ME8595 - THERMAL ENGINEERING – II

UNIT – I: STEAM NOZZLES

SHORT QUESTIONS AND ANSWERS

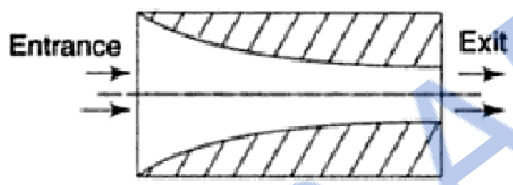
1. Define the steam nozzle.

The steam nozzle is a passage of varying cross-section by means of which the thermal energy of steam is converted into kinetic energy.

2. What are the various types of nozzles and their functions? [Anna Univ. Apr'04 & Apr'05]

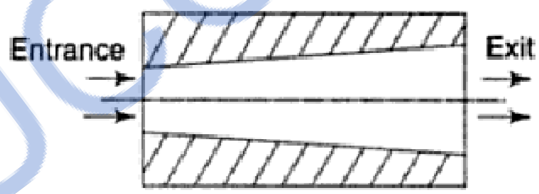
a) Convergent nozzle:

In the convergent nozzle, the cross-sectional area decreases from the inlet section to the outlet section. It is used in a case where the back pressure is equal to or greater than the critical pressure ratio.



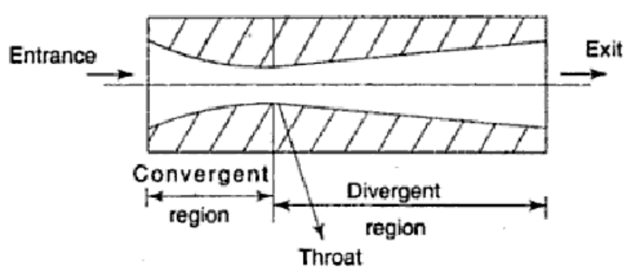
b) Divergent nozzle:

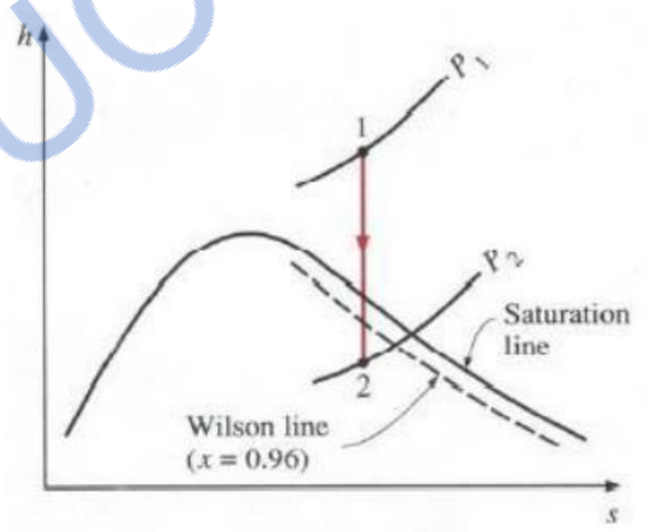
In the divergent nozzle, the cross-sectional area increases from the inlet section to the outlet section. It is used in a case where the back pressure is less than the critical pressure ratio.



c) Convergent-Divergent nozzle:

The cross-section of nozzle first decreases from the inlet section to the throat and then it increases from throat to outlet section. It is called a Convergent-divergent nozzle. This case is used in the case where the back pressure is less than the critical pressure. Also, in present day application, it is widely used in many types of steam turbines.



3.	**State the relation between the velocity of steam and heat during any part of a steam nozzle.** [Anna Univ. May'11 & May'12]
	Velocity, C = $\sqrt{2000x\ (h1 - h2)}$ Where $(h_1\text{-}h_2)$ = Heat contained in steam.
4.	**Define nozzle efficiency** [Anna Univ.Nov'03, Apr'04, Nov'10,Dec'11 & Dec'13]
	Co-efficient of Nozzle or Nozzle efficiency is defined as the ratio of actual enthalpy drop to isentropic enthalpy drop. Nozzle efficiency = (actual enthalpy drop) / (isentropic enthalpy drop)
5.	**Explain the function of a nozzle.**
	i. To supply high-velocity jet of steam in a steam turbine ii. To inject feed water into the boiler in a steam injector.
6.	**Explain the phenomenon of supersaturated expansion in steam nozzle** [Anna Univ. Apr'03] **Or** **What is metastable flow?** [Anna Univ. 'Nov'03,Nov'10 & May'13] **Or** **What are the conditions that produce supersaturation of steam in nozzles**? [Anna Univ.Nov'04, Dec'08 & May'15]
	 As steam expands in the nozzle, the pressure and temperature in it drop, and it is likely that the steam starts condensing when it strikes the saturation line. But this is not always the situation. Due to the high velocities, the time up to which the steam resides in the nozzle is small, and there may not be sufficient time for the needed heat transfer and the formation of

liquid droplets due to condensation. As a result, the condensation of steam is delayed for a while. This phenomenon is known as supersaturation, and the steam that remains in the wet region without holding any liquid is known as supersaturated steam. The locus of points where condensation occurs regardless of the initial temperature and pressure at the entrance of the nozzle is called the Wilson line. The Wilson line generally lies between 4 and 5 percent moisture curves in the saturation region on the h-s diagram in case of steam and is often taken as 4 percent moisture line.

7. What are the effects of supersaturation in a steam nozzle? [Anna Univ. Nov'02, June'09, Dec'12 & Nov'12]

The dryness fraction of the steam is increased.

Entropy and specific volume of the steam are increased.

The exit velocity of the steam is reduced.

Mass of steam discharged is increased.

8. What are the differences between supersaturated flow and isentropic flow through steam nozzles?

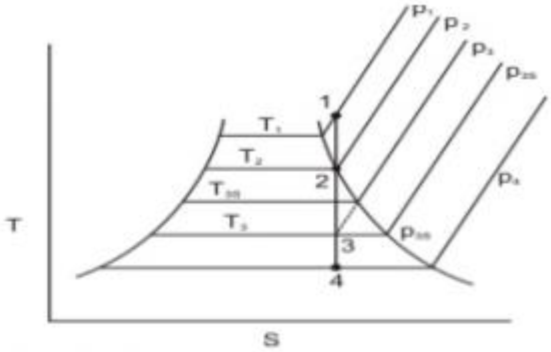
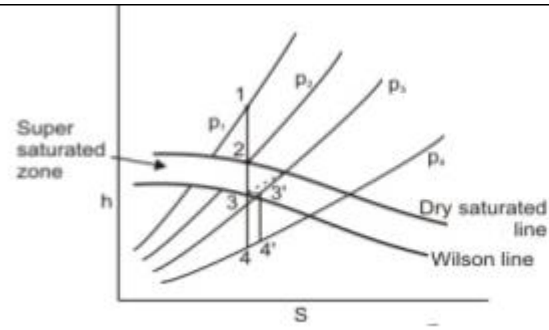
Supersaturated flow	Isentropic flow
Entropy is not constant	Entropy is constant
It reduces enthalpy drop	There is no reduction in enthalpy drop
Mollier diagram cannot be used to solve problems.	Mollier diagram can be used to solve problems.

9. What is the critical pressure ratio of a steam nozzle? [Anna Univ. May '08, Nov'03, Apr'04 & Nov'10]

Critical pressure ratio is one only value of the ratio (p_2/p_1) which produces maximum discharge from the nozzle. The ratio is called a critical pressure ratio.

10. Draw the shape of a supersonic nozzle [Anna Univ May'16]

11.	**Write down the expression for the velocity at the exit from the steam nozzle** (MU Apr'97]
	$Exit\ Velocity\ C_2 = \sqrt{2000\ x\ (h_1 - h_2)}$ or $C_2 = \sqrt{\frac{2n}{n-1}}\ x\ p_1\ x\ v_1\ x\ [1 - (p_2)]$
12.	**Describe the expression for the critical pressure ratio in a steam nozzle** [Anna Univ.Nov'02]
13.	**What are the effects of friction on the flow through a steam nozzle?** [Anna Univ. Apr'03, Nov'04, Nov'07, Nov'10, May'11 & May'14]
	The expansion is no more isentropic and the enthalpy drop is reduced thereby resulting in the reduced exit velocity. The final fraction of the steam is increased as a part of the kinetic energy gets converted into heat due to friction and absorbed by steam within the increase to enthalpy. The specific volume of steam is increased as the steam becomes drier due to this frictional reheating.
14.	**What are the factors reducing the final velocity of steam in nozzle flow?** [Anna Univ. Dec'10]
	The friction between nozzle surface and steam. The internal fluid friction in steam Shock losses.
15.	**Write the general energy equation for a steady flow system and from this obtain the energy equation for the nozzle.** [MU-Oct'96]

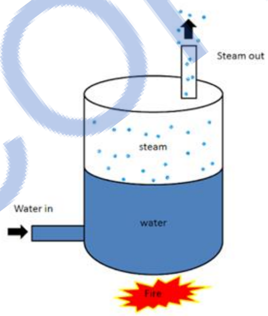
16.	**Draw T-s and h-s plot of supersaturated expansion of steam in a nozzle.** [Anna Univ. Apr'05]
	 
17.	**Calculate the value of the critical pressure ratio for saturated and supersaturated steam.** [Anna Univ. Apr'08, Dec'12 & Dec'13]
18.	**Define the critical pressure ratio.**
	The pressure which the area is minimum and discharge per unit area is maximum is called a critical pressure ratio. Critical pressure ratio = $(p_2/p_1) = (2/(n+1))^{(n/(n-1))}$
19.	**What is the significance of the critical pressure ratio?**
	The critical pressure gives the velocity of sound. The flow in the convergent portion of the nozzle is subsonic and divergent portion is supersonic For expanding the steam below critical pressure, the divergent portion of the nozzle is necessary. When p_2 approaches the critical value the rate of discharge will be maximum.
20.	**Define stagnation enthalpy**
	The stagnation enthalpy represents the enthalpy of fluid when it is brought rest adiabatically.
21.	**What are the reasons for the drop in velocity of the steam for a given pressure drop in the steam nozzle?**
	Friction between the surface of the nozzle and steam Due to internal fluid friction in the steam Due to shock losses
22.	**What are the limits for super saturation in steam nozzles? Why?**

	The super saturation occurs up to above 0.94 dryness fraction and beyond that, the condensation of steam occurs suddenly and irreversibly at constant enthalpy and then remain in stable condition.
23.	**Define indicated pressure ratio in steam nozzles.**
	There is only one value of the ratio (P_2/P_1), which produces maximum discharge from the nozzle. That ratio is called Critical Pressure Ratio.
24.	**What are the factors that change the fluid properties while fluid flows through a nozzle with no work or heat transfer?**
	Change in flow area Frictional forces
25.	**Mention the applications of the nozzle.**
	To inject feed water into the boiler in steam injectors. To maintain, high vacuum in power plant condensers. To supply, high-velocity jet of the steam jet in steam turbines. To remove, the air in the condenser.
26.	**What are the advantages of a convergent-divergent nozzle?**
	The steam enters the nozzle at high pressure with negligible velocity and leaves at high velocity with low pressure. Convergent-divergent nozzles are used in back pressure turbine.
27.	**What is the purpose of the divergent portion after the throat section of the nozzle?**
	It accelerates the steam leaving the nozzle. It does not affect the discharge of steam passing through the nozzle.
28.	**Define the degree of super saturation.**
	The ratio of super saturation pressures corresponding to the temperature between supersaturated region is known as the degree of super saturation.
29.	**Define the degree of reaction.**
	It is defined as the ratio of the actual isentropic heat drop to the total heat drop in the entire stage.
30	**Define Isothermal efficiency.**
	It is the ratio of isothermal power to Indicated or actual power.

ME8595 - THERMAL ENGINEERING – II

UNIT – II: BOILERS

SHORT QUESTIONS AND ANSWERS

1.	**What is a Boiler?**
	A boiler is a closed vessel which is used to convert the water into high pressure steam. The high pressure steam so generated is used to generate power.
2.	**What is the function of a boiler?**
	A boiler supplies dry and saturated steam at the required pressure.
3.	**Explain the working Principle of a Boiler.**
	The boiler works on the same principle as the water is heated in a closed vessel and due to heating, the water changes into steam. This steam possesses high pressure kinetic energy. The boiler contains water. The water is heated to its boiling temperature by the use of heat from the furnace. Due to heating of water, it gets converted into high pressure steam. The steam generated is passed through the steam turbines. As the high pressure steam strikes the turbine, it rotates the turbine. A generator is attached to the turbine and the generator also starts to rotate with the turbine and produces electricity. 
4.	**Briefly explain the boiler mounting, and name its classifications?**
	A particular apparatus or equipment is placed on the boiler to improve its safety, maintenance convenience and steam supply is known as boiler mounting. following are the different boiler mountings, ➢ water level ➢ supply valves ➢ pressure gauge ➢ stop valve ➢ feed check valve ➢ blow off cock ➢ anti printing pipe ➢ fusible plugs etc
5.	**What is valve?**

	A valve is used to control the flow of fluid inside the pipeline.
6.	**What is Safety valve**?
	This type of valve is used to keep the boiler safe by controlling the working pressure in the boiler and resist the blasting due to the high pressure; the valve is mounted with a boiler.
7.	**What is stop valve?**
	This type of valve is used to control the flow of steam from the boiler to the engine.
8.	**What is feed check valve?**
	This type of valve is used to control the supply of feed water to the boiler. The water level always remains constant when it works.
9.	**What is the effect of sulfur in coal when used in a boiler?**
	Sulfur will get oxidized to SO_2 and fraction of SO_3 and will react with water to form sulfuric acid and this occurs at a temperature called the acid dew point which normally is about 120°C. The sulfuric acid so formed corrodes the steel when it comes in contact with it.
10.	**What do you mean by IBR steam boiler?**
	Any closed vessel exceeding 22.75 litres in capacity and which is used expressively for generating steam under pressure and includes any mounting or other fitting attached to such vessel, which is wholly or partly under pressure when the steam is shut off is called IBR steam boilers.
11.	**What do you understand by 'water tube boilers'?**
	In water tube boilers the water passes through the tubes and the hot gases pass outside the tubes.
12.	**What do you understand by 'fire tube boilers'?**
	In case of fire tube boiler the hot gases pass through the tubes and the water passes over the tubes.
13.	**What are the parameters required to estimate the boiler efficiency by 'direct method'?**
	steam flow rate GCV of fuel fuel flow rate steam conditions (pressure and temperature) feed water temperature
14.	**Why boiler blow-down is required?**

	As the feed water evaporates into steam, dissolved solids concentration in the boiler. Above a certain level of concentration, these solids encourage carryover of water into steam. This leads to scale formation inside the boiler, resulting in localized overheating and ending finally in tube failure. Hence blow-down is very much required for boilers.
15.	**What is the principle of mechanical deaeration (pressure type) of boiler feed water?**
	The pressure-type de-aerators operates by allowing steam into the feed water through a pressure control valve to maintain the desired operating pressure, and hence temperature at a minimum of 105°C. The steam raises the water temperature causing the release of O_2 and CO_2 gases that are then vented from the system. This type can reduce the oxygen content to 0.005 mg/litre.
16.	**What is the effect of boiler loading on boiler efficiency?**
	The maximum efficiency of the boiler does not occur at full load but at about two-thirds of the full load. If the load on the boiler decreases further, efficiency also tends to decrease. As the load falls, so does the value of the mass flow rate of the flue gases through the tubes. This reduction in flow rate for the same heat transfer area reduced the exit flue gas temperatures by a small extent, reducing the sensible heat loss. Below half load, most combustion appliances need more excess air to burn the fuel completely. This increases the sensible heat loss.
17.	**What are the principal heat losses that occur in a boiler?**
	loss of heat due to dry flue gas loss of heat due to moisture in fuel and combustion air loss of heat due to the combustion of hydrogen loss of heat due to radiation loss of heat due to unburned fuel
18.	**What do you mean by tangential firing with respect to pulverized coal-fired boiler?**
	The method of firing used for coal firing in pulverized fuel-fired boiler is the tangential firing. In this type of firing four burners are used at the corner to corner to create a fireball at the centre of the furnace.
19.	**What are the disadvantages of 'direct method' of boiler efficiency evaluation over 'indirect method'?**
	Do not give clues to the operator as to why the efficiency of the system is lower. Do not calculate various losses accountable for various efficiency levels.
20.	**List out the data required for calculation of boiler efficiency using 'indirect method'?**

	➢ ultimate analysis of fuel (H_2, O_2, S, C, moisture content, ash content) ➢ percentage of oxygen or CO_2 in the flue gas ➢ flue gas temperature in °C (tf) ➢ Ambient temperature in °C (ta) & humidity of air in kg/kg of dry air. ➢ GCV of fuel in kJ/kg ➢ percentage combustible in ash (in case of solid fuels) ➢ GCV of ash in kJ/kg (in case of solid fuels)
21.	**Explain the different external water treatment methods?**
	External treatment is used to remove suspended solids, dissolved solids (particularly the calcium and magnesium ions which is a major cause of scale formation) and dissolved gases (oxygen and carbon dioxide). The techniques include precipitation processes, in which chemicals are added to precipitate calcium and magnesium as compounds of low solubility. The lime-soda process is typical of this class, but other precipitating agents such as caustic soda and sodium phosphate can be used when the composition of the raw water permits. Ion-exchange progress, in which the hardness is removed as the water passes through a bed of natural zeolite or synthetic resin and without the formation of any precipitate. ion exchange processes can be used for almost total demineralization if required, as is the case in large electric power plant boilers. De-aeration, in which gases are expelled by preheating the water before entering the boiler system. Water normally contains approximately 10 mg/1 of dissolved oxygen at ambient temperature filtration, to remove suspended solids.
22.	**What are the salient features of a 'packaged boiler'?**
	➢ Small combustion space and high heat release rate resulting in faster evaporation. ➢ A large number of small diameter tubes leading to good convective heat transfer. ➢ Forced or induced draught systems resulting in good combustion efficiency. ➢ A number of passes resulting in better overall heat transfer. ➢ Higher thermal efficiency at lower capacity (say below 1 ton) levels compared with other boilers.
23.	**What are the two main classifications of a stoker-fired boiler?**
	➢ Chain grate or travelling grate stoker. ➢ Spreader stoker.
24.	**Briefly explain the principle involved in 'reverse osmosis'?**
	When solutions of differing concentrations are separated by a semi-permeable

	membrane, water from less concentrated solution passes through the membrane to dilute the liquid of high concentration. If the solution of high concentration is pressurized, the process is reversed and the water from the solution of high concentration flows to the weaker solution.
25.	**What are the various methods available to control the 'excess air' in a boiler?**
	Portable oxygen analyzers and draft gauges can be used to make periodic readings to guide the operator to manually adjust the flow of air for optimum operation. Excess air reduction up to 20% is feasible. The most common method is the continuous oxygen analyzer with a local readout mounted draft gauge, by which the operator can adjust air flow. A further reduction of 10-15% can be achieved over the previous system. The same continuous oxygen analyzer can have a remote controlled pneumatic damper positioner, by which the readouts are available in a control room. This enables an operator to remotely control a number of firing systems simultaneously.
26.	**Describe 'chain grate' and 'spreader stoker' type boiler?**
	Chain-grate or travelling-grate stoker boiler: Coal is fed onto one end of a moving steel grate. As grate moves along the length of the furnace, the coal burns before dropping off at the end as ash. Some degree of skill is required. particularly when setting up the grate, air dampers and baffles, to ensure clean combustion leaving the minimum of unburnt carbon in the ash. The coal-feed hopper runs along the entire coal-feed end of the furnace. A coal grate is used to control the rate at which coal is fed into the furnace by controlling the thickness of the fuel bed. Coal must be uniform in size as large lumps will not burn out completely by the time they reach the end of the grate. **Spreader stoker boiler:** Spreader stokers utilize a combination of suspension burning and grate burning. The coal is continually fed into the furnace above a burning bed of coal. The coal fines are burned in suspension; the larger particles fall to the grate, where they are burned in a thin, fast-burning coal bed. This method of firing provides good flexibility to meet load fluctuations since ignition is almost instantaneous when the firing rate is increased. Hence, the spreader stoker is favoured over other types of stokers in many industrial applications.
27.	**Write short notes on 'intermittent blow down' and 'continuous blow down' with respect to boilers?**

	Intermittent blow down: The 'intermittent blown down' is given by manually operating a valve fitted to discharge pipe at the lowest point of boiler shell to reduce parameters (tds or conductivity, ph, silica and phosphates concentration) within prescribed limits so that steam quality is not likely to be affected. In intermittent blow down, a large diameter line is opened for a short period of time, the time being based on a thumb rule such as "once a shift for 2 minutes". 'Intermittent blow down' requires large short-term increases in the amount of feed water put into the boiler, and hence may necessitate larger feed water pumps than if continuous blow down is used. Also, tds level will be varying, thereby causing fluctuations of the water level in the boiler due to changes in steam bubble size and distribution which accompany changes in concentration of solids. Also, a substantial amount of heat energy is lost with intermittent blow down. **Continuous blow down:** There is a steady and constant dispatch of a small stream of concentrated boiler water, and replacement by the steady and constant inflow of feed water. This ensures constant tds and steam purity at a given steam load. Once blow down valve is set for a given condition, there is no need for regular operator intervention. Even though large quantities of heat are wasted, the opportunity exists for recovering this heat by blowing into a flash tank and generating flash steam. This flash steam can be used for preheating boiler feed water or for any other purpose. This type of blow down is common in high-pressure boilers.
28.	**Explain the reasons for carrying out "blow down" in a boiler?**
	Water contains a certain percentage of dissolved solids. The percentage of impurities found in boiler water depends on the untreated feed water quality, the treatment process used and the boiler operating procedures. As a general rule, the higher the boiler operates pressure, the greater will be the sensitivity to impurities. As the feed water materials evaporate into steam, dissolved solids concentration in the boiler either in a dissolved or suspended state. Above a certain level of concentration, these solids encourage foaming and cause carryover of water into the steam. This leads to scale formation inside the boiler, resulting in localized overheating and ending finally in tube failure. it is, therefore, necessary to control the level of concentration of the solids and this is achieved by the process of 'blowing down', where a certain volume of water is blown off and is automatically replaced by feed water – thus maintaining the optimum level of total dissolved solids (tds) in the water. Blow down is necessary to protect the surfaces of the heat exchanger in the boiler.
29.	**What is Boiler Shell?**

	It is made up of steel plates bent into cylindrical form and riveted or welded together. The ends of the shell are closed by means of end plates. A boiler shell should have sufficient capacity to contain water and steam.
30.	**What is Combustion Chamber?**
	It is the space, generally below the boiler shell, meant for burning fuel in order to produce steam from the water contained in the shell.
31.	**What is Grate?**
	It is a platform, in the combustion chamber, upon which fuel (coal, wood) is burnt. The grate generally consists of cast iron bars which are spaced apart so that air (required for combustion) can pass through them. The surface area of the grate, over which the fire takes place is called grate surface.
32.	**What is Furnace?**
	It is the space, above the grate and below the boiler shell, in which the fuel actually burnt. The furnace is also called fire box.
33.	**What is Heating Surface?**
	It is that part of the boiler surface, which is exposed to the fire (or hot gases from the fire)
34.	**What is boiler Mountings?**
	These are the fittings which are mounted on the boiler for its proper and safe functioning. They include water level indicator, pressure gauge, safety valve etc. It may be noted that a boiler cannot function safely without the mountings.
35.	**What is boiler Accessories?**
	These are the devices, which form an integral part of a boiler, but are not mounted on it. They include superheat, economizer, feed pump etc. It may be noted that the accessories help in controlling and running the boiler efficiency.

