Refrigeration Basics

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Operating a chiller incorporates three major concepts: heat transfer, fluid circulation, and refrigeration.

Heat always flows from a higher temperature substance to a lower temperature substance

Heat Transfer

Heat transfer is the process of moving heat energy from a substance with high heat energy to another substance with lower heat energy. In the case of the chiller, temperature is the measure of energy and heat is the energy itself. Heat energy cannot be destroyed but can be transferred. Heat always flows from a higher temperature substance to a lower temperature substance. This rate of heat flow is commonly expressed in terms of Btu/hr—the quantity of heat, in Btu's, that flows from one substance to another over a period of one hour.

Chiller operation utilizes heat transfer in two key place: the evaporator and the condenser. In the evaporator, heat transfers from the process recirculating fluid (higher temperature) into the refrigerant (lower temperature). The condenser transfers this heat from the refrigerant (higher temperature) to the cooling source (air or water) at a lower temperature. Each is a part of the refrigeration cycle which will be explained in more detail below.

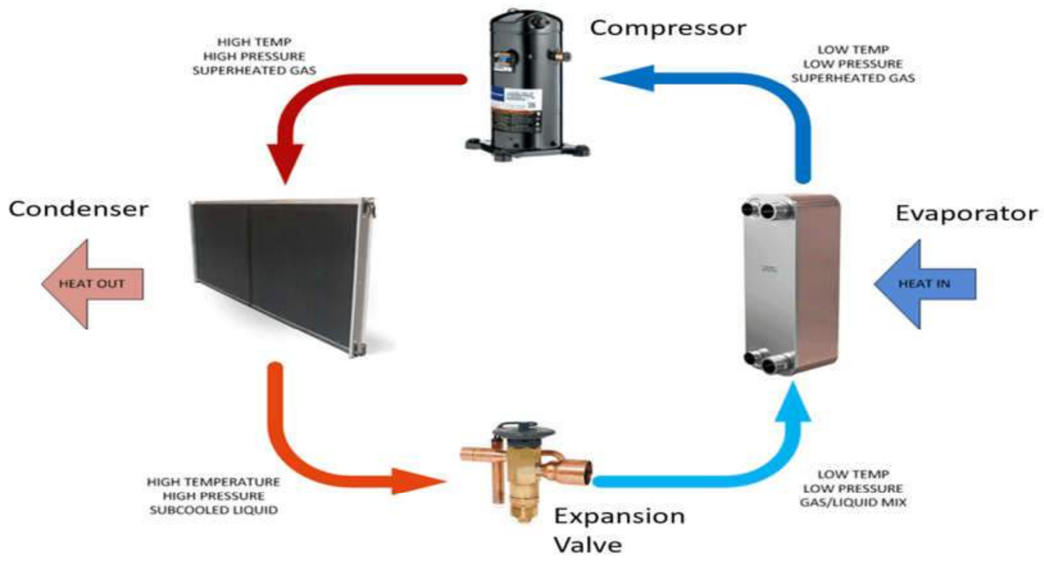
Fluid Circulation

Chillers use fluid circulation to deliver the heat from the process to the chiller. This fluid is typically water or a water/glycol mixture. The fluid removes heat from the process, returns to the chiller, transfers heat to the refrigerant through the evaporator, and exits the chiller cold to return to the process.

Refrigeration

Refrigeration is a thermodynamic cycle. Chillers use refrigeration to extract heat from the process circulation fluid and then ultimately reject it to the atmosphere. This system uses a chemical compound called a refrigerant. There are many types of refrigerants and applications depending on the temperatures required, but they all work on the basic principle of compression and phase-change of the refrigerant from a liquid to a gas and back to a liquid. This process of heating and cooling the refrigerant and changing it from a gas to a liquid and back again is the refrigeration cycle. Changing the physical state of a compound (for example, from gas to liquid) is an extremely efficient means to absorb or expel energy.

The refrigeration cycle in a chiller consists of four key components: compressor, condenser, expansion valve, and evaporator as illustrated below.



The Refrigeration Cycle – the process of heating and cooling the refrigerant and changing it from a gas to a liquid and back again is the refrigeration cycle.

