Density Corrections for Moist Air and Other Gases

Introduction

The reader needs to have a thorough understanding of the principles outlined in article FE-1600, "Temperature and Altitude Effects on Fans," before proceeding with this article.

In addition to explaining how to compensate for temperatures other than 70°F, elevations above sea level and inlet suction pressure, article FE-1600 also explains how fans are tested and rated in order to establish uniformity in ratings among AMCA member companies.

In addition to the aforementioned items this article expands our understanding of density corrections to include relative humidity (moist air) and for gases other than air.

The discussion in this article is limited to temperatures of 200°F or less. As the air temperature approaches the boiling point of water, errors in the calculation procedure can be significant and are best referred to a qualified fan engineer.

Moist Air

Moist Air – A two-component mixture of dry air and water vapor. The amount of water vapor in moist air varies from zero (dry air) to a maximum of 100% (saturated air).

Saturated Air – In a given volume of space there can exist no more than a certain definite weight of water vapor at any given temperature and pressure. When the atmosphere contains this limiting maximum of water vapor it is called "saturated." The vapor in the atmospheric mixture is in a saturated state.

Humidity – Humidity is moisture or vapor present in the atmospheric air, or in any mixture of air and water vapor.

Relative Humidity – The ratio of the vapor pressure of the mixture of air and vapor to the vapor pressure of saturated air at the same temperature, or the ratio of the weight of water vapor to the weight of dry saturated vapor at the same temperature.

Specific Humidity – The weight of water vapor per unit weight of air expressed in grains (or pounds) per pound of dry air. This is also referred to as "humidity ratio."

Dry Bulb Temperature – The dry bulb temperature of atmospheric air is the temperature that is determined by an ordinary thermometer and is not affected by the vapor content or relative humidity of the air. If the dry bulb temperature remains constant, an increase in the relative humidity can only be due to an increase in the amount of water vapor in the air.

Wet Bulb Temperature – Wet bulb temperature is the temperature of evaporation. It is the lowest temperature a surface film of water can assume when evaporating freely into the air. The wet bulb thermometer is similar to the dry bulb thermometer except that the bulb is covered with a piece of wet muslin, silk or other fine material from which the water evaporates into the air. This lowers the temperature of the bulb to an extent which depends upon the cooling effect of evaporation. When the wet bulb and the dry bulb temperatures are the same, the air is said to be saturated.

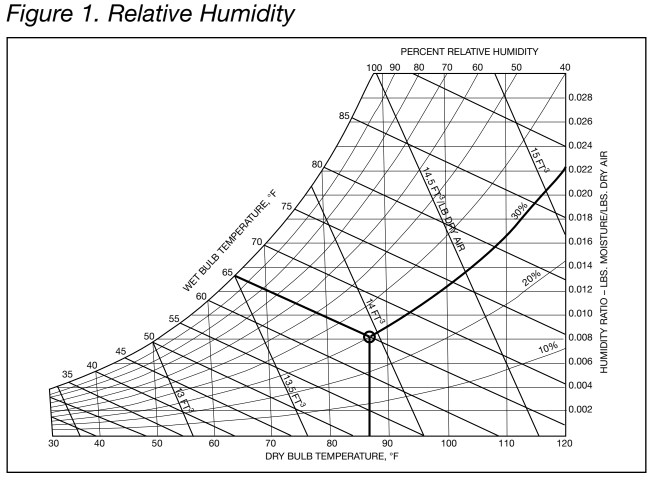
Specific Volume Dry Air – The volume in (cubic feet) occupied by one pound of dry air. The reciprocal of the specific volume is specific weight. As pointed out in article FE-1600, the fan industry has adopted a standard density (specific weight) of 0.075 lb/ft of dry air at 70°F, sea level and at a barometric pressure of 29.92" Hg. Therefore, the specific volume for standard air is 1 ÷ 0.075 or 13.33 ft/lb dry air.

Familiarity with the aforementioned terms and an understanding of the psychrometric charts found on the ASHRAE Handbook CD: 2001 Fundamentals (Chapter 6: Psychrometrics, page 6.15) are a requirement for determining the density of moist air. With the aid of the charts shown throughout this article, we will examine a few examples to assist in this process.

