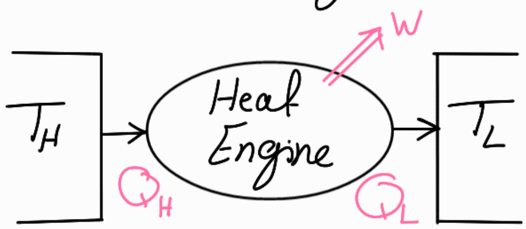
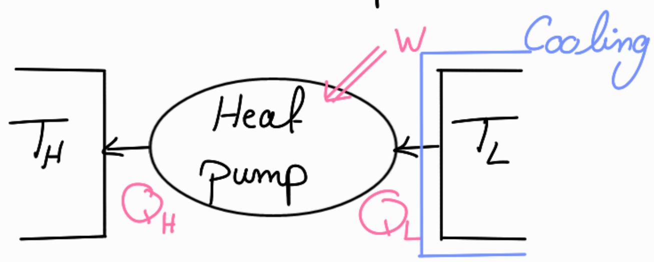
Heat Engines & Heat pumps

Heat engines



Heat Pump

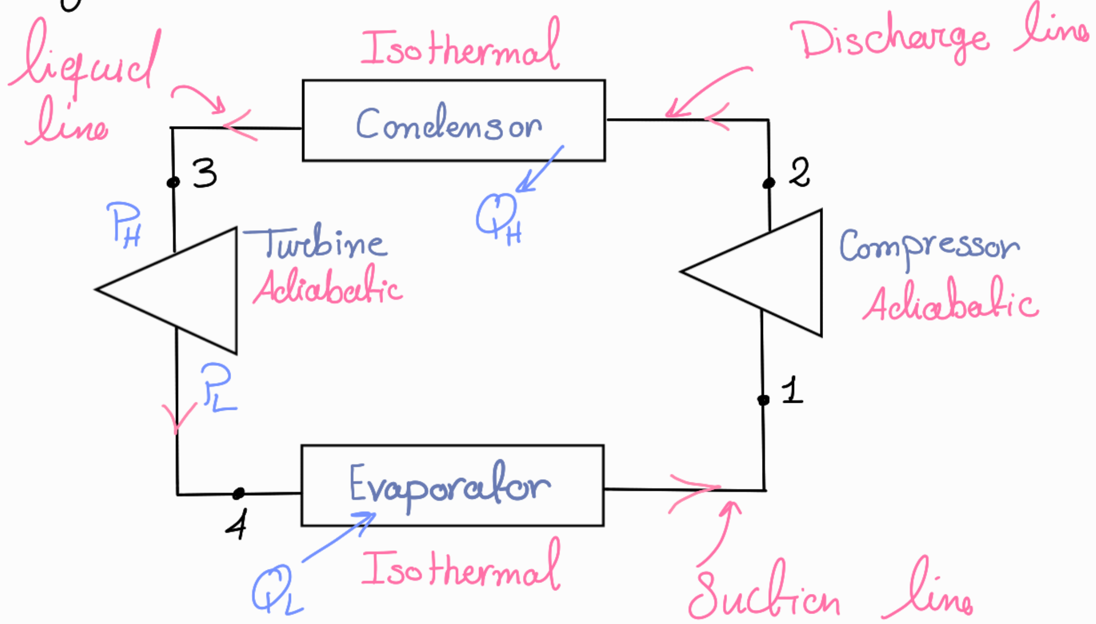


$$\eta_{Th} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

If carnot replace Q with T

$$C.O.P = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L}$$

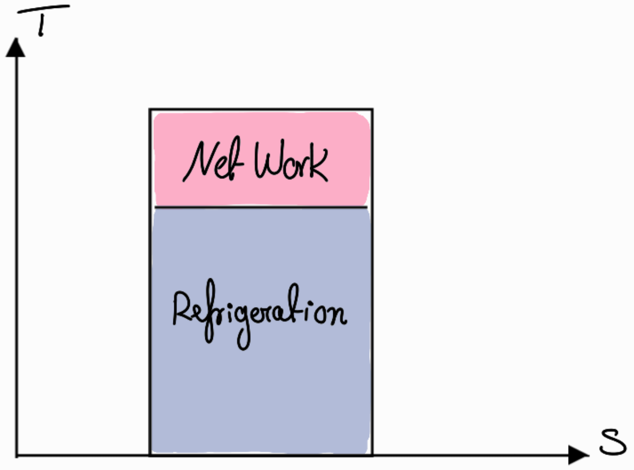
Carnot Refrigeration Cycle



1–2 Adiabatic Compression
2–3 Isothermal heat Rejection
3–4 Adiabatic Expansion
4–1 Isothermal heat Addition

$$\text{Coefficient of Preformance} = \frac{\text{Energy Sought}}{\text{Energy Cost}} = \frac{\text{Useful Refrigeration}}{\text{net Work}}$$

For the Carnot Cycle

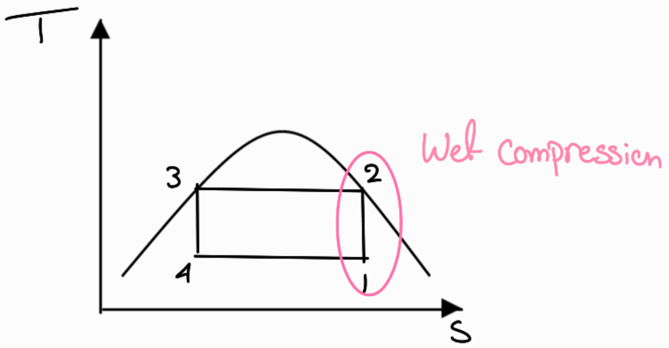


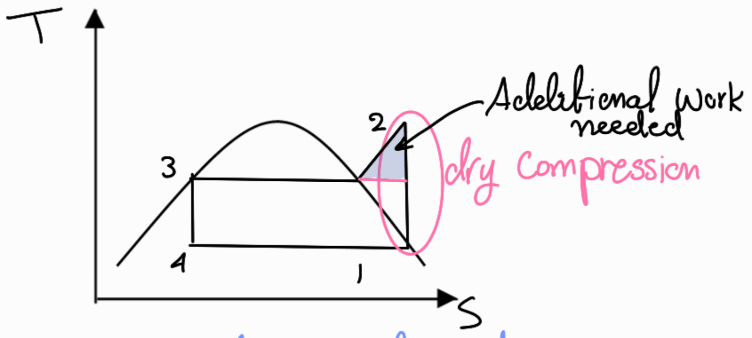
$$C.O.P = \frac{T_1}{T_2 - T_1}$$

$$P.F = C.O.P + 1$$

Wet compression Vs Dry Compression

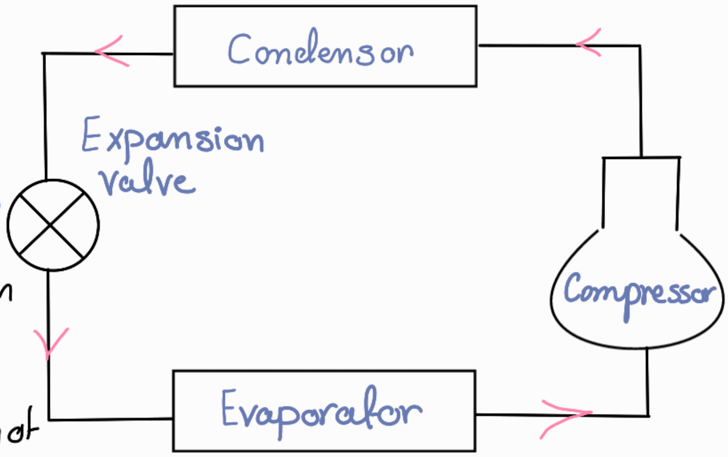
In the carnot Refrigeration cycle:



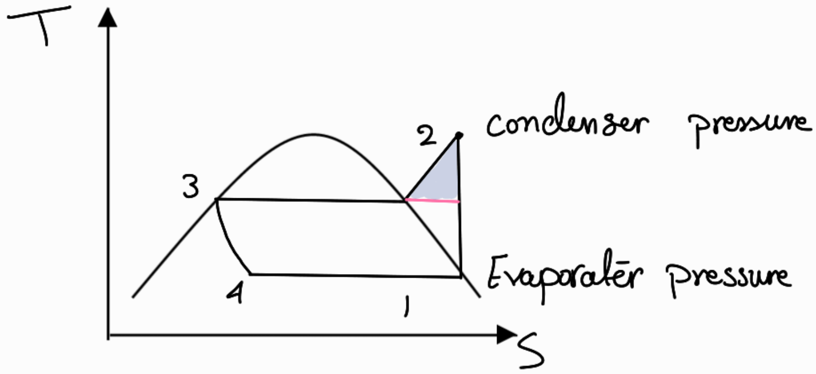


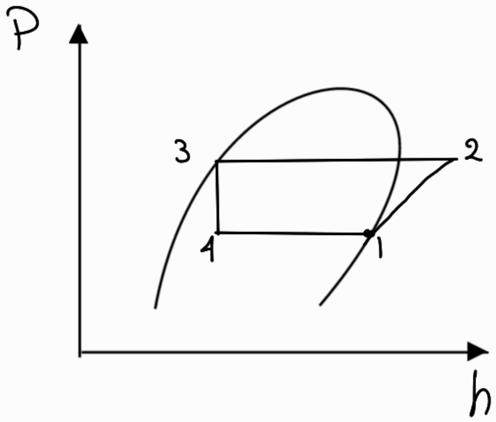
Wet compression can damage the Compressor (when it reaches piston head) since the refrigerant can be trapped in the head of the cylinder. Also, droplets can wash lubricating oil from the walls of the cylinder

Vapor Compression Cycle : Work-operated Cycle



used instead of a turbine because work given by the turbine is so small and so not useful





1-2: Reversible & adiabatic compression

2-3: Reversible rejection of heat at constant pressure

3-4: Irreversible expansion at constant enthalpy

4-1: Reversible addition of heat at constant pressure

Preformance:

Compressor Work: $W = h_1 - h_2$

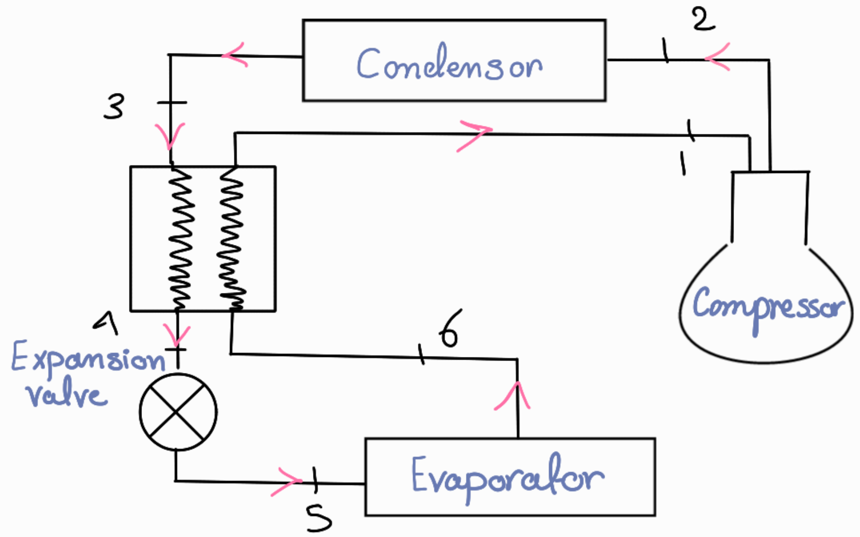
Heat Rejection: $q_{32} = h_3 - h_2$ (Negative)

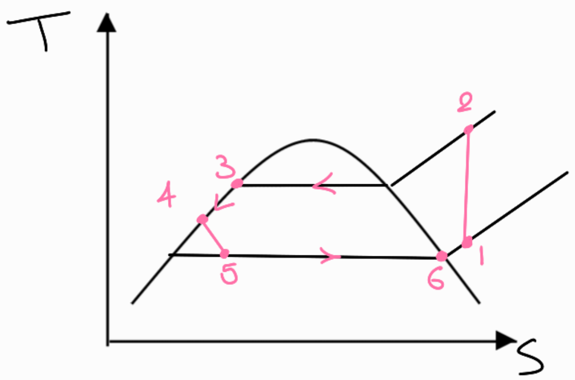
Refrigerating effect: $q_{41} = h_1 - h_4$

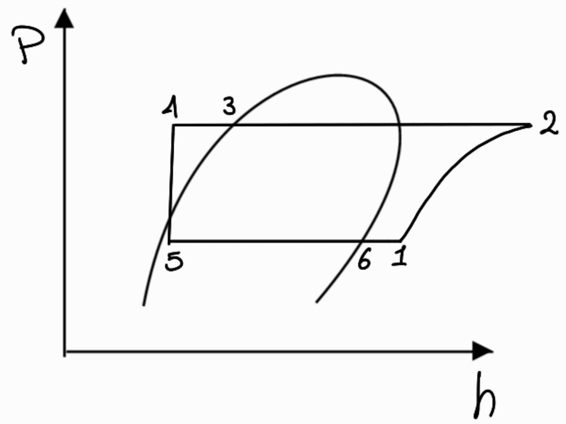
$$C.O.P = \frac{h_1 - h_4}{h_2 - h_1}$$

Note: v_1 : represents the capacity of the compressor

Vapor Compression Cycle with a heat exchanger







Preformance:

heat balance: $h_3 - h_4 = h_1 - h_6$

Heat Rejection: (Negative)

Refrigerating effect: $q_{1,4} = h_1 - h_3 = h_6 - h_5$

$$C.O.P = \frac{h_5 - h_6}{h_2 - h_1}$$

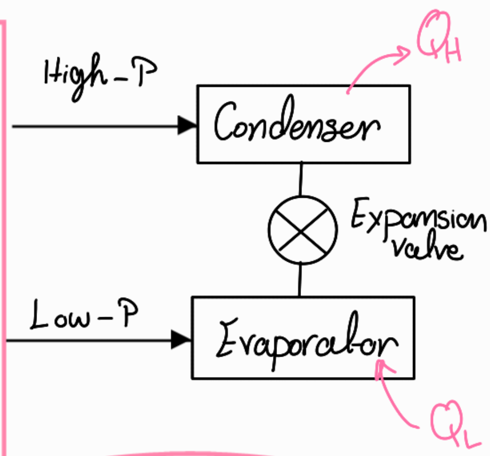
Advantages
- Increased Refrigerating effect
→ C.O.P ↑
- v intake is higher
- Dry Compression is Guaranteed

Chapter 17 : Absorption refrigeration : heat operated cycle

heat is needed to drive off the vapor from the high pressure liquid (cost)