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UNIT – III: STEAM TURBINES

SHORT QUESTIONS AND ANSWERS

1.	**What is a steam turbine?**
	The steam turbine is a device which is used to convert the kinetic energy of steam into mechanical energy.
2.	**State the use of large sizes and small sizes turbines.**
	In large sizes, it is used for driving electric generators. In small sizes, it is used to drive pumps, fans, compressors etc.
3.	**How are steam turbines classified?**
	Steam turbines are classified as follows: 1. On the basis of the method of steam expansion (a) Impulse turbine (b) Reaction turbine (c) Combination of impulse and reaction turbine. 2. On the basis of the number of stages (a) Single stage turbine (b) Multi-stage turbine 3. On the basis of steam flow directions (a) Axial turbine (b) Radial turbine (c) Tangential turbine (d) Mixed flow turbine 4. On the basis of the pressure of steam (a) High-pressure turbine (b) Low-pressure turbine (c) Medium pressure turbine
4.	**How does the impulse turbine work?**
	The high-velocity jet of steam which is obtained from the nozzle impinges on blades fixed on a rotor. The blades change the direction of the steam flow without changing its pressure. It causes the change in momentum and the force developed drives the turbine rotor.
5.	**What is meant by carryover loss?**
	The velocity of steam at exit is sufficiently high thereby resulting in the kinetic energy loss called “carryover loss” or “leading velocity loss”.

6.	**What are the principles of impulse and reaction turbines? [Anna Univ. Dec'11]**
	In impulse turbines, the high-velocity jet of steam which is obtained from the nozzle impinges on blades fixed on a rotor. The blades change the direction of the steam flow without changing its pressure. It causes the change in momentum and the force developed drives the turbine rotor. In reaction turbines, there is no sudden pressure drop. There is a gradual pressure drop and it takes continuously place over the fixed and moving blades. A number of wheels are fixed to the rotating shaft. Fixed guideways are provided in between such pair of rotating wheels.
7.	**State the function of fixed blades.**
	The function of fixed blades is to guide the steam as well as to allow it for expansion to a larger velocity.
8.	**What is the fundamental difference between the operation of impulse and reaction steam turbine? [Anna Univ.Nov'03, Apr'04, Dec'10, May'11&May'16]**

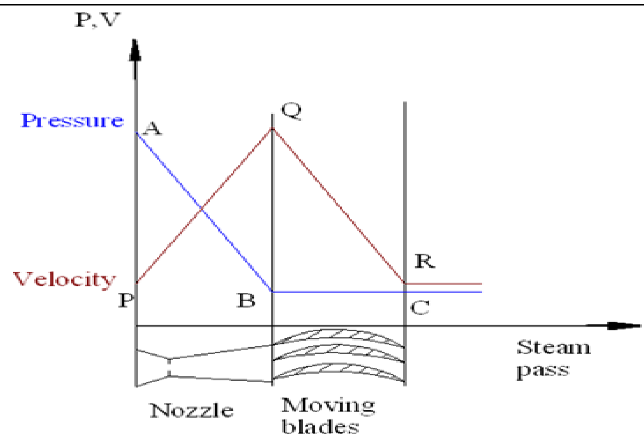
Impulse Turbine	Reaction turbine
It consists of nozzles and moving blades.	It consists of fixed blades and moving blades
Pressure drop occurs only in nozzles, not in moving blades.	Pressure drop occurs in fixed as well as moving blades.
Steam strikes the blade with kinetic energy.	Steam passes over the moving blades with pressure and kinetic energy.
It has constant blades channels area.	It has varying blade channels area.
Due to more pressure drop per blade, the number of stages required is less.	A number of stages required is more due to more pressure drop.

9.	**State the function of moving blades.**
	❖ It converts the kinetic energy of the steam into useful mechanical energy. ❖ The steam expands while flowing over moving blades and thus, it gives reaction to moving blades. Hence, the turbine is called a reaction turbine. ❖ The velocity of the steam decreases as the kinetic energy of the steam is absorbed.
10.	**What is meant by the compounding of steam turbines? [Anna Univ.Nov'10]**
	Compounding is a method of absorbing the jet velocity in stages when the steam flows over moving blades.
11.	**Explain the need of compounding in steam turbine: Anna Univ. Apr'03, Nov'04, Apr'08& Nov'15]**

	In a simple impulse turbine, the expansion of steam from the boiler pressure to condenser pressure takes place in a single stage turbine. The velocity of steam at the exit of the turbine is very high. Hence, there is a considerable loss of kinetic energy (i.e. about 10 to 12%). Also, the speed of the rotor is very high (i.e up to 30000rpm). There are several methods of reducing this speed to lower value. Compounding is a method of absorbing the jet velocity in stages when the steam flows over moving blades.
12.	**What are the different methods of compounding?**
	❖ Velocity compounding. ❖ Pressure compounding ❖ Pressure-velocity compounding
13.	**How are fixed and moving blades arranged in velocity compounding?**
	A number of moving blades are arranged in the form of rings of fixed blades keyed in series on a common shaft.
14.	**State any two advantages and disadvantages of velocity-compounded turbines.**
	Advantages: ❖ Its initial cost is less because of few numbers of stages. ❖ Less space is required. **Disadvantages:** ❖ Frictional losses are high due to the high initial velocity. Hence, the efficiency is low. ❖ The ratio of blade velocity to steam velocity is not optimum for all wheels. It also reduces efficiency.
15.	**What is pressure compounding? [Anna Univ'May'15]**
	The pressure is reduced in each stage of nozzle rings and hence, it is called pressure compounding.
16.	**How is pressure-velocity compounding done?**
	This method is a combination of pressure and velocity compounding. The total pressure drop is carried out in two stages and the velocity obtained in each stage is also compounded.
17.	**What is the optimum blade ratio of impulse turbine for maximum blade efficiency?**
	$$\frac{U}{V_1} = \frac{\cos\alpha}{2}$$ Where α be the nozzle outlet angle C_b be the blade velocity C_1 be the absolute velocity of steam

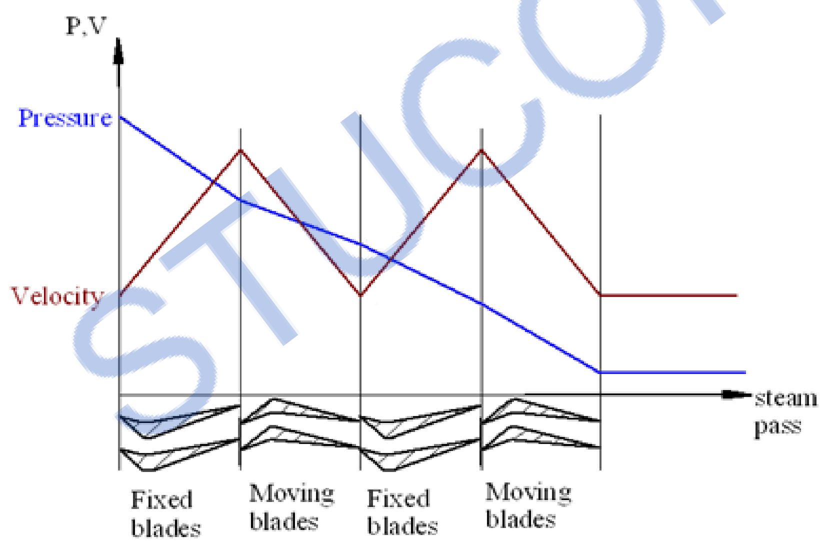
18.	**What is blading efficiency? [Anna Univ.Nov'07]**
	Blade efficiency is defined as the ratio between work done on the blade and energy supplied to the blade. $\eta b = \frac{\text{Work done on the blade}}{\text{Energy supplied to the blade}} = \frac{2U(Vw1+Vw2)}{V_1^2}$
19.	**Define the degree of reaction. [Anna Univ. Apr'04 & May'14]**
	It is defined as the ratio of isentropic heat drop in moving blades to isentropic heat drop in the entire stage of the reaction turbine. $R = \frac{\text{Enthalpy drop in moving blades}}{\text{Enthalpy drop in the entire stage}} = \frac{h_2 - h_3}{h_1 - h_3}$
20.	**30% reaction turbine refers to …………………**
	30% enthalpy drop in moving blades and 70% enthalpy drop in fixed blades..
21.	**50% reaction indicates that ……………………**
	An equal amount of enthalpy occurs in moving and fixed blades.
22.	**What is the optimum blade ratio in the case of reaction turbines?**
	$U / V_1 = \cos\alpha$
23.	**What is meant by the term governing in turbines?**
	The method of maintaining the speed of the turbine is constant irrespective of variation of the load on the turbine known as governing of turbines.
24.	**What is the function of governors in steam turbines? [Anna Univ.Dec'08]**
	Maintaining the speed of the turbine is constant irrespective of variation of the load on the turbine known as governing of turbines. The governors regulate the supply of steam to the turbine in such a way that the speed of the turbine is maintained as far as possible a constant under varying load condition.
25.	**What are the different methods of governing steam turbines [Anna Univ. Nov'04 & May'13]**
	❖ Throttle governing ❖ Nozzle control governing ❖ By-pass governing ❖ Combination of throttle and nozzle governing or throttle and by-pass governing.
26.	**How is throttle governing done?**
	Steam pressure at the inlet to a steam turbine is reduced by throttling process to maintain the speed of the turbine constant at part load.

27.	**Where nozzle control governing is used?**
	Nozzle control governing is used in large power steam turbines to which very high-pressure steam is supplied.
28.	**Where by-pass governing is more suitable?**
	By-pass governing is more suitable for reaction turbine and a single by-pass valve.
29.	**Enumerate the energy losses in the steam turbine [Anna Univ. June'09, May'11 & May'12]**
	❖ Losses in regulating valves ❖ Losses due to steam friction ❖ Losses due to mechanical friction ❖ Losses due to leakages ❖ Residual velocity losses ❖ Carryover losses ❖ Losses due to the wetness of steam ❖ Losses due to radiation.
30.	**Explain Impulse Steam Turbine**
	Impulse or impetus means the sudden tendency of action without reflexes. A single-stage impulse turbine consists of a set of nozzles and moving blades as shown in the figure. High-pressure steam at boiler pressure enters the nozzle and expands to low condenser pressure in the nozzle. Thus, the pressure energy is converted into kinetic energy increasing the velocity of steam. The high-velocity steam is then directed on a series of blades where the kinetic energy is absorbed and converted into an impulse force by changing the direction of flow of steam which gives rise to a change in momentum and therefore to a force. This causes the motion of blades. The velocity of steam decreases as it flows over the blades but the pressure remains constant, i.e. the pressure at the outlet side of the blade is equal to that at the inlet side. Such a turbine is termed as an impulse turbine. Examples: De-Laval, Curtis, Moore, Zoelly, Rateau etc.



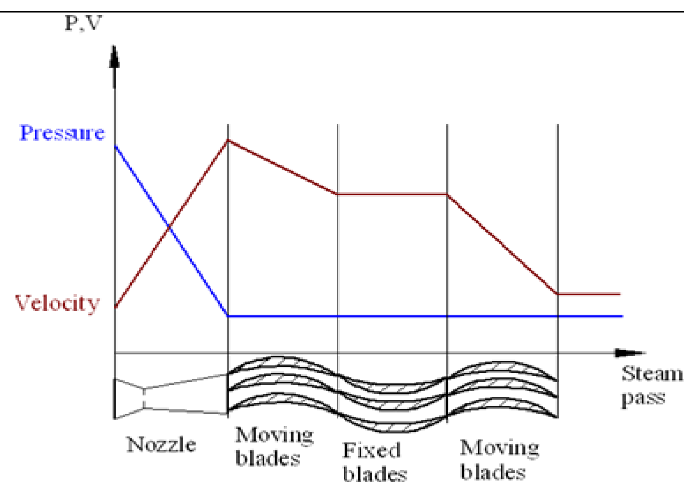
31. Explain Impulse Reaction Steam Turbine

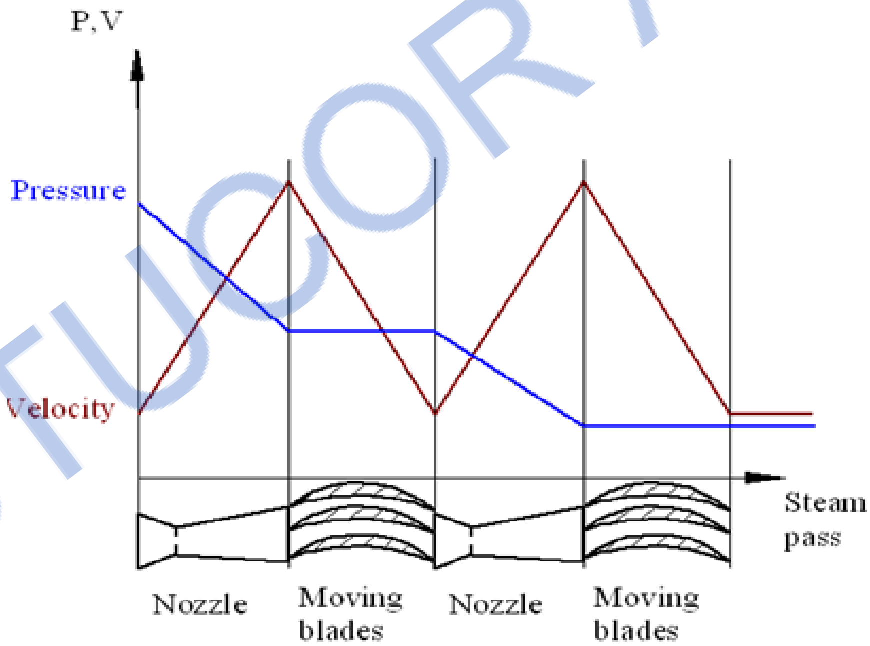
In the impulse reaction turbine, power is generated by the combination of impulse action and reaction by expanding the steam in both fixed blades (act as nozzles) and moving blades as shown in the figure. Here the pressure of the steam drops partially in fixed blades and partially in moving blades. Steam enters the fixed row of blades, undergoes a small drop in pressure and increases in velocity. Then steam enters the moving row of blades, undergoes a change in direction and momentum (impulse action), and a small drop in pressure too (reaction), giving rise to increase in kinetic energy. Hence, such a turbine is termed as an impulse reaction turbine. Examples: Parson, Ljungstrom etc.

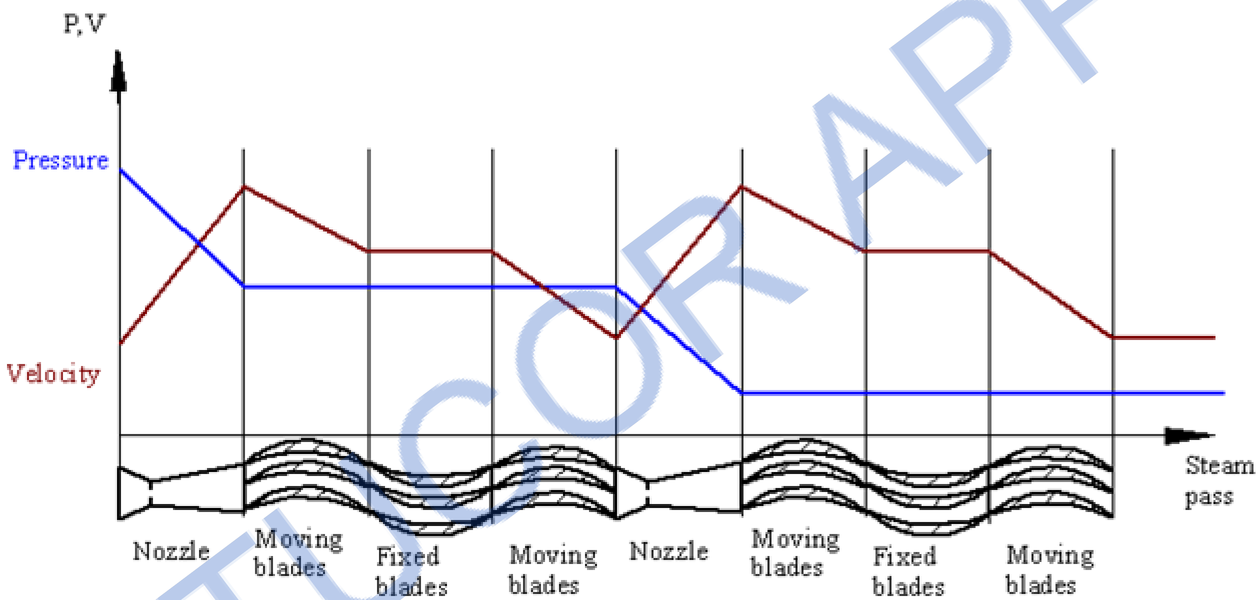


32. Differentiate Impulse and Reaction Turbines

Impulse Turbine	Reaction Turbine
The complete expansion of the steam takes place in the nozzle, hence steam is ejected with very high kinetic energy.	Partial expansion of the steam takes place in the fixed blade (acts as a nozzle) and further expansion takes place in the rotor blades.

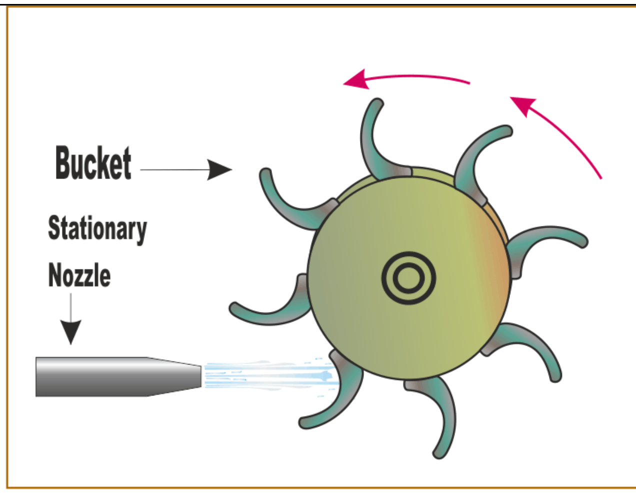
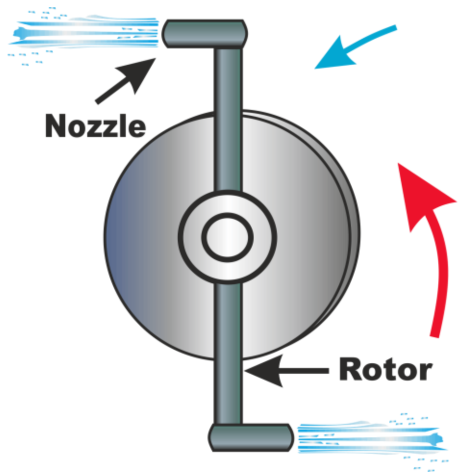
	Blades are symmetrical in shape.	Blades are non-symmetrical in shape, i.e. aerofoil section.
	Pressure remains constant between the ends of the moving blade. Hence relative velocity remains constant i.e., $V_{r1} = V_{r2}$	Pressure drops from inlet to outlet of the moving blade. Hence relative velocity increases from inlet to outlet i.e., $V_{r2} > V_{r1}$
	Steam velocity at the inlet of the machine is very high, hence needs compounding.	Steam velocity at the inlet of the machine is moderate or low, hence doesn't need compounding.
	Blade efficiency is comparatively low.	Blade efficiency is high.
	Few number of stages required for given pressure drop or power output, hence machine is compact.	More number of stages required for given pressure drop or power output, hence machine is bulky.
	Used for small power generation.	Used for medium and large power generation.
	Suitable, where the efficiency is not a matter of fact.	Suitable, where efficiency is a matter of fact.
33.	**What is the need for compounding in steam turbines?**	
	If the steam pressure drops from boiler pressure to condenser pressure in a single stage, exit velocity of steam from the nozzle will become very high and the turbine speed will be of the order of 30,000 rpm or more. As turbine speed is proportional to steam velocity, the carryover loss or leaving loss will be more (10% to 12%). Due to this very high speed, centrifugal stresses are developed on the turbine blades resulting in blade failure. In order to overcome all these difficulties, it is necessary to reduce the turbine speed by the method of compounding. *Compounding is the method of reducing blade speed for a given overall pressure drop.*	
34.	**Explain with the help of a schematic diagram a two-row velocity compounded turbine stage.**	
	 A simple velocity compounded impulse turbine is shown in the figure. It consists of a set of nozzles	

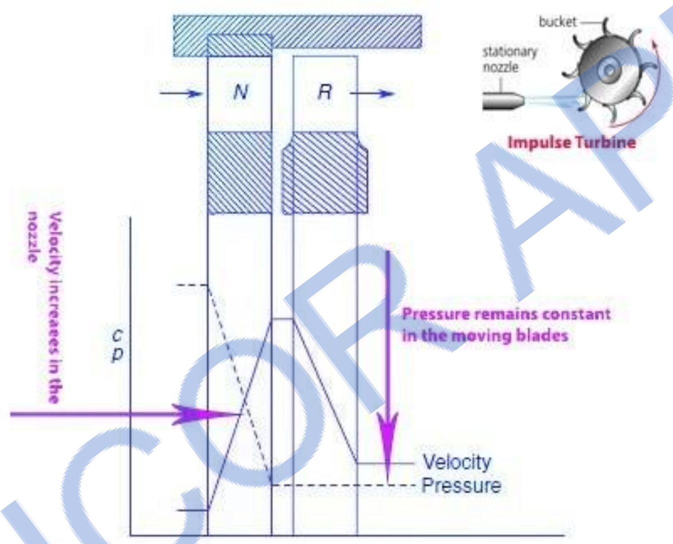
	and a rotating wheel fitted with two or more rows of moving blades. One row of fixed blades fitted between the rows of moving blades. The function of the fixed blade is to direct the steam coming from the first row of moving blades to the next row of moving blades without appreciable change in velocity. Steam from the boiler expands completely in the nozzle, hence the whole of the pressure energy converts into kinetic energy. The kinetic energy of steam gained in the nozzle is successively absorbed by rows of moving blades and steam is exited from the last row axially with very low velocity. Due to this, the rotor speed decreases considerably. The velocity compounded impulse turbine is also called the Curtis turbine stage.
35.	**Explain briefly a two-stage pressure compounded impulse turbine and show the pressure and velocity variations across the turbine. (VTU, Jul-07, May/Jun-10, Dec-12)**
	If a number of simple impulse stages arranged in series are known as pressure compounding. The arrangement contains one set of nozzles (fixed blades) at the entry of each row of moving blades. The total pressure drop doesn't take place in the first row of nozzles but divided equally between all the nozzles as shown in the figure.  The steam from the boiler is passed through the first set of nozzles in which it is partially expanded. The steam then passes over the first row of moving blades where almost all its velocity is absorbed. This completes expansion of steam in one stage. In the next stage, steam again enters the second set of nozzles and partially expands and enters the moving blades. Again the steam velocity is absorbed. This process continues until steam reaches the condenser pressure. Due to pressure compounding, the smaller transformation of heat energy into kinetic energy takes place. Hence steam velocities become much lower and rotor speed

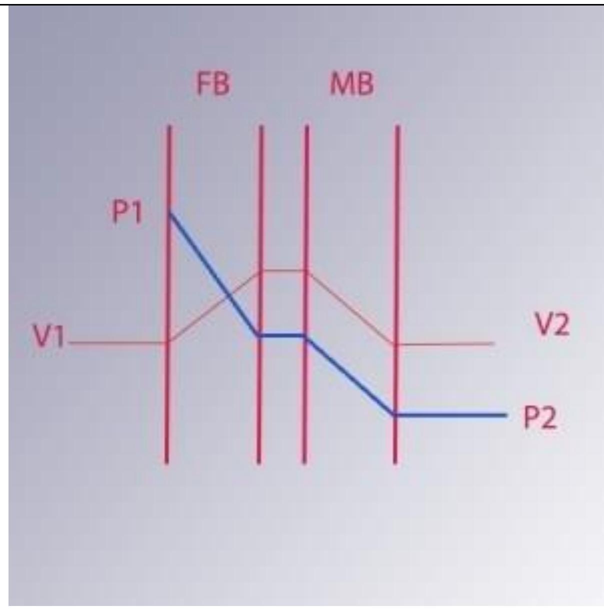
	decreases considerably. The pressure compounded impulse turbine is also called the Rateau turbine stage.
36.	**Explain with a neat sketch pressure-velocity compounding. (Dec-06/Jan-07, Jun/Jul-13)**
	If pressure and velocity are both compounded using two or more number of stages by having a series arrangement of simple velocity compounded turbines on the same shaft, it is known as pressure-velocity compounding. In this type of turbine, both pressure compounding and velocity compounding methods are used. The total pressure drop of the steam is dividing into two stages and the velocity obtained in each stage is also compounded. Pressure drop occurs only in nozzles and remains constant in moving and fixed blades. As pressure drop is large in each stage only a few stages are necessary. This makes the turbine more compact than the other two types. Pressure-velocity compounding is used in Curtis turbine. 
37.	**Define and explain blade coefficient**
	It is also known as the nozzle velocity coefficient. The losses in the flow over blades are due to friction, leakage and turbulence. Blade coefficient is the ratio of the velocity at the exit to the velocity at the inlet of the blade. i.e., $$C_b = \frac{V_{r2}}{V_{r1}} = \frac{V_2}{V_1}$$
38.	**Define and explain nozzle efficiency**
	It is defined as the ratio of actual enthalpy change per kg of steam to the isentropic enthalpy change per kg of steam. i.e., $$\eta_n = \frac{\Delta h}{\Delta h'}$$ For impulse turbine,

