

Properties and Behavior of Air

Chapter 2

Nature and Composition of Air

<u>Gas</u>	<u>Vol %</u>	<u>Wgt %</u>
Nitrogen	78.09	75.55
Oxygen	20.95	23.13
Carbon Dioxide	0.03	0.05
Argon, others	0.93	1.27

For calculations, use dry air, volume basis, and 21% O₂ and 79% N₂ and inert gases

Nature and Composition of Air

- ▶ Thermodynamically ... consider it a mixture of dry air and water vapor
- ▶ Behavior is complicated by changes of state in water vapor and “contaminants”
- ▶ The gas percentages given before were for dry air at sea level
- ▶ Dry air doesn't really exist; normal air is moist (0.1 to 4% water vapor)

Properties of Air

- ▶ **Chemical:** colorless, odorless, tasteless; supports combustion and life
- ▶ **Physical:** properties of fluid, at rest and in motion
- ▶ **Psychrometric:** relate to thermodynamic behavior of “moist” air

Useful General Air Constants

Molecular weight, m	28.97
Specific gravity, s	1
Gas constant, R ft.lb/lbmass.°R (287.045 J/kg.K)	53.35
Specific weight w at Standard conditions (29.92 in. Hg, 70°F)	0.0750 lb/ft ³

Useful General Air Constants

Standard barometric pressure, p_b (sea level)	29.92 in. Hg 14.696 psi
Specific heat at constant pressure, c_p	0.2403 Btu/lb. °F
Specific heat at constant volume, c_v	0.1714 Btu/lb. °F
Ratio of specific heats at constant pressure and Volume, γ (for any diatomic gas)	1.402

Psychrometric Properties (heat and humidity)

- ▶ Thermodynamics of air-water vapor mixtures involved
- ▶ Air and water vapor behave as nearly perfect gases
- ▶ Changes of state of water vapor require analysis of mixtures via thermodynamic principles

Psychrometric Properties

- ▶ Determination of psychrometric properties of air at given conditions (*state point*) are necessary to solve air conditioning problems
- ▶ Can use psychrometric charts or tables
- ▶ At a known pressure, any two psychrometric properties of air fix the state point: dry-bulb and wet-bulb temperatures are easiest to use

Psychrometric Properties

- ▶ As many other psychrometric properties as desired may then be determined, although the one property essential to all process calculations is *enthalpy*
- ▶ Next we'll go over three definitions:
 - * barometric pressure
 - * dry-bulb temperature
 - * wet-bulb temperature

Psychrometric Properties

- ▶ Barometric pressure, p_b , is the atmospheric pressure as read by a barometer, in in. Hg or psi
- ▶ Dry-bulb temperature, t_d , is the temperature indicated by a conventional dry thermometer, a measure of the sensible heat content of the air, in °F

Psychrometric Properties

- ▶ Wet-bulb temperature, t_w , is the temperature at which water evaporating into air can bring the air to saturation adiabatically at that temperature; a measure of the evaporating capacity of the air; indicated by a thermometer with a wetted wick in °F
- ▶ Adiabatic – refers to any change of state with no gain or loss of heat

Psychrometric Properties

- ▶ Note: $p_b = p_a + p_v$ (Eq. 2.1)
where: p_a – partial pressure of dry air in in. Hg or psi
 p_v – partial pressure of water vapor in in. Hg or psi
- ▶ Next we'll discuss psychrometric tables and calculations using them

Use of Psychrometric Tables

- See Appendix Table A. 2 – give psychrometric properties of air under dry and saturated conditions
- Note: “steam” tables are abbreviated psychrometric tables at high temperatures
- Using the tables, needed psychrometric properties at dry or saturated conditions can be read and the properties at any state point can then be calculated

Process for Solving a Problem

From the tables, read properties of saturated air, as follows:

1. Saturation vapor pressure at t_d , p_s in in. Hg
2. Saturation vapor pressure at t_w , p_s' in in. Hg
3. Saturation specific humidity at t_d , W_s in lb/lb

Process for Solving a Problem

If steam tables are not available, calculate saturation vapor pressures by using the following formula:

$$p_s = 0.18079 \exp \left[\frac{17.27 t_d - 552.64}{t_d + 395.14} \right] \text{ in. Hg (Eq. 2.2)}$$

To compute p_s' , substitute t_w for t_d . Then use Eq. 2.5 to calculate W_s , substituting p_s for p_v .

Process for Solving a Problem

Next find all properties at the state point, steps 1-7, as follows:

1. *Vapor pressure* – partial pressure of water vapor in air (related to barometric pressure and partial pressure of dry air by equation 2.1):

$$p_v = p_s' - \frac{(p_b - p_s')(t_d - t_w)}{2800 - 1.3t_w} \text{ in. Hg (Eq. 2.3)}$$

Process for Solving a Problem

2. *Relative humidity* – ratio of vapor pressures of air at given conditions and at saturation, with temperature constant (note that relative humidity and degree of saturation are not numerically equal):

$$\phi = \frac{p_v}{p_s} \times 100\% \quad (\text{Eq. 2.4})$$

Process for Solving a Problem

3. *Specific humidity* – weight of water vapor contained per unit weight of dry air:

$$W = 0.622 \frac{p_v}{p_b - p_v} \text{ lb/lb dry air} \times 7000 \quad (\text{Eq. 2.5})$$

(= grains/lb dry air)

