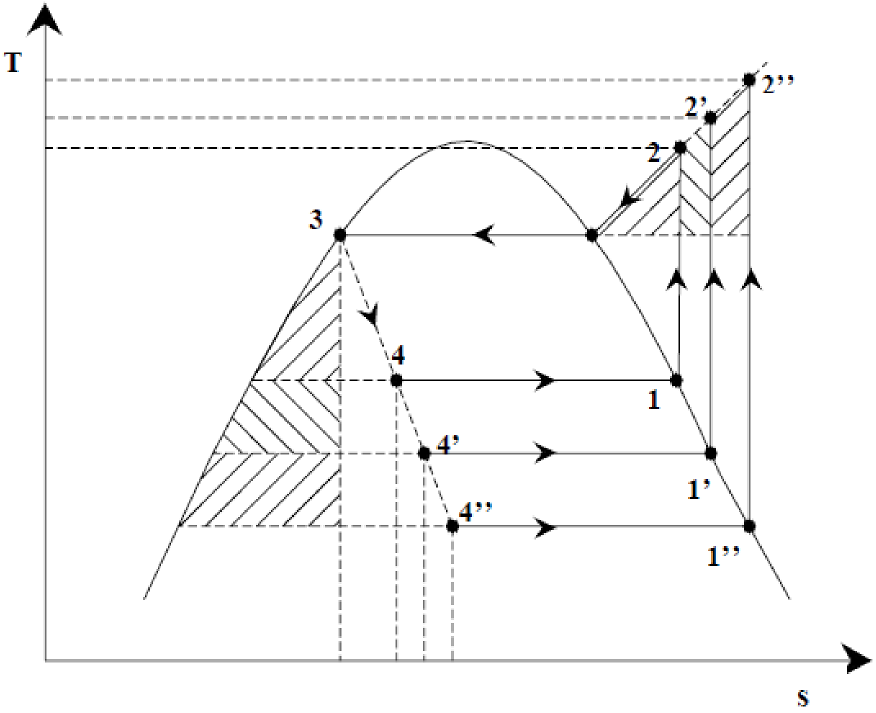
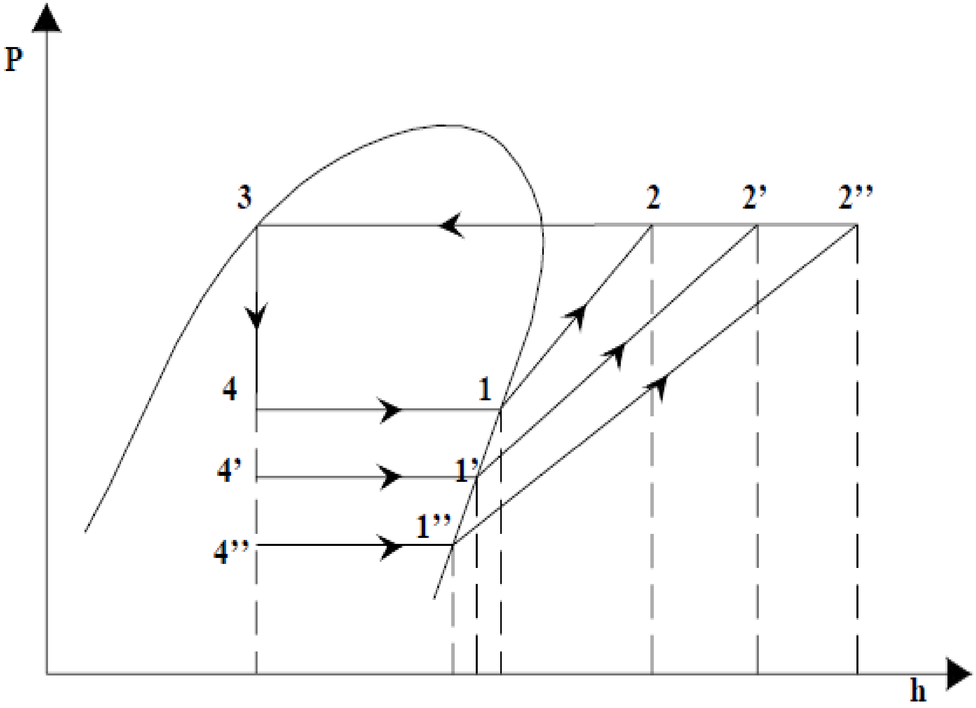
MULTI-STAGE VAPOUR COMPRESSION REFRIGERATION SYSTEMS(VCR)

WHY MULTI-STAGE ???

- The performance of single stage systems shows that these are adequate as long as the temperature difference between evaporator and condenser (**temperature lift**) is small.
- The temperature lift can become large either due to the requirement of **very low evaporator temperatures** and/or due to the requirement of **very high condensing temperatures.**
- For example, in **frozen food industries** the required evaporator can be as low as –40^{o}C, while in **chemical industries** temperatures as low as –150^{o}C may be required for liquefaction of gases.
- On the condenser side, Refrigeration system is used as a heat pump for heating applications such as process heating, drying etc.

As the temperature lift increases the single stage systems become inefficient and impractical.





- **As evaporator temperature decreases:**

1. Throttling losses increase
2. Superheat losses increase
3. Compressor discharge temperature increases
4. Quality of the vapour at the inlet to the evaporator increases
5. Specific volume at the inlet to the compressor increases

- ➢For fluorocarbon and ammonia based refrigeration systems:
- Single stage system is used up to an evaporator temperature of –30°C.
- A two-stage system is used up to –60°C and
- A three-stage system is used for temperatures below –60°C.

- Multi-stage systems are also used in applications requiring **refrigeration at different temperatures.**
- For example, in a dairy plant refrigeration may be required at -30^{o}C for making ice cream and at 2^{o}C for chilling milk.
- In such cases it may be advantageous to use a multi-evaporator system

- A multi-stage system is a refrigeration system with two or more low-side pressures.
- Multi-stage systems can be classified into:

a) Multi-compression systems

b) Multi-evaporator systems

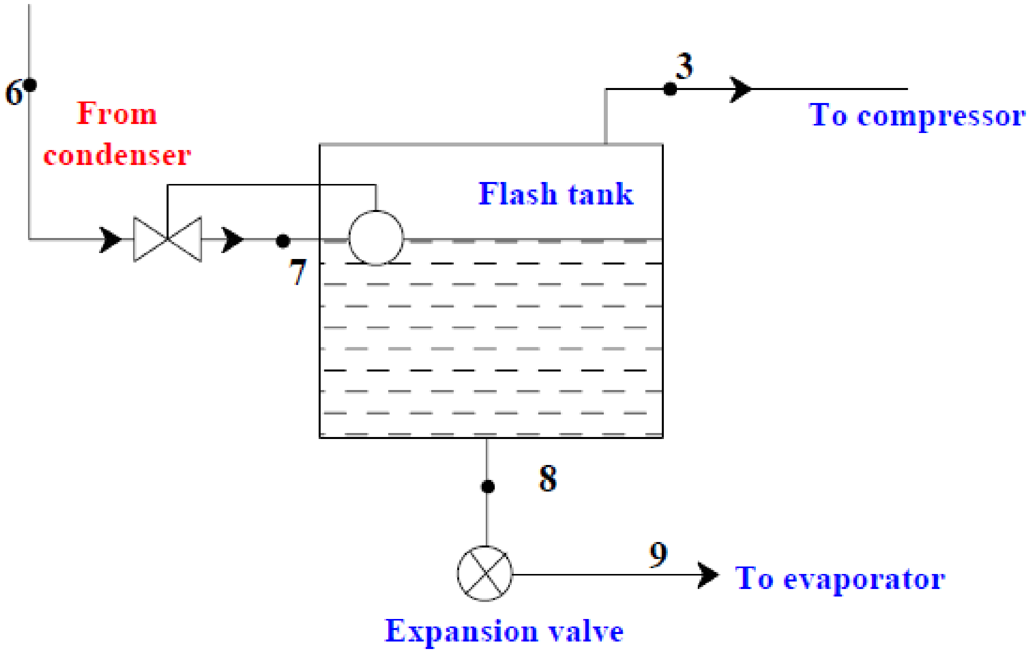
c) Cascade systems, etc.

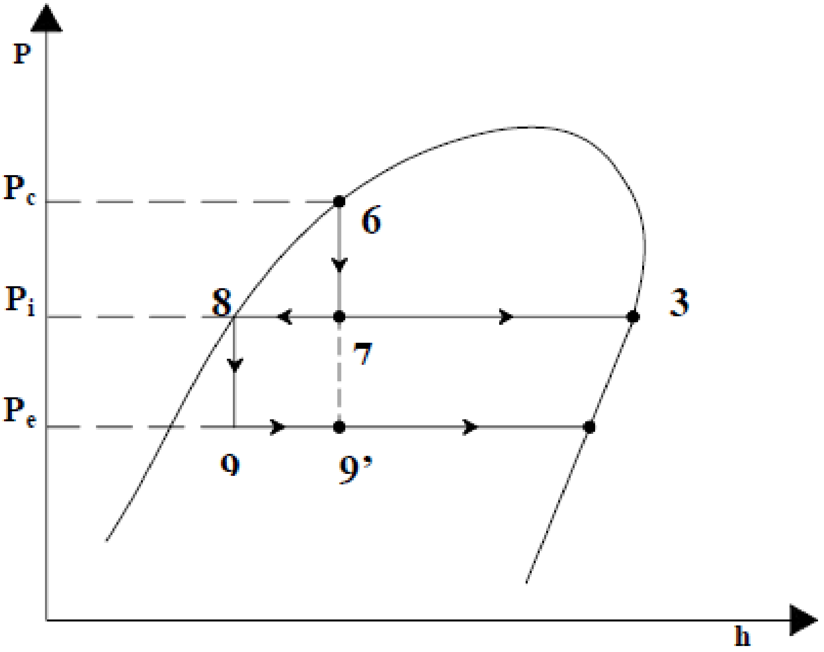
- Two concepts which are normally integral to multi-pressure systems are, i) **flash gas removal**, and ii) **intercooling**.

Flash gas removal using flash tank

- Flash gas does not contribute to the refrigeration effect as it is already in the form of vapour, and it increases the pressure drop in the evaporator.
- It is possible to improve the COP of the system if the flash gas is removed as soon as it is formed and recompressed to condenser pressure but it is not practical.
- To improve the COP of the system, **remove the flash gas** at an intermediate pressure using a **flash tank**.

- A flash tank is a pressure vessel, wherein the refrigerant liquid and vapour are separated at an intermediate pressure. The refrigerant from condenser is first expanded to an intermediate pressure corresponding to the pressure of flash tank, P_i using a low side float valve (process 6-7).



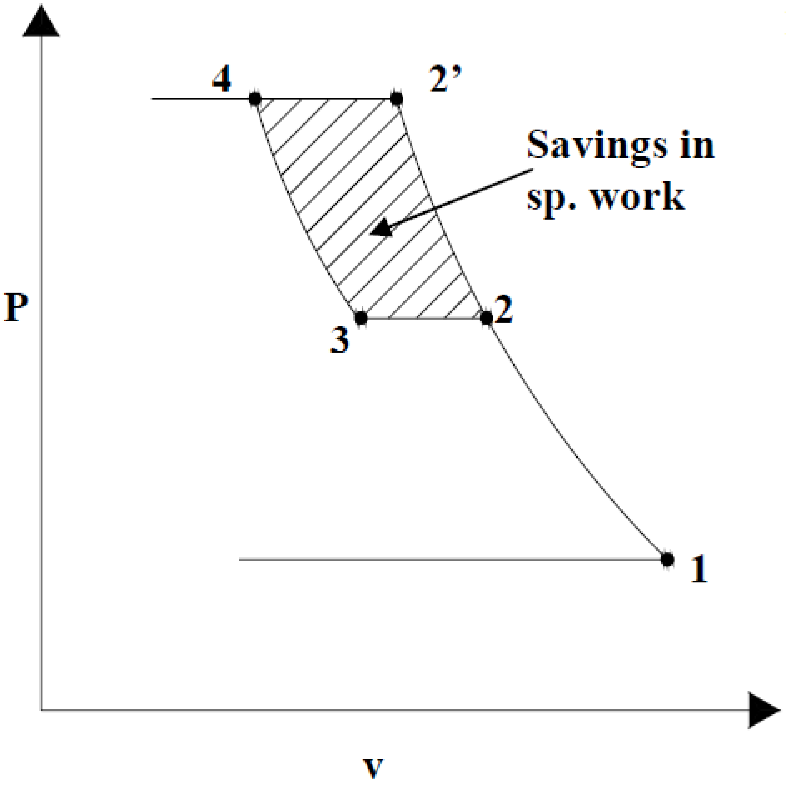


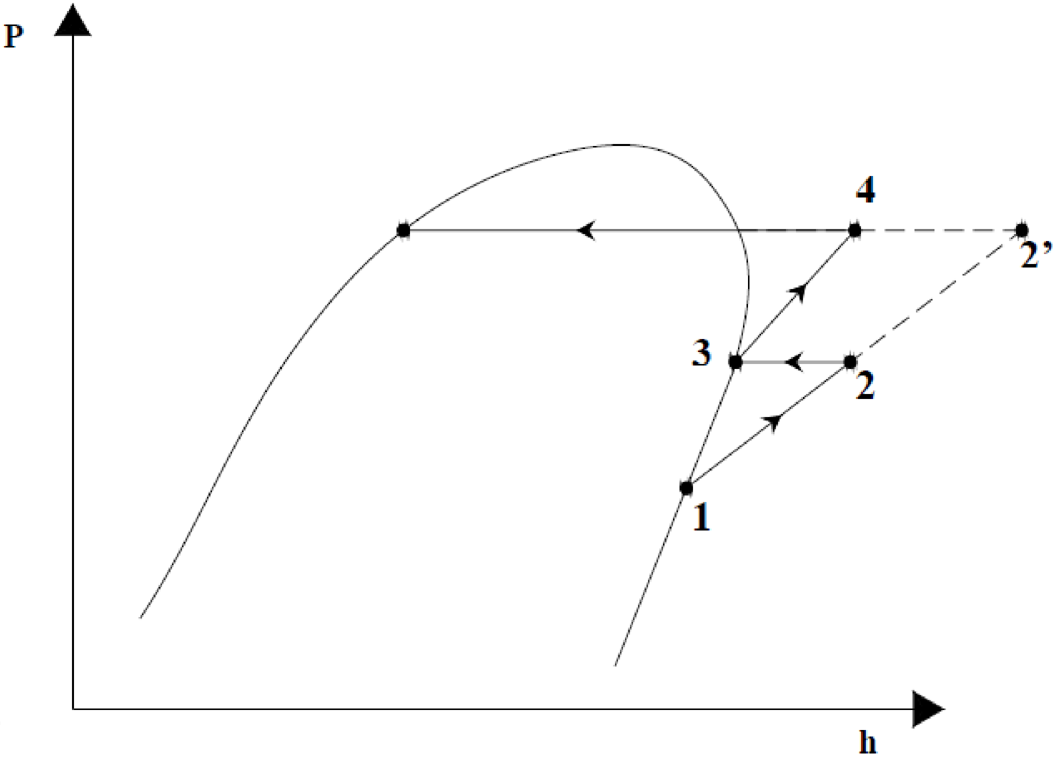
- The float valve also maintains a constant liquid level in the flash tank.
- In the flash tank, the refrigerant liquid and vapour are separated.
- The saturated liquid at point 8 is fed to the evaporator after throttling it to the required evaporator pressure, P_e (point 9) using an expansion valve.
- Depending upon the type of the system, the saturated vapour in the flash tank (point 3) is either compressed to the condenser pressure or throttled to the evaporator pressure

Intercooling in multi-stage compression

$$w = -\int_1^2 v.dP = \left(\frac{n}{n-1}\right) P_1 v_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{(n-1)/n}\right]$$

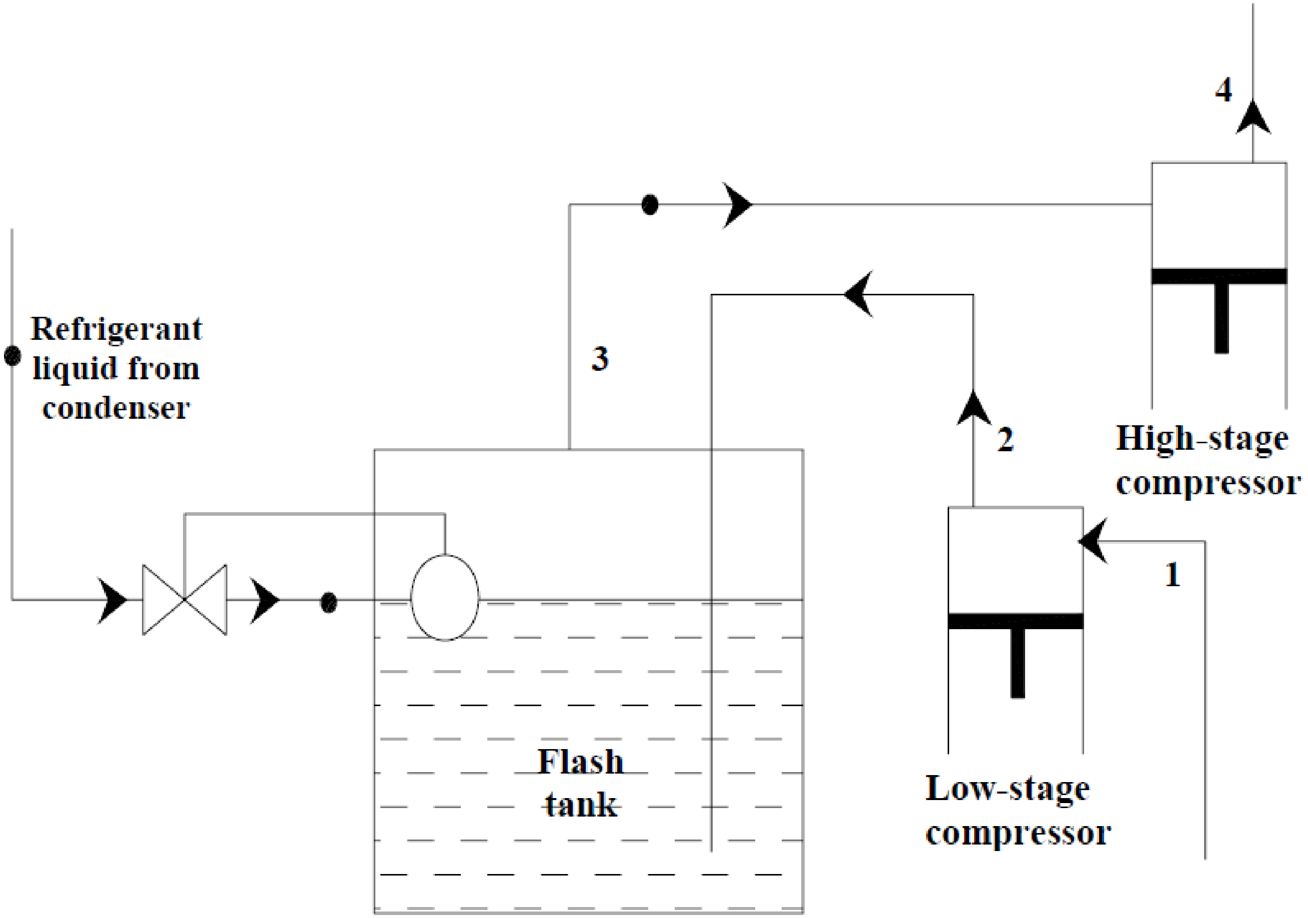
- Specific work input reduces as specific volume, v_1 is reduced.
- At a given pressure, the specific volume can be reduced by reducing the temperature.
- This is the principle behind intercooling in multi-stage compression.

