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PART - A

2 Marks Questions

1.
Sol. A reversed Carnot cycle using air as working medium (or refrigerant) is shown on p-v and T-s diagrams in (a) and (b) respectively.

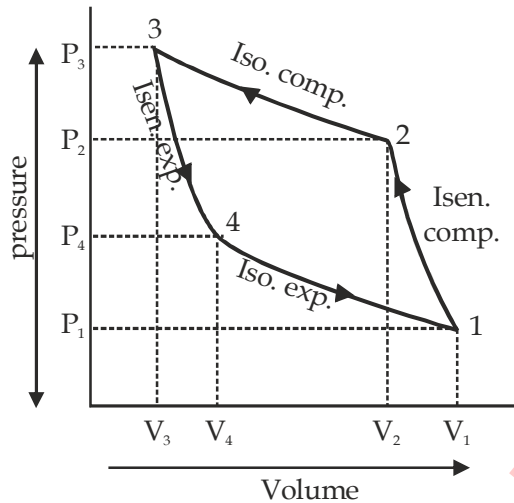


Fig.: (a) - p-v diagram

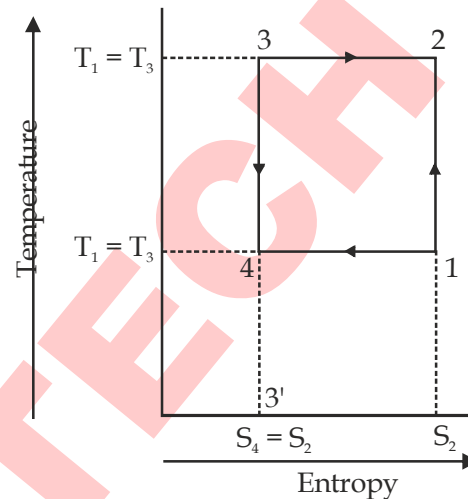


Fig.: (b)- T-s diagram

2.
Sol. The absorber's function in a vapor absorption refrigeration (VAR) system is to act as a thermal compressor, replacing the mechanical compressor used in vapor compression systems. It absorbs the low-pressure refrigerant vapor from the evaporator, creating a high-pressure liquid solution that can then be pumped to the generator.
3.
Sol. **Advantages of capillary tube:** The advantage of a capillary tube as a metering device is inexpensive and has no moving parts. Because it cannot change in order to match the different amounts of refrigerant that may be flowing through the system however, its use is restricted to those systems that have a relatively constant load.
4.
Sol. **Purpose of dehydrator (filter drier):** Dehydrators (filter drier) serves a dual purpose, first they act to strain out any particles that may be in the system.
 Most commonly, these particles might be oxidation that has formed on the inside of brazed tubing which breaks loose during operation of the system.
 The second function of a dehydrator (filter drier) is to dry the refrigerant that does not mean that it removes liquid but that it absorbs and holds water that may have not been properly removed when the system was put together.
5.
Sol. 24°C DBT, 60% RH
6.
Sol. **Introduction**
 Leak testing in refrigeration and air conditioning systems may be categorized into 2 ways
 1. Nitrogen leak testing



2. Refrigerant leaktesting

Nitrogen leak testing

This method is applicable/used when the system is under processing/reprocessing before charging refrigerant

This method requires dry nitrogen cylinder set and soap solution to perform bubble test

7.

Sol. Alternatively 'dry air 100%' can be also used in the place of nitrogen gas

Refrigerant leak testing

This method is applicable when the system (existing) is affected with the problem/complaint 'short of gas/ poor cooling effect'.

This method requires some instruments according to the refrigerant type

The methods which can be used with specific refrigerants are as follows in increasing order of efficiency.

8.

Sol. Given:

Infiltration = 1 air change per hour

cmm = volumetric flow rate cubic meter per minute = $(20 \times 30 \times 4)/60 = 40 \text{ m}^3/\text{min}$

$\Delta T = (40^\circ - 25^\circ) = 15^\circ\text{C}$

Sensible heat load due to infiltration,

$\text{SHL} = [0.0204 \times \text{cmm} \times \Delta T] \text{ kW}$

$= 0.0204 \times 40 \times 15 = 12.24 \text{ KJ/s} = 12.24 \text{ kW}$

9.

Sol. Given, SH = 3, LH = 1

$$\text{SHF} = \frac{\text{SH}}{\text{SH} + \text{LH}} = \frac{3}{3 + 1} = 0.75$$

10.

Sol. Thermoelectric refrigeration system operates on the principle of 'Peltier effect'.

11.

Sol. Main precaution to be taken is that very hot things should not be put in refrigerator, if it is done it will quickly evaporate the refrigerant in evaporator coils producing a large vapour pressure resulting in increase in the duty of the compressor and as such motor has to work for longer duration in order to bring down the temperature in the freezer compartment. It may damage the motor, which is short-time rated. Also moisture released from hot things will freeze around the freezer compartment which has to be defrosted.

12.

Sol. The door is provided with automatic closing mechanism-door hinges are provided in such a way that door flap when left in open position automatically comes to closing position due to gravity and as it approaches closing position it is attracted by the magnetic strip fitted behind the sealing rubber ring and thus the door is closed with snap action. All this is done to prevent leakage of atmospheric heat inside the refrigerator.

13.

Sol. Capacitor-start single phase induction motor is used in open type refrigerators and split-phase single phase induction motor is used in sealed unit refrigerator. Electromagnetic relay is provided to connect auxiliary winding on the start and disconnect it when the motor picks up the speed.

If the automatic starter relay keeps the auxiliary winding open after the motor has been operating, little harm should occur since the motor is provided with overcurrent protection. The motor simply won't start on the next attempt. On the other hand, should the switch remain closed, the motor will start and run. The auxiliary winding will get quickly overheated, and if not detected, or cut out by a protective relay, this winding may cause damage to the main winding due to their proximity.

14.

Sol. In this modern age every body is trying to improve his surroundings in order to make living conditions more comfortable. Air conditioning is one of the important contribution in this respect. The technique of maintaining of air condition inside a building in such a way that produces comfort to human beings, ensures trouble free operation of delicate equipment or helps in industrial manufacturing operations is called air conditioning. It involves control of temperature, cleanliness, humidity and circulation of air.

15.

Sol. The purpose of compressor is to remove the vapour from the evaporator and to raise its temperature and pressure to a point such that vapour can be condensed with normally available condensing media.

16.

Sol. The purpose of Expansion Valve is to meter the proper amount of refrigerants to the evaporator and to reduce the pressure of liquid entering the evaporator so that liquid will vaporize in the evaporator at the desired low temperature.

17.

Sol. The purpose of Evaporator is to provides a heat transfer surface through which heat can pass from the refrigerated space or product into the Vaporizing refrigerants.

18.

Sol. If the Vapour is Super-Heated at the end of compression, then the operation is know as Dry Compression.

19.

Sol. The ton measure of air conditioners indicates their cooling capacity, with 1 ton equal to 12,000 BTUs per hour.

- 1 ton = 12,000 BTUs/hour, which is the standard measure for cooling capacity.
- Common residential units range from 1.5 to 5 tons, depending on the size of the space.
- Larger commercial units can exceed 20 tons for extensive cooling needs.
- The tonnage needed is calculated based on factors like room size, insulation, and climate.

20.

Sol. The chemical formula of R134a is $C_2H_2F_4$.

- R134a is also known as 1,1,1,2-Tetrafluoroethane.
- It is a non-ozone depleting refrigerant commonly used in air conditioning systems.
- The chemical formula $C_2H_2F_4$ represents the two carbon atoms, two hydrogen atoms, and four fluorine atoms in R134a.

21.

Sol. A shell and tube type condenser is a heat exchanger used in HVAC systems to transfer heat from the refrigerant gas to the cooling water or air.

- Consists of a series of tubes through which the refrigerant flows, surrounded by a shell through which the cooling medium flows
- Efficient in transferring heat due to large surface area provided by the tubes
- Commonly used in air conditioning systems and refrigeration units
- Examples include water-cooled condensers in large commercial HVAC systems

22.

Sol. The gap between an AC indoor unit and the ceiling is typically 6 to 12 inches for optimal airflow and maintenance access.

- A gap of 6 to 12 inches allows for proper airflow and prevents overheating.
- This space facilitates easy access for maintenance and cleaning.
- If the gap is too small, it can restrict airflow and reduce efficiency.
- In some installations, local building codes may specify minimum clearance requirements.



23.

Sol. **Absolute humidity** is the mass of water vapour present in one kg of dry air.

Relative humidity is the ratio of the actual mass of water vapour present in one kg of dry air at the given temperature to the maximum mass of water vapour it can withhold at the same temperature. Absolute humidity is expressed in terms of kg/kg of dry air. Relative humidity is expressed in terms of percentage.

24.

Sol. **Psychrometry**

The psychrometry is that branch of engineering science which deals with the study of moist air, i.e. dry air mixed with water vapour or humidity.

25.

Sol. **Dry air:** The pure dry air is a mixture of number of gases such as nitrogen, oxygen, carbon dioxide, hydrogen, argon, neon, helium etc. but the nitrogen and oxygen have the major portion of the combination.

26.

Sol. **Moist air:** It is a mixture of dry air and water vapour. The amount of water vapour, present in the air, depends upon the absolute pressure and temperature of the mixture.

27.

Sol. **Saturated air:** It is a mixture of dry air and water vapour, when the air has diffused the maximum amount of water vapour into it.

28.

Sol. **Degree of saturation:** It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it is saturated at the same temperature and pressure.

29.

Sol. **Humidity:** It is the mass of water vapour present in 1 kg of dry air, and is generally expressed in terms of gram per kg of dry air (g/kg of dry air). It is also called specific humidity or humidity ratio.

30.

Sol. **Absolute humidity:** It is the mass of water vapour present in 1 m³ of dry air, and is generally expressed in terms of gram per cubic metre of dry air (g/m³ of dry air).

31.

Sol. **Relative humidity:** It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure.

32.

Sol. **Dry bulb temperature** is the temperature of air recorded by a thermometer, when it is not affected by the moisture present in the air.

33.

Sol. **Wet bulb temperature:** It is the temperature of air recorded by a thermometer, when its bulb is surrounded by a wet cloth exposed to the air. Such a thermometer is called wet bulb thermometer.

34.

Sol. **Wet bulb depression:** It is the difference between dry bulb temperature and wet bulb temperature at any point. The wet bulb depression indicates relative humidity of the air.

35.

Sol. **Dew point temperature:** It is the temperature of air recorded by a thermometer, when the moisture (water vapour) present in it begins to condense. In other words, the dew point temperature is the saturation temperature corresponding to the partial pressure of water vapour.

36.

Sol. Dew point depression: It is the difference between the dry bulb temperature and dew point temperature of air.

37.

Sol. Dalton's Law of Partial Pressures

It states, "The total pressure exerted by the mixture of air and water vapour is equal to the sum of the pressures, which each constituent would exert, if it occupied the same space by itself". Or in other words, the total pressure exerted by air and water vapour mixture is equal to the barometric pressure. Mathematically, barometric pressure of the mixture,

$$P_b = P_a + P_v$$

where

P_a = Partial pressure of dry air, and

P_v = Partial pressure of water vapour.

38.

Sol. Refrigerants

The refrigerant is a heat carrying medium which during their cycle (i.e. compression, condensation, expansion and evaporation) in the refrigeration system absorb heat from a low temperature system and discard the heat so absorbed to a higher temperature system.

39.

Sol. A good refrigerant should have the following properties :

1. Low boiling point,
2. High critical temperature,
3. High latent heat of vaporisation,
4. Low specific heat of liquid,
5. Low specific volume of vapour,
6. Non-corrosive to metal,
7. Non-flammable and non-explosive,
8. Non-toxic,
9. Low cost,
10. Easy to liquify at moderate pressure and temperature,
11. Easy of locating leaks by odour or suitable indicator, and
12. Mixes well with oil.

40.

Sol. Coefficient of Performance of Refrigerator

Theoretically, a refrigerator is a reversed heat engine or a heat pump which pumps heat from a cold body and delivers it to a hot body. The substance which works in a heat pump to extract heat from a cold body and deliver it to a hot body, is called a refrigerant.

The coefficient of performance (briefly written as C.O.P.) is the ratio of heat extracted in the refrigerator to the workdone on the refrigerant. It is also known as theoretical coefficient of performance.

Notes:

1. The coefficient of performance is the reciprocal of the efficiency of a heat engine. It is thus obvious that the value of C.O.P. is always greater than unity.
2. The ratio of the actual C.O.P. to the theoretical C.O.P. is known as relative coefficient of performance. Mathematically,

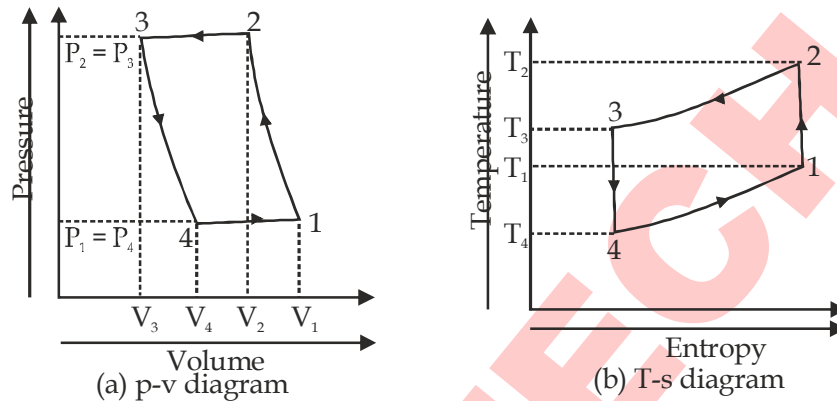
$$\text{Relative C.O.P.} = \frac{\text{Actual C.O.P.}}{\text{Theoretical C.O.P.}}$$

PART - B

5 Marks Questions

41.