Example 1: Given a moist air dry bulb temperature of 87°F and a wet bulb temperature of 65°F, at standard barometric pressure. Using Figure 1, we can determine the relative humidity, the specific volume and the specific humidity at this condition.

1. **Relative Humidity –** Locate the 87°F dry bulb temperature on the horizontal scale at the bottom and proceed vertically upward to the intersection of the 65°F wet bulb curve (diagonal lines running downward

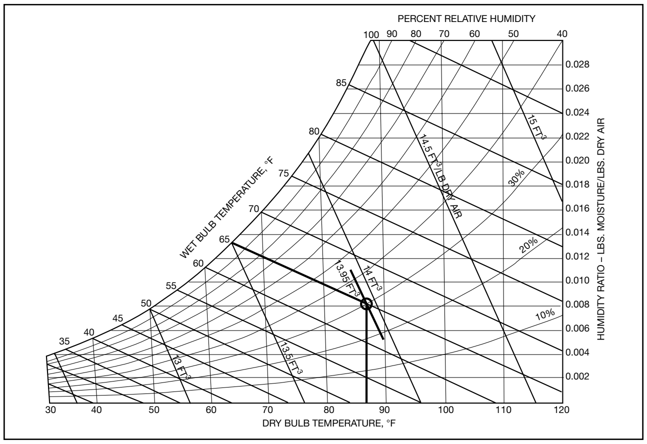
Figure 1. Relative Humidity



from left to right). By inspection of the psychrometric chart we can see that these curves intersect on the 30% relative humidity curve (parabolic curve proceeding upward and to the right).

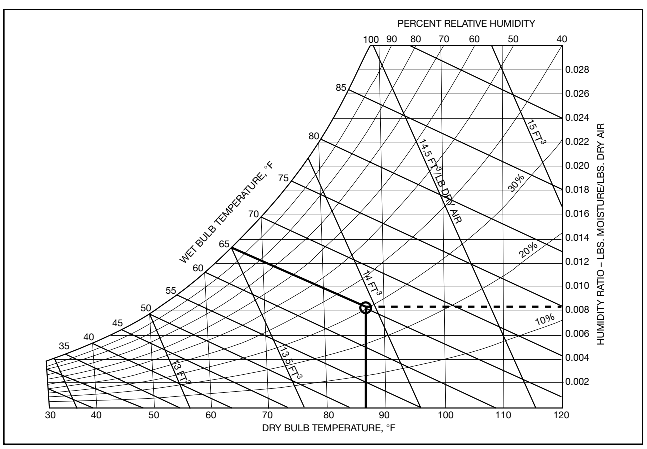
2. **Specific Volume –** Locate the point of intersection of the 87°F dry bulb temperature and the 65°F wet bulb temperature, same as shown in Figure 1. Interpolation of this point between the diagonal specific volume lines 13.5 ft/lb dry air and 14.0 ft/lb dry air, yields a volume of 13.95 ft/lb of dry air. See Figure 2.

Figure 2. Specific Volume



3. **Specific Humidity (Humidity Ratio) –** locate the point of intersection of the 87°F dry bulb and wet bulb temperatures, same as in Figures 1 and 2, and proceed horizontally to the right scale to find a humidity ratio of 0.0082 lbs. of moisture per pound of dry air. See Figure 3.

Figure 3. Specific Humidity



Having determined the humidity ratio and the specific volume of the air mixture in Example 1, we are now prepared to calculate the density of this moist air condition.

By plugging in the values determined in Example 1 into the following formula, we can calculate the moist air density (c).

$$\text{Density (lbs/ft)} = \frac{1 + \text{humidity ratio (lb moisture/lb. dry air)}}{\text{Specific volume of mixture (ft/lb dry air)}}$$

$$\text{Density} = \frac{1 + .0082}{13.95} = \frac{1.0082}{13.95} = 0.0723 \text{ lb/ft} = c$$

It then follows that the density ratio (DR) for the moist air becomes:

$$\text{DR} = c \div \text{standard air density} = 0.0723 \div 0.075 = 0.964$$

Additional elevation or barometric corrections, when required, can be applied to this density ratio. For example, if the installation in Example 1 was at 5000 ft elevation, the density ratio of 0.964 would be corrected by the factor for 5000 ft. (from Table 2, article FE-1600) of 1.20.

$$0.964 \times \frac{1}{1.2} = \text{new DR} = 0.803$$

Remember, the reciprocal of the factor is the density ratio.

