



Refrigeration:

A process by which, for a given space, a lower temperature is provided than that which exists in an adjacent space. [achievement of a temperature below that of the immediate surrounding].

-Use of refrigeration:

a- food preparations (dairy products, frozen products, cold stores, house hold refrigerators & freezers) ... etc.

b- industrial processes:

1. separation of gases, air is separated into its constituents by cooling, liquifying & then fractional distillation.

2. Dehumidification of air.

3. drug industries.

4. removal of heat of reaction (exothermic reactions) ...etc.

c- Industrial and comfort (Air Conditioning) (A/C).

i. Comfort A/C of offices, buildings, houses, hotels, ..etc.

ii. Industrial laboratories-clean comfortable atmosphere.

iii. Control of humidity (ex: photographic products,)

iv. Printing industry particularly color printing.

Methods of refrigeration.

a. Rise in temperature of a coolant:

The objects are brought into contact with a coolant (i.e. air, brine, chilled water or even solid).

The quantity of heat removed by the coolant for a constant pressure process or a steady flow process.

$$Q = m \cdot C_p \cdot (T_h - T_c) \text{ Watt or Joule depending on } (m) \text{ or } (\dot{m}) \dots \quad (1).$$

m = mass rate of flow.

C_p = specific heat J/kg °K.

T = temperature °K.



b. Change of phase:

Heat absorbed in either melting, vaporization or sublimation can be utilized for refrigeration.

$$Q=m.L \text{ J or watt.} \dots\dots\dots (2).$$

M= mass of the coolant kg or kg/sec.

L= latent heat.

c. steady flow expansion of gas:

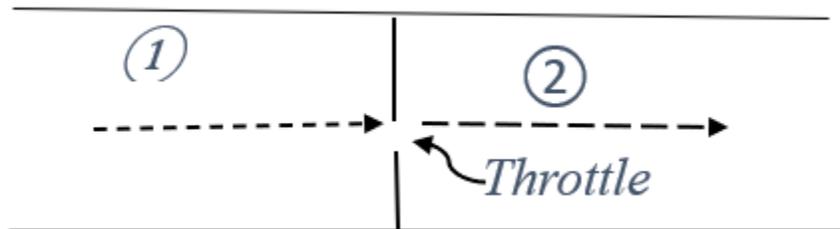
The steady flow energy equation (S. F. E. E.)

is given by:

$$Q-W=\dot{m}\left[\frac{1}{2}(u_2^2 - u_1^2) + g.(z_2 - z_1) + (h_2-h_1)\right] \dots\dots\dots (3).$$

Q- heat added, W- work, u- velocity, z-elevation & h- enthalpy.

1- Adiabatic throttling:



$$W=0, \quad Q=0, \quad \Delta u=0, \quad \Delta z=0$$

$$\therefore h_2=h_1 \quad \text{from equation (3).}$$

$$C_p.(T_2-T_1) =0 \rightarrow (T_2=T_1), \text{ as } C_p \neq 0.$$

i.e. no drop in temperature in an adiabatic throttling process of an ideal gas.

However, in an actual situation $p_2 < p_1$. & $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$.

For no appreciable change in temperature $\rightarrow v_2 > v_1$ as $p_2 < p_1$.

$$\text{From continuity: } [\rho.A.u=\text{constant} \rightarrow \frac{1}{V}.A.u=\text{constant}] \rightarrow \frac{u_1 A_1}{V_1} = \frac{u_2 A_2}{V_2}.$$

$$u_2 > u_1 \quad \text{as } v_2 > v_1.$$

i.e. increase in velocity accompanying reduction in pressure.



If we substitute in the (S. F. E. E.) with $W=Q=\Delta z=0$.

$$\dot{m}\left[\frac{1}{2}(u_2^2 - u_1^2) + (h_2 - h_1)\right] = 0.$$

$$\dot{m} \neq 0 \rightarrow \frac{1}{2}u_2^2 + h_2 = \frac{1}{2}u_1^2 + h_1$$

$$\text{But } u_2 > u_1 \therefore h_2 < h_1.$$

$\therefore C_p \cdot T_2 < C_p \cdot T_1 \rightarrow T_2 < T_1$. [Not very effective in producing low temperature].

