Spring Semester course

CH31010: Mass Transfer II

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L2: Psychrometry

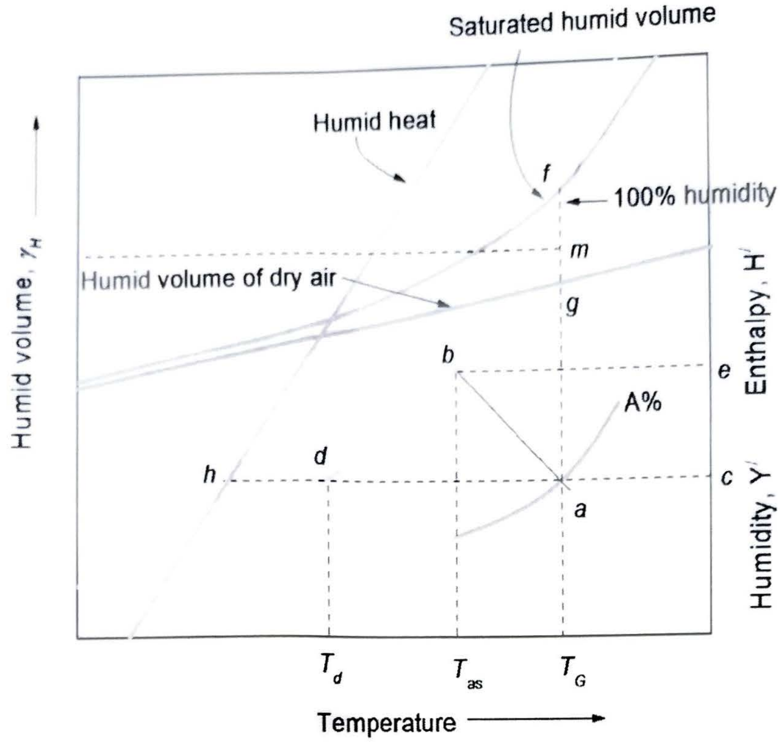
Importance

Seven important quantities:

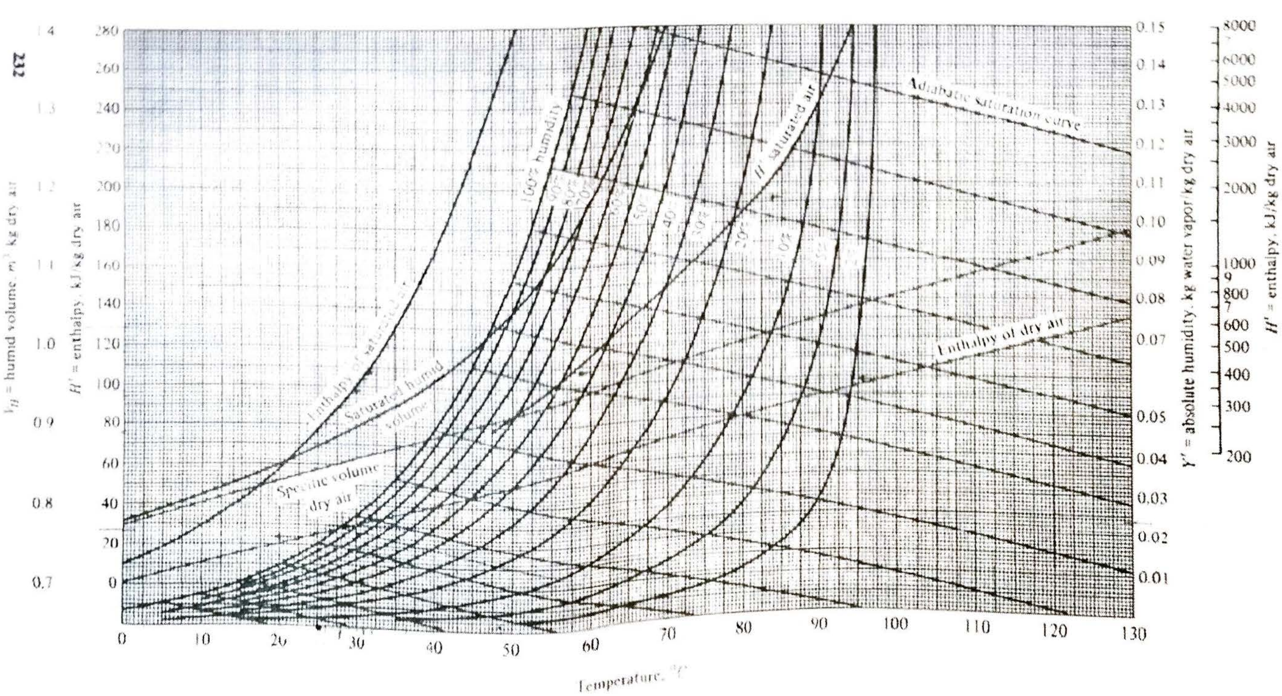
- Dry-bulb temperature,
- wet-bulb temperature,
- relative humidity,
- absolute humidity,
- dew point, enthalpy and
- specific volume, are all inter-related.

