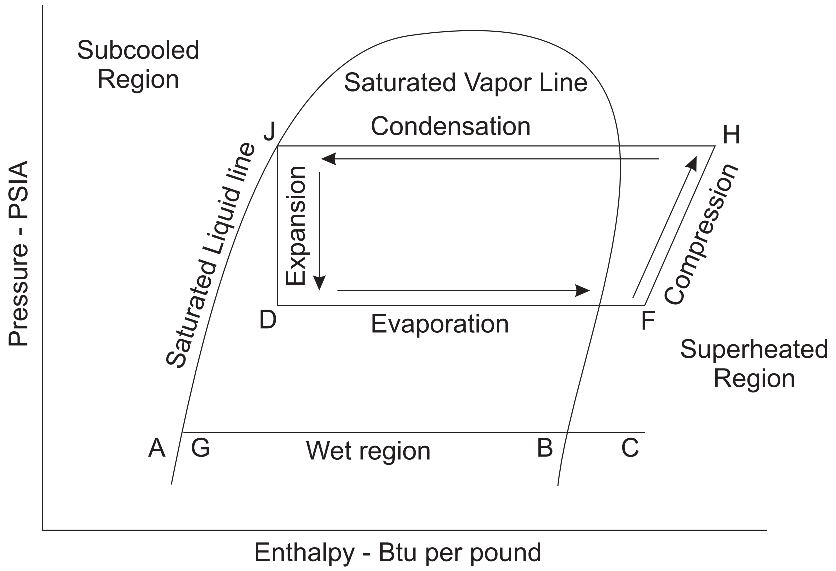
BASIC REFRIGERATION CYCLE

Mechanical refrigeration is used to remove heat from a colder medium and reject it to a warmer medium by using the latent heat properties of the refrigerant. Simply stated, in order to accomplish this transfer of heat energy, the refrigeration system must provide a refrigerant temperature below the temperature of the medium to be cooled and raise the temperature of the refrigerant to a level above the temperature of the medium that is used for rejection. Although the entire chiller package is more complex, the basic components required for mechanical refrigeration are the compressor, evaporator, condenser and thermostatic expansion valve. A complete typical chiller layout follows this section.

The P-H chart is an important tool in understanding the property changes that take place during each phase of the cycle and provides a graphical means of study. Horizontal lines on the P-H Chart are lines of constant pressure and vertical lines are lines of constant enthalpy or heat energy. The line labeled “Saturated liquid line” and “Saturated Vaopr Line” are plots of the pressure-vs-enthalpy for the saturated state of a given refrigerant. The chart is divided into three regions. The area to the left is the subcooled region, to the right is the superheated region and in the middle is the wet region or mixture state. The constant temperature lines are horizontal in the mixture region indicating that phase change occurs at constant pressure. Likewise, expansion of the gas takes place at constant enthalpy.



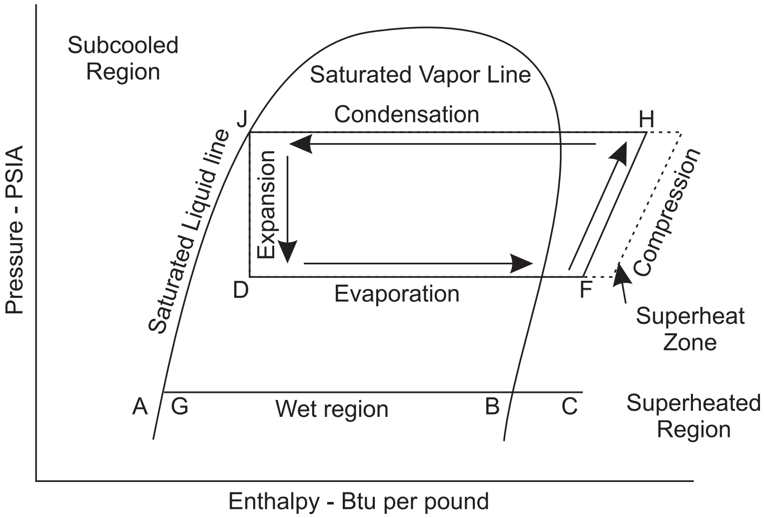
Following the chart, if refrigerant liquid at point A absorbs heat at constant pressure, it will begin to boil. Evaporation takes place with no change in temperature. As heat is added, the enthalpy increases and it enters a mixture state of vapor and liquid. At point B, the mixture becomes a saturated vapor. Any additional heat applied at constant pressure causes the refrigerant to enter the superheat region indicated by point C.