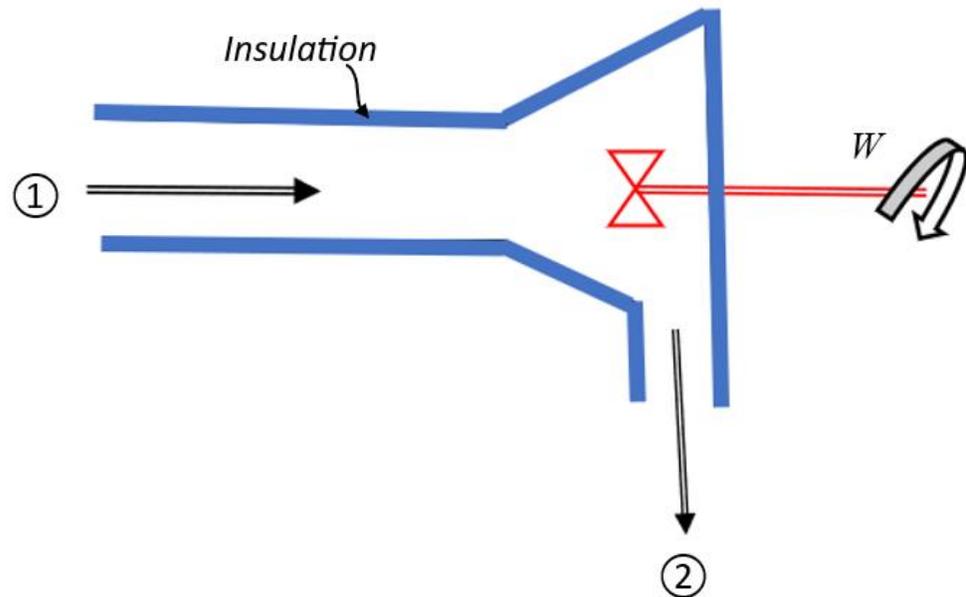
2- Expansion through a turbine.

S.F.E.E., $Q=0$, $\Delta z=0$

$$h_1 = h_2 + W$$

since work is positive $\therefore h_2 < h_1$

i.e. $T_2 < T_1$



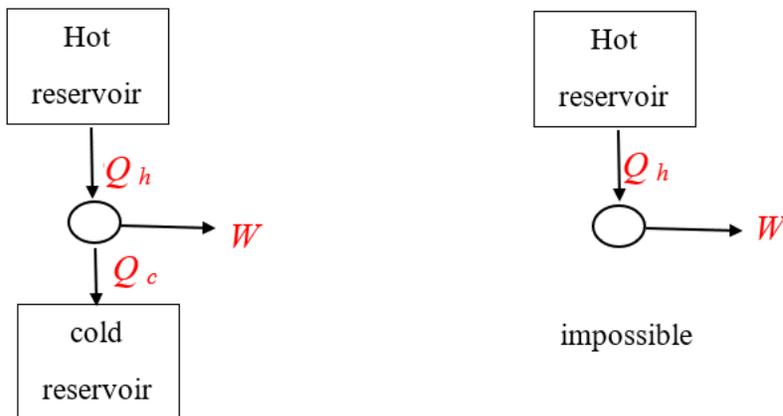
Employed in the air cycle refrigeration system.



Fundamental of vapour compression refrigeration:

1- The second law of thermodynamics:

Kelvin-Plank statement: (heat engine): [No cyclic process is possible whose sole result is the absorption of heat from a reservoir and the conversion of this heat into work]

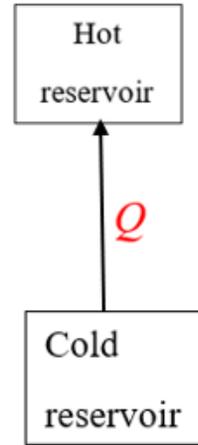
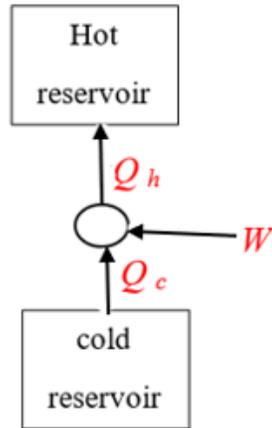


If the heat engine is reversed, we obtain a refrigerator. That is removal of heat from a low temperature reservoir to a high temperature reservoir.