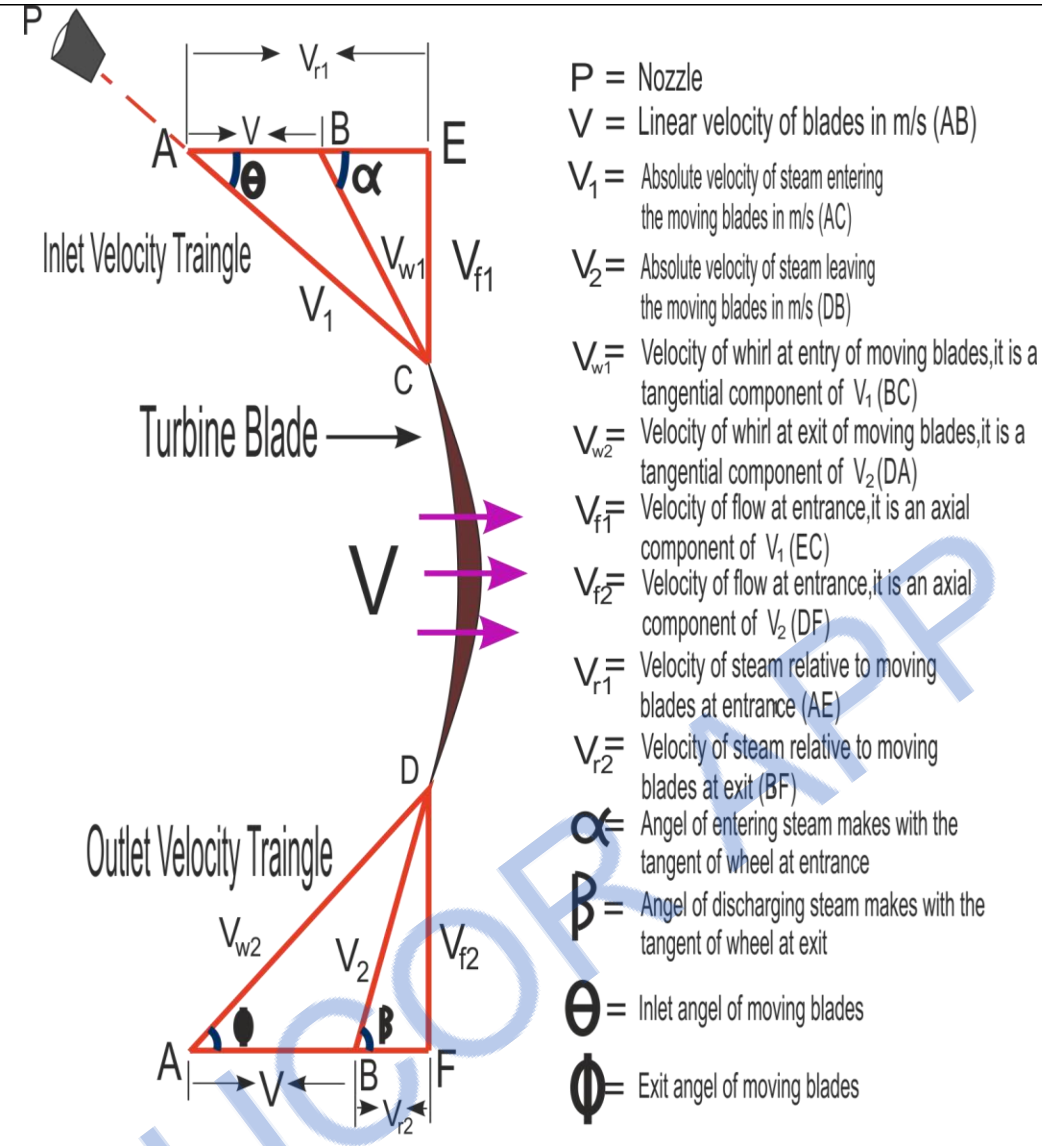
	$$\eta_n = \frac{\frac{1}{2}V_1^2}{\Delta h'}$$ For a reaction turbine the stator efficiency is, $$\eta_p = \frac{\frac{1}{2}V_1^2 - \frac{1}{2}(V_{r1}^2 - V_{r2}^2)}{\Delta h'}$$
39.	**Define and explain diagram efficiency**
	It is also known as blade efficiency or rotor efficiency. It is defined as the ratio of work done per kg of steam by the rotor to the energy available at the inlet per kg of steam. i.e., $$\eta_b = \frac{w}{e_a} = \frac{U\Delta V_u}{e_a}$$ For impulse turbine, $e_a = \frac{1}{2}V_1^2$ For reaction turbine, $e_a = \frac{1}{2}V_1^2 - \frac{1}{2}(V_{r1}^2 - V_{r2}^2)$
40.	**Define and explain stage efficiency**
	It is defined as the ratio of work done per kg of steam by the rotor to the isentropic enthalpy change per kg of steam in the nozzle. i.e., $$\eta_s = \frac{w}{\Delta h'}$$ For impulse turbine, $$\eta_s = \frac{U\Delta V_u}{\frac{1}{2}V_1^2} \times \frac{\frac{1}{2}V_1^2}{\Delta h'}$$ Or, $$\eta_s = \eta_b \times \eta_n$$ For reaction turbine, $$\eta_s = \frac{U\Delta V_u}{\frac{1}{2}V_1^2 - \frac{1}{2}(V_{r1}^2 - V_{r2}^2)} \times \frac{\frac{1}{2}V_1^2 - \frac{1}{2}(V_{r1}^2 - V_{r2}^2)}{\Delta h'}$$ Or, $$\eta_s = \eta_b \times \eta_p$$
41.	**Write short notes on bleeding of steam turbines.**
	Bleed steam is steam tapping taken from different stages of the turbine according to the required temperature and pressure. They are many in numbers, such as bleed steam is used for high pressure and low-pressure feed water heating, gland steam seals.

	Bleed steam is extracted from the turbine in a regulated manner to prevent a decrease in overall efficiency of the cycle.
42.	**What are the different sources of losses in steam turbines?**
	Losses in steam turbines can be mainly classified into two types. They are: ❖ Internal losses (which occur within the flow of steam) and ❖ External losses (which occur outside the turbine casing). **Internal Losses in Steam Turbines:** The internal losses in steam turbines may be enumerated as follows: 1. Losses in regulating valves 2. Nozzle friction losses 3. Blade friction losses 4. Disc friction losses 5. Partial admission losses 6. Gland leakage losses 7. Residual velocity loss 8. Carry-over losses **External losses in steam turbines:** There are some energy losses in the bearings and governing mechanisms which can be reduced by improving the lubrication system. Some energy is consumed by oil pumps. Since the turbines are adequately insulated the surface heat loss by convection and radiation is small.
43.	**List out some internal losses in steam turbines. [AU, May / June – 2009]**
	The internal losses in steam turbines may be enumerated as follows: 1. Losses in regulating valves 2. Nozzle friction losses 3. Blade friction losses 4. Disc friction losses 5. Partial admission losses 6. Gland leakage losses 7. Residual velocity loss 8. Carry-over losses
44.	**Give the working principle of an impulse turbine. [AU, May / June –2007]**

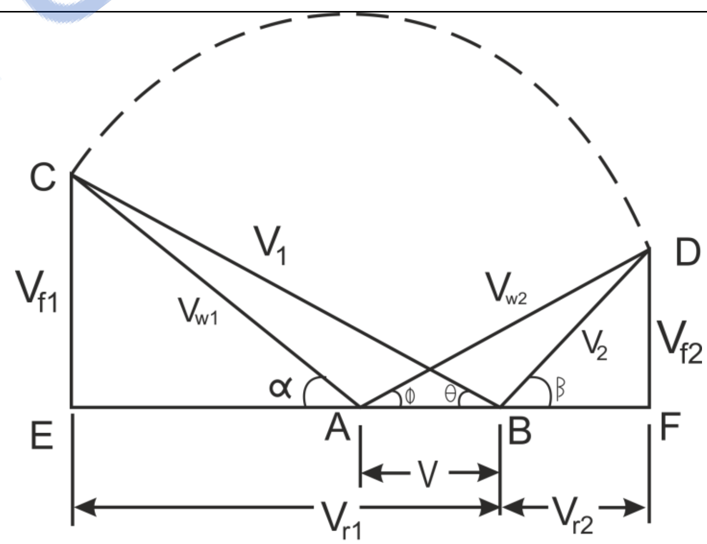
	 In Impulse Steam Turbine, there are some fixed nozzles and moving blades are present on a disc mounted on a shaft. Moving blades are in symmetrical order. The steam enters the turbine casing with some pressure. After that, it passes through one or more no. of fixed nozzles into the turbine. The relative velocity of steam at the outlet of the moving blades is the same as the inlet to the blades. During Expansion, steam's pressure falls. Due to high-pressure drop in the nozzles the velocity of steam increases. This high-velocity jet of steam flows through fixed nozzles and it strikes the blade with constant pressure. An impulse turbine, steam produced only impulsive force to the blades. Now blades are starting to move in the same direction of the steam flow. Due to the change in momentum, the turbine's shaft is starting to rotate. An example of Simple Impulse turbine is a DA-Laval turbine.
45.	**Give the working principle of an impulse reaction turbine.**
	Working principle of Impulse Reaction turbine depends on the reaction force produced by steam. Here steam flows through the nozzles at the end of the tubes and it is supported on the bearings. The outlet relative velocity of steam is much less than at the inlet to the blades.  In a reaction turbine, nozzles will move on bearing in the opposite direction of the steam flow

	and the pressure is not constant in this turbine. That's why; a reaction force is always applied on the nozzles and tubes. In this turbine, steam produces both impulsive and reactive force. So, the resultant force produces to the rotor is the vector sum of impulsive and reactive force and the reaction force is an unbalanced condition. Generally, this turbine is not used for commercial purpose. Due to this reactive force, it is called a reaction turbine. An example of this turbine is Parson's Turbine.
46.	**Draw the pressure and velocity graph of steam in a simple impulse turbine.**
	Steam passes the nozzles and there is an increase in the velocity. The pressure is dropped in the nozzle. When the steam enters the moving blades the velocity is decreased and the pressure remains constant. 
47.	**Draw the pressure and velocity graph of steam in a reaction turbine.**
	The figure shows a simple graph which represents pressure and velocity lines of a reaction turbine. In reaction, there is no presence of nozzles sets of Fixed Blades and Moving Blades are arranged in an order. When the steam passes the fixed blades it's velocity increases and there is a drop in the velocity after passing the moving blade. And the pressure is dropped in the fixed blade and there is another drop of pressure in the moving blades. So it is seen that both pressure and velocity changes in the reaction turbine when the fluid passes the runner

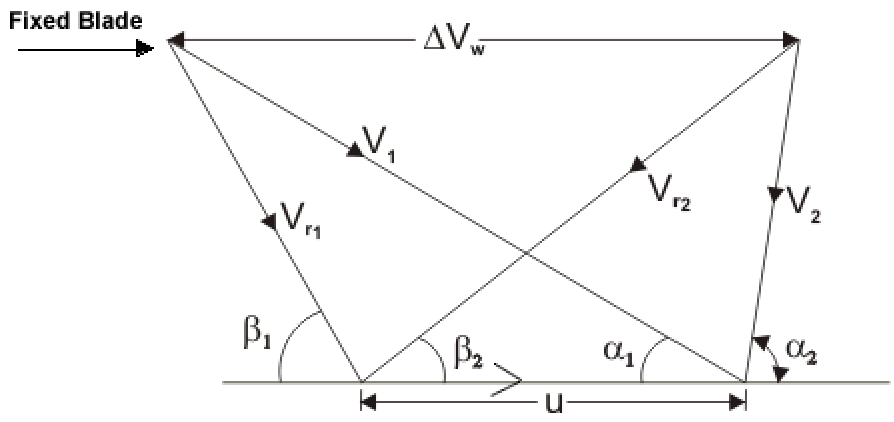
	
48.	**Draw the velocity triangle of an impulse steam turbine.**
	The picture shows a **steam turbine velocity diagram**. The upper portion represents the inlet condition of steam and lower portion represents the outlet portion of steam.



49. **Draw the combined velocity triangle of an impulse steam turbine.**



50. **Sketch the velocity triangles of a reaction turbine with the notations used at inlet and exit.**

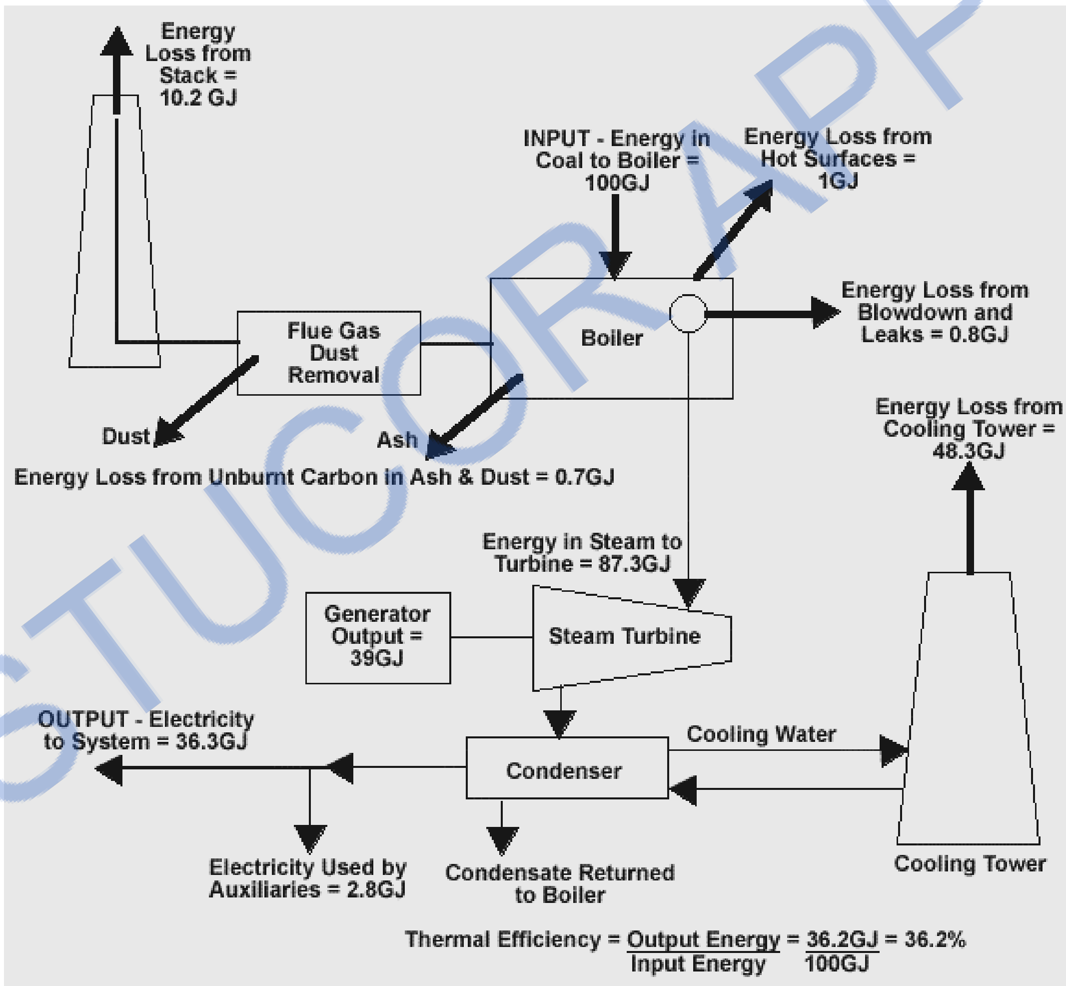


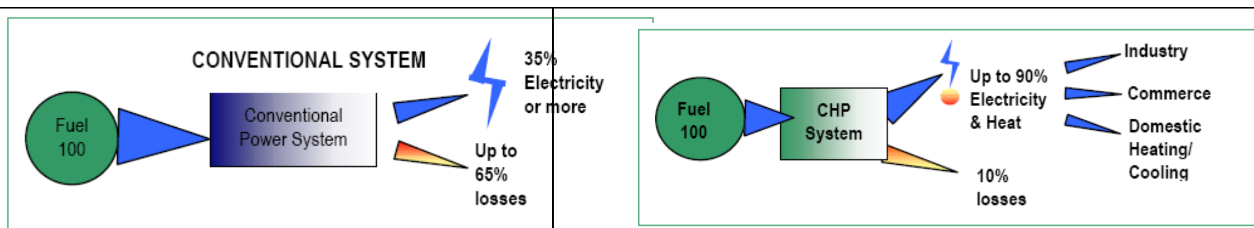
51.	**Define the degree of reaction.**
	Degree of reaction or reaction ratio (R) is defined as the ratio of the static pressure drop in the rotor to the static pressure drop in the stage or as the ratio of static enthalpy drop in the rotor to the static enthalpy drop in the stage.
52.	**Explain the reheat factor.**
	Reheat factor is the ratio of the cumulative heat to the adiabatic drop from an initial condition to exhaust pressure. It is the ratio of cumulative heat drop to isentropic heat drop in a multistage steam turbine
53.	**Discuss the advantages of steam turbines over steam engines.**
	❖ It requires less shaft workspace compared to the steam engine. ❖ The absence of various links such as a piston, piston rod, crosshead, etc. makes the mechanism simple. The steam turbine is quiet and smooth in operation. ❖ In steam turbine power is generated at a uniform rate. Therefore, the flywheel is not needed. ❖ The internal lubrication is not required in a steam turbine. This reduces the cost of lubrication. ❖ Steam turbine overload capacity is large. ❖ The steam turbine can be designed for much greater capacities of power as compared to the steam engine. Steam turbines can be built in for generating power ranging from a few horsepowers to over 200,000 horsepower in single units. ❖ It can be designed for a greater range of speed of operation. ❖ Thermodynamic efficiency of the steam turbine is higher compared to the steam engine. ❖ In a steam turbine, the steam consumption does not increase with an increase in years of service.

SHORT QUESTIONS AND ANSWERS

1. What is the Need for cogeneration?

Thermal power plants are a major source of electricity supply in India. The conventional method of power generation and supply to the customer is wasteful in the sense that only about a third of the primary energy fed into the power plant is actually made available to the user in the form of electricity. In a conventional power plant, efficiency is only 35% and the remaining 65% of energy is lost. The major source of loss in the conversion process is the heat rejected to the surrounding water or air due to the inherent constraints. Also, further losses of around 10-15% are associated with the transmission and distribution of electricity in the electrical grid.





2.	**Explain the Principle of Cogeneration**
	Cogeneration is the simultaneous production of power and heat, with a view to the practical application of both products. Cogeneration or Combined Heat and Power (CHP) is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used to drive a generator for producing electricity, or rotating equipment such as motor, compressor, pump or fan for delivering various services. Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling. The overall efficiency of energy use in cogeneration mode can be up to 85 per cent and above in some cases.
3.	**What are the Applications of Cogeneration?**
	In recent years cogeneration has become an attractive and practical proposition for a wide range of applications. These include the process industries (pharmaceuticals, paper and board, brewing, ceramics, brick, cement, food, textile, minerals etc.), commercial and public sector buildings (hotels, hospitals, leisure centres, swimming pools, universities, airports, offices, barracks (lodgings/ housings/ quarters), etc.) and district heating schemes.
4.	**What are the Benefits of Cogeneration?**
	Provided the cogeneration is optimized according to the heat demand, the following benefits can be obtained: ❖ Increased efficiency of energy conversion and use ❖ Lower emissions to the environment, in particular of CO_2, the main greenhouse gas ❖ In some cases, biomass fuels and some waste materials such as refinery gases, process or agricultural waste are used. These substances which serve as fuels for cogeneration schemes increase the cost-effectiveness and reduces the need for waste disposal. ❖ Large cost savings, providing additional competitiveness for industrial and commercial users while offering affordable heat for domestic users also. ❖ An opportunity to move towards more decentralized forms of electricity generation, where plants are designed to meet the needs of local consumers, providing high efficiency, avoiding transmission losses and increasing flexibility in system use. This will particularly be the case if natural gas is the energy carrier. ❖ An opportunity to increase the diversity of generation plant, and provide competition in

	generation. Cogeneration provides one of the most important vehicles for promoting liberalization in energy markets.
5.	**Where is cogeneration suitable?**
	Cogeneration has a long history of use in many types of industry, particularly in the paper and bulk chemicals industries, which have large concurrent heat and power demands. In recent years the greater availability and wider choice of suitable technology have meant that cogeneration has become an attractive and practical proposition for a wide range of applications. These include the process industries, commercial and public sector buildings and district heating schemes, all of which have considerable heat demand.
6.	**What are the Possible opportunities for application of cogeneration?**
	Industrial: ❖ Pharmaceuticals & fine chemicals ❖ Paper and board manufacture ❖ Brewing, distilling & malting ❖ Ceramics ❖ Brick ❖ Cement ❖ Food processing ❖ Textile processing ❖ Minerals processing ❖ Oil Refineries ❖ Iron and Steel ❖ Motor industry ❖ Horticulture and glasshouses ❖ Timber processing **Buildings:** ❖ District heating ❖ Hotels ❖ Hospitals, Leisure centres & swimming pools ❖ College campuses & schools ❖ Airports ❖ Supermarkets and large stores ❖ Office buildings

- Individual Houses, etc,

Renewable Energy:

- Sewage treatment works
- Poultry and other farm sites
- Short rotation coppice woodland
- Energy crops
- Agro-wastes (ex: biogas)

Energy from waste:

- Gasified Municipal Solid Waste
- Municipal incinerators
- Landfill sites
- Hospital waste incinerators

7. Explain the Classification of Cogeneration Systems

Cogeneration systems are normally classified according to the sequence of energy use and the operating schemes adopted.

A cogeneration system can be classified as either a topping or a bottoming cycle on the basis of the sequence of energy use.

Topping cycle Cogeneration Systems:

In a topping cycle, the fuel supplied is used to first produce power and then thermal energy, which is the by-product of the cycle and is used to satisfy process heat or other thermal requirements. Topping cycle cogeneration is widely used and is the most popular method of cogeneration.

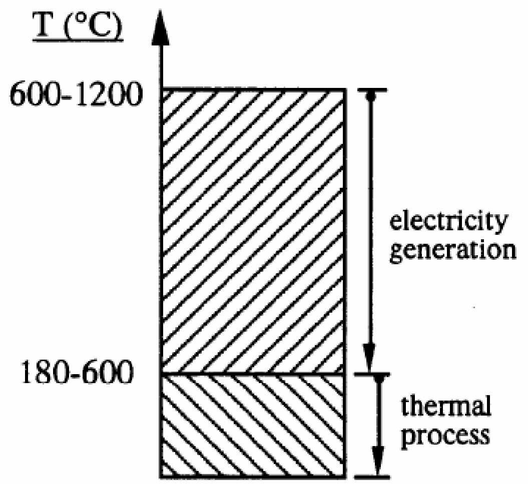
Bottoming cycle Cogeneration Systems:

In bottoming cycle, high-temperature heat is first produced for a process (e.g. in a furnace of a steel mill or of glass-works, in a cement kiln) and after the process hot gases are used either directly to drive a gas-turbine generator, if their pressure is adequate or indirectly to produce steam in a heat recovery boiler, which drives a steam-turbine generator.

