BYJU'S EXAM PREP

Mechanical Engineering

Refrigeration & Air Conditioning

Short Notes

IMPORTANT FORMULAS TO REMEMBER

CHAPTER-1 INTRODUCTION

- **Refrigeration** is the process of maintaining a space at a lower temperature than that of surrounding.
- **Heat pump** works in the same principle as that of refrigerator. In case of Heat Pump, our objective is to maintain a space at a temperature higher than surrounding.
- **Refrigeration effect** is the amount of the heat that has to be removed from the space to maintain it at a temperature lower than the surrounding per kg of refrigerant. Its **unit** is kJ/kg
- **Refrigerating Capacity** is the product of refrigeration effect to the mass flow rate of refrigerant. Its **unit** is kW.

$$\text{Refrigeration Capacity} = \dot{m} \times \text{Refrigeration Effect}$$

- **Unit of Refrigeration (Tons of refrigeration)**

  It is defined as the amount of heat which is required to extract from 1 ton of water at 0°C in order to convert it into ice at 0°C in a day or 24 hours.

  $1TR = 3.5kW$ = 210kJ/min = 50kcal/min = 4.71 HP (1 horse power = 746W = 0.746kW)

- **Coefficient of performance COP / Energy performance Ratio EPR**

  It is defined as the ratio of desired effect to the work input.

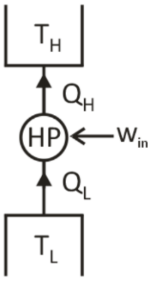
  $$COP = ER = EPR = \frac{\text{Desired Effect}}{\text{Work Input}}$$

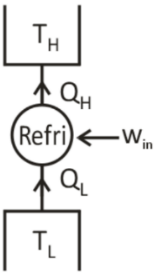
  Refrigerator – Desire effect is cooling at lower temperature, Thus $COP = \frac{Q_L}{W_{input}} = \frac{Q_L}{Q_H - Q_L}$

  If the refrigerator is reversible, Then, $Q \propto T \Rightarrow COP = \frac{T_L}{T_H - T_L}$

  Heat pump – Desire effect is Heating at higher temperature, Thus, $COP = \frac{Q_H}{W_{input}} = \frac{Q_H}{Q_H - Q_L}$

  If the refrigerator is reversible, Then, $Q \propto T \Rightarrow COP = \frac{T_H}{T_H - T_L}$



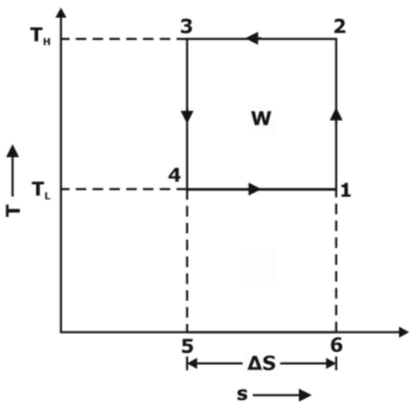


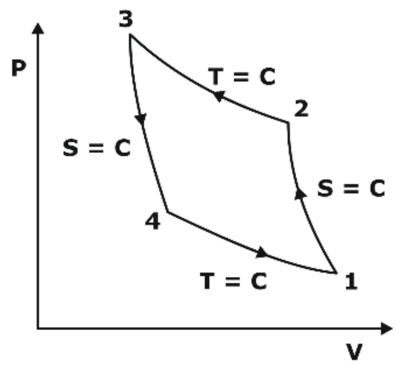
- **Relationship** between COP of a heat pump and COP of refrigerator and efficiency of heat engine operating between same temperature limits $(COP)_{HP} = 1 + (COP)_{Ref.} = \frac{1}{\eta_{HE}}$
- In a refrigerating machine, the heat exchanger that absorbs heat is connected to the conditioned space whereas in a heat pump, the heat exchanger that rejects heat is connected to the conditioned space.
- We can conclude that the same machine can be used either for cooling or for heating. When used for cooling, it is called a Refrigerating Machine and when used for heating it is called a Heat Pump.
- **Heat Rejection Ratio-** ratio of heat rejected in the condenser to the refrigeration effect

$$HRR = \frac{Q_C}{R.E} = 1 + \frac{1}{COP} \qquad \text{Also } HRR > 1$$

REVERSED CARNOT CYCLE

- A reversible heat engine can be reversed in operation to work as a refrigerating. The cycle consists of two isothermal and two isentropic.



