APPROXIMATE COMPUTATION METHOD FOR UNSTEADY MOISTURE-CONTENT FIELDS OF MATERIAL BEING DRIED

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The approximate computational method presented can be used for unsteady moisture-content and moisture-diffusion fields, as well as for local and layer drying rates.

The problem of the mass-transport mechanism is an urgent one for drying technology. Its solution requires that we establish the type of variation in both the average (integral) and local moisture content of the body in the course of time, i.e., that we determine the unsteady moisture-content fields for the material.

Here we report some results obtained in an investigation of this problem.

In the absence of thermal transport of matter, the analytic solution for the moisture-content fields during a period of constant drying rate for bodies of classical shape (infinite plate, cylinder, sphere) takes the form [1]

$$\frac{\bar{u}_0 - u_{(X,\tau)}}{\bar{u}_0} = \mathrm{Ki}_m \left[\Pi \,\mathrm{Fo}_m - 0.5(\chi - X^2)\right]. \tag{1}$$

To make practical use of (1), however, we must know the values of the Kirpichev and Fourier mass-transport criteria, which in addition to other quantities contain the moisture-diffusion coefficient, which depends on the moisture content and temperature of the material.

This considerably complicates the utilization of (1). Thus it is necessary to seek approximate computational methods.

A relationship has been proposed in [4] for determining the moisture diffusion coefficient from the integral kinetic drying curve, i.e., directly under the conditions experienced by the material being dried:

$$a_m = \frac{q_m R(\bar{u}_0 - \bar{u}_c)}{\Gamma(\bar{u}_c - u_c)(\bar{u}_0 - \bar{u})\gamma_0}. \tag{2}$$

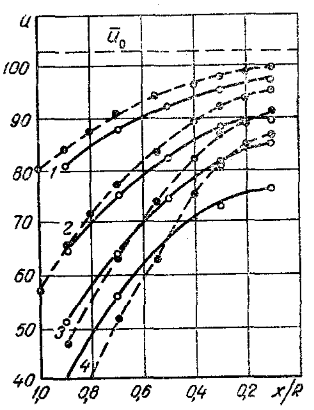

Fig. 1. Distribution of moisture content (%) over thickness of nonfabric material during constant-drying-rate period. The solid and dashed curves were plotted from experimental [9] and computed (5) values. The numbers on the curves indicate the duration of drying (hours), measured from the initial instant of drying.

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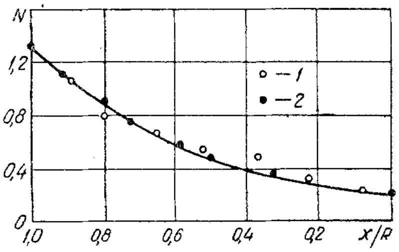

Fig. 2. Distribution of local drying rates over thickness of layer of milled peat [5]: 1) experimental; 2) calculated values of local drying rates.

By using (2), we can represent (1) in the following form that is convenient for practical use:

$$\frac{\bar{u}_0 - u_{(X,\tau)}}{\bar{u}_0 - \bar{u}} = \Pi - 0{,}5\Gamma \frac{\bar{u}_C - u_C}{\bar{u}_0 - \bar{u}_C} \left(\frac{\Pi}{\Gamma} - X^2 \right) = A_{(X)}, \tag{3}$$

where $\bar{u}_C$ is the average (by volume) critical moisture content; u_C is the critical moisture content at the body surface, equaling the maximum hygroscopic moisture content for colloidal bodies.

Relationship (3) can be simplified with the elimination of $\bar{u}_C$ and u_C if we let $\bar{u}_{rc} - u_e = 0.56\bar{u}_0$, $\bar{u}_{rc} = \bar{u}_C$, and $u_C = 2.25u_e$, which is the case when

$$a_m = \frac{0.8 q_m R}{\Gamma(\bar{u}_0 - \bar{u})\gamma_0}. \tag{4}$$

In the given case, Eq. (3) becomes

$$\frac{\bar{u}_0 - u_{(X,\tau)}}{\bar{u}_0 - \bar{u}} = 0.375\Pi + 0.625\Gamma X^2 = A_{(X)} \tag{5}$$

or

$$u_{(X,\tau)} = \bar{u}_0 - A_{(X)} N\tau_1, \tag{6}$$

where $A_{(X)}$ is a coefficient that is constant in time but varies along the dimensionless coordinate X. The time τ_1 is measured from the initial instant of drying.

On the basis of (6), we can find the local drying rate,

$$N_{(X)} = \frac{\bar{u}_0 - u_{(X,\tau)}}{\tau_1} = A_{(X)} N. \tag{7}$$

To find the integral mean drying rate for a layer of material with thickness h, a distance h_1 from the center of a plate, for example, we use (7) to obtain

$$N_{(h)} = N\left[0.375 + 1.88\left(\frac{h_1 + 0.58h}{R}\right)^2\right]. \tag{8}$$

The applicability of the proposed method for determining $u_{(X,\tau)}$ was tested by comparing calculated and experimental data for radiative drying of a sheet of nonfabric material measuring 100 × 100 × 25 mm ($\bar{u}_0$ = 1.03 kg/kg, q_m = 0.54 kg/m²·h, γ_0 = 212 kg/m³, R = 0.025 m [9]).

The layer-by-layer drying rates (8) were found from the experimental data of [5].

Figures 1 and 2 illustrate the results of this comparison; as we see, there is good agreement between the experimental data and the values computed from (5) and (8).

As a consequence, to determinte the unsteady moisture-content fields (5), (6) and the local and layer drying rates (7), (8) during the period under consideration, we need only have the integral mean drying rate.

