Spring Semester course

CH31010: Mass Transfer II

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L2: Psychrometry

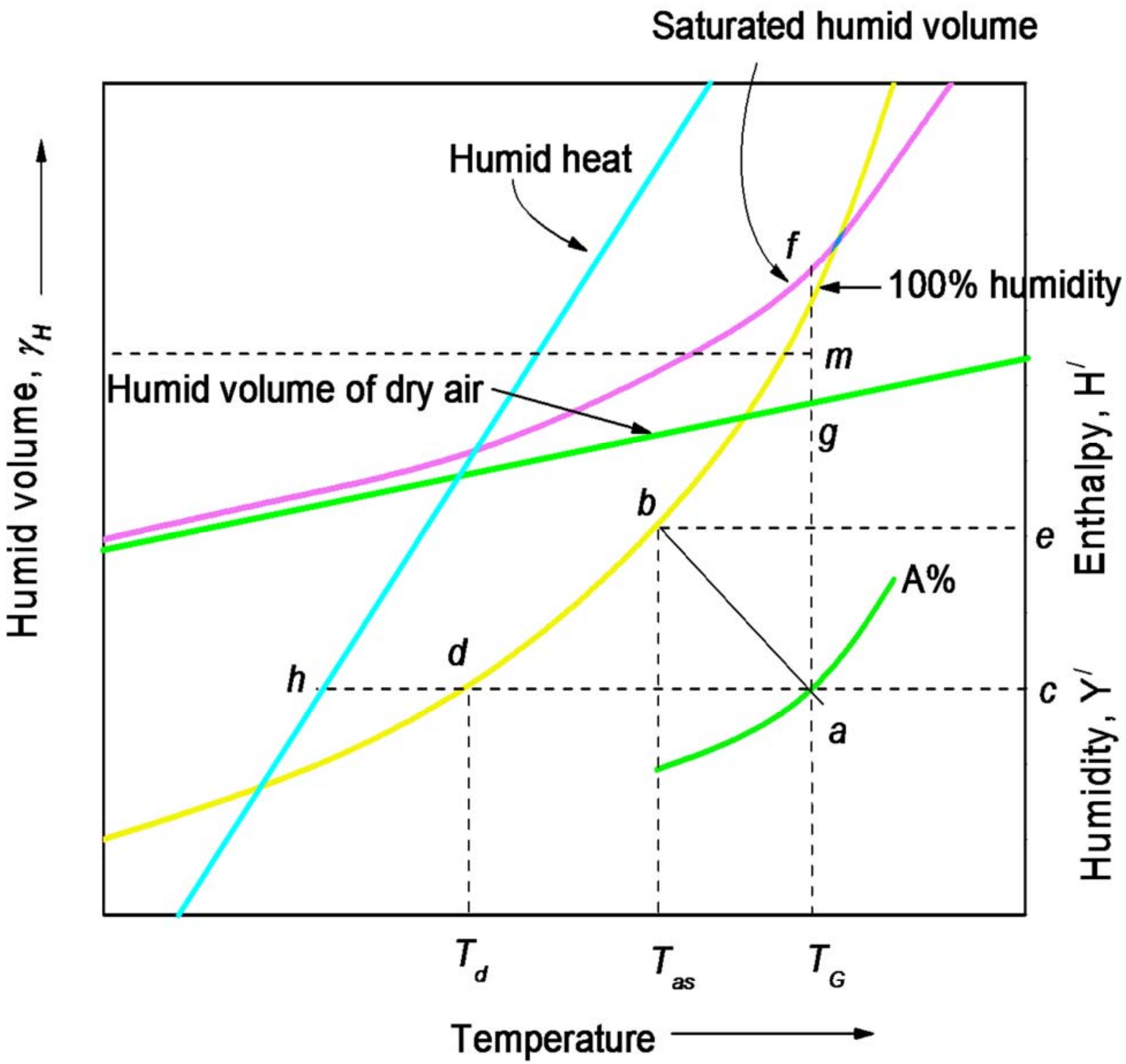
Importance

Seven important quantities:

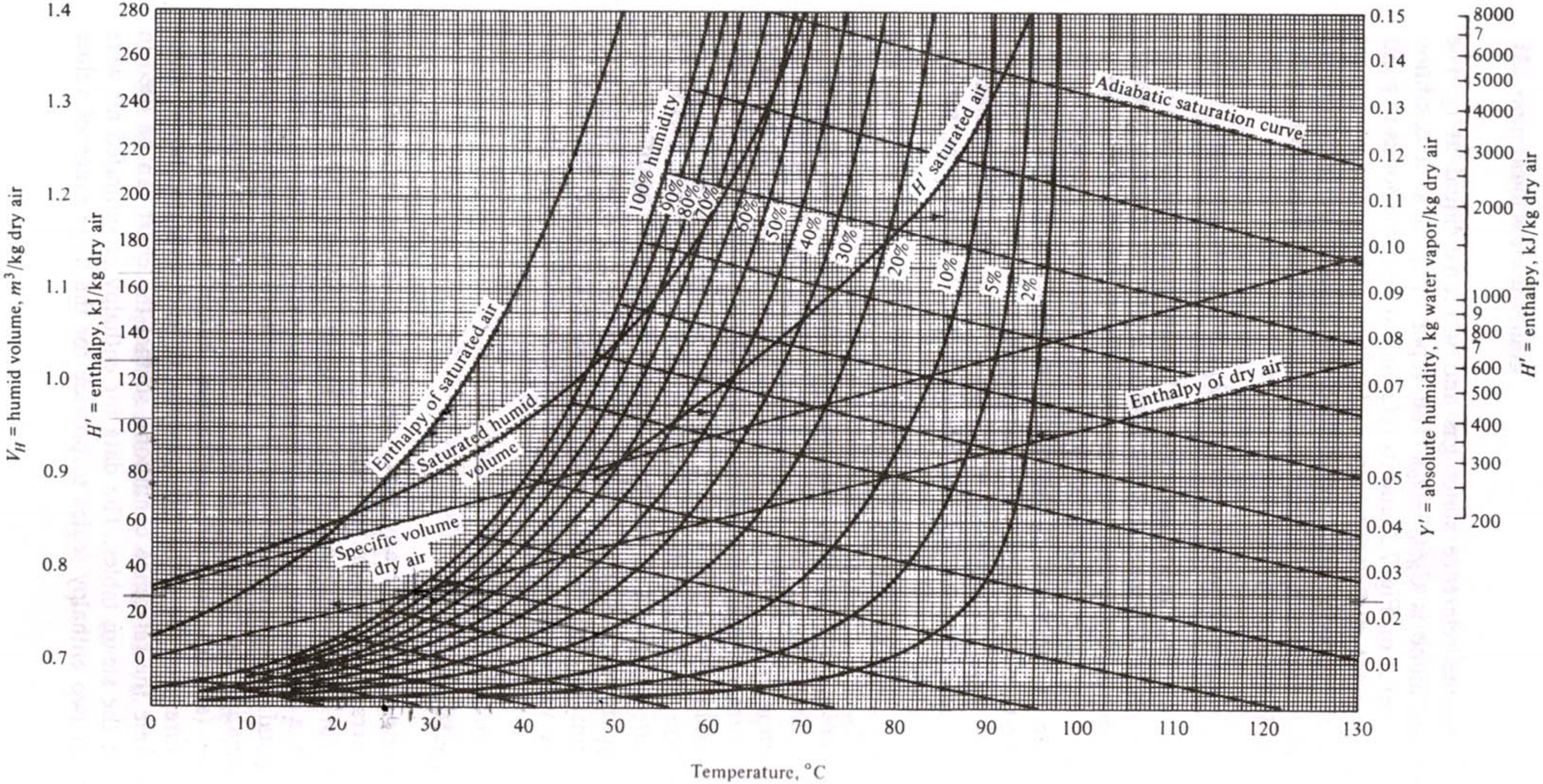
- Dry-bulb temperature,
- wet-bulb temperature,
- relative humidity,
- absolute humidity,
- dew point, enthalpy and
- specific volume, are all inter-related.

