



# Fundamentals of Refrigeration



*Changing the way you think about refrigeration*



## 3

# Refrigeration Cycles

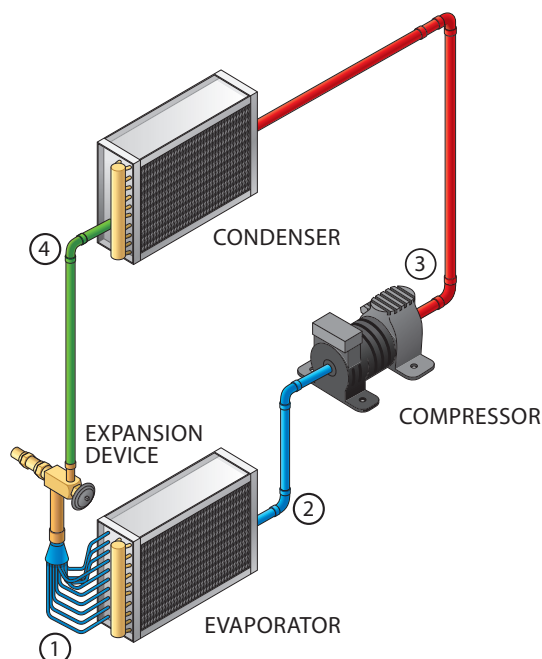
A refrigeration system moves heat from a space, fluid or material for the purpose of lowering its temperature. In the past, this was done by collecting ice in the winter and using its specific heat to cool as the ice melted. When 1 pound of ice melts, it absorbs 144 Btu, as latent energy. When 1 ton (2000 lbs) melts over a 24-hour period:

$$Q = 2000 \text{ lbs} \times 144 \text{ Btu/lb/24 hrs} = 12,000 \text{ Btu/h}$$

This is the definition of 1 ton of refrigeration.

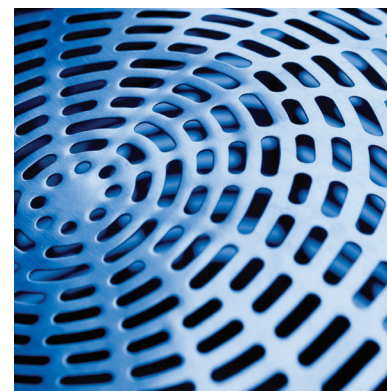
## Ideal Basic Refrigeration Cycle

The **ideal basic refrigeration cycle** consists of four components, connected by piping with refrigerant flowing through the system. **Figure 13** shows the components in the cycle and **Figure 14** shows the basic cycle on the Ph diagram.



**Figure 13**  
Basic Refrigeration Cycle

The **evaporator** is between points 1 and 2. In this component, the refrigerant starts as a cold, two-phase substance (part liquid, part vapor) and is boiled to a saturated gas by absorbing heat from the space/fluid/item that needs to be cooled.

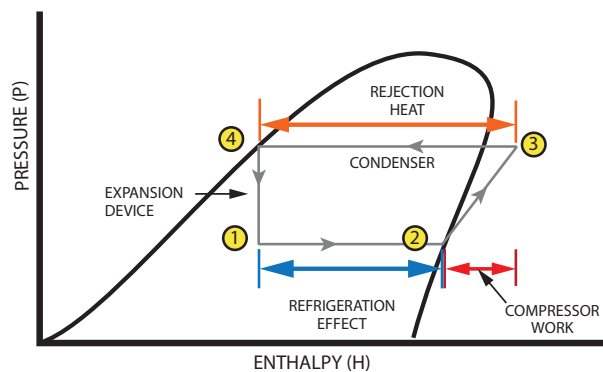


1 ton of cooling is the effect of 1 ton of ice melting over a 24 hour period.

# Refrigeration Cycles

The **compressor** is between points 2 and 3. The compressor does work on the refrigeration system (consumes energy). It raises the pressure, temperature and enthalpy of the refrigerant by compressing the saturated gas, in an isentropic process, to a superheated gas (i.e. entropy is constant – reversible process).

The **condenser** is between points 3 and 4. It cools the refrigerant until it condenses back into a (high-pressure) liquid by rejecting heat from the refrigerant to the surroundings. When complete, the refrigerant is a saturated liquid. The condenser rejects not only the heat gained in the evaporator but also the work of compression added by the compressor.

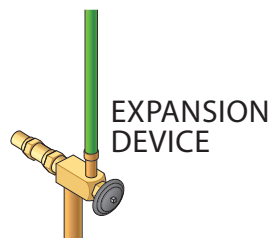


**Figure 14**

Ph Diagram For Basic Refrigeration Circuit

The **expansion device** is between points 4 and 1. In an ideal cycle, it drops the pressure and temperature of the refrigerant with no heat transfer to the surroundings (adiabatically).