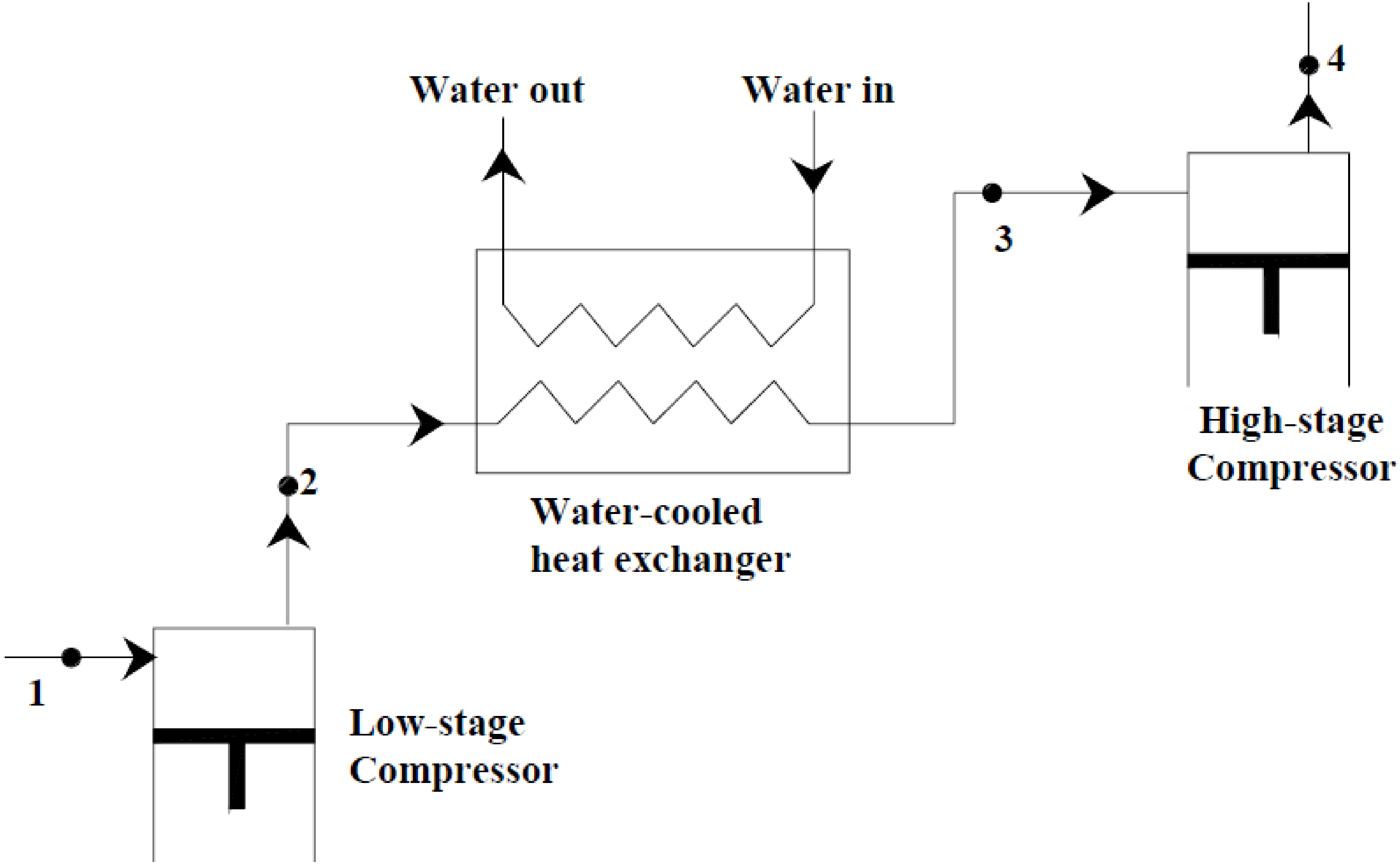




$$(h_4-h_3) < (h_{2'}-h_2) \Rightarrow (h_2-h_1)+(h_4-h_3) < (h_{2'}-h_1)$$

- Intercooling of the vapour may be achieved by using either a **water-cooled heat exchanger** or by **the refrigerant in the flash tank.**




Water out
Water in
4
3
2
1
Water-cooled heat exchanger
High-stage Compressor
Low-stage Compressor

- With water cooling the refrigerant at the inlet to the high stage compressor may not be saturated.
- Intercooling not only reduces the work input but also reduces the compressor discharge temperature leading to better lubrication and longer compressor life.

- Intercooling using liquid refrigerant from condenser in the flash tank may or may not reduce the power input to the system, as it depends upon the nature of the refrigerant.
- The heat rejected by the refrigerant during intercooling generates additional vapour in the flash tank, which has to be compressed by the high stage compressor.
- Thus the mass flow rate of refrigerant through the high stage compressor will be more than that of the low stage compressor.

- For ammonia, the power input usually decreases with intercooling by liquid refrigerant.
- For refrigerants such as R12, R22, the power input marginally increases.
- Thus intercooling using liquid refrigerant is not effective for R12 and R22.

- **Using both water-cooling and flash-tank**, the amount of refrigerant vapour handled by the high-stage compressor reduces leading to lower power consumption.

Selection of suitable intermediate pressure

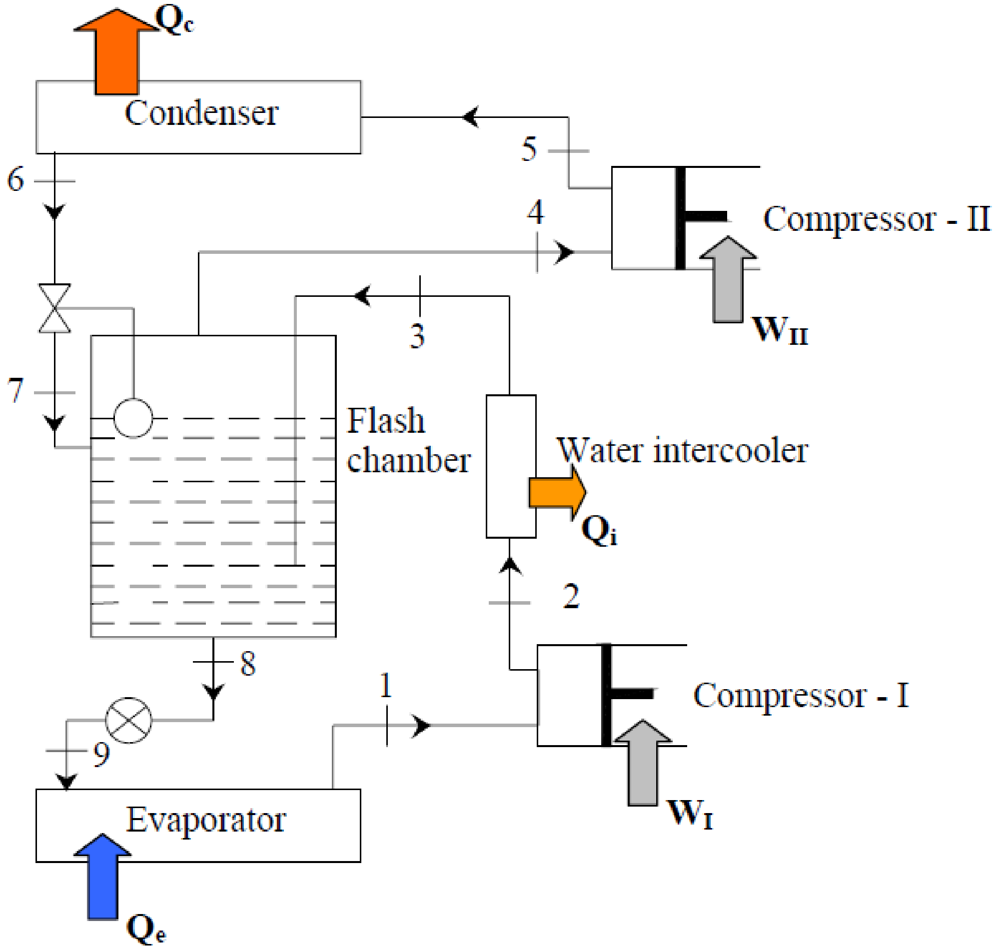
- For air compressors with **intercooling to the initial temperature**, the theoretical work input to the system will be minimum when the pressure ratios are equal for all stages.

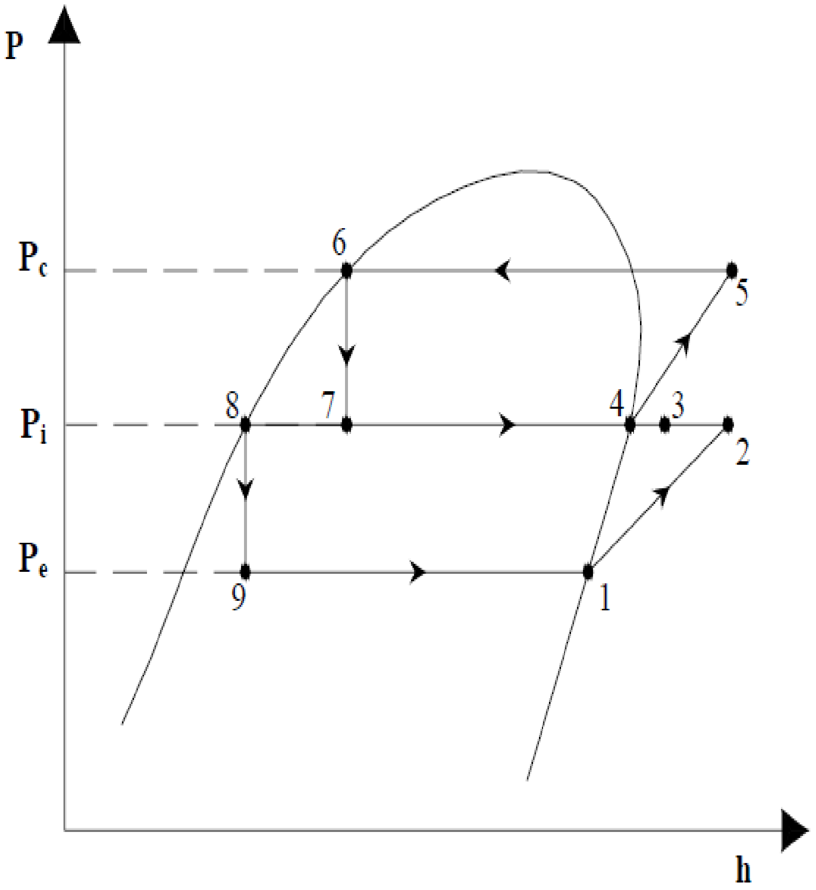
$$P_{i,opt} = \sqrt{P_{low} . P_{high}}$$

- For refrigerants, correction factors to the above equation are suggested.

$$P_{i,opt} = \sqrt{P_e . P_c \frac{T_c}{T_e}}$$

Multi-stage system with flash gas removal and intercooling





- The above system offers several advantages,

a) **Quality of refrigerant entering the evaporator reduces** thus giving rise to higher refrigerating effect, lower pressure drop and better heat transfer in the evaporator

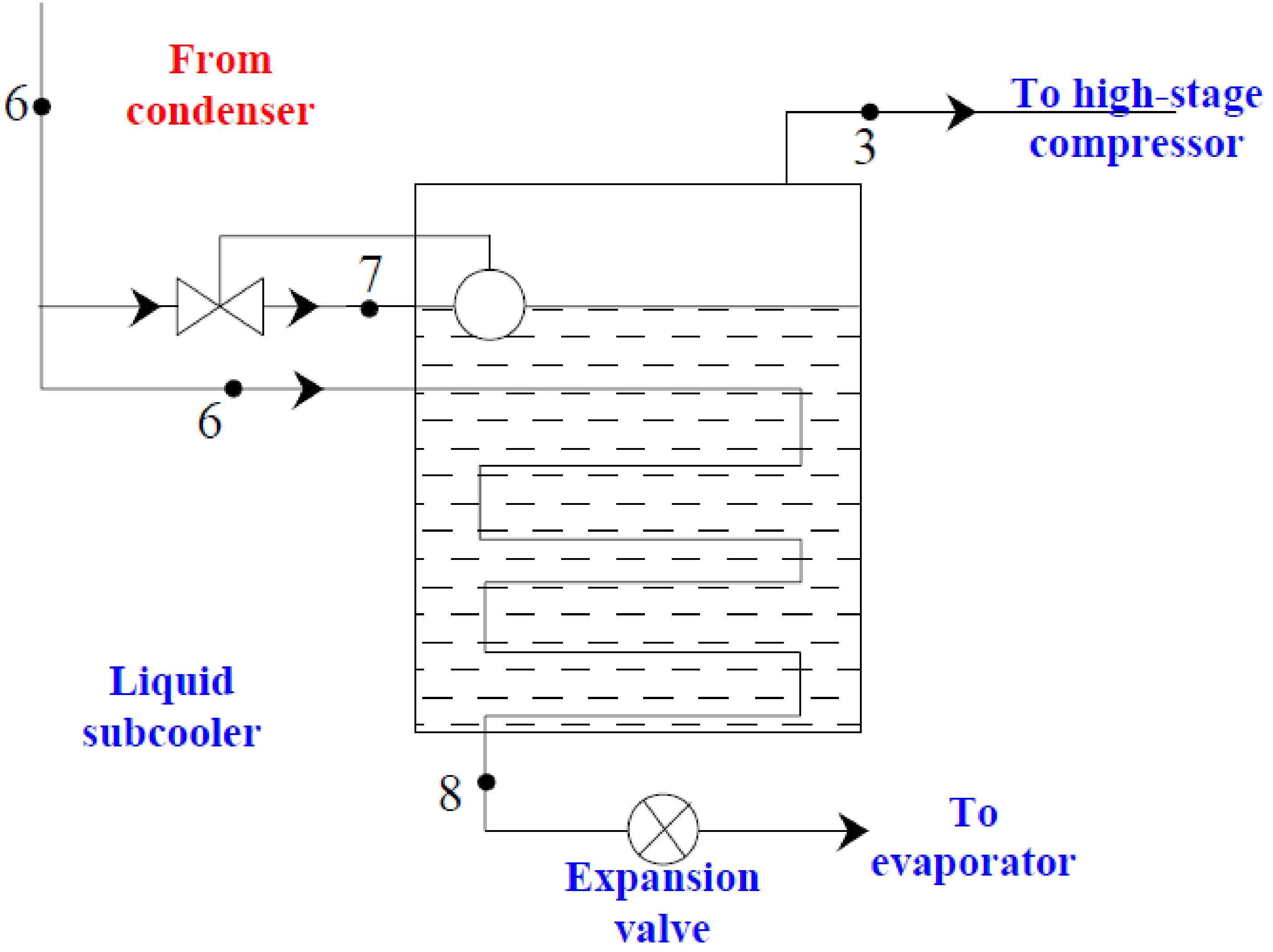
b) **Throttling losses are reduced** as vapour generated during throttling from P^c to P^i is separated in the flash tank and recompressed by Compressor-II.

c) **Volumetric efficiency of compressors will be high due to reduced pressure ratios**

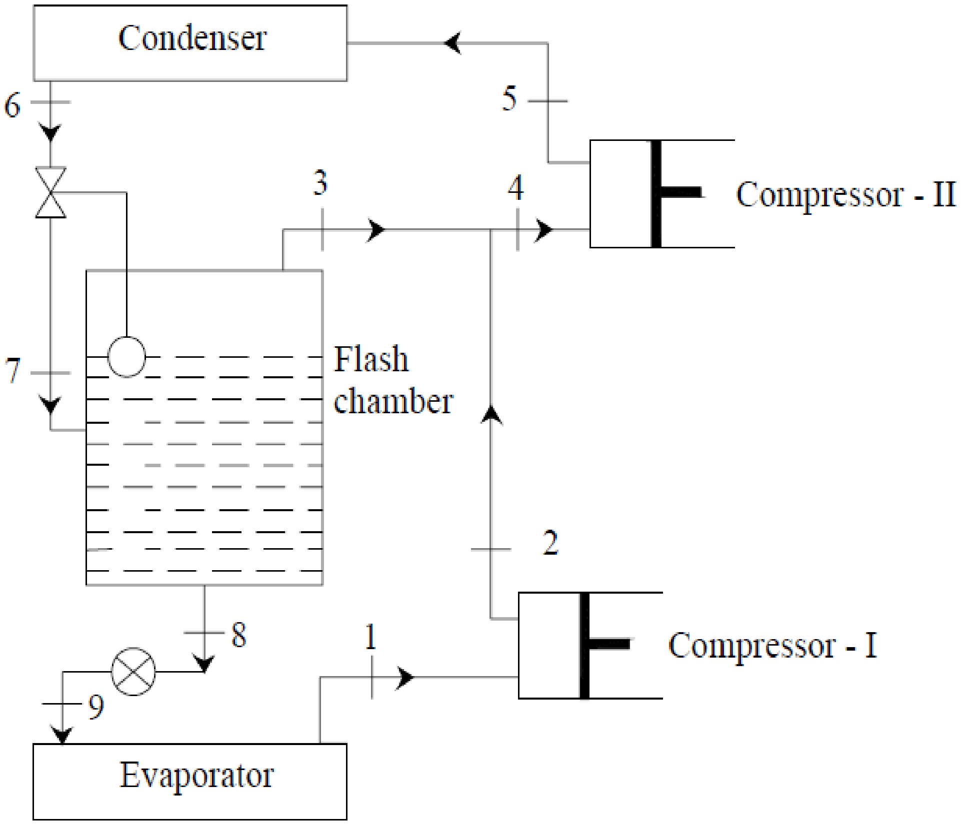
d) **Compressor discharge temperature is reduced** considerably.