Perhaps the elevation was unknown in our example, but a barometric pressure reading for that area indicated a reading of 24.9" Hg. We then simply multiply the density ratio by the ratio of measured barometric pressure to the standard air barometric pressure.

$$0.964 \times \frac{24.90\text{"Hg}}{29.92\text{"Hg}} = 0.802 \text{ DR}$$

If the dry bulb temperature and relative humidity are known, an alternative to using the psychrometric charts and calculating the density ratio, is to use Table 1 and read the density ratio directly. Like the temperature and altitude correction tables from FE-1600, it is acceptable to interpolate between values.

From Example 1, we have a dry bulb temperature of 87°F and a relative humidity of 30%. By interpolation from Table 1 we obtain a density ratio of 0.963, which compares favorably with our calculated value of 0.964 from the psychrometric chart.

$$\frac{0.997 + 0.995}{2} = 0.996 \text{ for } 70°\text{F DB and } 30\% \text{ RH}$$

$$\frac{0.959 + 0.956}{2} = 0.9575 \text{ for } 90°\text{F DB and } 30\% \text{ RH}$$

$$87°\text{F DB} - 70°\text{F DB} = 17°\text{F DB and}$$
$$90°\text{F DB} - 70°\text{F DB} = 20°\text{F DB}$$

$$17 \div 20\ (0.996 - 0.9575) - 0.996 = \text{DR} = 0.963$$

Table 1. Moist Air Density Ratios

TEMP DRY BULB (°F)	PERCENT RELATIVE HUMIDITY					
	0	20	40	60	80	100
0	1.149	1.151	1.151	1.151	1.151	1.151
10	1.127	1.129	1.127	1.126	1.126	1.126
30	1.078	1.080	1.080	1.081	1.079	1.079
50	1.038	1.037	1.036	1.035	1.034	1.033
70	1.000	0.997	0.995	0.993	0.992	0.990
90	0.962	0.959	0.956	0.952	0.949	0.946
110	0.928	0.923	0.916	0.910	0.903	0.896
130	0.900	0.887	0.876	0.866	0.854	0.844
150	0.868	0.851	0.834	0.816	0.789	0.781
170	0.842	0.814	0.786	0.774	0.733	0.705
190	0.824	0.775	0.733	0.705	0.652	0.611
200	0.817	0.754	0.706	0.659	0.611	0.563

Other Gas Mixtures

Atmospheric Air – A mixture of gases and water vapor. Its main components are oxygen and nitrogen, but air also contains a portion of water vapor, some carbon dioxide, traces of other gases like argon, neon, xenon, hydrogen, krypton, etc.; and a certain amount of dust particles.

Standard Air (Dry Air) – In article FE-1600 and so far in this article we have been referencing everything back to standard air, or dry air without any moisture whatsoever. Actually, atmospheric air at ordinary temperature contains up to four percent by weight of moisture. However, for the sake of standardization of ratings, we use dry air containing no water vapor.

As can be seen in Table 2, standard dry air has a molecular weight of 28.967.

Any gas mixture with a molecular weight other than 28.967 requires a density ratio correction. Therefore:

If DR = actual air density (lb/ft) ÷ std. air density (lb/ft) and standard air density = 0.075 lb/ft = 28.967 molecular weight, then the DR also = actual molecular weight/standard air molecular weight.

So, if the molecular weight of the gas is given in a specification, simply divide it by 28.967 to obtain the density ratio correction. If the molecular weight of the gas is not given, but instead the components are listed individually by percent of volume, simply reference the molecular weights of the components and multiply them by the percent of volume and total them up for the actual molecular weight of the gas.

