Course Code: **MEG411**

Course Title: **Refrigeration and Air Conditioning**

Course Unit: 2

Lecturer: Dr. S.O. Giwa

Course Outline:

Fundamentals of vapour compression refrigeration. Analysis of refrigeration cycles. Heat pumps. Refrigerants and their properties. Absorption refrigeration. Principles of air-conditioning with emphasis on thermodynamics processes involving air-water vapour mixture.

Course objectives:

- 1. Learning the fundamental principles and different methods of refrigeration and air conditioning.
- 2. Study of various refrigeration cycles and evaluation of performance using Mollier charts and/ or refrigerant property tables.
- 3. Comparative study of different refrigerants with respect to properties, applications and environmental issues.
- 4. Understand the basic air conditioning processes on psychometric charts, calculate cooling load for its applications in comfort and industrial air conditioning.

Learning outcomes:

1. Illustrate the fundamental principles and applications of refrigeration and air conditioning system.
2. Obtain cooling capacity and coefficient of performance by conducting test on vapor compression refrigeration systems.
3. Present the properties, applications and environmental issues of different refrigerants.
4. Calculate cooling load for air conditioning systems used for various applications.
5. Operate and analyze the refrigeration and air conditioning systems.

6. Use P-h, T-S and Psychometric charts to solve refrigeration and Air conditioning design problems.

Course Materials:

Textbooks and other materials are available for download on the Microsoft Team.

Schedule of lectures:

- Week 1: Introduction to the course.
- Week 2: Fundamentals of vapour compression refrigeration.
- Week 3: Analysis of refrigeration cycles.
- Week 4 and 5: Refrigerants and their properties.
- Week 6 & 7: Absorption refrigeration.
- Week 8 and 9: Principles of air-conditioning with emphasis on thermodynamics processes involving air-water vapour mixture.

Course grade distribution:

- Tests (1 and 2) – 10 marks each = 20 marks
- Quizzes, Assignments and attendance – 10 marks
- Examination – 70 marks
- Total – 100 marks

- <u>Note: minimum of 70% class attendance qualifies you for the examination</u>

Heat Engine, Heat Pump, and Refrigeration

- Heat engine
- Heat Pump
- Refrigeration

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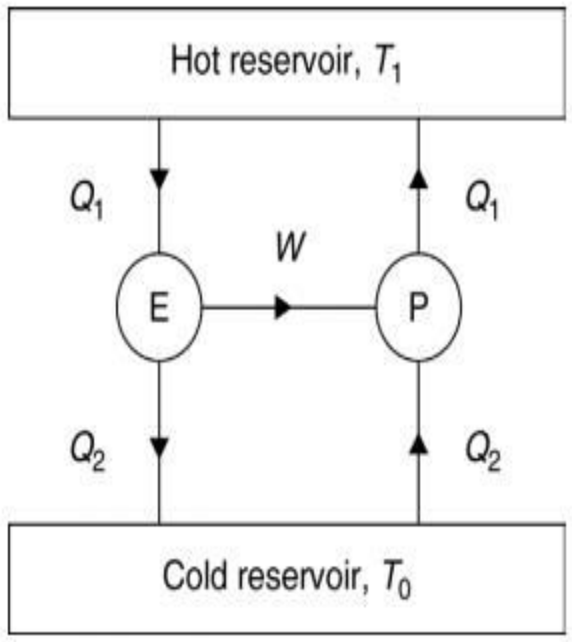


Figure 1.1 *Ideal heat engine, E, driving an ideal refrigerator (heat pump), P.*

Refrigeration:

- It is the process of removing heat from a substance under controlled condition.
- It is a process of reducing and maintaining the temperature of a body below the general temperature of the surroundings.

Refrigerating machine:

Refrigerant

- A refrigerant is a working fluid or thermal medium used for transferring heat within a refrigeration and air conditioning system
- It is a medium of heat transfer, which absorbs heat by evaporating at low temperature and gives out heat at high temperature.
- A refrigerant must satisfy chemical, physical, safe working, and thermodynamic properties and economical aspects.

- Earlier refrigerants used in mechanical and vapour refrigeration systems are:
- CO_2, ethyl chloride, SO_2, dichloromethane (CH_2Cl_2), dichloroethylene ($C_2H_2Cl_2$), monobromomethane (CH_3Br),
- Organic (Chloro-fluloro derivatives of CH_4 and C_2H_6 – HCs, HFCs, HCFCs, and CFCs) and inorganic (Ammonia - NH_3, CO_2, air,).

Classification of refrigerants:

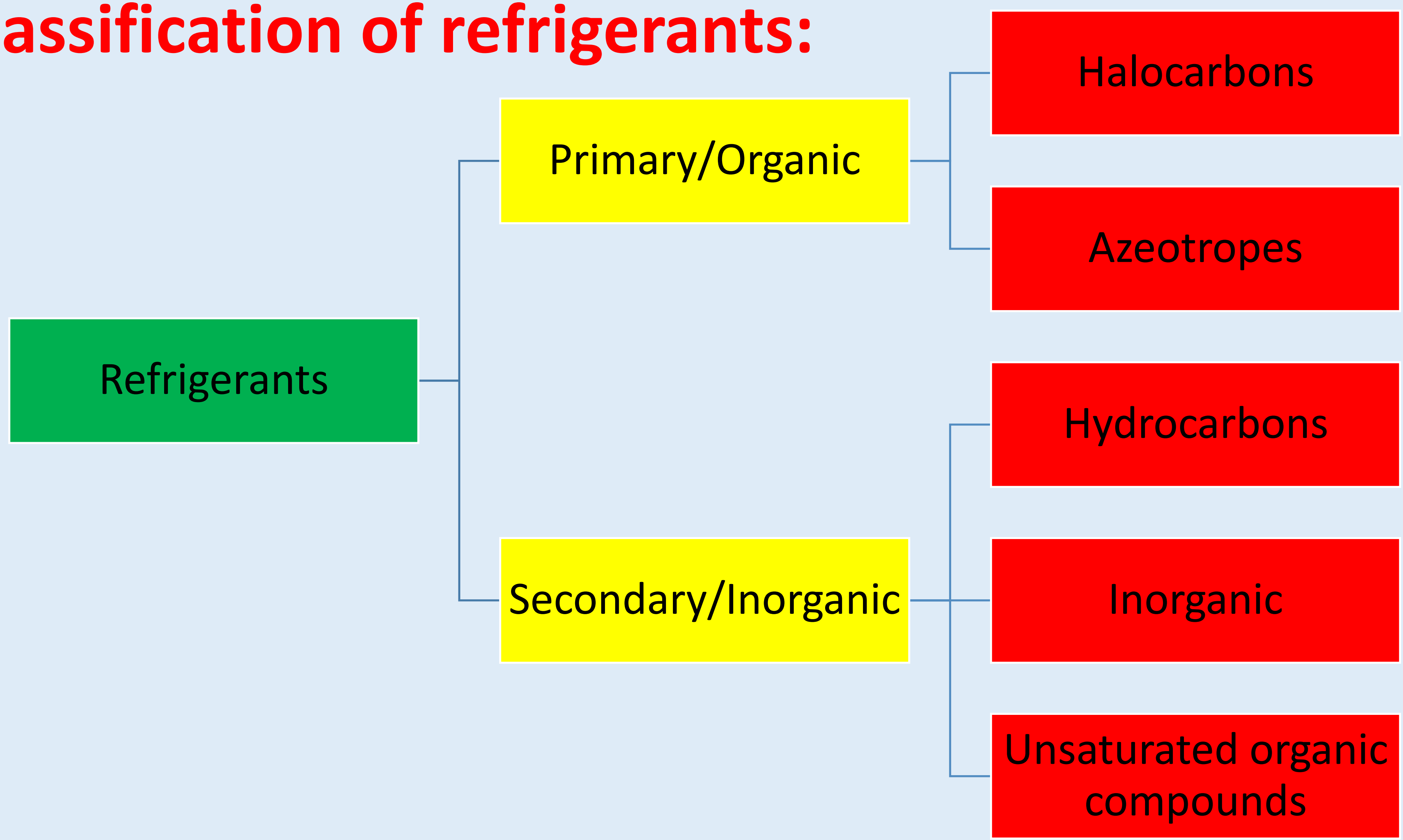
1. Primary refrigerants, 2. Secondary refrigerants

* Primary refrigerants absorbs heat and generate coolness by changing their phase from liquid to vapour.

- They are working media in refrigeration systems which are directly used as carrier of heat.

* Secondary refrigerants absorb heat from the bodies or space to be cooled and further transfer the same to the primary refrigerants.

Classification of refrigerants:



Halocarbon compounds:

- Fluorinated hydrocarbons from methane, ethane, etc.
- Freon, frigen, arcton, etc. (Commerciallly)
- Important examples
  - R11 –Trichloromonofluoromethane (CCl_3F)
  - R12 - Dichlorodifluoromethane (CCl_2F_2)
  - R22 - Monochlorodifluoromethane ($CHClF_2$)
  - R40 – Methyl chloride (CH_3Cl)

Azeotropes:

- This is a mixture of different refrigerants that cannot be separated under pressure and temperature.
- Their thermodynamic properties are fixed.
- They are refrigerants whose code starts with digit "5" eg. R502
- R500 – 73.8% R12 + 26.2% R152
- R502 – R22 + R115
- R503 – R13 + R23

Hydrocarbons:

- Refrigerants derived from hydrocarbons
- Desirable thermodynamics properties but highly inflammable
- R50 (methane –CH_4)
- R170 (Ethane – C_2H_6)
- R290 (Propane – C_3H_8)

Inorganic compounds:

- Refrigerants sourced from inorganic materials
- R717 (Ammonia – NH_3)
- R718 (Water – H_2O)
- R744 (Carbon dioxide – CO_2)
- R729 (Air)
- R764 (Sulphur dioxide – SO_2)

Unsaturated organic compounds:

- These are refrigerants derived from ethylene and propylene
- R1120 (Trichloroethylene – $C_2H_4Cl_3$)
- R1130 (Dichloroethylene – $C_2H_4Cl_2$)
- R1150 (Ethylene – C_2H_4)
- R1270 (Propylene – C_3H_6)

Secondary refrigerants:

- They absorb heat from refrigerated space/body and transfer it to primary refrigerants for it to be discarded to the environment
- Water,
- Brines (Calcium chloride – $CaCl_2$)
- Glycols (Ethylene glycol, propylene glycol, etc.