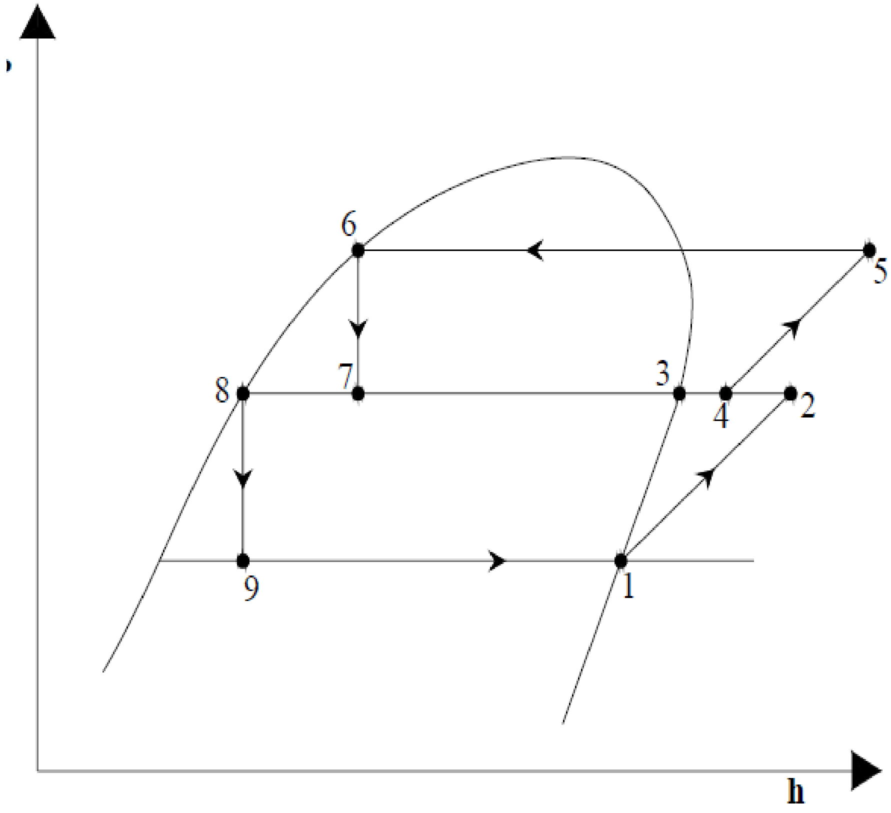
- One disadvantage of the above system is that **since refrigerant liquid in the flash tank is saturated, there is a possibility of liquid flashing ahead of the expansion valve** due to pressure drop or heat transfer in the pipelines connecting the flash tank to the expansion device.

Refrigeration system with liquid sub cooler

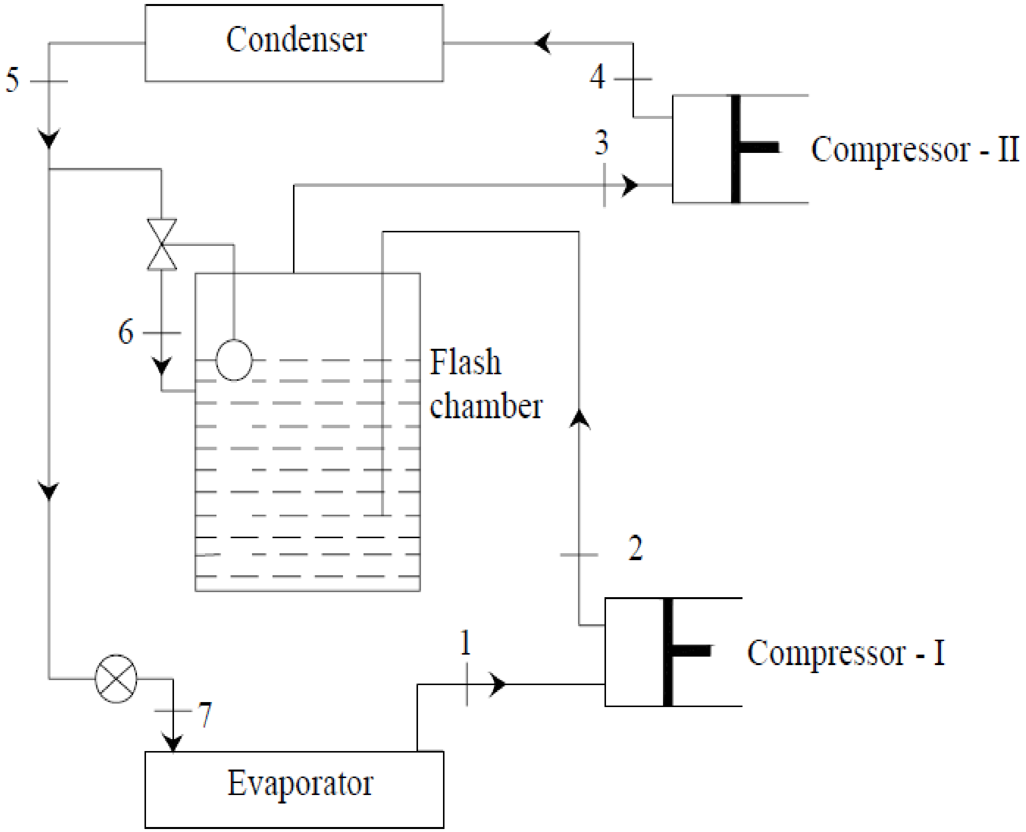


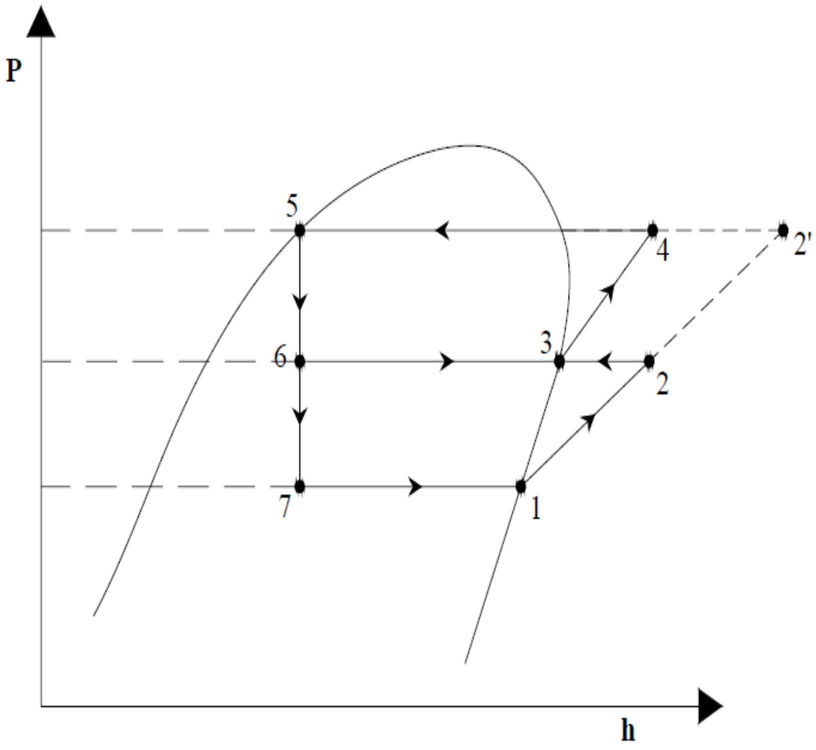
Use of flash tank for flash gas removal





Use of flash tank for intercooling only





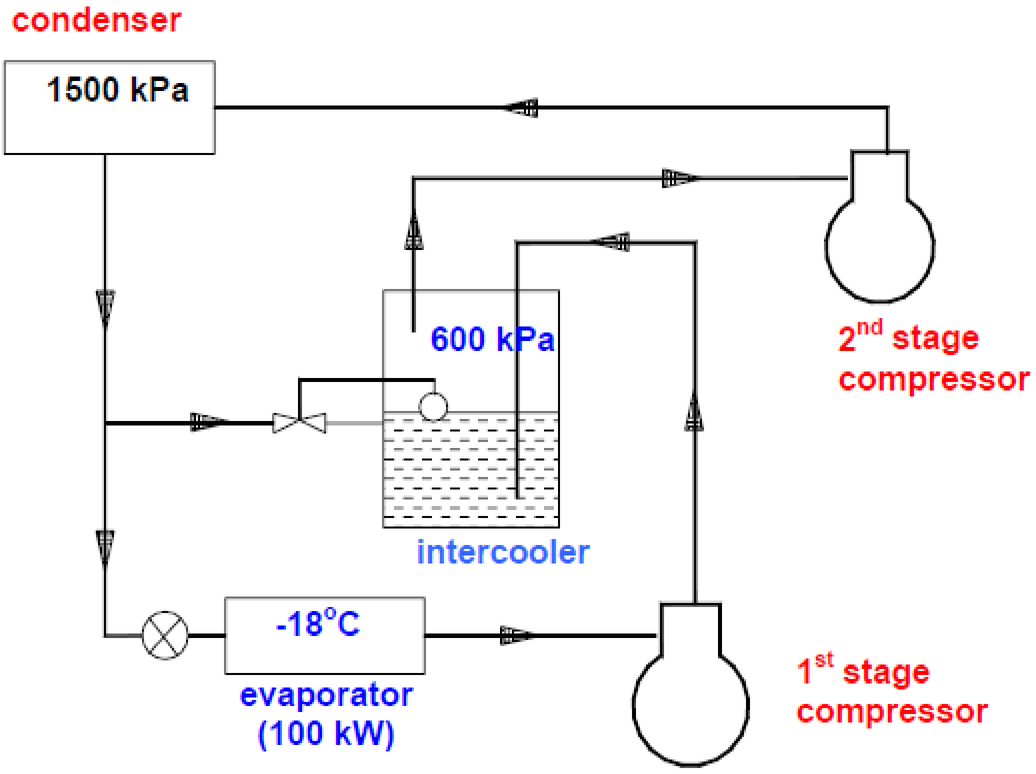
Problem 2

The required refrigeration capacity of a vapour compression refrigeration system (with R-22 as refrigerant) is 100 kW at –30°C evaporator temperature. Initially the system was single-stage with a single compressor compressing the refrigerant vapour from evaporator to a condenser operating at 1500 kPa pressure.

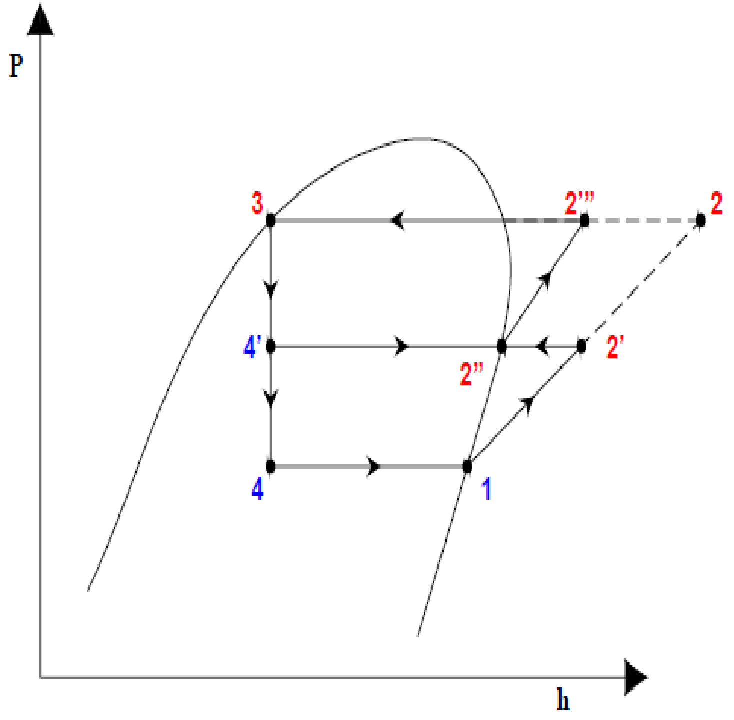
Later the system was modified to a two-stage system operating on the cycle shown below. At the intermediate pressure of 600 kPa there is intercooling but no removal of flash gas. Find

a) Power requirement of the original single-stage system;

b) Total power requirement of the two compressors in the revised two-stage system. Assume that the state of refrigerant at the exit of evaporator, condenser and intercooler is saturated, and the compression processes are isentropic.



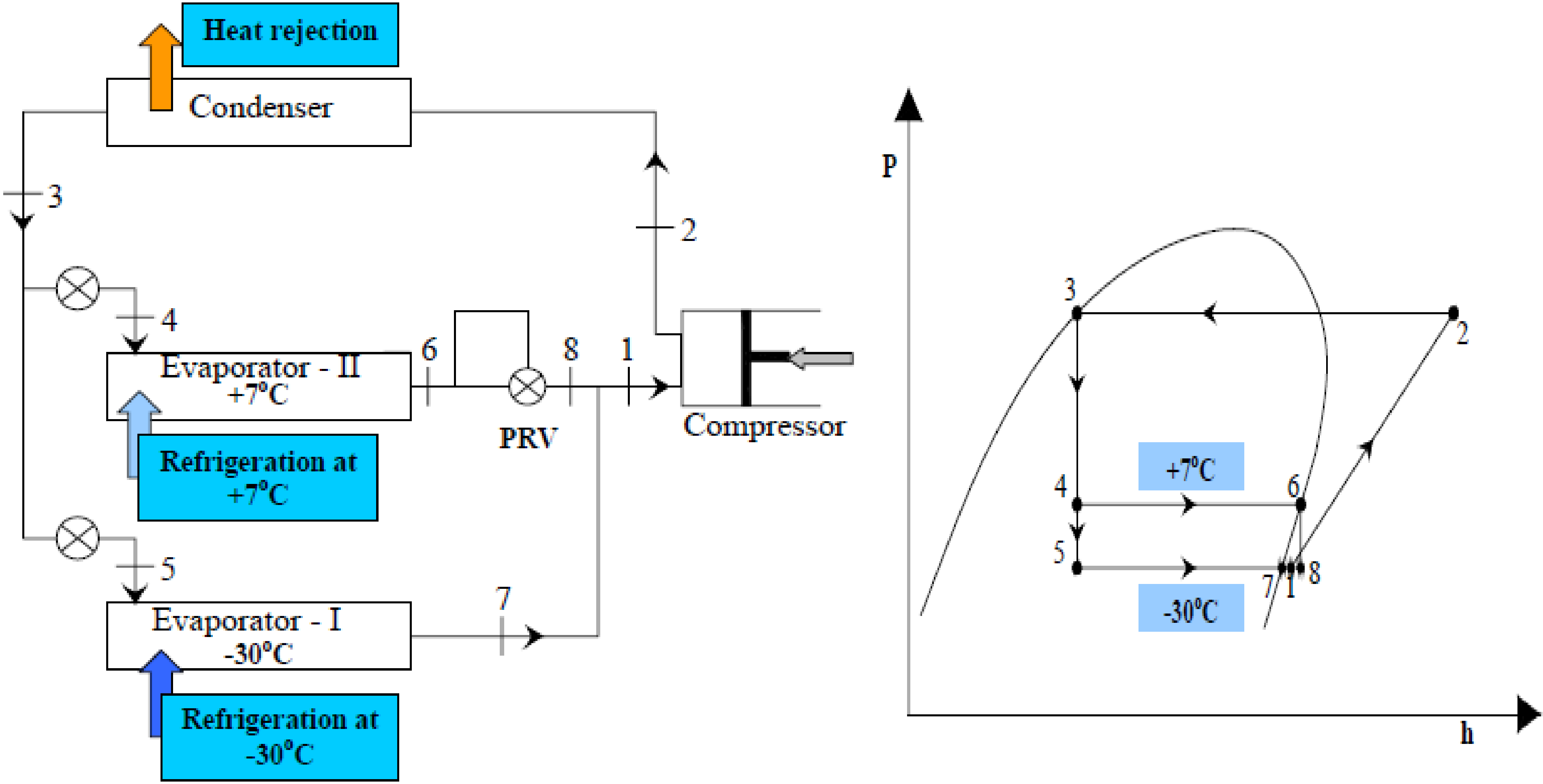
Two-stage system with flash tank for intercooling only:



Multi-Evaporator Systems

Individual evaporators and a single compressor with a pressure-reducing valve

1. <u>Individual expansion valves</u>



Problem 3:

The high temperature evaporator (Refrigeration capacity 5 TR) of a multi-evaporator VCR system, working with ammonia, is operating at –6°C and the low temperature evaporator (Refrigeration capacity 10 TR) is operating at –34°C. The condenser pressure is 10.99 bar. The system using individual expansion valves for each evaporator. Assuming saturated conditions at the exit of evaporators and condenser and isentropic compression:

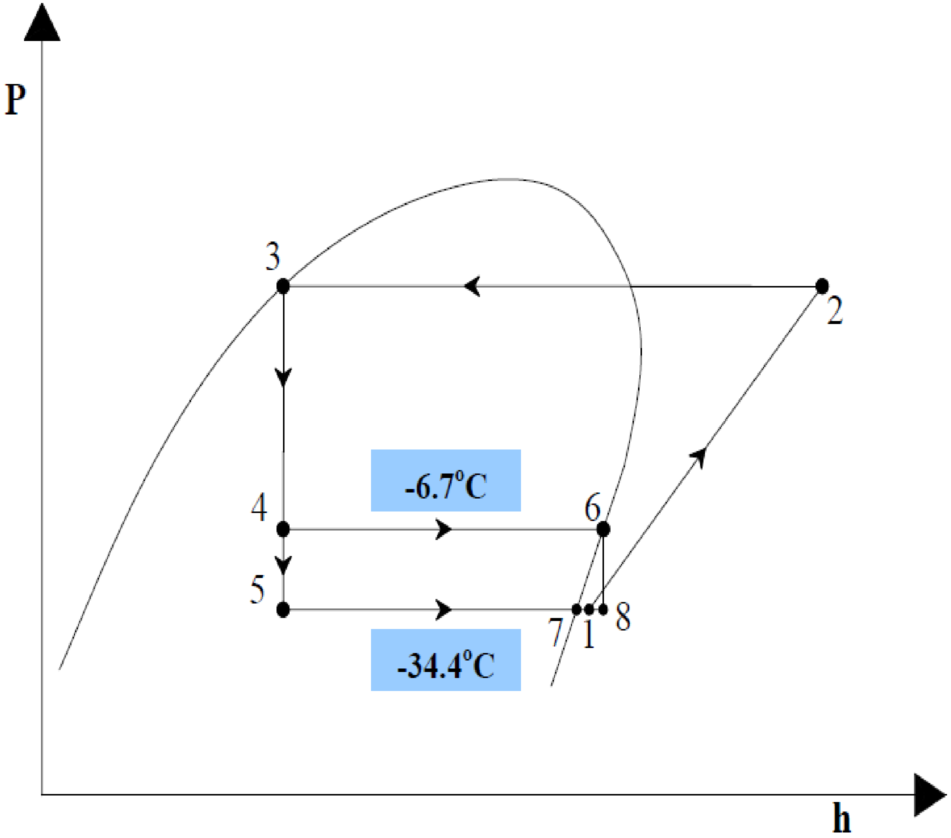
a) Find the required power input and COP if a single compressor is used.

b) If individual compressors are used for both stage find the power input and COP.