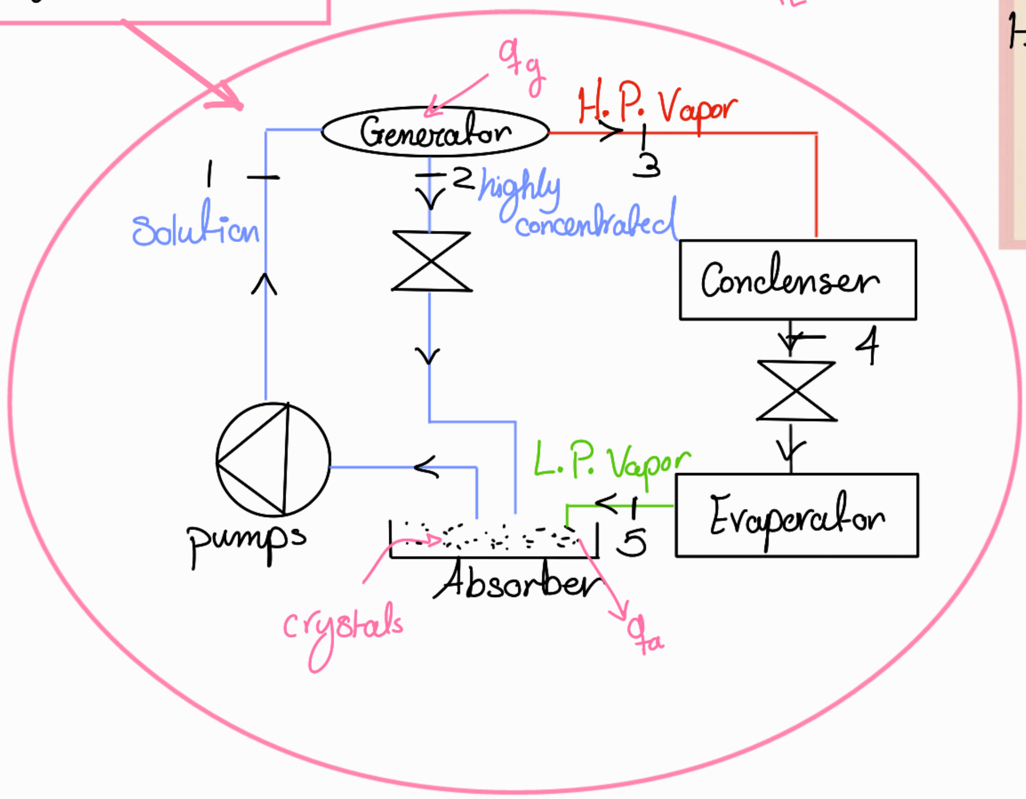
Absorption:

1. Absorbs vapor in liquid while removing heat
2. Elevates pressure (pump)
3. Releases vapor by Applying heat



Absorber

- High capacity: Water (ice), Ref: NH_3
- Low capacity: Li-Br, Ref: H_2O



- Low pressure vapor from the evaporator is absorbed by the liquid solution in the absorber
- The absorber is cooled by air or water to reject heat
- The pump increases the pressure of liquid
- In the generator, heat from a high temp source to extract the vapor. This results in a high pressure vapor and a highly concentrated solution

$$C.O.P = \frac{\text{refrigeration rate}}{\text{rate of heat addition to generator}} = \frac{Q_L}{q_g + W_p}$$

(Q_L = q_e; W_p very small)

$$\dot{m}_1 X_1 = \dot{m}_2 X_2$$

X : concentration

$\dot{m}$ crystals is constant ⟹ Concentration differs

$$\dot{m}_1 - \dot{m}_2 = \dot{m}_{refrigerant}$$

$$q_g = (\dot{m}_3 h_3 + \dot{m}_2 h_2) - (\dot{m}_1 h_1)$$

- h_3: h_g at $T_{generator}$
- h_2: h at X_2, $T_{generator}$
- h_1: h at X_1, $T_{absorber}$

$$q_a = (\dot{m}_2 h_2 + \dot{m}_5 h_5) - \dot{m}_1 h_1$$

- $\dot{m}_5 = \dot{m}_4 = \dot{m}_3$
- h_5: h_g at $T_{evaporator}$

$$q_c = \dot{m}_{3,4,5} (h_3 - h_4)$$

- h_4: h_f at $T_{condenser}$

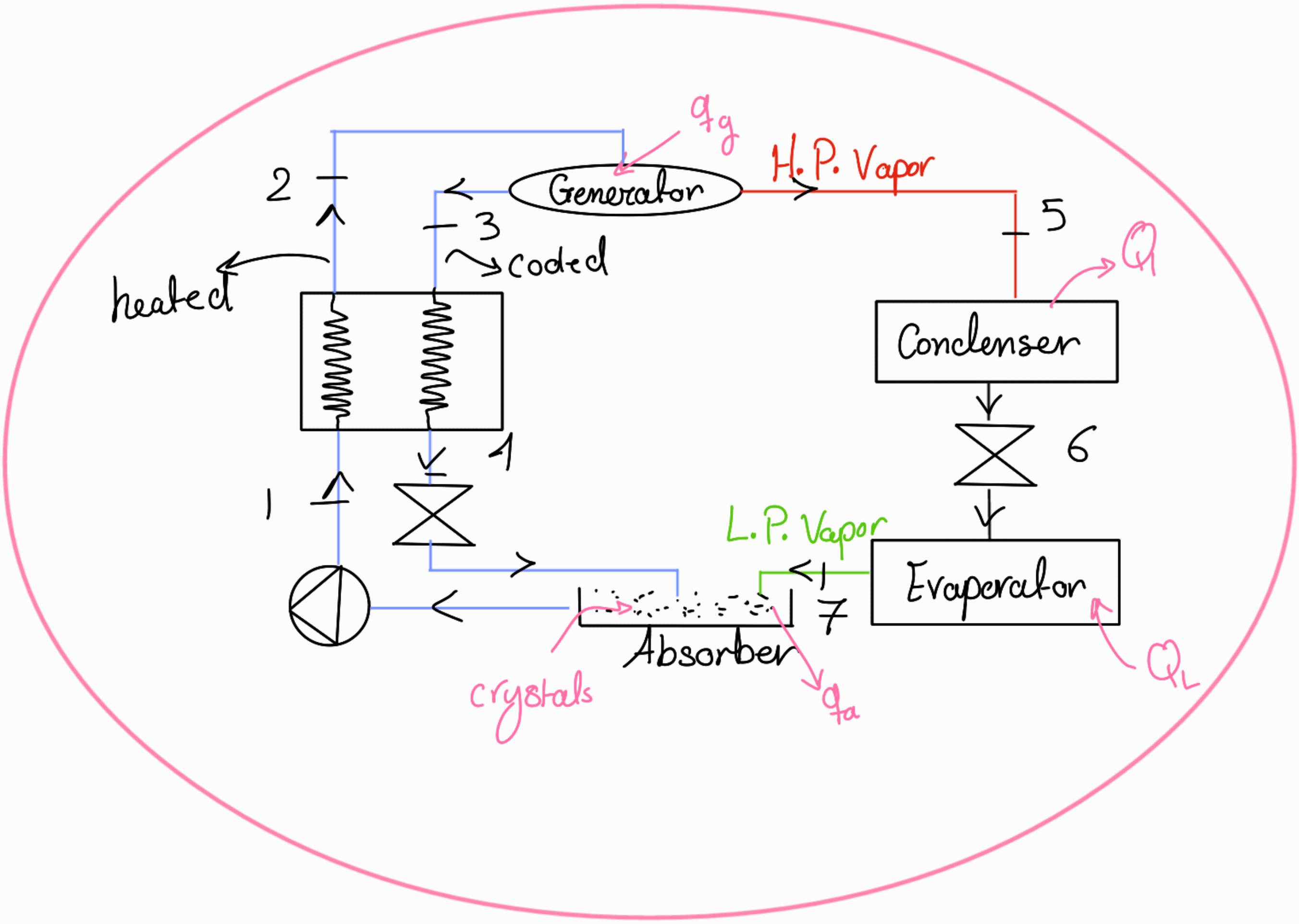
$$q_e = \dot{m}_{3,4,5} (h_5 - h_4)$$

To get concentration:
Using Fig 17-5

At Absorber
- $P = P_{sat}$ at $T_{sat\,evap}$
- $T = T_{absorber}$ ← should be higher

At Generator
- $P = P_{sat}$ at $T_{sat\,cond}$
- $T = T_{generator}$

Absorption refrigeration with a heat exchanger



- Low pressure vapor from the evaporator is absorbed by the liquid solution in the absorber
- The absorber is cooled by air or water to reject heat
- The pump increases the pressure of liquid
- In the generator, heat from a high temp source to extract the vapor. This results in a high pressure vapor and a highly concentrated solution

$$C.O.P = \frac{\text{refrigeration rate}}{\text{rate of heat addition to generator}} = \frac{Q_L}{q_g + W_p}$$

