



ME1251 THERMAL ENGINEERING

UNIT V

REFRIGERATION AND AIR CONDITIONING

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TECHNICAL TERMS

1. SPECIFIC HEAT

It is the ratio between the quantities of heat required to change the temperature of 1 pound of any substance 1°F, as compared to the quantity of heat required to change 1 pound of water 1°F. Specific heat is equal to the number of Btu required to raise the temperature of 1 pound of a substance 1°F. For example, the specific heat of milk is .92, which means that 92 Btu will be needed to raise 100 pounds of milk 1° F. The specific heat of water is 1, by adoption as a standard, and specific heat of another substance (solid, liquid, or gas) is determined experimentally by comparing it to water. Specific heat also expresses the heat-holding capacity of a substance compared to that of water.

2. SENSIBLE HEAT

Heat that is added to, or subtracted from, a substance that changes its temperature but not its physical state is called sensible heat. It is the heat that can be indicated on a thermometer. This is the heat human senses also can react to, at least within certain ranges. For example, if a person put their finger into a cup of water, the senses readily tell that person whether it is cold, cool, tepid, hot, or very hot. Sensible heat is applied to a solid, a liquid, or a gas/vapor as indicated on a thermometer. The term sensible heat does not apply to the process of conversion from one physical state to another.

3. LATENT HEAT

It is the term used for the heat absorbed or given off by a substance while it is changing its physical state. When this occurs, the heat given off or absorbed does NOT cause a temperature change in the substance. In other words, sensible heat is the term for heat that affects the temperature of things; latent heat is the term for heat that affects the physical state of things. To understand the concept of latent heat, you must realize that many substances may exist as solids, as liquids, or as gases, depending primarily upon the temperatures and pressure to which they are subjected.

4. SUPERHEAT

It is a very important term in the terminology of refrigeration - but it is unfortunately used in different ways. It can be used to describe a process where refrigerant vapour is heated from its

saturated condition to a condition at higher temperature. The term superheat can also be used to describe - or quantify - the end condition of the before-mentioned process.

5. PRESSURE

It is defined as a force per unit area. It is usually measured in pounds per square inch (psi). Pressure may be in one direction, several directions, or in all directions. The ice (solid) exerts pressure downward. The water (fluid) exerts pressure on all wetted surfaces of the container. Gases exert pressure on all inside surfaces of their containers.

6. VAPORIZATION

It is the process of changing a liquid to vapor, either by evaporation or boiling. When a glass is filled with water, as shown in figure 6-10, and exposed to the rays of the sun for a day or two, you should note that the water level drops gradually. The loss of water is due to evaporation. Evaporation, in this case, takes place only at the surface of the liquid. It is gradual, but the evaporation of the water can be speeded up if additional heat is applied to it. In this case, the boiling of the water takes place throughout the interior of the liquid. Thus the absorption of heat by a liquid causes it to boil and evaporate.

7. CONDENSATION

It is the process of changing a vapor into a liquid. For example, in figure 6-12, a warm atmosphere gives up heat to a cold glass of water, causing moisture to condense out of the air and form on the outside surface of the glass. Thus the removal of heat from a vapor causes the vapor to condense.

8. COP of REFRIGERATION

The COP of a refrigeration system is the ratio of net refrigeration effect to the work required to produce the effect.

9. UNIT OF REFRIGERATION

The capacity of refrigeration is expressed in tonnes of refrigeration (TOR).

1 tones of refrigeration = 210 kJ/min (or) = 3.5 kJ/sec (kW)

A tone of refrigeration is defined as the quantity of heat to be removed in order to form one tone of ice at 0°C in 24 hours.

10. REFRIGERATION EFFECT

The amount of heat extracted in a given time is known as refrigeration effect.

11. EFFECTS OF UNDER COOLING

It increases the refrigeration effect therefore the COP increases. The mass flow rate of the refrigeration is less than that for the simple saturated cycle. The reduced mass flow rate reduces the piston displacement per minute. Power per tones of refrigeration losses due to reduction in mass flow rate. The increased efficiency may be offering some extent by the rise in the condenser pressure. Work input almost remains same. The heat rejection capacity of the condenser increases.

12. EFFECTS OF SUPER HEATING

Super heating increases the net refrigeration effect, but super heating requires more work input therefore super heating reduces the COP.

No moisture contents in the refrigerant therefore no corrosion in the machines part.

13. PROPERTIES OF IDEAL REFRIGERANT

It should have low boiling point and low freezing point.

It must have low specific heat and high latent heat.

It should have high thermal conductivity to reduce the heat transfer in evaporator and condenser.

It should have low specific volume to reduce the size of the compressor.

It should be non-flammable, non-expensive, non-toxic and non-corrosive.

It should have high critical pressure and temperature to avoid large power requirements.

It should give high COP to reduce the running cost of the system.

It must be cheap and must be readily available

14. RSHF

Room sensible heat factor is defined as the ratio of room sensible heat load to the room total heat load.

15. RELATIVE HUMIDITY

It is defined as the ratio of partial pressure of water vapour (p_w) in a mixture to the saturation pressure (p_s) of pure water at the same temperature of mixture.

16. SPECIFIC HUMIDITY

It is defined as the ratio of the mass of water vapour (m_s) in a given volume to the mass of dry air in a given volume (m_a).

17. DEGREE OF SATURATION

It is the ratio of the actual specific humidity and the saturated specific humidity at the same temperature of the mixture.

18. DEW POINT TEMPERATURE

The temperature at which the vapour starts condensing is called dew point temperature. It is also equal to the saturation temperature at the partial pressure of water vapour in the mixture. The dew point temperature is an indication of specific humidity.

19. SENSIBLE HEAT AND LATENT HEAT

Sensible heat is the heat that changes the temperature of the substance when added to it or when abstracted from it. Latent heat is the heat that does not affect the temperature but change of state occurred by adding the heat or by abstracting the heat.

20. PSYCHOMETRIC PROCESSES

1. Sensible heating and sensible cooling, 2. Cooling and dehumidification, 3. Heating and humidification, 4. Mixing of air streams, 5. Chemical dehumidification, 6. Adiabatic evaporative cooling.

21. ADIABATIC MIXING

The process of mixing two or more stream of air without any heat transfer to the surrounding is known as adiabatic mixing. It is happened in air conditioning system.

22. DRY BULB TEMPERATURE (DBT)



The temperature recorded by the thermometer with a dry bulb. The dry bulb thermometer cannot be affected by the moisture present in the air. It is the measure of sensible heat of the air.

23. WET BULB TEMPERATURE (WBT)

It is the temperature recorded by a thermometer whose bulb is covered with cotton wick (wet) saturated with water. The wet bulb temperature may be the measure of enthalpy of air. WBT is the lowest temperature recorded by a moistened bulb.