As for the unsteady moisture diffusion field, using (6), (7) in (4), we obtain

$$a_{m(X)} = \frac{0.8 A_{(X)} q_m R}{\Gamma\gamma_0(\bar{u}_0 - \bar{u})} \tag{9}$$

or

$$a_{m(X)} = \frac{0.8 q_m R}{\Gamma\gamma_0[\bar{u}_0 - u_{(X,\tau)}]}. \tag{10}$$

For the second period (decreasing drying rate), the equation for the drying curve has the following form [1]:

$$\frac{\bar{u} - u_p}{\bar{u}_{r.c} - u_p} = \exp(-\varkappa N\tau_2). \tag{11}$$

The time τ_2 is measured from the beginning of the second period, which corresponds to the time at which the reduced critical moisture content $\bar{u}_{rc}$ is reached.

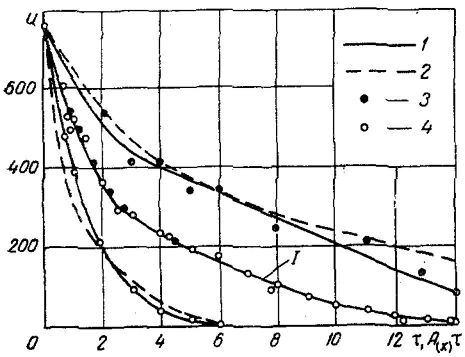

Fig. 3

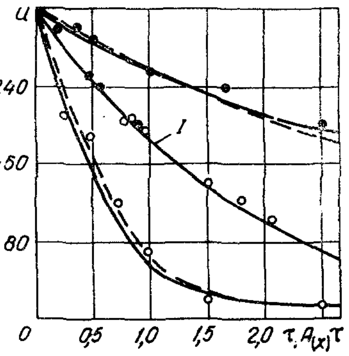

Fig. 4

Fig. 3. Local curves and combined curve (I) for drying of peat-insulated plates (u, %; τ, h). Drying conditions: $T_d = 373°K$, $\varphi = 0.04$, v = 4 m/sec [6]: 1) experimental curves; 2) calculated curves; 3, 4) at center and at surface of specimen.

Fig. 4. Local curves and combined curve (I) for drying of lumps of peat [8] (u, %; τ, h): 1-4) see Fig. 3.

Replacing the integral mean drying rate N by the local rate $N_{(X)}$ in (11), we obtain

$$u_{(X,\tau)} - u_p = (\bar{u}_{r.c} - u_p)\exp(-\varkappa A_{(X)} N \tau_2). \tag{12}$$

Equations (6), (12) can be represented as the generalized formula

$$u_{(X,\tau)} - u_p = [\bar{u}_0 - A_{(X)} N \tau_1 - u_p]\exp(-\varkappa A_{(X)} N \tau_2). \tag{13}$$

In fact, we obtain (13) from (6) when $\tau_2 = 0$, as is the case during the first period of the drying process; when $\tau_1 = \tau_c$, which corresponds to the time at which the first period ends and the second begins, Eq. (13) is represented as (12).

It follows from (13) that $u_{(X,\tau)} - u_e$ is a function of the new complex parameter $A_{(X)}\tau$ [3].

If we assume that the numerical value of the reduced critical moisture content does not change over the thickness of the specimen, the family of curves $u_{(X,\tau)} - u_e = f(\tau)$ can be reduced to the general curve

$$u_{(X,\tau)} - u_p = f[A_{(X)}\tau].$$

Figures 3, 4 show experimental [6, 8] and calculated, Eq. (13), curves for drying of peat-insulated plates and peat lumps.

Similar treatment of local drying curves for fabric [4], peat [8], flax fibers [7], peat-insulated plates [6], and other materials indicates that the combined drying curve is widely applicable.

The greatest discrepancy between the experimental data and the values found from (5) for local water content does not exceed 20-25% (see Figs. 1, 3, 4).

Thus our method, although approximate, still offers a certain advantage: the integral mean drying curve can be used as a basis for computing the nonstationary moisture-diffusion fields during the period of constant drying rate, and the unsteady moisture-content fields for any time during the drying process.

NOTATION

a_m, $a_{m(X)}$	are the mean-integral and local moisture diffusion coefficients, m^2/h;
$\bar{u}$, $\bar{u}_0$, $\bar{u}_{rc}$, $\bar{u}_c$, u_c, u_e	are the local, integral-mean, initial, reduced critical, mean (volume) critical, surface critical, and equilibrium moisture contents, %, kg/kg;
N, $N_{(X)}$, $N_{(h)}$	are the mean-integral and local drying rates, and the drying rate for a layer of thickness h during the first period (constant rate);
q_m	is the drying rate, $kg/m^2 \cdot h$;
T_d, φ, v	are the temperature, moisture, and rate of motion of the air;
R	is the characteristic length of the body, m;

R_V is the hydraulic radius, m;
γ_0 is the density of the perfectly dry material, kg/m^3;
$\varkappa$ is the relative drying coefficient;
τ_1, τ_2 are the times respectively pertaining to the periods of constant and decreasing drying rate, h;
X is the dimensionless coordinate equaling x/R for a plate, and r/R for a cylinder or a sphere, where r is the radius of the cylinder or sphere;
x is the current coordinate;
Γ, Π, χ are form constants of the body: for an infinite plate, $\Gamma = 3$, $\Pi = 1$; for an infinite cylinder, $\Gamma = 4$, $\Pi = 2$; for a sphere, $\Gamma = 5$, $\Pi = 3$, $\chi = \Pi/\Gamma$.

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