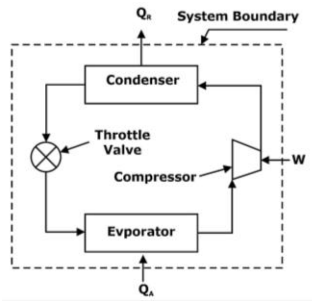


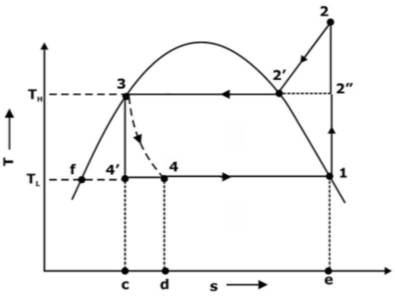
- A reversed Carnot cycle or reversible refrigeration cycle would measure maximum possible COP operating between two temperatures T_H of heat rejection and T_L of refrigeration.
- The Carnot COP depends on the operating temperatures T_H and T_L only. It does not depend on the working substance (refrigerant) used.

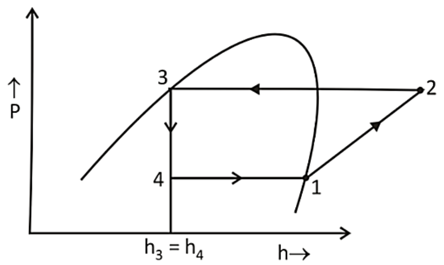
- for cooling, T_L is the refrigeration space temperature and its lowest possible value is '0' (absolute zero temp.) & maximum value T_H (ambient). Thus, **COP for Refrigeration varies between 0 and** ∞
- for heating, T_L is heat absorption temp. from the surroundings and its lowest possible value is '0' (absolute zero temp.) & maximum value T_H. So, **COP for Heat Pump varies between 1 and** ∞
- It may, therefore, be noted that to obtain maximum possible COP in any application,
    - the cold body temperature T_L should be as high as possible, and
    - the hot body temperature T_H should be as low as possible.
- For the purpose of comparison between the actual and Carnot cycle, a new efficiency is defined known as second law efficiency which is also known as exergy efficiency.
- Second law effieciency, $\eta_{II} = \dfrac{COP_{actual}}{COP_{ideal\ or\ carnot}}$
- **CASCADE REFRIGERATION SYSTEM** $(COP)_{cascade} = \dfrac{(COP)_1 \times (COP)_2}{1 + (COP)_1 + (COP)_2}$

CHAPTER-2 VAPOUR COMPRESSION REFRIGERATION SYSTEM

- VCRS is modified cycle over reversed Carnot cycle (practically not possible) with vapour as a refrigerant. it is most widely used in commercial refrigeration systems. Consequently, the theoretical COP of the vapour compression cycle is lower than that of the reversed Carnot cycle.
- VCRS consists of four basic components: Evaporator, Compressor, Condenser, Expansion device.
- **Refer below modifications**-
  - The isothermal processes of heat rejection and heat absorption in reverse Carnot cycle, replaced by **condensation** and **evaporation** respectively.
  - **Wet compression** advantages and disadvantages
    - liquid refrigerant may be trapped in the head of the cylinder and may damage the compressor valves and the cylinder itself.
    - liquid-refrigerant droplets may wash away the lubricating oil from the walls of the compressor cylinder, thus increasing wear.
    - With a reciprocating compressor, wet compression is not found suitable
  - **Dry compression** advantages and disadvantages
    - In dry compression refrigeration effect is more compare to wet compression.
    - Refrigerant leaves the compressor superheated due to which compressor work will increase.
  - The isentropic expansion process of the Carnot cycle replaced by simple **throttling process** as the positive work of isentropic expansion is not large enough to justify cost of an expander.







