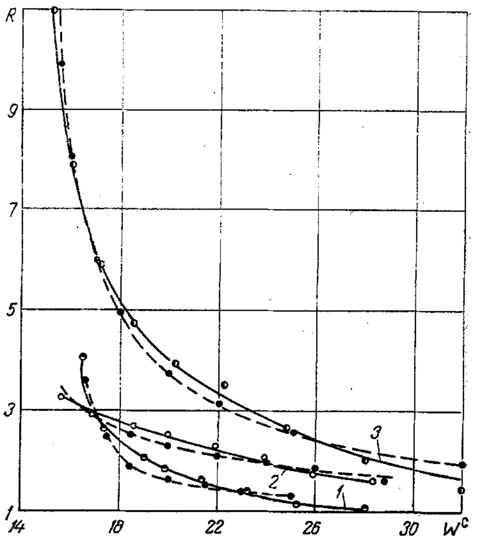

Fig. 3

Fig. 2. **Drying and drying-rate curves for grain: 1) dense bed (W^c_H = 40.6%; T = 348°K; V = 0.5 m/sec; 2) pneumatic transport (W^c_H = 39.9%; T = 573°K; V = 20 m/sec); 3) fluidized bed (W^c_H = 38.1%; T = 393°K; V = 2 m/sec). W^c, %; τ, min.**

Fig. 3. Relative diffusion distance as a function of water content: 1) dense bed; 2) pneumatic transport; 3) fluidized bed. The dashed curves are the approximations given by (5).

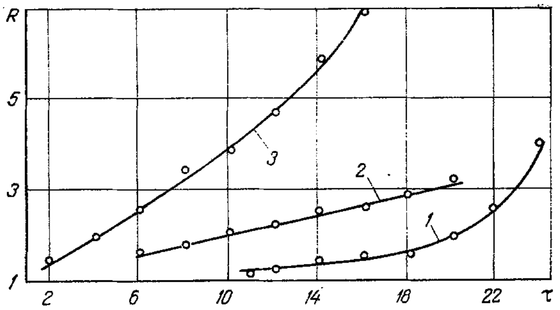

Fig. 4. Relative diffusion resistance as a function of drying time: 1) dense bed; 2) pneumatic transport; 3) fluidized bed.

The relative diffusion resistance enables one to determine when the evaporation zone begins to penetrate inward, and the curves of Figs. 2 and 3 enable one to relate R to τ (Fig. 4). This kinetic curve is linear, except at the end, and it is clear that the evaporation surface area is almost equal to the geometrical surface area in drying to the conditioned state only for the pneumatic-transport mode ($1 < R < 3.2$); then the point where the $R(\tau)$ curve meets the abscissa corresponds to extension of the evaporation zone.

A major characteristic is the surface temperature, which is dependent on the drying technique; for instance, the maximum permissible temperature for grain dried in solid beds is 50°C, as against 55-60°C for a fluidized bed and pneumatic transport.

The formula

$$T_{\text{sur}} = T_a - N^{*0.43}(T_a - T_w) \tag{3}$$

has [9] been suggested for a colloidal porous material, which allows one to determine the temperature in the second drying stage. Our experiments show that this formula is applicable for the surface temperature and gives an error of 10-15%.

Our results indicate that the relative diffusion resistance is very important in the choice of optimum drying designed to provide specified grain properties. The working conditions can be adjusted to control the heat and water transport mechanisms to influence the physicochemical and biochemical features in the desired direction.

NOTATION

$\tan \alpha = N_I$	is the drying rate in the first period;
$\tan \chi = (dW^c/d\tau)_{II}$	is the drying rate in the second period;
τ	is the drying time;
W_e^c	is the equilibrium water content;
W^c	is the water content of grain on dry mass;
$N^* = (1/N_I)(dW^c/d\tau)$	is the dimensionless drying rate;
T_{sur}	is the surface temperature;
T_a	is the ambient temperature;
T_w	is the wet-bulb temperature;
A, α, γ	are the experimental coefficients.

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