ELECTROTHERMAL ANALOGIES AND THE RESULTANT HEAT FLUX ABSORBED BY A POROUS COLLOID DURING DRYING

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Measurements are reported on the effective thermal conductivities and resultant heat fluxes in the drying of potato starch.

Design calculations on drying systems and proper organization of drying require a knowledge of the heat-flux kinetics $q(\tau)$ at the material, in particular, to analyze heat and mass transfer.

Direct measurement of heat fluxes requires special detectors in conjunction with a knowledge of the optical parameters of the material; in general, there are serious experimental difficulties.

For this reason, considerable interest attaches to the use of an electrothermal analog, which requires a knowledge of the effective thermal conductivity λ_{ef} as a function of position.

We have examined the problem with an ÉINP-3/66 electrical integrator used with an RC network model based on R-33 resistance boxes, which were used to simulate λ_{ef}, together with sets of nonpolar film capacitors type MPGT, which simulated the bulk specific heat c_γ [1].

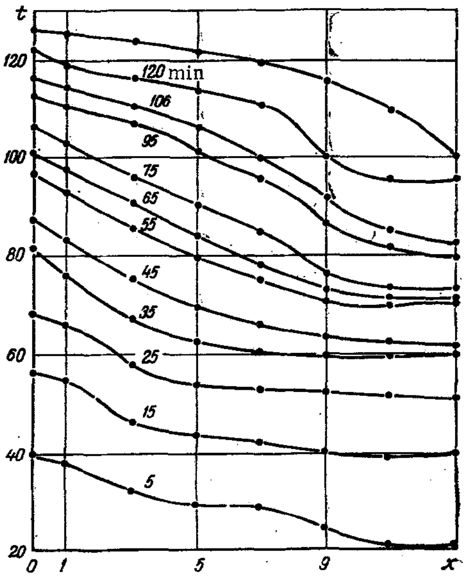

Fig. 1. Temperature distributions in IR drying of starch; t in °C, x in mm (top curve 130 min).

To calculate $q(\tau)$ we used measurements on the drying of unaltered potato starch by infrared radiation applied from one side, with natural convection in air. The radiation flux at the surface of the starch was 4300 W/m^2, while the layer thickness was 15 mm. The temperatures in the layers were measured with copper–Constantan thermocouples working into an ÉPP-09MI chart recorder. Special balances were used to record the mass loss by the moist starch, with automatic recording [2].

Figure 1 shows the temperatures in layers during drying of starch with an initial water content $\bar{U}_0 = 30\%$; these curves were used with the method of [3] to determine the λ_{ef}, and parts a and b of Fig. 2 show the variations with time in the layers.

It is clear the λ_{ef} varies in a complex fashion during drying, which is due to the general trends in the internal heat and water transport, the rise in λ_{ef} for layers close to the middle is due to rapid thermal diffusion, which occurs roughly for 30 min during drying and extends down to $x = 9$ mm depth. The rise in λ_{ef} is also due to the heating; the fall in λ_{ef} in the surface layers is clearly due to the water loss by evaporation.

The shape of the $\lambda_{ef} = f(x)$ curves alters considerably for times greater than 30 min; the marked increase in λ_{ef} above 30 min (Fig. 2a) is ascribed to the virtually horizontal disposition of the curves above 30 min, i.e., for $x > 10$ mm the

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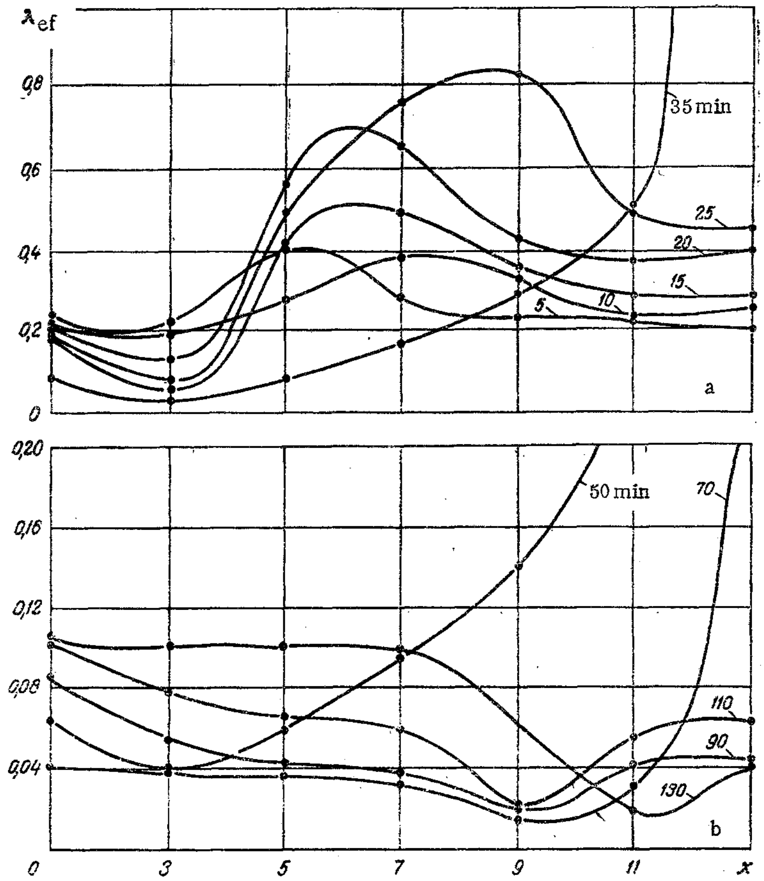

Fig. 2. Variation in λ_{ef} (W/m · deg) with position in drying starch for τ(min) of: a) 5-35; b) 50-130.

temperatures in the layers are identical. As a consequence, λ_{ef} increases considerably in response to the marked reduction in grad t as $q = -\lambda \text{grad } t$ (for restricted values of q).

