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Discussion 5-03
Psychrometrics Review
(Part 3)
Psychrometric Processes

INTRODUCTION

In thermodynamics, the state of a fluid is its condition as described by the various fluid properties. Properties, in turn are any observable characteristics of the fluid. Since psychrometric dynamics include mass changes as well as changes in fundamental thermodynamic properties such as temperature and density, the statepoint cannot always be defined simply by two coordinates. However, for the purpose of engineering analyses, if the system is in a fixed location (i.e., fixed barometric pressure) the necessary statepoint can be described by any two adequately independent properties. For instance, the two properties cannot be dewpoint temperature and humidity ratio since these are not adequately independent; they are two ways of describing the same characteristics

$w_s = p_s/(p_b - p_s)$, where p_s is the saturation pressure at the dry bulb temperature.

Also, two properties that do differ but not "adequately" would be enthalpy (Btu/lb dry air) and wet bulb temperature.

Considering this, in performing engineering calculations, the first assumption is usually a fixed elevation (barometric or total pressure). Then, the *adequately independent* property sets that can be used to describe a statepoint, using symbols, are:

t_{db} and t_{wb}, t_{dp}, h, w, rh, ?, or p_H
t_{wb} and t_{dp}, w, rh, ?, or p_H
t_{dp} and h, rh, or ?
h and w, rh, ?, or p_H
rh and ?, or p_H
? and p_H

However, in the vast majority of design or diagnostic engineering calculations, the known characteristics are two of the three temperatures or one of the three temperatures and the relative humidity, since these are the easily measurable properties.

When a fluid changes from one state to another it is said to undergo a process. As air is conditioned it is made to change from one state to another such as warmer to cooler, more moisture to less moisture, etc. Thus, the understanding of psychrometric processes and the control of psychrometric processes is the foundation of the science of air conditioning.

In the design of air conditioning systems the first challenge is to *understand* the psychrometric process that takes place in the space to be conditioned (the *space* process) - this phenomenon is basically the heating or cooling load. The reactive challenge is to "design" controlled processes to maintain the desired condition or statepoint within the occupied space - these are usually called the system processes.

Common Processes

A thermodynamic system is said to undergo a process whenever it changes from one statepoint to another. In psychrometric analyses this change in state can be caused by adding or removing heat, causing work to be performed on or by the fluid, adding or removing mass (usually of water vapor), or mixing two fluids which are at dissimilar states.

Most processes encountered in air conditioning practice are one of, a combination of or a sequence of the following:

Sensible Cooling or Heating.

A sensible cooling or heating process is one in which the *air* (for purposes of this discussion, *air* means the dry air and water vapor mixture) changes temperature only, with no change in moisture content (humidity ratio). This type of process is the result of heat flowing into or out of the air or work being done on it (such as by a fan).

Observable features of a sensible heating or cooling process are:

- The humidity ratio is constant.
- The dewpoint temperature is constant.
- The vapor pressure is constant.
- For a heating process
    1. the relative humidity decreases,
    2. the enthalpy increases,
    3. the wet bulb temperature increases,
    4. the specific volume increases,
- For a cooling process
    1. the relative humidity increases,

2. the enthalpy decreases,
3. the wet bulb temperature decreases,
4. the specific volume decreases,

Typical sensible cooling or heating processes include space heating loads, sensible cooling loads, heating coils, space heating devices, fans that move the air, sensible cooling coils and radiant cooling or heating devices.

Cooling and Dehumidification

The combined process of cooling and dehumidification is one of the most common methods of dehumidification used in the science of air conditioning. The reason is that this is by far the easiest or simplest way to remove moisture from the air. The process is observed in nature as dew on the grass and water forming on the outside surface of a glass containing a cold drink.

The air, when cooled by a coil, the surface of which is below the dewpoint temperature of the air, will first cool sensibly until the water vapor starts to condense, as the vapor condenses the cooling and condensing take place simultaneously until the airstream separates from the coil. The coil used in this process is designed to provide the desired leaving condition of dry bulb temperature and humidity ratio.

Observable characteristics of a cooling and dehumidifying process are:

- dry bulb temperature decreases
- humidity ratio decreases
- vapor pressure decreases
- dewpoint temperature decreases
- wet bulb temperature decreases
- enthalpy decreases
- relative humidity increases

Typical cooling and dehumidifying process include chilled water and refrigerant cooling coils which condition recirculated room air or mixtures of recirculated air and outdoor air which is introduced for ventilation.

Heating and Dehumidification

The combined process of heating and dehumidification is much less common in air conditioning systems then the cooling and dehumidifying process, but it is seeing increasing use. When air is brought into contact with a desiccant or sorption material the water vapor molecules will be adsorbed and the air will become "drier". As this occurs, the heat of condensation will enter the air stream, thereby increasing its temperature. The process is essentially adiabatic or isenthalpic.

Observable characteristics of a heating and dehumidification process are:

- dry bulb temperature increases
- humidity ratio decreases
- dewpoint temperature decreases
- vapor pressure decreases
- relative humidity decreases
- enthalpy remains essentially constant
- wet bulb temperature remains essentially constant

Typical heating and dehumidification processes are desiccant heat wheels which can be configured for controlled dehumidification (usually dewpoint control) or for latent heat recovery in ventilation air streams in warm humid climates.