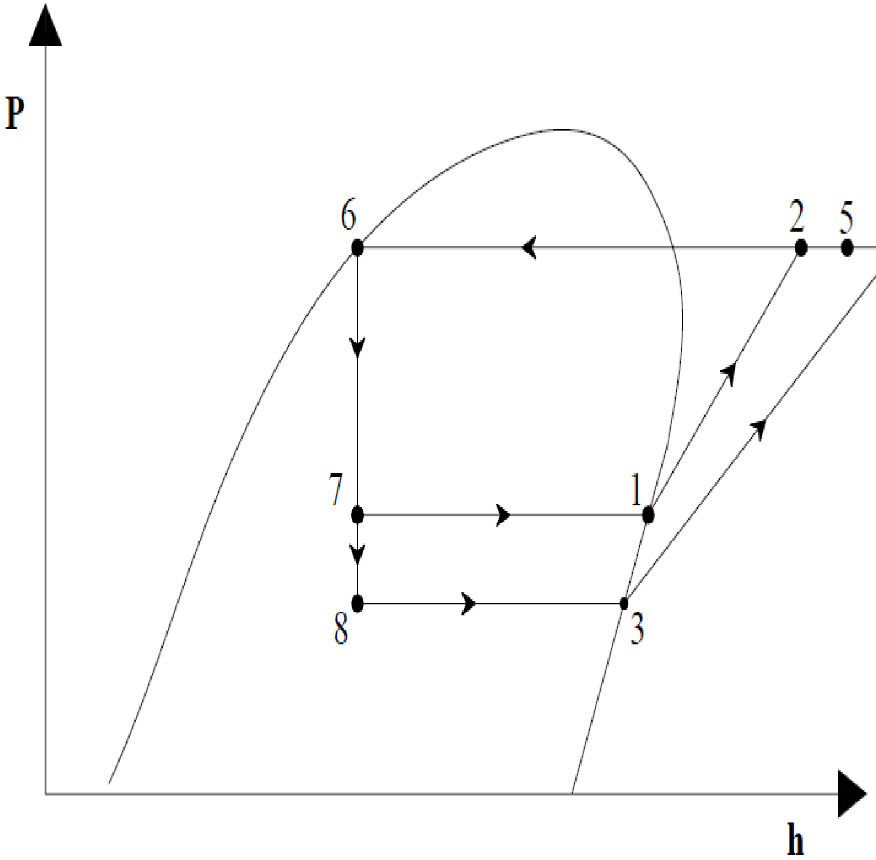
c) Compare both cases.

SOLUTION

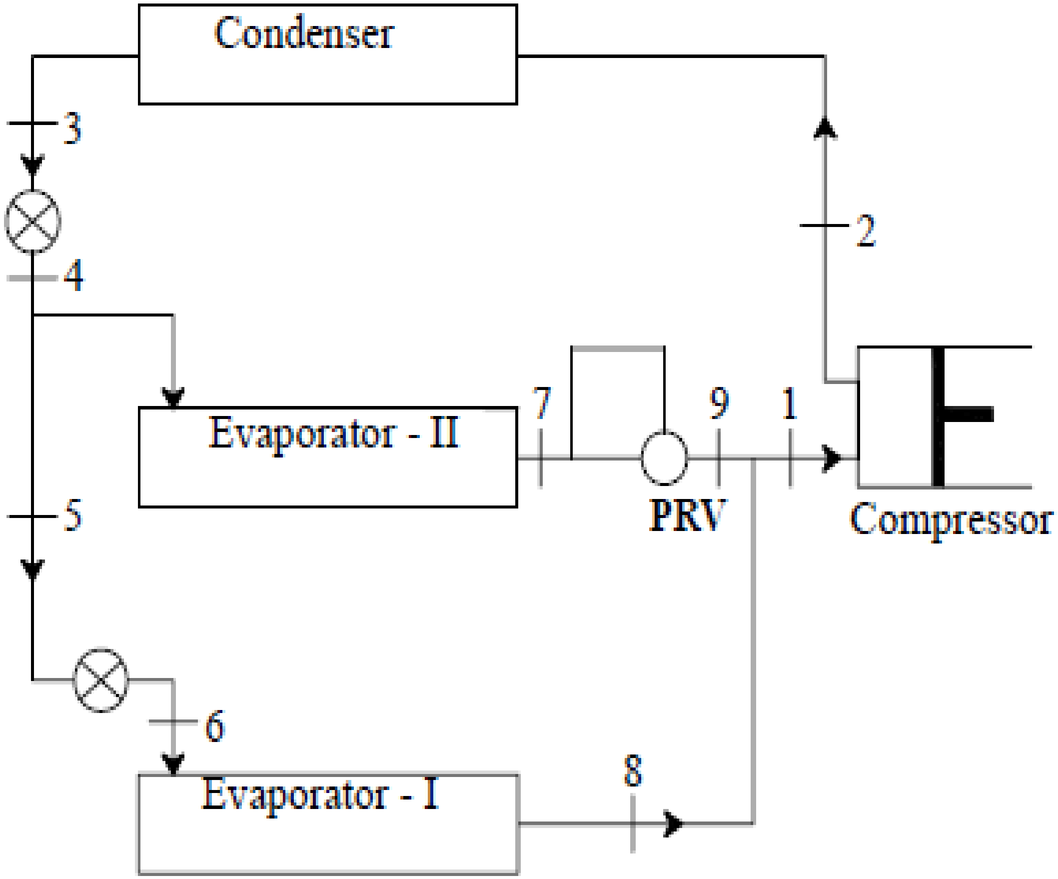
Single Compressor

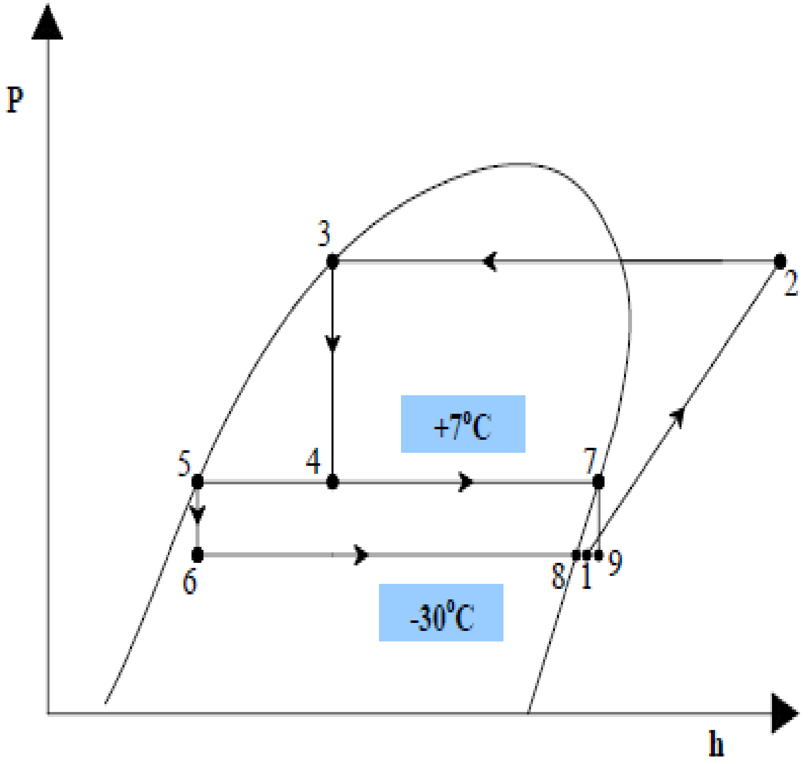


Individual Compressors

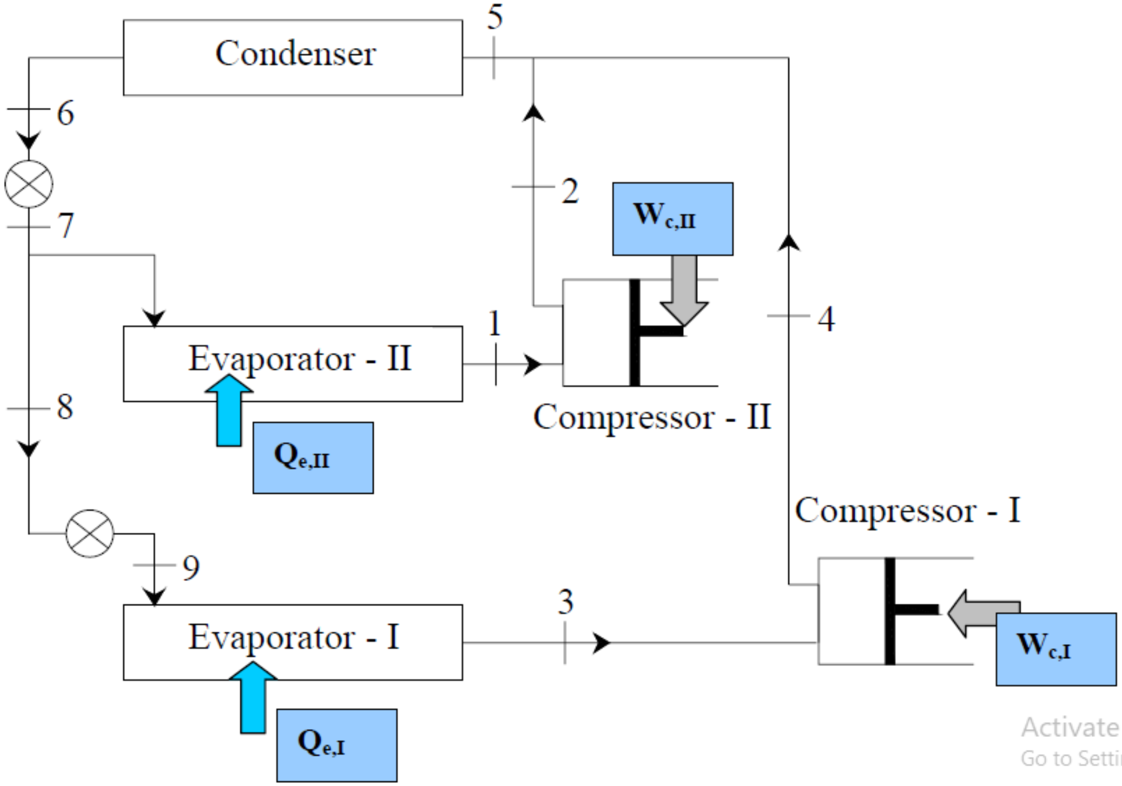


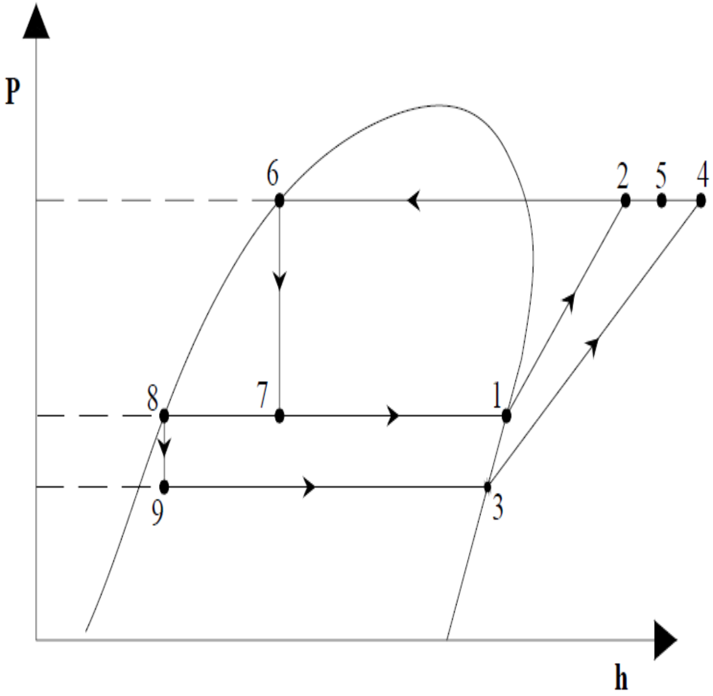
2. **Multiple expansion valves**



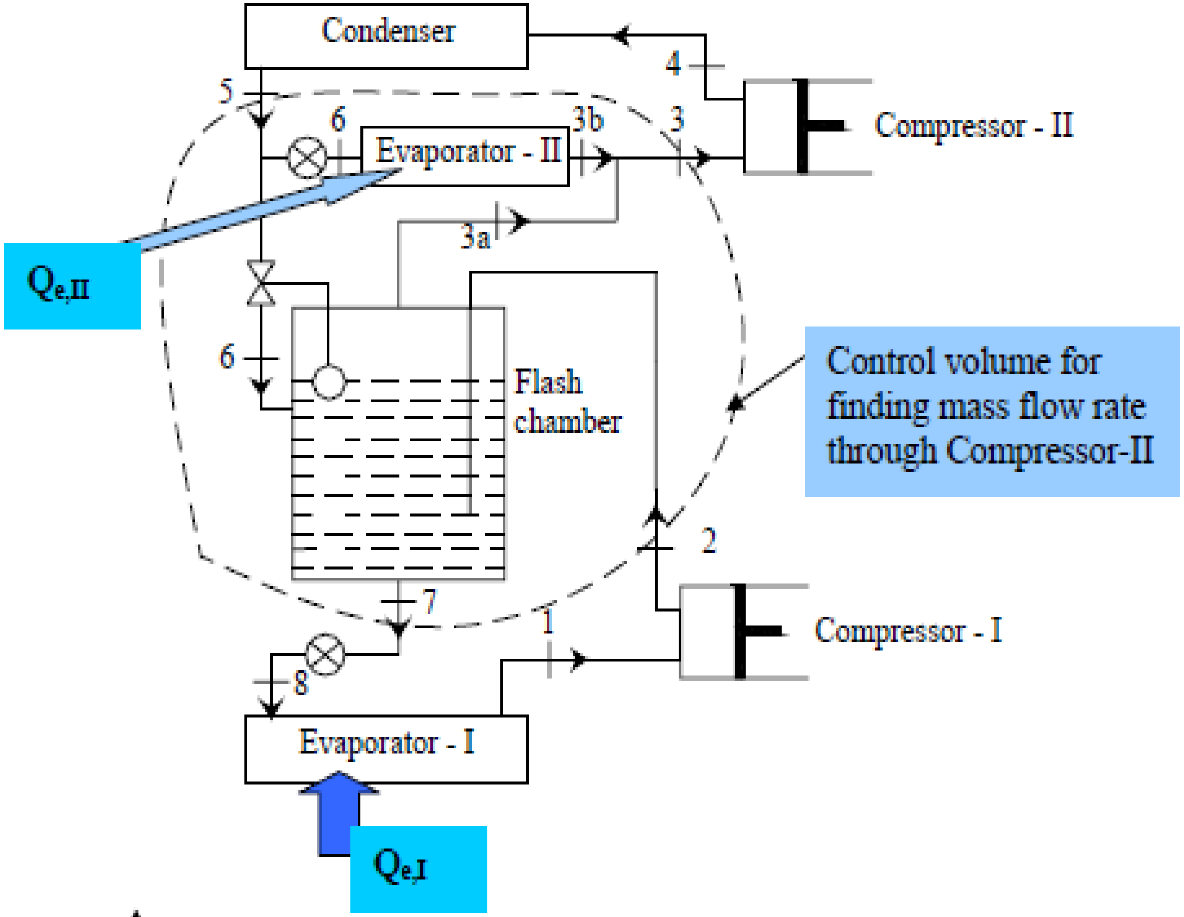


Multi-evaporator system with individual compressors and multiple expansion valves

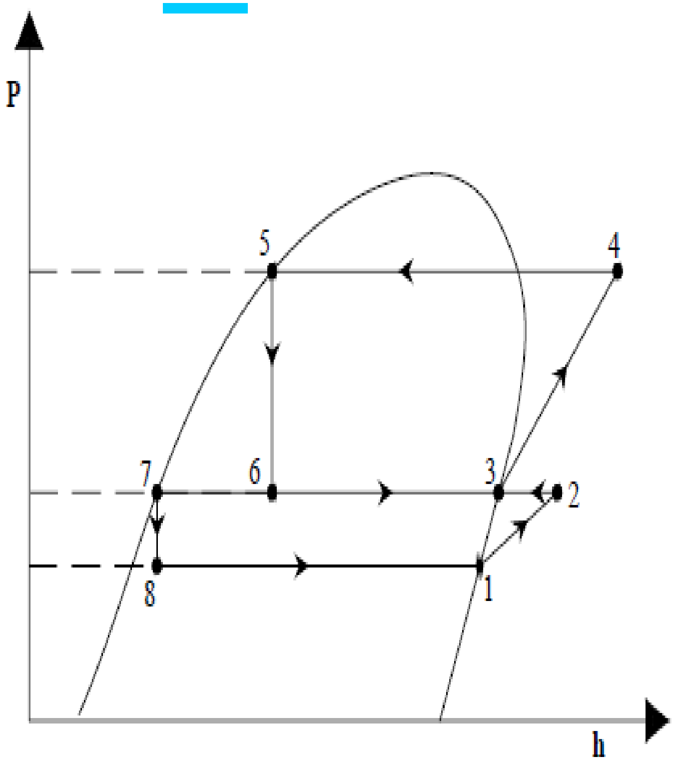




Multi-evaporator system with multi-compression, intercooling and flash gas removal