Designation of refrigerants

- Naming of refrigerants
- Three/four codes (R0123)

- First – Number of carbon atoms – 1
- Second – Number of hydrogen atoms + 1
- Third – Number of fluorine atoms
- Four – Number of chlorine atoms
- $C_mH_nF_pCl_o$ (Chemical formula)
- $n + p + o = 2m + 2$

$R-(m-1)(n+1)(p)$

Examples (halogencarbon)

1. R22 or R022

$m-1=0 \Rightarrow m=1$

$n+1=2 \Rightarrow n=1$

$p=2$

Using $n+p+o=2m+2$

$o=1$

$\Rightarrow$ R22 = $CHClF_2$

Designation for inorganic refrigerants

- According to molecular weight
- Molecular weight is added to 700

*Eg. water (H_2O) = 18 (molecular weight)

R700 + 18 = R718

* Eg. ammonia (NH_3) = 17 (molecular weight)

- R700 + 17 = R717

Desirable Properties of a refrigerant

- Chemical properties,
- Physical properties,
- Thermodynamic properties

Chemical Properties

- Flammability (inflammable before air or oil)
- Toxicity (not poisonous)
- Action of refrigerant with water
- Corrosiveness
- Leak detection/tendency (low)
- Flash point (high)
- Miscibility with oil
- Stability (chemically and physically)
- Environmentally friendly

Physical Properties

- Specific volume (low)
- Viscosity (low)
- Thermal conductivity (high)
- Dielectric strength (high)
- Handling and maintenance (safe)
- Cost and availability (low cost)

Thermodynamic Properties

- Latent heat of vaporization (high)
- Boiling point (low at atmospheric temp.)
- Freezing temperature (below evaporator temp.)
- Evaporating pressure (above atm. Pressure)
- Condensing pressure (low)
- Critical temperature and pressure (above condensing pressure)
- Index of compression process (small)

Properties of an ideal refrigerant

- It should have zero ODP and zero GWP
- It should be non-toxic and non-flammable
- It should be non-corrosive
- It should have high latent heat
- It should have high critical pressure and temperature
- It should have low condensing pressure and the evaporating pressure should be slightly above the atmospheric pressure
- It should not be miscible with lubricating oil
- It should be easily available and cheap
- Leak detection should be easy
- It should be environmentally friendly

Refrigerant selection

- Working temperatures of the refrigerant
- Evaporator and condenser pressures needed and the pressure ratio
- Oil miscibility
- High latent heat of vaporization and low specific volume
- Toxicity, flammability, explosiveness and corrosiveness
- Space requirements

New refrigerants

- R134a replaces R12
- R123 replaces R11
- Bio-based refrigerants
- Nano-based refrigerants

Desirable properties of secondary refrigerants

- They should have low freezing point
- They should have good stability
- They should have low vapour pressure
- They should have high heat transfer coefficients
- They should have high specific heat
- They should be non-flammable

Advantages of secondary refrigerants

- They can be easily handled
- Adjusting the temperature allows the cooling of different rooms in a building
- Control is easy
- Piping size required is reduced
- Absolute safety in air conditioning installation due to leakage

Class assignment

1. Discuss the effect of chlorofluorocarbons and hydrogen chlorofluorocarbons on the environment and the way forward.
2. What do you understand by nano-based and bio-based refrigerants?
3. What do you understand by environmentally friendly?