Isothermal Dehumidification

Isothermal dehumidification is a process of reducing the humidity ratio at a constant dry bulb temperature. Thermodynamically, this process can only be produced in machines which perform multiple changes in the state of the air before discharging it at the isothermal condition. The energy utilized to achieve this is significantly greater than that represented by the product of the mass flow rate of the air stream and the enthalpy difference.

Observable characteristics of an isothermal dehumidification process are:

- humidity ratio decreases
- dewpoint temperature decreases
- vapor pressure decreases
- dry bulb temperature is constant
- wet bulb temperature decreases
- specific volume decreases
- relative humidity decreases
- enthalpy decreases

Typical devices that provide this process are liquid desiccant dehumidifiers which utilize direct fired or high temperature fluids for motivation power.

Evaporative Cooling Process (Cooling and Humidification)

The evaporative cooling process is essentially an adiabatic saturation process. Recall, from *Psychrometrics Review Part 1* (March 2003) that the adiabatic saturation chamber contains two inlet streams, one outlet stream and a reservoir of water at the temperature of the outlet stream. One inlet stream is the ambient air (i.e., air-water vapor mixture). As this air stream flows through the chamber, water from the reservoir evaporates into the air stream until the air at the interface is saturated. Since the water is at the leaving air temperature, the only heat available to evaporate the moisture must come from the higher temperature air stream. Thus, the temperature of the inlet air stream drops until moisture stops evaporating, then the air leaves the chamber. The leaving air stream is at a lower temperature than was the entering air stream and this temperature was defined as the *adiabatic saturation temperature* of the inlet stream, commonly referred to as the *wet bulb temperature*.

The evaporative cooling process, is commonly employed to reduce the dry bulb temperature of the air without refrigeration. It is a constant wet bulb process of reducing dry bulb temperature. The hardware used to achieve this process usually consists of the basic components of the adiabatic saturation chamber plus some type of device to amplify the interface surface area between the water reservoir and the air, such as wetted wick, matting, plates, spray, etc.

Observable features of the evaporative cooling process are:

- Constant wet bulb temperature
- Decreasing dry bulb temperature
- Increasing humidity ratio
- Increasing dewpoint temperature
- Increasing vapor pressure
- Essentially constant enthalpy
- Decreasing specific volume

A Typical Evaporative Cooling Process is the direct conditioning of air for human comfort conditions in hot-dry climates and other applications where sensible cooling effects are desired and increasing humidity ratios can be tolerated.

Isothermal Humidification

An isothermal humidification process is the addition of water vapor with no change in dry bulb temperature. The significant objective of this process is that the humidity ratio increases with no change in the dry bulb temperature.

The actual dynamics used to achieve this process may cause some changes in the temperature during the process, but such changes are irrelevant when analyzing either the end results or statepoint or the theoretical energy consumed.

Observable features of an isothermal humidification process are:

- Humidity ratio increases
- Dewpoint temperature increases
- Vapor pressure increases
- Dry bulb temperature remains constant
- Relative humidity increases
- Wet bulb temperature increases
- Enthalpy increases
- Specific volume increases

Typical isothermal humidification processes include latent cooling loads and the controlled humidification of outdoor ventilation air or of the indoor space during outdoor weather conditions of low humidity ratio.

Mixing Process (Steady Flow)

The steady flow mixing process is used extensively in system processes of air conditioning technology. The process consists of mixing two or more streams at different states. The vast majority of mixing processes are stable, in which all conditions take place within the superheat region of the water vapor in the mixture (except that the initial state of one of the streams could be saturated). In these processes, the properties of the mixed stream will lie between the values of the respective properties of the initial streams. The properties of enthalpy, dry bulb temperature and saturation ratio for the mixed stream can be determined by simple proportional mass and energy balances.

Examples of steady flow mixing process include the outdoor air - return air mixing chamber of an air handling unit; warm stream - cold stream mixing in dual stream systems (double duct or multi-zone); and supply air - recirculated air mixing in fan powered terminals

Large Reservoir Mixing Process

Unlike all of the previously discussed processes which were equilibrium processes, this is a non-equilibrium, time dependent process expressed mathematically as a first order negative exponential. For this process, a time constant can be expressed as the large volume (usually the space) divided by the volumetric flow rate of an entering and leaving stream. If complete and perfect mixing is assumed, the leaving stream fluid is at the state of the fluid in the room. If storage dynamics are ignored, the changes in the temperature, humidity ratio or enthalpy in the space move 63.21% of the difference between the space and the entering stream values in one time constant. The result of this is that in a typical warm humid climate (example summer in St. Louis, MO) on a 1% design wet bulb day, (78 °Fwb) and at an outdoor air dry bulb (evening) temperature of 80 °F with 0.2 cfm/square foot ventilation rate, in a space with an 8 foot ceiling height, if the air handling unit compressor cycles off with the air handling unit running, the indoor air relative humidity would rise from 50% to 72.65% in one time constant or 40 minutes.

These significant increases in indoor relative humidity caused by this phenomenon is one of the major causes of both discomfort and poor air quality in air conditioning systems.

This process also explains why, without additions or removal of moisture within a space or a ventilation air inlet device, the space humidity ratio will *always* approach that of the outdoors after a relatively short time (the time constant is simply determined by the mechanical ventilation rate or the infiltration rate (1 air change = 60 minutes time constant).

A clear understanding of the psychrometric processes is necessary to both understand the dynamics of air conditioning loads and to designing the systems and controls to maintain desired indoor air conditions and air quality.