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?



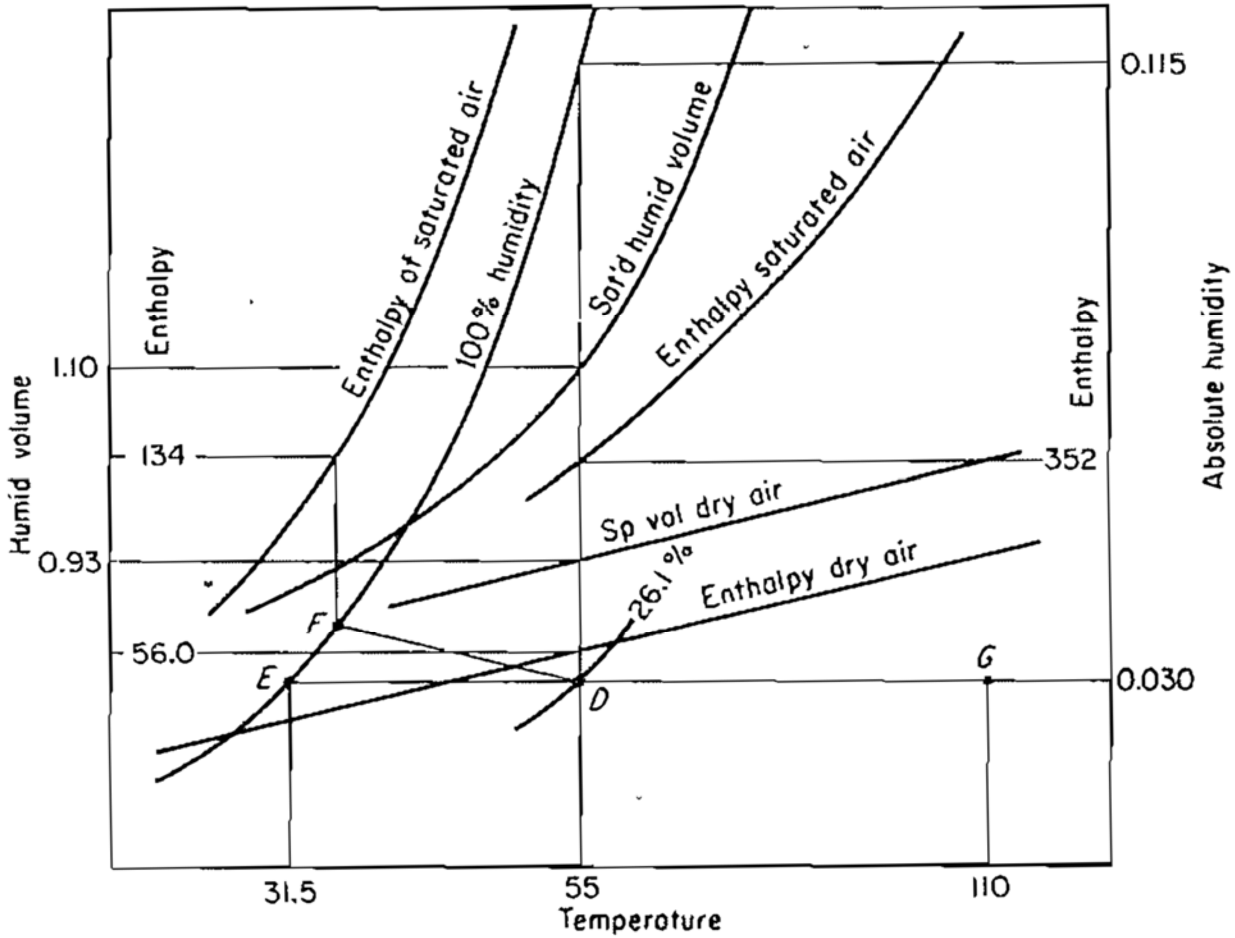
Psychrometric chart



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.