24. DEW POINT DEPRESSION

It is the difference between dry bulb temperature and dew point temperature of air vapour mixture.

UNIT V

REFRIGERATION AND AIR CONDITIONING

5.1 Fundamentals of refrigeration

The first mechanical refrigerators for the production of ice appeared around the year 1860. In 1880 the first ammonia compressors and insulated cold stores were put into use in the USA. Electricity began to play a part at the beginning of this century and mechanical refrigeration plants became common in some fields: e.g. breweries, slaughter-houses, fishery, ice production, for example. After the Second World War the development of small hermetic refrigeration compressors evolved and refrigerators and freezers began to take their place in the home. Today, these appliances are regarded as normal household necessities.

Refrigeration is the process of removing heat from an area or a substance and is usually done by an artificial means of lowering the temperature, such as the use of ice or mechanical refrigeration.

Mechanical Refrigeration is defined as a mechanical system or apparatus so designed and constructed that, through its function, heat is transferred from one substance to another. Since refrigeration deals entirely with the removal or transfer of heat, some knowledge of the nature and effects of heat is necessary for a clear understanding of the subject.

5.2 Common Refrigerants

Today, there are three specific types of refrigerants used in refrigeration and air-conditioning systems:

1. Chlorofluorocarbons or CFCs, such as R-11, R-12, and R-114
2. Hydrochlorofluorocarbons or HCFCs, such as R-22 or R-123
3. Hydro fluorocarbons or HFCs, such as R-134a. All these refrigerants are "halogenated," which means they contain chlorine, fluorine, bromine, astatine, or iodine.



Refrigerants, such as Dichlorodifluoromethane (R-12), Mono chloro difluoromethane (R-22), and Refrigerant 502 (R-502), are called primary refrigerants because each one changes its state upon the application or absorption of heat, and, in this act of change, absorbs and extracts heat from the area or substance.

The primary refrigerant is so termed because it acts directly upon the area or substance, although it may be enclosed within a system. For a primary refrigerant to cool, it must be placed in a closed system in which it can be controlled by the pressure imposed upon it. The refrigerant can then absorb at the temperature ranges desired. If a primary refrigerant were used without being controlled, it would absorb heat from most perishables and freeze them solid.

Secondary Refrigerants are substances, such as air, water, or brine. Though hot refrigerants in themselves, they have been cooled by the primary refrigeration system; they pass over and around the areas and substances to be cooled; and they are returned with their heat load to the primary refrigeration system. Secondary refrigerants pay off where the cooling effect must be moved over a long distance and gastight lines cost too much.

Refrigerants are classified into groups. The National Refrigeration Safety Code catalogs all refrigerants into three groups:

- Group I – safest of the refrigerants, such as R-12, R-22, and R-502
- Group II – toxic and somewhat flammable, such as R-40 (Methyl chloride) and R-764 (Sulfur dioxide)
- Group III – flammable refrigerants, such as R-170 (Ethane) and R-290 (Propane).

R-12 Dichlorodifluoromethane (CCl₂F₂) Dichlorodifluoromethane, commonly referred to as R-12, is colorless and odorless in concentrations of less than 20 percent by volume in air. In higher concentrations, its odor resembles that of carbon tetrachloride. It is nontoxic, noncorrosive, nonflammable, and has a boiling point of -21.7°F (-29°C) at atmospheric pressure.

5.3 Required Properties of Ideal Refrigerant

1) The refrigerant should have low boiling point and low freezing point.

- 2) It must have low specific heat and high latent heat. Because high specific heat decreases the refrigerating effect per kg of refrigerant and high latent heat at low temperature increases the refrigerating effect per kg of refrigerant.
- 3) The pressures required to be maintained in the evaporator and condenser should be low enough to reduce the material cost and must be positive to avoid leakage of air into the system.
- 4) It must have high critical pressure and temperature to avoid large power requirements.
- 5) It should have low specific volume to reduce the size of the compressor.
- 6) It must have high thermal conductivity to reduce the area of heat transfer in evaporator and condenser.
- 7) It should be non-flammable, non-explosive, non-toxic and non-corrosive.
- 8) It should not have any bad effects on the stored material or food, when any leak develops in the system.
- 9) It must have high miscibility with lubricating oil and it should not have reacting properly with lubricating oil in the temperature range of the system.
- 10) It should give high COP in the working temperature range. This is necessary to reduce the running cost of the system.

5.4 Coefficient of Performance (COP)

The performance of refrigerators and heat pumps is expressed in terms of coefficient of performance (COP), defined as

$$COP_R = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Cooling effect}}{\text{Work input}} = \frac{Q_L}{W_{net,in}}$$

$$COP_{HP} = \frac{\text{Desired output}}{\text{Required input}} = \frac{\text{Heating effect}}{\text{Work input}} = \frac{Q_H}{W_{net,in}}$$

5.5 Vapour Compression Refrigeration

Heat flows naturally from a hot to a colder body. In refrigeration system the opposite must occur i.e. heat flows from a cold to a hotter body. This is achieved by using a substance called a refrigerant, which absorbs heat and hence boils or evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained

to ambient air or water and turns back (condenses) into a liquid. In this way heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source.

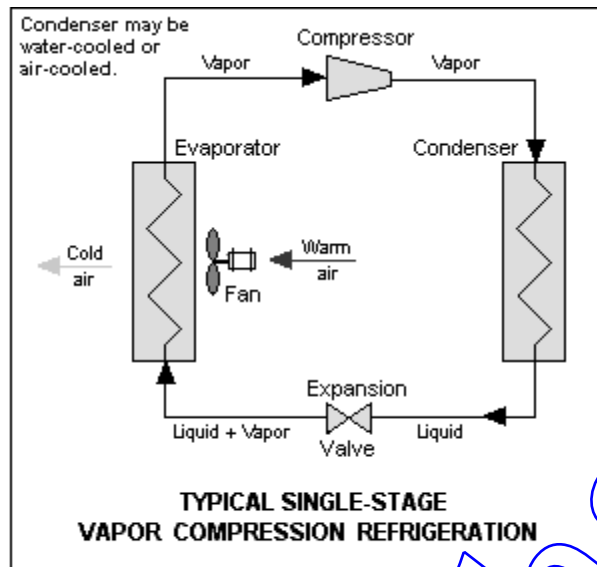


Fig 5.1 Vapour Compression Refrigeration

The refrigeration cycle can be broken down into the following stages

1 - 2 Low pressure liquid refrigerant in the evaporator absorbs heat from its surroundings, usually air, water or some other process liquid. During this process it changes its state from a liquid to a gas, and at the evaporator exit is slightly superheated.

2 - 3 The superheated vapour enters the compressor where its pressure is raised. There will also be a big increase in temperature, because a proportion of the energy input into the compression process is transferred to the refrigerant.