Sol. The Bell-Coleman cycle is a modification of reversed Carnot cycle. The cycle is shown on p-v and T-s diagrams in Fig. (a) and (b) respectively.



Process of reversed Brayton cycle are :

Process 1-2 : Isentropic compression ($S = \text{constant}$)

The cold air from the refrigerator is drawn into the compressor cylinder during suction.

Process 2-3 : Constant pressure heat rejection ($p = \text{constant}$).

Heat absorbed by the air is exchange to water (cooling medium), thus it become cooled at constant pressure.

Process 3-4 : Isentropic expansion ($S = \text{constant}$).

Air from the cooler is now drawn into the expander cylinder where it is expanded at constant enthalpy, pressure fall from P_3 to the refrigeration pressure P_4 which is equal to atmospheric pressure.

Process 4-1 : Constant pressure heat addition ($p = \text{constant}$).

Cold air from the expander is now passed to the refrigerator where it is cooled at constant pressure. Heat extracted from the refrigerator is out desired effect known as refrigerant effect.

$$\text{And, work done per cycle} = \frac{\text{RE}}{\text{COP}}$$

where,

$$\text{COP} = \frac{1}{\left[(r_p)^{\frac{\gamma-1}{\gamma}} - 1 \right]}$$

42.

Sol. Given;

$$\text{Work/Power input (W)} = 0.75 \text{ kW} = 0.75 \text{ kJ/s} = 0.75 \times 3600 = 2700 \text{ kJ/h}$$

$$\text{Refrigeration Capacity (R.C.)} = 12000 \text{ kJ/h}$$

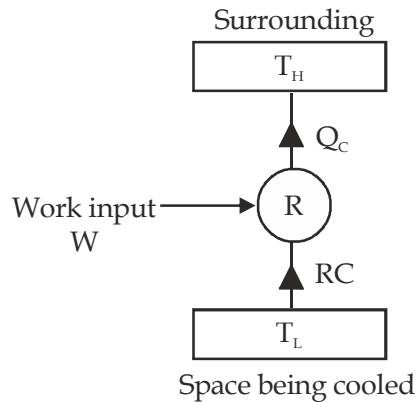


Fig.:- Refrigerator

Coefficient of performance of the refrigerator :

$$(C.O.P.)_{ref} = \frac{\text{Desired effect}}{\text{Work input}} = \frac{\text{Heat absorbed at lower temperature}}{\text{Work input}}$$

$$(C.O.P.)_{ref} = \frac{12000}{2700}$$

$$(C.O.P.)_{ref} = 4.444$$

Now, heat transfer rate in the condenser :

$$\begin{aligned} Q_c &= W + R.C. \\ &= 2700 + 12000 \\ Q_c &= 14700 \text{ kJ/h} \end{aligned}$$

Hence, the coefficient of performance of the refrigerator is 4.44 and heat transfer rate in the condenser is 14700 kJ/h.

43.

- Sol.**
- The purpose of undercooling is to increase the refrigerating effect and COP so that the requirement of refrigerant flow rate and compressor capacity is reduced as compared to simple saturated cycle.
 - If the compression is carried out before the refrigerant reaches saturation state then it is known as wet compression, but if the refrigerant is compressed after reaching dry saturation state, it is known as dry compression.
 - The wet compression is not preferred in reciprocating compressors as wet liquid droplets can damage the compressed valves and cylinders. Although if the compression is done in superheated region the work requirement increases. Wet compression is usually done in screw compressors with ammonia as the refrigerant.

44.

- Sol.** Given: COP = 0.1; Volume = $0.35 \times 10^{-3} \text{ m}^3$; $\Delta T = 20 - 4 = 16^\circ\text{C}$;
 $t = 30 \text{ minutes}$; $p = 1000 \text{ kg/m}^3$; $c_p = 4.18 \text{ kJ/kg-K}$

$$\text{Refrigeration capacity} = \frac{m c_p \Delta T}{t} = \frac{10^3 \times 0.35 \times 10^{-3} \times 4.18 \times 16}{30 \times 60} = 0.013 \text{ kW}$$

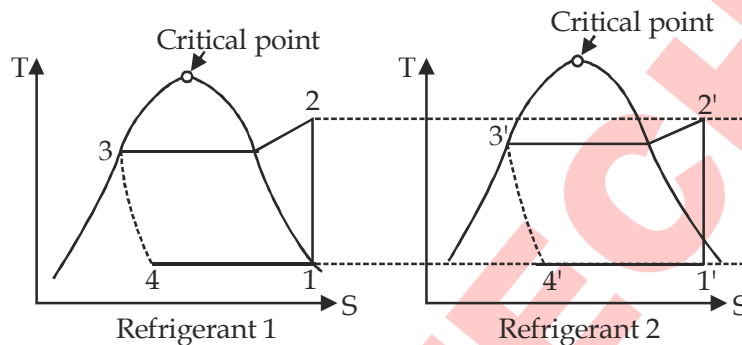
$$\text{COP} = \frac{\text{Refrigeration capacity}}{\text{Power input}}$$



$$\text{Power input} = \frac{0.013}{0.1} = 0.13 \text{ kW}$$

45.

Sol. For high COP, in general, the critical temperature should be very high so that the condenser temperature line on the p-h diagram is far removed from the critical point. This ensures reasonable refrigerating effect which becomes very small if the state of the liquid before expansion is near the critical point. Also, the critical pressure should be low so as to result in low condensing pressure, except for carbon dioxide for which the critical temperature is 31°C for most of the common refrigerants, critical temperature is much above the normal condensing temperature.



In the above figure, we can see that both refrigerant but the refrigerant effect for 1 (i.e. temperature $(h_1 - h_4)$) is more than refrigerant effect for 2 (i.e. temperature $(h'_1 - h'_4)$) thus $(\text{COP})_1$ would be more as compared to $(\text{COP})_2$.

∴ We can say that, refrigerant with more critical temperature will perform better than refrigerant with less critical temperature.

46.

Sol. (i) Household refrigerator:

- Specific volume should be small because for larger specific volume the size of compressor required is large
- Compressor discharge temperature should not be very high e.g. Ammonia has to be water cooled after compression.
- It should be non toxic and easy to detect in case of leakage.

(ii) Ice Plant:

- Should be cheaper
- High enthalpy of vapourisation
- Should not be flammable
- In case of vapours degree of super heat should be small.

(iii) Cinema Hall:

- Environment friendly and non toxic
- Higher COP is desired
- Higher critical temperature

47.

Sol.

Applications	Conventional Refrigerants	Alternative Refrigerants
Domestic Refrigerators	R-11	R-134a, R-290
Central Air-conditioning plants	R-12	R-123, R-134a, R-410a

48.

Sol.

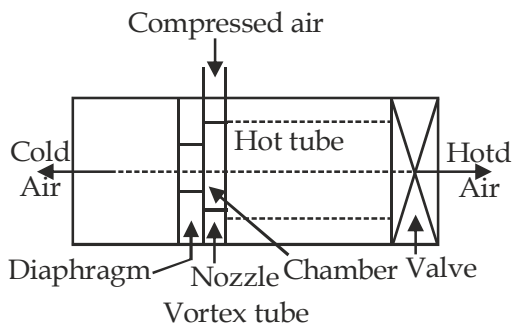


Figure shows a Vortex tube refrigeration system. It consists of following parts:

1. Nozzle
2. Diaphragm
3. Valve

Working: Compressed air is passed through the nozzle. Inside nozzle, air expands and acquires high velocity. A vortex flow is created in chamber and air travels in spiral like motion along periphery of hot side. This flow is restricted by valve. When pressure of air near the valve is increased more than outside by partially closing the valve, a reversed axial flow through the core of hot side starts from high pressure region to low pressure region. During this period, energy transfer takes place between reversed stream and forward stream and therefore air stream, through the core gets cooled below the inlet temperature of air in vortex tube while air stream in forward direction gets heated.

The cold stream is escaped through the diaphragm hole into the cold side, while hot stream is passed through the opening of valve.

Advantages of Vortex tube:

1. It only uses air as refrigerant so there is no leakage problem.
2. Vortex tube is simple in design and it avoids control system.
3. There is complete absence of moving parts in Vortex tube.
4. It is light in weight and requires less space.
5. Cheaper in initial cost.
6. Working expenses are less as compressed air is readily available.
7. Maintenance is simple and no expert attendant is required.

49.

Sol. Humidity: It is the mass of water vapour present in 1 kg of dry air, and is generally expressed in terms of gram per kg of dry air (gm/kg of dry air). It is also called specific humidity or humidity ratio.

Dry bulb temperature: It is the temperature of air recorded by a thermometer, when it is not affected by the moisture present in the air. The dry bulb temperature (briefly written as DBT) is generally denoted by t_a or t_{db} . **Wet bulb depression:** It is the difference between dry bulb temperature and wet bulb temperature at any point. The wet bulb depression indicates relative humidity of the air.

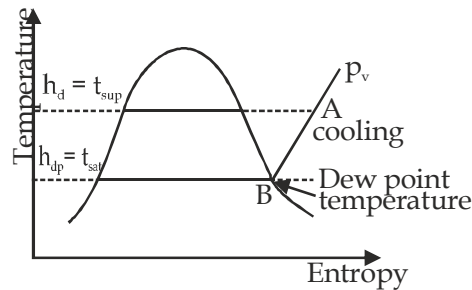
50.

Sol. Thermodynamic wet bulb temperature: It is the temperature at which air can be brought to saturation state, adiabatically by the evaporation of water into the flowing air. It is measured by adiabatic saturation process.

Wet bulb temperature: It is temperature of air measured by thermometer when its bulb is covered with wet cloth. It indirectly indicates the moisture content in air. When air is saturated, dry bulb temperature is equal to wet bulb temperature.

51.

Sol. Dry bulb temperature: It is the temperature of air recorded by a thermometer, when it is not affected by the moisture present in the air. The dry bulb temperature (briefly written as DBT) is generally denoted by t_d or t_{ab} .



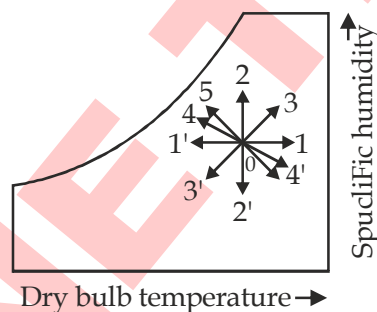
Wet bulb temperature : It is the temperature of air recorded by a thermometer, when its bulb is surrounded by a wet cloth exposed to the air. Such a thermometer is called wet bulb thermometer. The wet bulb temperature (briefly written as WBT) is generally denoted by t_w or t_{wb} .

Dew point temperature : It is the temperature of air recorded by a thermometer, when the moisture (water vapour) present in it begins to condense. In other words, the dew point temperature is the saturation temperature (t_{sat}) corresponding to the partial pressure of water vapour (p_v). It is, usually, denoted by t_{dp} . Since p_v is very small, therefore the saturation temperature of water vapour at p_v is also low (less than the atmospheric or dry bulb temperature).

Specific humidity or humidity ratio: It is the mass of water vapour present in 1 kg of dry air (in the air-vapour mixture) and is generally expressed in gm/kg of dry air.

52.

Sol. The various psychrometric processes on a psychrometric chart is as shown below:



- 0-1: Sensible heating: Only the heating of air without any change in its specific humidity done.
- 0-1': Sensible cooling is the decreasing in dry bulb temperature of air without changing the specific humidity.
- 0-2: Humidification is the process of increasing the specific humidity of air without changing the dry bulb temperature.
- 0-2': Dehumidification is the process of decreasing the specific humidity of air without changing the dry bulb temperature.
- 0-3: Combination of heating and humidification. It is used in winter air conditioning.
- 0-3': Combination of cooling and dehumidification. It is used in summer air conditioning.
- 0-4: It is cooling and humidification.
- 0-4': It is heating and dehumidification.
- 0-5: Adiabatic humidification, here the enthalpy remains constant. Specific humidity increases and dry bulb temperature decreases.

53.

Sol. Heating and Humidification: (0-1)

- Dry bulb temperature increases.
- Specific humidity increases.
- Enthalpy increases.
- Dew point temperature increases.

5. Wet bulb temperature increases.
6. Specific volume increases.
7. It is used in winter air conditioning.

Cooling and Humidification (0-1')

1. Dry bulb temperature decreases.
2. Specific humidity increases.
3. Dew point temperature decreases
4. RH increases

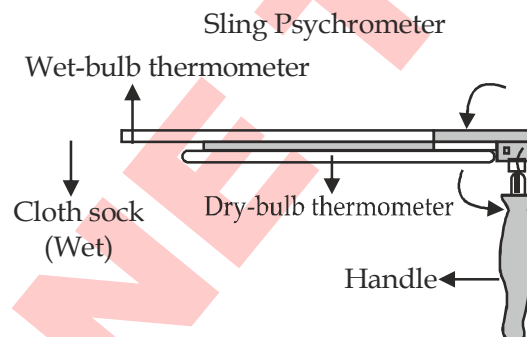
Adiabatic saturation (0-2')

1. Dry bulb temperature decreases.
2. Specific humidity increases.
3. Enthalpy and wet bulb temperature remains same.
4. Specific volume decreases.
5. RH increases

All the 3 processes are possible in air-washer.

54.

