$t$ = air temperature, Fahrenheit.
$t'$ = stock temperature, Fahrenheit.
$t''$ = average stock temperature over short time interval, in a batch dryer, Fahrenheit.
$t_w$ = wet-bulb temperature, Fahrenheit.
$s_1$ = specific heat of the stock, Btu per pound.
$Q_{rc}$ = total radiation and conduction losses, Btu per hour.
$W$ = pounds of water per pound of dry stock.
$\lambda$ = heat of evaporation of water, Btu per pound.
$c_s$ = humid heat of air, *i.e.*, heat necessary to raise 1 lb of dry air + $H$ lb of steam 1 F deg.

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, batch and continuous.

In any continuously operating dryer, the relation between moisture content of the stock and quantity of air required for the drying operation is given by the equation

$$N_a\ (H_2 - H_1) = S(W_1 - W_2) \qquad (24)$$

*where* $H_2$ is constant.

In discontinuous dryers, the drying operation is given by the equation

$$N_a(H_2 - H_1) = S'\frac{dW}{d\theta} \qquad (25)$$

*where* $H_2$ is a variable during a portion of the cycle.

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

$$\frac{Q}{\theta} = N_a c_{s1}(t_2 - t_1) + N_a(\lambda_2 + t_2 - t'_2)(H_2 - H_1) + S(t'_2 - t'_1)(s_1 + W_1) + Q_{rc} \qquad (26)$$

Equation 26 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:

$$S'(t''_2 - t''_1)\ (s_1 - W_1)$$

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, is not serious. The evaluation of Equation 25 may be approximated in a similar manner.

The first term of the right hand member of Equation 26 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 ($N_a$), 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 if 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.

The second term of the right member of Equation 26 represents the latent heat of evaporation of the water plus the heat to raise this water to the temperature of evaporation. The third term of the equation represents heat to raise the temperature of the stock plus the water which remains unevaporated in the stock.

The changes taking place in the air during the drying process can be illustrated on the skeleton psychrometric chart, Fig. 9. The case illus-

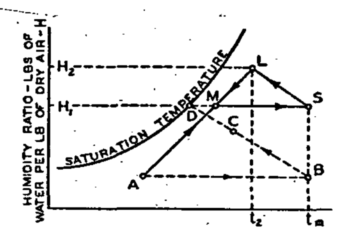


FIG. 9. CHANGES IN AIR DURING DRYING PROCESS

trated is typical of tunnel and rotary dryers where heat is applied to the air at one point only. After the first adjustment stage, during which both the material and the dryer reach the working temperature, the only heat losses from the dryer are those of radiation and conduction from the housing, and these are practically negligible for an insulated dryer. Hence, the drying process can be considered to be adiabatic.

If 100 percent outside air is used, the air can be considered to enter at point A, Fig. 9 (the prevailing outside air condition), and be heated to point B (the maximum permissible temperature $t_m$ or the temperature determined by previous test). As the air evaporates moisture, it cools along the constant wet-bulb line BD to point C. The difference between the moisture content of air at B and at C represents the moisture *pick up* of the air. The maximum possible *pick up* from B to D is never achieved in practical dryers, the actual *pick up* being anywhere from 10 to 75 percent of the maximum.

In order to conserve heat and to control the wet-bulb temperature at which the drying takes place, recirculation is used. The process is shown on Fig. 9. The outside air at A is mixed with recirculated air until the moisture level is raised to the desired point. The mixture is represented at point M, the heaters heat the mixture to the desired dry-bulb temperature $t_m$ at point S. The moisture is picked up from S to L. Point L is the condition at which air is exhausted.