- The thermodynamic processes are as follows:

Process 1-2	Reversible Adiabatic compression	$S_2 = S_1$, Q = 0 Compression work, $W = h_2 - h_1$
Process 2-3	Constant Pressure Heat rejection (condensation)	P_H = const., W = 0 Heat rejected $Q_R = (h_2 - h_3)$
Process 3-4	Isenthalpic expansion	$h_3 = h_4 = h_{f4} + x(h_1 - h_{f4})$ Expansion Work, W = 0
Process 4-1	Constant pressure heat absorption (Evaporation)	P_L = const., W = 0 Heat absorbed $Q_A = (h_1 - h_4)$

- Refrigerating effect, RE = area 1-4-d-e = $h_1 - h_4$
- Refrigeration Capacity = $\dot{m}(h_1 - h_4)$

- Heat rejected: Q_R= area 2-2′-3-c-e $= \dot{m}(h_2 - h_3)$
- Work done: W= Q_A – Q_R = area 1-2-2′-3-c-d -4-1 = $\dot{m}(h_2 - h_1)$
- COP for cooling $COP = \frac{\text{Desired effect}}{\text{Work Input}} = \frac{R.E}{w_{in}} = \frac{h_1 - h_4}{h_2 - h_1}$
- The isentropic discharge temperature T_2 may be found by using saturation properties and the specific heat of vapour

$$s_1 = s_2 = s_2' + C_p \ln \frac{T_2}{T_2'} \quad \text{where } s_2' = s_{g2} \text{ and } T_2' = T_H$$

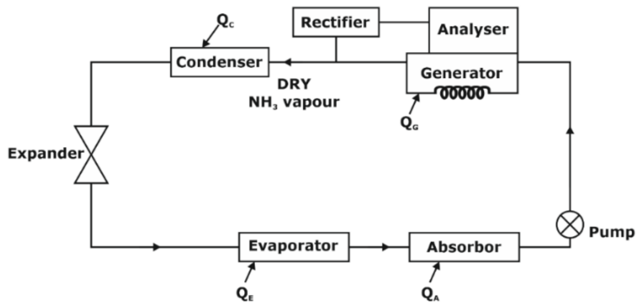
EFFECT OF OPERATING CONDITIONS ON THE PERFORMANCE OF VCRS

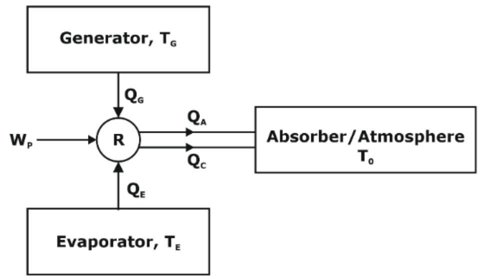
- **Decrease in evaporator pressure/temperature**
  - Decrease in refrigeration effect
  - Increase in work input
  - Decrease in COP
  - Decrease in η_{vol} due to the increase in pressure ratio
  - Increase in the specific volume of suction vapour
- **Increase in condenser pressure/temperature**
  - Decrease in refrigeration effect
  - Increase in work input
  - Decrease in COP
  - Decrease in η_{vol} due to the increase in pressure ratio
- **Super heating (within evaporator)**
  - Increase in Refrigeration effect.
  - Increase in w_{in} to the compressor as w_{in} is a function of inlet temp. to the compressor
  - COP may increase or decrease depending on the type of refrigerant used
  - In case of R–12 refrigerant, superheating would result an increase in COP whereas in case of NH_3 superheating would result in decrease in COP.
- **Liquid Subcooling (within condenser)**
  - Increase in refrigeration effect
  - No change in work input
  - Increase in COP
- **Liquid-Vapour Regenerative Heat Exchanger**
  - Keeping mass flow rate of the liquid and vapour same, from energy balance of the heat exchanger Q= $h_1' - h_1 = h_3 - h_3'$ but $T_3 - T_3' \neq T_{1'} - T_1$
  - both refrigeration effect and work input to compressor increases, COP may increase or decrease depending on the type of refrigerant used.

FLASH CHAMBER- The vapour is separated from the liquid refrigerant in the flash chamber & therefore only liquid enters the evaporator.

CHAPTER 3- VAPOUR ABSORPTION REFRIGERATION SYSTEM

- In VCRS, main cost of the refrigeration unit is compressor due to vapour phase compression. So, in VARS, compressor is replaced with:
  - **Absorption unit** to convert refrigerant vapour into liquid state.
  - **Pump** to compress it from evaporator pressure to compressor pressure in liquid state only
  - **Generator unit** to convert compressed liquid refrigerant into vapour form.
  - **Analyser and Rectifier** is optional. It is used remove water particles from the refrigerant vapour. The complete elimination of water particles is taken place in rectifier.
- In VARS heat rejection occurs in condenser & absorber and heat absorption occurs in evaporator & generator as shown in schematic diagram.





