1.5 Humidity measurement.

The humidity of stream gas may be found by measuring either the dew point or wet bulb temperature or direct absorption method or by chemical method.

1.6 Humidity data for air-water system.

Various type of humidity chart is available, based on either the temperature or enthalpy of the gas.

1.6.1 Temperature –Humidity Chart (Psychrometric Chart).

From this chart (see figure 2) the following quantities can be estimated:-

1. Humidity (absolute and relative $\mathcal{H}$).
2. Specific volume of dry gas.
3. Saturated volume.
4. Latent heat of vaporization.
5. Humid heat.
6. Dry and wet bulb temperature.
7. Dew and saturation temperature.

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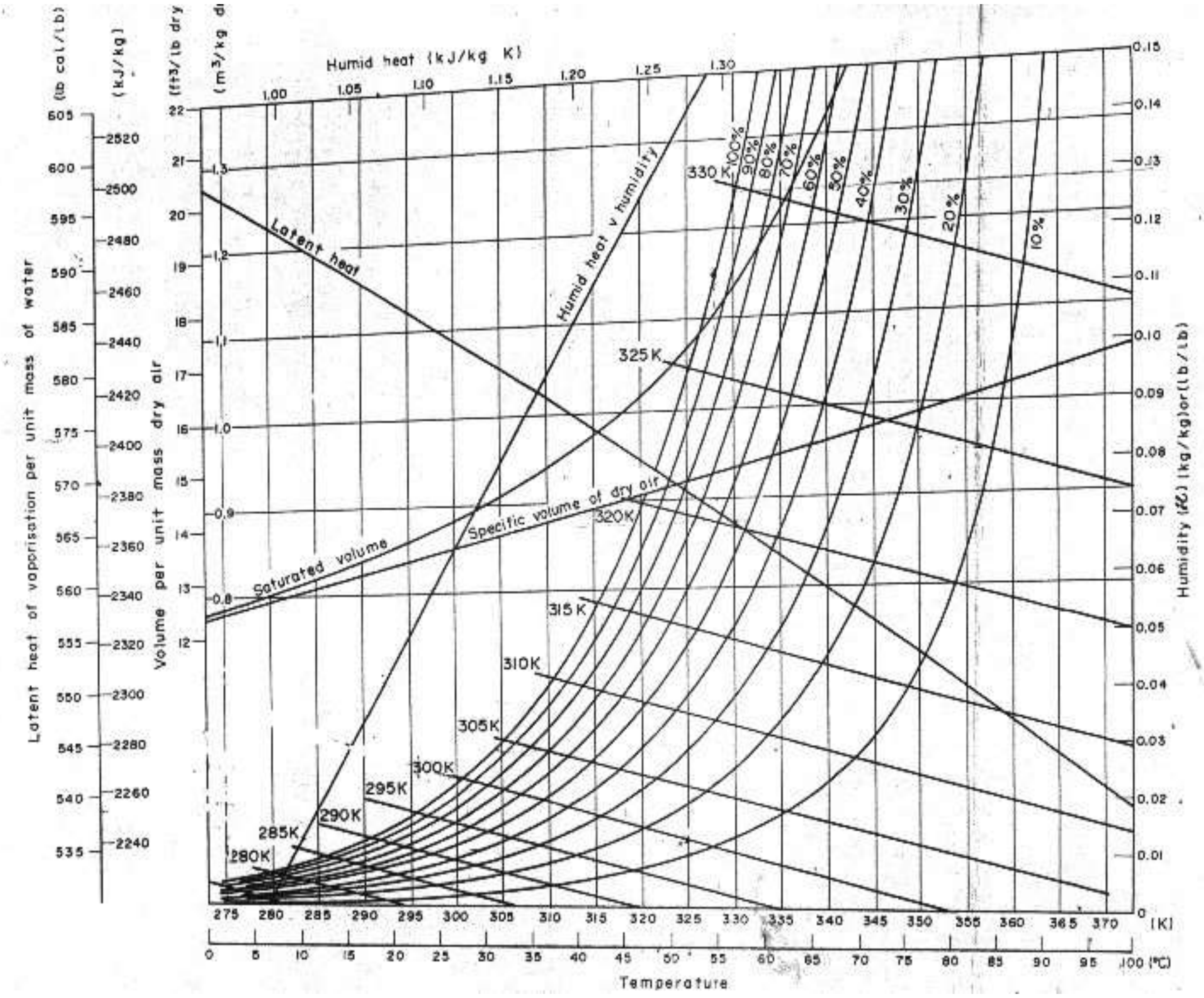

Figure (3) Temperature-humidity chart (psychrometric chart) for air water system.