8. Explain the indicative temperature ranges for the two types of cycles

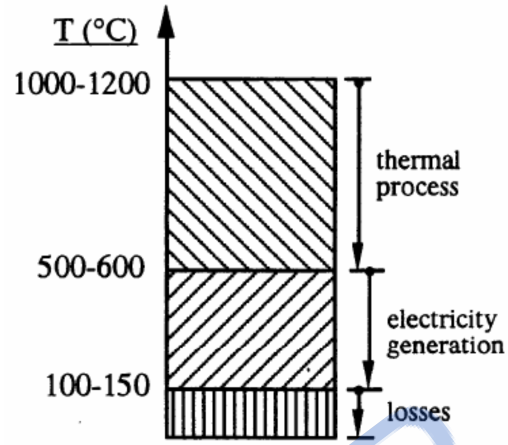
In topping systems, a high-temperature fluid (exhaust gases, steam) drives an engine to produce electricity, while low-temperature heat is used for thermal processes or space	In bottoming systems, high-temperature heat is first produced for a process (e.g. in a furnace of a steel mill or of glass-works, in a cement kiln) and after the process hot gases are used either directly to drive a gas-turbine generator, if their pressure is adequate, or

heating (or cooling).



Topping system

indirectly to produce steam in a heat recovery boiler, which drives a steam-turbine generator.



Bottoming system

9. Explain the important Technical Parameters for Cogeneration

While selecting a cogeneration system, one should consider some important technical parameters that assist in defining the type and operating scheme of different alternative cogeneration systems to be selected.

- Heat-to-power ratio
- Quality of thermal energy needed(Temperature & Pressure)
- Load patterns
- Fuels available
- System reliability
- Grid dependent system versus an independent system
- Retrofit versus new installation
- Electricity buy-back
- Local environmental regulation

10. Explain the important Technical Parameters for Cogeneration

Heat-to-power ratio:

- It is defined as the ratio of thermal energy to the electricity required by the energy-consuming facility.
- The heat-to-power ratio of a facility should match with the characteristics of the cogeneration system to be installed.
- The steam turbine cogeneration system can offer a large range of heat-to- power ratios.

Quality of thermal energy needed:

The quality of thermal energy required (temperature and pressure) also determines the type of cogeneration system. For a sugar mill needing thermal energy at about 120°C, a topping cycle cogeneration system can meet the heat demand. On the other hand, for a cement plant requiring thermal energy at about 1450°C, a bottoming cycle cogeneration system can meet both high-quality thermal energy and electricity demands of the plant.

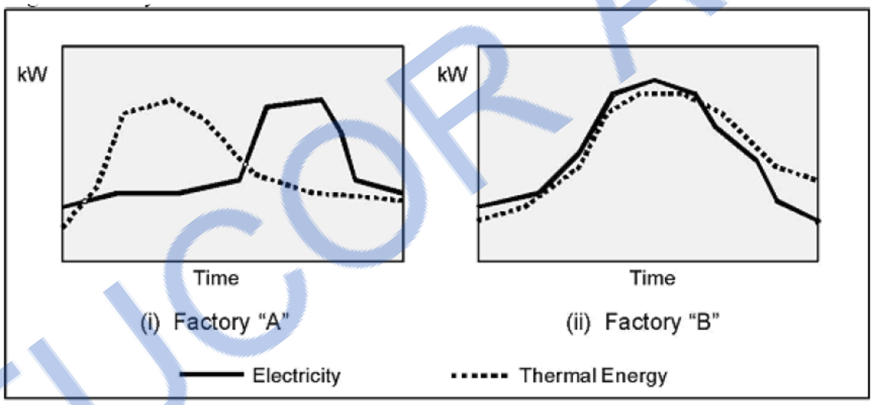
Fuels available:

Depending on the availability of fuels, some potential cogeneration systems may have to be rejected. The availability of cheap fuels or waste products that can be used as fuels at a site is one of the major factors in technical consideration because it determines the competitiveness of the cogeneration system.

A rice mill needs mechanical power for milling and heat for paddy drying. If a cogeneration system were considered, the steam turbine system would be the first priority because it can use the rice husk as the fuel, which is available as a waste product from the mill.

Load patterns:

The heat and power demand patterns of the user affect the selection (type and size) of the cogeneration system. For instance, the load patterns of two energy-consuming facilities would lead to two different sizes, possibly types also, of cogeneration systems.



System reliability:

Some energy-consuming facilities require very reliable power and/or heat; for instance, a pulp and paper industry cannot operate with prolonged unavailability of process steam. In such instances, the cogeneration system to be installed must consist of more than one unit so that shut down of a specific unit cannot seriously affect the energy supply.

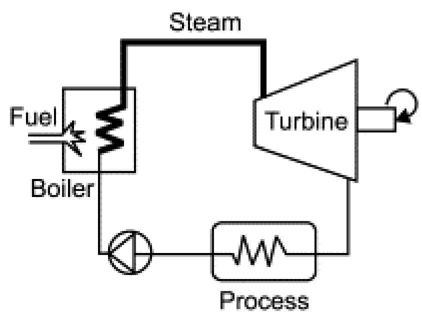
Grid dependent system versus independent system:

A grid-dependent system has access to the grid to buy or sell electricity. The grid-independent system is also known as a "stand-alone" system that meets all the energy demands of the site. It is obvious that for the same energy-consuming facility, the technical configuration of the cogeneration system designed as a grid-dependent system would be different from that of a stand-alone system.

Retrofit versus new installation:

	If the cogeneration system is installed as a retrofit, the system must be designed so that the existing energy conversion systems, such as boilers, can still be used. In such a circumstance, the options for the cogeneration system would depend on whether the system is a retrofit or a new installation. **Electricity buy-back:** The technical consideration of the cogeneration system must take into account whether the local regulations permit electric utilities to buy electricity from the cogenerators or not. The size and type of cogeneration system could be significantly different if one were to allow the export of electricity to the grid. **Local environmental regulation:** The local environmental regulations can limit the choice of fuels to be used for the proposed cogeneration systems. If the local environmental regulations are stringent, some available fuels cannot be considered because of the high treatment cost of the polluted exhaust gas and in some cases, the fuel itself.
11.	**Explain types of Cogeneration Systems/Technologies.**
	Various types of cogeneration systems ❖ The steam turbine cogeneration system ❖ Gas turbine cogeneration system, and ❖ Reciprocating engine cogeneration system.
12.	**Explain Steam Turbine Cogeneration System.**
	Steam turbines are one of the most versatile and oldest prime mover technologies still in general production. Power generation using steam turbines has been in use for about 100 years when they replaced reciprocating steam engines due to their higher efficiencies and lower costs. The capacity of steam turbines can range from 50 kW to several hundred MWs for large utility power plants. Steam turbines are widely used for combined heat and power (CHP) applications. The thermodynamic cycle for the steam turbine is the Rankine cycle. The two types of steam turbines most widely used are the backpressure and the extraction of condensing types. The choice between a backpressure turbine and extraction-condensing turbine depends mainly on the quantities of power and heat, quality of heat, and economic factors. The extraction points of steam from the turbine could be more than one, depending on the temperature levels of heat required by the processes.
13.	**Explain Back Pressure Steam Turbine**

A back pressure steam turbine is the simplest configuration. Steam exits the turbine at a pressure higher or at least equal to the atmospheric pressure, which depends on the needs of the thermal load. This is why the term back pressure is used. After the exit from the turbine, the steam is fed to the load, where it releases heat and is condensed. The condensate returns to the system with a flow rate which can be lower than the steam flow rate, if the steam mass is used in the process or if there are losses along the piping. Make- up water retains the mass balance.



14. List the disadvantages of Back Pressure Steam Turbine

The steam turbine is larger for the same power output because it operates under a lower enthalpy difference of steam.

The steam mass flow rate through the turbine depends on the thermal load. Consequently, the electricity generated by the steam is controlled by the thermal load, which results in little or no flexibility in directly matching electrical output to an electrical load. Therefore, there is a need for a two-way connection to the grid for purchasing supplemental electricity or selling excess electricity generated. Increased electricity production is possible by venting steam directly to the atmosphere, but this is very inefficient. It results in a waste of treated boiler water and, most likely, in poor economical as well as energetic performances.

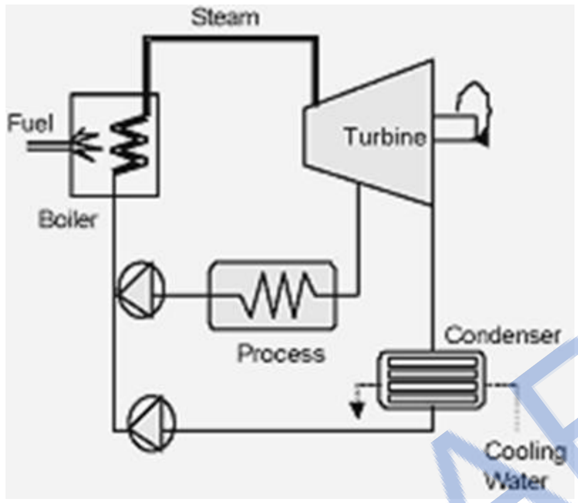
15. List the advantages of Back Pressure Steam Turbine

The back - pressure system has the following advantages:

- Simple configuration with few components.
- The costs of expensive low-pressure stages of the turbine are avoided.
- Low capital cost.
- Reduced or even no need for cooling water.
- High total efficiency, because there is no heat rejection to the environment through the condenser.

16. Explain the Extraction-condensing turbine

Another variation of the steam turbine topping cycle cogeneration system is the extraction-back pressure turbine that can be employed where the end-user needs thermal energy at two different temperature levels. The full-condensing steam turbines are usually incorporated at sites where heat rejected from the process is used to generate power. In backpressure cogeneration plants, there is no need for large cooling towers.



17. Explain Gas turbine cogeneration systems

Gas turbine systems operate on the thermodynamic cycle known as the Brayton cycle. In a Brayton cycle, atmospheric air is compressed, heated, and then expanded, with the excess of power produced by the turbine or expander over that consumed by the compressor used for power generation.

Gas turbine cogeneration systems can produce all or a part of the energy requirement of the site, and the energy released at high temperature in the exhaust stack can be recovered for various heating and cooling applications. Though natural gas is most commonly used, other fuels such as light fuel oil or diesel can also be employed. The typical range of gas turbines varies from a fraction of a MW to around 100 MW.

Gas turbine cogeneration has probably experienced the most rapid development in recent years due to the greater availability of natural gas, rapid progress in the technology, significant reduction in installation costs, and better environmental performance.

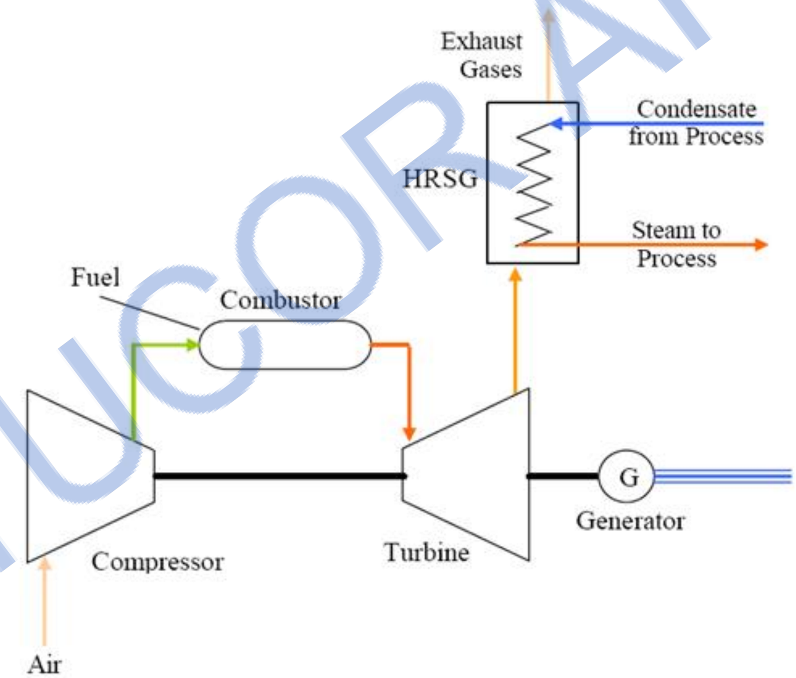
Furthermore, the conception period for developing a project is shorter and the equipment can be delivered in a modular manner.

Gas turbines have a short start-up time and provide the flexibility of intermittent operation. Though they have a low heat to power conversion efficiency, more heat can be recovered at higher temperatures.

18. Explain Open-cycle gas turbine cogeneration systems

Most of the currently available gas turbine systems, in any sector of applications, operate on the open Brayton (also called Joule cycle when irreversibilities are ignored) cycle where a compressor takes in air from the atmosphere and derives it at an increased pressure to the combustor. The air temperature is also increased due to compression. Older and smaller units operate at a pressure ratio in the range of 15:1, while the newer and larger units operate at pressure ratios approaching 30:1

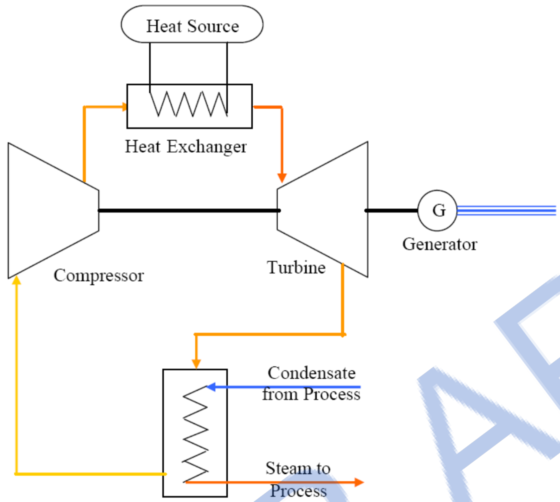
The air is delivered through a diffuser to a constant-pressure combustion chamber, where fuel is injected and burned. The diffuser reduces the air velocity to values acceptable in the combustor. There is a pressure drop across the combustor in the range of 1.2%. Combustion takes place with high excess air. The exhaust gases exit the combustor at high temperature and with oxygen concentrations of up to 15-16%. The highest temperature of the cycle appears at this point; the higher this temperature is, the higher the cycle efficiency is. With current technology, this is about 1300°C.

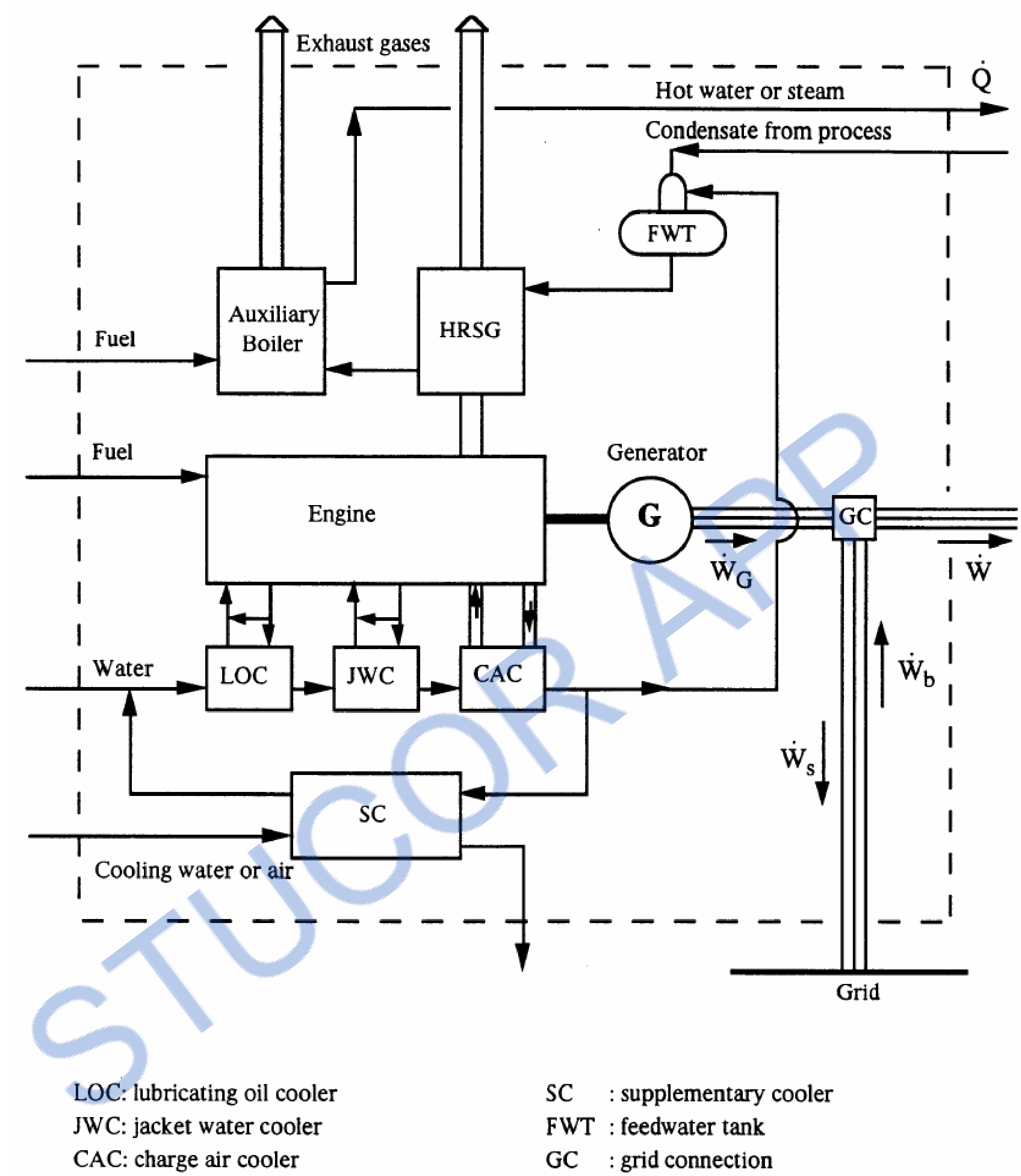


The high pressure and temperature exhaust gases enter the gas turbine producing mechanical work to drive the compressor and the load. The exhaust gases leave the turbine at a considerable temperature (450-600°C), which makes high-temperature heat recovery ideal. This is affected by a heat recovery boiler.

The steam produced can have high pressure and temperature, which makes it appropriate not only for thermal processes but also for driving a steam turbine thus producing additional power.

19. **Explain Closed-cycle gas turbine cogeneration systems**

	In the closed-cycle system, the working fluid (usually helium or air) circulates in a closed circuit. It is heated in a heat exchanger before entering the turbine, and it is cooled down after the exit of the turbine releasing useful heat. Thus, the working fluid remains clean and it does not cause corrosion or erosion. Source of heat can be the external combustion of any fuel. Also, nuclear energy or solar energy can be used. 
20.	**Explain Reciprocating Engine Cogeneration System**
	Reciprocating engines are well suited to a variety of distributed generation applications, industrial, commercial, and institutional facilities for power generation and CHP. Reciprocating engines start quickly, follow load well, have good part-load efficiencies, and generally have high reliabilities. In many cases, multiple reciprocating engine units further increase overall plant capacity and availability. Reciprocating engines have higher electrical efficiencies than gas turbines of comparable size, and thus lower fuel-related operating costs. In addition, the first costs of reciprocating engine gen-sets are generally lower than gas turbine gen-sets up to 3-5 MW in size. Reciprocating engine maintenance costs are generally higher than comparable gas turbines, but the maintenance can often be handled by in-house staff or provided by local service organizations. With heat recovery from the three coolers, water is heated up to 75-80°C. The pre-heated water enters the exhaust gas heat exchanger where it is heated up to 85-95°C, or it is evaporated. Medium size engines usually produce saturated steam of 180-200°C, while large units can deliver superheated steam at pressure 15–20 bar and temperature 250-350°C.



The minimum exhaust gas temperature at the exit of the heat exchanger is 160- 170°C for fuels containing sulphur, like Diesel oil, or 90-100°C for sulphur-free fuels like natural gas. Some industrial CHP applications use the engine exhaust gas directly for process drying.

Generally, the hot water and low-pressure steam produced by reciprocating engine CHP systems is appropriate for low-temperature process needs, space heating, potable water heating, and to drive absorption chillers providing cold water, air conditioning, or refrigeration.

21.	**List the classification of the cogeneration system is based on the size of the engine**
	❖ Small units with a gas engine (15–1000 kW) or Diesel engine (75–1000 kW). ❖ Medium power systems (1–6 MW) with a gas engine or Diesel engine. ❖ High power systems (higher than 6 MW) with the Diesel engine.
22.	**Explain the Relative Merits of Cogeneration Systems**

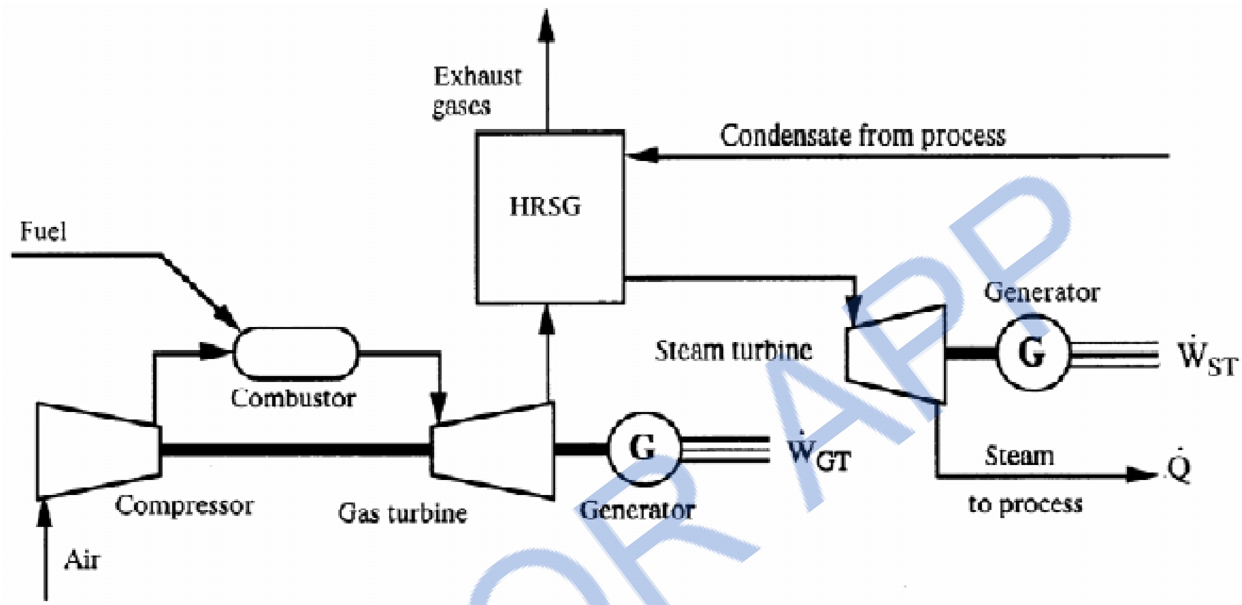
Variant	Advantages	Disadvantages
Back pressure	High fuel efficiency rating	Little flexibility in design and operation
Steam turbine & fuel firing in the boiler	Simple plant Well-suited to low-quality fuels	More capital investment Low fuel efficiency rating High cooling water demand More impact on the environment -High civil const. cost due to complicated foundations
Gas turbine with the waste heat recovery boiler	Good fuel efficiency Simple plant Low civil const. Cost Less delivery period Less impact on the environment High flexibility in operation	Moderate part load efficiency Limited suitability for low-quality fuels
Combined gas & steam turbine with the waste heat recovery boiler	Optimum fuel efficiency rating Low relative capital cost Less gestation period Quick start-up & stoppage Less impact on the environment High flexibility in operation	Average to moderate part-load efficiency Limited suitability for low-quality fuels
Diesel Engine & waste heat recovery Boiler & cooling water heat exchanger	Low civil const. Cost due to block foundations & least no. of auxiliaries High Power efficiency Better suitability as a standby power source	Low overall efficiency Limited suitability for low-quality fuels Availability of low-temperature steam Highly maintenance prone.
Back pressure	High fuel efficiency rating	Little flexibility in design and operation

23.	**Explain Combined Cycle Cogeneration Systems**
	The term "combined cycle" is used for systems consisting of two thermodynamic cycles, which are connected with a working fluid and operate at different temperature levels.

