Psychrometrics

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Psychrometrics is the measurement of the heat and water vapor properties of air. Commonly used psychrometric variables are temperature, relative humidity, dew-point temperature, and wet-bulb temperature.

Psychrometric Chart

The psychrometric chart describes the relationships between these variables. Figure 1 is a psychrometric chart in customary units which describes the relationship between the variables.

Temperature, sometimes called dry-bulb temperature after the unwetted thermometer in a psychrometer, is the horizontal axis of the chart. The vertical axis is the moisture content of the air, called humidity ratio (sometimes called mixing ratio or absolute humidity). The units of humidity ratio are mass of water vapor per mass of dry air. Under typical California conditions, the humidity ratio of outside air varies between 0.004 and 0.015 lb/lb. Even though water vapor represents only 0.4 to 1.5 percent of the weight of the air, this small amount of water vapor plays a very significant role in rice drying and storage.

The maximum amount of water vapor that air can hold at a specific temperature is given by the leftmost, upward-curved line in the psychrometric chart. Notice that air holds more water vapor at increasing temperatures. As a rule of thumb, the maximum amount of water that the air can hold doubles for every 20°F increase in temperature. This line is also called the 100 percent relative humidity line. A corresponding 50 percent relative humidity line is approximated by the points that represent the humidity ratio when the air contains one-half of its maximum water content. The other relative humidity lines are formed in a similar manner.

Notice that relative humidity without some other psychrometric variable does not determine a specific air condition on the chart. For instance, 80 percent relative humidity at 32°F has much lower humidity ratio than air with 80 percent relative humidity at 68°F.

If a mass of air is cooled without changing its moisture content, it loses capacity to hold moisture. If cooled enough, it becomes saturated (has 100 percent relative humidity) and if cooled further, begins to lose water in the form of dew or frost. The temperature at which condensation begins to form is called the dew point temperature if it is above 32°F or the frost point temperature if it is below 32°F.

Another commonly used psychrometric variable is wet-bulb temperature. On the chart this is represented by lines that slope diagonally upward from right to left. These lines represent the temperature of a thermometer covered with water-soaked gauze. In practice, wet-bulb lines are used to determine the exact point on the psychrometric chart that represents the air conditions in a given location as measured by a psychrometer. The intersection of the diagonal wet-bulb temperature line (equal to the temperature of a wet-bulb thermometer) and the vertical dry-bulb temperature line defines the temperature and humidity conditions of air.

Psychrometric charts and calculators are based on a specific atmospheric pressure, usually a typical sea-level condition. Precise calculations of psychrometric variables require an adjustment for barometric pressures different from those listed on a standard chart. Consult the ASHRAE Handbook listed in the references for more information on this. Most field measurements do not require adjustment for atmospheric pressure.

Measuring Psychrometric Variables

All psychrometric properties of air are determined by measuring two psychrometric variables (three, if barometric pressure is considered). For example, if wet- and dry-bulb temperatures are measured, then relative humidity, vapor pressure, dew point, and so on can be determined with the aid of a psychrometric chart. Many variables can be measured to determine the psychrometric state of air, but dry-bulb temperature, wet-bulb temperature, dew point temperature, and relative humidity are most commonly measured.

Dry-bulb temperature

Dry-bulb temperature can be simply and inexpensively measured by an alcohol-in-glass thermometer. The thermometer should be marked in divisions of at most 0.5°F if it is used in conjunction with a wet-bulb thermometer. The thermometer should be shielded from radiant heat sources such as motors, lights, external walls, and people. This can be done by placing the thermometer where it cannot "see" the warm object or by protecting it with a radiant heat shield assembly.

Hand-held thermistor, resistance bulb, or thermocouple thermometers can also be used. They are more expensive than a glass thermometer but are not necessarily more accurate. These instruments can be purchased with a sharp probe allowing them to be used for measuring product pulp temperature. Inexpensive alcohol-in-glass and bimetallic dial thermometers are not recommended unless their calibrations have been checked against a calibrated thermometer. In field situations, an ice-water mixture is an easy way to check calibration at 32°F.

Wet-bulb temperature

Use of a wet-bulb thermometer in conjunction with a dry-bulb thermometer is a common method for determining the state point on the psychrometric chart. The wet-bulb thermometer is basically an ordinary glass thermometer (although electronic temperature sensing elements can also be used) with a wetted cotton wick secured around the bulb. Air is forced over the wick, causing it to cool to the wet-bulb temperature. The wet- and dry-bulb temperatures together determine the state point of the air on the psychrometric chart, allowing all other variables to be determined.

An accurate wet-bulb temperature reading depends on 1) sensitivity and accuracy of the thermometer, 2) maintenance of an adequate air speed past the wick, 3) shielding of the thermometer from radiation, 4) use of distilled or deionized water to wet the wick, and 5) use of a cotton wick.

The thermometer sensitivity required to determine an accurate humidity varies according to the temperature range of the air. More sensitivity is needed at low than at high temperatures. For example, at 150°F a 1°F error in wet-bulb temperature reading results in a 2.6 percent error in relative humidity determination, but at 32°F that same error results in a 10.5 percent error in relative humidity. In most cases, absolute calibration of the wet- and dry-bulb thermometer is not as important as ensuring that they read the same at a given temperature. For example, if both thermometers read 1°F low, this will result in less than a 1.3 percent error in relative humidity at dry-bulb temperatures between 65°C and 32°F (at a 50C difference between dry- and wet-bulb temperatures). Before wetting the wick of the wet-bulb thermometer, operate both thermometers long enough to determine if there is any difference between their readings. If there is a difference, assume that one is correct and adjust the reading of the other accordingly when determining relative humidity.