If any two of the above quantities are known the others can be readily obtained. For a given wet bulb temperature equation (5) can be plotted on humidity chart (H vs. T) as a straight line having a slope of $-\frac{h}{h_D \rho \lambda}$ which known **Psychrometric line**. Also, equation (7) can be plotted which gave adiabatic cooling (saturation) line having the slope -S/λ.

For air-water system ($T_s = T_w$); therefore,

$$-\frac{S}{\lambda} = \frac{h}{h_D \rho \lambda} \dots\dots\dots\dots 8$$

So, the adiabatic cooling (saturation) line and Psychrometric line become essentially the same.

1.6.2 Uses of humidity chart.

1. The air dry bulb temperature T_G and its humidity H, is known and denoted in the figure (4) by the point a. The humidity of air is denoted by point b from the humidity coordinate.

2. The dew point Td, is found by the point d that can be reached by moving horizontally from the point **a** to the RH=100% line at **c** and then moving vertically down to the temperature axis **d**.

3. The adiabatic saturation line through **a** is **ae** (these are a series of almostparallel lines as shown in figures (2 and 3). The adiabatic saturation temperature is obtained by drawing the vertical line from **e** then down to the temperature axis **g**. For air -water system the wet bulb temperature is the same as adiabatic saturation temperature. The humidity of the adiabatically saturated air is given by the point **f**. Interpolation between the adiabatic lines may be necessary.

4. If the air originally is subsequent saturated at constant temperature, the humidity is found by following the temperature line through point a to point h on the R$\mathcal{H}$=100% line and reading the humidity at point j.

5. The humid volume of saturated air at temperature TG corresponds to the point k, and that of dry air at T_G is given by the point I. The point m gives the humid volume if the humidity is H. It reached by interpolation between I and k.

6. The humid heat of the air is found by locating point O, the intersection of the humidity line through point a and the humid heat line, and reading the humid heat at point p on the scale at the top.

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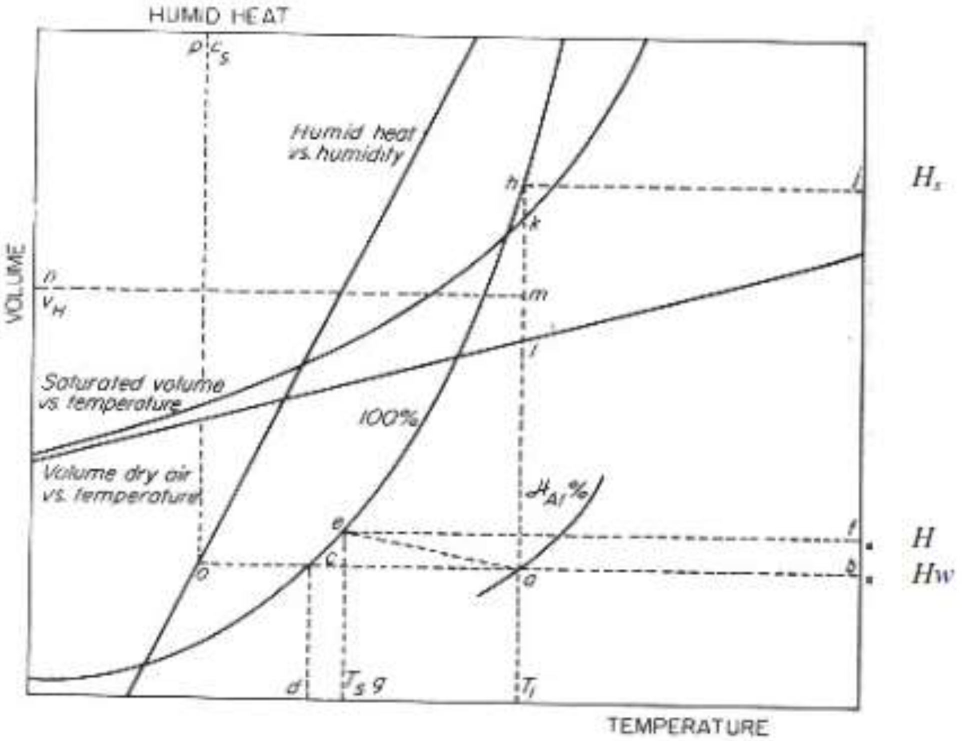


Figure 4: Uses temperature-humidity chart (psychrometric chart) for air-water system.