- Sol.** The dry-bulb temperature (DBT) is the temperature of air measured by a thermometer freely exposed to the air but shielded from radiation and moisture. DBT is the temperature that is usually thought of as air temperature, and it is the true thermodynamic temperature. Wet Bulb temperature can be measured by using a thermometer with the bulb wrapped in wet muslin. The adiabatic evaporation of water from the thermometer bulb and the cooling effect is indicated by a "wet bulb temperature" lower than the "dry bulb temperature" in the air.



Sling Psychrometer

For measuring the relative humidity in the air, an instrument known as a hygrometer is used.

Of the several different types of hygrometers available for use, the sling psychrometer is the simplest, both in terms of design and ease-of-use.

It gets its name from the fact that this instrument comprises a chain/handle on one end, which has to be used to swing the two thermometers mounted on its frame around in circles to generate air flow. This process allows the device to measure a temperature difference, which is directly proportional to the humidity in the air. Thus the user is able to determine the value of humidity with an appreciable level of accuracy.

Principle of Working

This instrument works on the principle of vaporation of water. When water on a surface evaporates, it extracts a significant amount of heat from it, cooling the surface down. This is how sweat is able to cool down our body and skin when it gets hot.

However, air can only hold a limited amount of water, after which it becomes saturated. This can be observed in beaches and coastal regions, where since the air is humid, the sweat from our bodies doesn't evaporate easily.

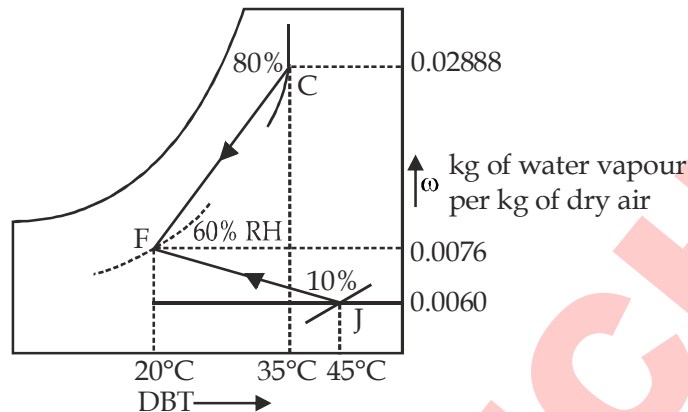
The psychrometer is designed to make use of both these facts, to help us measure the humidity of air.



55.

Sol. **Note:** This psychrometric chart is provided in exam, but the solution you can refer your own psychrometric chart.

Attach th Psychrometric chart shown below.



(ii) For jaisalmer: Cooling coil with humidifier is required

For Chennai: Cooling coil with dehumidifier is required.

(iii) For Jaisalmer:

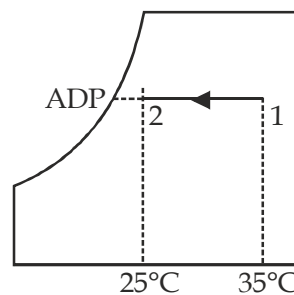
$$\begin{aligned}\text{Moisture added} &= w_f - w_j \\ &= 0.0076 - 0.0060 \\ &= 0.0016 \text{ kg of w.v./kg of d.a.} \\ &= 1.6 \text{ gm of w.v./kg of d.a.}\end{aligned}$$

For Chennai:

Moisture revolved = $w_c - w_f$
 = $0.0288 - 0.0076 = 0.0212$ kg of w.v./kg of d.a. = 21.2 gm of w.v./kg of d.a.

56.

Sol. Refer figure,



- It is a sensible cooling process.
- From Psychrometric chart, coil surface temperature, we get

$$t_{\text{ADP}} = 17.5^{\circ}\text{C}$$

By pass factor,

$$\text{BPF} = \frac{t_2 - t_{\text{ADP}}}{t_1 - t_{\text{ADP}}} = \frac{25 - 17.5}{35 - 17.5} = 0.428$$

57.

Sol. The proper combination of temperature, humidity and air movement, which induce a feeling such that any human being feels comfortable is known as human comfort condition.

Factors governing optimum effective temperature are:

1. Temperature of air
2. Relative humidity of air
3. Velocity of air
4. Purity of air
5. Standing wall temperature

Cooling load estimate:

Room load

(A) Room sensible heat (RSH)

- (i) Solar and transmission heat gain through walls, roofs, etc.
- (ii) Solar and transmission heat gain through glass.
- (iii) Transmission gain through partition walls, ceiling, floor, etc.
- (iv) Infiltration
- (v) Internal heat gain not accounted above.
- (vi) By passed outside air load.

The sum of items (i) to (vi) gives the effective room sensible heat (ERSH).

(B) Room latent heat (RLH)

- (i) Infiltration
- (ii) Internal heat gain from people, steam, appliances, etc.
- (iii) Vapour transmission
- (iv) Additional heat gain
- (v) Supply duct leakage loss

The sum of (i) to (v) gives the effective room latent heat ERLH and $ERLH + ERSR = ERTH$ (Effective room total heat).

Heating load estimate:

The following points are considered:

- (i) **Transmission Heat Loss:** The transmission heat loss from walls, roofs, etc. is calculated on the basis of outside and inside air temperature difference $Q = UA (t_i - t_o)$.
- (ii) **Solar Radiation:** There is generally no solar radiation present and hence, there is no solar heat gain at the time of the peak load which normally occurs in the early hours of the morning.
- (iii) **Internal Heat Gains:** Internal heat gains from occupants, lights motors and machinery, etc. diminish the heating requirement. These negative loads should be accounted for in application such as theatres, assembly halls, stores, office, building etc.

58.

Sol. There are three common methods for the sizing of ducts. They are:

Equal friction (EF) method: In the equal friction method, the frictional pressure drop per unit length of the duct is maintained constant throughout the duct system. Knowing the air flow rate and the velocity in the main duct, the size and friction loss are determined from the chart.

If an equal friction design has a mixture of short and long runs of duct, the shortest duct will need a considerable amount of dampering. This is a drawback of the equal friction design.

Velocity reduction method: The main duct is designed in the same manner as in the equal friction method. Thereafter, arbitrary reductions are made in the air velocity as we go down the duct run. Equivalent diameters are found, as before, from the friction chart.

It is not normally adopted unless the person using it has considerable practical experience and knowledge to design within reasonable accuracy.

Static regain (SR) method: The principle of the static regain method is to maintain a constant static pressure before each terminal and each branch. This is achieved by sizing the duct in such a manner that after each branch or outlet, the static pressure gain due to reduction in velocity exactly balances the pressure drop in the succeeding duct section.

59.

Sol. **RSHF:** It is defined as the ratio of room sensible heat to the room total heat,

$$\text{RSHF} = \frac{\text{RSH}}{\text{RSH} + \text{RLH}}$$

RSH = Room sensible heat, RLH = Room latent heat, and RTH = Room total heat

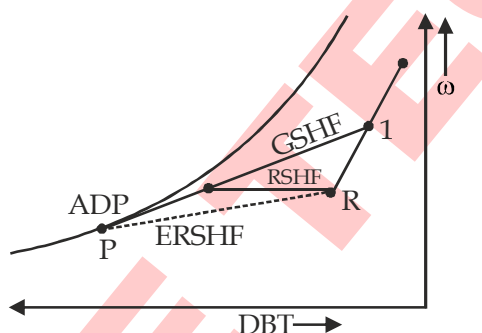
The conditioned air supplied to the room must have the capacity to take up simultaneously both the room sensible heat and room latent heat loads. The point S on the psychrometric chart, as shown in figure, represents the supply air condition and the point R represents the required final condition in the room (i.e. room design condition).

The line SR is called the room sensible heat factor line (RSHF line). The slope of this line gives the ratio of the room sensible heat (RSH) to the room latent heat (RLH).

GSHF: It is defined as the ratio of the total sensible heat to the grand total heat which the cooling coil or the conditioning apparatus is required to handle. Mathematically, grand sensible heat factor,

$$\text{GSHF} = \frac{\text{TSH}}{\text{GTH}} = \frac{\text{TSH}}{\text{TSH} + \text{TLH}} = \frac{\text{RSH} + \text{OASH}}{(\text{RSH} + \text{OASH}) + (\text{RLH} + \text{OALH})}$$

ERSHF: It is defined as the ratio of the effective room sensible heat to the effective room total heat.



$$\text{ERSHF} = \frac{\text{ERSH}}{\text{ERTH}} = \frac{\text{ERSH}}{\text{ERSH} + \text{ERLH}}$$

$$\begin{aligned} \text{ERLH} &= \text{Effective room latent heat} \\ &= \text{RLH} + \text{OALH} \times \text{BPF} \end{aligned}$$

$$\text{ERSH} = \text{RSH} + \text{OASH} \times \text{BPF}$$

$$\begin{aligned} \text{ERTH} &= \text{Effective room total heat} \\ &= \text{ERSH} + \text{ERLH} \end{aligned}$$

$$\text{BPF} = \text{By-pass factor}$$

60.

Sol.

S.No	Conventional type	Frost free type
1	Periodical cleaning of frost formation has to be made	The automatic defrosting is provided
2	Initial investment is less	Comparatively costly
3	Consumption of current is less	Consumption of current is more
4	Freezing time of a product in conventional is more	The freezing time is less
5	The cooling is not uniform cooling/freezing	You can expect uniform cooling
6	No fan is provided inside	Two additional fans are used: - evaporator fan - condenser fan



61.

Sol. Leak testing**Sulphur Candles**

It is applicable for ammonia refrigerant vapour; when it is exposed to air containing ammonia vapour, these give off a white cloud of ammoniumchloride or ammonium sulphate.

The draw back of this method, it cannot be used to pinpoint leaks

Litmus paper

This is also applicable for ammonia only; When it is exposed to ammonia vapour, moist red litmus paper will turn blue.

The draw back of this method, it cannot be used with any of halogen family refrigerants.

Bubbletests

This method is followed in most common areas on pipes and fittings. Soapy water (mixture of soap and water) will indicate the locations of leaks by the formation of bubbles by escaping the gas/vapour/air.

The draw back of this method is applicable on the pressure of the system more than atmospheric pressure (1.01325 bar). When test solutions applied to low temperature, low pressure (below than atmospheric level) suction lines could cause considerable damage due to the test solution could be drawn into the system.

Halide test lamp/Halide torch

This kind of leak detection is used to locate - fluoro carbon refrigerant leaks by the fuel like propane, butane or methylated spirits which is filled into the fuel tank.

The fuel tank supplies pressurised fuel at a steady and controlled pressure and a jet to admit the fuel to a burner. When lit, the burner flame is supported by oxygen in the air which is drawn through a tube used as a sensing probe. The probe is passed slowly over the joints or surfaces being leak tested. If any fluorocarbon refrigerants are drawn into the tube, the colour of the lamp flame will change to green or blue depending on the quantity of gas passed over the burner element.

Electronic leak detectors

This type is highly sensitive and operated by batteries. The refrigerant is sensed by a plug in element exposed to air drawn through a probe or tube. Its pressure will be indicated by a flashing lamp an audible 'bleep or buzz' or a meter reading, each increasing in speed or intensity as more refrigerant passes over the element.

The halide torch and electronic leak detector are difficult to use around urethane insulation. Since urethane uses refrigerant as the expander such detection devices show a leak trace all the time. In this case the soap bubble test is best.

Test Pressure

Test pressure limit is important in the trade because it facilitates leak testing process useful.

Normally test pressures are based on the discharge pressure of the system/appliance. The discharge pressure will vary corresponding to the condensing temperature. Similarly the condensing temperature will vary according to the condensing medium (air, water or both).

For air cooled systems, the compressor manufacturers suggests the condensing temperature is 55°C maximum. The condensing pressure at 55°C for R 12 is 12.9Kg/cm² gauge (180 psig) and for R 22 is 21.25 Kg/cm² gauge (300 psig).

62.

Sol. Lithium Bromide Absorption Refrigeration System

The lithium bromide absorption refrigeration system uses a solution of lithium bromide in water. In this system, the water is being used as a refrigerant whereas lithium bromide, which is a highly hygroscopic salt, as an absorbent. The lithium bromide solution has a strong affinity for water vapour because of its very low vapour pressure. Since lithium bromide solution is corrosive, therefore inhibitors should be added in order to protect the metal parts of the system against corrosion. This system is very popular for air conditioning in which low refrigeration temperatures (not below 0° C) are required.

Note: Since water is used as a refrigerant in this system, therefore, the refrigeration temperature must be kept above the freezing point of water (0°C).

63.

Sol. Domestic Electrolux (Ammonia Hydrogen) Refrigerator

The main purpose of domestic electrolux refrigerator is to eliminate the pump so that in the absence of moving parts, the machine becomes noise-less. This type of refrigerator is also called three-fluids absorption system. The three fluids used in this system are ammonia, hydrogen and water. The ammonia is used as a refrigerant because it possesses most of the desirable properties. The hydrogen being the lightest gas, is used to increase the rate of evaporation of the liquid ammonia passing through the evaporator. The hydrogen is also non-corrosive and insoluble in water. The water is used as a solvent because it has the ability to absorb ammonia readily.

The C.O.P. of this type of refrigerator is given by the ratio of heat absorbed in the evaporator to the heat supplied in the generator.

64.

Sol. R-11 (CCl_3F): It is stable, non-flammable and non-toxic. It is considered to be a low-pressure refrigerant. It has a low side pressure of 0.202 bar at -15°C , and high side pressure of 1.2606 bar at 30°C . The latent heat at -15°C is 195 kJ/kg. The boiling point at atmospheric pressure is 23.77°C . Due to its low operating pressures, this refrigerant is exclusively used in large centrifugal compressor systems of 200 TR and above. The leaks may be detected by using a soap solution, a halide torch or by using an electronic detector. The cylinder colour code for R - 11 is orange.