Process for Solving a Problem

4. *Degree of saturation* – ratio of weights of water vapor in air at given conditions and at saturation, with temperature constant (usually specific humidities are employed):

$$\mu = \frac{W}{W_s} \times 100\% \quad (\text{Eq. 2.6})$$

Process for Solving a Problem

5. *Specific volume* – volume per unit weight of dry air (not equal mathematically to the reciprocal of the specific weight of the mixture):

$$v = \frac{RT_d}{P_a} \text{ ft}^3/\text{lb dry air} \quad (\text{Eq. 2.7})$$

where R is the gas constant for air and T_d is the absolute dry-bulb temperature (units of P_a are in psi)

See p. xv for value of R

Process for Solving a Problem

6. *Specific weight* – specific weight of moist air or mixture:

$$w = \frac{1}{v} (W + 1) \text{ lb/ft}^3 \quad (\text{Eq. 2.8})$$

Process for Solving a Problem

7. *Enthalpy* – total heat content of air, the sum of enthalpies of dry air and water vapor, per unit weight of dry air:

$$\begin{aligned} h &= h_a + h_v = c_p t_d + W(h_{fg} + h_f) \quad (\text{Eq. 2.10}) \\ &= 0.24t_d + W(1060 + 0.45t_d) \text{ Btu/lb dry air} \end{aligned}$$

The meaning of certain variables will be defined in the next slide.

Process for Solving a Problem

7. *Enthalpy* – meaning of variables:

c_p is specific heat of air at constant pressure

h_a is enthalpy of dry air (sensible-heat part)

h_v is enthalpy of water vapor (latent-heat part)

h_f is heat of the liquid

h_{fg} is heat of vaporization ~ 1060 Btu/lb at normal temperatures

Process for Solving a Problem

- “Dry” air has been used as a reference base in defining several of the psychrometric properties of air
- This imaginary standard (1 lb of dry air) because it is the only property that remains constant when air undergoes thermodynamic changes during air conditioning processes
- Its use simplifies calculations in temperature-humidity control

- Check out the example problem given on pp. 17-18 in your book.
- Next we'll look at using the psychrometric chart, which is considerably more simple to use although less accurate.
- When designing an air conditioning system, make the calculations.

Using the Psychrometric Chart

- Useful for occasional determinations
- You can read all values directly
- The chart will also represent the psychrometric process the air is undergoing
- Using the chart, the state point of the air can be located at a given barometric pressure if any two properties, usually temperatures, are known

Using the Psychrometric Chart

- A psychrometric chart plotted at standard barometric pressure and normal temperatures is provided for problem solving in Fig. 2.2 (p. 20 of your book)
- A major drawback of charts is that they are designed only for a single barometric pressure or elevation and a limited temperature range
- Laborious corrections must be made when using them for conditions differing by more than 1 in. Hg or 1000 ft from sea level
- Additional charts are given in the Appendix, Figures A.4 – A.6

Using the Psychrometric Chart

- Use of the chart can best be demonstrated by solving a problem.
- See p. 19 in your book for a solution to example for which calculations were made
- Note that the two values for enthalpy, h , were 20.14 Btu/lb by calculation and 20.23 by chart

Gas Laws: Behavior of Air

Boyle's, Charles', General Gas, Dalton's and Graham's laws are sufficiently accurate for normal air in air conditioning calculations, although they are strictly correct only for the hypothetical ideal gas

See pp. 22-24 in your book

Gas Laws: Behavior of Air

- Note particularly Graham's Law, which relates to the Diffusion rate of a gas into air
- Basically, a gas lighter than air will diffuse faster than one heavier than air; also, the smaller the specific gravity, the more rapid the diffusion
- Turbulence and temperature aid diffusion; can have stratification in quiescent air

Gas Laws: Behavior of Air Effect of Altitude

Relationship between specific weights of air at any elevation, at constant temperature:

$$\frac{w_2}{w_1} = e^{-Z/RT} \quad (\text{Eq. 2.16})$$

where Z is elevation above sea level in ft

Gas Laws: Behavior of Air Effect of Altitude

Where a change in temperature occurs, use the following equation to determine specific weight at a desire elevation:

$$\frac{w_2}{w_1} = \left[\frac{288 - 0.00198Z}{288} \right]^{4.256} \quad (\text{Eq. 2.17})$$

Appendix Table A.1 lists air specific weights, barometric pressures and temperatures for various elevations

Pressure-Head Relationship

Use the following equation to convert between pressure, p , and head, H_i :

$$p = w_1 H_1 = w_2 H_2 \quad (\text{Eq. 2.18})$$

where w_i is specific weight

Pressure-Head Relationship

- Pressure is the force exerted by air per unit area
- Head is the height of a column of water or mercury equivalent to the pressure exerted by the air
- These terms have to be refered to carefully
- Note: 1" w.g. = 5.2 lb/ft²

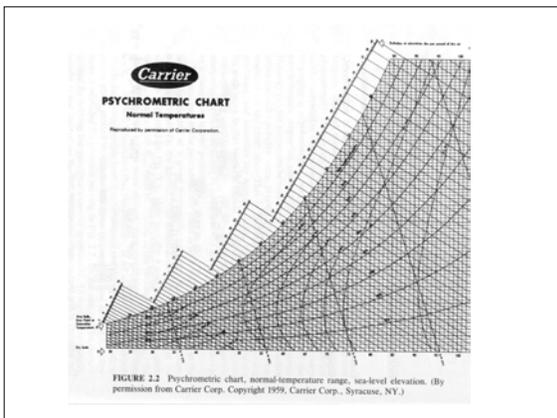


FIGURE 2.2 Psychrometric chart, normal-temperature range, sea-level elevation. (By permission from Carrier Corp., Copyright 1959, Carrier Corp., Syracuse, NY.)