The high-temperature cycle rejects heat, which is recovered and used by the low-temperature cycle to produce additional electrical/ mechanical energy, thus increasing the electrical efficiency.

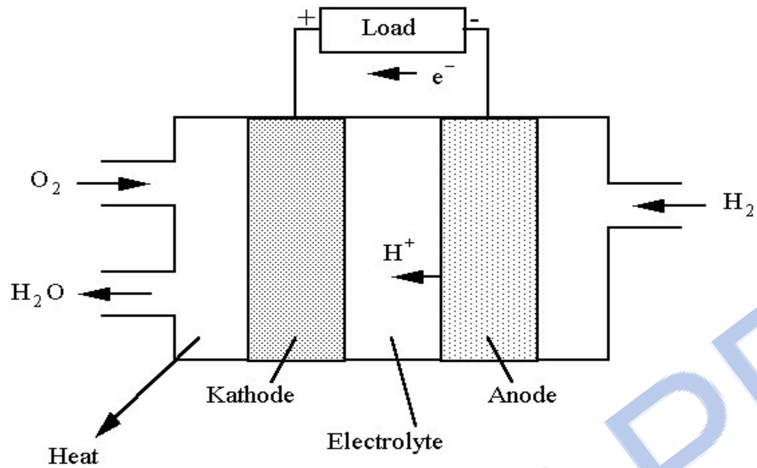
24. Explain Combined Joule – Rankine Cycle Systems

The most widely used combined-cycle systems are those of gas turbine – steam turbine (combined Joule – Rankine cycle). They so much outnumber other combined cycles that the term "combined cycle", if nothing else is specified, means combined Joule – Rankine cycle.



- ❖ The maximum possible steam temperature with no supplementary firing is by 25-40°C lower than the exhaust gas temperature at the exit of the gas turbine, while the steam pressure can reach 80 bar.
- ❖ If higher temperature and pressure is required, then an exhaust gas boiler with burner(s) is used for firing supplementary fuel. Usually, there is no need for supplementary air because the exhaust gases contain oxygen at a concentration of 15–16%. With supplementary firing, the steam temperature can approach 540°C and pressure can exceed 100 bar. Supplementary firing not only increases the capacity of the system but also improves its partial load efficiency.
- ❖ Constructed with medium and high power output (20–400 MW). Smaller systems (4–15 MW).
- ❖ The power concentration (i.e. power per unit volume) of the combined cycle systems is higher.
- ❖ Regarding the fuels used, those mentioned for gas turbines are valid also here.
- ❖ The installation time is 2–3 years.
- ❖ The reliability of (Joule – Rankine) combined cycle systems is 80–85%.
- ❖ The annual average availability is 77–85% and the economic life cycle is 15–25 years.

	❖ The electric efficiency is in the range 35–45%, the total efficiency is 70-88% and the power to heat ratio is 0.6–2.0.
25.	**Explain Combined Diesel – Rankine Cycle Systems**
	❖ It is also possible to combine Diesel cycle with Rankine cycle. ❖ The arrangement is similar to the difference that the gas turbine unit (compressor – combustor – gas turbine) is replaced by a Diesel engine. ❖ Medium to high power engines may make the addition of the Rankine cycle economically feasible. ❖ Supplementary firing in the exhaust gas boiler is also possible. ❖ Since the oxygen content in the exhaust gases of a Diesel engine is low, the supply of additional air for the combustor in the boiler is necessary.
26.	**Explain Fuel Cell Cogeneration Systems**
	❖ A fuel cell is an electrochemical device, which converts the chemical energy of fuel into electricity directly, without intermediate stages of combustion and production of mechanical work. ❖ Systematic research during the last 30–40 years has been fruitful and several pilot plants have been built and operated successfully. ❖ Fuel cells are still considered as an emerging technology and very promising both for electricity generation and for cogeneration.
27.	**Explain the Basic Operation Principle of Fuel Cells**
	Hydrogen reacts with oxygen in the presence of an electrolyte and produces water, while at the same time an electrochemical potential is developed, which causes the flow of an electric current in the external circuit (load). The following electrochemical reactions take place on the two electrodes: Anode: $H_2 \rightarrow 2H^+ + 2e^-$ Cathode: $2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O$ Thus, the total reaction is: $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ At the anode, ions and free electrons are produced. Ions move towards the cathode through the electrolyte. Electrons move towards the cathode through the external circuit, which includes the load (external resistance). The reaction is exothermic. The released heat can be used in thermal processes.
28.	**Explain the basic principle of a hydrogen-oxygen fuel cell**

	The required hydrogen is usually produced from hydrocarbons, most frequently natural gas, by a process known as reforming, which can be either external or internal to the fuel cell unit, depending on the type of the fuel cell. Also, it can be produced by electrolysis of water. In certain types of fuel cells, carbon monoxide can be used as fuel, instead of hydrogen.  A single cell develops an electric voltage slightly lower than 1 Volt. The proper numbers of cells connected in series produce the required voltage, while with parallel connection the required power is produced. Thus, a stack of cells is created. A direct current is produced; a (usually static) inverter is used to transform the direct current to alternating current of the appropriate voltage and frequency.
29.	**What are the types of Fuel Cells?**
	Several classifications of fuel cells have appeared in the literature throughout the years. The most prevailing one is based on the type of electrolyte. ❖ Alkaline fuel cells (AFC) ❖ Polymer electrolyte fuel cells (PEFC) ❖ Phosphoric acid fuel cells (PAFC) ❖ Molten carbonate fuel cells (MCFC) ❖ Solid oxide fuel cells (SOFC)
30.	**Explain Alkaline fuel cells (AFC)**
	❖ Potassium hydroxide (KOH), is the electrolyte, at a concentration of around 30%. ❖ Pure hydrogen is the fuel and pure oxygen or air is the oxidiser. ❖ Alkaline fuel cells operate at a temperature 60-80°C. ❖ The operating pressure is a few atmospheres, but most often it has been the atmospheric pressure. ❖ They are used in space applications.

	❖ Also, they are one of the most attractive systems for transportation applications. ❖ Units with a power up to 100 kW have been constructed.
31.	**Explain Polymer electrolyte fuel cells (PEFC)**
	❖ They are also known with the initials PEM (Polymer Electrolyte Membranes). ❖ The electrolyte consists of a solid polymeric membrane, which is sandwiched between two platinum-catalysed porous electrodes. ❖ The operating temperature is around 80ºC and the operating pressure 1-8 atm. ❖ PEFC units with a power output up to 100 kW have been constructed.
32.	**Explain Phosphoric acid fuel cells (PAFC)**
	❖ PAFC is the most advanced fuel cell technology for terrestrial applications. ❖ Packaged units of 200-250 kWe are already commercially available for electricity generation or cogeneration, while demonstration systems of 25 kW–11 MW have been constructed in Europe, USA and Japan. ❖ Phosphoric acid (H^3PO^4) is the electrolyte. ❖ Hydrogen is produced by an external reformer from fuels such as natural gas or methanol. Air is the oxidiser. ❖ The operating temperature is around 200ºC, which makes PEFC's attractive for cogeneration applications, in particular in the tertiary sector.
33.	**List the applications of cogeneration**
	Cogeneration applications are usually classified with reference to the sector they appear: a) utility sector, b) industrial sector, c) building sector (called also residential-commercial-institutional sector), d) Rural sector.
34.	**Write a short note on cogeneration in the utility sector**
	❖ Thermal power plants can either be built as or converted to cogeneration systems supplying with heat nearby cities or part of a city, industries, greenhouses, fisheries, water desalination plants (in particular on islands or in countries with scarce water resources), etc. ❖ The distance of the users of heat from the plant and their dispersion are of crucial importance for the feasibility of the project. ❖ When a city or a district is supplied with heat, the system is also called a "district heating cogeneration system". ❖ In district heating applications, in addition to the distance and dispersion of users, the

	thermal power required and the annual number of degree-days are important parameters for the feasibility. ❖ In most of the cases, the economic distance for transfer of heat does not exceed 10 km; in exceptional cases, it may reach 30 km. ❖ In hot climates, district cooling during the summer may also be economically feasible. In such a case, heat supplied by the plant is used to drive an absorption cooling or air-conditioning unit. ❖ Two other applications, which can be mentioned here, are landfills and sewage treatment plants. In both cases, fuel gas is produced, which can fuel a gas engine cogeneration unit. ❖ Another alternative for city wastes, instead of being buried in landfills, is to be burned in boilers of steam turbine cogeneration systems. The heat produced can serve near-by communities.
35.	**Explain the classifications of industrial cogeneration**
	Many industrial processes require heat in order to be completed. They are classified according to the temperature level of the required heat: ❖ Low-temperature processes (lower than 100°C), e.g. drying of agricultural products, space heating or cooling, domestic hot water. ❖ Medium temperature processes (100-300°C), e.g. pulp and paper industry, textile industry, sugar factories, etc. In these processes, heat is usually supplied in the form of steam. ❖ High-temperature processes (300-700°C),e.g. in chemical industries. ❖ Very high-temperature processes (higher than 700°C), e.g. cement factories, glass works. **Significant cogeneration potential:** Significant cogeneration potential exists in the following industries: ❖ food and beverage ❖ textile ❖ pulp and paper ❖ Chemicals & petroleum refineries ❖ cement ❖ primary metals The lower but non-negligible potential exists also in the following industries: ❖ glass

	❖ ceramics ❖ wood ❖ Most of the industries which produce or reject heat at such a quantity and quality (temperature) that it is feasible to recover this heat for appropriate use. ❖ On the other hand, certain industrial processes have fuel gases as a by-product, which can be burned either in a boiler or in the cogeneration system itself. ❖ Pulp and paper industry has large amounts of burnable wastes that can be used as fuels in cogeneration systems. ❖ In the steel industry, off-gases from the open-hearth steel making process provide a ready source of fuel to produce steam for driving blast furnace air compressors and other uses. ❖ In the cement industry, bottoming-cycle cogeneration is applicable, in which heat of the kiln exhaust gas is recovered and used to produce steam for electricity generation.
36.	**Write a short note on cogeneration in the building sector**
	A combination of electrical and thermal load with level and duration appropriate for cogeneration often appears in buildings such as the following: ❖ houses and apartment buildings ❖ hotels ❖ hospitals ❖ schools and universities ❖ office buildings ❖ stores, supermarkets, shopping centres ❖ restaurants ❖ swimming pools and leisure centres
37.	**Write a short note on rural cogeneration**
	Cogeneration is not widespread in the rural sector, but its application can result in energy savings and economic benefits in rural communities. Promising rural applications of cogeneration include ethanol production, drying crops or wood, and heating greenhouses, animal shelters, or homes. However, of more interest and benefit to the rural communities are technologies that can use locally available biomass fuels such as crop residues, wood, and animal wastes. Gasifiers that convert crop residues or wood to low or medium heating value gas can be connected with internal combustion engines, which have been properly modified for long and trouble-free operation with this fuel. Anaerobic digestion of animal wastes from confined

	livestock operations also could be used to produces biogas (a mixture of 60% methane and 40% carbon dioxide) to fuel an internal combustion engine.
38.	**Define Waste Heat**
	Waste heat is heat generated in a process by way of fuel combustion or chemical reaction, which is then "dumped" into the environment and not reused for useful and economic purposes.
39.	**What is Waste Heat Recovery?**
	❖ Large quantities of hot flue gases are generated from boilers, kilns, ovens and furnaces. ❖ If some of the waste heat could be recovered then a considerable amount of primary fuel could be saved. ❖ The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered by adopting the right measures can minimize losses.
40.	**Classification and Application of Waste Heat Recovery**

S.No.	Source	Quality
1.	Heat in flue gases.	The higher the temperature, the greater the potential value for heat recovery
2.	Heat in vapour streams.	As above but when condensed, latent heat also recoverable.
3	Convective and radiant heat lost from exterior of equipment	Low grade – if collected may be used for space heating or air preheats.
4.	Heat losses in cooling water.	Low grade – useful gains if heat is exchanged with incoming fresh water.
5.	Heat losses in providing chilled water or in the disposal of chilled water.	a) High grade if it can be utilized to reduce demand for refrigeration. b) Low grade if refrigeration unit used as a form of heat pump.
6.	Heat stored in products leaving the process	Quality depends upon temperature.
7.	Heat in gaseous and liquid effluents leaving process.	Poor if heavily contaminated and thus requiring alloy heat exchanger.

41.	**High-Temperature Heat Recovery devices**

Types of Device	Temperature, °C
Nickel refining furnace	1370 –1650
Aluminium refining furnace	650-760
Zinc refining furnace	760-1100
Copper refining furnace	760- 815
Steel heating furnaces	925-1050
Copper reverberatory furnace	900-1100
Open hearth furnace	650-700
Cement kiln (Dry process)	620- 730
Glass melting furnace	1000-1550
Hydrogen plants	650-1000
Solid waste incinerators	650-1000
Fume incinerators	650-1450

42. Medium Temperature Heat Recoverydevices

Type of Device	Temperature, °C
Steam boiler exhausts	230-480
Gas turbine exhausts	370-540
Reciprocating engine exhausts	315-600
Reciprocating engine exhausts (turbo charged)	230- 370
Heat treating furnaces	425 - 650
Drying and baking ovens	230 - 600
Catalytic crackers	425 - 650
Annealing furnace cooling systems	425 - 650

43. Low-Temperature Heat Recovery devices

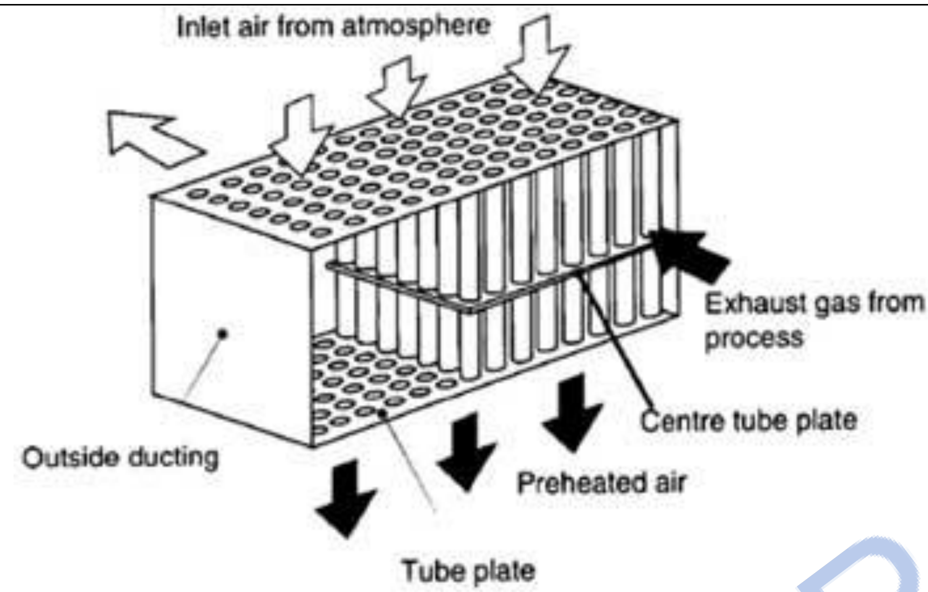
Source	Temperature, °C
Process steam condensate	55-88
Cooling water from: Furnace doors	32-55
Bearings	32-88
Welding machines	32-88
Injection molding machines	32-88
Annealing furnaces	66-230
Forming dies	27-88
Air compressors	27-50
Pumps	27-88
Internal combustion engines	66-120
Air conditioning and refrigeration condensers	32–43
Liquid still condensers	32-88
Drying, baking and curing ovens	93-230
Hot processed liquids	32-232
Hot processed solids	93-232

44. What are the direct and indirect benefits of waste heat recovery?

Direct Benefits:

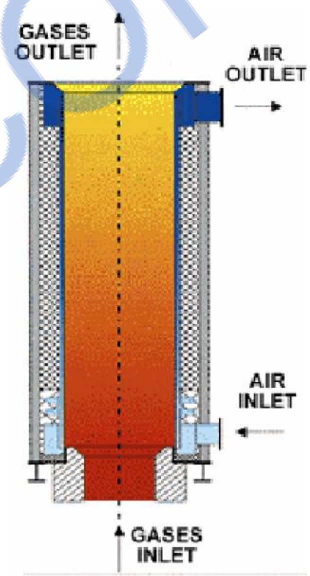
Recovery of waste heat has a direct effect on the efficiency of the process. This is

	reflected by a reduction in utility consumption & costs, and process cost. **Indirect Benefits:** **a) Reduction in pollution** A number of toxic combustible wastes such as carbon monoxide gas, sour gas, carbon black off-gases, oil sludge, Acrylonitrile and other plastic chemicals etc, releasing to the atmosphere if/when burnt in the incinerators serves dual purpose i.e. recovers heat and reduces the environmental pollution levels **b) Reduction in equipment sizes** Waste heat recovery reduces fuel consumption, which leads to a reduction in the flue gas produced. This results in a reduction in equipment sizes of all flue gas handling equipments such as fans, stacks, ducts, burners, etc **c) Reduction in auxiliary energy consumption** Reduction in equipment sizes gives additional benefits in the form of a reduction in auxiliary energy consumption like electricity for fans, pumps etc.
45.	**List the types of waste heat recovery equipment**
	❖ Recuperators • Metallic radiation recuperator • Convective recuperator • Hybrid recuperator • Ceramic recuperator ❖ Regenerators ❖ Heat Wheels ❖ Heat Pipe ❖ Economizers ❖ Shell and Tube Heat Exchangers ❖ Plate Heat Exchanger ❖ Run Around Coil Exchangers ❖ Waste Heat Recovery Boilers ❖ Heat Pumps ❖ Thermo-compressor
46.	**Explain the various types of recuperators**

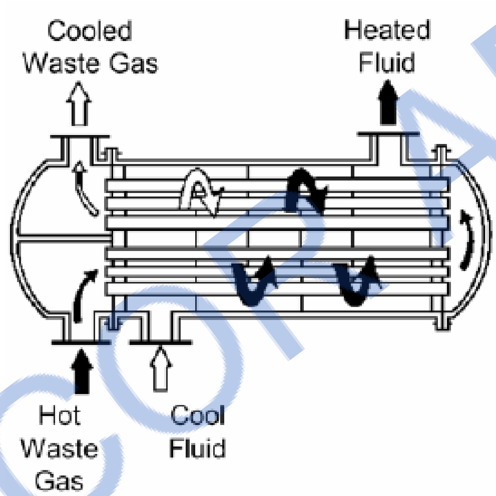


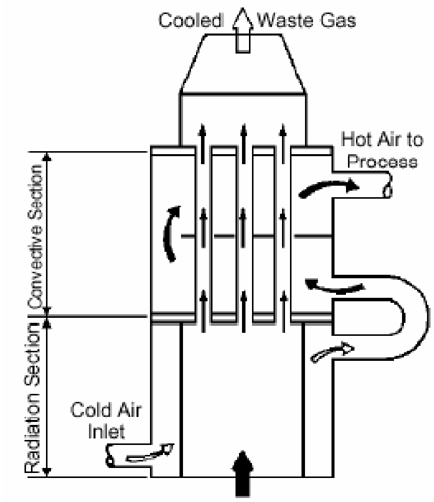
In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be pre-heated, the other side contains the waste heat stream. A recuperator for recovering waste heat from flue gases is shown in Figure.

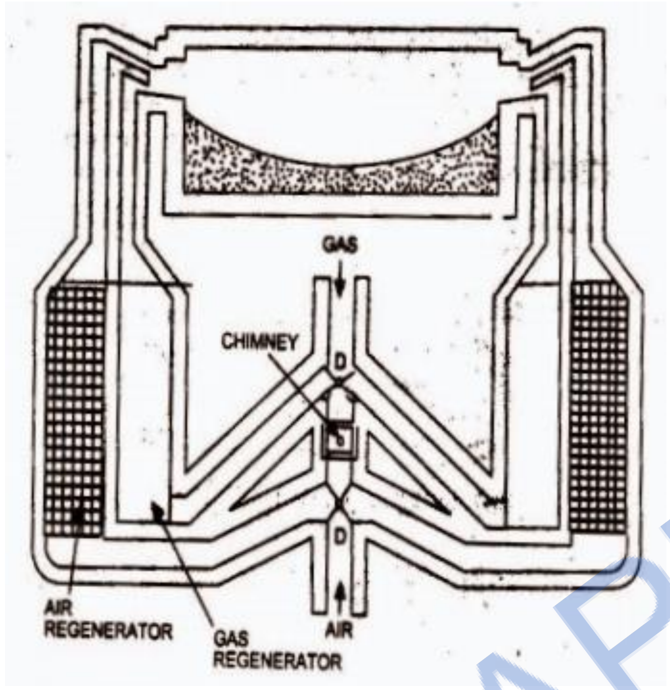
The simplest configuration for a recuperator is the metallic radiation recuperator, which consists of two concentric lengths of metal tubing as shown in Figure.

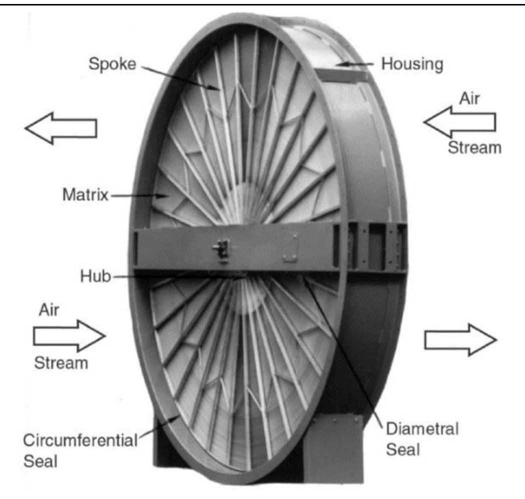


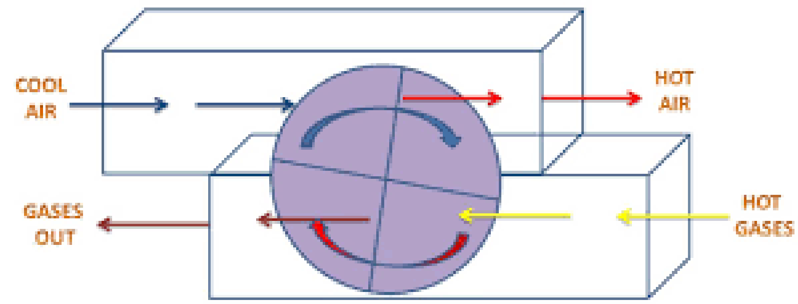
The inner tube carries the hot exhaust gases while the external annulus carries the combustion air from the atmosphere to the air inlets of the furnace burners. The hot gases are cooled by the incoming combustion air which now carries additional energy into the combustion chamber. This is energy which does not have to be supplied by the fuel; consequently, less fuel is burned for a given furnace loading. The saving in fuel also means a decrease in combustion air and therefore stack losses are decreased not only by lowering the stack gas temperatures but also

	by discharging smaller quantities of exhaust gas. The radiation recuperator gets its name from the fact that a substantial portion of the heat transfer from the hot gases to the surface of the inner tube takes place by radiative heat transfer. The cold air in the annuals, however, is almost transparent to infrared radiation so that only convection heat transfer takes place to the incoming air. As shown in the diagram, the two gas flows are usually parallel, although the configuration would be simpler and the heat transfer more efficient if the flows were opposed in direction (or counter flow). The reason for the use of parallel flow is that recuperators frequently serve the additional function of cooling the duct carrying away the exhaust gases and consequently extending its service life. A second common configuration for recuperators is called the tube type or convective recuperator.  As seen in the figure, the hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in a direction normal to their axes. If the tubes are baffled to allow the gas to pass over them twice, the heat exchanger has termed a two-pass recuperator; if two baffles are used, a three-pass recuperator, etc. Although baffling increases both the cost of the exchanger and the pressure drop in the combustion air path, it increases the effectiveness of heat exchange. Shell and tube type recuperators are generally more compact and have a higher effectiveness than radiation recuperators, because of the larger heat transfer area made possible through the use of multiple tubes and multiple passes of the gases.
47.	**Write a short note on Radiation/Convective Hybrid Recuperator:**

	 For maximum effectiveness of heat transfer, combinations of radiation and convective designs are used, with the high-temperature radiation recuperator being first followed by convection type. These are more expensive than simple metallic radiation recuperators but are less bulky. A Convective/radiative Hybrid recuperator is shown in Figure.
48.	**Write a short note on Ceramic Recuperator**
	The principal limitation on the heat recovery of metal recuperators is the reduced life of the liner at inlet temperatures exceeding 1100°C. In order to overcome the temperature limitations of metal recuperators, ceramic tube recuperators have been developed whose materials allow operation on the gas side to 1550°C and on the preheated air side to 815°C on a more or less practical basis. Early ceramic recuperators were built of tile and joined with furnace cement, and thermal cycling caused cracking of joints and rapid deterioration of the tubes. Later developments introduced various kinds of short silicon carbide tubes which can be joined by flexible seals located in the air headers. Earlier designs had experienced leakage rates from 8 to 60 percent. The new designs are reported to last two years with air preheat temperatures as high as 700°C, with much lower leakage rates.
49.	**Explain the operating principle of a regenerator**
	The Regeneration which is preferable for large capacities has been very widely used in glass and steel melting furnaces. Important relations exist between the size of the regenerator, the time between reversals, the thickness of brick, the conductivity of brick and heat storage ratio of the brick. In a regenerator, the time between the reversals is an important aspect. Long periods would mean higher thermal storage and hence higher cost. Also, long periods of reversal result in the lower average temperature of preheat and consequently reduce fuel economy. Accumulation of dust and slagging on the surfaces reduce the efficiency of the heat transfer as the furnace becomes old. Heat losses from the walls of the regenerator and air in leaks during the gas period

	and out leaks during air period also reduces the heat transfer. 
50.	**What are the heat wheels? Explain with a sketch.**
	A heat wheel is finding increasing applications in low to medium temperature waste heat recovery systems. Figure 8.6 is a sketch illustrating the application of a heat wheel is a sizable porous disk, fabricated with a material having a fairly high heat capacity, which rotates between two side-by-side ducts: one a cold gas duct, the other a hot gas duct. The axis of the disk is located parallel to, and on the partition between, the two ducts. As the disk slowly rotates, sensible heat (moisture that contains latent heat) is transferred to the disk by the hot air and, as the disk rotates, from the disk to the cold air. The overall efficiency of sensible heat transfer for this kind of regenerator can be as high as 85 percent. Heat wheels have been built as large as 21 metres in diameter with air capacities up to 1130 m3 / min. A variation of the Heat Wheel is the rotary regenerator where the matrix is in a cylinder rotating across the waste gas and air streams. The heat or energy recovery wheel is a rotary gas heat regenerator, which can transfer heat from the exhaust to incoming gases. Its main area of application is where heat exchange between large masses of air having small temperature differences is required. Heating and ventilation systems and recovery of heat from dryer exhaust air are typical applications.