3 - 4 The high pressure superheated gas passes from the compressor into the condenser. The initial part of the cooling process (3 - 3a) desuperheats the gas before it is then turned back into liquid (3a - 3b). The cooling for this process is usually achieved by using air or water. A further reduction in temperature happens in the pipe work and liquid receiver (3b - 4), so that the refrigerant liquid is sub-cooled as it enters the expansion device.



4 - 1 The high-pressure sub-cooled liquid passes through the expansion device, which both reduces its pressure and controls the flow into the evaporator.

$$\text{Refrigeration effect} = Q_R = m (h_1 - h_4)$$

Since process 3-4 is a throttling process, $h_4 = h_3$.

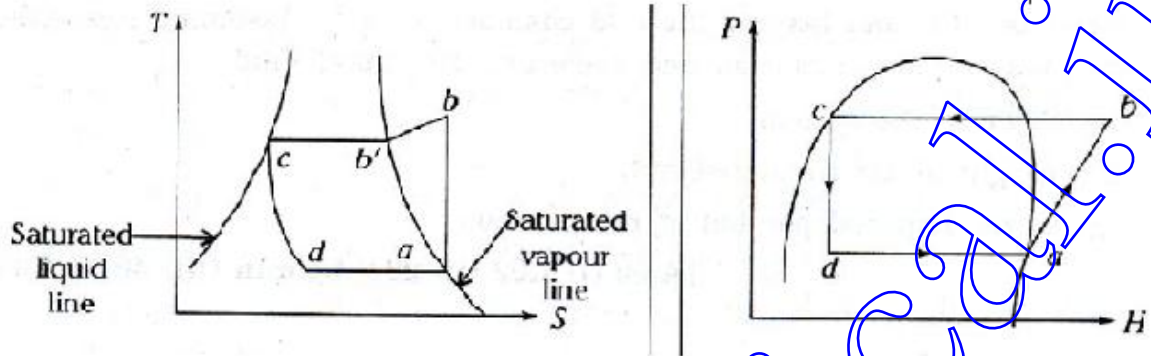
$$\text{Hence } Q_R = m (h_1 - h_3)$$

Similarly, by applying steady flow, steady state energy equation to compressor we get

$$\text{Compressor work input} = W_c = m (h_2 - h_1)$$

Hence

$$\text{COP} = \frac{Q_R}{W_c} = \frac{(h_1 - h_4)}{(h_2 - h_1)}$$



Sub cooling or Under cooling:

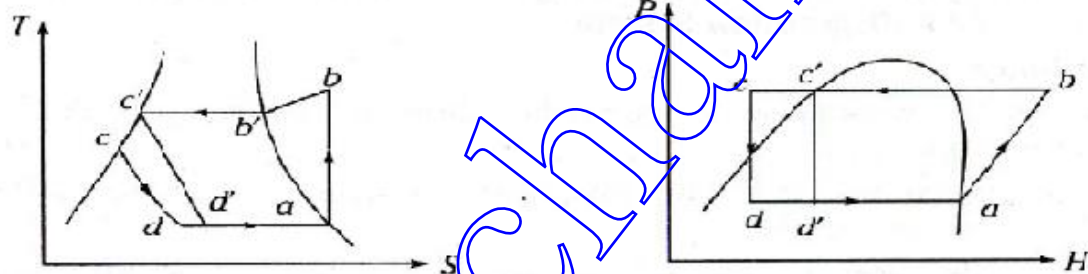


Fig 5.2 TS Diagram

PH Diagram

It can be seen that the condenser has to be capable of rejecting the combined heat inputs of the evaporator and the compressor; i.e. $(1 - 2) + (2 - 3)$ has to be the same as $(3 - 4)$. There is no heat loss or gain through the expansion device.

Super Heating:

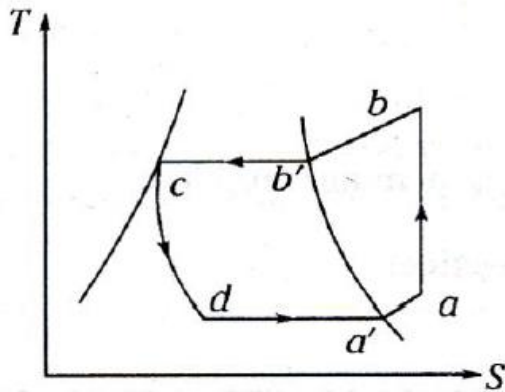


Fig 5.3 TS diagram

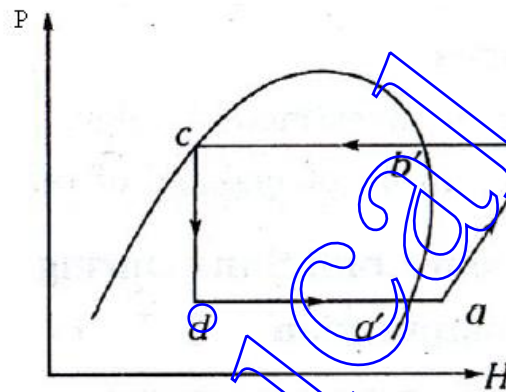


Fig 5.4 PH Diagram

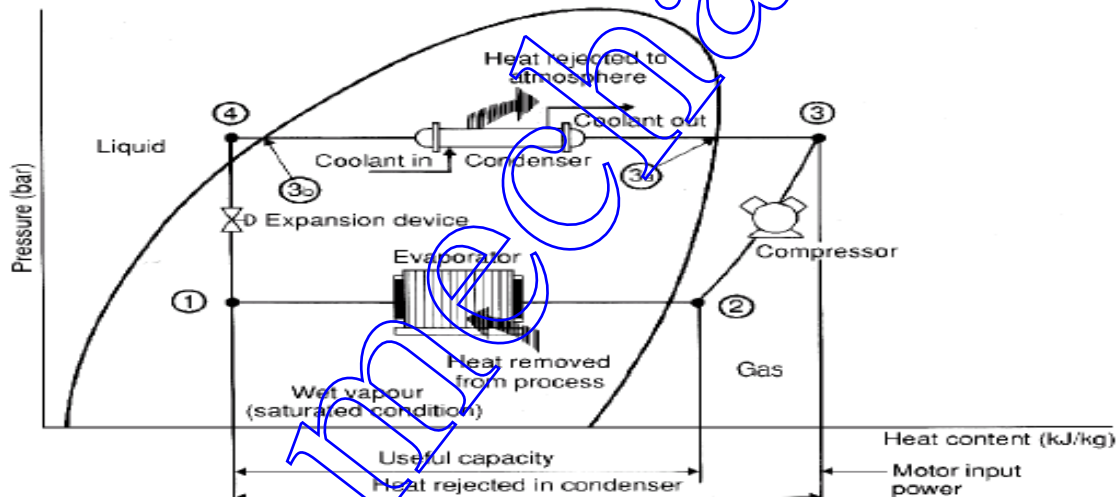


Fig 5.5 condition of Refrigeration System

5.5.1 Schematic of a Basic Vapor Compression Refrigeration System

Advantages of Vapour compression refrigeration system over air refrigeration system:

- Since the working cycle approaches closer to Carnot cycle, the C.O.P is quite high.
- Operational cost of vapour compression system is just above 1/4th of air refrigeration

system.