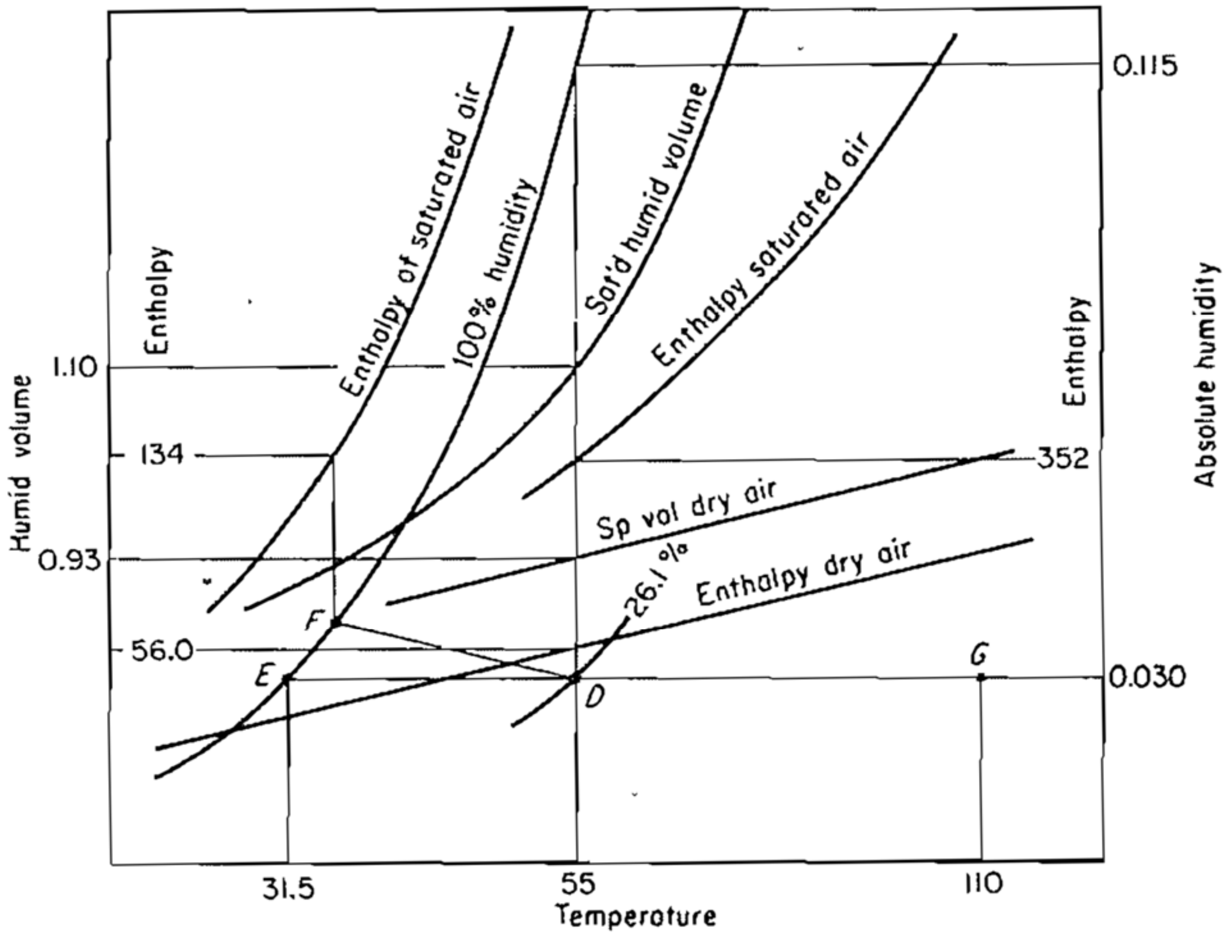
(*a*) By vertical interpolation between the adjacent curves of constant percent humidity, the sample has a percentage humidity = 26.1%. Alternatively, the saturation humidity at 55°C is $Y'_s = 0.115$, and the percentage humidity at D is therefore $(0.030/0.115)100 = 26.1\%$.