The psychrometric chart characterizes this interdependence. If any two of these quantities are known, the other five quantities can be readily obtained from the Psychrometric chart.

How to use this chart?



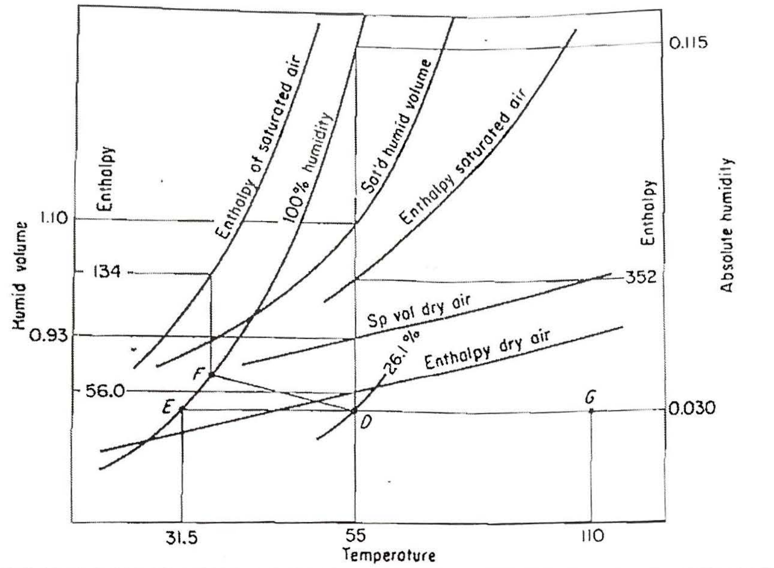
Psychrometric chart



Example problem on use of psychrometric chart

An air (A) water-vapour(B) sample has a DBT of 55°C and an absolute humidity 0.030 kg water/kg dry air at 1 atm pressure. Tabulate its characteristics.

The point of coordinates, $t_G = 55^oC, Y' = 0.03$ is located on the psychrometric chart, a schematic is shown here, marked as point D.



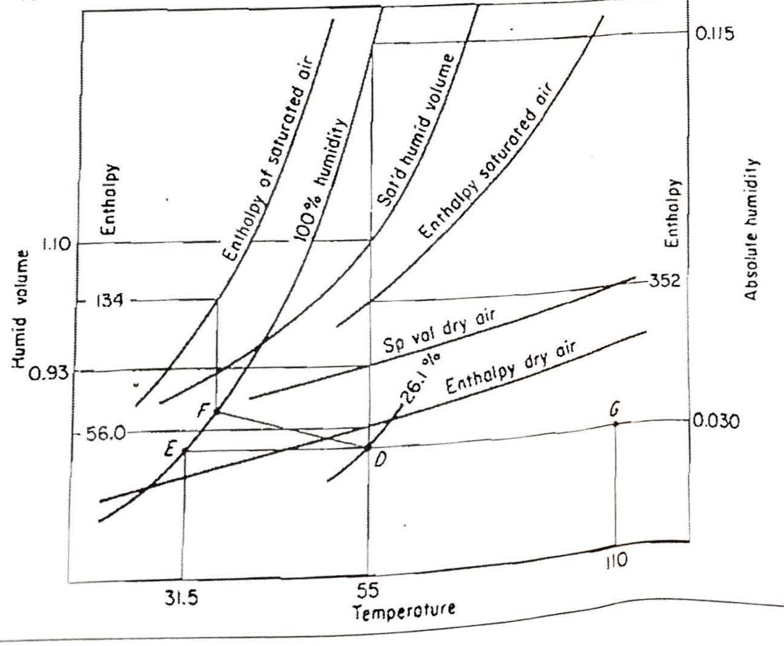
(*a*) By vertical interpolation between the adjacent curves of constant percent humidity, the sample has a percentage humidity = 26.1%. Alternatively, the saturation humidity at 55°C is $Y'_s = 0.115$, and the percentage humidity at D is therefore (0.030/0.115)100 = 26.1%.