65.

Sol. R-12 (CCl_2F): It is a very popular refrigerant. It is a colourless, almost odourless liquid with boiling point of -29°C at atmospheric pressure. It is non-toxic, non-corrosive, non-irritating and non-flammable. It has a relatively low latent heat value which is an advantage in small refrigerating machines. This refrigerant is used in many different types of industrial and commercial applications such as refrigerators, freezers, water coolers, room and window air conditioning units etc. Its principal use is found in reciprocating and rotary compressors, but its use in centrifugal compressors for large commercial air conditioning is increasing.

R-12 has a pressure of 0.82 bar at -15°C and a pressure of 6.4 bar at 30°C . The latent heat of R-12 at -15°C is 159 kJ/kg. The leak may be detected by soap solution, halide torch or an electronic leak detector. The refrigerant is available in a variety of cylinder sizes and the cylinder colour code is white.

66.

Sol. R-22 (CHClF_2): It has also been successfully used in air conditioning units and in household refrigerators. It is used with reciprocating and centrifugal compressors. It is not necessary to use R-22 at below atmospheric pressures in order to obtain the low temperatures.

The boiling point is -41°C at atmospheric pressure. It has a latent heat of 216.5 kJ/kg at -15°C . The normal head pressure at 30°C is 10.88 bar. This refrigerant is stable and is non-toxic, non-corrosive, non-irritating and non-flammable. The evaporator pressure of this refrigerant at -15°C is 1.92 bar. This refrigerant has good solubility in oil down to -9°C . However, the oil remains fluid enough to flow down the suction line at temperatures as low as -40°C . The oil will begin to separate at this point. Since oil is lighter, therefore it will collect on the surface of the liquid refrigerant. The leaks may be detected with a soap solution, a halide torch or with an electronic leak detector. The cylinder colour code for R-22 is green.

67.

Sol. Ammonia (NH_3): It is one of the oldest and most widely used of all the refrigerants. Its greatest application is found in large and commercial reciprocating compression systems where high toxicity is secondary. It is also widely used in absorption systems. It is a chemical compound of nitrogen and hydrogen and under ordinary conditions, it is a colourless gas. Its boiling point at atmospheric pressure is -33.3°C and its melting point from the solid is -78°C . The low boiling point makes it possible to have refrigeration at temperature considerably below 0°C without using pressures below atmospheric in the evaporator. Its latent heat of vaporisation at 15°C is 1315 kJ/kg. Thus, large

refrigerating effects are possible with relatively small sized machinery. The condenser pressure at 30°C is 10.78 bar. The condensers for ammonia are usually of water cooled type. This refrigerant is used in large compression machines using reciprocating compressors and in many absorption type systems. The use of this refrigerant is extensively found in cold storage, warehouse plants, ice cream manufacture, ice manufacture, beer manufacture, food freezing plants etc.

The leaks of this refrigerant may be quickly and easily detected by the use of burning sulphur candle which in the presence of ammonia forms white fumes of ammonium sulphite.

68.

Sol. Carbon dioxide (CO₂): The principal refrigeration use of carbon dioxide is same as that of dry ice. It is non-toxic, non-irritating and non-flammable. The boiling point of this refrigerant is so extremely low (-73.6°C) that at -15°C, a pressure of well over 20.7 bar is required to prevent its evaporation. At a condenser temperature of + 30°C, a pressure of approximately 70 bar is required to liquify the gas. Its critical temperature is 31°C and triple point is -56.6°C. Due to its high operating pressure, the compressor of a carbon dioxide refrigerator unit is very small even for a comparatively large refrigerating capacity. However, because of its low efficiency as compared to other common refrigerants, it is seldom used in household units but is used in some industrial applications and aboard ships.

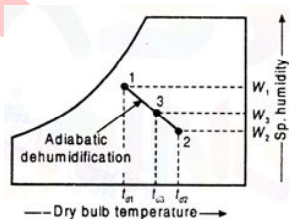
69.

Sol. Sulphur dioxide (SO₂): This refrigerant is produced by the combustion of sulphur in air. In the former years, it was widely used in household and small commercial units. The boiling point of sulphur dioxide is -10°C at atmospheric pressure. The condensing pressure varies between 4.1 bar and 6.2 bar under normal operating conditions. The latent heat of sulphur dioxide at -15°C is 396 kJ/kg. It is a very stable refrigerant with a high critical temperature and it is non-flammable and non-explosive. It has a very unpleasant and irritating odour. This refrigerant is not injurious to food and is used commercially as a ripener and preservative of foods. It is however, extremely injurious to flowers, plants and shrubbery.

The leaks in the system with sulphur dioxide may be easily detected by means of soap solution or ammonia swab. A dense white smoke forms when sulphur dioxide and ammonia fumes come in contact.

70.

Sol. **Heating and Dehumidification (Adiabatic chemical Dehumidification):** This process is mainly used in industrial air conditioning and can be used for some comfort air conditioning installations requiring either a low relative humidity or low dew point temperature in the room.



In this process, the air is passed over chemicals which have an affinity for moisture. As the air comes in contact with these chemicals, the moisture gets condensed out of the air and gives up its latent heat. Due to the condensation, the specific humidity decreases and the heat of condensation supplies sensible heat for heating the air and thus increasing its dry bulb temperature. The process, which is the reverse of adiabatic saturation process, is shown by the line 1-2 on the psychrometric chart as shown in Fig. The path followed is a constant enthalpy line.

during the process is along the constant wet bulb temperature, Keprise

The effectiveness or efficiency of the dehumidifier is given as

$$\eta_H = \frac{\text{Actual increase in DBT}}{\text{Ideal increase in DBT}} = \frac{t_{d3} - t_{d1}}{t_{d2} - t_{d1}}$$

71.

Sol. Cooling Loads Classified by Kinds of Heat:

There are two distinct components of the air conditioning load;

- (1) The sensible load (heat gain) and
- (2) The latent load (water vapour gain)

Sensible Loads:

Sensible heat gain is the direct addition of heat to a space, which shall result in increase in space temperatures.

The factors influencing sensible cooling load:

- (1) Solar heat gain through building envelope (exterior walls, glazing, skylights, roof, floors over crawl space)
- (2) Partitions (that separate spaces of different temperatures)
- (3) Ventilation air and air infiltration through cracks in the building, doors, and windows
- (4) People in the building
- (5) Equipment and appliances operated in the summer (fan, Cooler, AC)
- (6) Lights

Latent Loads:

A latent heat gain is the heat contained in water vapour. Latent heat does not cause a temperature rise, but it constitutes a load on the cooling equipment. Latent load is the heat that must be removed to condense the moisture out of the air.

The sources of latent heat gain are:

- (1) People (breathing)
- (2) Cooking equipment
- (3) Housekeeping, floor washing etc.
- (4) Appliances or machinery that evaporates water
- (5) Ventilation air and air infiltration through cracks in the building, doors, and windows

Total Cooling load = Sensible Cooling load + Latent Cooling load

PART - C**20 Marks Questions**

72.

Sol. Air Refrigeration Cycle :

It is also known as Reversed Braton or Joule cycle. In this type of refrigeration cycle air is used as working fluid (Refrigerant) to give desired output. At first air is compressed and then heat removed then air is expanded to a lower temperature this low pressure, low temperature air is use to create refrigerating effect.

COP:

$$\text{COP} = \frac{\text{RE}}{W_{\text{net}}}$$

We know that

$$\begin{aligned} \text{RE} &= Q_a \\ W_{\text{net}} &= W_c + W_T \end{aligned}$$

$$\text{COP} = \frac{\text{RE}}{W_c + W_T}$$

$$\text{RE} = h_1 - h_4 = C_p(T_1 - T_4)$$

$$W_c = h_2 - h_1 = C_p(T_2 - T_1)$$



$$W_T = h_3 - h_4 = C_P(T_3 - T_4)$$

$$W_{\text{net}} = W_C + W_T$$

$$W_{\text{net}} = (h_2 - h_1) - (h_3 - h_4) = C_P [(T_2 - T_1) - (T_3 - T_4)]$$

$$\text{COP} = \frac{C_P(T_1 - T_4)}{C_P(T_2 - T_1) - C_P(T_3 - T_4)}$$

$$\text{COP} = \frac{T_1 - T_4}{(T_2 - T_1) - (T_3 - T_4)}$$

$$\text{COP} = \frac{(T_1 - T_4)}{(T_2 - T_3) - (T_1 - T_4)}$$

$$\text{COP} = \frac{1}{\left(\frac{T_2 - T_3}{T_1 - T_4}\right) - 1}$$

$$\text{COP} = \frac{1}{\frac{T_2}{T_1} \left[\frac{\left(1 - \frac{T_3}{T_2}\right)}{\left(1 - \frac{T_4}{T_1}\right)} \right] - 1}$$

Process 1 - 2:-

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\frac{\gamma-1}{\gamma}} \quad \dots(i)$$

Process 3 - 4:-

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\frac{\gamma-1}{\gamma}} \quad \dots(ii)$$

From equation (i) and (ii)

$$\frac{T_2}{T_1} = \frac{T_3}{T_4}$$

$$\frac{T_4}{T_1} = \frac{T_3}{T_2}$$

$$\text{COP} = \frac{1}{\frac{T_2}{T_1} - 1}$$

$$\text{COP} = \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

$$\text{COP} = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$$

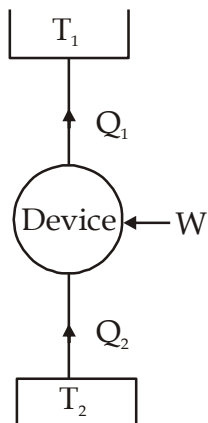
This expression only use when expansion and compression is isentropic.



73.

Sol. Difference between heat pump and refrigeration cycle:

A refrigerator is a device which, operating in a cycle, maintains a body at a temperature lower than the temperature of surroundings. Performance parameter in a refrigerator cycle called the coefficient of performance, abbreviated to COP, which is defined as



$$\text{COP} = \frac{\text{Desired effect}}{\text{Work input}} = \frac{Q_2}{W}$$

$$\therefore [\text{COP}]_{\text{ref.}} = \frac{Q_2}{Q_1 - Q_2} \quad \dots(i)$$

A heat pump is a device which, operating in a cycle, maintains a body, at a temperature higher than the temperature of the surroundings. By virtue of the temperature difference, there will be heat leakage Q_1 from the body to the surroundings. The body will be maintained at the constant temperature t_1 , if heat is discharged into the body at the same rate at which heat leaks out of the body.

The COP is defined as

$$(\text{COP}) = \frac{Q_1}{W}$$

$$\therefore [\text{COP}]_{\text{H.P.}} = \frac{Q_1}{Q_1 - Q_2} \quad \dots(ii)$$

Relation between $(\text{COP})_{\text{hp}}$ and $(\text{COP})_{\text{R}}$

We know that

$$(\text{COP})_{\text{REF}} = \frac{Q_2}{Q_1 - Q_2}$$

Add one both side

$$(\text{COP})_{\text{REF}} + 1 = \frac{Q_2}{Q_1 - Q_2} + 1$$

$$(\text{COP})_{\text{REF}} + 1 = \frac{Q_1}{Q_1 - Q_2}$$

$$(\text{COP})_{\text{REF}} + 1 = (\text{COP})_{\text{HP}}$$

The COP of heat pump is greater than the COP is a refrigerator by unity.

74.

Sol. Given :

Pressure of air at inlet of the compressor (p_1) = 1 barPressure of air at outlet of the compressor (p_2) = 5.5 barTemperature of air at inlet (T_1) = $10^\circ\text{C} = 273 + 10 = 283\text{K}$ Temperature of cooled air (T_3) = $30^\circ\text{C} = 273 + 30 = 303\text{K}$ Air flow rate ($\dot{m}$) = 1700 kg/hCOP of the actual plant = $0.65 \times \text{COP}$

Air refrigeration system work on Bell Coleman cycle / reversed Brayton cycle :

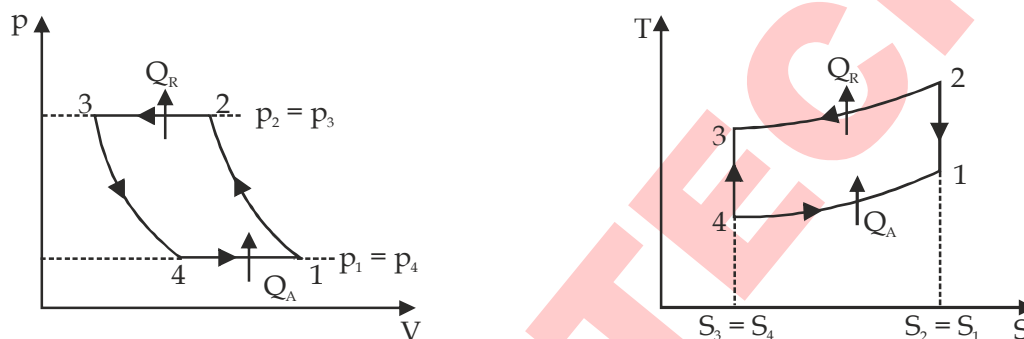


Fig.: P-V and T-s diagram (Bell Coleman cycle)

On the basis of above mentioned different processes we get,

From Process 1-2 :