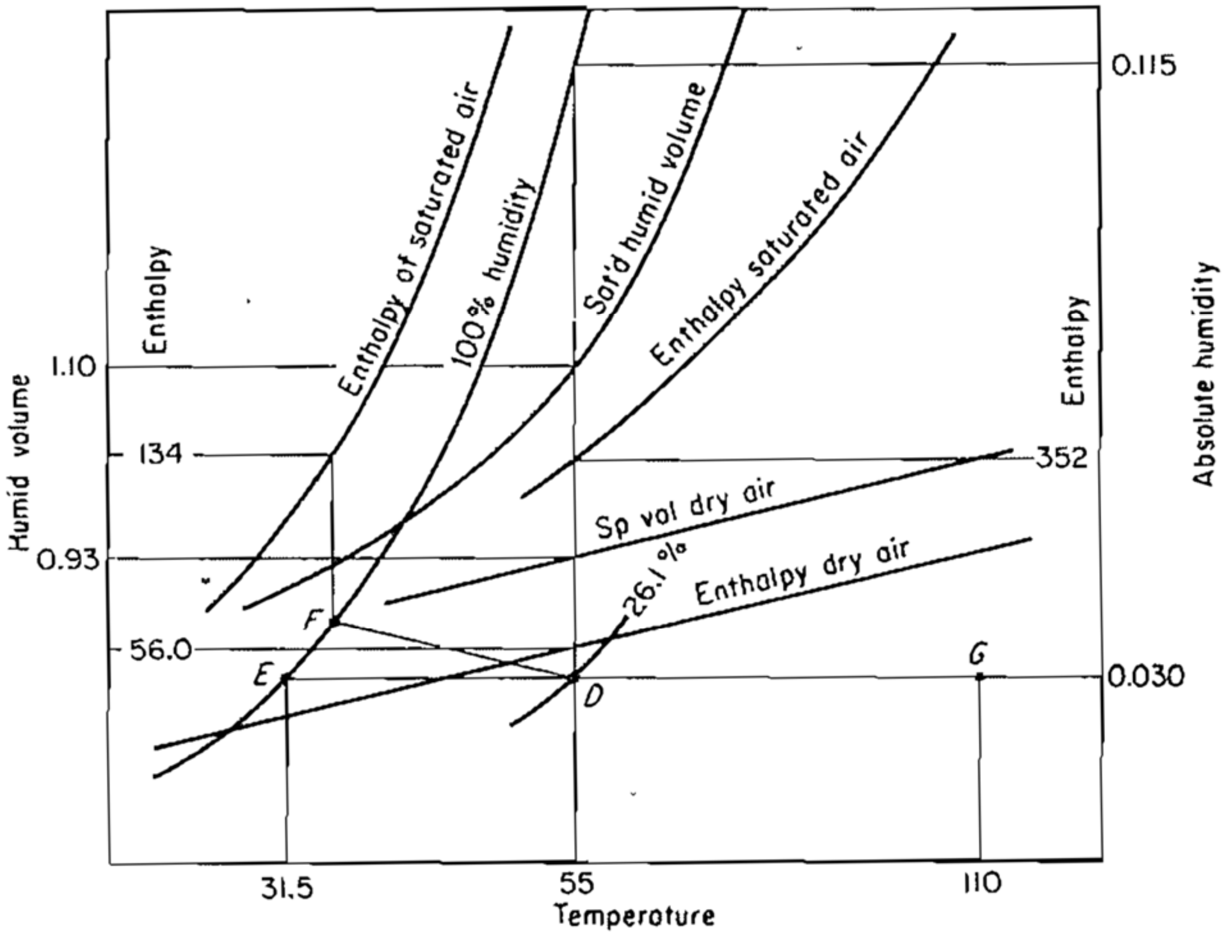
(*b*) The molal absolute humidity $= Y = Y'(M_B/M_A) = 0.030(28.97/18.02) = 0.0482$ kmol water/kmol dry air.