Vapour Compression Refrigeration

Components

1. Evaporator
2. Compressor
3. Condenser
4. Expansion valve

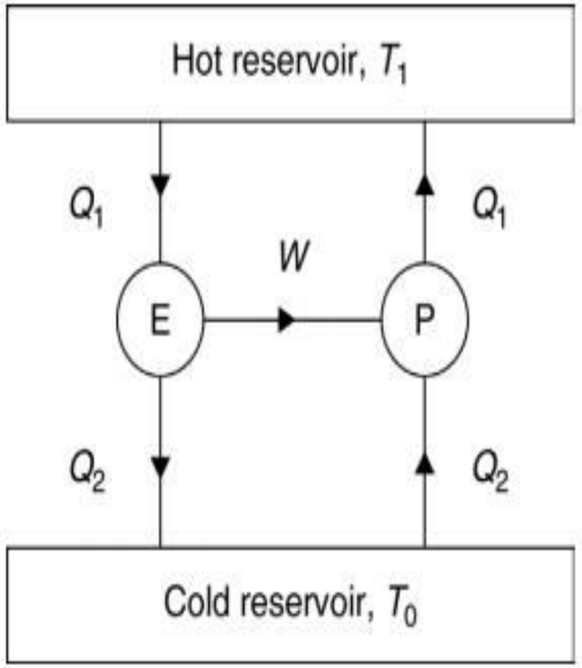
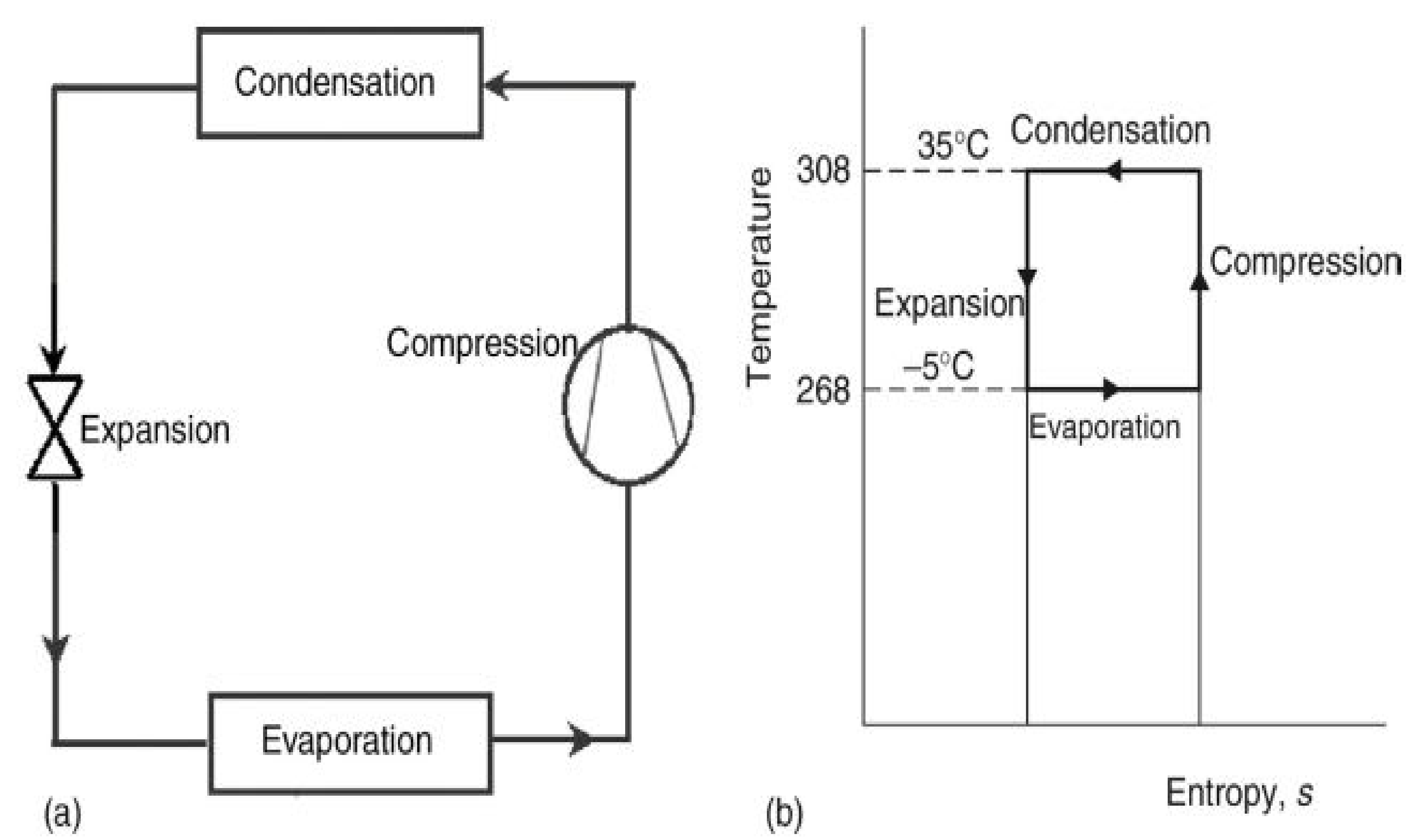


Figure 1.1 *Ideal heat engine, E, driving an ideal refrigerator (heat pump), P.*

Types of Refrigeration Cycles

1. Ideal cycle
2. Simple vapour compression cycle
3. Transcritical cycle
4. Heat powered cycles (absorption, adsorption and desiccant cooling)
5. Stirling cycle
6. Thermoelectric cooling
7. Magnetic refrigeration



Condensation
Compression
Expansion
Evaporation
(a)
Temperature
308
268
35°C
–5°C
Condensation
Compression
Expansion
Evaporation
Entropy, s
(b)