For convenience we have listed in Table 3 the molecular weights for a variety of dry gases at 70°F and 29.92" Hg barometric pressure.

All of the gases shown with molecular weights less than 28.967 are lighter than standard air and conversely gases with molecular weights greater than 28.967 are heavier than standard air.

It is likely that when gases other than air are to pass through fan systems, the density or molecular weight will be specified. It then becomes a simple calculation to determine the density ratio, by using the methods previously established in this article to convert the requirements to standard air, allowing one to make a fan selection from a manufacturer's rating table or performance curve.

However, there are cases when the molecular weight of the gas(es) are only listed by percent of volume. When this occurs the molecular weight of the gas must be established before a fan can be selected. For example:

A fan system required to handle 100% carbon dioxide would require looking up the molecular weight for CO in Table 3, which is 44.01. Because this molecular weight is heavier than standard air, the density ratio = 44.01 ÷ 28.967 = 1.52 DR.

Perhaps the specification calls for a gas mixture comprising 50 percent by volume of air, 20 percent by volume of ammonia, 20 percent by volume of helium and 10 percent by volume of sulfur dioxide. In this instance, we need to establish a molecular weight for the entire mixture. To do this, simply multiply the molecular weight of each component by its percent of volume.

Gas	Molecular Weight	Percent Volume	Molecular Weight As a Percent of Total Volume
Air	28.97	50	14.485
Ammonia	17.03	20	3.406
Helium	4.00	20	0.800
Sulfur Dioxide	64.07	10	6.407
		Total	25.098

By adding the results we can establish a gas mixture molecular weight of 25.1. It then follows that the density ratio for this gas mixture is 25.1 ÷ 28.967 = 0.866 DR.

Table 2. Composition of Dry Air

GAS	MOLECULAR WEIGHT	PERCENT BY VOLUME	MOLECULAR WEIGHT AS % OF TOTAL VOLUME
Nitrogen	28.016	78.03	21.861
Oxygen	32	10.99	6.717
Argon	39.95	0.94	0.376
Carbon Dioxide	44.01	0.03	0.013
Hydrogen	2.016	0.01	—
Xenon, Krypton Neon & Other Gases	—	—	—

Table 3. Miscellaneous Gases

GAS	MOLECULAR WEIGHT	FORMULA
Acetylene	26.04	C_2H_2
Air	28.97	—
Ammonia	17.03	NH_3
Argon	39.95	A
Benzol	78.05	C_6H_6
Butane	58.12	C_4H_{10}
Butylene	56.06	C_4H_8
Carbon Dioxide	44.01	CO_2
Carbon Monoxide	28.01	CO
Chlorine	70.91	Cl_2
Duoderane	170.21	$C_{12}H_{26}$
Ethene	28.05	C_2H_4
Ethane	30.07	C_2H_6
Ethylene	28.05	C_2H_4
Ethyl Alcohol	46.05	C_2H_6O
Fluorine	38.00	F_2
Helium	4.00	He
Hexane	86.11	C_6H_{14}
Hydrogen	2.02	H_2
Hydrogen Sulfide	34.09	H_2S
Isobutane	58.12	C_4H_{10}
Methane	16.04	CH_4
Methyl Alcohol	32.03	CH_4O
Methyl Chloride	50.49	CH_3Cl
Nitrogen	28.00	N_L
Nitric Oxide	30.01	NO
Nitrous Oxide	44.02	N_2O
Octane	114.14	C_8H_{18}
Oxygen	32.00	O_2
Pentane	72.10	C_5H_{12}
Pentylene	70.08	C_5H_{10}
Propane	44.06	C_3H_8
Propylene	42.05	C_3H_6
Steam	18.01	H_2O
Sulfur Dioxide	64.07	SO_2
Toluol	92.06	C_7H_8
Water Vapor	18.01	H_2O
Xylol	106.08	C_8H_{10}

Conclusion

With the information and methodology provided in this article, in conjunction with that provided in article FE-1600, the reader has the necessary tools and insight to handle the majority of applications requiring density corrections. For those applications involving conditions other than discussed in these two articles, it is recommended that an air moving specialist be consulted.

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