Condenser is a heat exchanger that transfers heat from the refrigerant gas to an external cooling source (water or air are typical mediums). This transfer causes a phase change from gas to liquid condensation.

Expansion valves reduce high temperature, high pressure liquid refrigerant to a low temperature, low pressure liquid/vapor mixture. This small amount of phase change cools the mixture for a low temperature refrigerant supply to the evaporator. The expansion valve controls the amount of refrigerant supplied to the evaporator by maintaining superheat at the outlet of the evaporator.

Evaporators are heat exchangers that transfer heat from the process fluid into the refrigerant causing a phase change, evaporation.

Other common refrigeration circuit components are: liquid line solenoid valve, filter dryer, hot gas bypass valve, and sight glass.

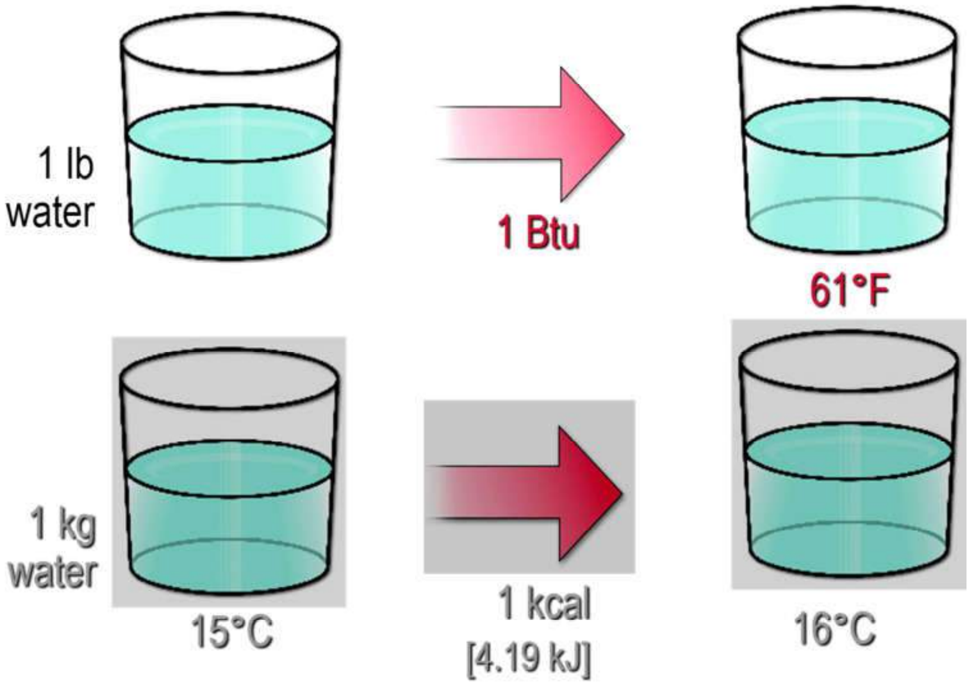
With limited resources and a heightened awareness of the need to reduce energy and water consumption, the use of fluid coolers has become a popular alternative to conventional evaporative cooling towers.

Similarly, a fluid cooler uses ambient air to cool the process water. However, this is done through a cooling coil and without exposing water to the atmosphere. This method is effective but limited by the temperature of the ambient air. In most cases, the practical limit is a process water temperature leaving the dry fluid cooler about 10°F warmer than the entering air temperature.