1.7 Rate of drying.

The time required for drying of a moist solid to final moisture content can be determined from a knowledge of the rate of drying under a given set of conditions The drying rate of a solid is a function of temperature, humidity, flow rate and transport properties (in terms of Reynolds number and Schmidt number) of the drying gas.

In drying, it is necessary to remove free moisture from the surface and also moisture from the interior of the material. If the change in moisture content for a material is determined as a function of time (see figure (5)), a smooth curve is obtained from which the rate of drying at any given moisture content may be evaluated. The form of the drying rate curve varies with the structure and type of material.

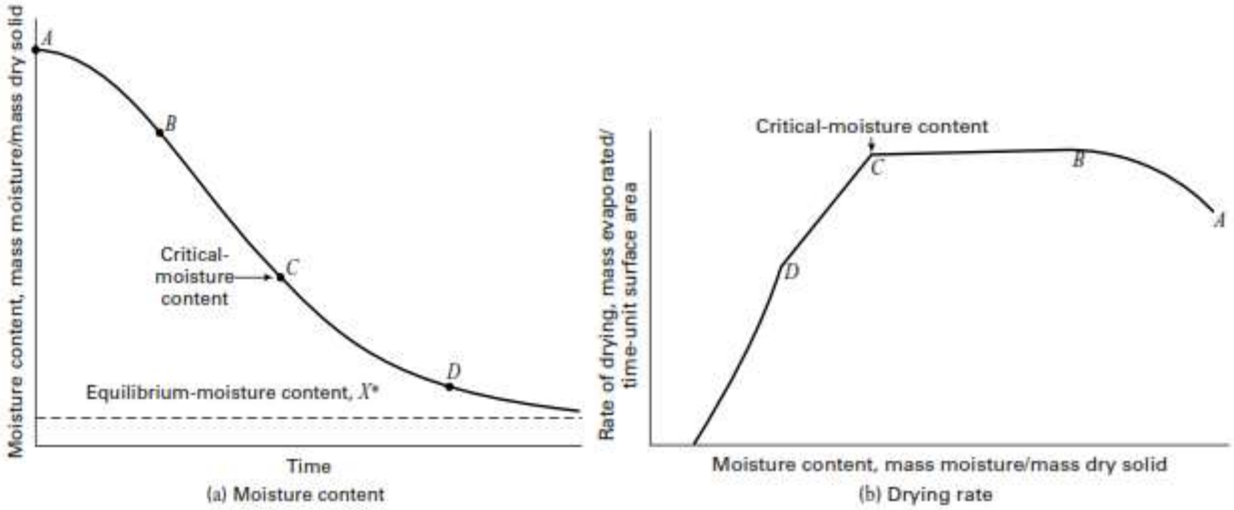
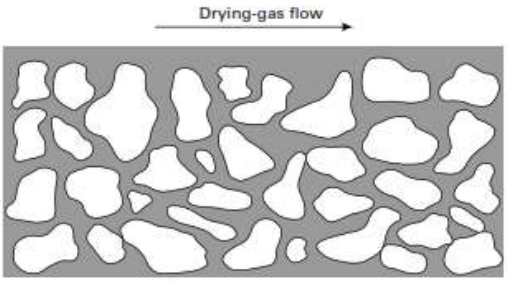


Figure (5) Rate of drying of a granular material.

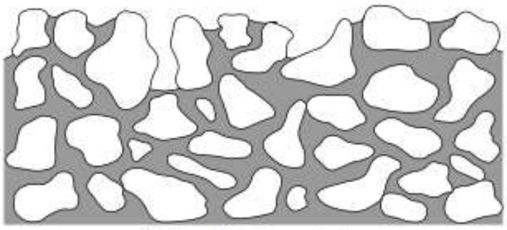
Wet materials and/or some hot-gas conditions, drying periods are observed in figure 5. From figure 5 (a to b), the wet solid is being preheated to an exposed-surface temperature equal to the wet-bulb gas temperature, while moisture is evaporated at an increasing rate. At the end of the preheat period, if the wet solid is of the granular, first category, a cross section has the appearance of Figures 5 and 6a, where the exposed surface is still covered by a film of moisture.

