$r$ = 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:

$$G\,(H_2 - H_1) = S(w_1 - w_2) \qquad (4)$$

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

$$G\,(H_2 - H_1) = S^1 \frac{dw}{d\Theta} \qquad (4a)$$

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

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

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 $t$, $t^1$ and $H$ may be employed provided the third term of the right hand member of the equation is modified to read:

$$S^1\,(t''_2 - t''_1)\,(s^1 - w_1)$$

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 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.



**Ventilation Phase**

The technique of attack of the *ventilation phase* of a drying problem is best made clear by an illustration. Assume that a material containing 40 per cent moisture is to be dried until this quantity of moisture is reduced to 5 per cent by weight. The material will stand an air temperature of 150 F and it is possible to provide sufficiently good contact between the material and the drying air so that the effluent air can be brought up to 50 per cent humidity at 150 F. The dryer is to use room air, the temperature and humidity of which may be assumed to average 70 F and 50 per cent. A counter-current dryer will be employed and the air in this dryer will be kept at a substantially constant temperature of 150 F by heaters thermostatically controlled. The stock enters at 70 F, rises quickly to the wet-bulb temperature of the air, with which it is in contact, and, as has been found experimentally, remains at this wet-bulb temperature until the moisture content has fallen to 20 per cent. From this point its temperature rises progressively as it dries. In this range

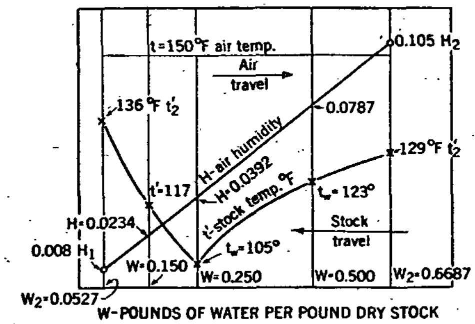


FIG. 7. TEMPERATURE HUMIDITY RELATIONS IN A DRYER

the difference in temperature between stock and air, divided by the wet-bulb depression, may be assumed proportional to the moisture content.

The moisture content of the entering stock, in the units here employed, is:

$$w_1 = \frac{40 \text{ per cent water}}{60 \text{ per cent dry stock}} = 0.6667:\ w_2 = \frac{5 \text{ per cent water}}{95 \text{ per cent dry stock}} = 0.0527$$

$w_1 - w_2 = \Delta w = 0.614$ lb water evaporated per pound of dry stock. Since the air leaving the dryer is 50 per cent saturated at 150 F from Fig. 6, $H_2 = 0.105$. Similarly, $H_1 = 0.008$, corresponding to 50 per cent humidity at 70 F. Consequently $H_2 - H_1 = \Delta H = 0.097$ lb water evaporated per pound dry air.

An analysis of Equation 4 shows that ($H$) is linear in $w$. Hence, one can construct on Fig. 7, the line marked ($H$) being drawn connecting the initial and final points just computed.

Since the air leaving the dryer has a temperature of 150 F and a humidity of 0.105, Fig. 6 shows that its wet-bulb temperature is 129 F. This is plotted at the right hand side of Fig. 7. Since the stock maintains a wet-bulb temperature down to 20 per cent moisture, where $w = 0.25$, the corresponding humidity can be computed by the use of Equation 4 or by reading directly from the diagram, the value being 0.0392. Fig. 6 shows that the corresponding wet-bulb temperature is 105 F. Any