(*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 $= \bar{p}_A(100)/p_A = 4660(100)/15\,730 = 29.6\%$.





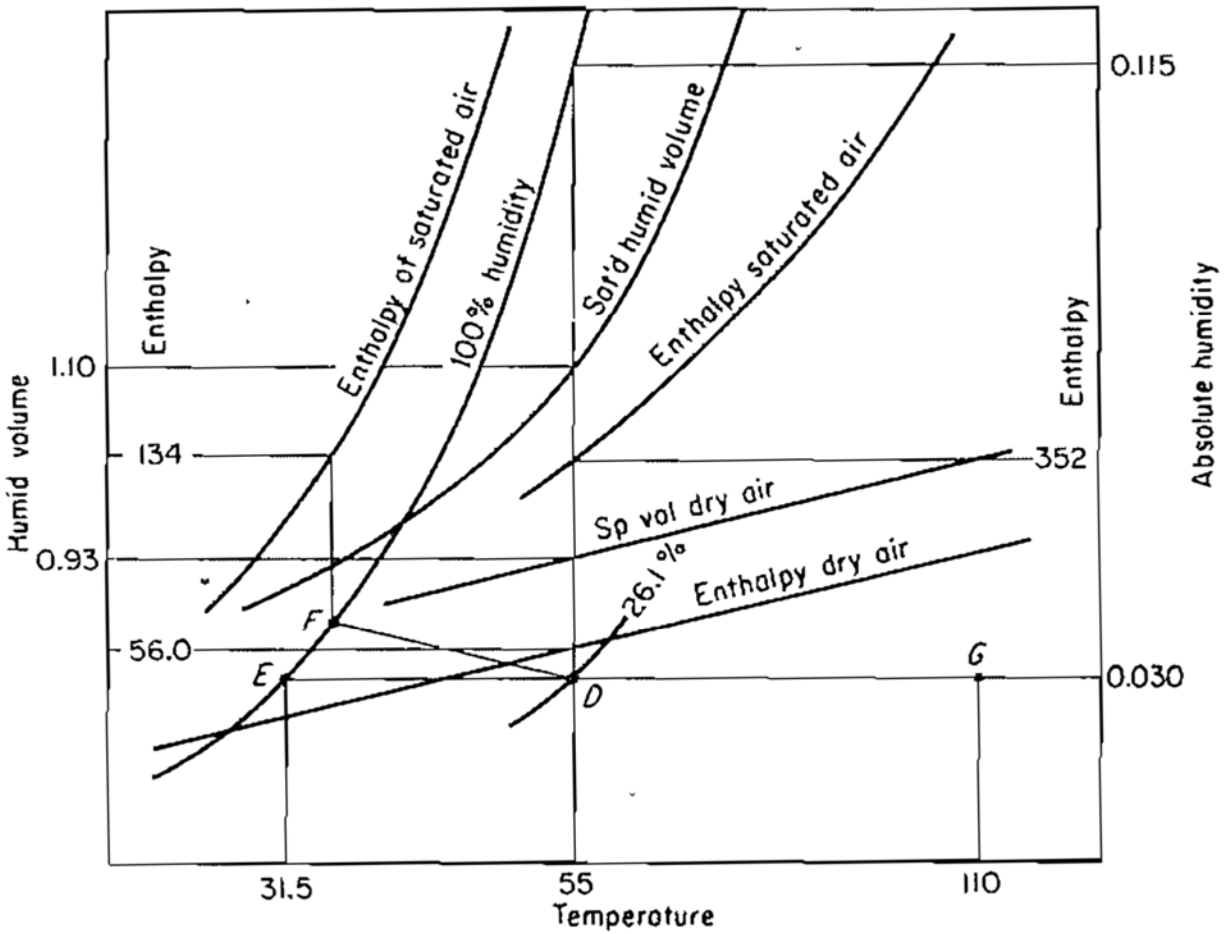
(*e*) Dew point. From point *D* proceed at constant humidity to the saturation curve at point *E*, at which the dew point temperature is 31.5°C.

(*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,

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



(*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*.