## Expansion Device



Point 4 can be identified by finding the properties of a saturated liquid at the condensing temperature or pressure. In an ideal cycle, the expansion process has constant enthalpy so the enthalpy at point 1 is the same as point 4. This can be used to calculate the quality of the refrigerant entering the evaporator.

In an ideal cycle, the expansion device is indicated as a vertical line on a Ph diagram because there is no change in enthalpy of the refrigerant. In a Carnot cycle, the expansion process is both adiabatic and isentropic.

## 3

## Refrigeration Cycles

**Expansion Device Example**

An R-134a refrigeration system condenses at 95° F and evaporates at 45° F. The capacity is 100 tons.

Find the properties at point 4, the pressure drop across the expansion device, the quality of the refrigerant and properties at point 1.

Answer:

From **Appendix C - Refrigerant Properties**, we can get the following information by looking at the saturated conditions for the two temperatures:

Temperature (° F)	45	95
Pressure (p) psia	54.75	128.6
Density ( $\rho$ ) lb/ft <sup>3</sup>	79.32	72.88
Enthalpy ( $h_l$ ) Btu/lb	26.51	43.39
Enthalpy ( $h_v$ ) Btu/lb	109.5	115.7
Entropy ( $s_l$ ) Btu/lb° R	0.05724	0.08877
Entropy ( $s_v$ ) Btu/lb° R	0.2217	0.2192

The properties at point 4 can be found because they are the saturated liquid condition of the refrigerant at 95° F.

$$T_4 = 95^\circ \text{ F}$$

$$h_4 = 43.39 \text{ Btu/lb}$$

$$s_4 = 0.08877 \text{ Btu/lb}^\circ \text{ R}$$

$$p_4 = 128.6 \text{ psia}$$

Pressure drop across the expansion device

$$\Delta P = 128.6 - 54.75 = 73.85 \text{ psi}$$

$$\text{Quality } (\chi) = \frac{(h - h_l)}{(h_v - h_l)}$$

Since an ideal expansion device is adiabatic,  $h_1 = h_4 = 43.39 \text{ Btu/lb}$

$$\chi = \frac{(43.39 - 26.51)}{(109.5 - 26.51)} = 0.203$$

The properties at point 1 can be found as follows;

$$T_1 = 45^\circ \text{ F}$$

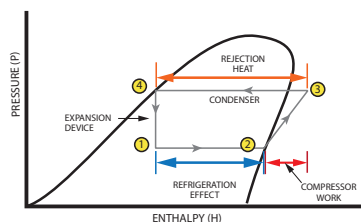
$$h_1 = 43.39 \text{ Btu/lb}$$

$$s_1 = s_l + \chi (s_v - s_l) = 0.05724 + 0.203 \times (0.2217 - 0.05724) = 0.0906 \text{ Btu/lb}^\circ \text{ R}$$

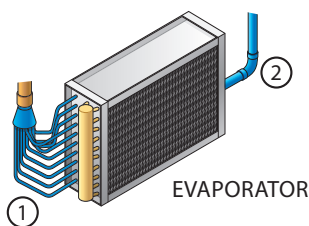
$$p_1 = 54.75 \text{ psia}$$

# Refrigeration Cycles

The blue line under the line 1-2 in a Ph diagram indicates the cooling effect.



## Evaporator



The evaporator introduces energy into the refrigerant from the air that is passing through the coil. The energy balance gives:

$$q = m (h_2 - h_1)$$

Where:

$q$  = heat absorbed, Btu/h (W)

$h_2$  = enthalpy of the refrigerant at point 2, Btu/lb (kJ/kg)

$h_1$  = enthalpy of the refrigerant at point 1, Btu/lb (kJ/kg)

There is a phase change associated with the evaporation process that occurs at a constant temperature and pressure (in an ideal cycle). To capture the total heat transfer, we use the mass flow rate multiplied by the change in enthalpy. In a real (non-ideal) evaporation process, there will be some pressure drop as the fluid moves through the evaporator which causes some temperature change in the fluid and therefore some sensible heat transfer.

## 3

## Refrigeration Cycles

**Evaporator Example**

Using the previous example, find the properties at point 2 and the required mass flow rate to deliver 100 tons cooling.

Answer:

The properties at point 2 can be found because they are the saturated vapor condition of the refrigerant at 45° F.

$$T_2 = 45^\circ \text{ F}$$

$$h_2 = 109.5 \text{ Btu/lb}$$

$$s_2 = 0.2217 \text{ Btu/lb}^\circ \text{ R}$$

$$p_2 = 54.75 \text{ psia}$$

We can use the energy balance equation to find the required mass flow rate,

$$m = \frac{Q}{(h_2 - h_1)} = \frac{100 \text{ tons} \times 12,000 \text{ Btu/h/ton}}{(109.5 \text{ Btu/lb} - 43.39 \text{ Btu/lb})} = 18,152 \text{ lb/hr}$$