In evaporation, the refrigerant enters the evaporator as a mixture of vapor and liquid at point D of the chart. It enters the evaporator by being metered through a thermostatic expansion valve, TXV, which lowers it’s pressure and therefore its temperature. Because the refrigerant is at a temperature below the process fluid, it absorbs heat from the process fluid, and boils, and changed phase from a liquid to a gas. In order for the refrigerant to change state, it must take in heat energy. During this transfer of heat energy, only latent heat is absorbed resulting in the refrigerant remaining at a constant temperature. In theory, it leaves the evaporator as a vapor at point E, however, in application, additional heat, called “superheat” is added to prevent liquid condensation in the lines that can damage the compressor.

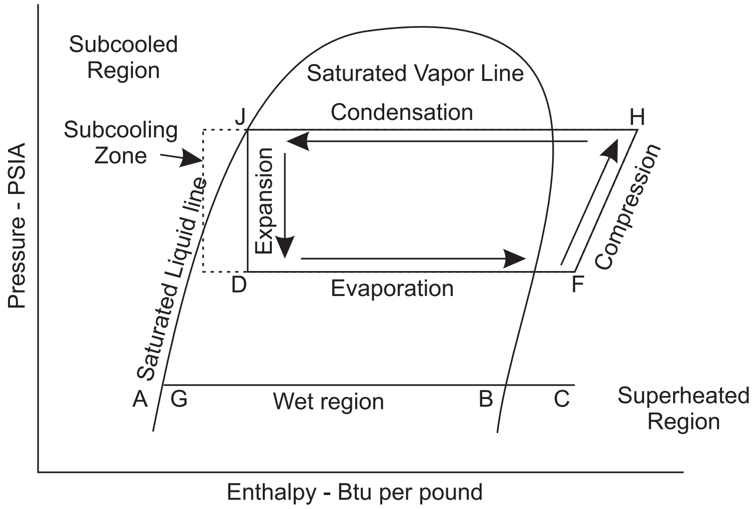
After absorbing the latent heat during evaporation and superheating, the refrigerant gas is compressed from a low pressure gas to a high pressure gas. During the compression process, the refrigerant gas absorbs additional heat known as the Heat of Compression, which is merely the friction of molecules being rapidly forced into a confined space. The additional heat energy caused by compression is represented by the line between points F and H. Note that point H is to the right of point F, indicating the additional enthalpy resulting from the Heat of Compression.

The now hot, high pressure gas is passed through a condenser to remove the heat of compression plus the latent heat of evaporation, collectively known as the “Total Heat of Rejection”, or THR. This heat is typically rejected to a water source in the case of a water cooled chiller package, or to ambient air in an air cooled condenser package. From the P-H chart, it can be seen that condensation takes place at constant pressure. The heat transfer is represented by the difference in enthalpy between points H and J. At point J the refrigerant is totally condensed into a liquid and remains at constant pressure.

Superheat is the heat added to the vapor beyond what is required to vaporize all of the liquid. Superheat therefore is not latent, but sensible heat and is measured in degrees. From the chart below, it can be seen that superheat from the evaporation phase has a corresponding increase in the total heat of rejection at the condenser and results in the compressor operating at higher temperature. While some amount of superheat is required to protect the refrigeration system and prevent liquid entering the compressor, too much superheat can contribute to oil breakdown and increased system downtime.