(W_p ← very small)

$$\dot{m}_3 X_3 = \dot{m}_2 X_2$$

X : concentration

$\dot{m}$ crystals is constant ⟹ Concentration differs

$$\dot{m}_2 - \dot{m}_3 = \dot{m}_{\text{refrigerant (water)}} \to \dot{m}_5$$

$$q_g = (\dot{m}_3 h_3 + \dot{m}_5 h_5) - (\dot{m}_2 h_2)$$

h_3: h at X_3, $T_{generator}$

h_5: h_g at $T_{generator}$

h_2: h at X_2, T_{HX}

$$q_a = (\dot{m}_4 h_4 + \dot{m}_7 h_7) - \dot{m}_1 h_1$$

h_4: from equation of HX

h_7: h_g at $T_{evaporator}$

h_1: h at X_2, $T_{absorber}$

$$\dot{m}_2 h_2 + \dot{m}_4 h_4 = \dot{m}_1 h_1 + \dot{m}_3 h_3$$

$$q_c = \dot{m}_5 (h_5 - h_6)$$

h_6: h_f at $T_{condenser}$

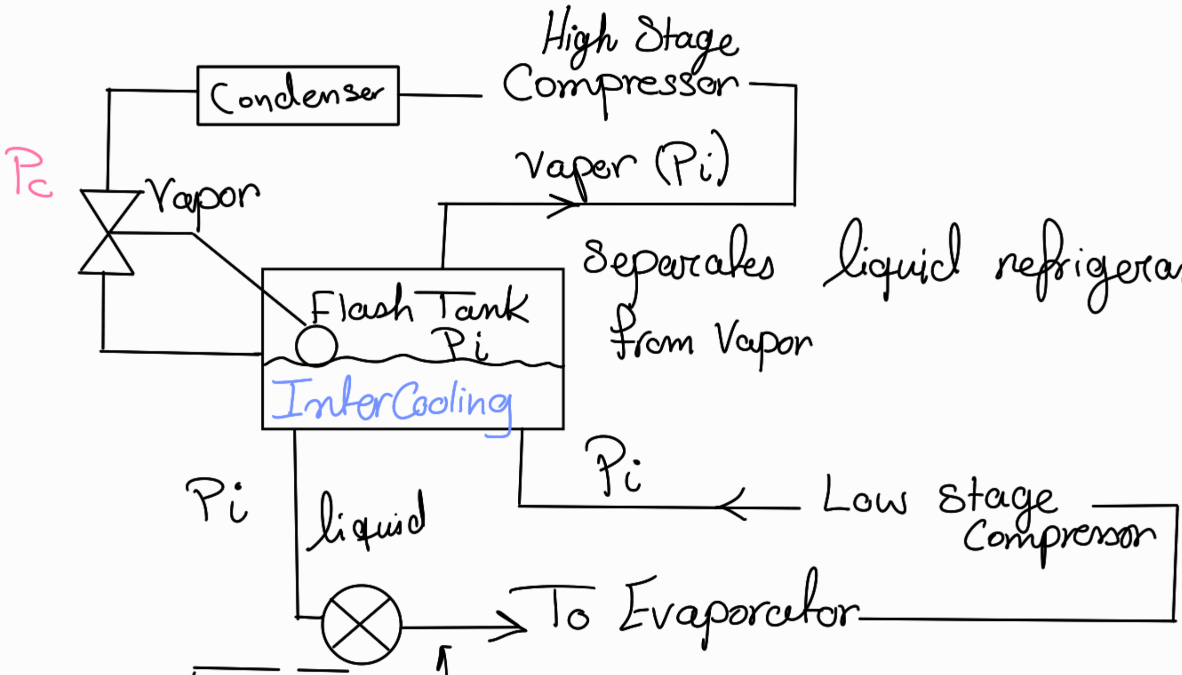
$$q_e = \dot{m}_6 (h_5 - h_4)$$

Chapter 16 : Multiple pressure Systems

- A system that has two or more side pressures (low side & high side).
- The low side pressure is the pressure of the refrigerant between the expansion valve and the intake of the compressor

Flash gas removal

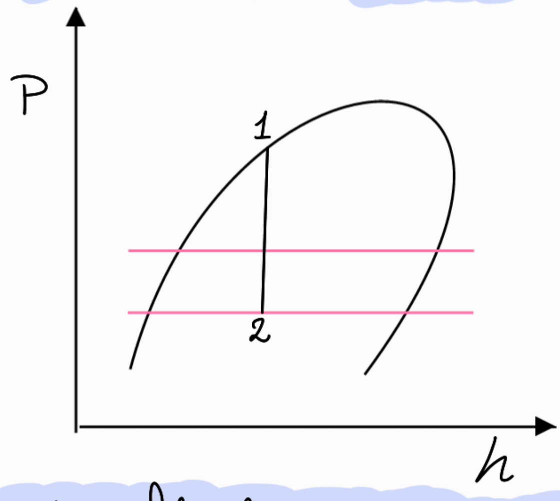
- It is the vapor developed in the throttling process between Condenser & expansion valve
- This vapor is removed and recompressed before complete expansion