Control volume for finding mass flow rate through Compressor-II



- The mass flow rate of refrigerant through the high-stage compressor which can be obtained by taking a control volume which includes the flash tank and high temperature evaporator (as shown by dashed line in the schematic) and applying mass and energy balance:

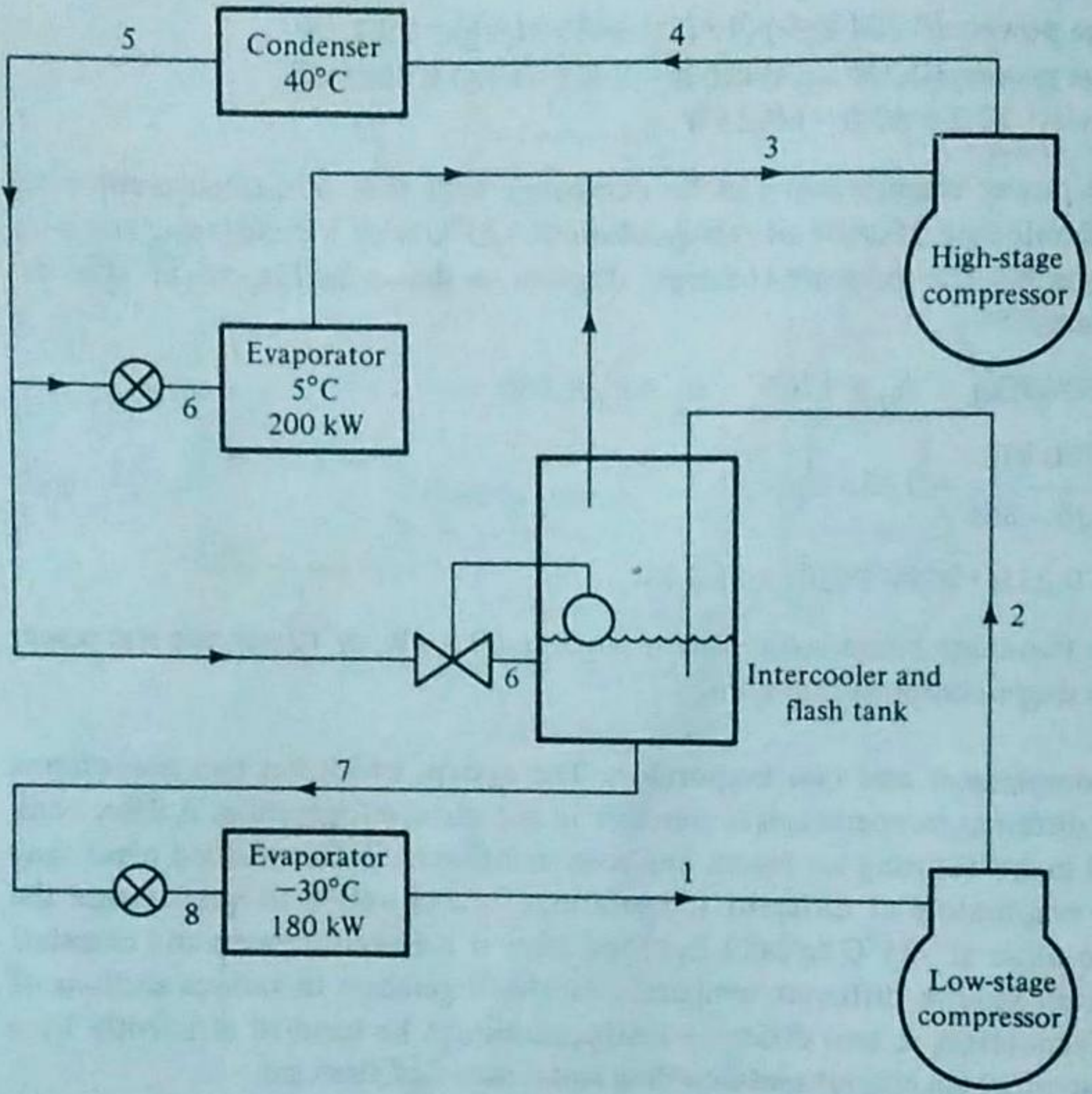
$$m_5 + m_2 = m_7 + m_3;\ m_5 = m_3\ \&$$

$$m_2 = m_7 = m_I$$

$$\dot{m}_5 h_5 + \dot{m}_2 h_2 + Q_{e,II} = m_7 h_7 + m_3 h_3$$

Problem 4

In an ammonia system one evaporator is to provide 180 kW of refrigeration at -30^0C and another evaporator is to provide 200 kW at 5^0C. The system uses two stage compression with intercooling and flash gas removal as shown below. The condensing temperature is 40^0C. Calculate the power requirement and COP of the system.

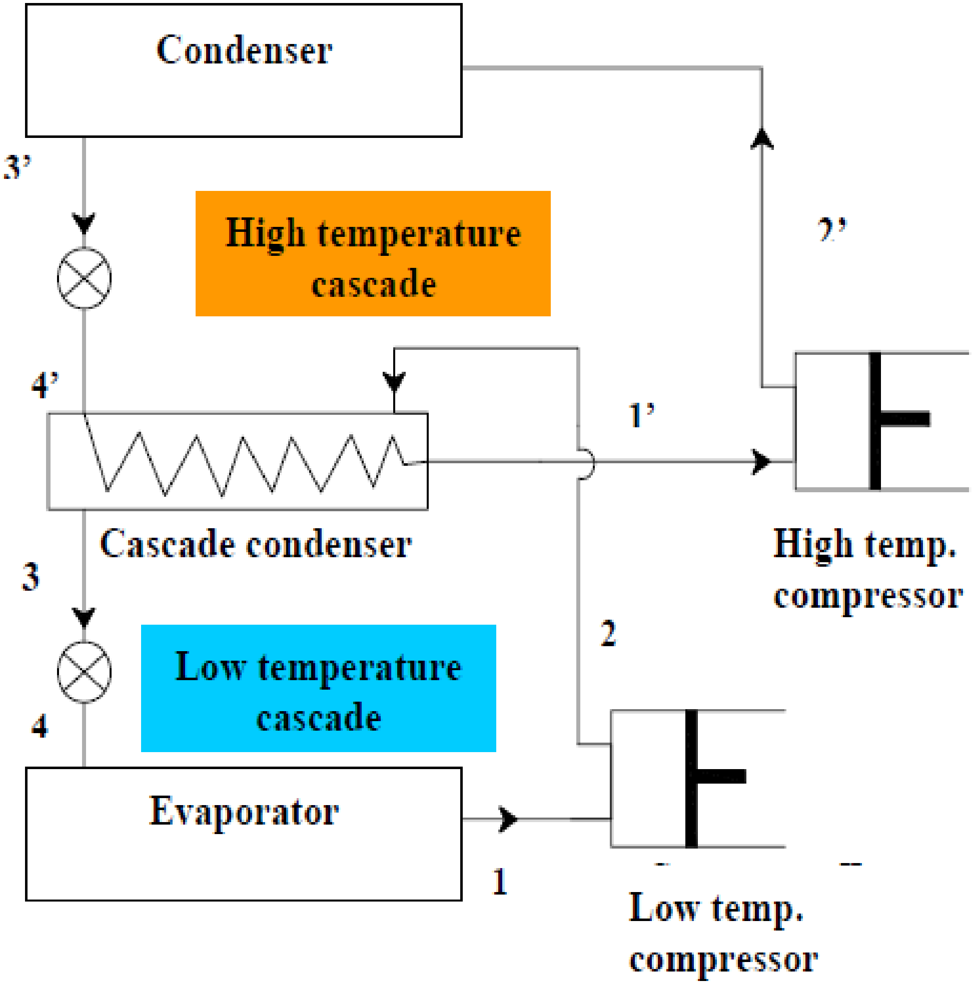

5
Condenser
40°C
4
3
High-stage
compressor
Evaporator
5°C
200 kW
6
2
6
Intercooler and
flash tank
7
Evaporator
−30°C
180 kW
8
1
Low-stage
compressor

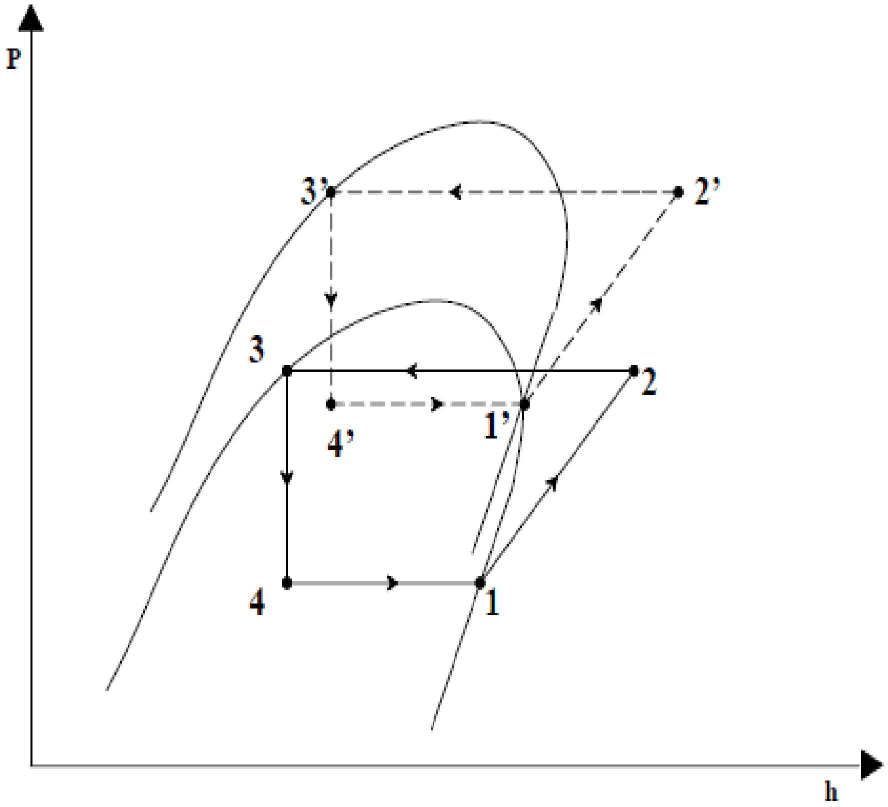
Limitations of multi-stage systems

- The refrigerant used should have high critical temperature and low freezing point.
- Generally only R12, R22 and NH_3 systems have been used in multi-stage systems as other conventional working fluids may operate in vacuum at very low evaporator temperatures- leads to leakages into the system.
- Possibility of migration of lubricating oil from one compressor to other leading to compressor break-down.

Cascade Systems

- In a cascade system a series of refrigerants with progressively lower boiling points are used in a series of single stage units.
- The condenser of lower stage system is coupled to the evaporator of the next higher stage system and so on.
- The component where heat of condensation of lower stage refrigerant is supplied for vaporization of next level refrigerant is called as **cascade condenser**.


Condenser
3'
High temperature cascade
2'
4'
1'
Cascade condenser
High temp. compressor
3
2
Low temperature cascade
4
Evaporator
1
Low temp. compressor


P
3'
2'
3
2
4'
1'
4
1
h

- Two different refrigerants operating in two individual cycles.
- They are thermally coupled in the cascade condenser.
- The refrigerants selected should have suitable pressure-temperature characteristics.
- It is possible to use more than two cascade stages, and it is also possible to combine multi-stage systems with cascade systems.

Applications of cascade systems

- Liquefaction of petroleum vapors
- Liquefaction of industrial gases
- Manufacturing of dry ice
- Deep freezing etc.

Advantages of cascade systems

- Since **each cascade uses a different refrigerant**, it is possible to select a refrigerant that is best suited for that particular temperature range. Very high or very low pressures can be avoided
- Migration of lubricating oil from one compressor to the other is prevented

Optimum cascade(coupling) temperature

$$T_{cc,opt} = \sqrt{T_e \cdot T_c}$$

Where T_e and T_c are the evaporator temperature of low temperature cascade and condenser temperature of high temperature cascade, respectively.

Problem 5

A cascade system is to be designed to attain a temp. of 213K in an environment of 313K. The refrigerant for the high temp. side is R-12 and that for low side is R-13. The condensing temp. of the low side is 5K above the evaporation temp. in the cascade. Compute using appropriate tables and charts

a) COP
b) Pressure ratios
c) Mass flow rates of each refrigerants
d) Volume flow rate per TR.

Problem 6

The refrigeration system using R-22 as refrigerant consists of 3 evaporators of capacities 30 TR, 20 TR and 10 TR with individual expansion valves and compressors. The temperature in the 3 evaporators is to be maintained at -10^{0}C, 5^{0}C and 10^{0}C respectively. The vapor leaving the evaporator is dry and saturated. The condenser temperature is 40^{0}C and the liquid refrigerant leaving the condenser is sub cooled to 30^{0}C. Assuming isentropic compression, find:

a) Mass of refrigerant flowing through each evaporator,
b) Power required to drive the system and
c) COP of the system.

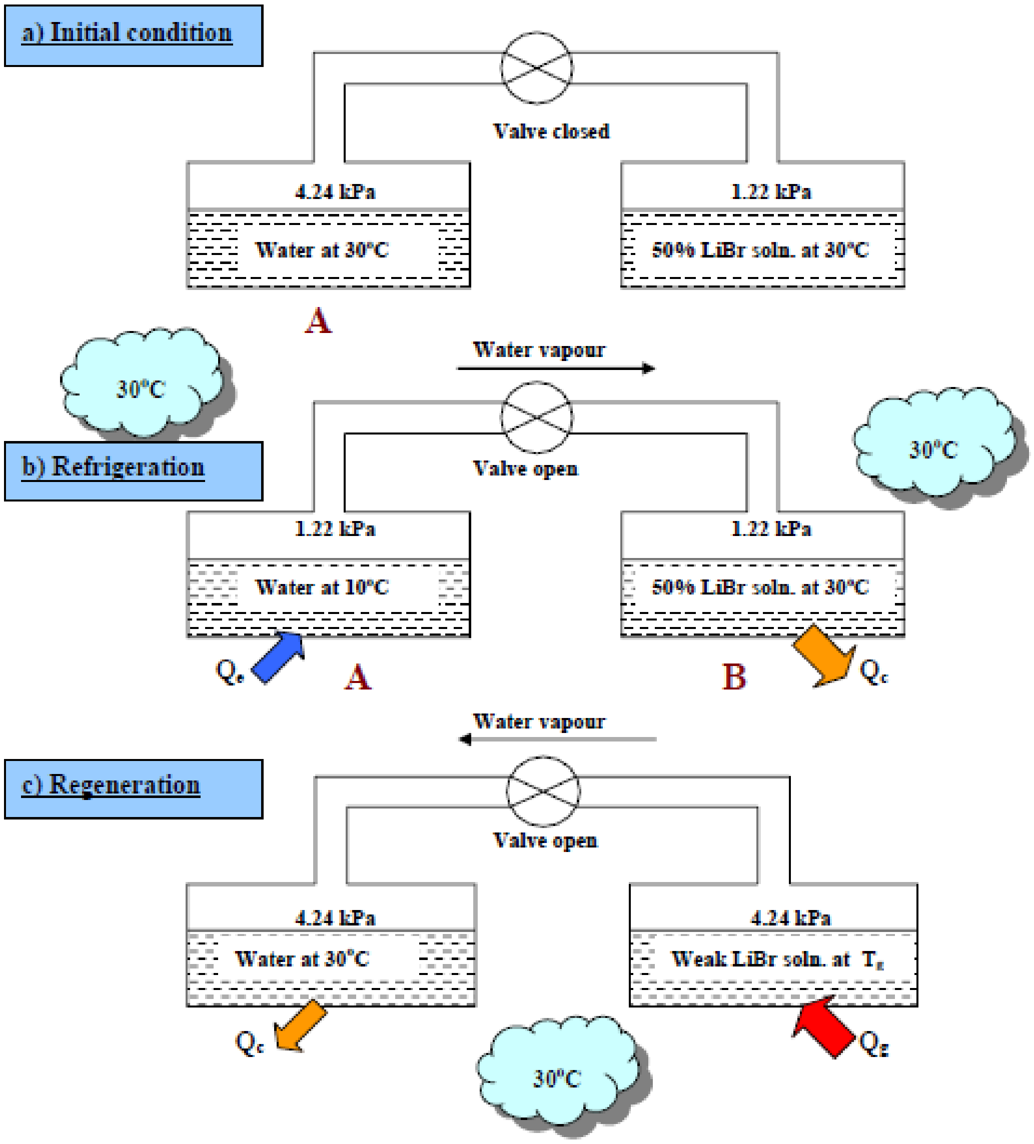
VAPOR ABSORPTION REFRIGERATION SYSTEMS(VARS)