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{(\gamma-1)}{\gamma}} \quad \left(\because \text{pressure ratio } (r_p) = \frac{p_2}{p_1} \right)$$

$$T_2 = \left(r_p \right)^{\frac{(1.4-1)}{1.4}} \times T_1$$

$$T_2 = (5.5)^{\frac{(0.4)}{1.4}} \times 283$$

$$T_2 = 460.59\text{K}$$

Similarly from Process 3-4 :

$$\frac{T_3}{T_4} = \left(\frac{p_2}{p_1} \right)^{\frac{(\gamma-1)}{\gamma}}$$

$$T_4 = \frac{T_3}{\left(r_p \right)^{\frac{(1.4-1)}{1.4}}}$$

$$T_4 = \frac{303}{(5.5)^{\frac{(1.4-1)}{1.4}}}$$



$$T_4 = 186.17 \text{ K}$$

Now,

(i) Refrigeration effect per unit mass

$$RE = C_p (T_1 - T_4)$$

$$= 1.005(283 - 186.17)$$

$$RE = 97.31 \text{ kJ/kg}$$

(ii) Heat rejection per unit mass

$$Q_r = C_p (T_2 - T_3)$$

$$= 1.005(460.59 - 303)$$

$$Q_r = 158.377 \text{ kJ/kg}$$

(iii) Co-efficient of performance

$$\text{COP} = \left(\frac{RE}{W_{\text{net}}} \right) = \frac{C_p (T_1 - T_4)}{C_p (T_2 - T_1) - C_p (T_1 - T_4)}$$

$$= \frac{C_p (T_1 - T_4)}{C_p [(T_2 - T_1) - (T_1 - T_4)]}$$

$$= \frac{283 - 186.17}{(460.59 - 283) - (283 - 186.17)}$$

$$\text{COP} = 1.198$$

Now, actual COP :

$$(\text{COP})_{\text{actual}} = 0.65 \times \text{COP}$$

$$= 0.65 \times 1.198$$

$$(\text{COP})_{\text{actual}} = 0.779$$

(iv) And, Power required for the plant :

$$(\text{C.O.P})_{\text{actual}} = \frac{\text{Cooling load}}{\text{Power input}}$$

$$(\text{C.O.P})_{\text{actual}} = \frac{\dot{m} \times R.E.}{P_{\text{in}}}$$

$$P_{\text{req}} = \frac{\dot{m} \times R.E.}{(\text{COP})_{\text{actual}}} \quad \left[\because \dot{m} = 1700 \text{ kg/hr} = \frac{1700}{3600} \text{ kg/s} \right]$$

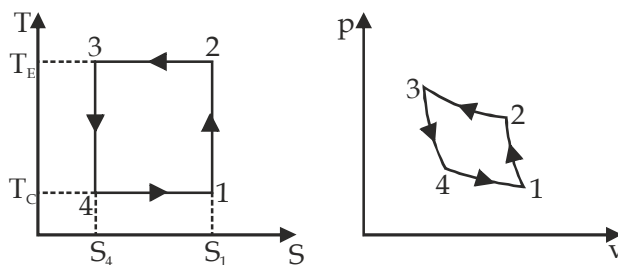
$$P_{\text{req}} = \frac{\frac{1700}{3600} \times 97.31}{0.779}$$

$$P_{\text{req}} = 58.988 \text{ kW}$$

Hence, the power required for the actual plant is 58.988 kW.

75.

Sol.



1 - 2 → Isentropic compression

2 - 3 → Isothermal compression

3 - 4 → Isentropic expansion

4 - 1 → Isothermal expansion

As we can see that in p-V diagram, both in process 1-2, and 2-3 the pressure is increasing so two compressors are required.

Similarly in process 3-4 and 4-1 the pressure is decreasing and volume is increasing so two expanders are required.

Work transfer in compressors (per kg) = $W_{12} + W_{23}$

$$= \frac{\gamma}{\gamma-1} R(T_1 - T_2) + RT_E \log_0 \left(\frac{V_3}{V_2} \right) = c_p (T_c - T_E) + RT_E \log_0 \left(\frac{V_3}{V_2} \right)$$

$$\text{Work transfer in expanders} = c_p (T_3 - T_4) + RT_c \log_0 \left(\frac{V_1}{V_4} \right) = c_p (T_E - T_c) + RT_c \log_e \left(\frac{V_1}{V_4} \right)$$

Alternatively Net work required = Heat rejected - Heat absorbed

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

$$(\text{COP})_R = \frac{\text{Heat absorbed}}{\text{Work done}} = \frac{T_c (S_1 - S_4)}{(T_E - T_c)(S_1 - S_4)} = \frac{T_c}{T_E - T_c}$$

$$\text{Net work required, } W = W_c + W_T = RT_E \log_0 \left(\frac{V_3}{V_2} \right) + RT_c \log_0 \left(\frac{V_1}{V_4} \right)$$

$$\therefore \frac{V_3}{V_2} = \frac{V_4}{V_1}$$

$$\text{So, } W = R(T_E - T_c) \log_0 \left(\frac{V_3}{V_2} \right) = (T_E - T_c)(S_2 - S_3) = (T_E - T_c)(S_1 - S_4)$$

76.

Sol.

In actual refrigeration cycles, the temperature of the heat sink will be several degrees lower than the condensing temperature to facilitate heat transfer. Hence it is possible to cool the refrigerant liquid in the condenser to a few degrees lower than the condensing temperature by adding extra area for heat transfer. In such a case, the exit condition of the condenser will be in the sub-cooled liquid region. Hence, this process is known as sub-cooling.

Similarly, the temperature of heat source will be a few degrees higher than the evaporator temperature, hence the vapour at the exit of the evaporator can be super-heated by a few degrees. If

the super-heating of refrigerant takes place due to heat transfer with the refrigerated space (low temperature heat source) then it is called as super-heating as it increases the refrigeration effect.

On the other hand, it is possible for the refrigerant vapour to become super-heated by exchanging heat with the surroundings as it flows through the connecting pipelines. Such a super-heating is called as useless super-heating as it does not increase refrigeration effect.

Effect of super-heating on vapour compression refrigeration cycle :

- Refrigeration effect increases.
- Work input increases.
- Coefficient of performance (COP) may increase or decrease depending on refrigerant.
For R-12, COP increases
For NH_3 , COP decreases
- Volumetric efficiency will remain almost constant.

Super-heating increases both the refrigeration effect as well as the work of compression. Hence the COP (ratio of refrigeration effect and work of compression) may or may not increase with superheat, depending mainly upon the nature of the working fluid. Even though superheating may or may not increase the COP of the system, a minimum amount of superheat is desirable as it prevents the entry of liquid droplets into the compressor.

The VCR cycle with superheating on $p-h$ and $T-S$ coordinates. As shown in the figure below, with super-heating, the refrigeration effect, specific volume at the inlet to the compressor and work of compression increases.

Whether the volumetric refrigeration effect (ratio of refrigeration effect by specific volume at compressor inlet) and COP increase or not depends upon the relative increase in refrigeration effect and work of compression, which in turn depends upon the nature of the refrigerant used.

The temperature of refrigerant at the exit of the compressor increases with superheat as the isentropic in the vapour region gradually diverge.

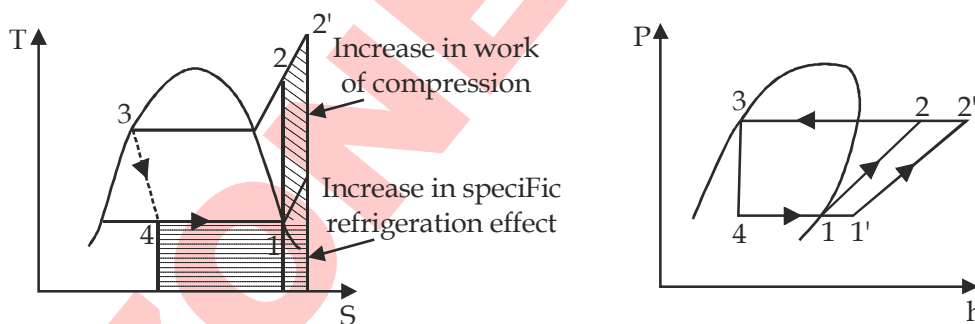


Fig.: $T-s$ and $p-h$ diagram (Vapour compression refrigeration system)

Effect of sub-cooling on vapour compression refrigeration cycle :

- Refrigeration effect increases.
- COP increases.
- Work input remains same.
- Volumetric efficiency remains same because condenser and evaporator pressure remain constant.

In sub-cooling, it increases the refrigeration effect by reducing the throttling loss at no additional specific work input. Also sub-cooling ensures that only liquid enters into the throttling device leading to its efficient operation. Given figure shows the VCRS cycle without and with sub-cooling on $p-h$ and $T-S$ coordinates. It can be seen from the $T-S$ diagram that without sub-cooling the throttling loss is equal to the hatched area $b-4'-4-c$, whereas with sub-cooling the throttling loss is given by the area $a-4''-4'-b$. Thus the refrigeration effect increases by an amount equal to

$(h_4 - h'_4) = (h_3 - h'_3)$. Another practical advantage of sub-cooling is that there is less vapour at the inlet to the evaporator which leads to lower pressure drop in the evaporator.

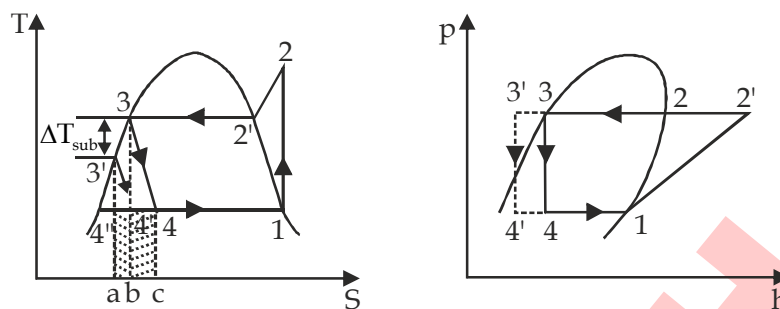


Fig.: Effect of sub-cooling on vapour compression refrigeration cycle

77.

Sol. Various factors which are affecting the performance of vapour compression cycle are

- (i) Superheat of evaporator outlet.
- (ii) Subcool of condenser outlet.
- (iii) Change in temperature of evaporation and condenser.
 - (a) Decrease in temperature and pressure of evaporator.
 - (b) Increase in temperature and pressure of condenser.
- (i) **Superheat at evaporator outlet or suction vapour superheat:** Suction vapour superheat is advisable because it ensures complete vapour suction of refrigerant before going to compressor. In general
 - It increases refrigeration effect.
 - Increases compression work and specific volume of vapour, which requires bigger compressor for given mass flow rate.
 But increase or decrease in COP depends upon type of refrigerant as for R-12 COP increases and for R-22 & NH_3 , COP decreases.

Note: NH_3 - Refrigerant is best suitable for wet compression.

- (ii) **Subcooling at condenser outlet:** It results in high refrigeration capacity and consequently it reduces compressor size and power consumption for all refrigerants except NH_3 which has high heat of evaporation.

The main advantage of sub-cooling is reduced refrigerant flow.

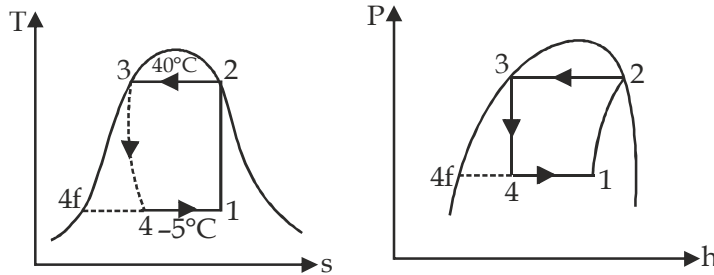
The positive points of these two parameters are combined in liquid vapour regenerative heat exchanger which superheats the suction vapour and subcools the liquid simultaneously (simply transfer of heat) so in most of the system liquid vapour regenerator is installed instead of single superheater or subcooler.

- (iii)(a) **Decrease in temperature and pressure of evaporator:** This increases the volume of suction vapour and decreases the volumetric efficiency of reciprocating compressor.
 - It reduces refrigeration effect.
 - Increases compression work.
- (b) Increase in condenser pressure:
 - It increases power consumption due to increased mass flow rate of refrigerant.
 - It reduces refrigeration effect and volumetric efficiency.

Note: But experiments show that increase in condenser pressure is not as severe on refrigeration effect and power consumption as decrease in evaporator pressure.

78.

Sol.



$$(h_{fg}) = 203.2 \text{ kJ / kg}$$

$$(c_p)_t = 0.963 \text{ kJ / kgK}$$

$$s_2 - s_3 = \left(\frac{h_{fg}}{T} \right)_{40^\circ\text{C}} = \frac{203.20}{273 + 40} = 0.649 \text{ kJ / kgK}$$

$$\therefore s_1 - s_3 = 0.649 \text{ kJ / kgK} \quad [\because s_1 = s_2]$$

$$\begin{aligned} \text{and } s_3 - s_{4f} &= \int c_p \frac{dT}{T} = c_p \ln \left(\frac{273 + 40}{273 - 5} \right) = c_p \ln \left(\frac{313}{268} \right) = 0.963 \times \ln \left(\frac{313}{268} \right) \\ &= 0.149 \text{ kJ / kgK} \end{aligned}$$

$$\therefore s_1 - s_{4f} = (s_1 - s_3) + (s_3 - s_{4f}) = 0.649 + 0.149 = 0.798 \text{ kJ / kgK}$$

$$\text{and } h_1 - h_{4f} = (268) \times (0.798) = 213.864 \text{ kJ / kg}$$

$$\text{Refrigeration effect} = h_1 - h_4 = (h_1 - h_{4f}) - (h_4 - h_{4f}) = (h_1 - h_{4f}) - (h_3 - h_{4f})$$

$$\text{and } h_3 - h_{4f} = (c_p)_t (313 - 268) = 0.963 \times (45) = 43.335 \text{ kJ / kg}$$

$$\therefore h_1 - h_4 = 213.864 - 43.335$$

$$\text{refrigeration effect} = 170.529 \text{ kJ / kg}$$

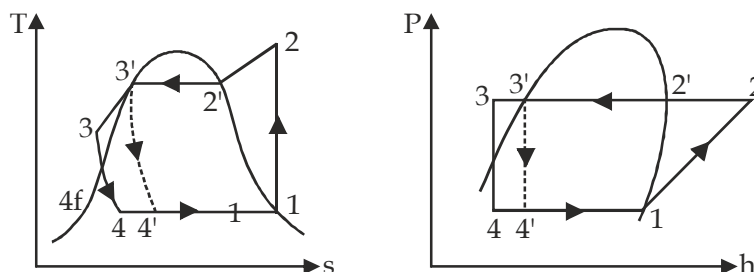
$$\begin{aligned} \text{Compressor work} &= h_2 - h_1 = (h_2 - h_3) - (h_1 - h_3) = 203.2 - (h_1 - h_4) \\ &= 203.20 - 170.529 = 32.671 \text{ kJ / kg} \end{aligned}$$

$$\text{COP} = \frac{\text{Refrigeration effect}}{\text{Compressor work}} = \frac{170.529}{32.671} = 5.22$$

79.