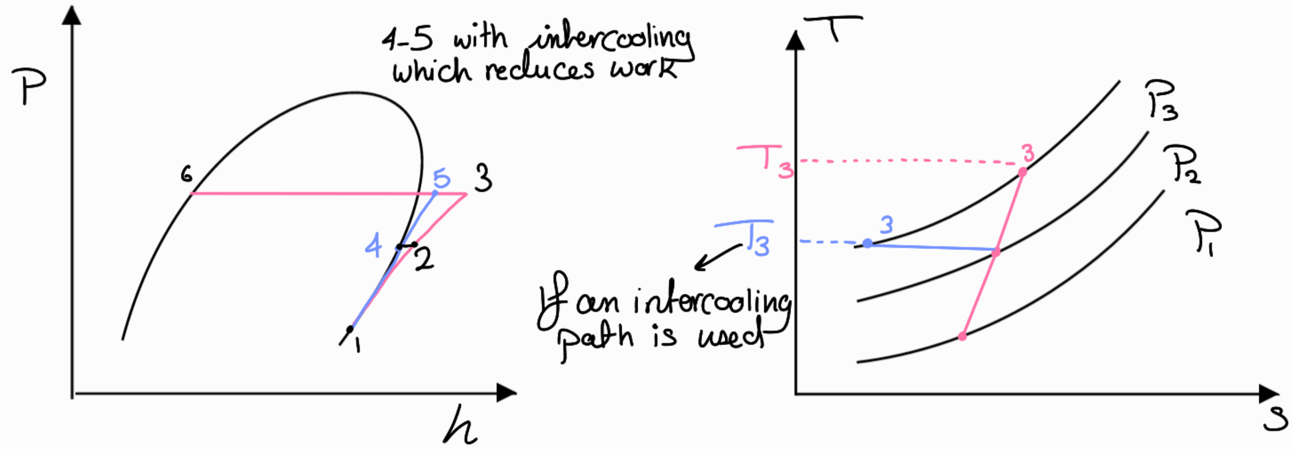
$$P_{interm} = \sqrt{P_e P_c}$$

Re

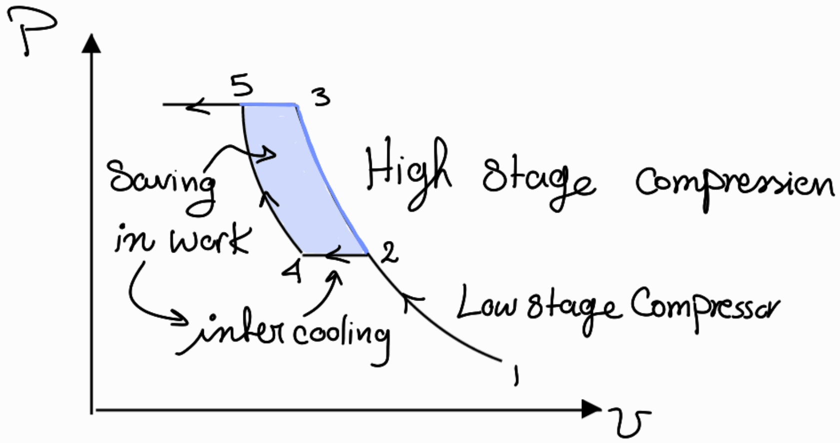
Normal Expansion path



When flash gas is removed

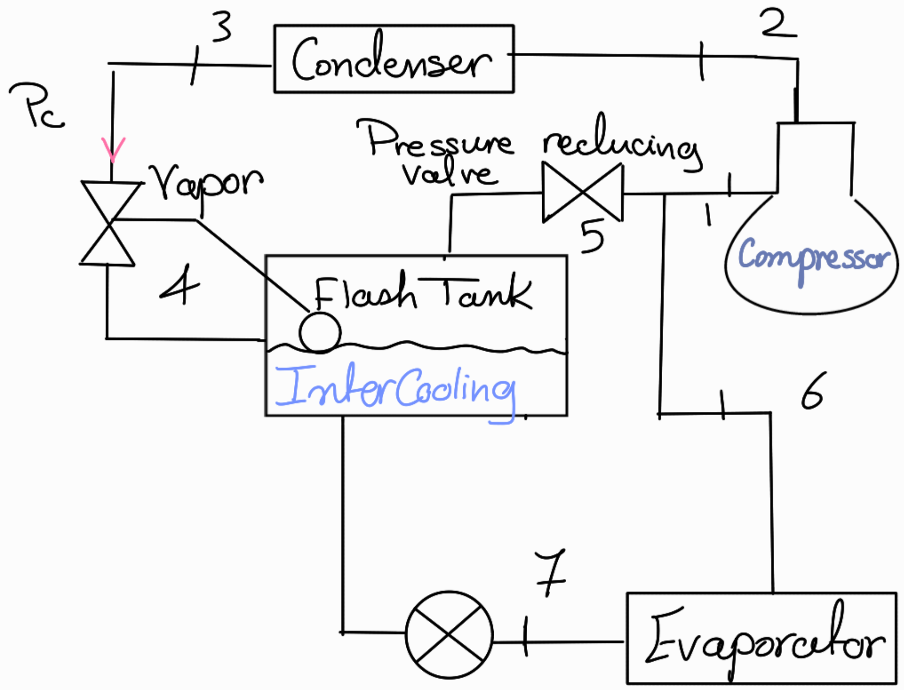


- With intercooling



Compressor & Evaporator Combinations

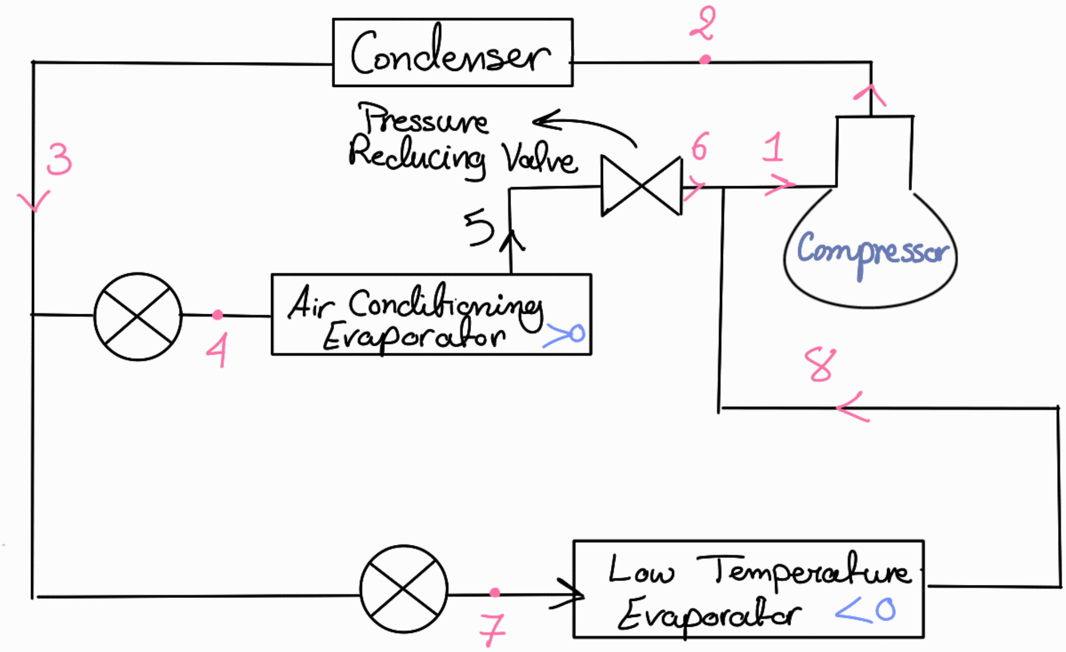
1. One evaporator & one compressor

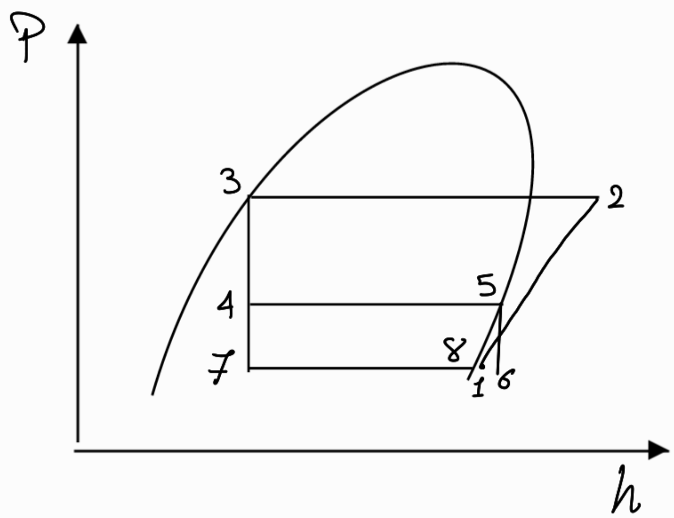


- The flash tank does not improve preformance here
- This system is used infrequently
- This system is used to Keep the flash gas in the machine room

2. Two evaporators and one compressor

- Used for systems that needs low temperature refrigeration for a process and needs to provide air conditioning for offices