- Since the heat removed consists of the latent heat of vapour, the amount of liquid circulated is less and as a result the size of the evaporator is smaller.
- Any desired temperature of the evaporator can be achieved just by adjusting the throttle valve.

Disadvantages of Vapour compression refrigeration system over air refrigeration system

- Initial investment is high
- Prevention of leakage of refrigerant is a major problem

5.5.2 Alternative Refrigerants for Vapour Compression Systems

The use of CFCs is now beginning to be phased out due to their damaging impact on the protective tropospheric ozone layer around the earth. The Montreal Protocol of 1987 and the subsequent Copenhagen agreement of 1992 mandate a reduction in the production of ozone depleting Chlorinated Fluorocarbon (CFC) refrigerants in a phased manner, with an eventual stop to all production by the year 1996. In response, the refrigeration industry has developed two alternative refrigerants; one based on Hydrochloro Fluorocarbon (HCFC), and another based on Hydro Fluorocarbon (HFC). The HCFCs have a 2 to 10% ozone depleting potential as compared to CFCs and also, they have an atmospheric lifetime between 2 to 25 years as compared to 100 or more years for CFCs (Brandt, 1992). However, even HCFCs are mandated to be phased out by 2005, and only the chlorine free (zero ozone depletion) HFCs would be acceptable.

Until now, only one HFC based refrigerant, HFC 134a, has been developed. HCFCs are comparatively simpler to produce and the three refrigerants 22, 123, and 124 have been developed. The use of HFCs and HCFCs results in slightly lower efficiencies as compared to CFCs, but this may change with increasing efforts being made to replace CFCs.

5.6 Vapour Absorption Refrigeration

In the absorption refrigeration system, refrigeration effect is produced mainly by the use of energy as heat. In such a system, the refrigerant is usually dissolved in a liquid. A concentrated solution of ammonia is boiled in a vapour generator producing ammonia vapour at high pressure. The high pressure ammonia vapour is fed to a condenser where it is condensed to liquid ammonia by rejecting energy as heat to the surroundings. Then, the liquid ammonia is throttled through a valve to a low pressure. During throttling, ammonia is partially vapourized and its temperature decreases.

This low temperature ammonia is fed to an evaporator where it is vapourized removing energy from the evaporator. Then this low-pressure ammonia vapour is absorbed in the weak solution of ammonia. The resulting strong ammonia solution is pumped back to the vapour generator and the cycle is completed. The COP of the absorption system can be evaluated by considering it as a combination of a heat pump and a heat engine

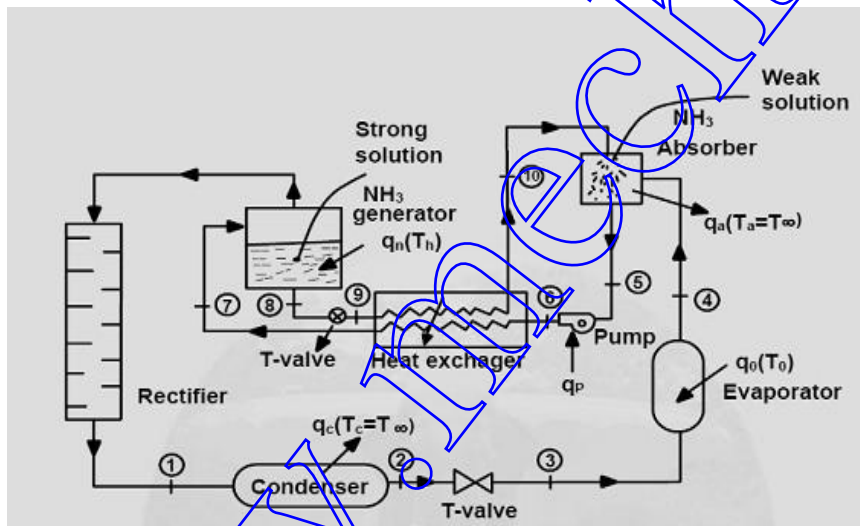


Fig 5.6 Vapour Absorption Refrigeration

5.7 Comparison between Vapor Compression and Absorption System

Table 1 Vapor Compression and Absorption System

Absorption system	Compression System
a) Uses low grade energy like heat. Therefore, may be worked on exhaust systems from I.C engines, etc.	a) Using high-grade energy like mechanical work.
b) Moving parts are only in the pump, which is a small element of the system. Hence operation is smooth.	b) Moving parts are in the compressor. Therefore, more wear, tear and noise.
c) The system can work on lower evaporator pressures also without affecting the COP.	c) The COP decreases considerably with decrease in evaporator pressure.
d) No effect of reducing the load on performance.	d) Performance is adversely affected at partial loads.
e) Liquid traces of refrigerant present in piping at the exit of evaporator	e) Liquid traces in suction line may damage the compressor.

5.8 Ton of refrigeration:

Amount of heat required to melt a Ton of Ice in a 24/h Period

One ton of refrigeration is the heat required to melt 1 ton of ice in 24 hrs. That is, a refrigeration machine rated at 1 ton cools as much in 24 hrs. as 1 ton of ice would by melting in the same period.

The heat required is the product of the latent heat of fusion and the mass in kg.

$$Q = mH,$$

$$1 \text{ ton} = 907 \text{ kg}$$

$$\text{Latent heat of fusion: } H = 340 \text{ kJ/kg}$$

$$Q = 907 * 340 = 308380 \text{ kJ}$$

The power required is then:

$$P = E/t = Q/t = 308380 \text{ kJ}/24 \text{ hr} = 308380/(24 \times 3600) = 3.57 \text{ kw}$$

Note: 1 watt = 1 J/s

So that 1 kw = 1 kJ/s

5.9 Air- Conditioning Systems:

The central air conditioning system is used for cooling big buildings, houses, offices, entire hotels, gyms, movie theaters, factories etc. If the whole building is to be air conditioned, HVAC engineers find that putting individual units in each of the rooms is very expensive initially as well in the long run. The central air conditioning system is comprised of a huge compressor that has the capacity to produce hundreds of tons of air conditioning. Cooling big halls, malls, huge spaces, galleries etc is usually only feasible with central conditioning units.