Here Q_E and Q_G → heat absorbed by the refrigerants across evaporator and generator

Q_c and Q_A → heat rejected by the refrigerant across condenser and absorber

T_o → atmospheric temperature

- Using first law of thermodynamics and Clausius inequality $(COP)_{actual} = \frac{Q_E}{W_p + Q_G}$
- Pump work $W_{pump} = -\int V_f dP$, specific volume of solution V_f very small. $W_p \to 0$ Neglected
- $(COP)_{VARS} = \frac{Q_E}{Q_G} = \frac{(T_G - T_O)}{T_G} \times \frac{T_E}{T_O - T_E} = \left(1 - \frac{T_O}{T_G}\right) \times \left(\frac{T_E}{T_O - T_E}\right) = \eta_{carnot} \times (COP)_{carnot}$

  here Carnot Engine operating between T_G & T_o and Carnot Refrigerator operating between T_0 & T_E.

COMMONLY USED ABSORBER REFRIGERANT PAIR AND THEIR WORKING

- **Ammonia - Water**
  - In this Ammonia is used as a refrigerant and water is used as absorber.
  - Ammonia absorb heat from the **evaporator**, then rejects heat in **absorber** and convert into liquid form. Due to special property of NH_3, ammonia absorb in water at lower temperature.

- Then ammonia water mixture is compressed to condenser pressure by **pump**. After this water get separated at higher temperature in **generator.** However, some water particle gets removed in analyser and rectifier assembly.

- **Li Br and water**
  - In this water is used as a refrigerant and lithium bromide is used as absorber.
  - The above pair is not preferable below 0°C (the freezing point of water is 0°C).

DIFFERENCE BETWEEN VCRS AND VARS

VCRS	VARS
1. Compressor is used.	1. Compressor is replaced with absorber, pump and generator.
2. COP of VCRS system is having higher value and lies b/w (3 to 5).	2. Relatively lower COP (0.3 to 0.5)
3. VCRS is work operated unit and runs on high grade energy.	3. It is heat operated unit or runs low grade energy.
4. Moisture related problem is more severe in VCRS.	4. Relatively lesser problem.
5. Chances for leakage of refrigerant are higher.	5. Relatively lesser
6. Creates more noise	6. Relatively lesser
7. Heat rejection occurs only in condenser.	7. Heat rejection occurs in condenser and absorber

ELECTROLUX REFRIGERATOR (R)

- Main aim of using this refrigerator system is to create noiseless operation. i.e., no use of pump.
- It is also called as **triple fluid** vaporization absorption system. Three-fluid are:
  - NH_3 → Refrigerant
  - Water (H_2O) → absorber
  - Hydrogen (H_2) → create low partial vapour pressure of NH_3 vapours (NH_3 Evaporates in H_2).
- In condenser pure NH_3 vapour pressure = Total pressure
- In Evaporator pure NH_3 vapour pressure = Total pressure – Partial pressure of H_2.

CHAPTER-4 GAS REFRIGERATION CYCLE

INTRODUCTION

- Gas is used as the working fluid which does not undergo any phase change during the cycle.
- Consequently, all internal heat transfer processes are sensible heat transfer.
- It finds applications in aircraft cabin cooling and also in liquefaction of various gases.
- Air is used as a refrigerant in aircraft system because of low weight per ton of refrigeration

STANDARD AIR REFRIGERATION CYCLE ASSUMPTION

- The working fluid is a fixed mass of air that behaves as an ideal gas.
- The cycle is assumed to be a close loop cycle heat transfer processes to or from surrounding.
- All the processes within the cycle are reversible, i.e. the cycle is internally reversible.
- The specific heat of air remains constant throughout the cycle.