OR

THERMAL ENERGY DRIVEN SYSTEMS

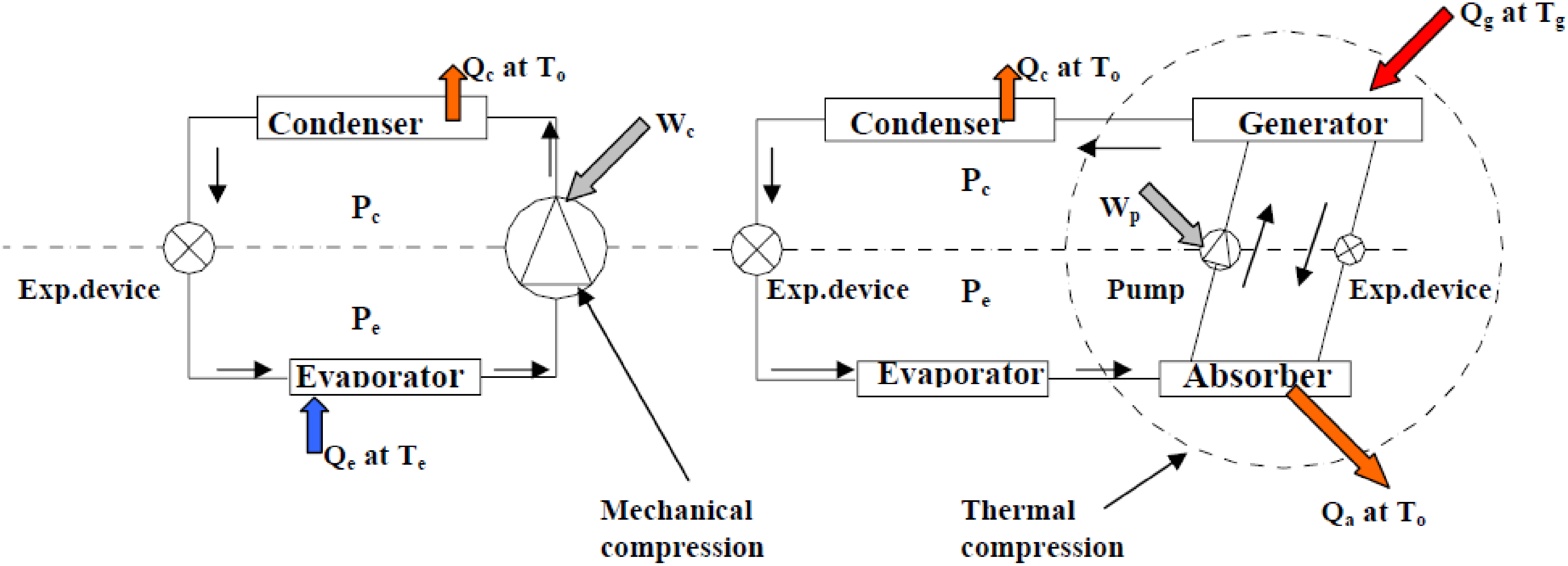
- The required input to absorption systems is in the form of heat so also called as **heat operated or thermal energy driven systems**.
- Since conventional absorption systems use liquids for absorption of refrigerant, these are also sometimes called as **wet absorption systems.**
- Since conventional absorption systems use natural refrigerants such as water or ammonia they are **environment friendly.**

BASIC PRINCIPLE



$T_g > T_o > T_e$

SIMPLE VARS



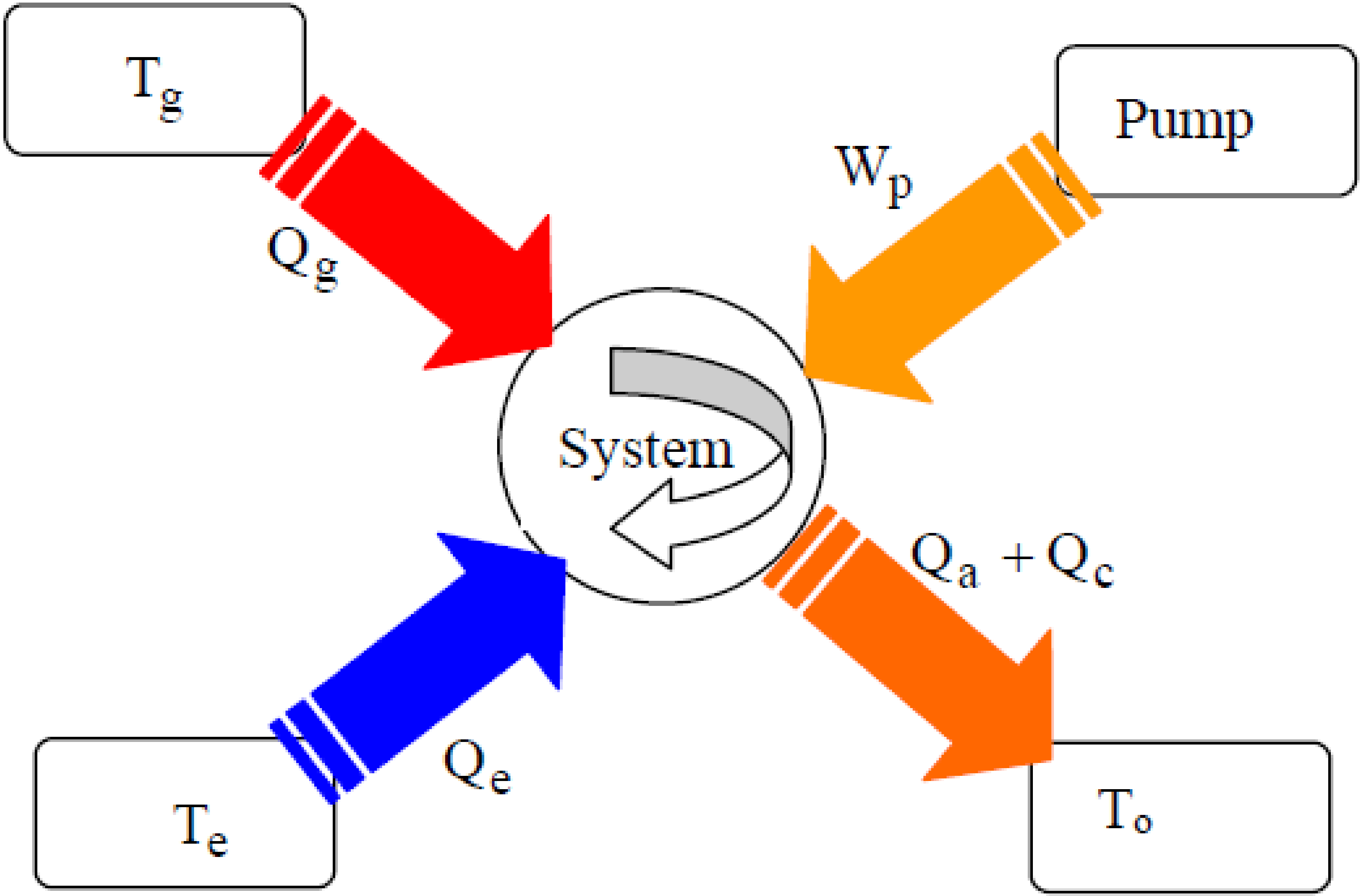
a) VCRS

b) VARS

- Continuous refrigeration is produced at evaporator, while heat at high temperature is continuously supplied to the generator.
- Heat rejection to the external heat sink takes place at absorber and condenser.
- A small amount of mechanical energy is required to run the solution pump.
- If we neglect pressure drops, then the absorption system operates between the condenser and evaporator pressures.
- Pressure in absorber is same as the pressure in evaporator and pressure in generator is same as the pressure in condenser.

- In VCRS - the vapour is compressed mechanically using the compressor.
- In VARS - the vapour is first converted into a liquid and then the liquid is pumped to condenser pressure using the solution pump.
- For the same pressure difference, the mechanical energy required to operate VARS is much less than that required to operate a VCRS.

Maximum COP of Ideal VARS



From first law of thermodynamics, if we neglect the pump work,

$$Q_{C+A} = Q_E + Q_G$$

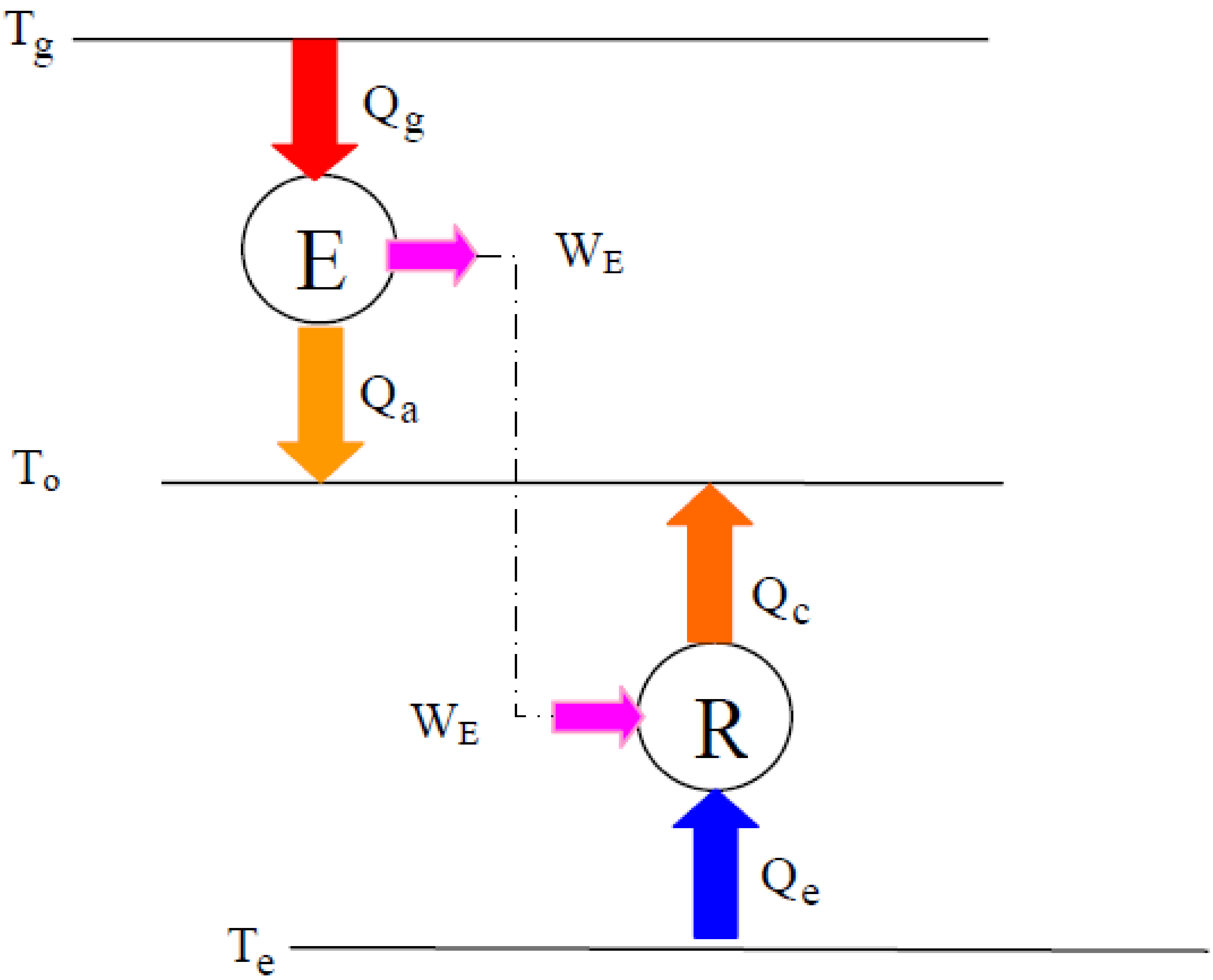
From second low of thermodynamics,

$$\Delta S_{\text{total}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} \geq 0$$

ie, $$\frac{Q_{C+A}}{T_0} = \frac{Q_E}{T_E} + \frac{Q_G}{T_G}$$

$$\frac{Q_E+Q_G}{T_0} = \frac{Q_E}{T_E} + \frac{Q_G}{T_G}$$

$$\mathrm{COP}_{\text{ideal VARS}} = \frac{Q_e}{Q_g} = \left(\frac{T_e}{T_o - T_e}\right)\left(\frac{T_g - T_o}{T_g}\right) = \mathrm{COP}_{\text{Carnot}} . \eta_{\text{Carnot}}$$


T_g
Q_g
E
W_E
Q_a
T_o
Q_c
W_E
R
Q_e
T_e

Refrigerant-absorbent combinations for VARS

The desirable properties of refrigerant-absorbent mixtures for VARS are:

- The refrigerant should exhibit **high solubility** with solution in the absorber.
- There should be large difference in **the boiling points** of refrigerant and absorbent (greater than 200^oC), so that only refrigerant is boiled-off in the generator - Only pure refrigerant circulates through refrigerant circuit (condenser-expansion valve-evaporator) leading to isothermal heat transfer in evaporator and condenser.

- It should exhibit small heat of mixing so that a high COP can be achieved
- The refrigerant-absorbent mixture should have high thermal conductivity and low viscosity for high performance.
- It should not undergo crystallization or solidification inside the system
- The mixture should be safe, chemically stable, non-corrosive, inexpensive and should be available easily.

Commonly used refrigerant-absorbent pairs are:

1. **Water-Lithium Bromide (H_2O-LiBr)** system for above 0°C applications such as **air conditioning**. Here water is the refrigerant and lithium bromide is the absorbent.
2. **Ammonia-Water (NH_3-H_2O)** system for **refrigeration applications** with ammonia as refrigerant and water as absorbent

Problem

The operating temperatures of a single stage vapour absorption refrigeration system are: generator: **90ºC**; condenser and absorber: **40ºC**; evaporator: **0ºC**. The system has a refrigeration capacity of **100 kW** and the heat input to the system is **160 kW**. The solution pump work is negligible.

a) Find the COP of the system and the total heat rejection rate from the system.

b) An inventor claims that by improving the design of all the components of the system he could reduce the heat input to the system to **80 kW** while keeping the refrigeration capacity and operating temperatures same as before. Examine the validity of the claim.

PRACTICAL AMMONIA-WATER VARS

- Ammonia is the refrigerant and water is the absorbent.
- More complex in design and operation due to the **smaller boiling point temperature difference** between the refrigerant and absorbent (about 133^{o}C).
- Due to smaller BP temp difference, the vapour generated in the generator consists of **both ammonia as well as water**.

If water is allowed to circulate with ammonia in the refrigerant circuit, then:

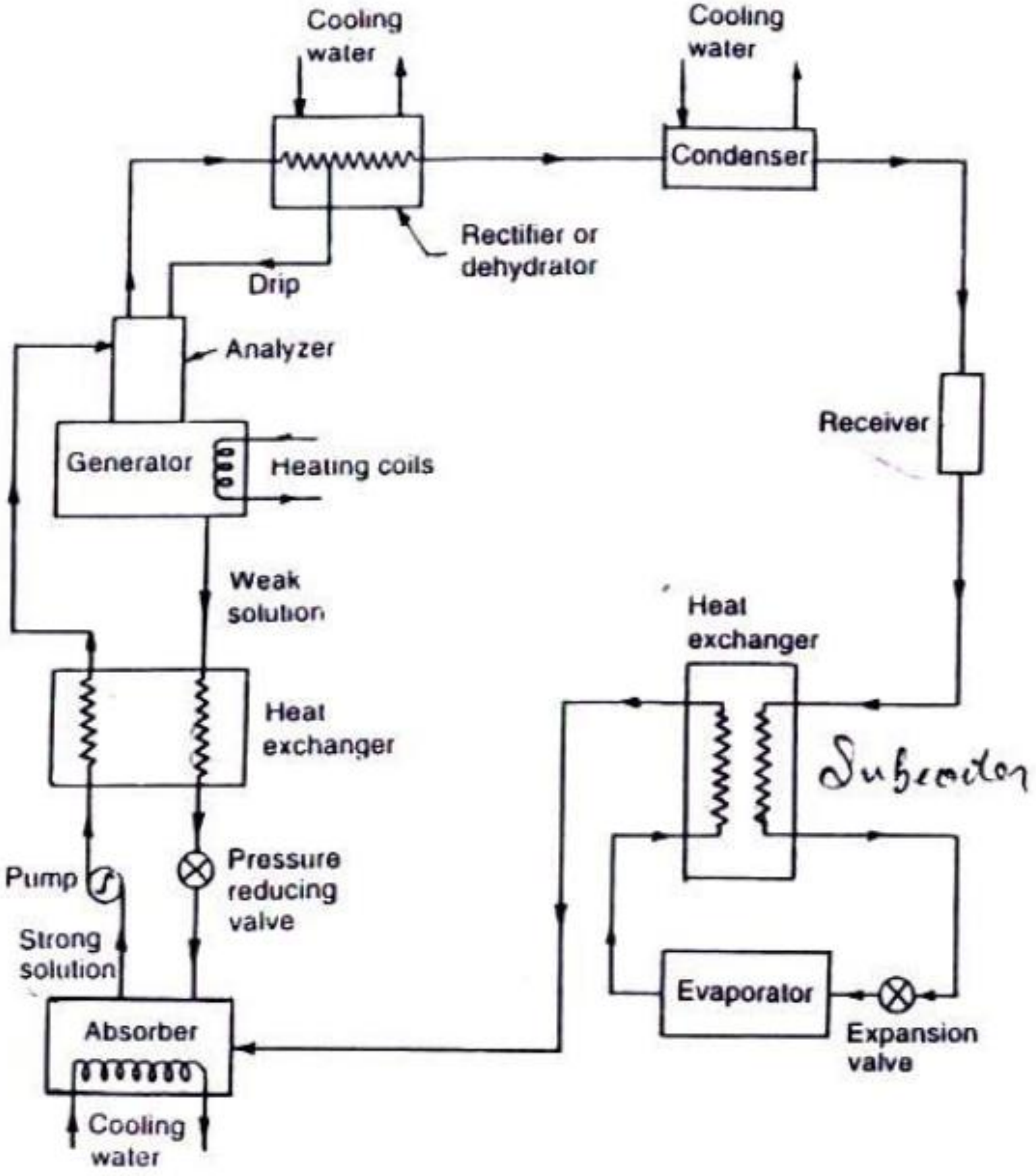
i. Heat transfer in condenser and evaporator becomes non-isothermal-pressure drop.

ii. Evaporator temperature increases.

iii. Evaporation will not be complete.

iv. Water may get accumulated in the evaporator leading to malfunctioning of the plant.

iv. Circulation ratio increases.


Cooling water
Cooling water
Condenser
Rectifier or dehydrator
Drip
Analyzer
Receiver
Generator
Heating coils
Weak solution
Heat exchanger
Heat exchanger
Subcooler
Pump
Pressure reducing valve
Strong solution
Evaporator
Expansion valve
Absorber
Cooling water

Analyzer

- It consists of a series of trays mounted above the generator.
- The strong solution from the absorber and the aqua from the rectifier are introduced at the top of the analyzer and flow downward over the trays into the generator.
- In this way, considerable liquid surface area is exposed to the vapour rising from the generator.
- The vapour is cooled and most of the water vapour condenses.