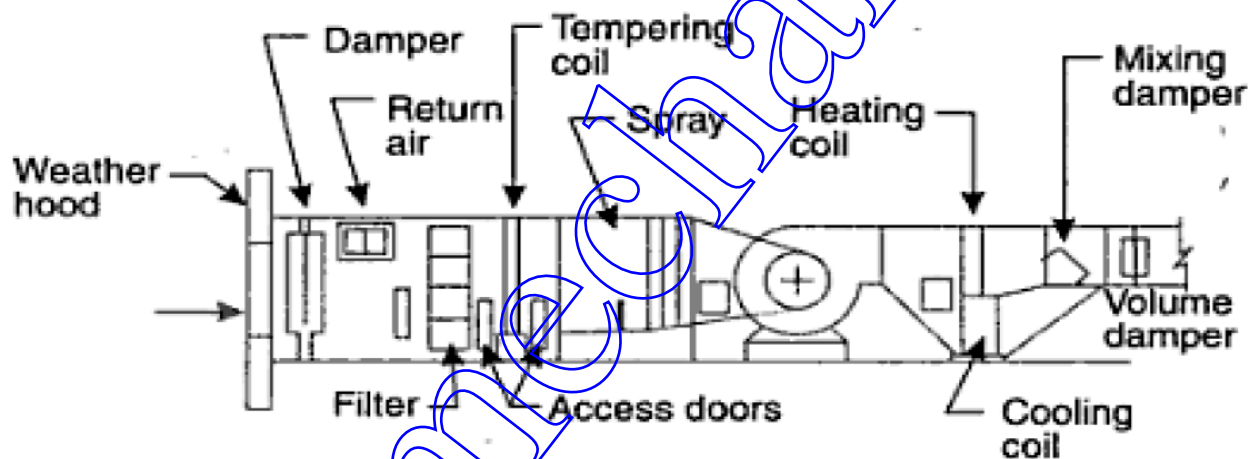


Fig.5.9 Air Condition System

5.9.1 Zoned Systems

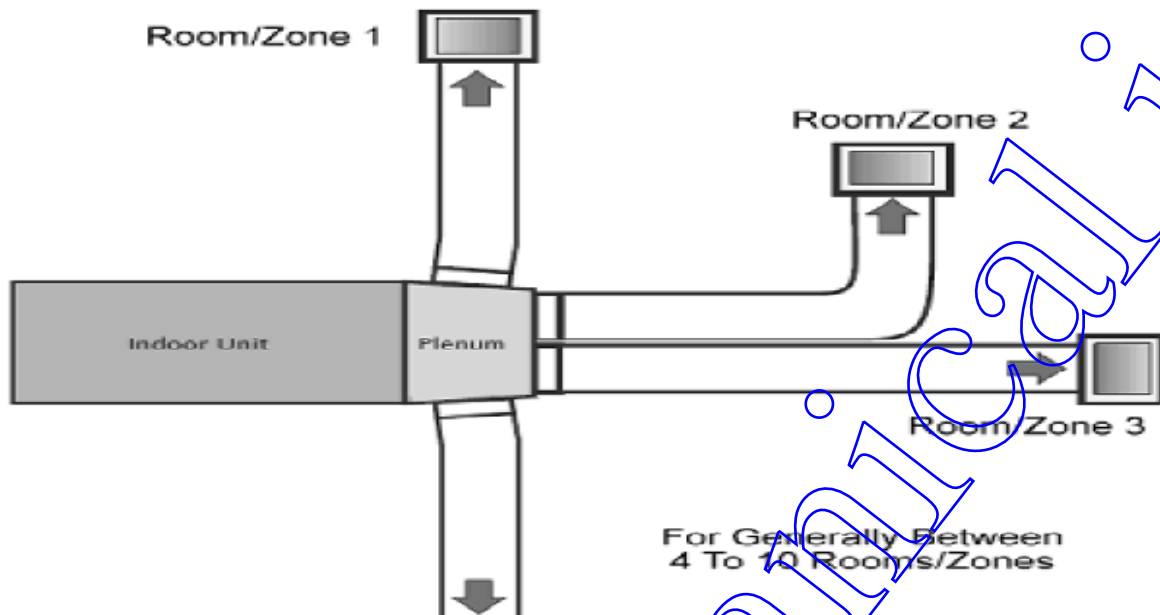


Fig.5.9.1 Zoned System

A zoned air conditioning system using a room air terminal which has the same horizontal dimensions as a floor tile of a raised tile floor such that the terminal may replace one tile in such a floor. The terminal includes a cool air inlet below the floor for drawing in cooling air circulated in the under floor space and a return air inlet in the top surface of the terminal. The cool air and return air is mixed in a mixing chamber and drawn from the mixing chamber by a fan and returned to the room through an outlet vent. The ratio of cool air to return air mixed in the mixing chamber is controlled by a modulating damper which is controlled in response to the temperature of the return air in order to control the room temperature in the region of the terminal in accordance with an adjustable set point. A heater is also provided in the terminal for those occasions where the return air is cooler than the set point.

5.9.2 Unitary Systems:

A unitary air conditioning system comprises an outdoor unit including a compressor for compressing a refrigerant, an outdoor heat exchanger for heat exchange of the refrigerant and an expander connected to the outdoor heat exchanger, for expanding the refrigerant; a duct installed inside a zone of a building; a central blower unit having a heat exchanger connected to the

outdoor unit through a first refrigerant pipe and a blower for supplying the air heat-exchanged by the heat exchanger to the duct; and an individual blower unit including a heat exchanger connected to the outdoor unit through a second refrigerant pipe and a fan for sending the air heat exchanged by the heat exchanger and disposed in a zone in the building, for individually cooling or heating the zone. Accordingly, cooling or heating operation is performed on each zone of the building, and simultaneously, additional individual heating or cooling operation can be performed on a specific space, so that a cost can be reduced and cooling or heating in the building can be efficiently performed.