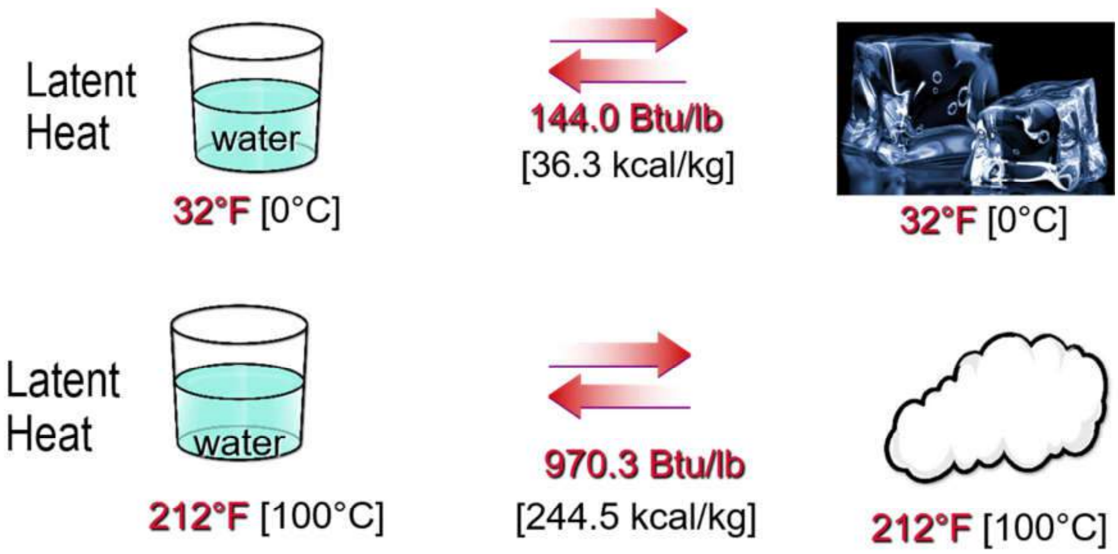
Heat Transfer Basics and Common Definitions

What is a BTU?

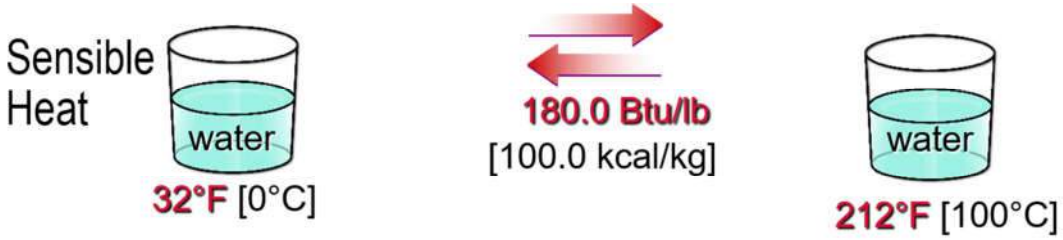
BTU (British Thermal Unit) is the most common unit of hear measurement. It is based upon the amount of energy to heat one pound of water by 1°F. A kcal (kilocalorie) is an International System of units (SI) measurement of heat. It is based upon the amount of energy to heat 1 kg of water by 1°C.



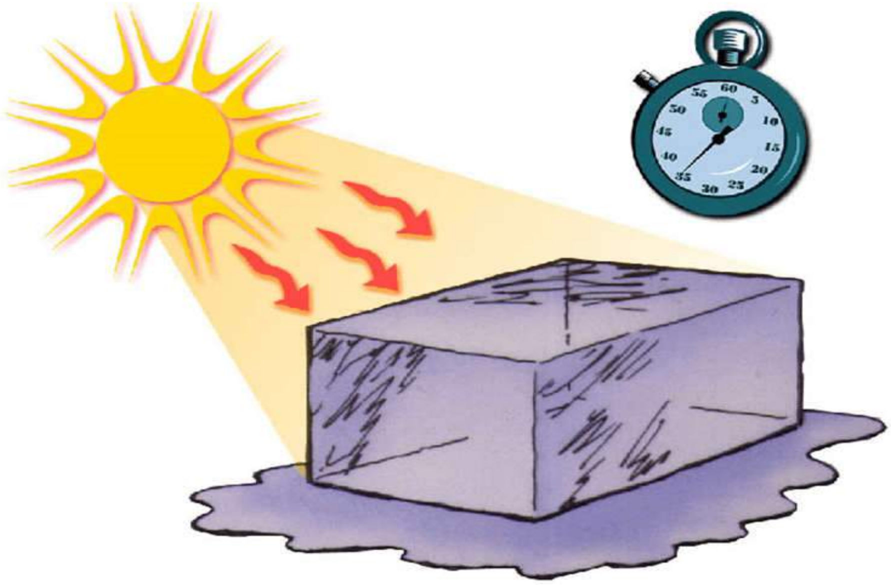
Latent Heat is the added heat that results in a phase change- for example to melt ice into water.