Schematic diagram

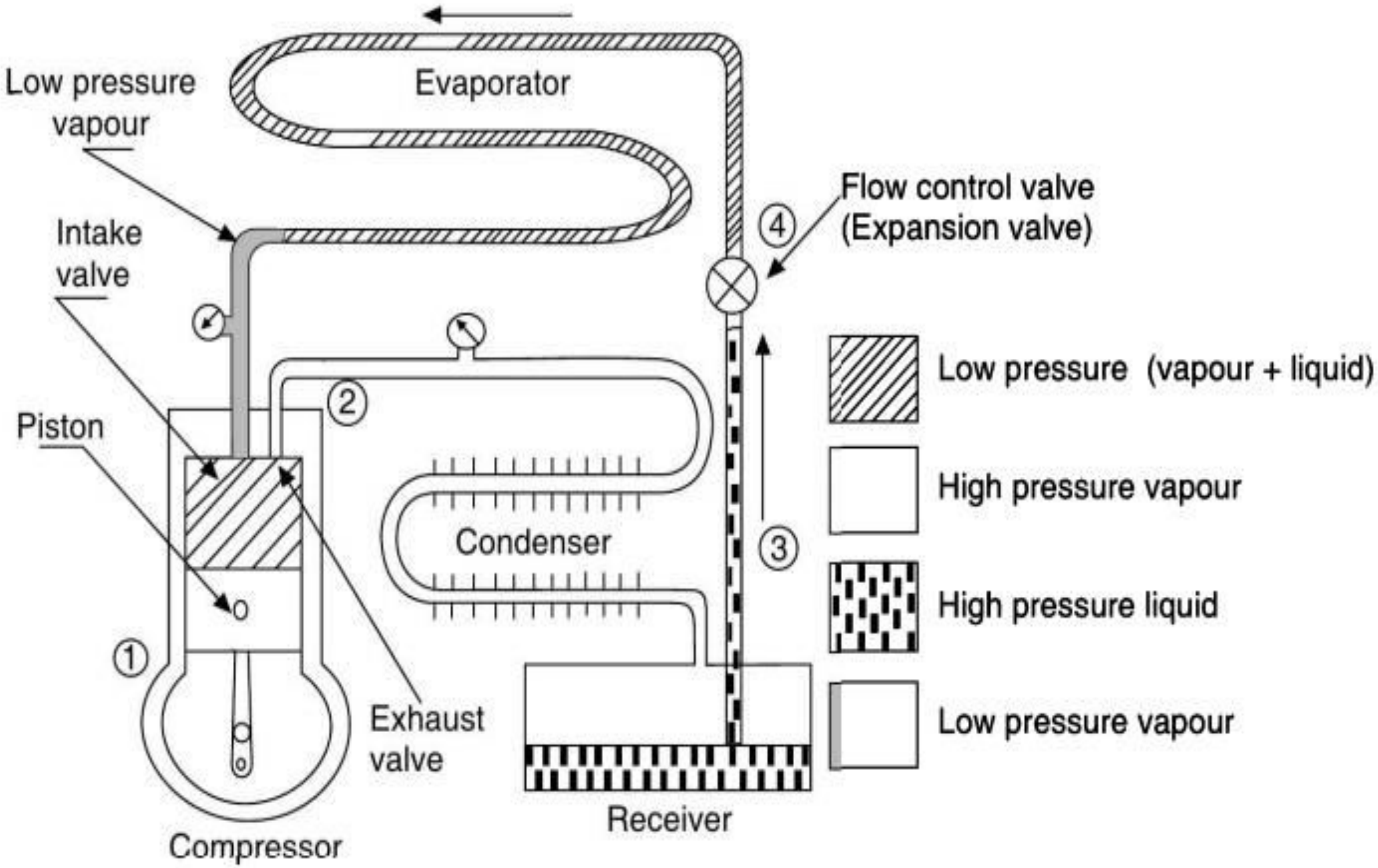


Figure 4.1 Vapour compression system with its components shown and also the condition of refrigerant in the flow circuit.