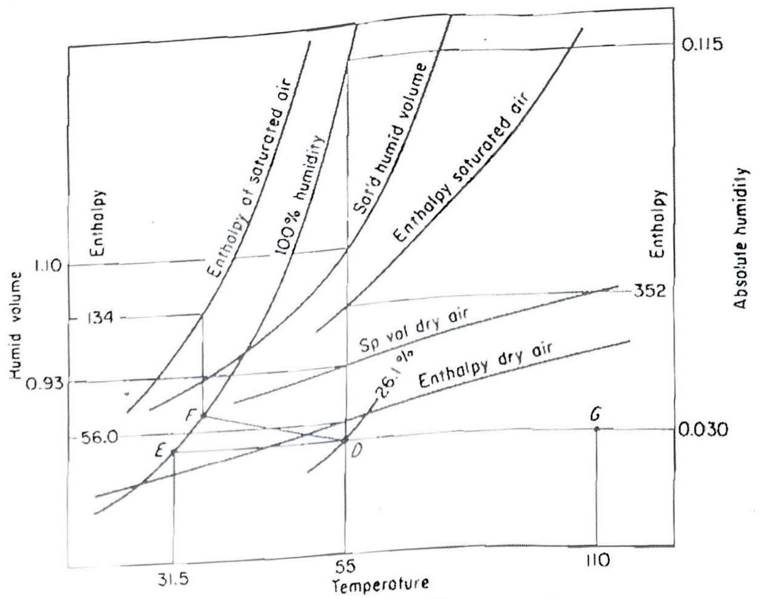
(*b*) The molal absolute humidity = $Y = Y'(M_B/M_A) = 0.030(28.97/18.02) =$ 0.0482 kmol water/kmol dry air.

(*c*) The partial pressure of water vapor in the sample,

$$\bar{p}_A = \frac{Yp_t}{1+Y} = \frac{0.0482(1.0133 \times 10^5)}{1.0482} = 4660 \text{ N/m}^2$$

(*d*) The vapor pressure of water at 55°C = 118 mmHg or 118(133.3) = 15 730 N/m² = p_A. The relative humidity = $\bar{p}_A(100)/p_A$ = 4660(100)/15 730 = 29.6%.





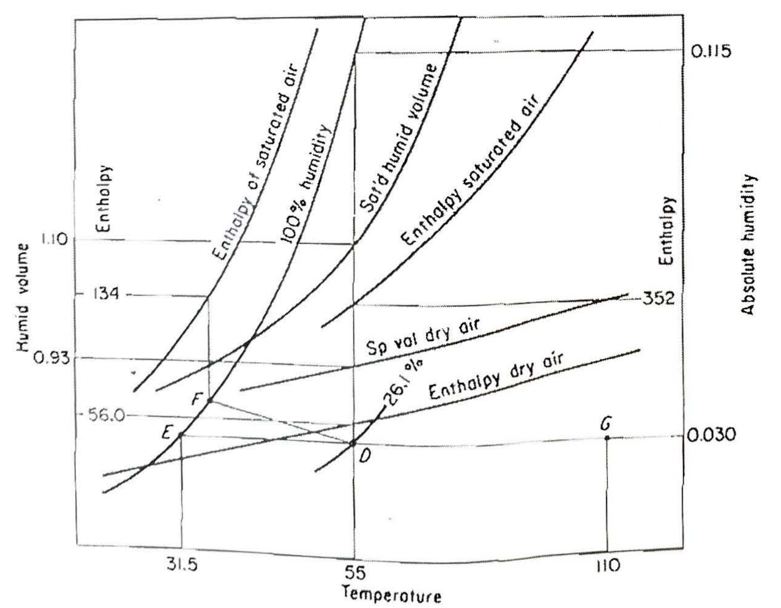
(*e*) Dew point. From point D proceed at constant humidity to the saturation curve at point E, at which the dew point temperature is 31.5°C.

