Table 1 gives an approximate classification of materials which are most likely to obey Equations 19 and 20.

Equations 18 and 20 hold for cross-circulation drying. When through-circulation drying is involved, the appropriate constant-rate expression given by Equation 4 must be used to determine K in Equation 16. Thus, for through-circulation drying in the falling-rate period when Equation 15 holds, the rate is given by

$$\left(\frac{dW}{d\theta}\right)_f = -\frac{0.37 c_s a G^{0.59} (\Delta t)_m}{\rho_s \lambda D_p^{0.41} (W_c - W_e)} (W - (W_e) \qquad (21)$$

where the symbols have been defined for Equations 4, 12, and 16.

Critical Moisture Content. In order to use the above equations for estimating the drying time in the falling-rate period, it is necessary to know values of the critical moisture content. Such values are usually difficult to obtain without making actual drying tests which, in themselves, would give the required drying time and thereby obviate the necessity of the calculations.

Table 1. Approximate Classification of Materials Most Likely to Obey Equations 19 and 20

Materials obeying Equation 19	Materials Obeying Equation 20
1. Singe-phase solid systems such as soap, gelatin, glue. 2. Wood and similar solids below the fiber saturation point. 3. Last stages of drying starches, textiles, paper, clay, hydrophilic solids, and other materials when bound water is being removed.	1. Coarse granular solids, such as sand, paint pigments, minerals, etc. 2. Materials in which moisture flow occurs at concentrations above the equilibrium moisture content at atmospheric saturation, or above the fiber saturation point.

It appears that the constant-rate period ends when the moisture content at the surface reaches some specific value. If the rate of drying is great, the moisture gradients within the solid will be steep and the average moisture content considerably greater than that at the surface. It is for this reason that the critical moisture content (average through the material) increases with increase in rate of drying, and with an increase in thickness of the layer being dried.

Approximate Equations for Estimating Drying Time

An estimate of the overall drying time for a given drying problem usually involves an estimate of the time required for the constant-rate period, plus an estimate of the time for the falling-rate period. An approximate equation for the overall drying time applicable to the cross-circulation drying of materials of the type listed in Table 1 as obeying Equation 20, may be written as follows:

$$\theta_t = \theta_c + \theta_f = \frac{(W_o - W_c)\lambda L \rho_s}{h_t(t_a - t_s)} + \frac{\rho_s L \lambda (W_c - W_e)}{h_t(t_a - t_s)} \log_e \frac{W_c - W_e}{W - W_e}$$

$$= B\left[\frac{W_o - W_c}{W_c - W_e} + \log_e \frac{W_c - W_e}{W - W_e}\right] \qquad (22)$$

where

$$B = \frac{\rho_s L \lambda (W_c - W_e)}{h_t(t_a - t_s)} = \frac{1}{K}$$

θ_t = total drying time, hours.
θ_c = drying time for constant-rate period, hours.
θ_f = drying time for falling-rate period, hours.
W_o = initial moisture content, pounds per pound of dry solid.
W_c = critical moisture content, pounds per pound of dry solid.
W_e = equilibrium moisture content, pounds per pound of dry solid.
W = moisture content at time θ_t, pounds per pound of material.
h_t = total overall heat transfer coefficient Btu per (hour) (square foot) (Fahrenheit degree).
t_a = air temperature, Fahrenheit degrees.
t_s = temperature of surface of material, Fahrenheit degrees.
L = depth of material in tray, feet.
λ = latent heat of evaporation at t_s, Btu per pound.
ρ_s = density of dry solid, pounds per cubic foot.

Equation 22 will apply to those materials satisfying Equation 20 when drying to very low moisture content is not involved.

For through-circulation drying, an expression similar to Equation 22 is obtained. Thus, the total drying time for through-circulation drying is given by

$$\theta_t = B'\left[\frac{W_o - W_c}{W_c - W_e} + \log_e \frac{W_c - W_e}{W - W_e}\right] \qquad (23)$$

where $$B' = \frac{2.7 \rho_s \lambda D_p^{0.41} (W_c - W_e)}{c_s a G^{0.59} (\Delta t)_m}$$

The drying times estimated from Equations 22 and 23 apply only to cross-circulation drying and through-circulation drying, respectively. Drying times for other methods, such as rotary drying or drum drying, must be estimated by other methods.

Equilibrium Moisture Content

In the drying of solids it is important to distinguish between hygroscopic and non-hygroscopic materials. A hygroscopic material is one which retains a definite percentage of moisture under definite conditions of air humidity. This bound moisture is in a state of equilibrium with the water vapor in the surrounding air, and a decrease in the water vapor content will decrease the amount of equilibrium bound water. Water so retained by a solid in equilibrium with the humidity of the surrounding air, is designated as the *equilibrium moisture content*. Such moisture may be held as adsorbed surface films or condensed in fine capillary structures at reduced vapor pressure.

The equilibrium moisture content varies with the temperature and humidity of the surrounding air. Consequently, any correlation of equilibrium moisture content should take these two factors into account. However, at low temperatures, *e.g.*, 60 to 120 F, a plot of equilibrium moisture content *vs.* percent relative humidity, expressed as 100 (p/p_s), is essentially independent of temperature. Such a plot usually results in a curve of double curvature with a point of inflection (see Fig. 5).

The equilibrium moisture content at a given relative humidity is not