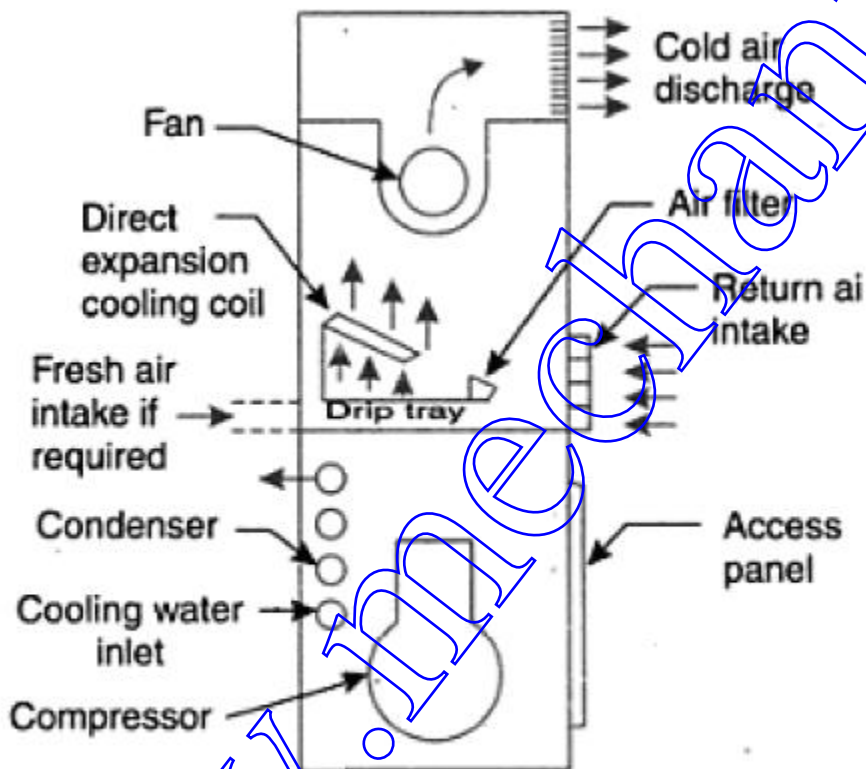


Fig.5.9.2 Unitary Systems

5.10 Window Air-conditioning System:

It is the most commonly used air conditioner for single rooms. In this air conditioner all the components, namely the compressor, condenser, expansion valve or coil, evaporator and cooling coil are enclosed in a single box. This unit is fitted in a slot made in the wall of the room,

or often a window sill.

Window air conditioners are one of the most widely used types of air conditioners because they are the simplest form of the air conditioning systems. Window air conditioner comprises of the rigid base on which all the parts of the window air conditioner are assembled. The base is assembled inside the casing which is fitted into the wall or the window of the room in which the air conditioner is fitted.

The whole assembly of the window air conditioner can be divided into two compartments: the room side, which is also the cooling side and the outdoor side from where the heat absorbed by the room air is liberated to the atmosphere. The room side and outdoor side are separated from each other by an insulated partition enclosed inside the window air conditioner assembly.

In the front of the window air conditioner on the room side there is beautifully decorated front panel on which the supply and return air grills are fitted (the whole front panel itself is commonly called as front grill). The louvers fitted in the supply air grills are adjustable so as to supply the air in desired direction. There is also one opening in the grill that allows access to the Control panel or operating panel in front of the window air conditioner.

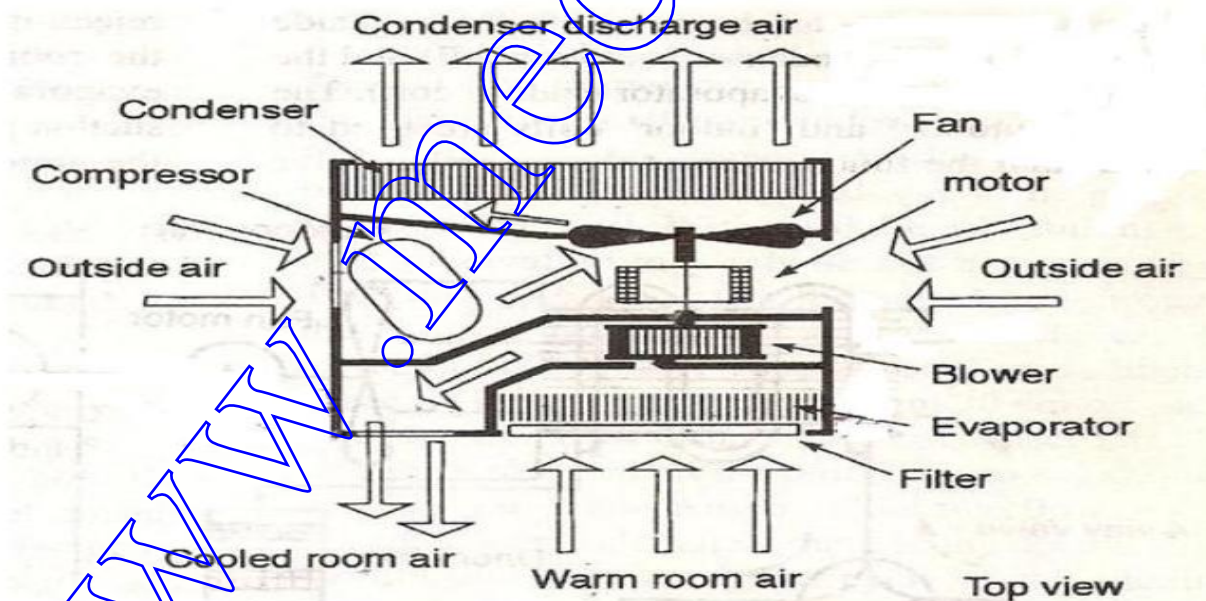


Fig.5.10 Window air conditioning system

5.10.1 Blower:

This is the small blower that is fitted behind the evaporator or cooling coil inside the assembly of the window air conditioner system. The blower sucks the air from the room which first passes over the air filter and gets filtered. The air then passes over the cooling coil and gets chilled. The blower then blows this filtered and chilled air, which passes through the supply air compartment inside the window air conditioner assembly. This air is then delivered into the room from the supply air grill of the front panel.

5.10.2 Propeller fan or the condenser fan:

The condenser fan is the forced draft type of propeller fan that sucks the atmospheric air and blows it over the condenser. The hot refrigerant inside the condenser gives up the heat to the atmospheric air and its temperature reduces.

5.10.3 Fan motor:

The motor inside the window air conditioner assembly is located between the condenser and the evaporator coil. It has double shaft on one side of which the blower is fitted and on the other side the condenser fan is fitted. This makes the whole assembly of the blower, the condenser fan and the motor highly compact.

5.11 Split Air-conditioning System:

The split air conditioner comprises of two parts: the outdoor unit and the indoor unit. The outdoor unit, fitted outside the room, houses components like the compressor, condenser and expansion valve. The indoor unit comprises the evaporator or cooling coil and the cooling fan. For this unit you don't have to make any slot in the wall of the room. Further, the present day split units have aesthetic looks and add to the beauty of the room. The split air conditioner can be used to cool one or two rooms.