A wet solid of the second category is covered on the exposed surface by free moisture. The drying rate now becomes constant during the period from B to C, which prevails as long as free moisture covers the exposed surface. This surface moisture may be part of the original moisture that covered the surface, or it may be moisture brought to the surface by capillary action in the case of wet solids of the first category or by liquid diffusion in the case of wet solids of the second category.

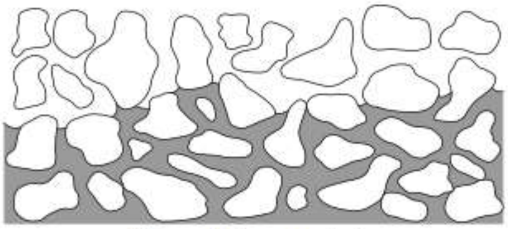
In either case, the rate of drying is controlled by external mass and heat transfer between the exposed surface of the wet solid and the bulk gas.



(a) Constant-rate period



(b) First falling-rate period



(c) Second falling-rate period

Figure 6 Drying stages for granular solids.

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Migration of moisture from the interior of the wet solid to the exposed surface is not a rate-affecting factor. This period, **the constant-rate drying period**, terminates at point C, **the critical moisture content**. When drying wet solids of the first category under agitated conditions as in a direct-heat rotary dryer, fluidized-bed dryer, flash dryer, or agitated batch dryer such that all particle surfaces are in direct contact with the gas, the constant-rate drying period may extend all the way to X.

At C, the moisture just barely covers the exposed surface; and then until point D is reached, as shown in Figures 5 and 6b, the surface tends to a dry state because the rate of liquid travel by diffusion or capillary action to the exposed surface is not sufficiently fast. In this period, the exposed-surface temperature remains at the wet-bulb temperature if heat conduction is adequate, but the wetted exposed area for mass transfer decreases. Consequently, the rate of drying decreases linearly with decreasing average moisture content. This is the first falling-rate drying period. It is not always observed with wet solids of the second category.

During the period from C to D, the liquid in the pores of wet solids of the first category begins to recede from the exposed surface. In the final period from D to E, as shown in Figures 5 and 6c, evaporation occurs from liquid surfaces in the pores, where the wet-bulb temperature prevails. However, the temperature of the exposed surface of the solid rises to approach the dry-bulb temperature of the gas. During this period, **the second falling-rate drying period**, the rate of drying may be controlled by vapor diffusion for wet solids of the first category and by liquid diffusion for wet solids of the second category. The rate falls exponentially with decreasing moisture content.

1.8 Calculation method of drying rate and time.

1.8.1 Drying rate

***Method used Experimental Drying Curve.**

Data obtained from batch drying experiments are usually obtained as W (total weight of the wet solid "dry + moisture") at different times t (h) in the drying period.

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$$X_t(dry\ basis) = \frac{W - L_s}{L_s} \ldots\ldots\ldots\ldots 9$$

Where

Ls: is the weight of dry solid.

For a given constant drying condition, the equilibrium moisture content X^* is determined then the free moisture is calculated for each value of X_t.

$$X = X_t + X^*$$

Plot X vs. t, to obtain the rate of drying (R) from this plot, the slope of the tangents drawn can be measured which give the value *dX/dt* at a given value of t. The rate R for each point is:

$$R = -\frac{L_s}{A}\frac{dX}{dt} \ldots\ldots\ldots\ldots 10$$

Where

R: is the rate of drying $KgH_2O/h.m^2$.

A: is the exposed surface area for drying m^2.

-The drying rate curve is then obtained by plotting R vs. the moisture content.

*Another method to obtain the value of drying curve is to calculate the weight loss

ΔX for a Δt time. For example; if $X_1=0.35$ at $t_1=1.68h$ and $X_2=0.325$ at $t_2=2.04h$, then:

$$\frac{\Delta X}{\Delta t} = \frac{0.35 - 0.325}{2.04 - 1.6}$$

and if $\frac{L_s}{A} = 2.5$; therefore $R = \frac{L_s \Delta X}{A \Delta t} = 1.493$

This rate is the average over the period 1.68h to 2.04h and should be plotted the average concentration.

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