BELL COLEMAN OR REVERSED BRAYTON CYCLE

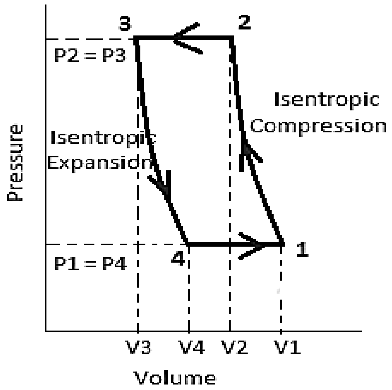
- Modification over reversed Carnot cycle (2 isothermal processes of reverse Carnot cycle replaced by two isobaric processes)
- The thermodynamic processes are as follows:

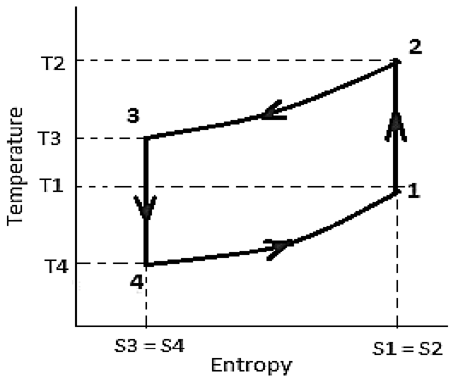
  1 – 2: Reversible adiabatic compression or isentropic compression

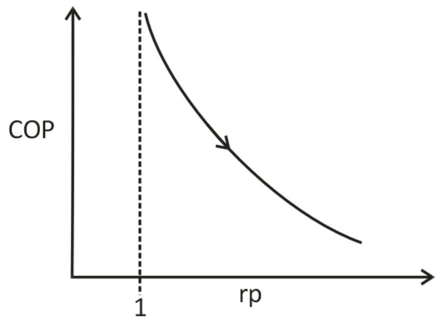
  2 – 3: Constant pressure heat rejection

  3 – 4: Reversible adiabatic expansion

  4 - 1: Constant pressure heat addition
- **Why not isenthalpic expansion as in VCRS-** Air is an ideal gas & for an ideal gas h = f(T) alone & hence if we are using isenthalpic expansion then, there would be no change in temperature i.e. (T_3 = T_4) hence instead of heat absorbing it will reject heat.





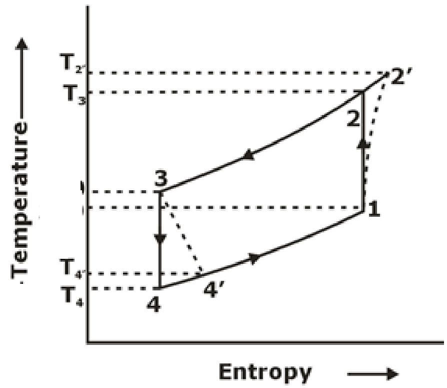


- $$COP = \frac{RE}{w_{in}(=w_c - w_t)} = \frac{h_1 - h_4}{(h_2 - h_1) - (h_3 - h_4)} = \frac{1}{(r_p)^{(\gamma-1)/\gamma} - 1}, \text{ where } r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4} \text{ (Pressure Ratio)}$$

ACTUAL CYCLE

- The actual reverse Brayton cycle differs from the ideal cycle due to:
  - Non-isentropic compression and expansion processes.

- Pressure drops in cold and hot heat exchangers.



- Isentropic efficiency of compressor $\eta_{is,compressor} = \frac{h_2 - h_1}{h_2' - h_1} = \frac{\text{Ideal work}}{\text{Actual work}}$
- Isentropic efficiency of turbine $\eta_{is,turbine} = \frac{h_3 - h_4'}{h_3 - h_4} = \frac{\text{Actual work}}{\text{Ideal work}}$
- Due to above irreversibilities net-work input increases. (compressor work $\uparrow$ & turbine work $\downarrow$)
- The refrigeration effect also reduces. COP of actual reverse Brayton cycles will decrease.

OPEN & CLOSE CYCLE

OPEN-AIR REFRIGERATION CYCLE	CLOSED AIR REFRIGERATION CYCLE
1. directly come in contact with space to be cooled	1. not come in contact with space to be cooled
2. suction pressure at atmospheric pressure	2. suction pressure higher than that of atmospheric pressure
3. volume of air handled by the compressor and expander is large	3. volume of air handled by the compressor and expander are smaller

CHAPTER-5 REFRIGERANTS

- Refrigerants are those working substance in a refrigerant cycle.
- **Primary Refrigerants-** those working refrigerants which directly flows into refrigerating machine and produce cooling effect. Ex: R – 11, R – 12, R – 22, R – 134
- **Secondary Refrigerants-** those working fluids which are first cooled by primary refrigerants & then used for cooling at the desired place. Ex: H_2O, Brine solution, sometimes ammonia.
- Almost all refrigerators are having similar value of COP when operating between same temp. limits.