Sensible Heat is the heat added that results in a temperature increase – for example increase water temperature from 50°F to 60°F.



Rate of Heat Transfer is the quantity of heat that flows from one substance to another in a given period of time. This is commonly expressed in Btu/hr (or Btuh) and kW (kilowatts) for SI units.



One pound of ice requires 144 Btus to melt.

For example: A ton of refrigeration represents the rate of energy absorbed to melt one ton (2,000 lb) of ice in one day. One pound of ice requires 144 Btus to melt. The amount to melt one ton of ice is 288,000 Btu's (144 x 2,000). Dividing that over 24 hours, one ton of refrigeration equals 12,000 Btu/hr (288,000 / 24).

Heat Transfer Formula

The heat transfer formula is $Q = M \times Cp \times \Delta T$.

- Q is the heating of cooling capacity (Btu/hr)

- M is the mass of the fluid per hour (lb/hr) (for water 8.34 pounds/gallon x 60 minutes/hour = 500.4 lb/hr per GPM)

- Cp is the specific heat of the fluid (Btu/lb/°F – the value for water is 1 Btu/lb/°F)

- ΔT is the temperature difference between entering and leaving fluid (°F) For water, with a Cp of 1 Btu/lb/°F and 8.34 lb/gal x 60 minutes/hr = 500.4 lb/hr per GPM, the heat transfer formula simplifies to Btu/hr = GPM x 500 x ΔT.

Saturation temperature is the temperature at which a fluid changes phase from liquid to vapor or vapor to liquid. Saturation temperature increases with pressure.

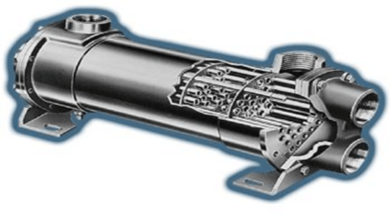
Superheating is raising a fluid's temperature above the boiling temperature without boiling. This requires elevated pressures. In the refrigeration circuit, this occurs after the evaporator and compressor.

Subcooling is cooling below the saturation temperature. In the refrigeration circuit, this occurs through the condenser before the expansion valve.

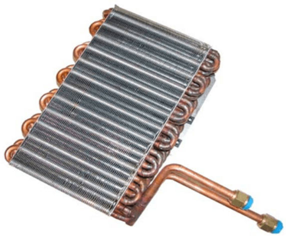
Heat Exchangers are designed to transfer heat from one fluid to another without mixing. The fluids are physically separated by the heat exchanger allowing heat energy to between them. The fluids can be a variety of compounds – water, oil, refrigerant, etc. There are three basic types of heat exchangers used within chiller design – plate and frame, shell and tube, and coil.

Plate and frame heat exchangers use multiple plates, known as plate packs, to isolate the two fluids from each other. The plate pack mounts on a frame. Two end plates are mechanically clamped onto the plate pack. The clamping force seals the space between the plates with gaskets. Heat transfer is efficient with the small passages between plates. The frame design maintains the ability to clean the exchanger. Small passages are susceptible to clogging, and the frames can require more floor space in your facility.

Brazed plate heat exchangers are a variation of the plate and frame design. The plate pack is permanently brazed together. This eliminates the need for the frame, gaskets, and end plates. This design improves the efficiency over a standard plate and frame. These are also much more compact but are not easily cleaned. Brazed plate units are often used as evaporators in chillers.



Shell and Tube Heat Exchangers use an outer shell vessel with internal tubes to isolate the two fluids. Large passageways between the tubes inside the shell avoid clogging but this reduces the efficiency of heat transfer. Shell and tube heat exchangers are commonly used in applications where one of the fluids contains high levels of contamination. Variations of these heat exchangers are used as condensers in water-cooled chillers.



Coil heat exchangers are most often air-to-water or air-to-refrigerant units. These consist of tubes with fins stacked together to form flat pieces. A common example of a coil heat exchanger is a radiator in a car. Forced air through the coil's fins conduct heat from the fluid in the tubes, through the fins and into the air. These are often condensers in air-cooled chillers.