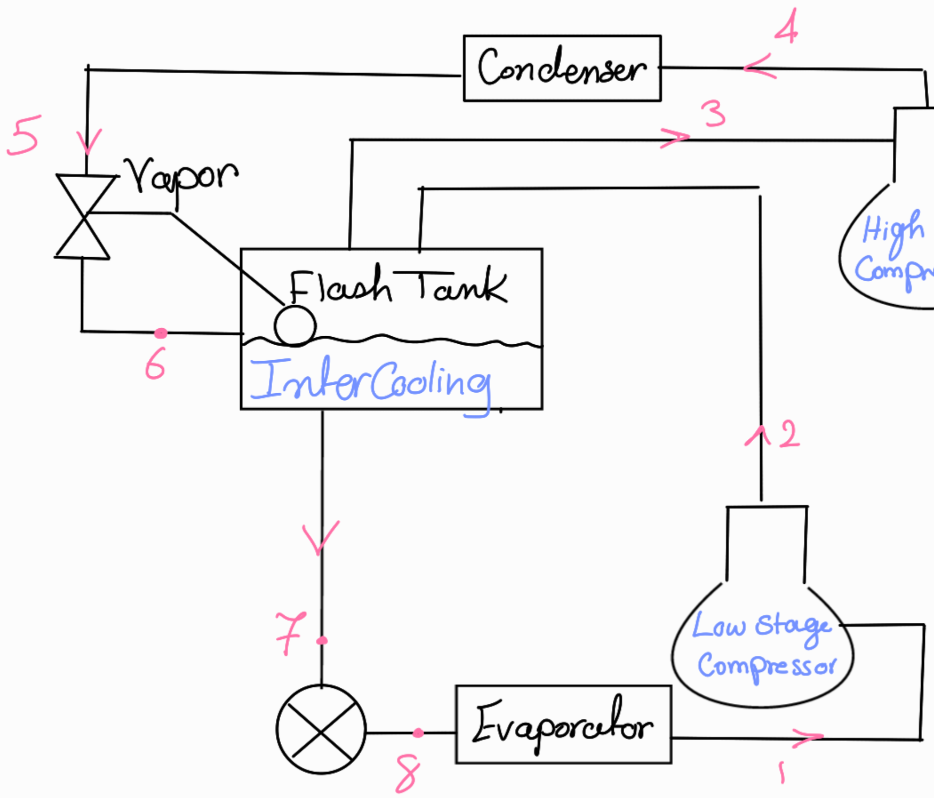


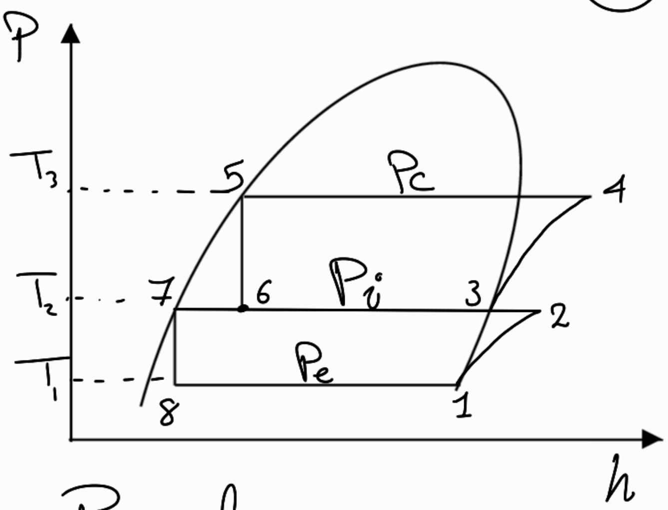


- The Pressure reducing valve regulates the pressure and maintains a temperature in the air conditioning > 0

3. Two Compressors and one evaporator

It serves one low temperature evaporator. It requires less power than with a single compressor since flow rate at each is lower





Procedure

$h_1 = h_g$ at P_e or T_1

$s_1 = s_g$ at P_e or T_1

h_2: $P = P_i$ & $S_1 = S_2$
(superheated graph)

$h_3 = h_g$ at P_i

$S_3 = S_g$ at P_i

h_4: $P = P_c$ & $S_3 = S_4$
(superheated graph

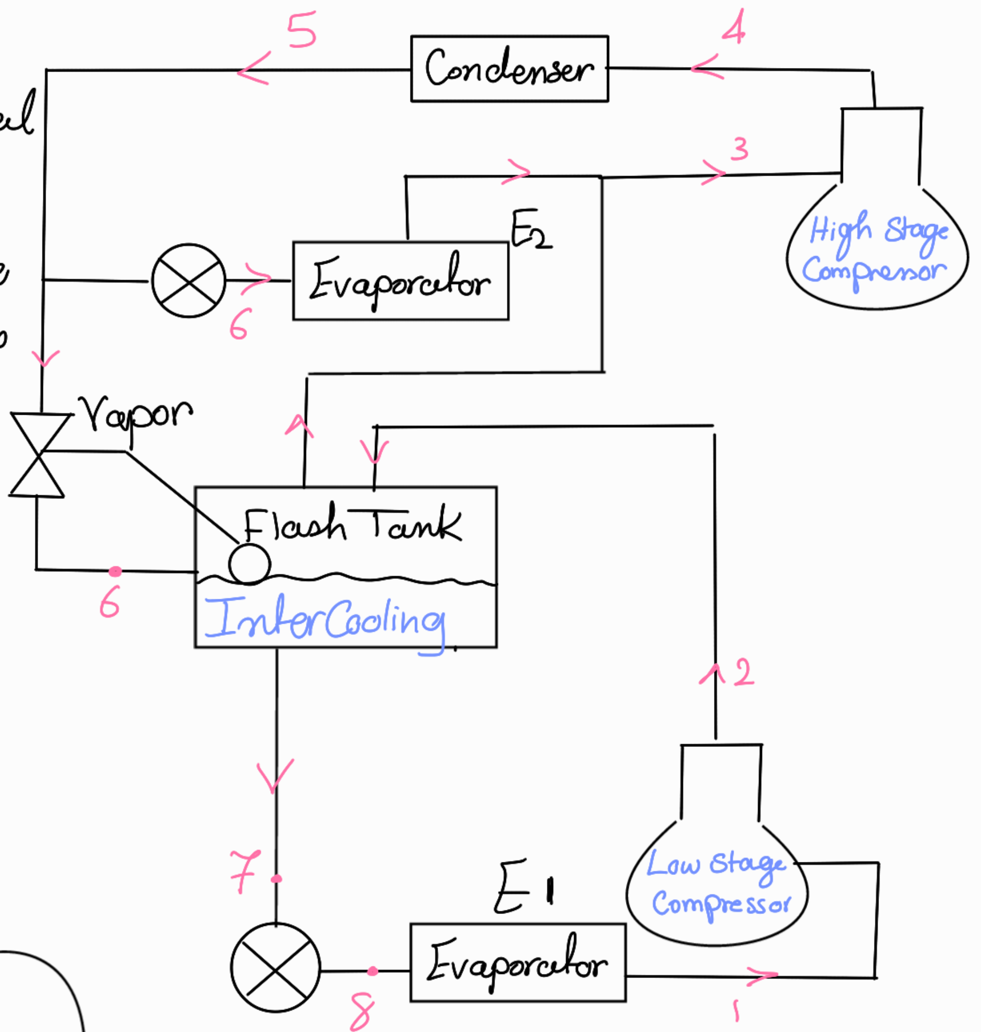
$h_5 = h_f$ at $P_c = h_6$

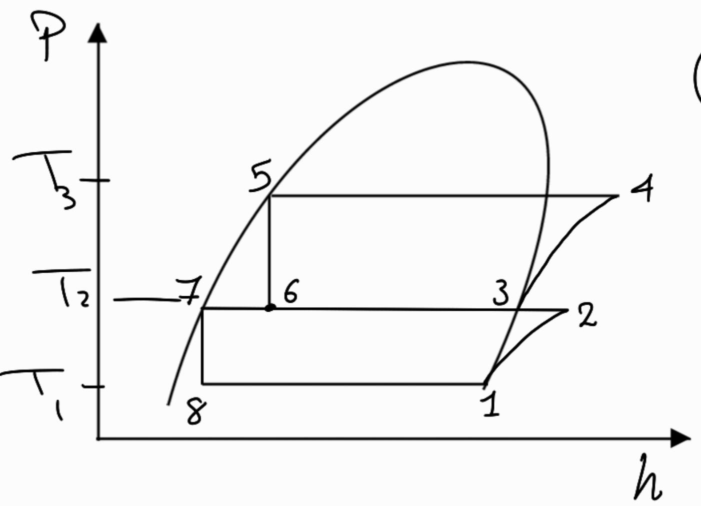
$h_7 = h_f$ at $P_i = h_8$

$$\dot{m}_5 h_5 + \dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{m}_7 h_7$$

4. Two Compressors and two evaporators

- Used in industrial refrigeration
- Used when two different temperatures are needed





$h_3 = h_g$ at $P = P_{E2}$ or $P = P_{sat}$ at T_2

$S_3 = S_g$ at $P = P_{E2}$ or $P = P_{sat}$ at T_2

Procedure

$h_1 = h_g$ at P_e or T_1

$S_1 = S_g$ at P_e or T_1

h_2: $P = P_{E2}$ or $P = P_{sat}$ at T_2 & $S_1 = S_2$ (superheated graph)

