MASS-TRANSFER COEFFICIENTS OF CITRUS FRUITS

M. A. Grishin and A. Ya. Listopad

UDC 533.73

The relationships between the mass-transfer coefficients and moisture contents of citrus fruits calculated from the desorption isotherms and characteristic curves are presented.

We studied Valencia, Navel, Double Fine, Shamauti, and Narencia oranges and Verdelli lemons of the 1968-1969 harvest grown in the countries of the Eastern Mediterranean. For the calculations we used the following initial data: humidity $W_i = 87\%$, moisture content $U_i = 6.68$ kg/kg, density of fresh fruits and dry materials $\rho = 880$ kg/m^3, $\rho_0 = 790$ kg/m^3, mean diameter of the calibrated fruits $d = 7 \cdot 10^{-2}$ m, ratio of the volume to the surface area of the fruits $R_V = (1.04\text{–}1.24) \cdot 10^{-2}$ m; these values were obtained by standard methods and averaged to an accuracy of 3%.

The desorption isotherms $U_p = f(\varphi, T)$ were obtained by a tensimetric method at t = 0, 10, 20, and 30°C in the range of relative air humidity $\varphi = 0.4\text{–}1.0$, and also by an accelerated dynamic method in an apparatus made by G. K. Filonenko and A. I. Chuprina [6]. For the zero-degree isotherm the point with $\varphi = 0.2$ was also obtained. Since the process of bringing the whole fruits into equilibrium was extremely protracted, and for $t > 20$°C and $\varphi > 0.9$ practically impossible, the experiments were carried out with small lobes of the fruits, previously dried at t = 40°C to a weight of about 0.3-0.5 of the original. The isotherms, typical of colloidal capillary-porous solids, intersect the $\varphi = 1.0$ line at different points. Under these conditions the loss of moisture by the fruits is caused by the temperature gradient which arises as a result of breathing processes [2, 4, 6]. In the range $\varphi = 0.2\text{–}0.9$ the zero-degree isotherm is described by the equation $\log U_p = 0.3 + 7\varphi^2$.

The chemical potential of mass transfer in the hygroscopic region, identical in absolute magnitude with the moisture/fruit binding energy, was calculated from the existing [3, 5] formula $|\mu| \equiv \varepsilon = RT\ln\varphi$, after which the characteristic curves $\mu = f(u_p)$ were plotted (Fig. 1). As a result of analyzing these curves and the desorption isotherms, we obtained the required coefficients of mass transfer and their dependence on the moisture content at t = 0°C. Using the method of A. V. Lykov, we plotted the experimental scale $\theta = f(U_p)$ and calculated the initial potential of moisture transfer $\theta = 450$°M.

It is well known that the dependence of the diffusion coefficient a_m on the moisture content of a material is determined by the form of binding of the moisture and the form of mass transfer (i.e., transfer of vapor or liquid). If the mass transfer takes place in the form of liquid, the coefficient a_m may either rise with increasing moisture content or remain constant, depending on the form of the differential pore-radius distribution curve [3] (Fig. 2). For citrus fruits involving osmotic moisture the coefficient a_m varies along a complex curve with singular points, at which the form of moisture binding changes from one type to another (in the same way as the points on the curve of thermal diffusivity a_q). In the range of moisture content 0-0.16 kg/kg, the coefficient a_m increases (this is not shown in the graph), the mass transfer taking place in the form of vapor and liquid. In the range of moisture content 0.16-1.50 kg/kg the coefficient a_m diminishes. Here the total moisture transfer is limited by the velocity of diffusive moisture transfer, which is considerably lower than the velocity of the molar motion of moisture under the influence of capillary forces. In the range of moisture content 1.50-6.68 kg/kg, i.e., in the moist state of the fruits, the coefficient a_m remains constant.

Allowance for the natural depreciation of whole fresh fruits enabled us to calculate and construct a curve representing the transpiration intensity $j = f(\varphi, T)$, thus enabling us to determine the natural loss knowing only the effective unscreened mass surface of the fruits. It was established experimentally that

---

M. V. Lomonosov Technological Institute, Odessa. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 20, No. 3, pp. 543-545, March, 1971. Original article submitted May 7, 1970.

