

The information and data contained in this document were prepared by a technical committee of the Association. The committee and the Association assume no liability or responsibility in connection with the use of such information or data, including but not limited to any liability under patent, copyright, or trade secret laws. The user is responsible for determining that this document is the most recent edition published.

Psychrometric charts

Scope

This Technical Information Paper contains psychrometric (humidity) charts. The charts cover temperature and humidity ranges of practical use in the pulp and paper industry. ASME and NBS tables of thermodynamic properties of water and air were used in preparing the charts.

Utility

Information about mixtures of air and water vapor is important in evaluating paper drying rates and drying uniformity. Local air humidity has a direct effect on drying rates.

Since water vapor generated in drying processes is exhausted with air, knowledge of humidity is necessary for efficient plant operation.

Definition of standard terms helps to promote clarity of reports. Charts of values representing moist air can simplify routine engineering calculations.

Safety precautions

There are no safety precautions required in use of psychrometric charts.

Definitions

Absolute Humidity

Absolute humidity (ω) is here defined as the ratio of the mass of water vapor to the mass of dry air. The quantity is dimensionless and may be expressed as kg of water vapor per kg of dry air or the English equivalent, pounds vapor/pound dry air. It is occasionally called humidity ratio, specific humidity, mixing ratio, or just humidity. The term absolute humidity is recommended here to distinguish it from relative humidity.

Relative Humidity

Relative humidity (ϕ) is the ratio of the amount of water vapor in the air to the maximum amount possible at the same temperature and pressure. It is technically defined as the ratio of the mole fraction of water vapor in the air to the mole fraction in a saturated mixture at the same temperature and total pressure.

Since water vapor and air are considered ideal gases, the definition reduces to the ratio of partial pressure of water vapor in a mixture to the saturation pressure of the vapor, again at the same temperature and total pressure. Relative humidity is generally expressed as a percentage.

Dry Bulb Temperature

Dry bulb temperature (T_{db}) of an air-water vapor mixture is the temperature measured by a conventional thermometer. It is sometimes called the test temperature. In this TIP, temperatures are expressed in °C or °F.

Wet Bulb Temperature

Wet bulb temperature (T_{wb}) of humid air is the temperature indicated by a thermometer whose bulb is covered with a wick wetted with water and placed in a stream of the humid air. The wet bulb will cool due to evaporation of the

water to the wet bulb temperature.

Adiabatic Saturation Temperature

Adiabatic saturation temperature (T_{as}) is the temperature of an air-water-vapor mixture at the end of an adiabatic saturation process. This temperature can be calculated from thermodynamic properties of air and water. For most practical uses, the adiabatic saturation temperature and the wet bulb temperature are considered to be equal. The adiabatic saturation temperature is sometimes called the thermodynamic wet bulb temperature.

Dew Point Temperature

The dew point temperature (T_{dp}) is the temperature to which unsaturated moist air must be cooled, at constant pressure, in order for water to just begin condensing, forming dew.

Total Pressure

The total pressure (P) of an air-water-vapor mixture is the absolute pressure indicated by a barometer. It is sometimes called the test pressure. Pressures in this TIP are expressed in units of Pa or psi.

Water-Vapor Partial Pressure

Partial pressure (P_v) of water-vapor in air is defined as the pressure water vapor would exert in the same volume, at the same temperature, if the air were removed. This value is normally assumed to follow Dalton's Law of partial pressures for ideal gases.

Saturation Pressure

Water-vapor saturation pressure (P_{sat}) is the absolute pressure at which air is fully saturated with water vapor, at a given temperature.

Mole Fraction

Mole fraction (x) is defined as the number of moles of water-vapor in one mole of mixture of air and water vapor. For ideal gases, the mole fraction is equal to the ratio of vapor partial pressure to total (ambient) pressure. The quantity is dimensionless.

Content

Relationships

Most studies of air-water vapor mixtures are based on the assumption that both air and water vapor behave as ideal gases, i.e. according to the Gibbs-Dalton law.

With this assumption and definitions given above, the following relationships can be determined:

$$\phi = P_v/P_{sat} \quad (1)$$

$$\omega = 0.622 P_v/(P - P_v) \quad (2)$$

$$\phi = \omega P/(\omega + 0.622)P_{sat} \quad (3)$$

$$x = P_v/P \quad (4)$$

$$= \omega/(\omega + 0.622)$$

The value 0.622 is the ratio of molar mass of water vapor and dry air.

Thermodynamic Analysis

Absolute humidity can often be determined from charts that show the relationships between humidity and wet bulb and dry bulb temperatures. These charts may be based on direct experimental measurement of humidity or on the results of analytical calculations.

In the analytical approach, an adiabatic saturation process is assumed to occur. This is a process in which unsaturated air is allowed to become saturated and cooled by passing over liquid water without any addition of external heat (the process is adiabatic).

The temperature of the saturated air at the end of an adiabatic saturation process is always less than the temperature of the air entering the process, since evaporation of water into the air requires energy. The energy comes

from the air and from the liquid water.