NOMENCLATURE OF REFRIGERANTS

- If the refrigerant is **saturated HC** $C_mH_nF_pCl_q$ i.e. $n+p+q=2m+2$ $\Rightarrow R-(m-1)(n+1)\,p$
- If the refrigerant is **unsaturated HC** $C_mH_nF_pCl_q$ i.e. $n+p+q=2m$

  $\Rightarrow R-1(m-1)(n+1)\,p$
- If the refrigerant is **inorganic** compound $\Rightarrow R-[700+Molecular\ weight]$
- **Azeotropes** are the mixture of refrigerants which behaves like a pure substance. Their designation is started with $\Rightarrow R-500$

SELECTION OF REFRIGERANT (Desirable properties of refrigerant)

- **THERMODYNAMIC PROPERTIES**
  - **Critical temperature** should be as high as possible above the condensing temperature (normally ambient temperature).
  - More the **enthalpy of vaporization**, lee will be the mass flow rate of refrigerant for same amount of refrigeration capacity, then size of evaporator will be less.
  - Low **freezing point** is desirable to avoid freezing of refrigerant in the evaporator coils and thus choking of coils.

    Note: Above 3 properties of some refrigerant are given below.

Critical Temperature	Enthalpy of Vaporization	Freezing Point
H_2O ⇒ 374°C	H_2O ⇒ 2261 kJ/kg	H_2O ⇒ 0°C
SO_2 ⇒ 156.5°C	NH_3 ⇒ 1369 kJ/kg	R–22 ⇒ – 160.5°C
NH_3 ⇒ 132.4°C	R–22 ⇒ 234.7 kJ/kg	R–12 ⇒ – 157.4°C
R–12 ⇒ 111.5°C	R–12 ⇒ 165.7 kJ/kg	R–13 ⇒ – 77°C
R–22 ⇒ 96.5°C	R–134 ⇒ 197.3 kJ/kg	R–134(a) ⇒ – 103.2°C
R–134 ⇒ 101.21°C		
CO_2 ⇒ – 31°C		
Ethylene ⇒ – 10.2°C		

  - **Specific heat of the vapour** should be high in order to limit the degree of superheat.

Specific heat of liquid of refrigerant should be low in order to reduce irreversibility.

- High value of **thermal conductivity** is desirable as it help in reducing size of evaporator & condenser.
- **Evaporator pressure** and **condenser pressure** both should be positive (more than or equal to atmospheric pressure) to avoid possibility for leakage of air.
- Low **compression ratio** is desirable because high compression ratio results increase in work input to the compression and decrease in volumetric efficiency.
- High **Compressor discharge temperature** not desirable because more temperature → more pressure ratio → reduced volumetric efficiency. Also, at high temperature compressor's material of construction may react with refrigerant due to change in its properties. So, compressor need to be cool down.

Ammonia compressors	water cooled (due to high compressor discharge temperature)
R – 11/R – 12 Compressors	air cooled

- Lower **COP** represent higher running cost of equipment.
- **Volume at the inlet** of the compressor should be low as possible to avoid higher work input.

Type of Compressor	Pressure	Volume	Ex:
Reciprocating Comp.	High	Low	NH_3, CO_2
Centrifugal or Rotary comp.	Low	High	R – 11, R – 113

- **CHEMICAL PROPERTIES**
  - **Toxicity**: The refrigerant should be Non-toxic in nature. E.g. Ammonia is toxic in nature.
  - **Flammability:** The refrigerants should be non-inflammable in nature.
    Note: Ammonia (NH_3) is both toxic as well as flammable in nature.
  - **Action with oil:**
    - At condenser pressure and temperature refrigerants which are **fully miscible** or **fully immiscible** with oil does not create any problem.
    - Refrigerants which are **partially miscible** with oil are very dangerous because they can wash away all the lubricants present in the compressor. To avoid this an **oil separator** is installed between compressor and condenser. It will separate lubricants from refrigerant and bring back to the compressor.