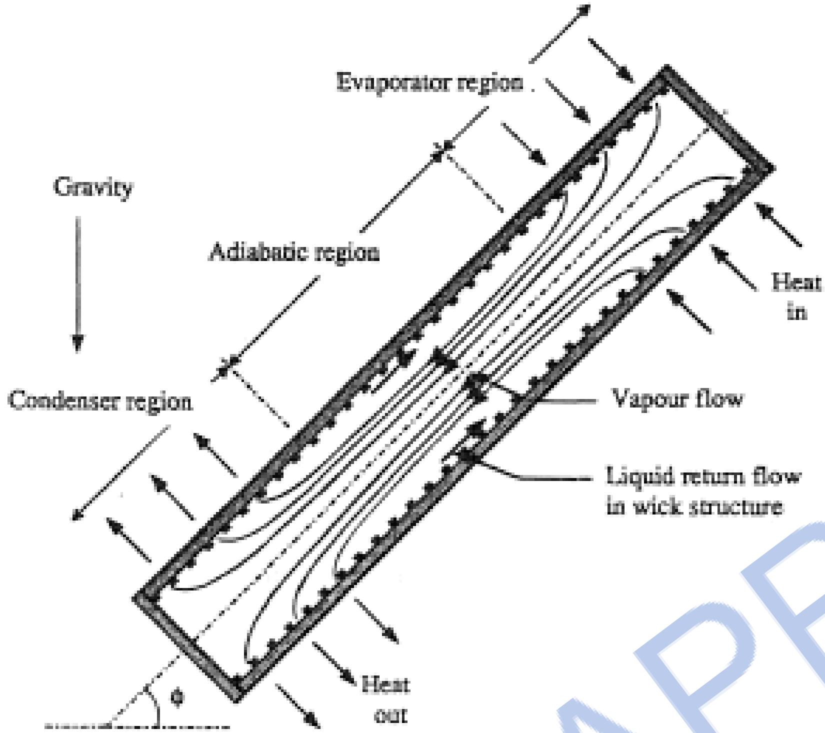




51. Explain the principle of operation of a heat pipe.

A heat pipe can transfer up to 100 times more thermal energy than copper, the best-known conductor. In other words, the heat pipes is thermal energy-absorbing and transferring system and have no moving parts and hence require minimum maintenance.

The Heat Pipe comprises of three elements - a sealed container, a capillary wick structure and a working fluid. The capillary wick structure is integrally fabricated into the interior surface of the container tube and sealed under vacuum. Thermal energy applied to the external surface of the heat pipe is in equilibrium with its own vapour as the container tube is sealed under vacuum. Thermal energy applied to the external surface of the heat pipe causes the working fluid near the surface to evaporate instantaneously. Vapour thus formed absorbs the latent heat of vapourisation and this part of the heat pipe becomes an evaporator region. The vapour then travels to the other end the pipe where the thermal energy is removed causing the vapour to condense into liquid again, thereby giving up the latent heat of the condensation. This part of the heat pipe works as the condenser region. The condensed liquid then flows back to the evaporated region. A figure of the Heat pipe is shown in Figure.



Performance and Advantage:

The heat pipe exchanger (HPHE) is a lightweight compact heat recovery system. It virtually does not need mechanical maintenance, as there are no moving parts to wear out. It does not need input power for its operation and is free from cooling water and lubrication systems. It also lowers the fan horsepower requirement and increases the overall thermal efficiency of the system. The heat pipe heat recovery systems are capable of operating at 315°C with 60% to 80% heat recovery capability.

52. What are the typical applications of a heat pipe in heat exchangers?

The heat pipes are used in the following industrial applications:

a) Process to Space Heating:

The heat pipe heat exchanger transfers the thermal energy from process exhaust for building heating. The preheated air can be blended if required. The requirement of additional heating equipment to deliver heated make up air is drastically reduced or eliminated.

b) Process to Process:

The heat pipe heat exchangers recover waste thermal energy from the process exhaust and transfer this energy to the incoming process air. The incoming air thus becomes warm and can be used for the same process/other processes and reduces process energy consumption.

c) HVAC Applications:

Cooling:

Heat pipe heat exchanger precools the building makeup air in summer and thus reduces the total tons of refrigeration, apart from the operational saving of the cooling system. Thermal energy is supply recovered from the cool exhaust and transferred to the hot supply makeup air.

Heating:

The above process is reversed during winter to preheat the makeup air.

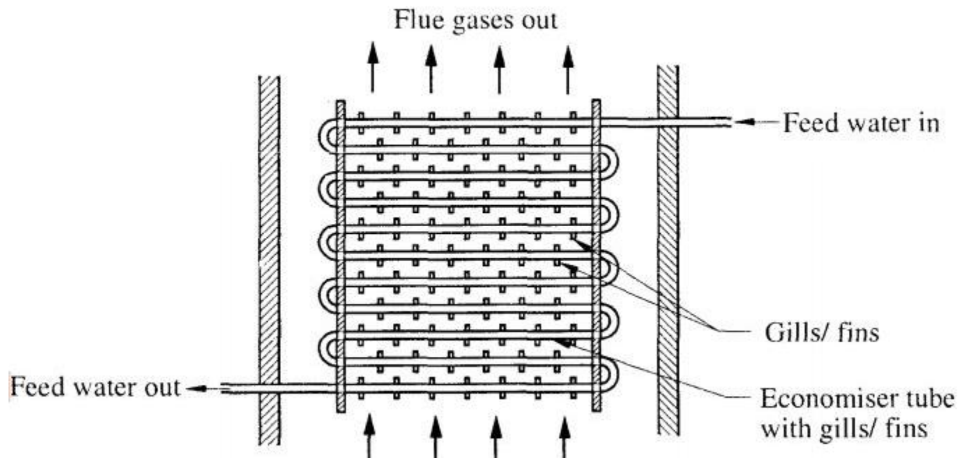
The other applications in industries are:

- Preheating of boiler combustion air
- Recovery of Waste heat from furnaces
- Reheating of fresh air for hot air driers
- Recovery of waste heat from catalytic deodorizing equipment
- Reuse of Furnace waste heat as a heat source for another oven
- Cooling of closed rooms with outside air
- Preheating of boiler feed water with waste heat recovery from flue gases in the heat pipe economizers.
- Drying, curing and baking ovens
- Waste steam reclamation
- Brick kilns (secondary recovery)
- Reverberatory furnaces (secondary recovery)
- Heating, ventilating and air-conditioning systems

53. Explain the operation of an economizer.

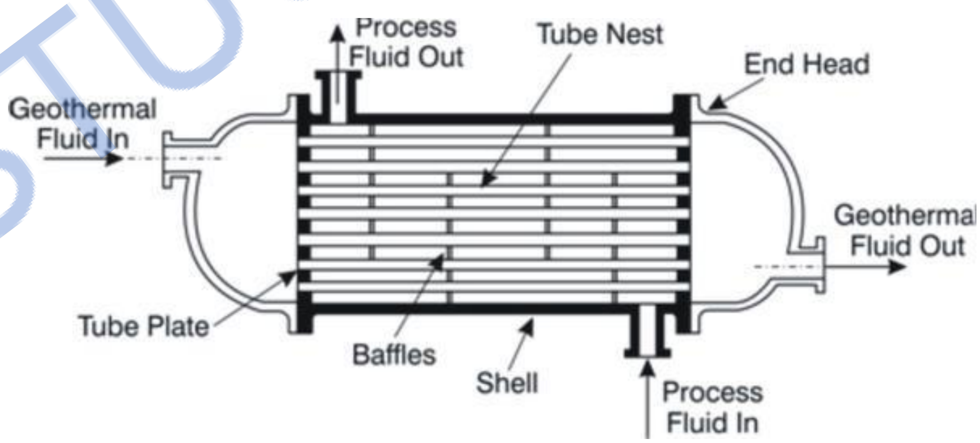
In the case of the boiler system, economizer can be provided to utilize the flue gas heat for preheating the boiler feedwater. On the other hand, in an air preheater, the waste heat is used to heat combustion air. In both cases, there is a corresponding reduction in the fuel requirements of the boiler. An economizer is shown in Figure.

For every 22°C reduction in flue gas temperature by passing through an economiser or a pre-heater, there is 1% saving of fuel in the boiler. In other words, for every 6°C rise in feed water temperature through an economiser, or 20°C rise in combustion air temperature through an air pre-heater, there is 1% saving of fuel in the boiler.



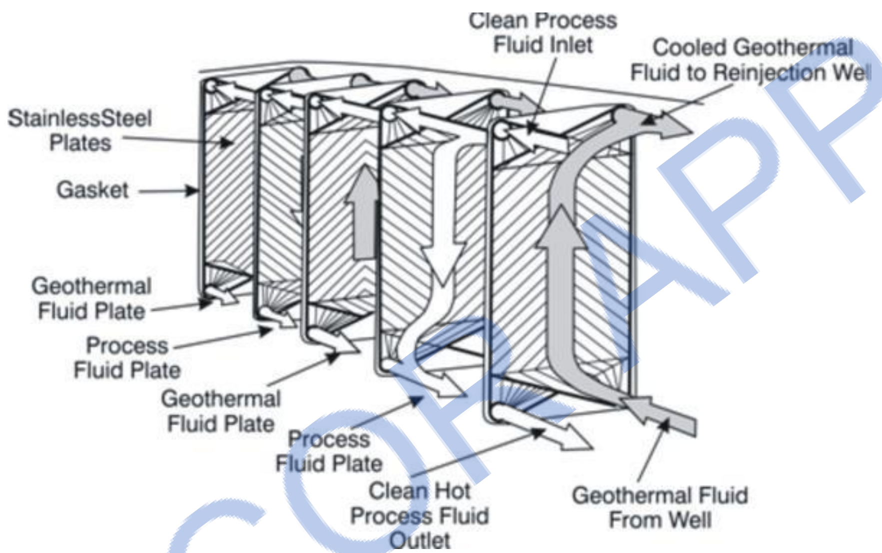
54.	**How does a shell and tube heat exchanger work? Give typical examples.**

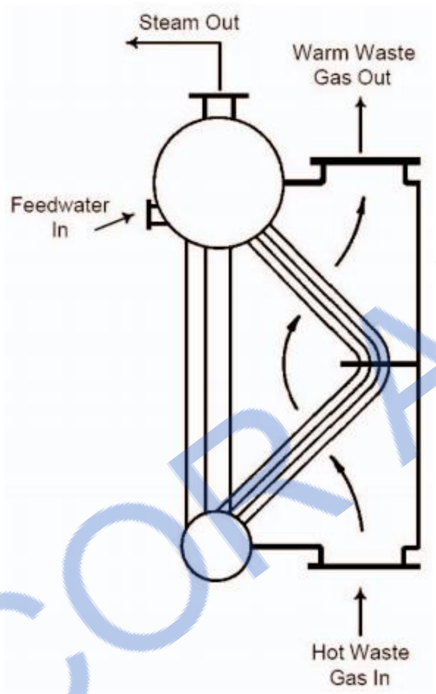
When the medium containing waste heat is a liquid or a vapour which heats another liquid, then the shell and tube heat exchanger must be used since both paths must be sealed to contain the pressures of their respective fluids. The shell contains the tube bundle, and usually internal baffles, to direct the fluid in the shell over the tubes in multiple passes. The shell is inherently weaker than the tubes so that the higher-pressure fluid is circulated in the tubes while the lower pressure fluid flows through the shell. When a vapour contains the waste heat, it usually condenses, giving up its latent heat to the liquid being heated. In this application, the vapor is almost invariably contained within the shell. If the reverse is attempted, the condensation of vapours within small diameter parallel tubes causes flow instabilities. Tube and shell heat exchangers are available in a wide range of standard sizes with many combinations of materials for the tubes and shells. A shell and tube heat exchanger is illustrated in Figure.



Typical applications of shell and tube heat exchangers include heating liquids with the heat contained by condensates from refrigeration and air-conditioning systems; condensate from process steam; coolants from furnace doors, grates, and pipe supports; coolants from engines, air compressors, bearings, and lubricants; and the condensates from distillation processes.

55.	**How does a plate heat exchanger work? Give typical examples.**

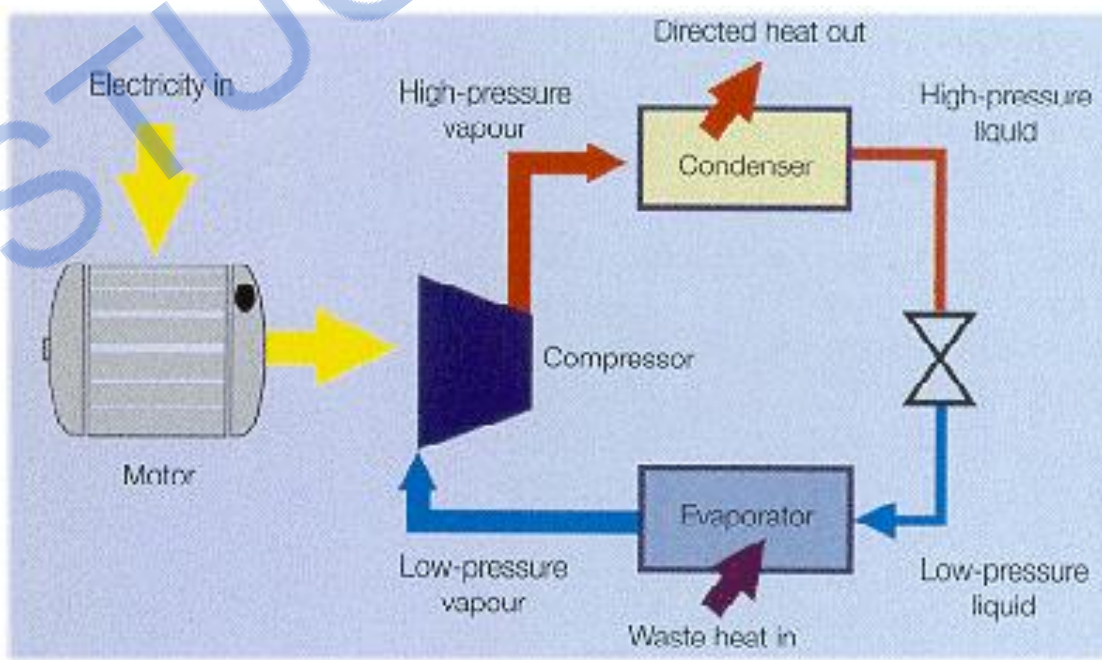
	The cost of heat exchange surfaces is a major cost factor when the temperature differences are not large. One way of meeting this problem is the plate type heat exchanger, which consists of a series of separate parallel plates forming a thin flow pass. Each plate is separated from the next by gaskets and the hot stream passes in parallel through alternative plates whilst the liquid to be heated passes in parallel between the hot plates. To improve heat transfer the plates are corrugated. Hot liquid passing through a bottom port in the head is permitted to pass upwards between every second plate while cold liquid at the top of the head is permitted to pass downwards between the odd plates. When the directions of hot & cold fluids are opposite, the arrangement is described as counter current. A plate heat exchanger is shown in Figure.  **Typical industrial applications are:** ❖ Pasteurisation section in a milk packaging plant. ❖ Evaporation plants in the food industry
57.	**Explain the operating principle of a waste heat recovery boiler with examples.**
	Waste heat boilers are ordinarily water tube boilers in which the hot exhaust gases from gas turbines, incinerators, etc., pass over a number of parallel tubes containing water. The water is vaporized in the tubes and collected in a steam drum from which it is drawn off for use as heating or processing steam. Because the exhaust gases are usually in the medium temperature range and in order to conserve space, a more compact boiler can be produced if the water tubes are finned in order to increase the effective heat transfer area on the gas side. The Figure shows a mud drum, a set of tubes over which the hot gases make a double pass, and a steam drum which collects the steam generated above the water surface. The pressure at which the steam is generated and the rate of steam production depends on the temperature of waste heat. The pressure of a pure vapour in

	the presence of its liquid is a function of the temperature of the liquid from which it is evaporated. The steam tables tabulate this relationship between saturation pressure and temperature. If the waste heat in the exhaust gases is insufficient for generating the required amount of process steam, auxiliary burners which burn fuel in the waste heat boiler or an after-burner in the exhaust gases flue are added. Waste heat boilers are built-in capacities from 25 m3 almost 30,000 m3 / min. of exhaust gas.  Typical applications of waste heat boilers are to recover energy from the exhausts of gas turbines, reciprocating engines, incinerators, and furnaces.
58.	**Explain the operating principle of a heat pump with examples**
	In the various commercial options previously discussed, we find waste heat being transferred from a hot fluid to a fluid at a lower temperature. Heat must flow spontaneously "downhill", that is from a system at high temperature to one at a lower temperature. When energy is repeatedly transferred or transformed, it becomes less and less available for use. Eventually, that energy has such low intensity (resides in a medium at such low temperature) that it is no longer available at all to perform a useful function. It has been taken as a general rule of thumb in industrial operations that fluids with temperatures less than 120°C (or, better, 150°C to provide a safe margin), as the limit for waste heat recovery because of the risk of condensation of corrosive liquids. However, as fuel costs continue to rise, even such waste heat can be used economically for space heating and other low-temperature applications. It is possible to reverse

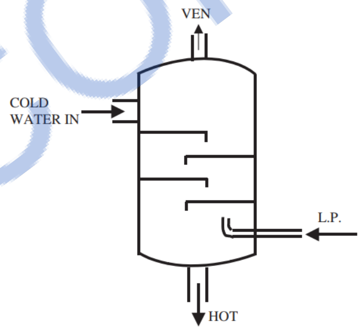
the direction of spontaneous energy flow by the use of a thermodynamic system known as a heat pump.

The majority of heat pumps work on the principle of the vapour compression cycle. In this cycle, the circulating substance is physically separated from the source (waste heat, with a temperature of Tin) and user (heat to be used in the process, Tout) streams, and is re-used in a cyclical fashion, therefore called 'closed cycle'. In the heat pump, the following processes take place:

- In the evaporator the heat is extracted from the heat source to boil the circulating substance;
- The circulating substance is compressed by the compressor, raising its pressure and temperature; The low-temperature vapour is compressed by a compressor, which requires external work. The work done on the vapour raises its pressure and temperature to a level where its energy becomes available for use
- The heat is delivered to the condenser;
- The pressure of the circulating substance (working fluid) is reduced back to the evaporator condition in the throttling valve, where the cycle repeats. The heat pump was developed as a space heating system where low-temperature energy from the ambient air, water, or earth is raised to heating system temperatures by doing compression work with an electric motor-driven compressor. The arrangement of a heat pump is shown in the figure.



The heat pumps have the ability to upgrade heat to a value more than twice that of the

	energy consumed by the device. The potential for application of heat pump is growing and a number of industries have been benefited by recovering low-grade waste heat by upgrading it and using it in the main process stream. Heat pump applications are most promising when both the heating and cooling capabilities can be used in combination. One such example of this is a plastics factory where chilled water from heat is used to cool injection-moulding machines whilst the heat output from the heat pump is used to provide factory or office heating. Other examples of heat pump installation include product drying, maintaining a dry atmosphere for storage and drying compressed air.
59.	**Write a short note on Direct Contact Heat Exchanger**
	Low-pressure steam may also be used to preheat the feedwater or some other fluid where miscibility is acceptable. This principle is used in Direct Contact Heat Exchanger and finds wide use in a steam-generating station. They essentially consist of a number of trays mounted one over the other or packed beds. Steam is supplied below the packing while the cold water is sprayed at the top. The steam is completely condensed in the incoming water thereby heating it. A figure of the direct contact heat exchanger is shown in Figure. A typical application is in the deaerator of a steam generation station. 
60.	**Explain the operating principle of a run around coil exchanger**
	It is quite similar in principle to the heat pipe exchanger. The heat from the hot fluid is transferred to the colder fluid via an intermediate fluid known as the Heat Transfer Fluid. One coil of this closed-loop is installed in the hot stream while the other is in the cold stream. Circulation of this fluid is maintained by means of a circulating pump. It is more useful when the hot and cold fluids are located far away from each other and are not easily accessible. Typical industrial applications are heat recovery from ventilation, air conditioning and low-temperature heat recovery.
61.	**What is the cost of cogeneration systems**

	❖ Investment Cost ❖ Equipment costs ❖ Installation costs ❖ "Soft" (or project) costs
62.	**What are Equipment costs?**
	Equipment costs consist of the cost for purchase of the equipment, including any taxes, and transportation on the site. The most important of those are the following. ❖ Prime mover and generator set. ❖ Heat recovery and rejection system. ❖ Supplementary firing. ❖ Exhaust gas system and stack. ❖ Fuel supply. ❖ Control board. ❖ Interconnection with the electric utility. ❖ Piping. ❖ Ventilation and combustion air systems. ❖ Shipping charges. ❖ Taxes, if applicable.
63.	**What are Installation costs?**
	They consist of: ❖ Installation permits, ❖ Land acquisition and preparation, ❖ Building construction, ❖ Installation of equipment, ❖ Documentation and as-built drawings.
64.	**What are Soft (or project) costs?**
	Design and professional service fees for the analysis, planning and development of a cogeneration system are frequently referred to as soft costs. They may be in the range of 15-30% of the equipment and construction cost. The most significant professional fees and other costs are the following. ❖ Architectural/engineering design fees. ❖ Construction management fees.