P-

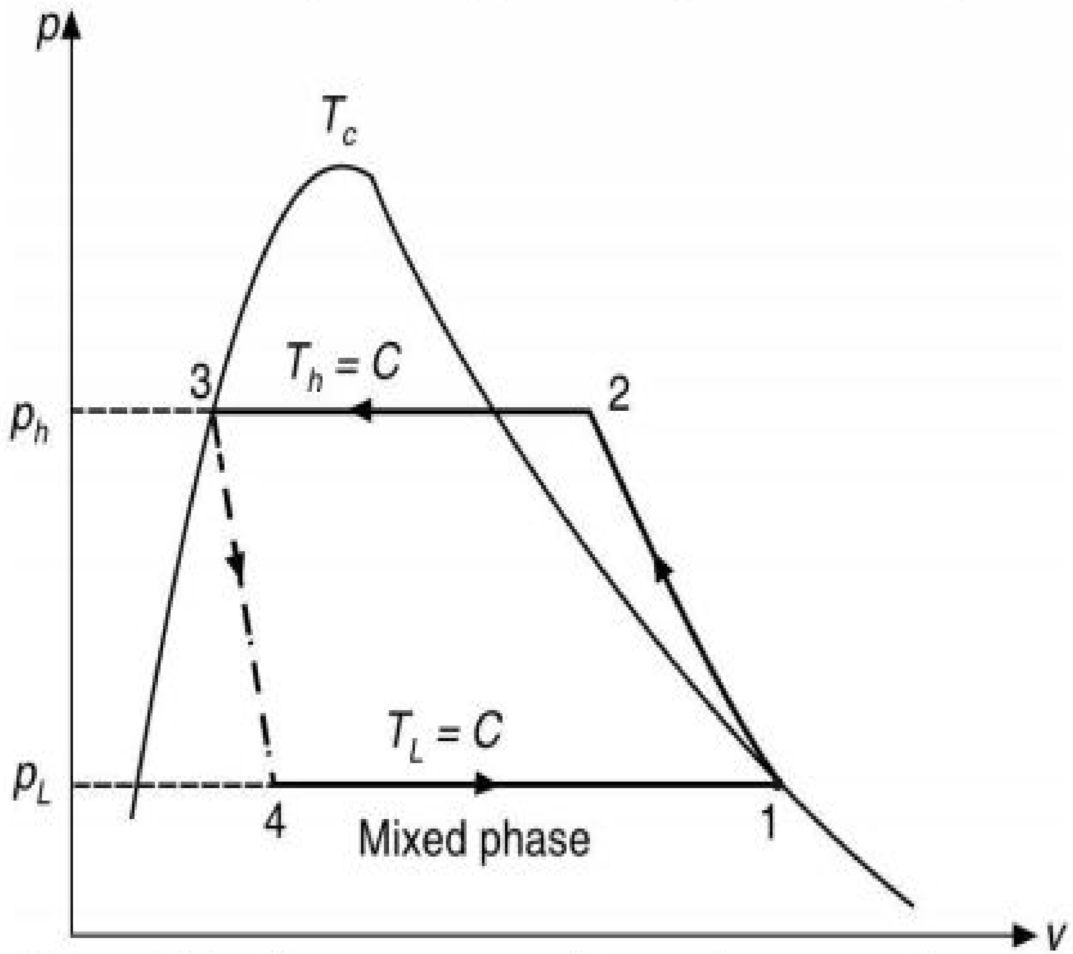


Figure 4.3 Vapour compression cycle on *p–v diagram.*

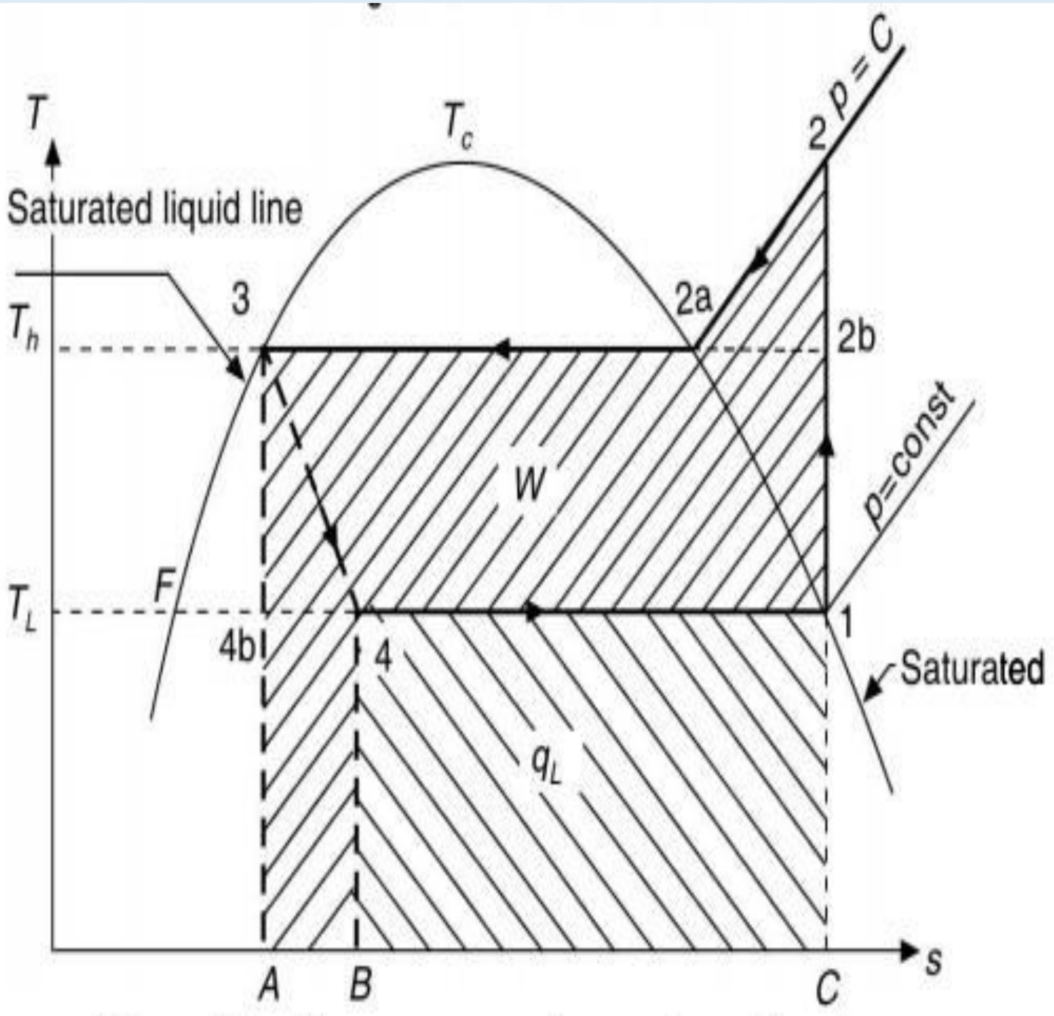


Figure 4.2 Vapour compression cycle on *T–s* diagram.