An energy balance for this process is given by:

$$(h_{a1} + \omega_1 h_{v1}) + (\omega_2 - \omega_1) h_{f1} = h_{a2} + \omega_2 h_{v2} \quad (5)$$

in which h_a is air enthalpy (heat content), h_v is water-vapor enthalpy, and h_f is liquid water enthalpy. State 1 represents values at the entering dry bulb temperature T_1 . State 2 represents values at the exiting adiabatic saturation temperature T_2 . The units of enthalpy are kJ/kg dry air (Btu/lb_m of dry air).

There are many thermodynamics textbooks, such as References 1 and 4, that provide derivation of the above equations.

The adiabatic saturation humidity ω_2 can be determined from Equation (5) using established thermodynamic properties of air and water at states 1 and 2 and the adiabatic saturation temperature T_2 . These properties can be found in many textbooks and used to prepare charts with the relationships between temperatures and humidity shown graphically.

For normal air-water-vapor mixtures of interest to the pulp and paper industry, wet bulb temperature and adiabatic saturation temperature are close in value. The assumption that they are equal normally gives answers of sufficient accuracy for practical use.

The above analysis was used to determine thermodynamic wet bulb temperatures for the charts included in this TIP.

Psychrometric Charts

Important parameters of air-water vapor mixtures are often plotted on a diagram called a psychrometric chart. Process changes for air-water vapor mixtures are easily read from these charts.

In order to cover the range of temperatures and humidities of interest to pulp and paper industry engineers, three psychrometric charts each were prepared, for English and SI units. These cover low humidity, high humidity, and low temperature ranges.

The temperature range of these charts is 0-500°C (0-1000°F) and the absolute humidity range is 0-1 kg/kg (0-1 lb/lb).

These charts contain five parameters: dry bulb temperature, saturation humidity, thermodynamic wet bulb temperature, dew point, and absolute humidity.

Relative humidity, and other parameters that have less engineering use, have not been included on these charts. Relative humidity does not have direct engineering use and is often confused with “degree of saturation”, a close but not identical parameter. Adding the lines would only make the charts harder to read, particularly for charts printed in one color.

Note that these charts are thermodynamic charts, not wet-bulb charts. As noted above, thermodynamic charts are based on thermodynamic properties. Wet bulb charts are based on experimental measurements.

Thermodynamic properties for water were taken from reference (2) and for air from reference (3), both reputable sources for these properties.

Barometric (atmospheric) pressure was assumed to be 101 kPa (14.7 psia) for the preparation of these charts.

Use of Charts

The psychrometric charts presented in this TIP can be used to determine air humidity from measured wet bulb and dry bulb temperatures. Humidities are often used in calculations of drying rates, hence the need for easily interpretable charts. The charts can also be used to determine dew points.

Four examples are presented below. Figure 1 represents a psychrometric chart to illustrate their use.

Consider an air-water-vapor mixture at a condition represented by point 1 in Figure 1. This air-water vapor mixture is identified by its dry bulb temperature T_1 and its (thermodynamic) wet bulb temperature T_2 . The absolute humidity ω_1 of this mixture can be determined by locating the intersection of the dry bulb temperature (vertical) line and the curved wet bulb temperature line.

For Case I, consider cooling the mixture that was initially at state 1. When the air temperature drops below the dew point temperature T_{dp} , water will begin to condense out of the mixture. This point is shown as state 3 in Figure 1. The dew point temperature T_{dp} is found on the chart where the horizontal (constant absolute humidity) line crosses the saturation line.

For Case II, consider adding water to the mixture initially at state 1, without changing the air temperature. This process would be a no adiabatic process. External heat would be added and the process would follow the vertical line (constant dry-bulb temperature) in Figure 1, until full saturation of the mixture is reached at point 4.

For Case III, consider adding water to the mixture initially at state 1 without adding any external heat. This would be an adiabatic process and it would follow the adiabatic exchange (wet bulb temperature) line from absolute humidity w_1 in Figure 1 until saturation is reached at point 2.

For case IV, consider a drying process in which air enters at humidity w_1 and exits at humidity w_5 . The amount of water vapor added to the air represents the amount of water evaporated. The drying rate is calculated by:

$$R = m_a (\omega_5 - \omega_1) \quad (6)$$

where R is the drying rate expressed in mass per unit time and m_a is the flow rate of dry air in mass per unit time. In SI units, drying rate and mass flow would generally be expressed in units of kg/hr. In English units, they would be expressed in units of lb/hr.

For a more detailed discussion of humidity and moisture, see reference (4).

Keywords

Humidity, Psychrometric charts, Moisture content.

Additional information

Effective date of issue: August 26, 2002

Working Group Members:

Jeff Reese, Chairman – Georgia-Pacific Corp.
 Gregory L. Wedel – Johnson Corporation
 Perry Deutsch – Voith
 Ray Krumenacker – Metso
 Eric Eisert – Consultant