Falling-Rate Period

The *critical moisture content* marks the end of the constant-rate period and the beginning of the falling-rate period. This falling rate may be due to the fact that the surface is no longer completely wetted, or it may result from a condition in which the moisture cannot reach the surface as fast as it can be evaporated. When this high resistance to capillary flow and diffusion is the governing factor in the drying process, the time of drying increases rapidly with the thickness of the material. During constant-rate drying the time required is directly proportional to the thickness of the bed (see *Example 1*), while the time required for drying during the falling-rate period is often proportional to the square of the thickness of the material.

Actual calculations of drying during the falling-rate period are not highly satisfactory because of the number of variables. It has been demonstrated empirically that the rate of drying is approximately proportional to the free water content of the material.

An approximate value of the critical moisture content which marks the beginning of the falling-rate period may be obtained from Table 3.

TABLE 3. CRITICAL MOISTURE CONTENT FOR VARIOUS MATERIALS[a]

MATERIAL	CRITICAL MOISTURE CONTENT, PER CENT
Sand	3 to 20
Clay; soil; pigments	5 to 40
Paper, book or coated	30 to 40
Paper, newsprint	60 to 70
Paper pulp and pulp-boards (wallboard)	75 to 150
Leather (heavy)	90 to 120

[a]The critical moisture content is expressed as weight of water in per cent of weight of dry material.

DESIGN

In all drying problems, data regarding temperatures, time, and humidity must be obtained by experiment or previous experience. Experiments are best performed at the temperatures, humidities, and velocities to be actually used in the full sized dryer, and with full size samples.

The following nomenclature and explanation of terms will be used in the discussion of design calculations:

H = humidity ratio of air, pounds of water vapor per pound of dry air.
G = pounds of dry air supplied to the dryer per unit of time.
S = pounds of stock dried per unit of time in a continuous dryer.
S' = pounds of stock charged per batch to a discontinuous dryer.
Θ = time.
Q = total heat supplied to the dryer.
t = air temperature.
t' = stock temperature.
t'' = average stock temperature over short time interval, in a batch dryer.
t_w = wet-bulb temperature.
s' = specific heat of the stock.
B = total radiation and conduction losses per unit time.
w = pounds of water per pound of dry stock.

r = heat of evaporation of water.
s = humid heat of air, *i.e.*, heat necessary to raise 1 lb of dry air + H lb of steam 1 F.

Subscript (1) designates conditions at the point where the material in question (air or stock) enters, and (2) where it leaves the dryer.

Air dryers may be divided into two classes, those in which *all moisture* evaporated from the stock *leaves the dryer as vapor* in the effluent air, and those in which *part or all* of the moisture *is condensed* from the air *in the drying equipment itself*. In any continuously operating dryer of the first type the relation between moisture content of the stock and quantity of air required for the drying operation is given by the equation:

$$G(H_2 - H_1) = S(w_1 - w_2) \tag{4}$$

In discontinuous dryers, *e.g.*, compartment dryers, the drying operation is given by the equation:

$$G(H_2 - H_1) = S' \frac{dw}{d\Theta} \tag{4a}$$

In the continuous dryer, the heat consumption per unit time is:

$$\frac{Q}{\Theta} = Gs_1(t_2 - t_1) + G(r_2 + t_2 - t'_2)(H_2 - H_1) + S(t'_2 - t'_1)(s' + w_1) + B \tag{5}$$

Equation 5 assumes continuity of operation. For charge or batch operations, the total time of the drying cycle may be broken up into a number of periods, sufficiently short so that over each period average values of t, t' and H may be employed provided the third term of the right hand member of the equation is modified to read:

$$S'(t''_2 - t''_1)(s' - w_1)$$

and in the second term t'_2 be replaced by

$$\frac{t'_1 + t''_2}{2}$$

Theoretically these periods should be very short and the equation integrated. Practically the error introduced by using a small number of long periods and employing average values of the variables over each, rarely introduces serious error. The evaluation of Equation 4a may be approximated in a similar manner.

The first term of the right hand member of Equation 5 represents heat lost as sensible heat in the effluent air. In many drying operations this becomes excessive. Each pound of air supplied should remove the maximum amount of moisture. This is best accomplished by bringing the air into contact with the stock with sufficient intimacy so that the air leaving the dryer is saturated, or nearly so. Counter-current as against parallel flow of air and stock gives rise to optimum operating conditions, resulting in a minimum quantity of air required (G), and a corresponding minimum loss, as sensible heat, in the exit air. Similarly, continuous operation is superior to intermittent operation.

Despite the fact that the sensible heat loss increases with the rise in temperature of the air, the percentage of heat lost from this source decreases, provided the increase in moisture carrying capacity of the air, due to high temperature, is actually utilized. To secure maximum thermal efficiency in drying, a high drying temperature and high saturation of the outlet air are imperative.