- Environmental studies and permitting costs.
- Special consultants and inspectors.
- Legal fees.
- Letters of credit.
- Training.

A contingency or allowance for unforeseen costs (15-20%) is taken into consideration.

65. What are Operation and Maintenance Costs

The major operation and maintenance costs are the following.

a) Fuel Cost (up to 80% of the total operation cost)

b) Personnel Cost:

- Smaller cogeneration systems (up to about 10 MW) can operate unattended.
- Medium-size systems (10-30 MW) will typically require attended operation (one person may be sufficient).
- Larger systems will require attended operation with two or more persons.

c) Maintenance costs:

- Depend on factors such as type of prime mover, type of fuel, operation cycle, and operating environment.
- A variety of maintenance contracts may also be available; if such a contract is signed, it will directly affect the cost.

d) Insurance Cost:

- The cost of insurance varies depending on the type of prime mover, the equipment performance history, and the system design and operating mode.
- It can be in the range of 0.25-2% of the capital cost.

e) Administrative and management fees, taxes, interest on a loan:

Operation and maintenance costs consist of fixed and variable costs. Fixed costs are those which occur no matter whether the system operates or not. Variable costs depend on the operation load and schedule of the system.

66. What are Economic Parameters:

- Interest and interest rate:
  - a) Borrowing interest rate
  - b) Market interest rate
- Economic life-cycle of an investment

	❖ Inflation and inflation rate ❖ Present worth (or present value)
67.	**What is Present worth (or present value)**
	If a principal P is invested at the present time (t = 0), the accumulated amount of principal and interest in the future, after N time periods, will be $$F = P \cdot \prod_{t=1}^{N} (1+d_t)$$ Where d_t is the market interest rate during the period t. ❖ Conversely, the amount of money, which must be invested at the present time in order to have a certain amount accumulated at a definite time in the future, is determined by the equation $$P = \frac{F}{\prod_{t=1}^{N} (1+d_t)}$$ The amount P is called the present worth (or present value) of the future amount F. ❖ If the interest rate d is considered constant throughout all the time periods, then, $$P = \frac{F}{(1+d)^N}$$ Since d is used to discount future amounts to their present worth, it is called also the market discount rate. ❖ The present worth of past cash flow can be determined by the equation $$P = F \cdot \prod_{t=-1}^{-n} (1+d_t)$$ If d_t is considered constant, $$P = F(1+d)^n$$
68.	**What is Present worth factor:**
	If a cash flow (expense or revenue) is repeated in every time period for N periods and it only changes due to inflation, then the present worth of all the N amounts is determined by the equation

$$P = \sum_{t=1}^{N} P_t = A \cdot PWF(N, i, d)$$

where

A- the first amount,

PWF- present worth factor,

i -inflation rate in a time period (e.g. annual inflation rate)

d -market discount rate.

69. What is Capital recovery factor

Let it be considered that a deposit of amount P is made today at an interest rate d. The depositor wishes to withdraw the same amount A at the end of each period so that when the last withdrawal is made, there should be no funds left on deposit. The amount A is determined by the equation

$$A = P \cdot CRF(N, d)$$

where CRF is the capital recovery factor, determined by

$$CRF(N, d) = \frac{d(1+d)^N}{(1+d)^N - 1} = \frac{d}{1-(1+d)^{-N}}$$

70. What is the Net present value of the investment (NPV)

It is called also net present worth. It is the present worth of the total profit of an investment, which results as the difference between the present worth of all expenses and the present worth of all revenues, including savings, during the life cycle of the investment (system).

$$NPV = \sum_{t=0}^{N} \frac{F_t}{(1+d_t)^t}$$

where Ft is the profit or net cash flow (revenue + savings – expenses) in year t.

71. What is Internal rate of return of investment (IRR)

It is called also the rate of return or return on investment (ROI). It is defined as the interest rate that causes the present worth of a series of expenses to be equal to the present worth of a series of revenues.

Alternatively, it is defined as the interest rate that will result in zero NPV.

The internal rate of return of an investment is the market discount rate d which satisfies the equation:

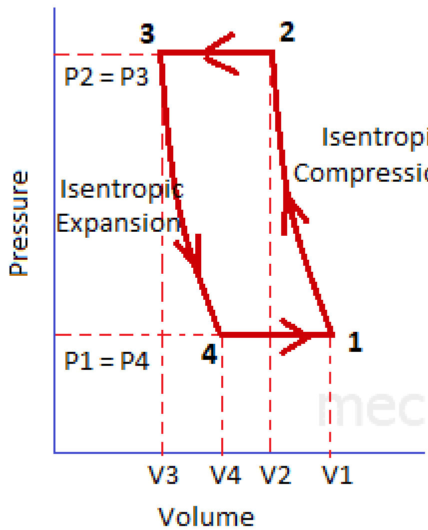
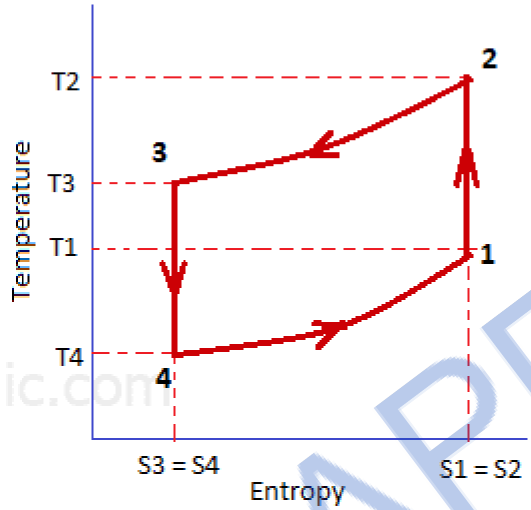
$$NPV = \sum_{t=0}^{N} \frac{F_t}{\left(1+d^*\right)^t} = 0$$

Hence, IRR = d*

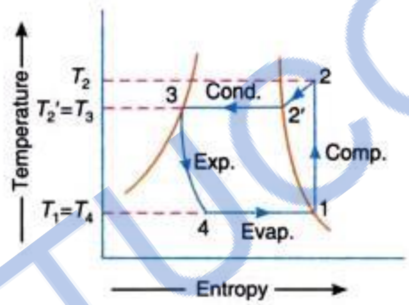
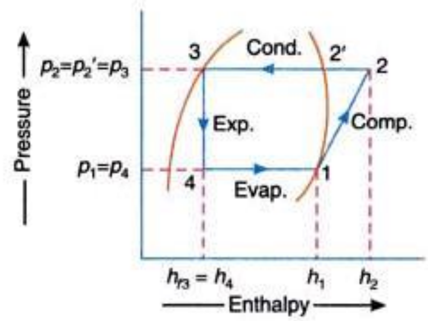
ME8595 - THERMAL ENGINEERING – II

UNIT – V: A: REFRIGERATION

SHORT QUESTIONS AND ANSWERS

1.	**Show the air-refrigeration cycle on p-V and T-s diagram [Anna Univ.Nov'03]**
	(a) P-V Diagram (b) T-S Diagram
2.	**Define refrigeration.**
	Refrigeration is the science of producing and maintaining temperatures below that of the surrounding atmosphere. This means the removing of heat from a substance to be cooled.
3.	**What is the tonnage of refrigeration? [AU, May/June – 2006] (or)** **Explain the unit of Refrigeration. [Anna Univ. Apr'95,Dec'06,May'14] (or)** **Define ton of refrigeration [Anna Univ. May'04 & May'15, May'06 & Nov'10]**
	A tonne of refrigeration is defined as the quantity of heat to be removed from one tonne of water (1000 kg) at 0^0C to convert that into ice at 0^0C in 24 hours. In actual practice 1tonne of refrigeration = 210 kJ/min = 3.5kW.
4.	**What should be the properties of an ideal refrigerant? [AU, May/June – 2006]**
	❖ The refrigerant should have a low boiling point and low freezing point. ❖ 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. ❖ 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. ❖ It must have high critical pressure and temperature to avoid large power requirements.

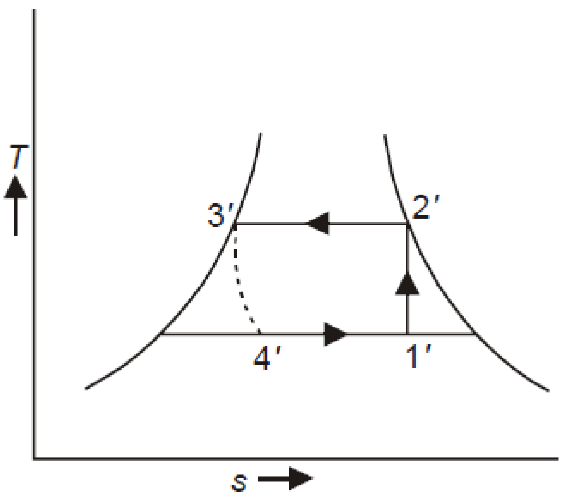
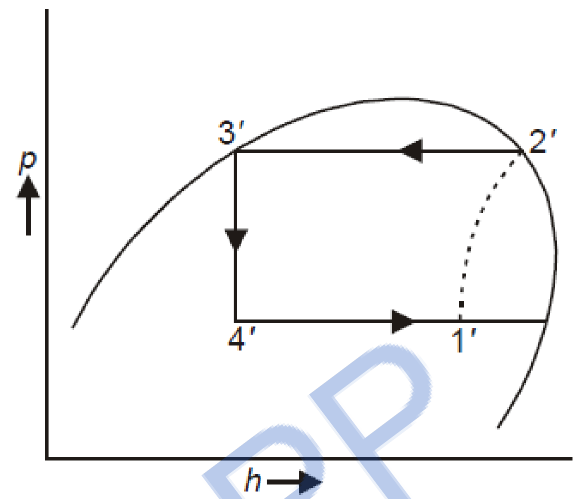
	❖ It should have a low specific volume to reduce the size of the compressor. ❖ It must have high thermal conductivity to reduce the area of heat transfer in evaporator and condenser. ❖ It should be non-flammable, non-explosive, non-toxic and non-corrosive. ❖ It should not have any bad effects on the stored material or food when any leak develops in the system. ❖ It must have high miscibility with lubricating oil and it should not have to react properly with lubricating oil in the temperature range of the system. ❖ It should give a high COP in the working temperature range. This is necessary to reduce the running cost of the system. ❖ It must be readily available and it must be cheap also
5.	**Define COP of a refrigerator. [Anna Univ. Nov'07 & Dec'10]**
	Coefficient of performance (COP) is defined as the ratio of heat absorbed by the evaporator or refrigeration effect to the compressor work. $$COP = \frac{\text{Refrigeration effect}}{\text{Work done}}$$
6.	**A Carnot's refrigerator requires 1.3 KW per tonne of refrigeration to maintain a region at a low temperature of – 38^{0}C. Determine the COP of the refrigerator and the highest temperature of the cycle. [AU, May / June –2007]**
7.	**State the important application of refrigeration**
	❖ Ice making ❖ Transportation of foods above and below freezing ❖ Industrial air-conditioning ❖ Comfort air-conditioning ❖ Chemical and related industries ❖ Medical and surgical aids ❖ Processing food products and beverages ❖ Oil refining and synthetic rubber manufacturing

	❖ Manufacturing and treatment of metals ❖ Freezing food products ❖ Miscellaneous applications : (i) Extremely low temperatures (ii) Plumbing (iii) Building construction etc.
8.	**Define standard commercial tonne of refrigeration”**
	The rating of the refrigeration machine is given by a unit of refrigeration known as “standard commercial tonne of refrigeration” which is defined as the refrigerating effect produced by the melting of 1 tonne of ice from and at 0°C in 24 hours
9.	**Name the components of a simple vapour compression refrigeration system.**
	Basic components of vapour compression refrigeration system are compressor, condenser, refrigerant control (capillary / expansion valve) and evaporator. There can be additional items like suction accumulator, filter drier, receiver, HP/LP Control, thermostat etc. depending on the application
10.	**Draw the P-V and T-S diagram of a vapour compression refrigeration cycle.**
	(a) T-s diagram. (b) p-h diagram.
11.	**Name the components of a vapour absorption refrigeration system.** **Name the various components used in the simple vapour absorption system. [Anna Univ. Apr’96 & Dec’13]**
	1. Absorber 2. Pump 3. Generator 4. Condenser 5. Throttle valve 6. Evaporator
12.	**Name some common refrigerants used in a refrigeration plant**

	Chlorofluorocarbons (CFCs), including R12. This is known to contribute to the greenhouse gas effect. Production of new stocks ceased in 1994. **Hydrochlorofluorocarbons (HCFCs), including R22.** Slightly less damaging to the ozone than R12, but the EPA has still mandated a phase-out as a result of the Clean Air Act of 2010. R22 will phase out completely by 2020. **Hydrofluorocarbons (HFCs), including R410A and R134.** With no chlorine in the mix, this is safer for the environment and is now being used in place of R22. Air conditioners that run on R410A are more efficient, offer better air quality, increase comfort and improve reliability.
13.	**Name any four commercial halocarbon- refrigerants? [AU, Nov / Dec – 2009]**
	❖ R-10 — Carbon tetrachloride (CCl_4) ❖ R-11 — Trichloro-monofluoro methane (CCl_3F) ❖ R-12 — Dichloro-difluoro methane (CCl_2F_2) ❖ R-13 — Mono-bromotrifluoro methane ($CBrF_3$) ❖ R-21 — Dichloro monofluoro methane ($CHCl_2F$) ❖ R-22 — Mono chloro difluoro methane ($CHClF_2$) ❖ R-30 — Methylene-chloride (CH_2Cl_2) ❖ R-40 — Methyle chloride (CH_3Cl) ❖ R-41 — Methyle fluoride (CH_3F) ❖ R-100— Ethyl chloride (C_2H_5Cl) ❖ R-113— Trichloro trifluoroethane ($C_2F_3Cl_3$) ❖ R-114— Tetra-fluoro dichloroethane ($Cl_2F_4Cl_2$) ❖ R-152— Difluoro-ethane ($C_2H_6F_2$)
14.	**Merits and Demerits of Air refrigeration System**
	Merits: ❖ Since air is non-flammable, therefore there is no risk of fire as in the machine using NH3 as the refrigerant. ❖ It is cheaper as air is easily available as compared to the other refrigerants. ❖ As compared to the other refrigeration systems the weight of air refrigeration system per tonne of refrigeration is quite low, because of this reason this system is employed in aircrafts. **Demerits:** ❖ The C.O.P. of this system is very low in comparison to other systems.

	❖ The weight of air required to be circulated is more compared with refrigerants used in other systems. This is due to the fact that heat is carried by air in the form of sensible heat.
15.	**What are the Effect of suction temperature and condenser temperature.**
	The performance of the vapour compression refrigerating cycle varies considerably with both vapourising and condensing temperatures. Of the two, the vapourising temperature has far the greater effect. It is seen that the capacity and performance of the refrigerating system improve as the vapourising temperature increases and the condensing temperature decreases. Thus refrigerating system should always be designed to operate at the highest possible vapourising temperature and lowest possible condensing temperature, of course, keeping in view the requirements of the application.
16.	**What are the effects of undercooling? [AU, Nov/Dec- 2004]**
	Sub-cooling' is the process of cooling the liquid refrigerant below the condensing temperature for a given pressure. The sub-cooling or undercooling may be done by any of the following methods : ❖ Inserting a special coil between the condenser and the expansion valve. ❖ Circulating greater quantity of cooling water through the condenser. ❖ Using water cooler than main circulating water.
17.	**What are the effects of superheating? [AU, Nov/Dec- 2002]**
	The effect of superheating is to increase the refrigerating effect but this increase in refrigerating effect is at the cost of increase in amount of work spent to attain the upper pressure limit. Since the increase in work is more as compared to increase in refrigerating effect, therefore overall effect of superheating is to give a low value of C.O.P.
18.	**Name the Hydrocarbon refrigerants used in refrigeration system**
	❖ R–50 Methane CH_4 ❖ R–170 Ethane C_2H_6 ❖ R–290 Propane C_3H_8
19.	**Name the Unsaturated organic compounds used in refrigeration system**
	❖ R–1120 Trichloro ethylene $C_2H_4Cl_3$ ❖ R–1130 Dichloro ethylene $C_2H_4Cl_2$ ❖ R–1150 Ethylene C_2H_4 ❖ R–1270 Propylene C_3H_6

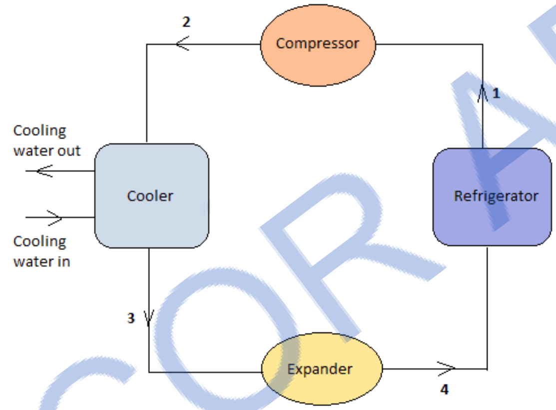
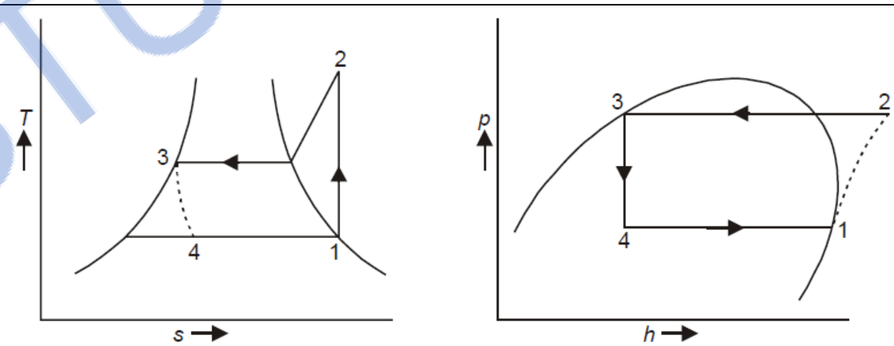
20.	**Heat is removed from space at a rate of 42.000 kJ/h. Express this heat removal rate in tons. [Anna Univ. May'05]**
21.	**A Carnot refrigerator requires 1.3 kW per tonne of refrigeration to maintain a region at a low temperature of -38^{0}C. Determine the** **i) COP of the refrigerator** **ii) the higher temperature of the cycle.** **iii) The heat delivered and C.O.P. when this device is used as a heat pump. [Anna Univ. May'07]**
22.	**Give COP of a simple cycle**
	$COP = \frac{\text{Refrigeration effect}}{\text{Work done}} = \frac{h_1 - h_2}{h_2 - h_1}$

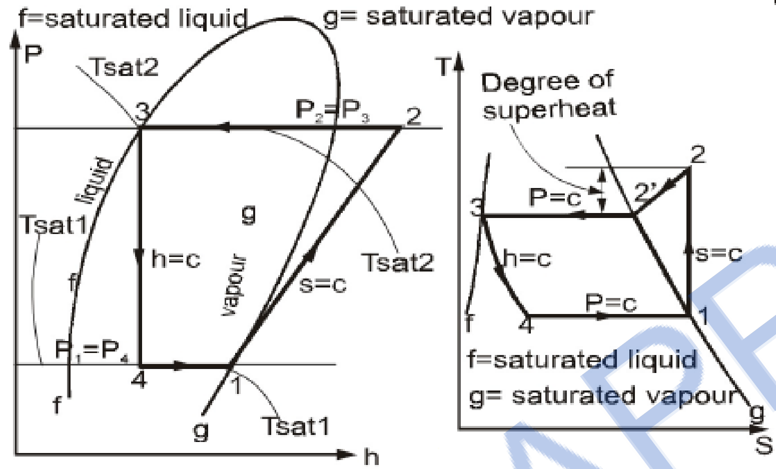
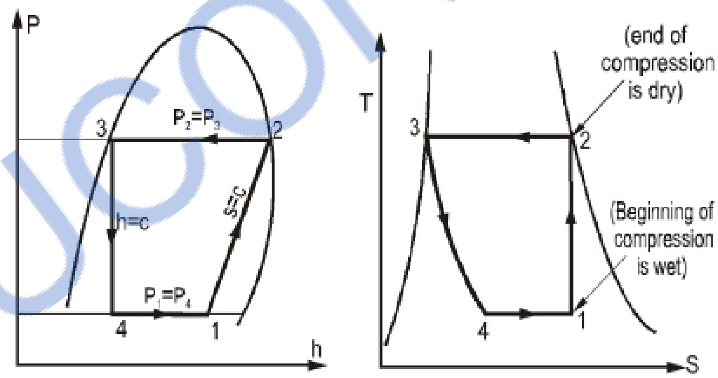
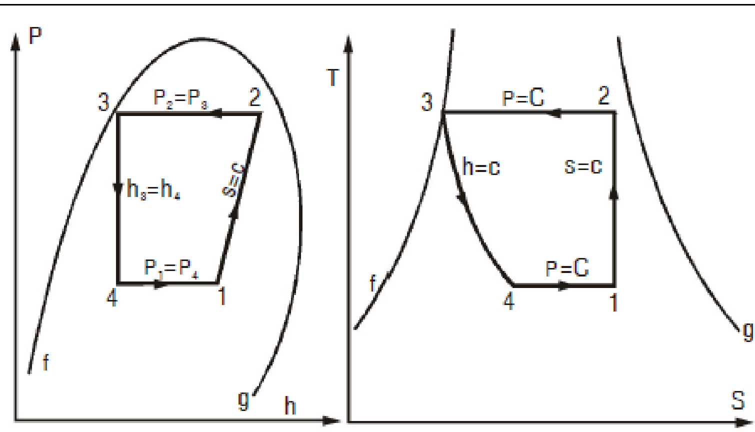
23.	**Sketch the T-s and p-h diagrams for the vapour compression cycle when the vapour after compression is dry saturated. [Anna Univ. Dec'11 & May'16]**
	
24.	**How does the actual vapour compression cycle differ from that of the ideal cycle? [Anna Univ.Apr'05]**
	❖ In actual cycles, pressure losses occur in both condenser and evaporator. ❖ Friction losses occur in the compressor.
25.	**Name important properties of a good refrigerant. [MU-Apr'99, Apr'95 & Oct'97]**
	❖ Low boiling point. ❖ High critical temperature and pressure ❖ Low specific heat of the liquid.
26.	**What is the function of the throttling valve in the vapour compression refrigeration system? [MU. Oct'99]**
	The function of the throttling valve (Expansion valve) is to allow the liquid refrigerant under high pressure and temperature to pass at a controlled rate after reducing its pressure and temperature.
27.	**Name any four commonly used refrigerants. [MU-Oct'00]**
	❖ Ammonia ❖ Carbon dioxide (CO_2) ❖ Sulphur dioxide (SO_2) ❖ Freon – 12
28.	**What are the expansion devices used in a vapour compression plant? When are they used? [Anna Univ. Dec'12]**

	Two widely used expansion devices in a vapour compression plan are: ❖ Throttling valve ❖ Capillary tubes. Capillary tubes are used for small plants. In these tubes, once the length and size are fixed, no modification in operation can be made since the evaporative pressure is fixed. Throttling valves are used in larger plants because they regulate the flow of the refrigerant according to the load on the evaporator.
29.	**Why throttle valve is used in place of expansion cylinder for vapour compression refrigerant machine. [Oct'95]**
	In the throttling process, enthalpy remains constant and pressure is reduced. So, a throttle valve is used.
30.	**What is the effect of superheating and subcooling on the vapour compression cycle? [Anna Univ. May'03]**
	Superheating increases the refrigeration effect and COP may be increased or decreased but subcooling always increases the COP of refrigeration and also decrease the mass flow rate of refrigerant.
31.	**What are the properties of good refrigerant? [Anna Univ. may'03, Oct'02, may'06, Dec'13 & May'14]**
	❖ The refrigerant should have a low freezing point. ❖ It must have high critical pressure and temperature to avoid large power requirements. ❖ It should have the low-specific volume to reduce the size of the compressor. ❖ It should be nonflammable, non-explosive, non-toxic and non-corrosive. ❖ It should give a high COP in the working temperature range. It is necessary to reduce the running cost of the system. ❖ It must have low specific heat and high latent heat. ❖ It should be of low cost.
32.	**What are the advantages and disadvantages of air refrigeration system? [Anna Univ. May'03& Dec'04]**
	Advantages: ❖ The refrigerant used namely air is cheap and easily available. ❖ There is no danger of fire or toxic effects due to leakages. ❖ The weight to a tonne of refrigeration ratio is less as compared to other systems. **Disadvantages:**

	❖ The quantity of refrigerant used per tonne of refrigeration is high as compared to other systems. ❖ The COP of the system is very low. Therefore, the running cost is high. ❖ The danger of frosting at the expander valves is more as the air contains moisture content.
33.	**What is meant by subcooling in vapour compression system? [Anna. Dec'04 & may '12]**
	The process of cooling the liquid refrigerant below its saturation temperature in the condenser is known as subcooling.
34.	**What are the methods to obtain subcooling of refrigerant? [Anna Univ. May'11]**
	❖ Suction-liquid heat exchanger ❖ Two stage reciprocating and centrifugal compressors with an economizer.
35.	**What is the net refrigeration effect of the refrigerant? [Apr'97]**
	COP = $\frac{\text{Refrigeration effect}}{\text{Work done}}$ Refrigerant effect =COP x work done
36.	**Define refrigerant [Oct'96]**
	Any substance capable of absorbing heat from another required substance can be used as a refrigerant.
37.	**What is the function of analyzer and rectifier in an absorption system?**
	Analyser prevents water vapours from entering the condenser. It helps in preventing the choking of pipelines. Even after passing through the analyzer if any water vapours present that will be removed in the rectifier.
38.	**What is the purpose of generator assembly in a vapour absorption refrigeration system? [Anna Univ. Nov'10]**
	The function of the generator is to heat the strong solution to form vapour of the refrigerant.
39.	**State the substances used in the Lithium Bromide system and their functions.**
	❖ Lithium bromide which acts as an absorbent ❖ Water acts as a refrigerant.
40.	**What is the difference between wet compression and dry compression? [Anna Univ. Apr'08, May'11 & May'12]**
	In wet compression, the compression starts between saturated liquid and saturated vapour region. The vapour enters the compressor at wet vapour conditions.