The rate of evaporation from the wick is a function of air speed past it. A minimum air speed of about 500 feet per minute is required for accurate readings. An air speed much below this will result in an erroneously high wet-bulb reading. Wet-bulb devices that do not provide a guaranteed air flow cannot be relied on to give an accurate reading.

As with the dry-bulb thermometer, sources of radiant heat such as motors, lights, and so on can affect the wet-bulb thermometer. The reading must be taken in an area protected from these sources of radiation or thermometers must be shielded from radiant energy.

A buildup of salts from impure water or contaminants in the air affects the rate of water evaporation from the wick and results in erroneous data. Distilled or deionized water should be used to moisten the wick and the wick should be replaced if there is any sign of contamination. The wick material should not have been treated with chemicals such as sizing compounds that affect the water evaporation rate.

Special care must be taken when using a wet-bulb thermometer when the wet-bulb temperature is near freezing. Most humidity tables and calculators are based on a frozen wick at wet-bulb temperatures below 32°F. At temperatures below 32°F, touch the wick with a piece of clean ice or another cold object to induce freezing, because distilled water can be cooled below 32°F without freezing. The psychrometric chart or calculator must use frost-bulb, not wet-bulb temperatures, below 32°F to be accurate with this method.

Under most conditions wet-bulb temperature data are not reliable when the relative humidity is below 20 percent or the wet-bulb temperature is above 212°F. At low humidities, the wet-bulb temperature is much lower than the dry-bulb temperature and it is difficult for the wet-bulb thermometer to be cooled completely because of heat transferred by the glass or metal stem. Water boils above 212°F, so wet-bulb temperatures above that cannot be measured with a wet-bulb thermometer.

In general, properly designed and operated wet- and dry-bulb psychrometers can operate with an accuracy of less than 2 percent of the actual relative humidity. Improper operation greatly increases the error.

Relative humidity

Direct relative humidity measurement usually uses an electric sensing element or a mechanical system. Electric hygrometers are based on substances whose electrical properties change as a function of their moisture content. As the humidity of the air around the sensor increases, its moisture increases, proportionally affecting the sensor's electrical properties. These devices are more expensive than wet- and dry-bulb psychrometers, but their accuracy is not as severely affected by incorrect operation. An accuracy of less than 2 percent of the actual humidity is often obtainable. Sensors lose their calibration if allowed to become contaminated, and some lose calibration if water condenses on them. Most sensors have a limited life. Mechanical hygrometers usually employ human hairs as a sensing element. Hair changes in length in proportion to the humidity of the air. The response to changes in relative humidity is slow and is not dependable at very high relative humidities. These devices are acceptable as an indicator of a general range of humidity but are not suitable for accurate measurements.

Dew point indicators

Two types of dew point sensors are commonly used today: a saturated salt system and a condensation dew point method. The saturated salt system operates at dew points between 10° to 100°F) with an error of less than ± 2°F. The system costs less than the condensation system, is not significantly affected by contaminating ions, and has a response time of about 4 minutes. The condensation type is very accurate over a wide range of dew point temperatures (less than ± 1°F from -100° to 212°F). A condensation dew point hygrometer can be expensive.

References

1. ASHRAE. 1986. ASHRAE handbook, fundamentals. Am. Soc. Heating, Refrigeration and Air Conditioning Engineers. Atlanta, GA.
2. Gaffney, J. J. 1978. Humidity: Basic principles and measurement techniques. HortScience 13(5): 551-55.
3. Wexler, A., and W. G. Brombacher. 1951. Methods of measuring humidity and testing hygrometers. National Bureau of Standards, Circ. 512.

Sample Psychrometric Calculations

1. A wet-bulb thermometer reads 60°F and a dry-bulb thermometer reads 72°F. What is the relative humidity?
Solution: The diagonal 60°F wet-bulb (wb) line and the vertical 72°F dry-bulb (db) line intersect at point A. Point A falls on the 50 percent relative humidity (rh) line.

2. What is the dew point temperature of the air in problem 1?
Solution: If the air represented by point A is cooled without changing its moisture content, it will follow a horizontal line until it reaches 52°F. At that temperature, it has 100 percent relative humidity, and any further cooling will cause water to condense out of the air (dew forms). The dewpoint (dpt) temperature is 52°F.

3. What is the humidity ratio of the air in problem 1?
Solution: Find the humidity ratio of the air represented by point A by reading horizontally across to the vertical axis of the psychrometric chart. The humidity ratio (w) is 0.0084 lb/lb.

4. If the air in problem 1 is heated to 120°F, what will be its relative humidity?
Solution: Heating is represented by moving horizontally to the right from the initial temperature conditions. The horizontal line intersects the vertical 120°F line at about 12% rh.
On calm, clear nights the air cools by radiation, following a horizontal line to the left. If the air cooled to 52°F (and 100% rh), it would still produce the same rh after heating to 120°F. If it cooled to less than 52°F, it would cause dew fall and the air would have less moisture content. If this air (even though its relative humidity is 100%) were heated to 120°F it would have less than 12% rh.

Psychrometric Chart with Rice Equilibrium Moisture