Clausius statement: (Refrigerator)

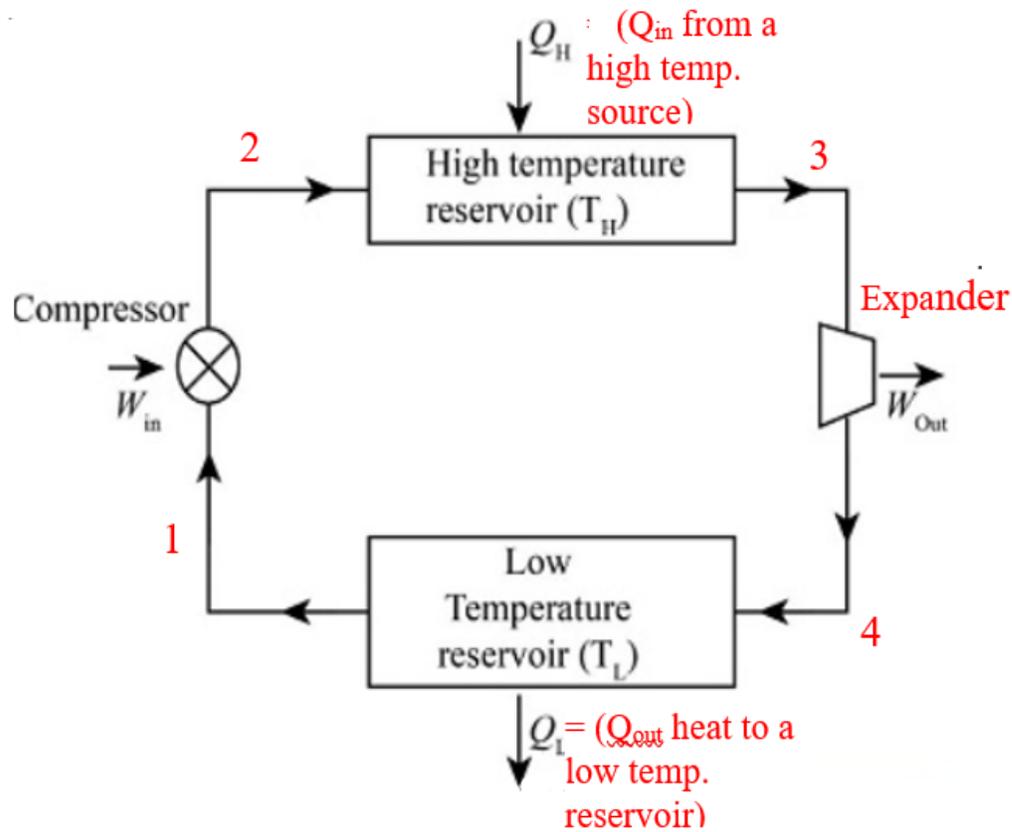
(No cyclic process is possible whose sole result is the transfer of heat from a cooler to a hotter reservoir).