Sol. (i) Effect of subcooling of the liquid in condenser:

The refrigerant after condensation process is cooled below the saturation temperature (T_3) before expansion by throttling. Such a process is called under cooling or subcooling of the refrigerant.



Here, 1 - 2 - 2' - 3' - 4' - 1: Cycle without subcooling.

and, 1 - 2 - 2' - 3' - 3 - 4 - 1: Cycle with subcooling.

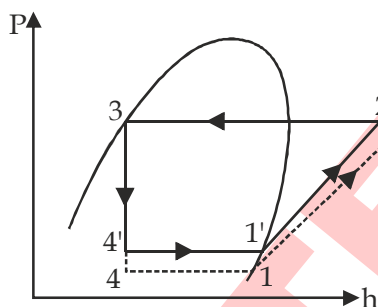
The process of subcooling is generally brought about by circulating more quantity of cooling water through the condenser or by using water colder than the main circulating water.

Due to subcooling, refrigeration effect increases while work of compression remains the same. So, the ultimate effect of subcooling is to increase the coefficient of performance (COP) under the same set of working conditions.

$$\text{COP} = \frac{\text{R.E.}}{W_c} = \frac{(h_1 - h_4)}{h_2 - h_1}$$

∴ As $(h_1 - h_4)$ increases, COP increases.

(ii) Effect of decrease in evaporator temperature:



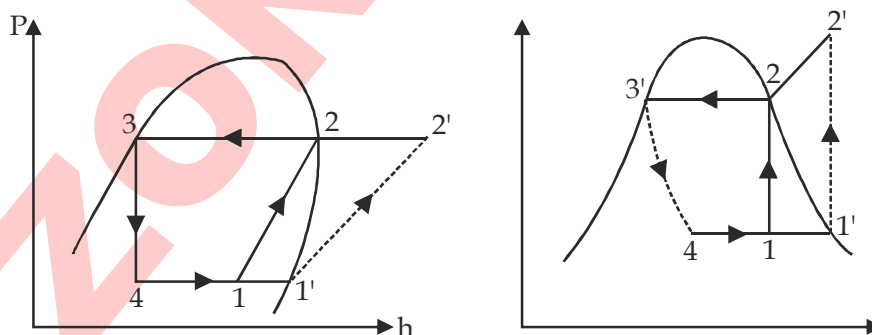
As the suction or evaporator temperature decreases

(a) refrigeration effect decreases from $(h_1 - h_4)$ to $(h_1' - h_4)$

(b) the work of compression increases from $(h_2 - h_1)$ to $(h_2' - h_1)$.

Since, the COP of the system is the ratio of refrigeration effect to the compression work, with decrease in evaporator temperature, the net effect is to decrease the COP of the refrigerating system for the same amount of refrigerant flow, thus increasing refrigeration cost.

(iii) Effect of wet compression:



Process: 1 - 2 - 3 - 4: Wet compression of refrigerant.

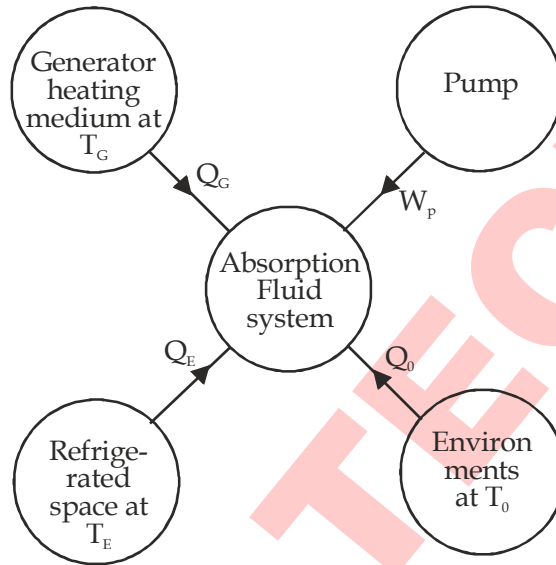
Process: 1' - 2' - 3 - 4: Dry compression of refrigerant.

Due to compression of refrigerant in wet region, following effects are observed :

- The presence of liquid refrigerant washes away the lubricating oil hence increasing wear and tear in the compressor.
- Liquid particles obstruct the opening and closing of valves, which may lead to valve damage.
- Loss of refrigeration effect due to incomplete vapourisation of refrigerant.
- The work of compression in wet compression is less than that of in dry compression because of reduced volume handling.

80.

Sol.

 Q_G = Heat added to absorption fluid W_p = Pump work added to absorption fluid system by pump Q_E = Heat added to absorption fluid system in the evaporator Q_0 = Heat rejected from absorption fluid system at condenser, absorber and heat exchangers to environments at temperature to assumed constant

Applying the energy balance equation,

$$Q_0 = Q_E + Q_G + W_p$$

Where pump work is very small and neglected

 $\therefore$

$$Q_0 = Q_E + Q_G$$

...(i)

Clausius's inequality for reversible cycle,

$$\oint \frac{\delta Q}{T} = 0$$

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} - \frac{Q_0}{T_0} = 0$$

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} - \frac{(Q_E + Q_0)}{T_0} = 0$$

$$\frac{Q_G}{T_G} - \frac{Q_G}{T_0} + \frac{Q_E}{T_E} - \frac{Q_E}{T_0} = 0$$

$$Q_G \left[\frac{1}{T_G} - \frac{1}{T_0} \right] = Q_E \left[\frac{1}{T_0} - \frac{1}{T_E} \right] = Q_E \left[\frac{T_E - T_0}{T_0 T_E} \right]$$

$$Q_G \left[\frac{T_0 - T_G}{T_G T_0} \right] = Q_E \left[\frac{T_E - T_0}{T_0 T_E} \right]$$

or

$$Q_G \left[\frac{T_0 - T_G}{T_G} \right] = Q_E \left[\frac{T_0 - T_E}{T_E} \right]$$

$$\frac{Q_E}{Q_G} = \left(\frac{T_E}{T_0 - T_E} \right) \left(\frac{T_G - T_0}{T_G} \right)$$

$$\therefore \text{COP} = \frac{Q_E}{Q_G} = \left(\frac{T_E}{T_0 - T_E} \right) \left(\frac{T_G - T_0}{T_G} \right)$$

Now is given that $T_G = 383 \text{ K}$, $T_E = 268 \text{ K}$, $T_0 = 308 \text{ K}$

$$\Rightarrow \text{COP} = \left(\frac{268}{308 - 268} \right) \left(\frac{383 - 308}{383} \right)$$

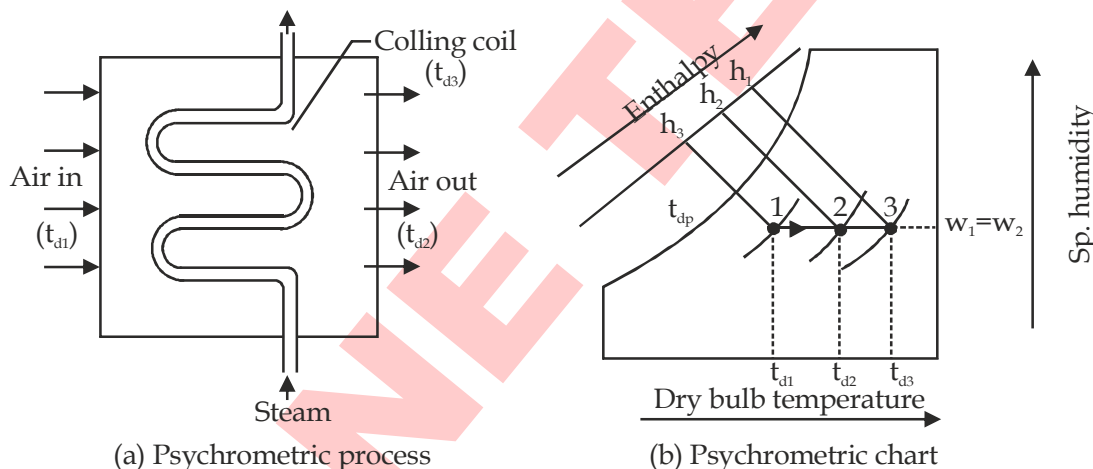
$$\text{COP} = 1.312$$

81.

Sol. Psychrometric Processes:

The various psychrometric processes involved in air conditioning to vary the psychrometric properties of air according to the requirement are as follows:

1. **Sensible heating:** The heating of air, without any change in its specific humidity, is known as sensible heating. Let air at temperature t_{d1} passes over a heating coil of temperature t_{d3} as shown in Fig. The temperature of air leaving the heating coil $t_{d2'}$ will be less than t_{d3} .



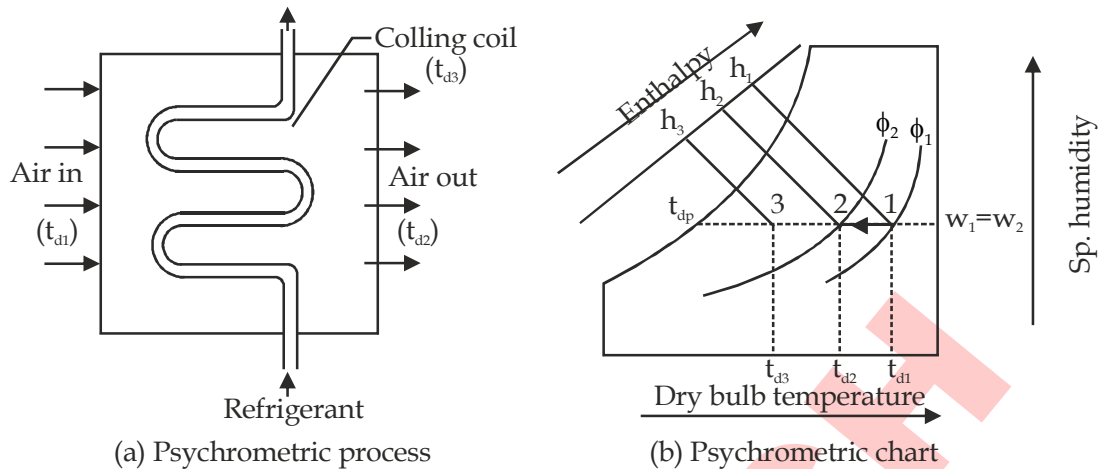
The process of sensible heating, on the psychrometric chart, is shown by a horizontal line 1-2 extending from left to right as shown in Fig. (b). The point 3 represents the surface temperature of the heating coil. It may be noted that during sensible heating, specific humidity remains constant (i.e. $W_1 = W_2$), dry bulb temperature increases from t_{d1} to $t_{d2'}$ and relative humidity decreases from ϕ_1 to ϕ_2 .

The by-pass factor (BPF) for the heating coil is given by

$$\text{BPF} = \frac{t_{d3} - t_{d2}}{t_{d3} - t_{d1}}$$

and efficiency of the heating coil, $\eta_H = 1 - \text{BPF} = \frac{t_{d2} - t_{d1}}{t_{d3} - t_{d1}}$

2. **Sensible cooling:** The cooling of air, without any change in its specific humidity, is known as sensible cooling. Let air at temperature t_{d1} passes over a cooling coil of temperature $t_{d3'}$ as shown in Fig. (a). The temperature of air leaving the cooling coil (t_{d2}) will be more than $t_{d3'}$.



The process of sensible cooling, on the psychrometric chart, is shown by a horizontal line 1-2 extending from right to left, as shown in Fig. (b). The point 3 represents the surface temperature of the cooling coil. It may be noted that during sensible cooling, specific humidity remains constant (i.e. $W_1 = W_2$), dry bulb temperature decreases from t_{d1} to t_{d2} and relative humidity increases from ϕ_1 to ϕ_2 . The by-pass factor (BPF) for the cooling coil is given by

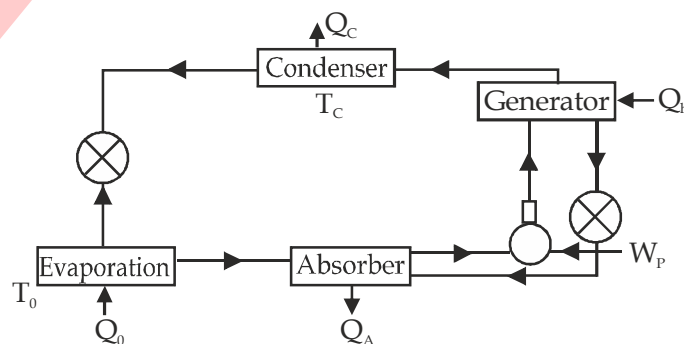
$$\text{BPF} = \frac{t_{d2} - t_{d3}}{t_{d1} - t_{d3}}$$

and efficiency of the cooling coil, $\eta_H = 1 - \text{BPF} = \frac{t_{d1} - t_{d2}}{t_{d1} - t_{d3}}$

82.