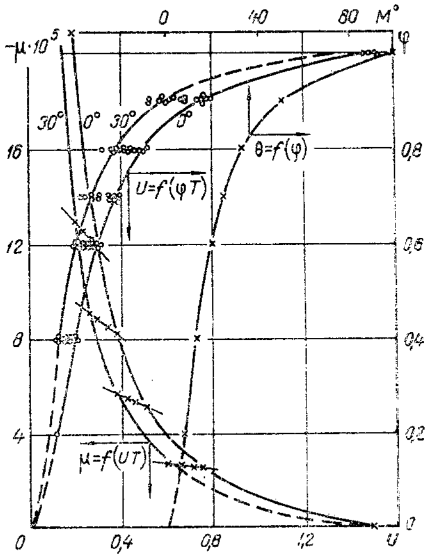

Fig. 1

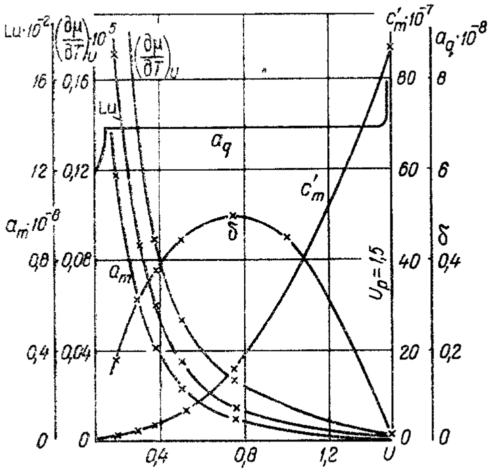

Fig. 2

Fig. 1. Desorption isotherms, characteristic curves, and experimental scale of the moisture transfer of citrus fruits (10 and 20 degree isotherms and curves denoted by points); μ, J/kmole; U, kg/kg.

Fig. 2. Dependence of the mass-transfer coefficient, the thermal-diffusivity coefficient, and the Lu number on the moisture content of citrus fruits; a_m, m^2/sec; $(\partial\mu/\partial T)_U$, J/kmole · °K; c_m, kmole/q · J; δ, %/deg; a_q, m^2/sec.

the specific mass surface of calibrated fruits of any class was a constant quantity, not depending on the variety, form, season, or region of growth, and hence the intensity of transpiration was determined solely by the parameters of the surrounding medium, i.e., the t and φ of the air, in confirmation of the fundamental views of N. A. Maksimov [4]. A special feature of the transpiration of the fruits is the fact that the zone of evaporation is relatively constant, i.e., the fruits dry up from within [2]. The period of constant rate of transpiration extends up to a critical moisture content of about 150%.

The thermal coefficients and their dependence on the moisture content of the fruits were also obtained. These relationships, also typical of colloidal capillary-porous solids, have characteristic singular points and a maximum at the boundary of the regions corresponding to the hygroscopic and moist state of the fruits. The Lu number is much less than unity, i.e., the inertia of the field of moisture content is much greater than the inertia of the temperature field. The Biot number is much smaller than unity, i.e., the guiding point is a long way from the surface, which justifies us, in subsequent practical calculations, in neglecting the temperature drop within the fruits by comparison with the temperature head, and eliminating the spatial coordinates from consideration. The computing method is set out in detail in [1, 3, 5].

LITERATURE CITED

1. V. D. Ermolenko, Inzh.-Fiz. Zhurn., No. 8 (1960).
2. V. Z. Zhadan, Author's Abstract of Doctor's Dissertation, OTIPKhP (1969).
3. A. V. Lykov, Theory of Drying [in Russian], Energiya, Moscow (1968).
4. N. A. Maksimov, Selected Works on the Resistance of Plants to Drying and Winter Conditions [in Russian], Izd. AN SSSR (1949).
5. L. M. Nikitina, Thermodynamic Parameters and Coefficients of Mass Transfer in Moist Materials [in Russian], Énergiya, Moscow (1968).
6. A. I. Chuprina, Author's Abstract of Candidate's Dissertation, OTIPKhP (1968).