      R + Fully Miscible with oil → R – 11, R – 12

      R + Fully immiscible with oil → NH_3, CO_2

      R + Partially Miscible with oil → R – 22
    - Presence of lubricating oil (liquid) in evaporation will decrease the heat transfer coefficient as if oil accumulates, the thickening oil film will act as an insulating layer.
  - **Action with material of construction:**

- Copper is not usually used in ammonia system because with the presence of little water only, ammonia becomes ammonium hydroxide, the OH^{-1} combined with Cu making cupric hydroxide of blue colour. Besides moist ammonia will not react with iron or steel. Therefore, only steel or ductile iron should be used for ammonia systems, ammonia containers.
- At high temperatures aluminium may act as catalysts for thermal breakdown of Freon refrigerant. Hence freons refrigerants are not used with aluminium construction.

Refrigerant	**Attack**	**Favourable**
NH_3	Copper	Wrought iron
Freon or Halocarbon compounds	Aluminium	Copper

- **PHYSICAL PROPERTIES**
  - **Cost:** It should be low.
  - **Viscosity:** viscosity of the refrigerant should be low for the easy flow of refrigerants.
  - **Leak detection:** there should not be leakage of refrigerant at any cost but if it leaks out then its detection should be as fastest as possible and by the simplest method.

Refrigerant used	**Leak detection Test**	**In case of refrigerant leak...**
Freon or Halo carbon compounds	Halide torch test	colour of light changes from blue to bluish green
NH_3	sulphur stick method	white fumes of Ammonium sulphite form
SO_2	Ammonia swab test	A dense white smoke form

- **Environmental Factor**
  - The chlorine element present in refrigerator, attacks the ozone layer which is situated in stratosphere. Therefore, refrigerants with lower ozone Depletion potential (ODP) preferred.
  - Eco-friendly refrigerants should use in which there is absence of chlorine elements.
  - E.g. Hydrocarbon,
    Flouro carbon,
    R-290 Propane (C_3H_8),
    R-134a Tetra-fluoroethane ($C_2H_2F_4$)
    R-600a Isobutane (C_4H_{10})

REFRIGERANT AND THEIR APPLICATIONS

- R – 11 : Large central AC plants.
- R – 12 : Domestic refrigerator, water cooler.
- R – 22 : Window AC
- NH_3: Cold storage plants.
- Brine : Milk chilling plants.
- CO_2 : Direct contact freezing of foods.
- AIR : Gas Liquification.
- Azeotropes: Aircraft refrigeration system.

CHAPTER-6 PSYCHROMETRY

It is the branch of science which deals with the study of properties of moist air

Moist air = Dry air + water vapour

Specific Humidity (w) $\omega = \frac{m_v}{m_a} = 0.622\left(\frac{Pv}{P - Pv}\right)$

Relative Humidity (ϕ) $\phi = \frac{m_v}{m_{v_s}} = \frac{\frac{P_v V}{R_v T}}{\frac{P_{v_s} V}{R_v T}} = \frac{P_v}{P_{v_s}}$

Degree of saturation $\boxed{\mu = \frac{\omega}{\omega_s}} = \phi\left[\frac{P - P_{vs}}{P - P_v}\right]$

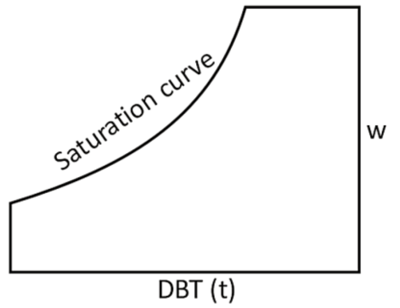
Enthalpy of Moist Air

$h_{moist} = 1.005t + w[2500 + 1.88t]$ kJ/kg

t is dry bulb temperature in °C.

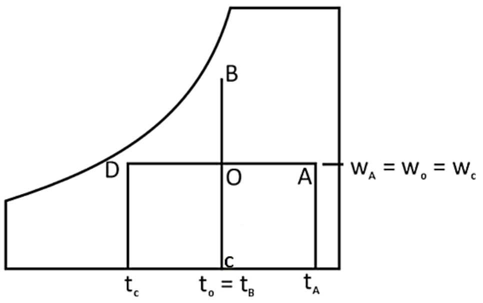
w is specific humidity.