Chillers incorporate two types of heat exchangers – evaporator and condenser.

In an **evaporator**, refrigerant enters as a low pressure liquid/vapor mixture and exits as a low pressure gas. The change of state from liquid to gas occurs at a constant temperature and absorbs energy. A chiller's evaporator achieves superheated refrigerant vapor. Superheat is when all the liquid refrigerant has evaporated, and the gas temperature increases above its saturation temperature. The process fluid enters as a hot liquid and exits at a lower temperature after transferring energy to the refrigerant.

In a **condenser**, refrigerant enters as a high temperature vapor and exits as a high temperature liquid. Condensers exhaust the heat from the chiller to the surrounding air or cooling water. The condenser design covers the "Total heat of rejection." This means the condenser rejects the heat from the evaporator as well as the compressor. The refrigerant exiting the condenser is a subcooled liquid. Subcooling is when all the vapor refrigerant is condenser and cooled below its saturation temperature.

Compressor types

A compressor is designed to increase pressure (and temperature) of refrigerant and circulate it though the system. By increasing the pressure of the refrigerant, the saturation temperature increases. With the elevated saturation temperature, the condenser easily subcools the refrigerant.

Scroll compressors use positive displacement to compress the refrigerant from a low pressure gas to a high pressure gas. The compressor motor is cooled by refrigerant passing over it. Oil is a critical component of a scroll compressor for lubrication. Scroll compressors are hermetically sealed and often replaced rather than repaired.

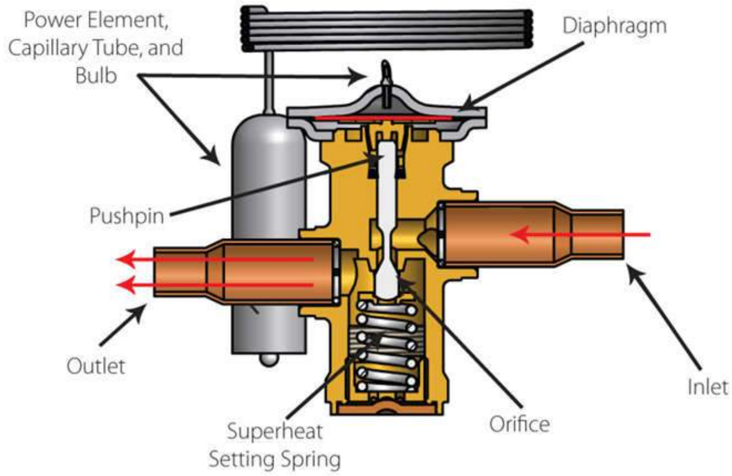
Screw compressors also use positive displacement to compress the refrigerant. The compressor uses two meshing screw-rotors. These rotate in opposite directions to increase the refrigerant gas pressure. Screw compressors require oil for lubrication. Screw compressors can be disassembled for maintenance and repair.

Centrifugal Compressors are dynamic and raise the refrigerant pressure by rotating an impeller. This creates centrifugal force which compresses the gas. Certain centrifugal compressor designs, like those on the Thermal Care TC and TCF series, use magnetic bearings and do not require any oil for lubrication. Centrifugal compressors can be disassembled for maintenance and repair.