(*f*) Humid volume. At 55°C, the specific volume of dry air is 0.93 m^3/kg. The humid volume of saturated air = 1.10 m^3/kg dry air. Interpolating for 26.1% humidity,

$$v_H = 0.93 + (1.10 - 0.93)(0.261) = 0.974 \text{ m}^3/\text{kg dry air}$$

(*g*) Humid heat,

$$C_S = C_B + Y'C_A = 1005 + 0.030(1884) = 1061.5 \text{ J (for wet air)/(kg dry air)} \cdot \text{K}$$



(*h*) Enthalpy. At 55°C, the enthalpy of dry air is 56 000 J/kg dry air; that for saturated air is 352 000 N · m/kg dry air. Interpolating for 26.1% humidity gives

$$H' = 56\,000 + (352\,000 - 56\,000)(0.261) = 133\,300 \text{ J/kg dry air}$$

Alternatively,

$$H' = C_S(t_G - t_0) + Y'\lambda_0 = (1005 + 1884Y')t_G + 2\,502\,300Y'$$
$$= [1005 + 1884(0.030)]55 + 2\,502\,300(0.030) = 133.4 \text{ kJ/kg dry air}$$

As another alternative line DF is drawn parallel to the adjacent adiabatic-saturation curves. At F, the enthalpy is 134 kJ/kg dry air, or nearly the same as at D.

Illustration 7.8 Air at 83°C, $Y' = 0.030$ kg water/kg dry air, 1 std atm is contacted with water at the adiabatic-saturation temperature and is thereby humidified and cooled to 90% saturation. What are the final temperature and humidity of the air?

The adiabatic-saturation curve / line through the point reaches the 100% saturation curve at 40°C (AST) which is the water temp. On this curve/line, 90% saturation occurs at 41.5°C, Y' = 0.0485 kg water / kg air.

Illustration 7.9 For an air–water-vapor mixture of dry-bulb temperature 65°C, a wet-bulb temperature 35°C was determined under conditions such that the radiation coefficient can be considered negligible. The total pressure was 1 std atm. Compute the humidity of the air.

The adiabatic-saturation line through AST of 35°C is followed to the DBT of 65°C, where Y' can be read as 0.0238 kg water / kg air.

Illustration 7.10 Estimate the wet-bulb and adiabatic-saturation temperatures for a toluene-air mixture of 60°C dry-bulb temperature, $Y' = 0.050$ kg vapor/kg air, 1 std atm.

SOLUTION *Wet-bulb temperature* $t_G = 60°C$, $Y' = 0.050$ kg toluene/kg air. $D_{AB} = 0.92 \times 10^{-5}$ m^2/s at 59°C, 1 std atm. At 60°C, ρ for air = 1.060 kg/m^3 and $\mu = 1.95 \times 10^{-5}$ kg/m · s.

Sc *should* be calculated for mean conditions between those of the gas-vapor mixture and the wet-bulb saturation conditions. However, for the dilute mixture considered here, the bulk-gas value of Sc is satisfactory and is essentially independent of temperature

$$Sc = \frac{\mu}{\rho D_{AB}} = \frac{1.95 \times 10^{-5}}{1.060(0.92 \times 10^{-5})} = 2.00$$

Eq. (7.28): $h_G/k_Y = 1223(2.00)^{0.567} = 1812$ J/kg · K (observed value = 1842). Eq. (7.26):

$$60 - t_w = \frac{\lambda_w}{1812}(Y'_w - 0.050)$$

Solution for t_w is by trial and error. Try $t_w = 35°C$. $p_{A,w} = 46.2$ mmHg, $Y'_w = [46.2/(760 - 46.2)]\ 92/29 = 0.2056$, $\lambda_w = (96.6\ \text{cal/gm})(4187) = 404\ 460$ J/kg. The equation provides t_w = 25.3°C instead of the 35°C assumed. Upon repeated trials, t_w is computed to be 31.8°C. Ans.

Adiabatic-saturation temperature $t_{G1} = 60°C$, $Y'_1 = 0.05$, C for toluene vapor = 1256 J/kg · K. $C_{S1} = 1005 + 1256(0.05) = 1067.8$ J/kg · K. Eq. (7.21):

$$60 - t_{as} = (Y'_{as} - 0.05)\frac{\lambda_{as}}{1067.8}$$

In the same fashion as the wet-bulb temperature, t_{as} is calculated by trial and found to be 25.7°C. Ans.