Rectifier

- Is a closed type vapour cooler also known as **dehydrator.**
- It is generally water cooled and may be of the double pipe, shell and coil or shell and tube type.
- Its function is to cool further the ammonia vapors leaving the analyzer so that the remaining water vapors are condensed.
- Thus, only dry or anhydrous ammonia vapors flow to the condenser.
- The condensate from the rectifier is returned to the top of the analyzer by a drip return pipe.

Heat exchangers

1. **The HXr between the pump and the generator** - cool the weak hot solution from the generator which raises the temperature of the strong solution. This reduces the heat supplied to the generator and the amount of cooling required for the absorber.
2. **The HXr b/w the condenser and the evaporator** also called **liquid sub-cooler -** the liquid refrigerant leaving the condenser is sub- cooled by the low temperature ammonia vapour from the evaporator.

ELECTROLUX REFRIGERATOR

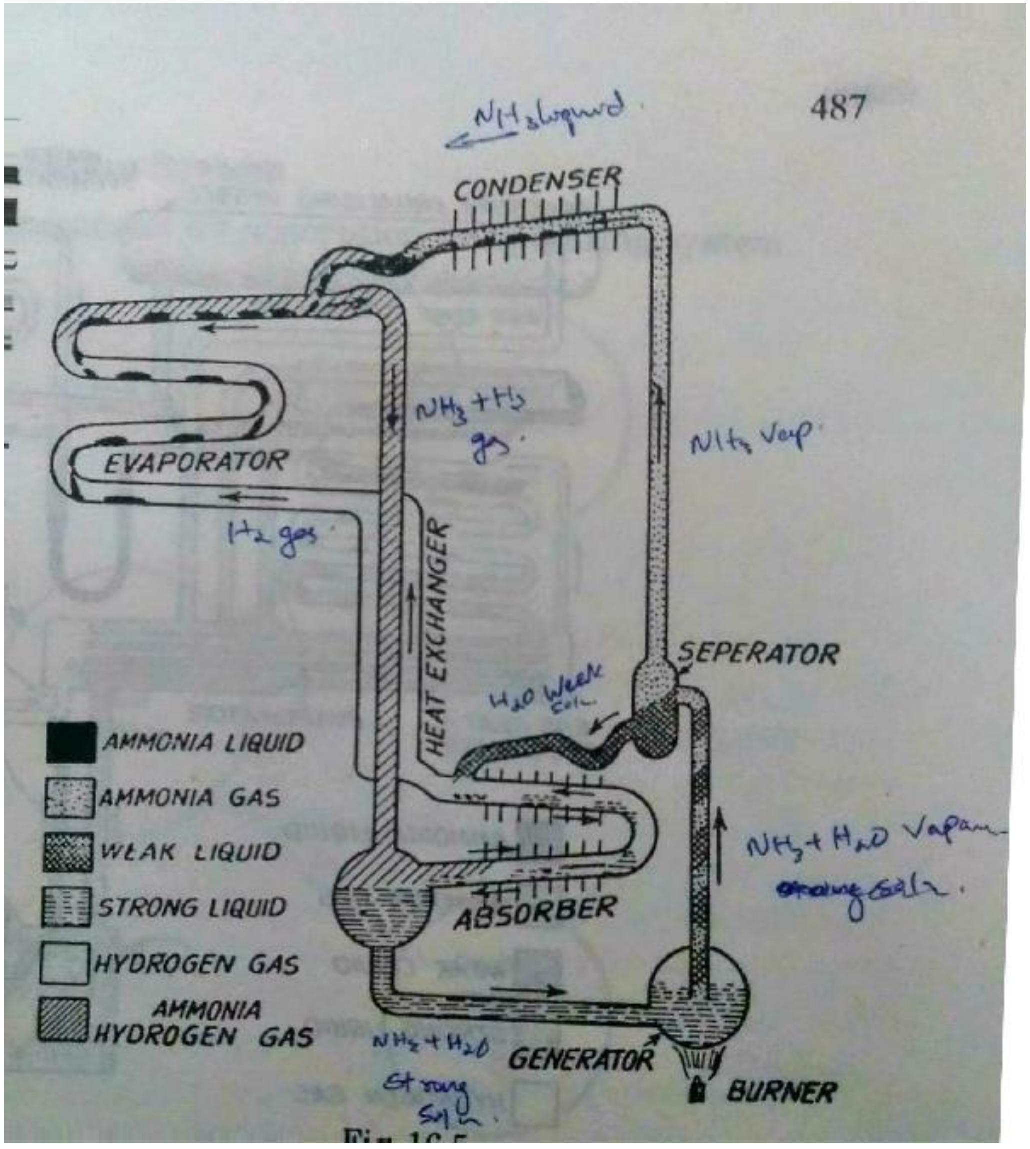
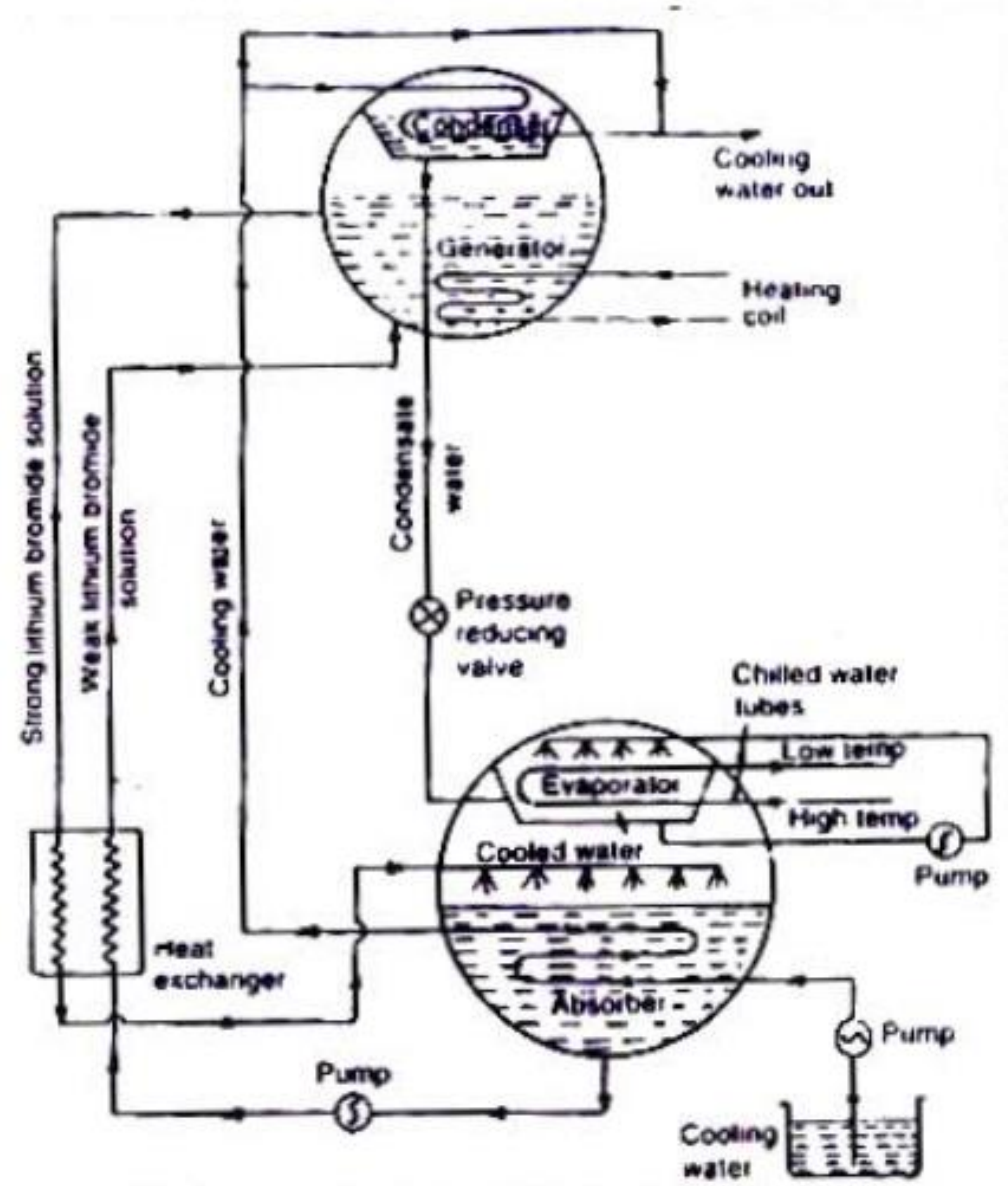


Fig. 16.5

- Invented by two Swedish engineers Carl Munters and Baltzer Von Platan in 1925.
- The idea was first developed by the ‘Electrolux Company’ of Luton, England.
- Also called **three-fluids absorption system**.
- The main purpose of this system is **to eliminate the pump** so the machine becomes noise-less.
- **Ammonia** is used as the refrigerant.
- The **hydrogen is used to increase the rate of evaporation of the liquid ammonia** passing through the evaporator and it is insoluble in **water**(solvent or absorbent).

- The hydrogen gas only circulates from the absorber to the evaporator and back.
- The whole cycle is carried out entirely by **gravity flow of the refrigerant**.
- It can not be used for industrial purposes as the C.O.P. of the system is very low.

LITHIUM BROMIDE VARS

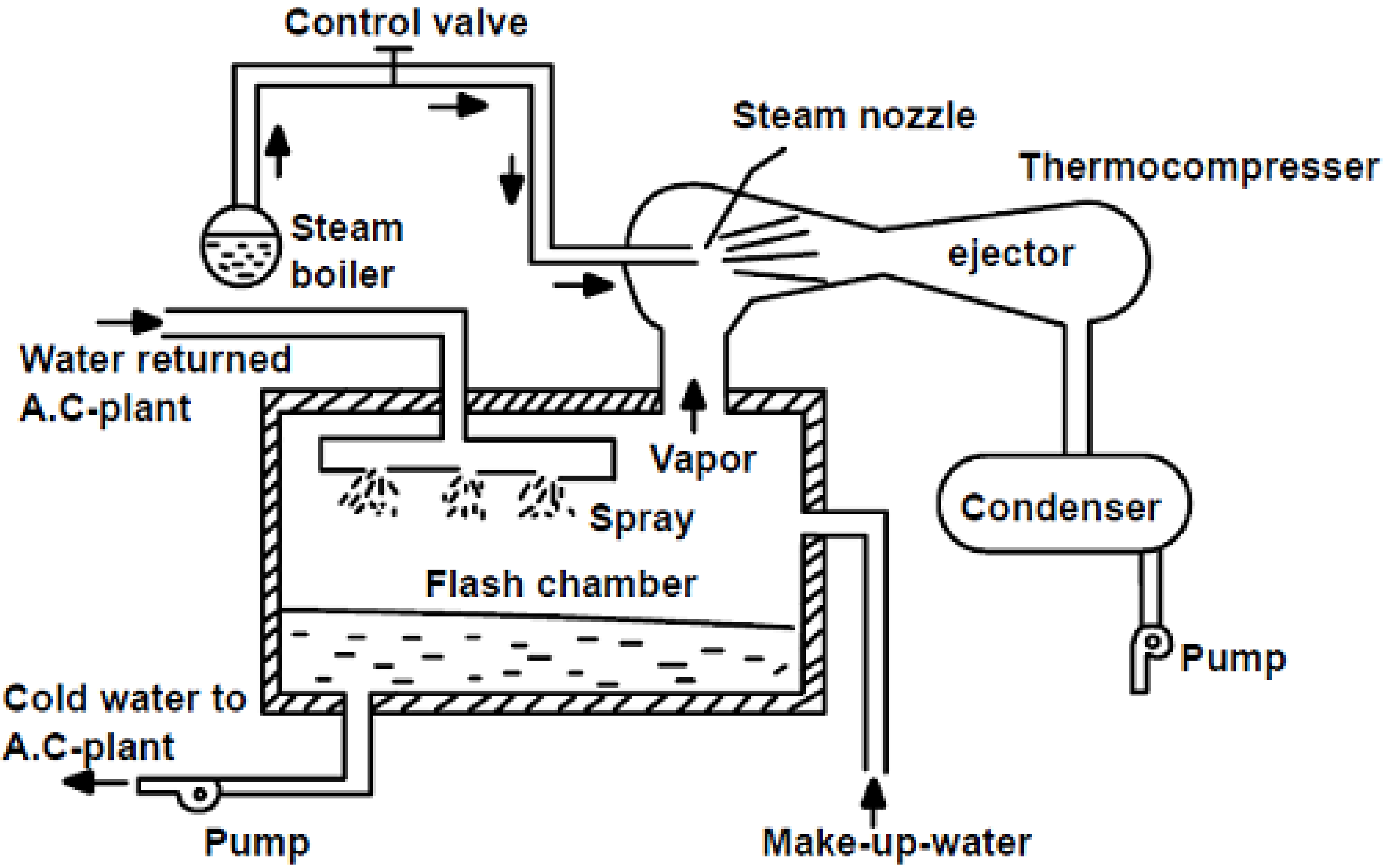


- The lithium bromide solution has a strong affinity for water vapour because of its very low vapour pressure.
- Lithium bromide solution is corrosive, therefore inhibitors should be added.
- **Lithium chromate** is often used as a corrosion inhibitor.
- The absorber and the evaporator are placed in one shell - low pressure of the system.
- The generator and condenser are placed in another shell - high pressure of the system.

Comparison between VC and VA systems

VAPOR COMPRESSION SYSTEM	***VAPOR ABSORPTION SYSTEM***
Compressor work operated	*Heat operated*
High COP because of using high grade energy(work)	*Low COP because of using low grade energy(heat)*
Performance is very sensitive to evaporator temperature	*Performance not very sensitive to evaporator temperature*
COP reduces considerably at part loads	*COP doesn’t reduce considerably at part loads*
Presence of liquid at the exit of the evaporator may damage compressor.	*Presence of liquid at the exit of the evaporator is not a problem*
Superheating at the evaporator exit increases compressor work	*Superheating at the evaporator exit is not a problem*
Many moving parts	*Few moving parts*
Regular maintenance required	*low maintenance required*
Higher noise and vibrations	*Less noise and vibrations*
Small systems are compact and large systems are bulky (e.g. house hold)	*Small systems are bulky and large systems are compact (e.g. ice plants)*
Economical when electricity is available (house, malls etc)	*Economical when waste heat is available in large quantity (industries)*

STEAM JET REFRIGERATION SYSTEM



- This system uses the principle of boiling the water below 100^0C.
- If the pressure on the surface of the water is reduced below atmospheric pressure, water can be made boil at low temperatures.
- High vacuum on the surface of the water can be maintained by throttling the steam through jets or nozzles.
- Water is the refrigerant.

- High pressure steam from the boiler is expanded in the nozzle.
- The water vapor originated from the flash chamber is entrained with the high velocity steam jet and it is further compressed in the thermo compressor.
- The kinetic energy of the mixture is converted into static pressure in the ejector and is discharged to the condenser.
- The condensate is usually returned to the boiler.
- Generally, 1% evaporation of water in the flash chamber is sufficient to decrease the temperature of chilled water to 6^0C.

- The chilled water in the flash chamber is circulated by a pump to the point of application.
- The warm water from the refrigerated space is returned to the flash chamber.
- The water is sprayed through the nozzles to provide maximum surface area for cooling.
- The water, which is splashed in the chamber and any loss of cold water at the application, must be replaced by makeup water added to the cold water circulating system.

REFRIGERANTS

Why Selection of Refrigerant is important?

- Important **practical issues** such as the **system design, size, initial and operating costs, safety, reliability, and serviceability** etc.
- Due to several **environmental issues** such as **ozone layer depletion and global warming** and their relation to the various refrigerants used.

Types:

- **Primary refrigerants**: Primary refrigerants are those fluids, which are used directly as working fluids. These fluids provide refrigeration by **undergoing a phase change** process in the evaporator.
- **Secondary refrigerants**: Liquids which are used for transporting thermal energy from one location to other. The secondary refrigerants **do not undergo phase change** as they transport energy from one location to other. **Eg:-** Brines such as solutions of water and ethylene glycol, propylene glycol or calcium chloride.

Refrigerant selection criteria

- Thermodynamic and thermo-physical properties.
- Environmental and safety properties, and
- Economics

Thermodynamic and thermo-physical properties

1. **Suction pressure** : At a given evaporator temperature, (a) The **saturation pressure** -**above atmospheric** - for prevention of air or moisture ingress and ease of leak detection. (b)**Suction pressure** – **higher** - it leads to smaller compressor displacement.
2. **Discharge pressure**: At a given condenser temperature, the **discharge pressure - small** - allows light-weight construction of compressor, condenser etc.
3. **Pressure ratio: small** - high volumetric efficiency and low power consumption

4. **Latent heat of vaporization: large** - the required mass flow rate per unit cooling capacity will be small.

From Clausius-Clapeyron Equation:

$$\frac{P_c}{P_e} = \exp\left[\frac{h_{fg}}{R}\left(\frac{1}{T_e} - \frac{1}{T_c}\right)\right]$$

For given condenser and evaporator temperatures as the latent heat of vaporization increases, the pressure ratio also increases. Hence a trade-off is required.

5. **Isentropic index of compression**: **Small** - Temperature rise during compression will be small.

6. **<u>Liquid specific heat</u>**: **Small** - Degree of sub cooling will be large - leading to smaller amount of flash gas at evaporator inlet.
7. **<u>Vapour specific heat</u>**: **Large** - Degree of superheating will be small.
8. **<u>Thermal conductivity</u>**: In both liquid as well as vapour phase should be **high** for higher heat transfer coefficients.
9. **<u>Viscosity</u>**: **Small** in both liquid and vapour phases for smaller frictional pressure drops.

- These properties are interrelated and mainly depend on **normal boiling point, critical temperature, molecular weight** .
- The **normal boiling point** indicates the useful temperature levels as it is directly related to the operating pressures.
- A **high critical temperature** yields higher COP due to smaller compressor superheat and smaller flash gas losses.
- For most of the refrigerants **the ratio of normal boiling point to critical temperature is in the range of 0.6 to 0.7**.