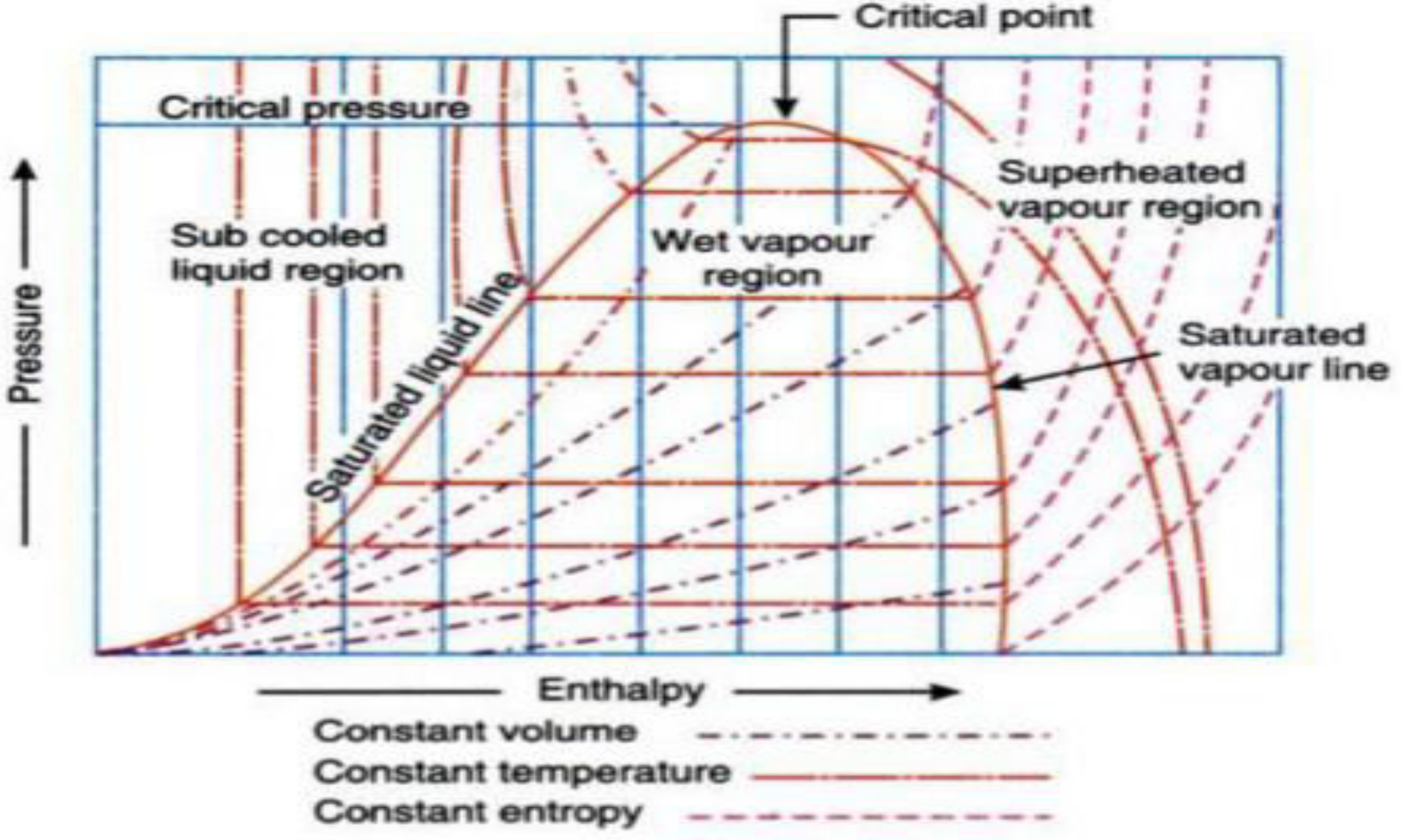


Fig. 4.2. Pressure - enthalpy (*p-h*) chart.

Processes

Compression (1-2)

(Isentropic compression

$s_1=s_2$; $q=0$; $W=h_2-h_1$)

Condensation (2-3)

(superheating and condensation

at constant pressure)

Heat rejected, $q_h=h_2-h_3$

Expansion (3-4)

Evaporation (4-1)

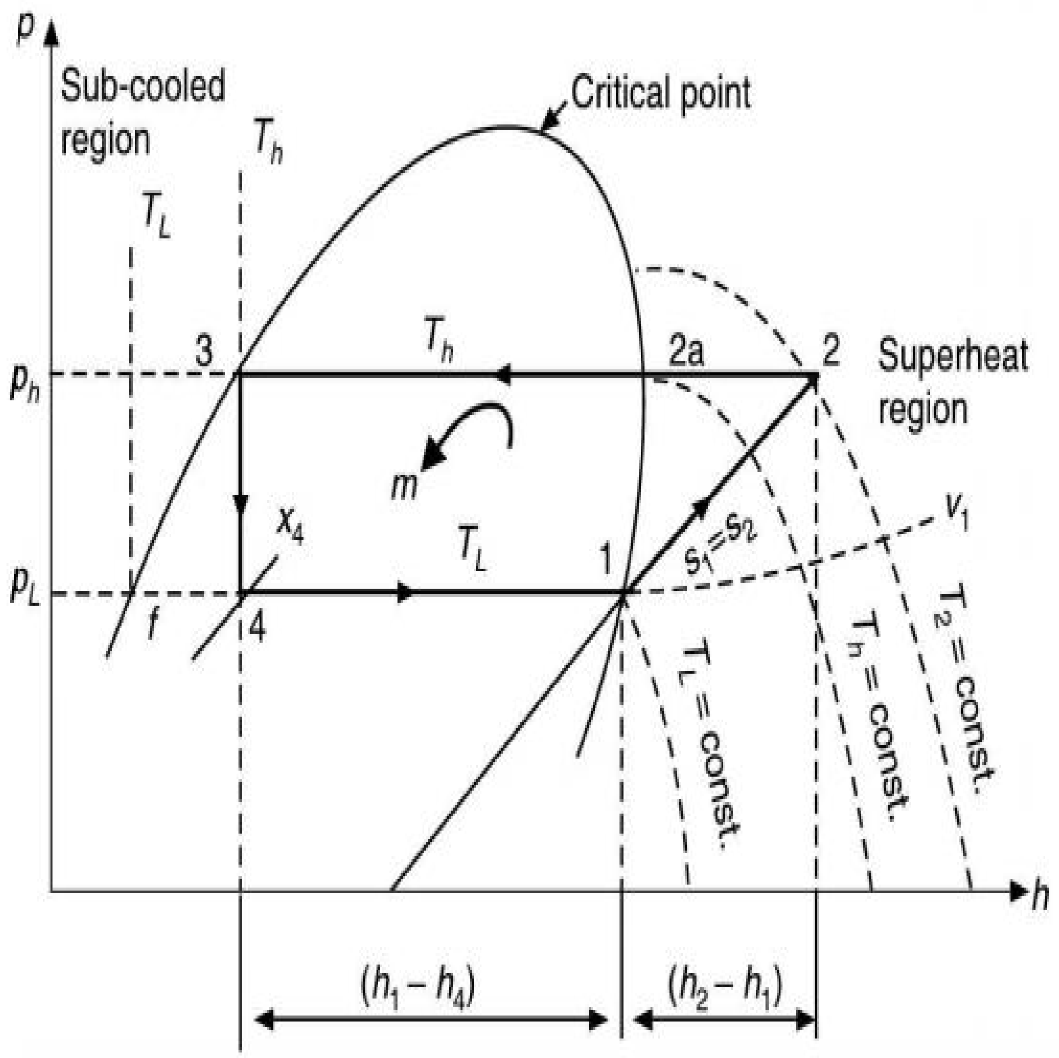


Figure 4.4 Vapour compression cycle on p–h diagram.