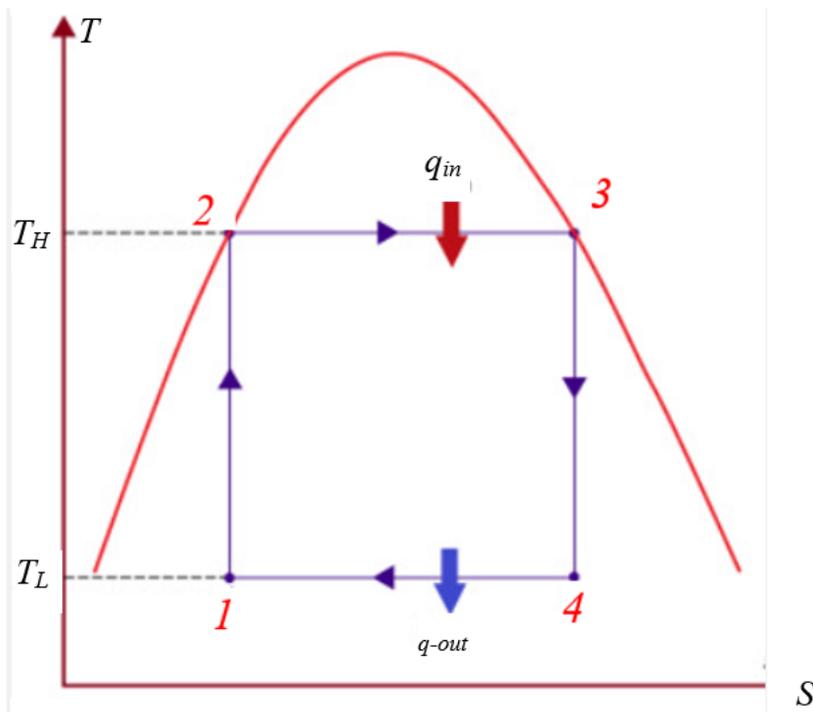


Impossible

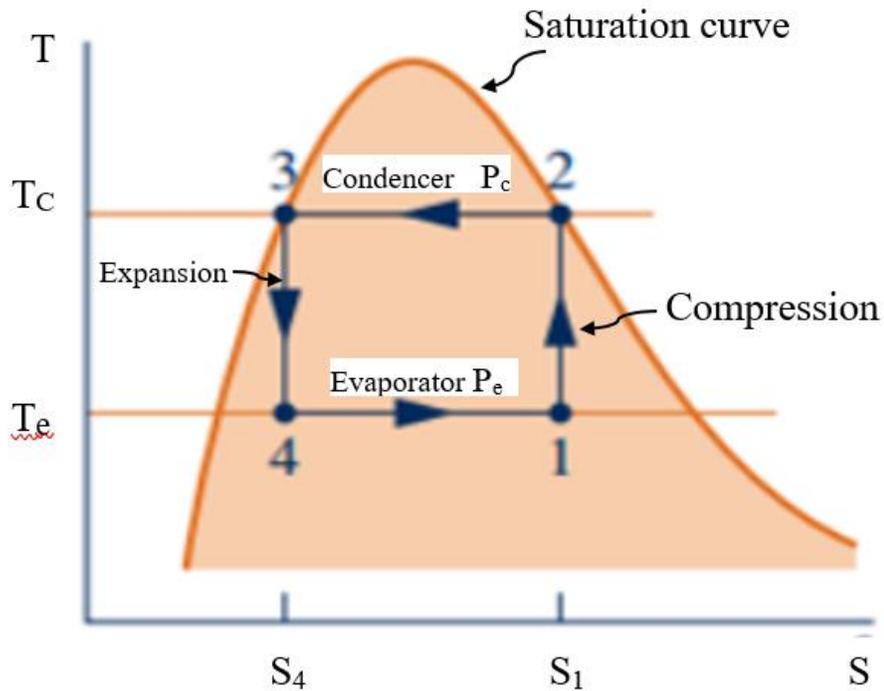
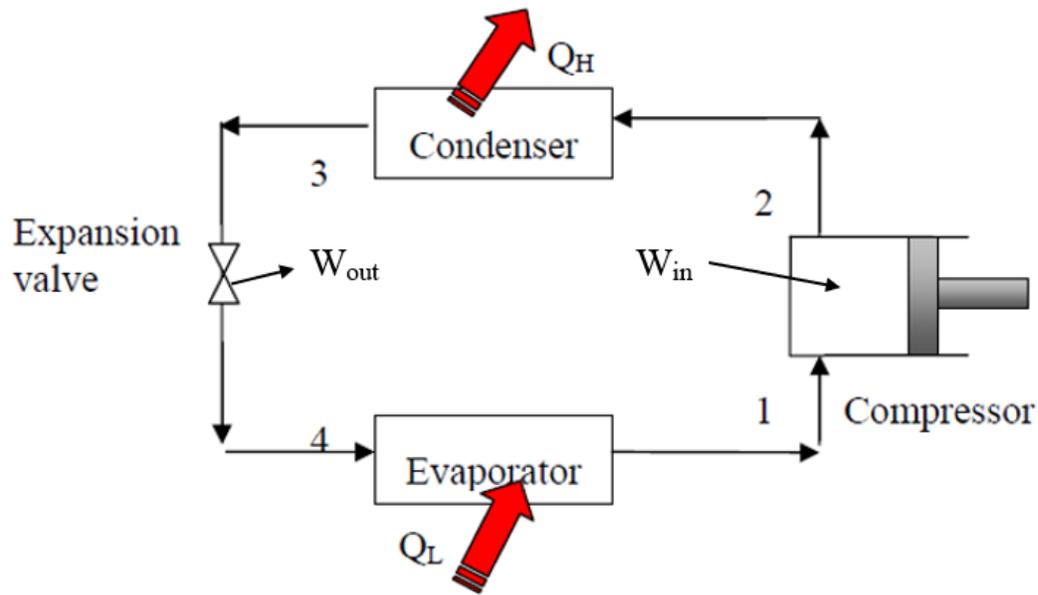