Subcooling is the process of cooling condensed gas beyond what is required for the condensation process. Subcooling is sensible heat and is measured in degrees. Subcooling can have a dramatic effect in the capacity of a refrigeration system by increasing the capacity of the refrigerant to absorb heat during the evaporation phase for the same compressor Kw input.



Subcooling assures that no gas is left at the end of the condensing phase, thus assuring maximum capacity at the TXV. Subcooling is best accomplished in a separate subcooler or a special subcooling section of a condenser because tube surface must be submerged in liquid refrigerant for subcooling to occur. Simply adding additional surface to a condenser is therefore not as effective. API manufactures a line of subcooling heat exchangers as well as special condensers with a condensing section and a subcooling section divided by a plate. Refrigerant is forced across the condensing section and then downward through the submerged tube section. It is important to pipe the condenser with the coldest water inlet countercurrent to the subcooling section.

As the high pressure cooled liquid from the condenser is reduced in pressure at the TXV, its corresponding temperature is reduced and the cycle is complete. It can be seen from the P-H chart that the heat load on the condenser is greater than that of the evaporator, or process load. This process load is traditionally expressed in “tons of refrigeration” and is equal to 12,000 Btu’s per hour. Process heat loads can be calculated by several methods including:

For clean water: Btuh = GPM x 500 x temperature change

For other fluids: Btuh = Lbs per hour x Specific Heat x temperature change

The condenser load, or THR is this 12,000 Btuh plus the heat of compression which is derived based on the compressor type.

For semi-hermetic compressors:	**Full load kW x 3,413 Btuh per kW**
For open drive compressors:	**Brake HP x 2,544 Btuh per HP**

Note: Tower cells are rated at 15,000 Btuh per ton

Example:

Cool 300 GPM of water from 60°F to 50°F with a 100 HP open drive R-22 chiller. The process heat load is:

300 GPM x 500 x 10° = 1,500,000 Btuh or 125 tons of refrigeration

The condenser load is:

(100 HP x 2,544 Btuh/HP) + 1,500,000 = 1,754,000 Btuh or 116.9 tower cell tons

Special Note:

The actual enthalpy capacity for R-22 operating at 105°F condensing temperature and 40°F saturated suction temperature is 14,400 Btu/Ton. Correction factors must be applied for other operating conditions and refrigerants. Tower cell manufacturers have established a widely used standard of 15,000 Btu per ton. This value is not to be confused with tons of refrigeration used for chiller process load calculations which is 12,000 Btu/ton.

Condenser Considerations

Water cooled condensers are typically specified when a supply of cooling water from a tower, lake, river or other source is readily available. Due to the cost of city water, water treatment, pumping costs and maintenence of a water delivery system, air cooled condensing is preferred in applications where service water is not required for other plant operations or where existing heat rejection capacity is insufficient.

Other reasons for selecting water cooled equipment are:

1. The refrigeration system consumes less electrical energy because the compression ratio is less. An air cooled condenser requires some potential temperature difference in order to reject heat, so the refrigeration system must operate at a higher head pressure and temperature to produce this temperature difference. Air cooled condensers normally requires between 125°F to 130°F condensing temperature to reject heat to a 100° ambient, while a water cooled condenser can operate at 105°F condensing temperature and reject its heat to a 95°F water stream. Because air is a poor conductor of heat, water cooled condensers can operate with a much lower approach temperature.

2. Water cooled condensers are much more compact and require no remote outdoor mounting and piping, rooftop structural preparation or outdoor NEMA-4 electrical service. Where equipment room floor space is at a premium, self contained air cooled chillers, or remote split systems are preferred.

3. Heat recovery is easier to obtain and control when using a water cooled condenser because the heat energy is more easily transported. Heated water from the refrigeration cycle can be diverted to heat other processes and even provide space heating during winter months.