Q. Air at 83^{o}C, Y' = 0.03 kg water vapour / kg dry air, 1 atm is contacted with water at the adiabatic saturation temperature and is thereby humidified and cooled to 90% saturation. What the final temp. and humidity of the air?

Q. For an air-water vapour mixture having dry-bulb temperature of 65^{o}C, a wet-bulb temperature 35^{o}C was determined under conditions such that the radiation coefficient can be considered negligible. The total pressure was 1 atm. Compute the humidity of air.

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

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

Air containing 0.005 kg water vap / kg of dry air is heated to 325 K in a dryer and passed to the lower shelves. It leaves these shelves @ 60% humidity and reheated to 325 K and passed again through the dryer, again leaving @ 60% humidity. This is repeated for <u>four</u> cycles, after which the air leaves the dryer. Assume the material on the shelf (in the dryer) has reached the wet-bulb temperature, calculate :

(a) temp. of the material on each tray,

(b) amount of water removed in kg/s, if 5 m^3/s moist air leaves the dryer, Part (a)

In each of the four cycles, the condition of air is changed to 60% Humidity along the ASL.

Init. cond. of air : $T \equiv 325$ K and $Y = 0.005$ kg/kg dry air

On humidifying to 60% humidity : $T = 301$ & $Y = 0.015$

Temp. of material $T_w = 296$ K

At the end of 2nd cycle : $T = 308$ K, $Y = 0.022$ & $T_w = 301$ K

Temp. of material

3rd cycle : $T = 312$ K, $Y = 0.027$ & $T_w = 305$ K

Temp. of material

4th cycle : $T = 315$ K, $Y = 0.032$ & $T_w = 307$ K

Temp. of material

Part (b)

Total increase in humidity : $(0.032 - 0.005) = 0.027$ kg/kg dry air

Air leaving the system is @ 315 K and 60% humidity.

Sp. vol. of dry air = 0.893 m^3/kg.

Sp. vol. of sat. air (sat. volm.) = 0.97 m^3/kg.

$\therefore$ humid vol. @ 60% humidity = 0.937 m^3/kg.

Mass of air passing through the dryer $= \frac{5}{0.937} = 5.34$ kg/s

Mass of water evap. $= 5.34 \times 0.027 \approx 0.144$ kg/s

Q. Estimate the wet bulb and adiabatic saturation temperature for a toluene-air mixture of 60°C dry-bulb temperature, $Y' = 0.05$ kg vapour / kg air, 1 atm.

SOLUTION ***Wet-bulb temperature*** $t_G = 60°C$, $Y' = 0.050$ kg toluene/kg air. $D_{AB} = 0.92 \times 10^{-5}$ m²/s at 59°C, 1 std atm. At 60°C, ρ for air $= 1.060$ kg/m³ 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

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

$$h_G/k_Y = 1223(2.00)^{0.567} = 1812 \text{ J/kg} \cdot \text{K (observed value} = 1842).$$

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

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.

Antoine Equation for Toluene is: $\log_{10}(\text{P in bar}) = 4.08 - \dfrac{1346.4}{\text{T (in K)} - 53.5}$

Antoine Equation Parameters of Toluene

Go To: Top, References, Notes

$\log_{10}(P) = A - (B / (T + C))$
P = vapor pressure (bar)
T = temperature (K)

Temperature (K)	A	B	C	Reference	Comment
273.13 - 297.89	4.23679	1426.448	-45.957	Besley and Bottomley, 1974	Coefficents calculated by NIST from author's data.
303. - 343.	4.08245	1346.382	-53.508	Gaw and Swinton, 1968	Coefficents calculated by NIST from author's data.
420.00 - 580.00	4.54436	1738.123	0.394	Ambrose, Broderick, et al., 1967	Coefficents calculated by NIST from author's data.
308.52 - 384.66	4.07827	1343.943	-53.773	Williamham, Taylor, et al., 1945	
273. - 323.	4.14157	1377.578	-50.507	Pitzer and Scott, 1943	Coefficents calculated by NIST from author's data.