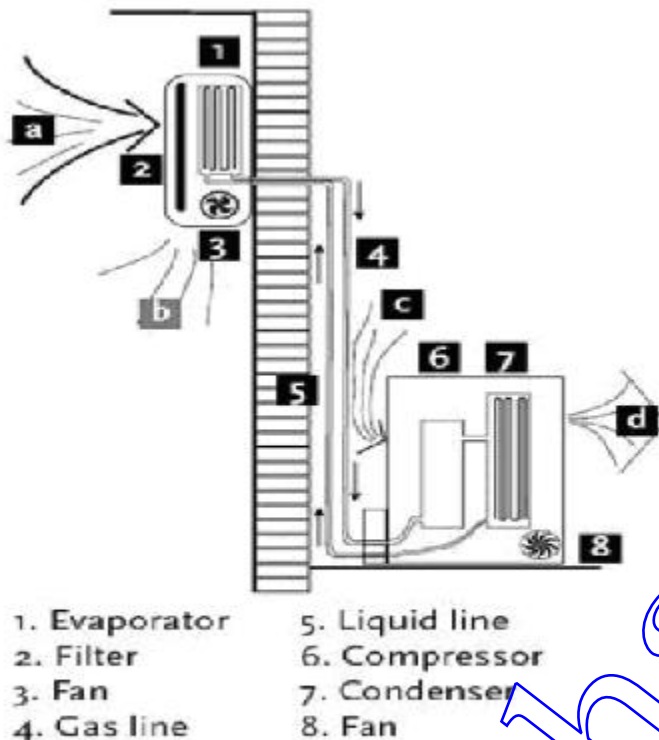


Fig 5.11 Split Air-conditioning System

5.11.1 Evaporator Coil or the Cooling Coil:

The cooling coil is a copper coil made of number turns of the copper tubing with one or more rows depending on the capacity of the air conditioning system. The cooling coil is covered with the aluminum fins so that the maximum amount of heat can be transferred from the coil to the air inside the room.

5.11.2 Air Filter:

The air filter is very important part of the indoor unit. It removes all the dirt particles from the room air and helps supplying clean air to the room. The air filter in the wall mounted type of the indoor unit is placed just before the cooling coil. When the blower sucks the hot room air, it is first passed through the air filter and then through the cooling coil.

5.11.3 Cooling Fan or Blower:

Inside the indoor unit there is also a long blower that sucks the room air or the atmospheric air. It is an induced type of blower and while it sucks the room air it is passed over the cooling coil and the filter due to which the temperature of the air reduces and all the dirt from it is removed. The blower sucks the hot and unclean air from the room and supplies cool and clean air back. The shaft of the blower rotates inside the bushes and it is connected to a small multiple speed motor, thus the speed of the blower can be changed. When the fan speed is changed with the remote it is the speed of the blower that changes.

5.11.4 Drain Pipe:

Due to the low temperature refrigerant inside the cooling coil, its temperature is very low, usually much below the dew point temperature of the room air. When the room air is passed over the cooling coil due to the suction force of the blower, the temperature of the air becomes very low and reaches levels below its dew point temperature. Due to this the water vapor present in the air gets condensed and dew or water drops are formed on the surface of the cooling coil. These water drops fall off the cooling coil and are collected in a small space inside the indoor unit. To remove the water from this space the drain pipe is connected from this space extending to some external place outside the room where water can be disposed off. Thus the drain pipe helps removing dew water collected inside the indoor unit.

5.11.5 Louvers or Fins:

The cool air supplied by the blower is passed into the room through louvers. The louvers help changing the angle or direction in which the air needs to be supplied into the room as per the requirements. With louvers one can easily change the direction in which the maximum amount of the cooled air has to be passed. There are two types of louvers: horizontal and vertical. The horizontal louvers are connected to a small motor and their position can be set by the remote control. One can set a fixed position for the horizontal louvers so that chilled air is passed in a



particular direction only or one can keep it in rotation mode so that the fresh air is supplied throughout the room. The vertical louvers are operated manually and one can easily change their position as per the requirements. The horizontal louvers control flow of air in upper and downward directions of the room, while vertical louvers control movement of air in left and right directions.

5.12 SOLVEDE PROBLEMS



1. A sling psychrometer gives reading of 25°C dry bulb temperature 15°C wet bulb temperature. The barometer indicates 760 mm of Hg assuming partial pressure of the vapour as 10 mm of Hg. Determine 1. Specific humidity 2. Saturation ratio.

Given Data:

Dry bulb temperature $t_d = 25^{\circ}\text{C}$

Wet bulb temperature $t_w = 15^{\circ}\text{C}$

Barometer pressure $p_b = 760\text{ mm of Hg}$

Partial pressure $p_v = 10\text{ mm of Hg}$

To Find:

Specific humidity

Saturation ratio.

Solution:**Specific humidity:**

We know that Specific humidity

$$W = \frac{.622 p_v}{p_b - p_v} = \frac{.622 \times 10}{760 - 10}$$

$$= 0.0083 \text{ kg/kg of dry air}$$

Saturation ratio:

From steam table corresponding to dry bulb temperature $t_d = 25^{\circ}\text{C}$

We find the partial pressure $p_s = 0.03166 \text{ bar}$

$$\frac{0.03166}{0.00133}$$

$$= 23.8 \text{ mm of Hg}$$

We know that Saturation ratio.

$$\mu = \frac{pv(pb - ps)}{ps(pb - pv)}$$

$$= \frac{10(760 - 23.8)}{23.8(760 - 10)} = 0.41$$

RESULT:

1. Specific humidity = 0.0083 kg/kg of dry air
2. Saturation ratio. = **0.41**

2. A two stages, single acting air compressor compresses air to 20bar. The air enters the L.P cylinder at 1bar and 27°C and leaves it at 4.7bar. the air enters the H.P. cylinder at 4.5bar and 27°C. the size of the L.P cylinder is 400mm diameter and 500mm stroke. The clearance volume In both cylinder is 4% of the respective stroke volume. The compressor runs at 200rpm, taking index of compression and expansion in the two cylinders as 1.3, estimate 1. The indicated power required to run the compressor; and 2. The heat rejected in the intercooler per minute.

GIVEN DATA:

Pressure (P4) = 20bar

Pressure (P1) = 1bar = $1 \times 10^5 \text{ N/m}^2$

Temperature (T1) = 27°C = 27 + 273 = 300K

Pressure (P2) = 4.7bar

Pressure (P3) = 4.5bar

Temperature (T3) = 27°C = 27 + 273 = 300K

Diameter (D1) = 400mm 0.4m

Stroke (L_1) = 500mm = 0.5m

$$K = \frac{v_{c1}}{v_{s1}} = \frac{v_{c3}}{v_{s3}} = 4\% = 0.04$$

$N = 200\text{rpm}$; $n = 1.3$

To Find:

Indicated power required to run the compressor

Solution :