Sol. A simple vapour absorption system, consists of a condenser, an expansion device and an evaporator as in the vapour compression system and in addition, an absorber, a pump, a generator and a pressure reducing valve to replace the compressor. The schematic representation of the system is shown in figure in which various components of the system are arranged according to their pressures and temperatures. The refrigerating effect is shown as Q_0 at temperature T_0 and the heat rejected in the condenser as Q_c at temperature $T_c = T_K$ of the environment. The compressor work is replaced by the heat supplied in the generator Q_h plus pump work W_p . Cooling must be done in the absorber to remove the latent heat of the refrigerant vapour as it changes into the liquid state by absorption by the weak solution. Heat rejected in the absorber be Q_A at absorber temperature $T_A = T_K$. Then the energy balance of the system,

$$Q_0 + W_p + Q_h = Q_c + Q_A$$



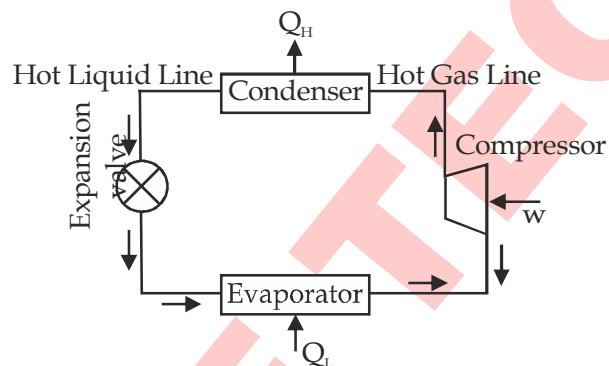
Schematic representation of simple vapour absorption system

The pump work $W_p = -\int v dP$ is very small compared to compressor work in the vapour compression system, as the specific volume v of the liquid is extremely small compared to that of the vapour ($v_l \ll v_g$). The energy consumption of the system is mainly in the generator in the form of heat supplied Q_h . In the vapour-absorption system, the function of the compressor is accomplished in a three step process by the use of the absorber, pump and generator. Functions of these devices are given below:

- (i) **Absorber:** Absorption of the refrigerant vapour by its weak or poor solution in a suitable absorbent or adsorbent, forming strong or rich solution of refrigerant in absorbent/adsorbent.
- (ii) **Pump:** Pumping of the rich solution raising its pressure to the condenser pressure.
- (iii) **Generator:** Distillation of the vapour from the rich solution leaving the poor solution for recycling.

83.

Sol. Consider that a room is maintained at constant temperature of 25°C . In the cooling coil, a liquid working substance (Refrigerant) enters at a temperature of say, 6°C and evaporates, thus absorbing the latent heat of vaporization from the room air. This equipment in which refrigerant evaporates is called an evaporator.



After evaporation refrigerant becomes vapour and this vapour is compressed to increase its temperature and pressure in a compressor. Following this the high pressure vapour enters the condenser. In the condenser, the outside atmospheric air say at a temperature of 40°C in summer is circulated by a fan. After picking up the latent heat of condensation from the condensing refrigerant the air is let out into the environment, say at a temperature of 55°C . The condensation of the refrigerant may occur, for example, at a temperature 60°C . Desirable qualities of refrigerant:

The desirable properties of refrigerants are:

1. Thermodynamic Requirements:

- **Condensing and Evaporating Pressures:** The evaporating pressure p_e should be positive and as near atmospheric as possible. If it is too low, it would result in a large volume of the suction vapour. If it is too high, overall higher pressure, including condenser pressure p_c , would result in heavier construction and consequently higher cost of equipment.
- **Freezing point:** As the refrigerant must operate in a cycle above its freezing point, it is evident that the same for the refrigerant must be lower than the system temperature.
- **Latent heat:** It is desirable that the refrigerants should have high latent heat.
- **Critical temperature and pressure:** For high COP in general, the critical temperature should be very high so that the condenser temperature like on the p-h diagram is far removed from the critical point. Also the critical pressure should be low so as to result in low condensing pressure.

2. Chemical Requirements

- **Flammability:** Refrigerant should not be flammable under operating conditions.
- **Toxicity:** Leakage of the refrigerant from system is inevitable. Therefore in order to avoid its harmful effects, refrigerant should be non toxic.



- **Corrosity and Reactivity:** Refrigerant should not react with the materials used in the refrigeration system. Therefore choice of particular refrigerant has also a bearing on the selection of the materials of construction. For example: Ammonia attacks copper bearing materials. Iron and steel are however found suitable for use with ammonia.

3. Physical Requirements:

- **Dielectric strength:** The dielectric strength of a refrigerant is primarily important in hermetically sealed units in which the electric motor is exposed to the refrigerant as the windings are cooled by suction vapour.
- **Thermal detection:** A high thermal conductivity is desirable for a high heat transfer coefficient.
- **Viscosity:** Low viscosity is desirable for a high heat transfer coefficient.
- **Leak tendency:** The detection of a leak should be easy. Several methods are available for the detection of leaks. The most common is the soap-bubble method and the other is halide torch method.

Substitutes for CFC and HCFC refrigerants: Hydrocarbons (HCs) and Hydrofluorocarbons (HFCs) provide an alternative to fully Halogenated CFC refrigerants. They contain zero chlorine atoms at all and therefore have zero ODP. Currently used such refrigerants are:

- | | |
|--|--|
| (a) R 134a ($\text{CH}_2\text{F} - \text{CF}_3$) | (b) R 600a (C_4H_{10}) |
| (c) R 290 (C_3H_8) | (d) Inorganic refrigerants such as R 717, R 718 and R 744. |

84.

Sol.

1. The common items of control involved in air-conditioning are given below:

- | | | |
|---------------------------------------|----------------------------------|----------------------------|
| (i) Expansion devices | | |
| (a) Automatic expansion valve | (b) Thermostatic expansion valve | |
| (ii) Cut outs for refrigeration units | | |
| (a) High pressure cut-out | (b) Low pressure cut-out | |
| (iii) Back pressure valves | | |
| (iv) Liquid level regulating devices | | |
| (a) High-side float valve | (b) Low-side float valve | |
| (v) Flow-regulating devices | | |
| (a) Solenoid valves | (b) Check valves | (c) Water and Brine valves |
| (vi) Thermostats | | |
| (a) Evaporator thermostat | (b) Room thermostat | |

2. **Adiabatic saturation temperature** is the temperature at which the air becomes adiabatically saturated by the evaporation of water into air.

If the bulb of wet bulb thermometer is covered by a wick thoroughly wetted by water, the temperature which is measured by the thermometer is the wet bulb temperature.

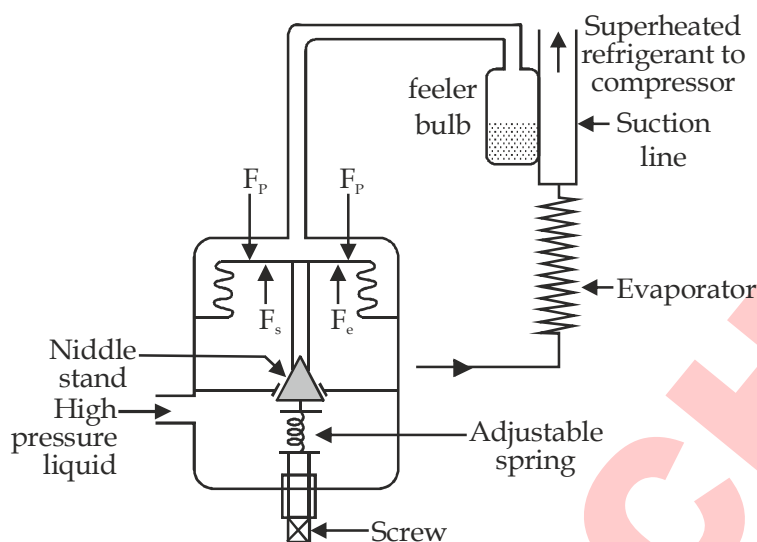
Both these temperature are equivalent when the air is fully saturated.

3. **Metabolism:** When food is digested and converted to energy, heat is released. This process is known as metabolism. For an average healthy person the metabolic rate is of the order of 50W - 75W. This value may be increased during hard work.

We are interested in the metabolic rate of the occupants of a building because human comfort condition cannot be achieved until the heat generated by metabolism is accounted and taken away.

85.

Sol. Thermostatic expansion valve: A thermostatic expansion valve is used to maintain a constant degree of superheat at the exit of evaporator, hence it is most effective for dry evaporators in preventing the slugging of the compressors since it does not allow the liquid refrigerant to enter the compressor. The schematic diagram of the valve is given as below:



It consists of a feeler bulb that is attached to the evaporator exit tube so that it senses the temperature at the exit of evaporator. The feeler bulb and the narrow tube contains some fluid that is called power fluid. The power fluid may be same as the refrigerant or it may be different. In case if it is different from the refrigerant then the TEV is called TEV with cross charge. Let P_p is the pressure of power fluid, P_e is the saturation pressure corresponding to evaporator exit temperature and evaporator temperature is T_e then the purpose of TEV is to maintain a temperature $(T_e + \Delta T)$ at evaporator exit where ΔT_s is the degree of superheat. Feeler bulb senses the temperature $(T_e + \Delta T_s)$ and its pressure P_p is saturation pressure at this temperature. So force exerted on the top area A_b of bellows:

$$F_p = P_p A_b \quad \dots(i)$$

Force exerted by evaporator pressure from bottom side of bellows:

This is called external equalizer if the evaporator is large and has significant pressure drop otherwise it is known as TEV with internal equalizer.

The difference of forces F_p and F_e is exerted on the top of the middle which controls the opening of orifice and is equal to spring force F_s i.e.

$$F_s = (P_p - P_e) A_b$$

Also

$$\Delta T_s \propto (P_p - P_e) A_b$$

As the compressor starts, P_e decreases so a positive spring force is applied on middle which opens the orifice and refrigerant flow starts.

When the cooling load increases, the refrigerant evaporates at a faster rate in evaporator than the compressor can suck. As a result, the saturation pressure (p_0) correspond to the temperature at the exit end of the evaporator and the degree of superheat in evaporator increases. The increase in superheat causes the valve to open more and to allow more refrigerant to enter the evaporator. At the same time, the increase in suction pressure (p_0) also enables the compressor to deliver increased refrigerating capacity.

When the cooling load decreases, the refrigerant evaporates at a slower rate than the compressor is able to suck. As a result, the evaporator pressure drops and the degree of superheat decreases. The valve tends to close and the compressor delivers less refrigerating capacity at a decreased suction pressure.

Thus the thermostatic expansion valve, is capable of meeting variable load requirements

86.

Sol. For process 1-2 which is sensible heating process

$$\text{Heat absorbed} = 50 \text{ kW} = m (h_2 - h_1)$$

At state 1-2 $\omega_1 = 0.0035 \text{ kg/kg of dry air (From psychrometric chart)}$ Specific volume $V_1 = 0.792 \text{ m}^3/\text{kg}$

$$h_1 = 14 \text{ kJ/kg}$$

Volume flow rate $V_1 = 100 \text{ m}^3/\text{min} = 1.67 \text{ m}^3/\text{s}$ Mass flow rate $m_{a1} = \frac{1.67}{0.792} = 2.104 \text{ kg/s}$

Now heat transferred, $Q = m_{a1} (h_2 - h_1) = 2.104 (h_2 - 14)$
 $50 = 2.104 (h_2 - 14)$
 $h_2 = 37.76 \text{ kJ/kg}$

Now at state 2, from psychrometric chart

 $\omega_2 = 0.0035 \text{ kg/kg of dry air;}$ and $h_2 = 37.76 \text{ kJ/kg}$

After humidification by steam injection

$$\omega_3 = \omega_2 + \frac{m_s}{m_a} = 0.0035 + \frac{35}{3600 \times 2.104} = 0.0081 \text{ kg}$$

Enthalpy of leaving air, $h_3 = h_2 + \frac{m_s}{m_a} (h_v)$
 $h_v = 2691.3 \text{ kJ/kg at } 110^\circ\text{C}$
 $h_3 = 37.76 + \frac{35}{3600 \times 2.104} \times 2691.3 = 50.19 \text{ kJ/kg}$

At state (3) $td_3 = 31^\circ\text{C}$
 $t_{w3} = 18.3^\circ\text{C}$

87.