2-The Carnot refrigeration cycle. Recall the Carnot heat engine.





if we were to reverse the cycle such that instead of expansion we have compression, instead of compression we have expansion and the heat transfer is also reversed. We obtain the Carnot refrigerator.





Refrigeration cycle.

- Process (1-2): isentropic compression of refrigerant from P_c to P_c , temperature rises from T_e to T_c . [The small amount of liquid at point (1) evaporates]. The refrigerant leaves the compressor as a saturated vapour. Process (1-2) is reversible adiabatic compression, i.e. (**isentropic**), (work is done by an external source).
- Process (2-3): saturated refrigerant vapour is liquified at constant pressure P_c and constant temperature T_c by the removal of latent heat of vaporization by an external cooling agent.
- Process (3-4): saturated liquid leaves the condenser & expands isentropically. The pressure drops from P_c to P_c & the temperature from T_c to T_e . Cooling the liquid refrigerant from (T_c to T_e) is achieved by the vaporization of a small amount of liquid known as (**flash gas**). Thus, we are inside the phase envelope.
- Process (4-1)- the refrigerant evaporates at a constant temperature (T_e)& constant pressure (P_c) by absorbing heat from the surrounding medium. Thus, cooling the surrounding medium, supplies the latent heat of vaporization and as a result it is cooled (refrigerated).

The area of T-S diagram represent heat.

Heat received at the evaporator (Refrigeration Effect).

$$Q_{in} = T_e(S_1 - S_4) \quad \dots \quad (1).$$

Heat rejected at the condenser.

$$Q_{out} = T_c(S_1 - S_4) \quad \dots \quad (2).$$

Network done: $W_{net} = Q_{out} - Q_{in}$

$$= T_c(S_1 - S_4) - T_e(S_1 - S_4)$$

$$\therefore W_{net} = (T_c - T_e)(S_1 - S_4) \quad \dots \dots \dots (3).$$

Define the coefficient of performance:

C.O.P.=The ratio of the energy received at the evaporator to the energy supplied to the machine.

$$\begin{aligned} \text{i.e. C.O.P.)}_c &= \frac{T_e(S_1 - S_4)}{(T_c - T_e)(S_1 - S_4)} = \frac{\text{Refrigeration effect}}{\text{Net Work}} \\ &= \frac{T_e}{(T_c - T_e)} \quad (\text{for Carnot Ref. only}). \quad \dots \dots (4). \end{aligned}$$



The refrigerator can also be used to heat up a space by the heat rejected at the condenser. In this case the useful energy obtained is the heating effect rather than the cooling effect. In such a case the machine is called a heat pump.

$$\begin{aligned} \text{C.O.P.})_h &= \frac{\text{heat delivered}}{\text{Net Work done}} = \frac{T_c(S_1 - S_4)}{(T_c - T_e)(S_1 - S_4)} \\ &= \frac{T_c}{(T_c - T_e)} \quad (\text{for Carnot heat pump only}). \end{aligned} \quad (5).$$

Add to the numerator ($T_c - T_e$).

$$(\text{COP})_h = \frac{T_c + T_e - T_e}{T_c - T_e} = \frac{T_c - T_e}{T_c - T_e} + \frac{T_e}{T_c - T_e} = 1 + (\text{COP})_c$$

$$(\text{COP})_h = (\text{COP})_c + 1 \quad (\text{for Carnot only}). \quad (6).$$

For a certain amount of refrigerating effect say (X) (kw).

$$\text{COP} = \frac{X}{W} \quad \text{or} \quad W = \frac{X}{\text{COP}} \text{ kw} \quad \dots\dots\dots (7).$$

For 1kw of refrigeration. $W = \frac{1}{\text{COP}}$ kw/kw of refrigeration.