The values of $\bar{U}$ in the surface layers were considerably lower, which means that there is little water transport by thermal diffusion in these layers, since a water monolayer is not thermally active [4]. This suppresses the peaks on the $\lambda_{ef} = f(x)$ curves. A subsequent slight increase in λ_{ef} for the surface layers is due to diffusion of water to the surface. The considerable fall in λ_{ef} in the lower layers at the end of drying is clearly due to rapid evaporation from these layers and heat transport by molecular means to the surface via the extensive pore structure.

These results on λ_{ef} were used in calculating $q(\tau)$; the heat flux going to heat the material $q_1(\tau)$ was represented as an equivalent current in the model. The relation between q_1 and I is

$$q_1 = \frac{I \lambda_{ef} R \Delta t_{max}}{U}. \tag{1}$$

The method of determing $q_1(\tau)$ is as follows. The drying period was split up into intervals $\Delta\tau$ that corresponded to the $\Delta\tau$ in temperature recording within the material. For each $\Delta\tau$ we selected resistors corresponding to the λ_{ef} for the individual layers. A special instrument was used to set the boundary conditions of the second kind, and a current was passed to the boundary through a limiting resistor R_{bc-II}; we adjusted R_{bc-II} to set the current through the model to be such that the temperature at the boundary varied in a known fashion for the given interval.

The currents were calculated from

$$I = \frac{U_{bc} - \dfrac{U}{2}}{R_{bc-II}}. \tag{2}$$

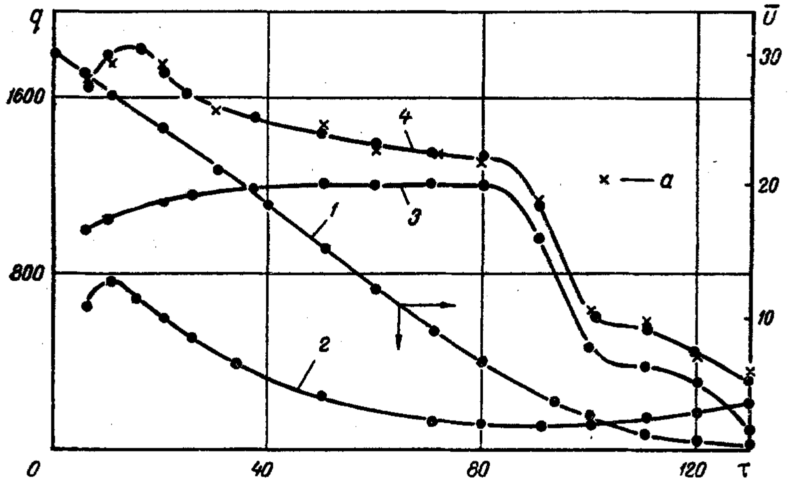

Fig. 3. 1) Water content of starch Ū; heat fluxes q (W/m²): 2) heating; 3) evaporation; 4) resultant. The solid lines are from electrothermal analog method, while points *a* are from Lykov's method.

In our case U_{bc} was 290 V; supply voltage was 25 V. From I we calculated $q_1(\tau)$ from (1) for each instant.

The drying curve (curve 1 on Fig. 3) was used with an approximate relationship between the latent heat of evaporation and the form of binding [5] to calculate the heat flux going to evaporation $q_2(\tau)$.

Figure 3 shows that there is initially some increase in $q(\tau)$, which is due to a transient distribution of the water content during the heating; during the period of constant drying rate, the heat flux is almost constant, but then there is a fall. This is due to the increased reflectivity of the starch as the water content falls, together with the rise in surface temperature; in addition, the bulk of the material is approaching the steady state.

The resultant heat flux can also be calculated by Lykov's method [4] in terms of the generalized variable Rb. Curve 4 of Fig. 3 shows these results, which agree well for both methods, with a mean discrepancy of not more than 3-5%. However, we consider that the electrothermal analog method gives more information and is reasonably efficient, while being accurate and simple to operate.

NOTATION

$q(\tau)$, net heat flux in W/m²; λ_{ef}, effective thermal conductivity of starch, W/m · deg; I, current in model, A; R, resistance per unit length of model, Ω; Δt_{max}, maximum temperature difference during drying, °C; $\Delta\tau$, time interval during drying, min; U_{bc}, voltage for boundary conditions of the second kind, V; U, supply voltage, V; $q_1(\tau)$, heating flux, W/m²; $q_2(\tau)$, evaporation heat flux, W/m²; $\bar{U}_0$ initial moisture content, %; $\bar{U}$, integral mean moisture content, %.

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