- The latent heat of vaporization will be high for refrigerants having **lower molecular weight.**
- The specific heat of refrigerant is related to the structure of the molecule.
- If **specific heat** of refrigerant vapour **is high** then **compression process will be dry**.
- But a large value of vapour specific heat results in a higher value of liquid specific heat, leading to higher flash gas losses.
- The optimum value of molar vapour specific heat lies in the range of **40 to 100 kJ/kmol.K**.
- The **freezing point** - lower than the lowest operating temperature of the cycle to prevent blockage of refrigerant pipelines.

Environmental and safety properties

a) **Ozone Depletion Potential (ODP):** According to the Montreal protocol, the **ODP should be zero**. ODP depends mainly on the presence of **chlorine or bromine** in the molecules. So refrigerants like R 11, R 12 are not used nowadays.

b) **Global Warming Potential (GWP):** Should have **low GWP value**. Refrigerants with zero ODP but a high value of GWP (e.g. R134a) are likely to be regulated in future.

c) **Total Equivalent Warming Index (TEWI):** The factor **TEWI considers both direct** (due to release into atmosphere) **and indirect** (through energy consumption) contributions of refrigerants to global warming.

d) Refrigerants should be **non toxic** and it should not become toxic when mixed with other substances.

e) **Flammability:** Should be Non-flammable and non-explosive. **ASHRAE** has divided refrigerants into **six safety groups** (A1 to A3 and B1 to B3). Refrigerants belonging to Group A1 (e.g. R11, R12, R22, R134a, R744, R718) are least hazardous, while refrigerants belonging to Group B3 (e.g. R1140) are most hazardous.

f) Refrigerants should be **chemically stable**. It should not decompose under operating conditions.

g) Refrigerant should be **non corrosive**. It increases life of the system.

h) Refrigerant should be **miscible with lubricating oils** and should not react with the lubricating oils.

i) Refrigerant should be **odorless**. It maintains the taste of food stuffs preserved.

Designation of refrigerants

- Since a large number of refrigerants have been developed over the years for a wide variety of applications, a numbering system has been adopted to designate various refrigerants.
- From the number one can get some useful information about the type of refrigerant, its chemical composition, molecular weight etc.
- All the refrigerants are designated by R followed by a unique number.

- Refrigerants are either **Organic** or **Inorganic.**
- **Organic compounds** – either **Hydrocarbon or Halocarbons**.
- **Halocarbons** - contains **chlorine and bromine** cause ozone depletion.
- **CFC** – contains chorine and Fluorine atoms.
- **Fluorine** does not cause ozone depletion.
- **Hydrogen atom** decreases ozone depletion.
- So new classification – **HC, FC, HFC, HCFC and CFC.**

Designation of Refrigerants

1. **<u>Organic Refrigerants</u>**

   a) **<u>Saturated compounds:</u>**

   R(c-1)(h+1)(f)

   b) **<u>Unsaturated compounds</u>**

   R1(c-1)(h+1)(f)

Where, c: No. of Carbon atoms

h: No. of Hydrogen atoms

f : No. of Fluorine(or Chlorine or Iodine) atoms

Note: **If the naming is two digits, then c-1=0**

Chemical Formula for refrigerant:

$$C_c H_h F_f Cl_{cl}$$

- For saturated compounds, **h+f+cl = 2c+2**

Eg:- R11(CCl_3F), R12(CCl_2F_2), R40, R160 etc.

- For unsaturated compounds, **h+f+cl = 2c**

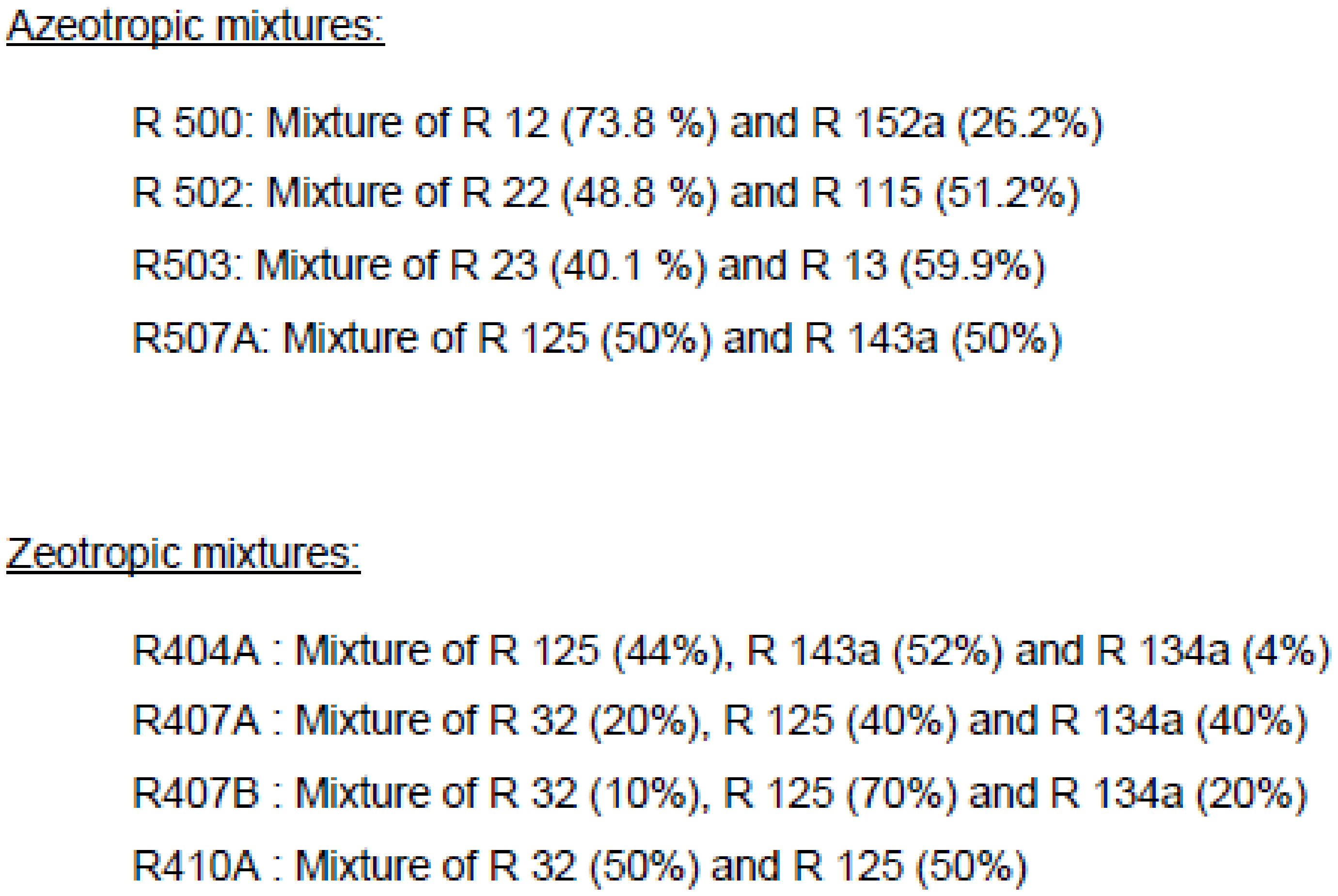
Eg:- R1150(C_2H_4), R1270 (C_3H_6)

2. <u>Inorganic Refrigerants</u> –

R(700+Molecular Wt.)

Eg:- R717(NH_3), R744(CO_2) R718(H_2O)

3. **Mixtures**: **Azeotropic mixtures** are designated by 500 series, where as **zeotropic refrigerants** are designated by 400 series.

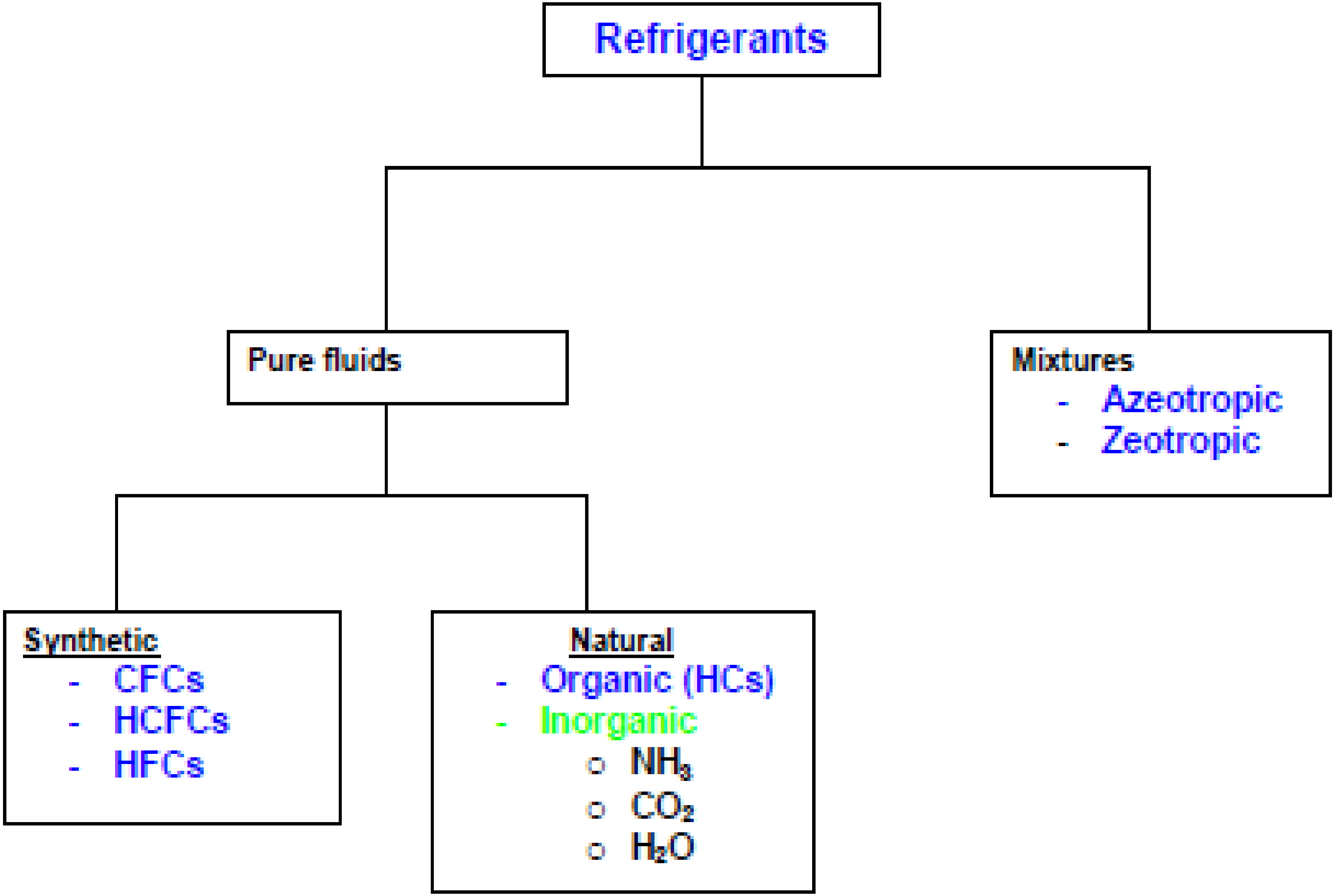


Azeotropic mixtures:

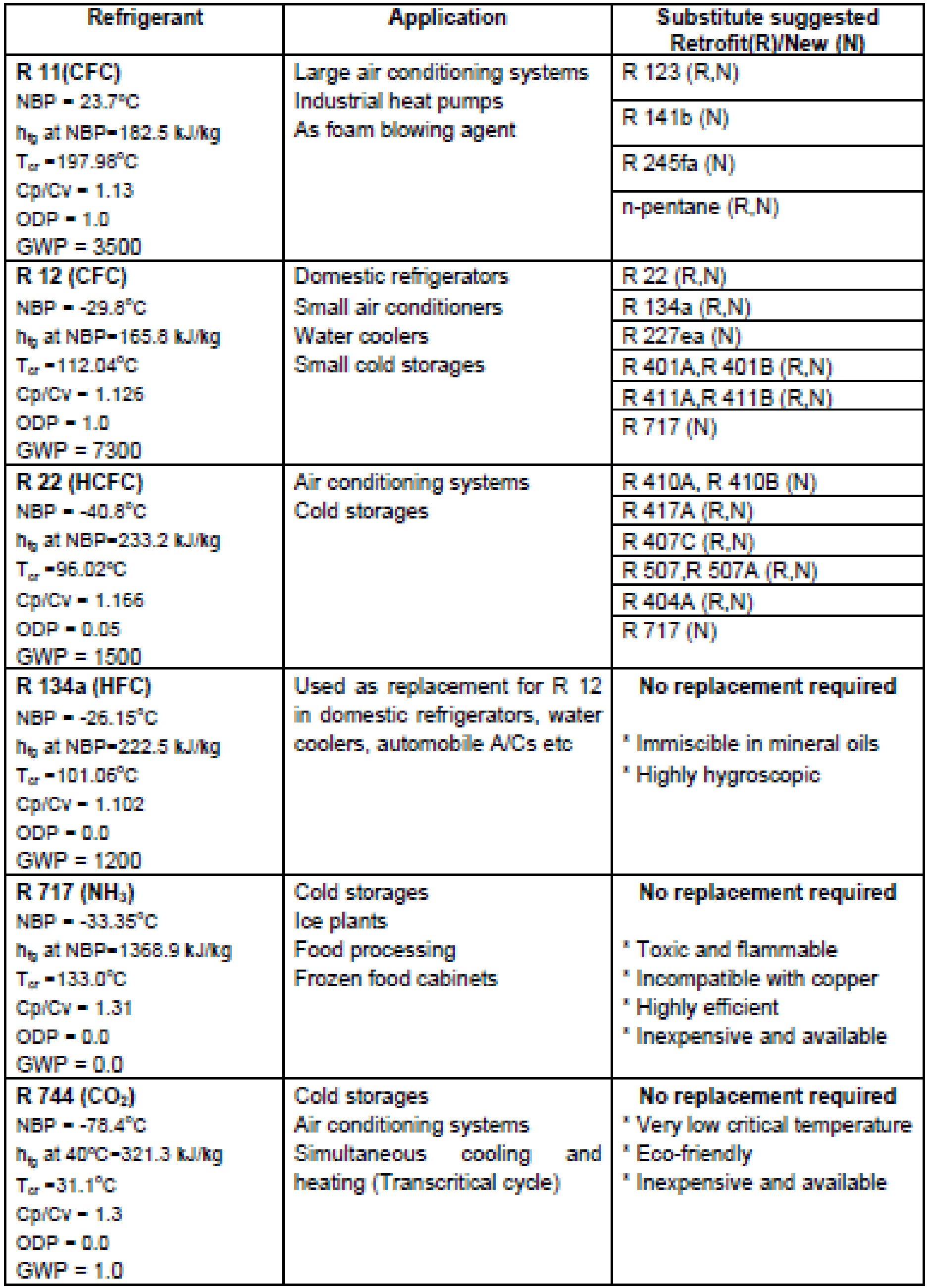
R 500: Mixture of R 12 (73.8 %) and R 152a (26.2%)
R 502: Mixture of R 22 (48.8 %) and R 115 (51.2%)
R503: Mixture of R 23 (40.1 %) and R 13 (59.9%)
R507A: Mixture of R 125 (50%) and R 143a (50%)

Zeotropic mixtures:

R404A : Mixture of R 125 (44%), R 143a (52%) and R 134a (4%)
R407A : Mixture of R 32 (20%), R 125 (40%) and R 134a (40%)
R407B : Mixture of R 32 (10%), R 125 (70%) and R 134a (20%)
R410A : Mixture of R 32 (50%) and R 125 (50%)


Refrigerants
Pure fluids
Mixtures
- Azeotropic
- Zeotropic
Synthetic
- CFCs
- HCFCs
- HFCs
Natural
- Organic (HCs)
- Inorganic
○ NH_3
○ CO_2
○ H_2O

Applications and Substitutes



Refrigerant	Application	Substitute suggested Retrofit(R)/New (N)
R 11(CFC) NBP = 23.7°C h_{fg} at NBP=182.5 kJ/kg T_{cr} =197.98°C Cp/Cv = 1.13 ODP = 1.0 GWP = 3500	Large air conditioning systems Industrial heat pumps As foam blowing agent	R 123 (R,N) R 141b (N) R 245fa (N) n-pentane (R,N)
R 12 (CFC) NBP = -29.8°C h_{fg} at NBP=165.8 kJ/kg T_{cr} =112.04°C Cp/Cv = 1.126 ODP = 1.0 GWP = 7300	Domestic refrigerators Small air conditioners Water coolers Small cold storages	R 22 (R,N) R 134a (R,N) R 227ea (N) R 401A,R 401B (R,N) R 411A,R 411B (R,N) R 717 (N)
R 22 (HCFC) NBP = -40.8°C h_{fg} at NBP=233.2 kJ/kg T_{cr} =96.02°C Cp/Cv = 1.166 ODP = 0.05 GWP = 1500	Air conditioning systems Cold storages	R 410A, R 410B (N) R 417A (R,N) R 407C (R,N) R 507,R 507A (R,N) R 404A (R,N) R 717 (N)
R 134a (HFC) NBP = -26.15°C h_{fg} at NBP=222.5 kJ/kg T_{cr} =101.06°C Cp/Cv = 1.102 ODP = 0.0 GWP = 1200	Used as replacement for R 12 in domestic refrigerators, water coolers, automobile A/Cs etc	**No replacement required** * Immiscible in mineral oils * Highly hygroscopic
R 717 (NH_3) NBP = -33.35°C h_{fg} at NBP=1368.9 kJ/kg T_{cr} =133.0°C Cp/Cv = 1.31 ODP = 0.0 GWP = 0.0	Cold storages Ice plants Food processing Frozen food cabinets	**No replacement required** * Toxic and flammable * Incompatible with copper * Highly efficient * Inexpensive and available
R 744 (CO_2) NBP = -78.4°C h_{fg} at 40°C=321.3 kJ/kg T_{cr} =31.1°C Cp/Cv = 1.3 ODP = 0.0 GWP = 1.0	Cold storages Air conditioning systems Simultaneous cooling and heating (Transcritical cycle)	**No replacement required** * Very low critical temperature * Eco-friendly * Inexpensive and available