h_4: $P = P_c$ & $S_3 = S_4$ (superheated graph

$h_5 = h_f$ at $P_c = h_6$

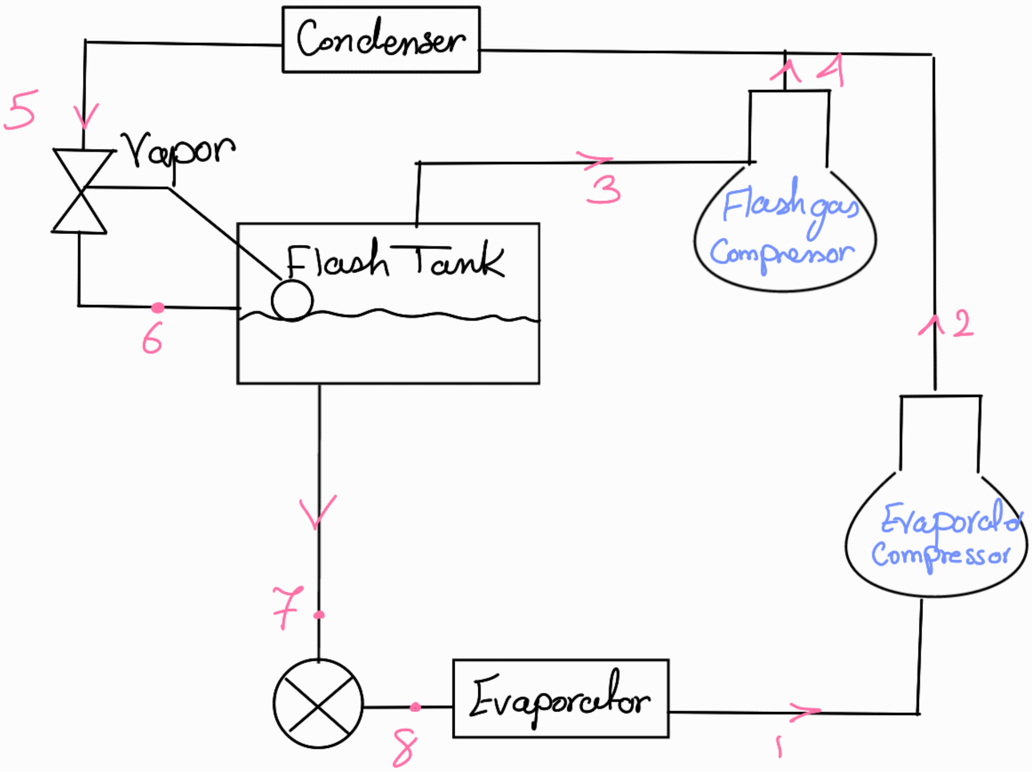
$h_7 = h_f$ at $P = P_{E2}$ or $P = P_{sat}$ at T_2

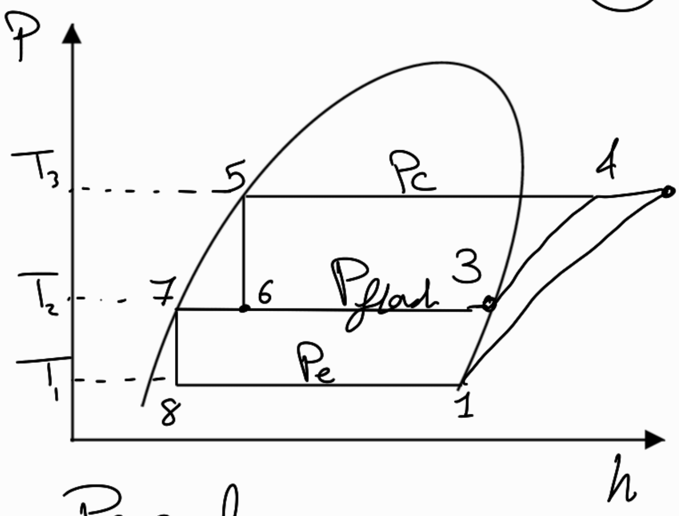
$h_7 = h_8$

$$Q_{E2} + \dot{m}_5 h_5 + \dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{m}_7 h_7$$

Extra but important Notes

Removal of flash gas with no intercooling





$h_3 = h_g$ at $P_{flash\,Tank}$

$S_3 = S_g$ at $P_{flash\,Tank}$

h_4: $P = P_c$ & $S_3 = S_4$ (superheated graph

Procedure

$h_1 = h_g$ at P_e or T_1

$S_1 = S_g$ at P_e or T_1

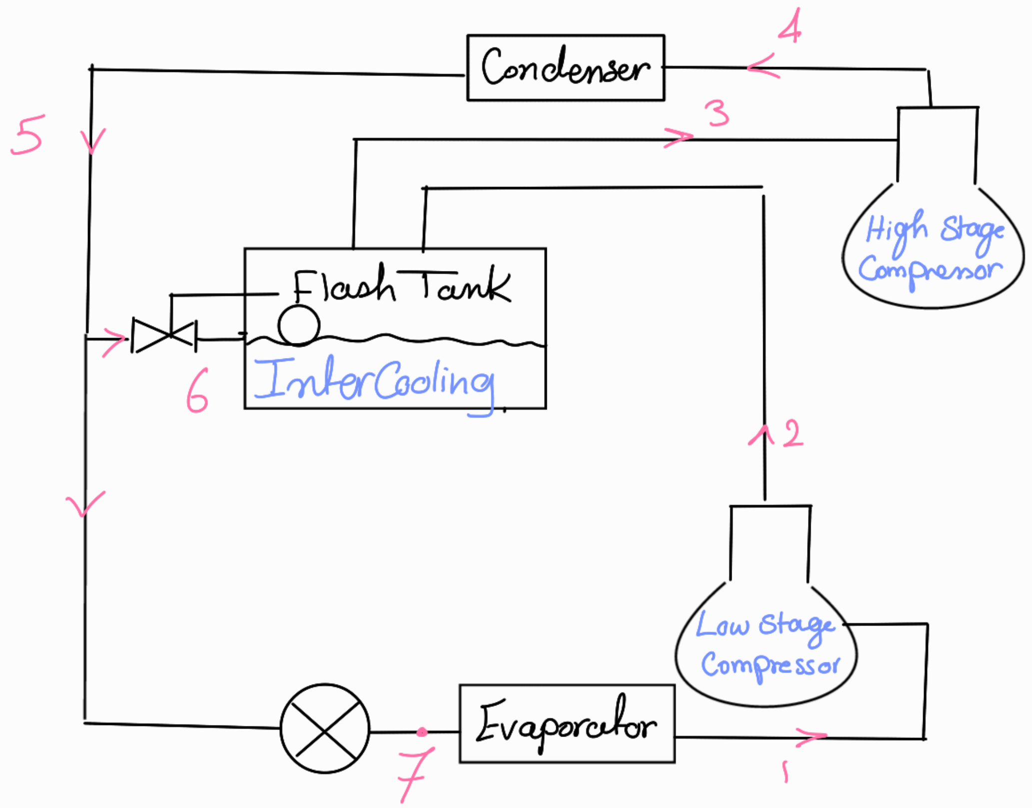
h_2: $P = P_c$ & $S_1 = S_2$ (superheated graph)

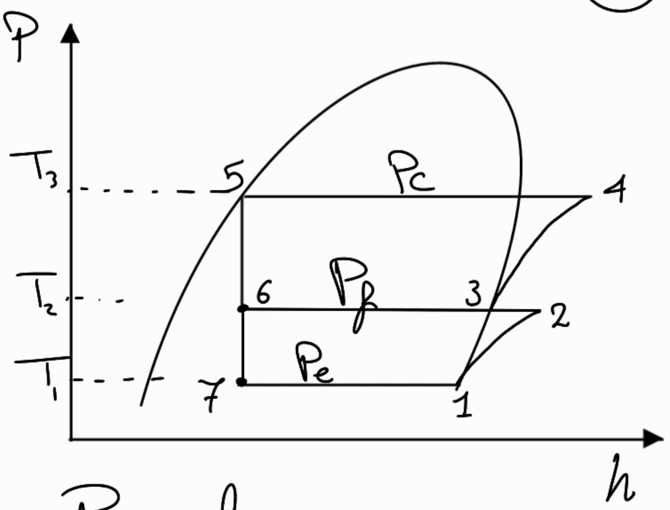
$h_5 = h_f$ at $P_c = h_6$

$h_7 = h_f$ at $P_{flash} = h_8$

$$\dot{m}_5 h_5 = \dot{m}_3 h_3 + \dot{m}_7 h_7$$

Intercooling with no flash gas removal





$h_3 = h_g$ at P_f

$S_3 = S_g$ at P_f

h_4: $P = P_c$ & $S_3 = S_4$

(superheated graph)

$h_5 = h_f$ at $P_c = h_6$

$h_6 = h_7$

Procedure

$h_1 = h_g$ at P_e or T_1

$S_1 = S_g$ at P_e or T_1

h_2: $P = P_f$ & $S_1 = S_2$

(superheated graph)