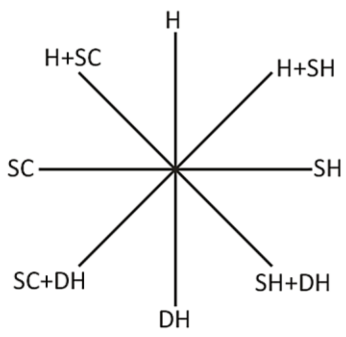
PSYCHROMETRIC CHART



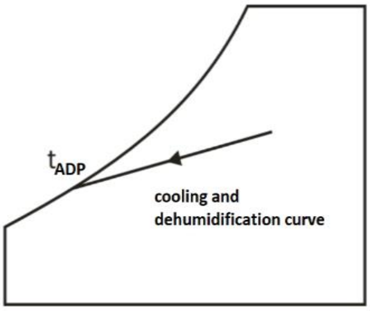
- W is specific humidity.
- DBT is dry bulb temperature.
- Saturation curve corresponds to 100 % relative humidity.

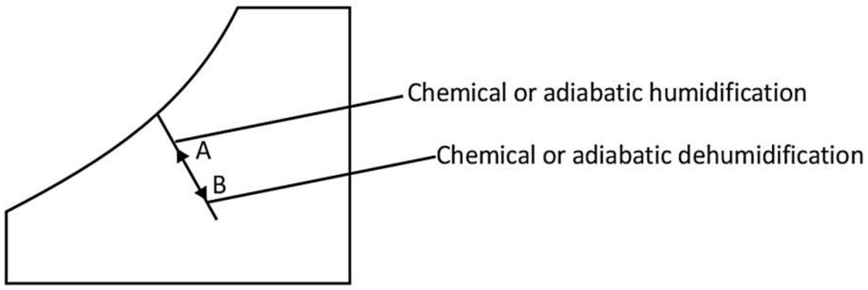
PSYCHROMETRIC PROCESSES



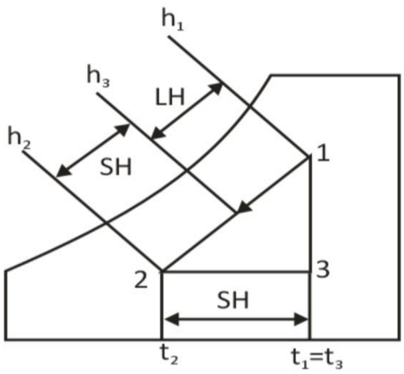


- H-Humidification
- DH-Dehumidification
- H+SC-Humidification and sensible cooling.
- H+SH-Humidification and sensible heating.
- SC- Sensible cooling
- SH-Sensible heating
- SC+DH-Sensible cooling and dehumidification.
- SH+DH-Sensible heating and dehumidification





Sensible Heat Factor $SHF = \frac{SH}{TH} = \frac{SH}{SH+LH}$



Bypass factor of a heating coil

$t_3 > t_2 > t_1$

$$(BPF)_{H.C.} = \frac{t_3 - t_2}{t_3 - t_1}$$

$$\eta_{H.C.} = 1 - (BPF)_{H.C.}$$

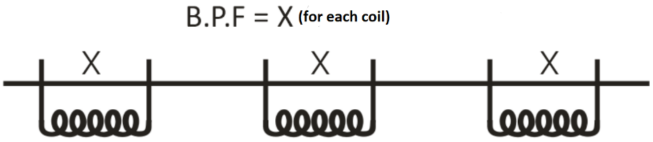
Bypass factor of cooling coil

$t_1 > t_2 > t_3$

$$(BPF)_{CC} = \frac{t_2 - t_3}{t_1 - t_3} \because t_2 > t_3$$

$$\eta_{cc} = 1 - (BPF)_{CC}$$

Bypass factor of a coil with more than one row of coils:



Combined BPF = X^N N → No. of coils

Where X = BPF of each coil

MIXING OF AIR STREAMS

t → DBT in °C

m → mass flow rate

h_2 → enthalpy

w → sp. Humidity

(a) $m_1 + m_2 = m_3$

(b) $m_1h_1 + m_2h_2 = m_3h_3$

(c) $m_1w_1 + m_2w_2 = m_3w_3$

(d) $m_1t_1 + m_2t_2 = m_3t_3$

Notes:

(1) Cooling and Dehumidification is possible when the cooling coil temperature is less than DPT of entering air.

(2) During heating and dehumidification, the dry bulb temperature increases and specific humidity decreases.

(3) Example of heating and humidification → steam spray in air

(4) In case of desert coolers, we achieve cooling and humidification

(5) Desert coolers are more effective when the value of "Wet Bulb depression = DBT – WBT is high"

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