We know the swept volume of the L/P cylinder

$$v_{s1} = \frac{\pi}{4} (D_1)^2 L_1 = \frac{\pi}{4} (0.4)^2 0.5$$

$$= 0.06284 \text{ m}^3$$

And volumetric efficiency,

$$\eta_v = 1 + K - K \left(\frac{P_2}{P_1} \right)^{\frac{1}{n}}$$

$$= 1 + 0.04 - 0.04 \left(\frac{4.7}{1} \right)^{\frac{1}{1.3}}$$

$$= 0.9085 \text{ or } 90.85\%$$

Volume of air sucked by air pressure compressor,

$$v_1 = v_{s1} \times \eta_v = 0.06284 \times 0.9085 = 0.0571 \frac{\text{m}^3}{\text{stroke}}$$

$$= 0.0571 \times N_w = 0.0571 \times 200 = 11.42 \text{ m}^3/\text{min}$$

And volume of air sucked by H.P compressor,

$$v_3 = \frac{P_1 V_1}{P_3} = \frac{1 \times 11.42}{4.5} = 2.54 \frac{\text{m}^3}{\text{min}}$$

We know that indicated work done by L.P compressor,

$$\begin{aligned} W_L &= \left(\frac{n}{n-1} \right) P_1 v_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] \\ &= \left(\frac{1.3}{1.3-1} \right) 1 \times 10^5 \times 11.42 \left[\left(\frac{4.7}{1} \right)^{\frac{1.3-1}{1.3}} - 1 \right] \\ &= 2123.3 \times 10^3 \text{ J/min} = 2123.3 \text{ KJ/min} \end{aligned}$$

And indicated work done by H.P compressor,

$$\begin{aligned} W_H &= \left(\frac{n}{n-1} \right) P_3 v_3 \left[\left(\frac{P_4}{P_3} \right)^{\frac{n-1}{n}} - 1 \right] \\ &= \left(\frac{1.3}{1.3-1} \right) 4.5 \times 10^5 \times 2.54 \left[\left(\frac{4.20}{4.5} \right)^{\frac{1.3-1}{1.3}} - 1 \right] \\ &= 2043.5 \times 10^3 \text{ J/min} = 2034.5 \text{ KJ/min} \end{aligned}$$

Total indicated work done by the compressor,

$$W = W_L + W_H = 2123.3 + 2034.5 = 4157.8 \text{ KJ/min}$$

Indicated power required to run the compressor

$$= 4157.8 / 60 = 69.3 \text{KW}$$

3. In an oil gas turbine installation, air is taken as 1 bar and 30°C . The air is compressed to 4bar and then heated by burning the oil to a temperature of 500°C . If the air flows at the rate of 90Kg/min. Find the power developed by the plant take γ for air as 1.4 C_p as 1KJ/KgK. If 2.4Kg of oil having calorific value of 40,000 KJ/Kg is burned in the combustion chamber per minute. Find the overall efficiency of the plant.

Given Data:

Pressure ($P_4 = P_3$) = 1bar

Pressure ($P_1 = P_2$) = 4bar

Temperature (T_2) = $500^\circ\text{C} = 500 + 273 = 773\text{K}$

Mass flow rate of air (m_a) = 90Kg/min = 1.5Kg/sec

Mass flow rate of fuel (m_f) = 2.4Kg/min = 0.04Kg/sec

Temperature (T_4) = $30^\circ\text{C} = 30 + 273 = 303\text{K}$

$\gamma = 1.4$; $C_p = 1\text{KJ/KgK}$; $C_v = 40,000 \text{KJ/Kg}$

To Find:

Power developed by the plant

Performance of the gas turbine

Overall efficiency of the plant

Solution:**Power developed by the plant:**

Let T_1, T_3 = temperature of air at points 1 and 3

We know that isentropic expansion 2-3,

$$\frac{T_3}{T_2} = \left(\frac{P_3}{P_2}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{1}{4}\right)^{\frac{1.4-1}{1.4}} = 0.673$$

$$T_3 = T_2 \times 0.673 = 773 \times 0.673 = 520\text{K}$$

Similarly for isentropic compression 4-1:

$$\frac{T_4}{T_1} = \left(\frac{P_4}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{1}{4}\right)^{\frac{1.4-1}{1.4}} = 0.673$$

$$T_1 = T_4 / 0.673 = 303 / 0.673 = 450\text{K}$$

Performance of the gas turbine:

We know that work developed by the turbine,

$$W_T = mC_p(T_2 - T_3) = 1.5 \times 1(773 - 520) = 379.5\text{KJ/s}$$

And work developed by the compressor,

$$W_c = mC_p(T_1 - T_4) = 1.5 \times 1(450 - 303) = 220.5/\text{s}$$

Net work or power of the turbine,

$$P = W_T - W_c = 379.5 - 220.5 = 159\text{KJ/s} = 159\text{KW}$$

Overall efficiency of the plant:

We know that the heat supplied per second



$$= m_f \times C = 0.04 \times 40,000 = 1600 \text{ KJ/s}$$

Therefore, overall efficiency of the plant,

$$\eta_o = 159/1600 = 0.099 \text{ or } 9.99\%$$

5.13 TWO MARK UNIVERSITY QUESTIONS:

**Part-A (2 Marks)**

1. Name four important properties of a good refrigerant
2. What is the difference between air conditioning and refrigeration?
3. What is the function of the throttling valve in vapour compression refrigeration system?
4. In a vapour compression refrigeration system, where the highest temperature will occur?
5. The vapour absorption system can use low-grade heat energy in the generator. Is true or false?
6. Name any four commonly used refrigerants.
7. Explain unit of Refrigeration.
8. Why throttle valve is used in place of expansion cylinder for vapour compression refrigerant machine.
9. What are the effects of super heat and subcooling on the vapour compression cycle?
10. What are the properties of good refrigerant?
11. How are air-conditioning systems classified?
12. How does humidity affect human comfort?
13. What are the various sources of heat gain of an air-conditioned space?
14. What do you mean by the term infiltration in heat load calculations?

5.14 UNIVERSITY ESSAY QUESTIONS:**Part-B (16 Marks)**

1. Draw neat sketch of simple vapor compression refrigeration system and explain. (16)
2. Explain with sketch the working principle of aqua Ammonia refrigeration system. (16)
3. Explain with sketch the working principle of water-Lithium bromide refrigeration system. (16)
4. Briefly explain the cooling load calculation in air conditioning system. (16)
5. Explain winter, summer, and year round Alc system. (16)
6. Explain unitary Alc and central Alc system. (16)
7. Explain any four psychometric processes with sketch. (16)
8. A refrigeration system of 10.5 tonnes capacity at an evaporator temperature of -12°C and a condenser temperature of 27°C is needed in a food storage locker. The refrigerant Ammonia is sub cooled by 6°C before entering the expansion valve. The compression in the compressor is of adiabatic type. Find 1. Condition of vapor at outlet of the compressor. 2. Condition of vapor at the entrance of the Evaporator 3. COP & power required. (16)
9. A sling psychrometer in a lab test recorded the following readings DBT= 35°C , WBT= 25°C Calculate the following 1. Specific humidity 2. Relative humidity 3. Vapor density in air 4. Dew point temperature 5. Enthalpy of mixing per kg of air .take atmospheric pressure= 1.0132 bar. (16)



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