Sol. Plotting the process on psychrometric chart,At point 1, $\omega_1 = 0.006 \text{ kg w.v/kg}$

$$h_1 = 27 \text{ kJ/kg}$$

At point 2, DBT = 36.5°C ; WBT = 21°C

$$h_2 = 60.8 \text{ kJ/kg d.a.}$$

$$\omega_2 = 0.0092 \text{ kg w.v/kg d.a.}$$

At point y, $\omega_y = \omega_2 = 0.0092 \text{ kg w.v / kg d.a.}$

$$h_y = 42 \text{ kJ/kg d.a.}$$

$$T_y = 18.2^\circ\text{C}$$

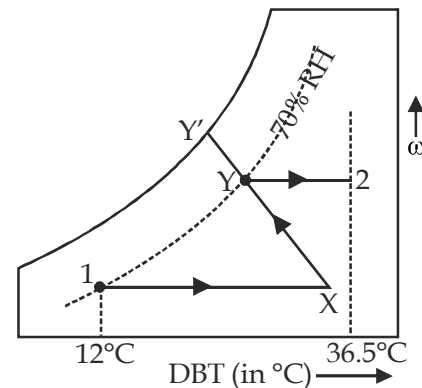
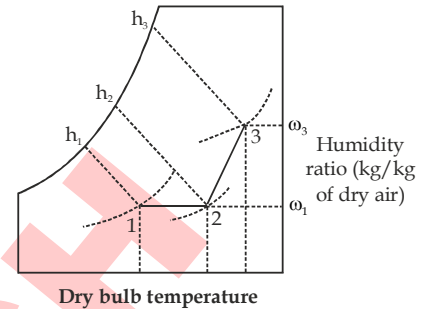
At point x, $h_x = h_y = 42 \text{ kJ/kg d.a.}$

$$\omega_x = \omega_1 = 0.006 \text{ kg w.v / kg d.a.}$$

$$T_x = 26.8^\circ\text{C}$$

(a) Temperature to which air is preheated = $T_x = 26.8^\circ\text{C}$

(b) Total heating required = $(h_x - h_1) + (h_2 - h_y) = (42 - 27) + (60.8 - 42)$
 $= 33.8 \text{ kJ/kg d.a.}$

(c) Make up water required in air washer = $\omega_y - \omega_x = 0.0092 - 0.006$ 

$$\omega_m = 3.2 \times 10^{-3} \text{ kg w.v / kg d.a.}$$

$$(d) \text{ Humidifying efficiency} = \frac{\omega_Y - \omega_X}{\omega_Y - \omega_X}$$

where ω_Y is specific humidity air RH 100% (point y' on chart)

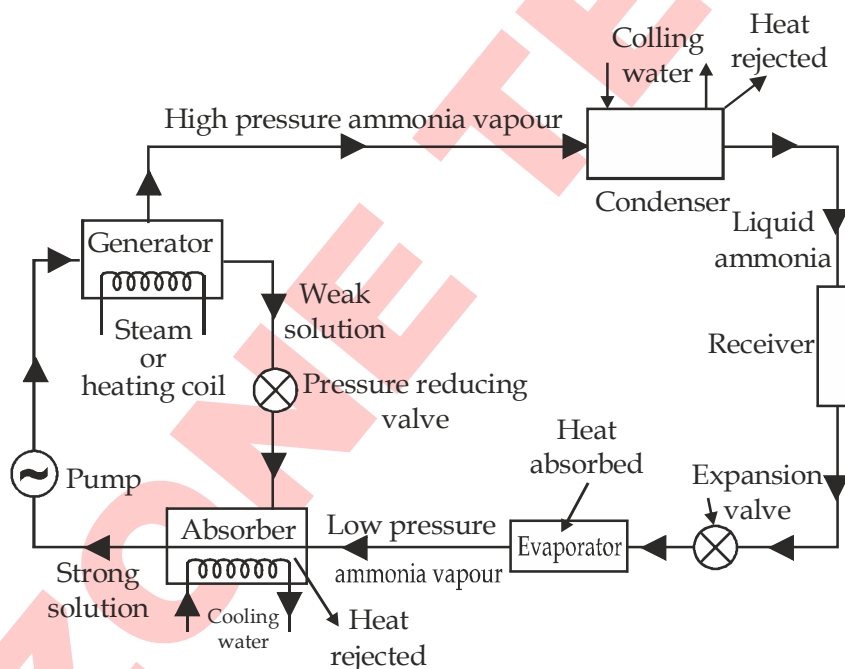
from chart, $\omega_Y = 0.0105 \text{ kg w.v/kg d.a.}$

$$\eta_H = \frac{3.2 \times 10^{-3}}{0.0105 - 0.006} = 0.7111 = 71.11\%$$

88.

Sol. Vapour Absorption Refrigeration System

It is one of the oldest method of producing refrigerating effect. This system may be used in both the domestic and large industrial refrigerating plants. The refrigerant commonly used in this system is ammonia. The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle.



The vapour absorption system as shown in Fig., consists of an absorber, a pump, a generator and a pressure reducing valve.

These components perform the same function as that of a compressor in vapour compression system. In the vapour absorption system, the vapour refrigerant from the evaporator is drawn into an absorber where it is absorbed by weak solution of the refrigerant forming a strong solution. This strong solution is pumped to the generator where it is heated by some external source. During the heating process, the vapour refrigerant is driven off by the solution and enters into the condenser where it is liquified. The liquid refrigerant then flows into the evaporator and thus the cycle is completed.

The C.O.P. of a vapour absorption system is given by

$$\text{C.O.P.} = \frac{T_E}{T_G} \left(\frac{T_G - T_C}{T_C - T_E} \right)$$

where

T_G = Temperature at which heat is given to the generator,

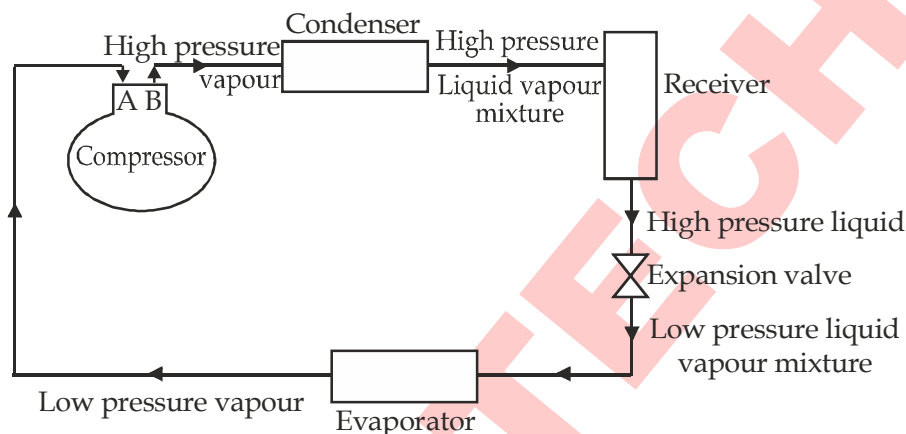
T_C = Temperature at which heat is discharged to the cooling water from the condenser and absorber, and

T_E = Temperature at which heat is absorbed in the evaporator.

89.

Sol. Vapour Compression Refrigeration System

A schematic diagram of a simple vapour compression refrigeration system is shown in Fig. In this system, a suitable working substance (known as refrigerant) such as ammonia, carbon dioxide, sulphur dioxide or Freon 12 is used. It consists of the following five essential parts:



1. **Compressor:** The low pressure and temperature vapour refrigerant from evaporator is drawn into the compressor through the inlet or suction valve A, where it is compressed to a high pressure and temperature. This high pressure and temperature vapour refrigerant is discharged into the condenser through the delivery or discharge valve B.
2. **Condenser:** The condenser or cooler consists of coils of pipe in which the high pressure and temperature vapour refrigerant is cooled and condensed.
3. **Receiver:** The condensed liquid refrigerant from the condenser is stored in a vessel known as receiver from where it is supplied to the evaporator through the expansion valve or refrigerant control valve.
4. **Expansion valve:** The expansion valve allows the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature.
5. **Evaporator:** An evaporator consists of coils of pipe in which the liquid-vapour refrigerant at low pressure and temperature is evaporated and changed into vapour refrigerant at low pressure and temperature.

Note: In any compression refrigeration system, there are two different pressure conditions. One is called the high pressure side and the other is known as low pressure side. The high pressure side includes the discharge line (i.e., piping from delivery valve B to the condenser), receiver and expansion valve. The low pressure side includes the evaporator, piping from the expansion valve to the evaporator and the suction line (i.e. piping from the evaporator to the suction valve A).

90.

Sol. Psychrometric Relations

The following psychrometric relations are important:

1. **Specific humidity, humidity ratio or moisture content:** It is the mass of water vapour present in 1 kg of dry air (in the air-vapour mixture) and is generally expressed in g/kg of dry air. It may

also be defined as the ratio of mass of water vapour to the mass of dry air in a given volume of the air-vapour mixture. Mathematically, humidity ratio,

$$W = 0.622 \times \frac{P_v}{P_b - P_v}$$

2. **Degree of saturation or percentage humidity:** It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it is saturated at the same temperature (dry bulb temperature). In other words, it may be defined as the ratio of actual specific humidity to the specific humidity of saturated air at the same dry bulb temperature. Mathematically, degree of saturation,

$$\mu = \frac{P_v}{P_s} \left[\frac{P_b - P_s}{P_b - P_v} \right]$$

where

P_s = Partial pressure of air corresponding to saturation temperature (i.e. dry bulb temperature).

3. **Relative humidity:** It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature and pressure. Mathematically, relative humidity,

$$\phi = \frac{\mu}{1 - (1 - \mu) \frac{P_s}{P_b}}$$

Note: For saturated air, the relative humidity is 100%.

4. **Pressure of water vapour:** According to Carrier's equation, the partial pressure of water vapour,

$$P_v = P_w - \frac{(P_b - P_w)(t_d - t_w)}{1544 - 1.44 t_w}$$

where

P_w = Saturation pressure corresponding to wet bulb temperature (from steam tables),

P_b = Barometric pressure,

t_d = Dry bulb temperature, and

t_w = Wet bulb temperature.

5. **Vapour density or absolute humidity:** It is the mass of water vapour present in 1 m³ of dry air.
6. **Thermodynamic wet bulb temperature or adiabatic saturation temperature:** It is the temperature at which the air can be brought to saturation state, adiabatically, by the evaporation of water into the flowing air.

91.

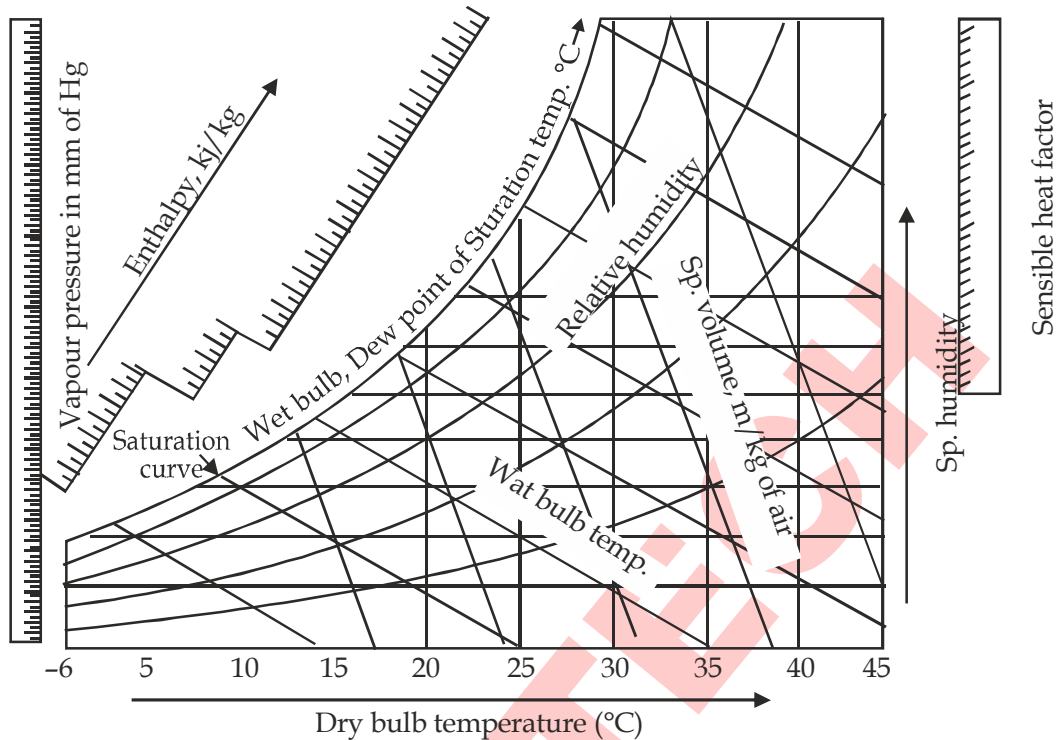
Sol. Psychrometric Chart

It is a graphical representation of the various thermodynamic properties of moist air. The psychrometric chart is very useful for finding out the properties of air (which are required in the field of air conditioning) and eliminate lot of calculations. This chart is normally drawn for standard atmospheric pressure of 760 mm of Hg (or 1.01325 bar).

In a psychrometric chart, dry bulb temperature is taken as abscissa and specific humidity (i.e. moisture contents) as ordinate, as shown in Fig. 10.10. The saturation curve is drawn by plotting the various saturation points at corresponding dry bulb temperatures. The saturation curve represents 100% relative humidity at various dry bulb temperatures. It also represents the wet bulb and dew point temperatures. The psychrometric chart contains the following important lines :

1. **Dry bulb temperature lines:** These lines are vertical i.e. parallel to the ordinate and uniformly spaced.
2. **Specific humidity or moisture content lines:** These lines are horizontal i.e. parallel to the abscissa and uniformly spaced.





3. **Dew point temperature lines:** These lines are horizontal i.e. parallel to the abscissa and non-uniformly spaced. At any point on the saturation curve, the dry bulb and dew point temperatures are equal.
4. **Wet bulb temperature lines:** These lines are inclined straight lines and non-uniformly spaced. At any point on the saturation curve, the dry bulb and wet bulb temperatures are equal.
5. **Specific volume lines:** These lines are obliquely inclined straight lines and uniformly spaced.
6. **Relative humidity lines:** These lines are curved lines and follow the saturation curve. The saturation curve represents 100% relative humidity.