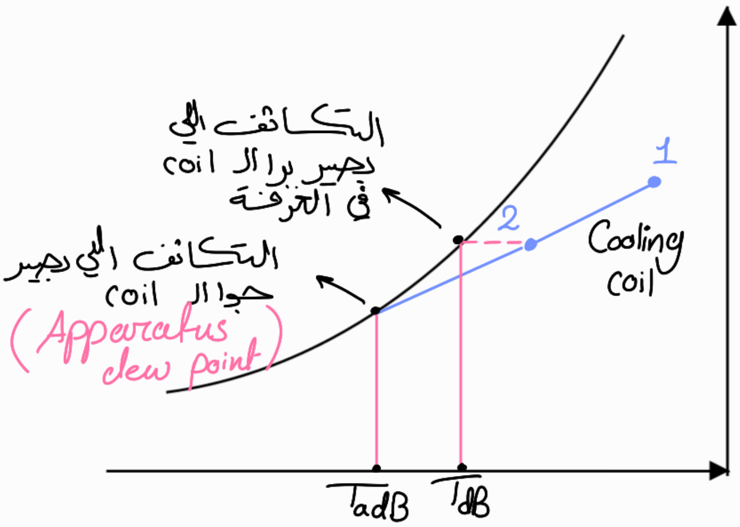
$\dot{m}_6 h_6 + \dot{m}_2 h_2 = \dot{m}_3 h_3$.

$\dot{m}_2 + \dot{m}_6 = \dot{m}_3$

$\underset{1,7}{\dot{m}_2}$ … $\underset{4,5}{\dot{m}_3}$

Defrosting

It is the process of removing ice or frost from the evaporator (freezer) to ensure the best heat transfer between air & refrigerant.



By Pass factor:

The amount of air That does not Contact the pipe

② الغرفة → T_{out}

$$BPF = \frac{T_{out} - T_{adB}}{T_{in} - T_{adB}}$$

من برا ① → T_{in}

$\simeq 0.2$

$CCF = 1 - BPF \simeq 0.8$

- 0.8 means that 80% of air contacts the pipe and so better Cooling effect

Defrosting Methods

1. Manual frost removal
   - Using a wire brush or edged tool
   - Slow & inefficient

2. Manual shut down defrost:
Equipement is turned off at the end of Business day
- Can cause products failure

3. Off cycle defrosting
- Done by controlling the compressor power
  - Pressure operated controller (ON/OFF)
  - Temperature operated controller (ON/OFF)

4. Time shut down defrosting
- Time clock (timer) → actuates a switch to control the process (at selected times)

5. Supplementary Heat defrosting
- By: water
  brine (water solute)
  Electrical Resistance (Heater)
  High Side vapor from compressor discharge

6. Cycle Reversing (4-way valve)

Cycle Controls & accessories

1) Expansion device

- Reduces pressure from High pressure coming from the condenser to the low pressure evaporator
- Regulates the refrigerant flow to the evaporator

2) Hand valves

For maintenance and items replacement

3) Filter drier

- Dries moisture before entering the compressor
- It is placed in the suction line
- Protects from systems moisture, acids & solid particles

4) Liquid reciever tank

a) Pump down the liquid refrigerant for the Evap & Expansion
b) Controls flow rate of liquid refrigerant
c) Complete drain for condenser

5) Sight Glass

Liquid indicator / Controls phase of Refrigerant

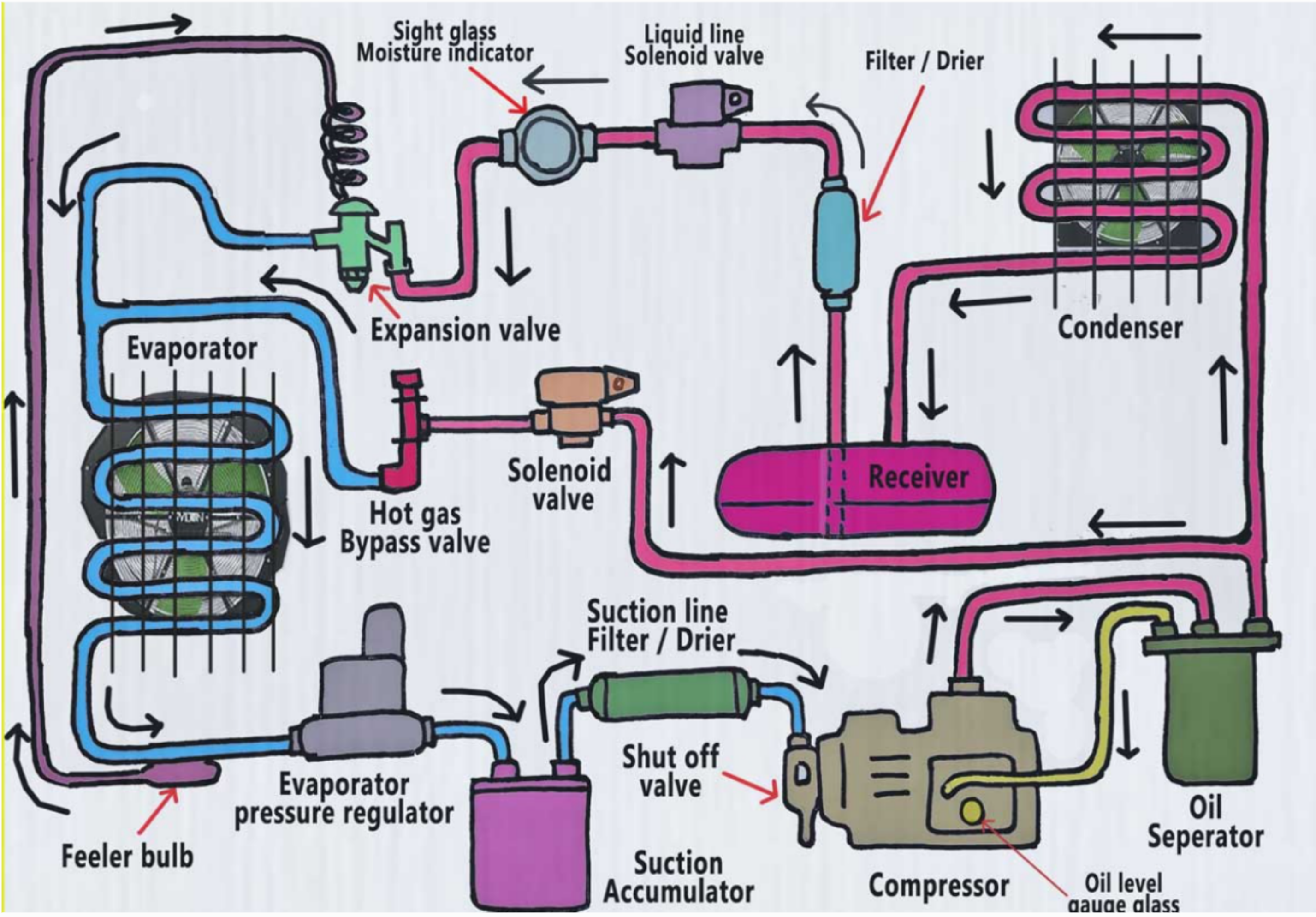
6) Flexible connection

7) Defrost system (For freezers only)

8) Oil separator

Separates oil from refrigerant

9) Thermostat- humidity



Refrigerated warehouse load calculations

1) Transmission load

$q = UA\Delta T$ $\qquad U = \frac{1}{\Sigma R}$ $\qquad R = L/K$

To add the solar load → $\Delta T + (3\text{–}5°C)$

2) Infiltration load → Table 7

$$q_{inf} = \frac{q_{removal} \times volume \times ACP(24H)}{18 \times 3600}$$

3) Product load

a) Sensible

$$Q_s = m C_{Pa}(T_1 - T_{freeze}) + m h_f + m C_{Pb}(T_{freeze} + T_{final})$$

b) Latent (Respiration load)

4) Heat given by people

5) Heat given by lights & Equipement

$$q_{lamp} = Wattage(lamp\ rating) \times F_u \times F_b \times CLF$$

F_b → 0.9