Expansion Valves

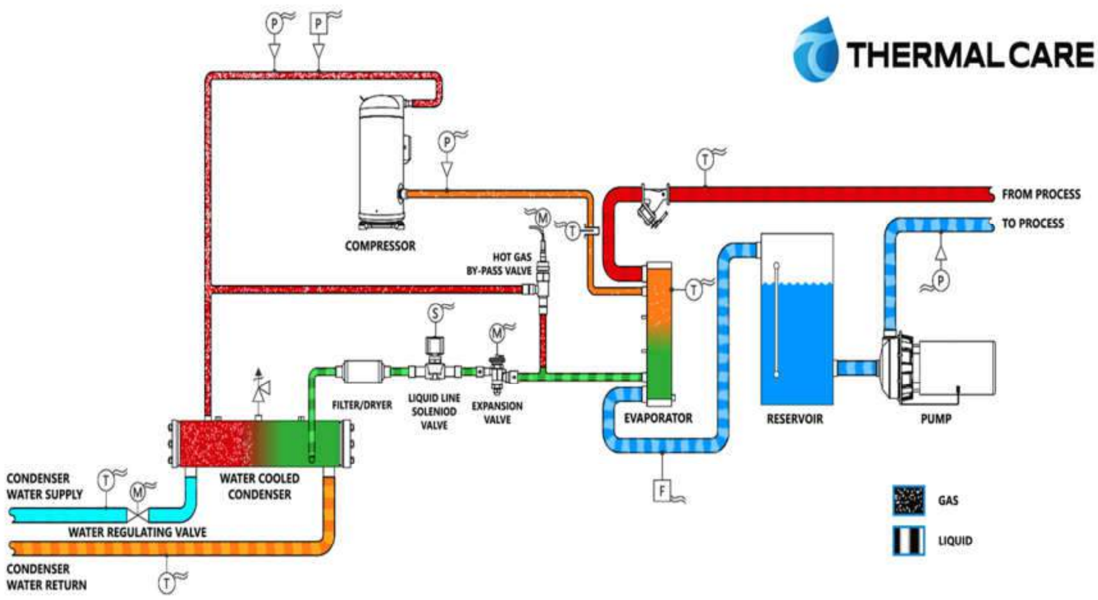
Expansion valves reduce the high pressure, high temperature refrigerant liquid to a low temperature, low pressure liquid/vapor mix. The valves are installed in the refrigeration circuit after the condenser and before the evaporator. Sensing the temperature at the evaporator's outlet (superheat), the valve controls the amount of refrigerant supplied to the evaporator by maintaining superheat.

There are thermal and electronic expansion valves. Thermal expansion valves use a bulb and capillary tube to mechanically control the position of the valve. The bulb is mounted at the outlet of the evaporator to sense the superheat. The capillary tube connects back to the valve adjusting the valve's position. An electronic expansion valve is controlled based upon the input of a sensor mounted in the refrigeration piping at the evaporator's outlet. A controller's algorithm adjusts the position of the valve.



Thermal expansion valves are robust, simple, and inexpensive. The electronic expansion valves are more expensive but offer greater level of control in the refrigeration circuit. This affords the system designers the ability to optimize the performance for greater performance and reliability.

Common Refrigeration Components and Definititions



Compressor is a vessel used to increase the pressure and temperature of refrigerant gas and circulate it through the process cooling system.

Condenser is a heat exchanger used to transfer heat from the refrigerant gas to an external cooling source (water or air are typical mediums). This transfer causes a phase change from gas to liquid condensation.

Expansion valve reduces the high pressure, high temperature refrigerant liquid to a low temperature, low pressure liquid/vapor mix.

Evaporator is a heat exchanger that transfesr heat from the process fluid into the refrigerant causing a phase change - evaporation.

Filter Dryer is installed in the refrigeration circuit. It filters any particles of dirt, metal or other debris. This protects the operation of the components especially the expansion valves. The dryer absorbs any residual moisture remaining in the system after evacuation and charging the refrigerant. It is important to remove moisture to prevent possible freezing. Moisture can also form acids when in contact with the oil in the system.


Loose desiccant


Steel housing


Solid core molecular sieve

Hot gas bypass valve is used for capacity control of a chiller. It provides an artificial load on the evaporator by introducing high pressure, high temperature gas to the evaporator. This prevents the compressor from short cycling the system when the demand for cooling is low. Additionally, the hot gas keeps the evaporator from freezing and prevents low refrigerant pressure alarms.

Liquid Solenoid Valve prevents liquid refrigerant migration to the compressor when the system is shutdown.

Process cooling is a method of removing heat from where it is not wanted (the process) and moving it into the air outside a manufacturing facility.

Refrigerant sight glasses provide a visual indication of refrigerant as it flows through the system. The sight glass includes a moisture indicator. Visual bubbles in the system can indicate a clogged filter-dryer or low refrigerant charge.

Reservoir is the tank where water or water/glycol mix is stored.

Sensors measure pressure in the system.