Processes

Expansion (3-4)

(Isenthalpic expansion; $h_3=h_4=hf_4+a(h_1-h_4)$)

Evaporation (4-1)

Evaporation at constant Pressure (P_L)

Refrigerating effect (q_L)= h_1-h_4

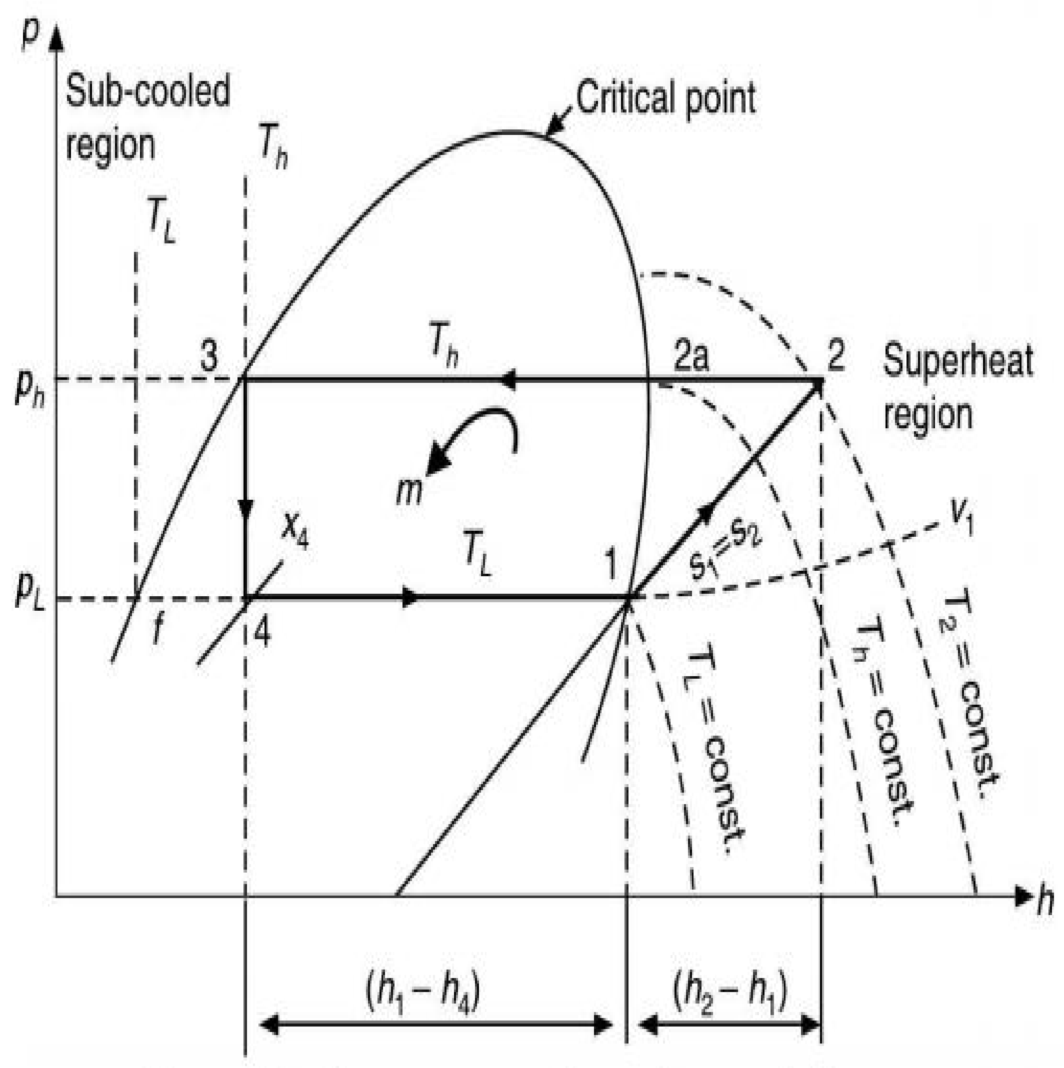


Figure 4.4 Vapour compression cycle on p–h diagram.

Processes

For cooling,

COPR = h1-h4/h2-h1

For heating,

COPR = h2-h3/h2-h1

Refrigerant flow rate, m= total refrigerating effect/refrigerating effect per unit mass

= QL/qL

Volume of suction vapour, V = $m\upsilon 1$

Actual piston displacement, Vp = $m\upsilon 1/\eta v$

Mass flow rate per ton of RE, $\dot{m}$ = 3.5164/qL (kg/s)

W* = w = 3.5164/qL w

Types of vapour compression cycles

1. Cycle with dry saturated vapour after compression
2. Cycle with wet vapour after compression
3. Cycle with superheated vapour after compression
4. Cycle with superheated vapour before compression
5. Cycle with undercooling or subcooling of refrigerant

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Course grade distribution:

- Tests (1 and 2) – 10 marks each = 20 marks
- Quizzes, Assignments and attendance – 10 marks
- Examination – 70 marks
- Practical – 40%
- Theory – 60%
- Total – 100 marks
- <u>Note: minimum of 70% class attendance qualifies you for the examination</u>

What do you understand by “Engineering”?