	In dry compression, the compression starts with saturated vapour. The vapour enters the compressor at dry vapour conditions.
41.	**Write the advantages and disadvantages of the vapour absorption system. [Anna Univ.Dec'12]**
	Advantages: ❖ There is no need for atomic power. ❖ Wear and tear are less. ❖ Tonne of capacity is high. ❖ There is no leakage of refrigerant. ❖ Heat energy is supplied. ❖ Space requirement is less. ❖ The energy requirement is high. **Disadvantage:** ❖ Charging of refrigerant is difficult.
42.	**State the condition of the refrigerant at the end of compression in the vapour compression system. [Oct'96]**
	Superheat vapour
43.	**What types of condensers are in commonly used for vapour absorption refrigeration system? [Oct'96]**
	Water-cooled condensers.
44.	**Define Volumetric efficiency, clearance volumetric efficiency and total volumetric efficiency**
	Volumetric efficiency is defined as the ratio of actual volume of gas drawn into the compressor (at evaporator temperature and pressure) on each stroke to the piston displacement. If the effect of clearance alone is considered, the resulting expression may be termed clearance volumetric efficiency. The expression used for grouping into one constant all the factors affecting efficiency may be termed total volumetric efficiency.
45.	**Define Clearance volume**
	Clearance volume is the volume of space between the end of the cylinder and the piston when the latter is in dead centre position.
46.	**Define Refrigerating effect.**
	Refrigerating effect is the amount of heat absorbed by the refrigerant in its travel through the evaporator.

47.	**Define Mass of refrigerant.**
	Mass of refrigerant circulated (per second per tonne of refrigeration) may be calculated by dividing the amount of heat by the refrigerating effect.
48.	**Define Theoretical piston displacement.**
	Theoretical piston displacement (per tonne of refrigeration per minute) may be found by multiplying the mass of refrigerant to be circulated (per tonne of refrigeration per sec.) by the specific volume of the refrigerant gas, $(vg)2$, at its entrance of compressor.
49.	**Define Power (Theoretical) required.**
	Theoretical power per tonne of refrigeration is the power, theoretically required to compress the refrigerant.
50.	**Draw Schematic diagram of Bell Coleman cycle based refrigeration system**
	
51.	**Sketch the T-s and p-h diagrams for the vapour compression cycle when the vapour after compression is superheated.**
	
52.	**Name Inorganic compound refrigerants**
	❖ R–717 Ammonia NH_3 ❖ R–718 Water H_2O ❖ R–729 Air ❖ R–744 Carbondioxide CO_2 ❖ R–764 Sulfurdioxide SO_2

<table>
<tr><td>53.</td><td>Unit of Refrigeration: (Ton of Refrigeration)</td></tr>
<tr><td></td><td>One ton of refrigeration is defined as heat removed from 1000 kg of water at 0°C to make (1000 kg) 1 ton of ice at 0°C within 24 hours.</td></tr>
<tr><td>54.</td><td>Sketch the T-s and p-h diagrams for the vapour compression cycle when the Beginning of compression is dry and end of compression is super heated</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td>55.</td><td>Sketch the T-s and p-h diagrams for the vapour compression cycle when the End of compression is dry and Beginning of compression is wet</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td>56.</td><td>Sketch the T-s and p-h diagrams for the vapour compression cycle when the End of compression is wet and Beginning of compression is also wet.</td></tr>
<tr><td></td><td>
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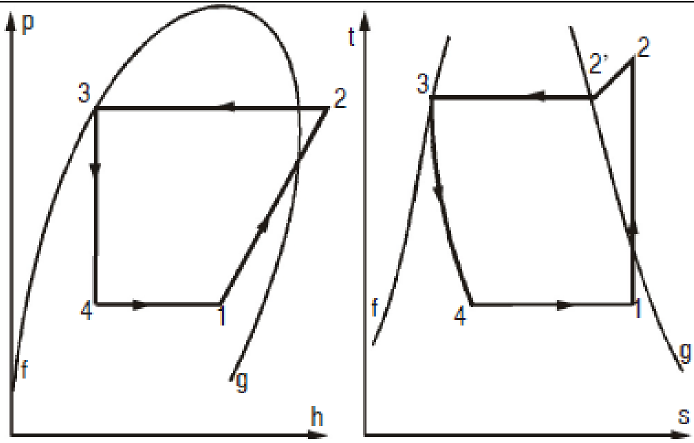
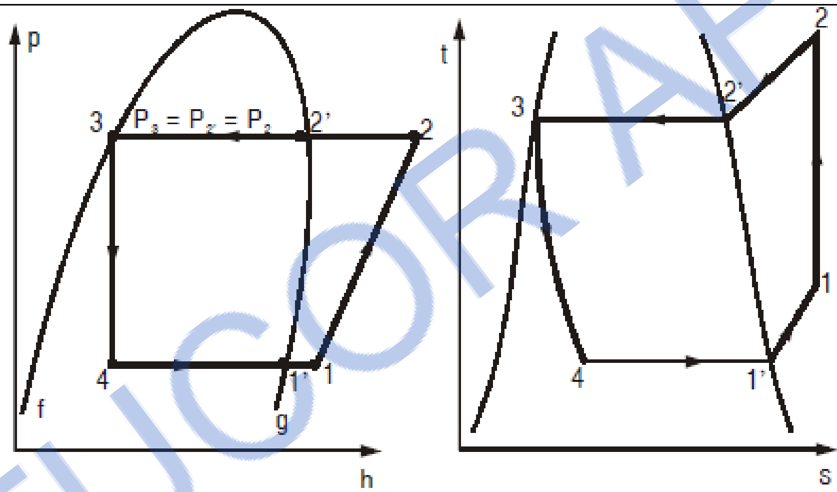
57.	**Sketch the T-s and p-h diagrams for the vapour compression cycle when the Beginning of compression is wet; End is superheated.**
	
58.	**Sketch the T-s and p-h diagrams for the vapour compression cycle when the Beginning of compression is superheated; [Also end of compression is superheated]**
	

UNIT – V: B: PSYCHROMETRY

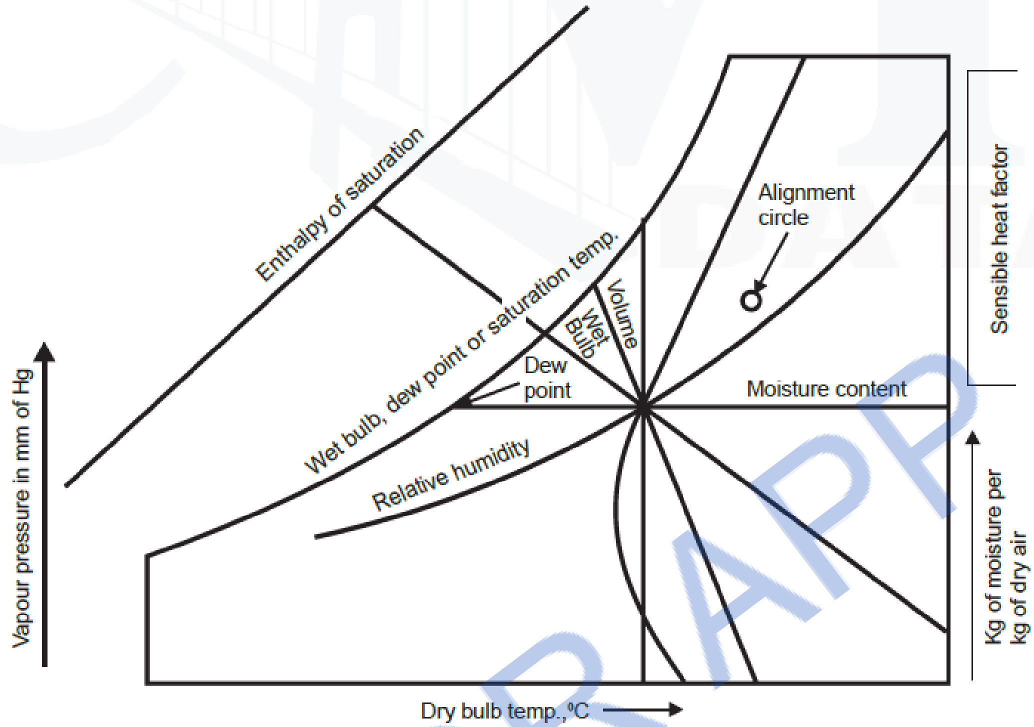
SHORT QUESTIONS AND ANSWERS

1.	**Define psychrometry.**
	The art of measuring the moisture content of air is termed "psychrometry".
2.	**Define psychrometrics**
	The science which investigates the thermal properties of moist air, considers the measurement and control of the moisture content of air, and studies the effect of atmospheric moisture on material and human comfort may properly be termed "psychrometrics''.
3.	**What is humidification and dehumidification?** [AU, April/May- 2005]
	The addition of water vapour into the air is humidification and the removal of water vapour from the air is dehumidification.
4.	**Define Dry air.**
	The term 'dry air' is used to indicate the water free contents of air having any degree of moisture. The pure dry air is a mixture of a 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.
5.	**What is meant by 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.
6.	**Define 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. The water vapours, usually, occur in the form of superheated steam as an invisible gas. However, when the saturated air is cooled, the water vapour in the air starts condensing, and the same may be visible in the form of moist, fog or condensation on cold surfaces.
7.	**What is meant by dry bulb temperature (DBT)?**
	The temperature recorded by the thermometer with a dry bulb. The dry bulb thermometer cannot affect by the moisture present in the air. It is the measure of the sensible heat of the air. It is denoted by t_d.
8.	**What is meant by wet bulb temperature (WBT)?** [Anna Univ.Dec'06 & Nov'07]
	It is the temperature recorded by a thermometer whose bulb is covered with a wet cotton wick and it is exposed to a current rapidly moving air. The wet bulb temperature may be the measure

	of enthalpy of air. WBT is the lowest temperature recorded by the moistened bulb. It is denoted by tw.
9.	**What is meant by adiabatic saturation temperature (or) thermodynamic wet bulb temperature?**
	It is the temperature at which the water or ice can saturate air by evaporating adiabatically due to the latent heat of vaporization.
10.	**Define 'Wet bulb depression'.** [AU, May / June – 2009]
	Wet bulb depression is the difference between dry bulb temperature and wet bulb temperature. WBD = DBT – WBT The value of wet bulb depression is zero when the air becomes saturated.
11.	**What is dew point temperature?** [AU, April 2004, May 2005, May'07,Dec'08, & Dev'10]
	It is the temperature to which air must be cooled at constant pressure in order to cause condensation of any of its water vapour. 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. For saturated air, the dry bulb, wet bulb and dew point temperature are all same.
12.	**What is meant by Dew point depression?**
	It is the difference between the dry bulb temperature and dew point temperature of air.
13.	**Define specific humidity or Humidity ratio** [Anna Univ. Dec'06]
	It is defined as the ratio of the mass of water vapour (mv) in a given volume to the mass of dry air in a given volume (ma). $\omega = mv / ma.$ It is the mass of water vapour present in 1 kg of dry air, and is generally expressed in terms of kg per kg of dry air (kg / kg of dry air).
14.	**Define Absolute humidity**:
	It is the mass of water vapour present in 1 m3 of dry air, and is generally expressed in terms of kg per cubic-meter of dry air (kg/m3 of dry air). It is also expressed in terms of grains per cubic meter of dry air.
15.	**Define relative humidity** [Anna Univ. Dec'06]
	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 the mixture. Relative humidity is expressed as a percentage. RH is the ratio of the mass of water vapour (mv) in a certain volume of moist air at Given

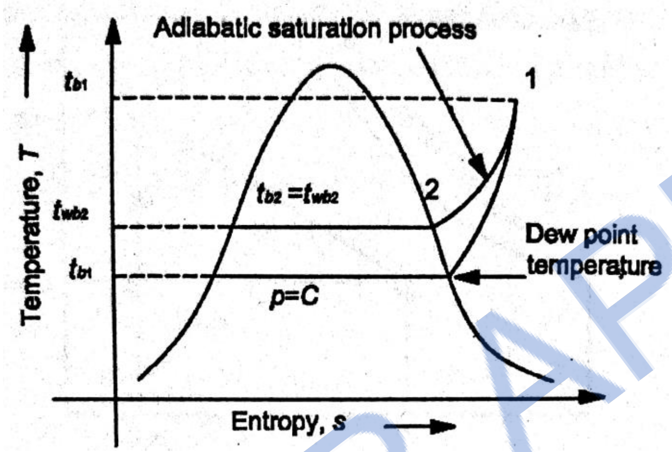
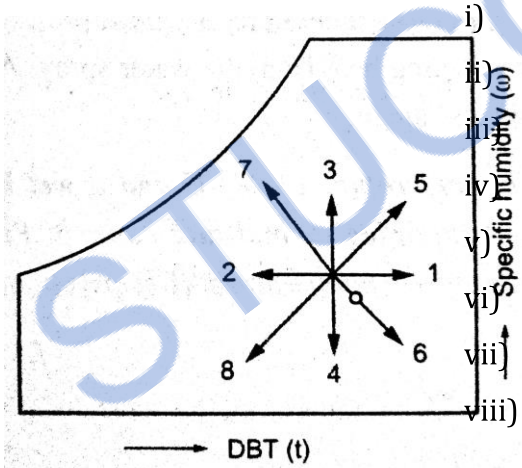
	temperature to the mass of water vapour in the same volume of saturated air at the Same temperature. i.e. RH (or) $\phi = \frac{m_v}{m_{vs}}$
16.	**Define Sensible heat.**
	It is the heat that changes the temperature of a substance when added to or abstracted from it.
17.	**Define Latent heat.**
	It is the heat that does not affect the temperature but changes the state of substance when added to or abstracted from it.
18.	**Define Enthalpy.**
	It is the combination energy which represents the sum of internal and flow energy in a steady flow process. It is determined from an arbitrary datum point for the air mixture and is expressed as kJ per kg of dry air (h).
19.	**Define Dalton's law of partial pressure.**
	The total pressure of a mixture of gases is equal to the sum of partial pressures which the component gases would exert if each existed alone in the mixture volume at the mixture temperature. $$Pb=Pa+Pv$$ Where, p_b = barometric pressure. P_a = partial pressure of dry air. P_v = partial pressure of water vapour
20.	**Define Specific Volume of Humid Air.**
	Specific Volume represents the space occupied by a unit weight of dry air (m^3/kg). Specific volume is indicated along the bottom axis of the psychrometric chart with the constant-volume lines slanting upward to the left.
21.	**Define degree of saturation(or) percentage humidity (or) saturation ratio** [Anna Univ.Dec'06 & Nov'07]
	It is defined as the ratio of specific humidity of the most air to the specific humidity of saturated air at the same temperature. Degree of saturation (μ)= $\frac{\text{Specific humidity of moist air}}{\text{Specific humidity of saturated air}}$

22.	**Define Moisture Content**
	The moisture content of air is expressed as the weight of water vapor per unit weight of dry air.
23.	**Explain adiabatic humidification of air.** [Anna Univ.Dec'08]
	The air is passed through an insulated chamber. This insulating chamber has sprays ij which water is maintained at a temperature higher than the dew point temperature of entering air but lower than its dry bulb temperature. So, both cooling and humidification are done without supplying or rejecting heat from the water spray. At the same time, the same water is recirculated again and again.
24.	**What is psychrometer?**
	A psychrometer is a device which is used for measuring dry bulb and wet bulb temperatures simultaneously.
25.	**What is psychrometric chart?**
	It is the graphical plot with specific humidity and partial pressure of water vapour in y-axis and dry bulb temperature along x-axis. The specific volume of the mixture, wet bulb temperature, relative humidity and enthalpy are the properties appeared in the psychrometric chart.
26.	**Define psychrometric processes**
	The processes affecting the psychrometric properties of air are called psychrometric processes.
27.	**What is meant by 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 happens in air conditioning system.
28.	**Name some important psychrometric process.**
	❖ Sensible heating ❖ Sensible cooling ❖ Humidifying ❖ Dehumidifying ❖ Heating and humidifying ❖ Heating and dehumidifying ❖ Cooling humidifying ❖ Cooling dehumidifying ❖ Adiabatic evaporative cooling.
29.	**What are the assumptions made while mixing two air streams?**
	Surrounding is small. Process is fully adiabatic.

	There is no work interaction Change in kinetic and potential energies are negligible
30.	**On a Psychrometric chart, show all the property lines.**
	
31.	**What is sensible heating or cooling?** [Anna Univ. Dec'12]
	Sensible heating: Air is heated at constant specific humidity. It means, heating is done without adding moisture. During heat addition, the dry bulb temperature increases from t_{d_1} to t_{d_2} . So, $\omega_+ = \omega_2$ but $t_{d_2} > t_{d_1}$. **Sensible cooling:** In sensible cooling process, refrigerant is sent inside the coil instead of steam to cool the air. During this process, the dry bulb temperature reduces from t_{d_1} to t_{d_2} . So, the heat present in the air is extracted by refrigerant. But, there is no additional of moisture in the air. So, $t_{d_1} > t_{d_2}$. And $\omega_1 = \omega_2$.
32.	**Define bypass factor (BPF) of a coil**
	The by-pass factor (BPF) for the process is defined as the ratio of the difference between the mean surface temperature of the coil and leaving air temperature to the difference between the mean surface temperature and the entering air temperature. ie. $\text{BPF} = \dfrac{\text{Amount of air bypassing the coil}}{\text{Total amount of air passed}}$

33.	**Define the humidification process.**
	Humidification is defined as the process of adding moisture at constant dry bulb temperature.
34.	**What is humidification and dehumidification?**
	The addition of water vapour into air is humidification and the removal of water vapour from air is dehumidification.
35.	**Define Cooling and Dehumidification.**
	Whenever air is made to pass over a surface or through a spray of water that is at a temperature less than the dew point temperature of the air, condensation of some of the water vapour in air will occur simultaneously with the sensible cooling process.
36.	**Define the term "Apparatus dew point?** [Anna Univ. May'11]
	For dehumidification, the cooling is to be kept at a mean temperature which is below the dew point temperature (DPT) of the entering. This temperature of the coil is called ADP temperature.
37.	**Define adiabatic saturation or evaporative cooling**
	If unsaturated air is passed through a spray of continuously recirculated water, the specific humidity will increase while the dry bulb temperature decreases. This is the process of adiabatic saturation or evaporative cooling.
38.	**Define saturating' or 'humidifying efficiency'**
	The 'saturating' or 'humidifying efficiency' is defined as the ratio of dry-bulb temperature decrease to the entering wet bulb depression usually expressed as percentage.
39.	**Define Heating and Dehumidification.**
	If air is passed over a solid absorbent surface or through a liquid absorbent spray simultaneous heating and dehumidification is accompanied.
40.	**Define Heating and Humidification.**
	If air is passed through a humidifier which has heated water sprays instead of simply recirculated spray, the air is humidified and may be heated, cooled or unchanged in temperature
41.	**What factors affect bypass factor?**
	➢ Pitch of fins. ➢ Number of coil tubes. ➢ Air velocity over the coil ➢ Direction of air flow.

42.	**State the effects of very high and a very low bypass factor.**
	Very high bypass factor: ➢ It requires lower ADP, Refrigerant plant should be of larger capacity ➢ It requires more air. Larger fan and motor are required. ➢ It requires less heat transfer area. ➢ It requires more chilling water. Larger piping is required. **Very low by pass factor:** ➢ Higher ADP is to be employed. ➢ It requires less air. Fan size and motor size are reduced.
43.	**Define RSHF.**
	Room sensible heat factor is defined as the ratio of room sensible heat load to the room total heat load.
44.	**Differentiate between absolute humidity and relative humidity.** [AU, Nov/Dec- 2004]
	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.
45.	**What is the difference between air conditioning and refrigeration?**
	❖ Refrigeration is the process of providing and maintaining the temperature in space below atmospheric temperature. ❖ Air conditioning is the process of supplying sufficient volume of clean air containing a specific amount of water vapour and maintaining the predetermined atmospheric condition with in a selected enclosure.
46.	**What is effective temperature?**
	The effective temperature is a measure of feeling warmth or cold to the human body in response to the air temperature, moisture content and air motion. If the air at different DBT and RH condition carries the same amount of heat as the heat carried by air at temperature T and 100% RH, then the temperature T is known as effective temperature.
47.	**Define sensible heat factor (or) sensible heat ratio.**
	The Sensible Heat Ratio (SHR) is used to describe the ratio of sensible heat load to total heat load and can be expressed as:

	SHR = SH / TH = SH / (SH+ LH) Where, SH = sensible heat load TH = total heat load - sensible heat and latent heat LH = latent heat load
48.	**Show the dew point and adiabatic saturation process on a T.S diagram.** *[AU, Nov/Dec-2004]*
	
49.	**Represent the following psychrometric process using skeleton psychrometric chart.** [AU, Nov/Dec- 2004]
	 i) Sensible heating (0 – 1) ii) Sensible cooling (0 – 2) iii) Humidifying (0 – 3) iv) Dehumidifying (0 – 4) v) Heating and humidifying (0 – 5) vi) Heating and dehumidifying (0 – 6) vii) Cooling humidifying (0 -7) viii) Cooling dehumidifying (0 – 8)
50.	**Atmospheric air with dry bulb temperature of 28⁰C and a wet bulb temperature of 17⁰C is cooled to 15⁰C without changing its moisture content. Find (a) original and final relative humidity (b) final wet bulb temperature. (Use psychometric chart).** [Anna Univ. Dec'11]
	Given data: Dry bulb temperature, t_{d_1} = 28^0C Wet bulb temperature, t_{w_1} = 17^0C

	Dry bulb temperature, t_{d_2} = 15^0C **Solution:** Corresponding to Dry bulb temperature, t_{d_1} = 28^0C and wet bulb temperature, t_{w_1} = 17^0C in Psychrometric chart. The original relative humidity, ϕ_1 = 34% The final relative humidity, ϕ_2 = 72.5% The final wet bulb temperature, t_{w_2} = 13.2^0C

UNIT – V: C: AIR CONDITIONING

SHORT QUESTIONS AND ANSWERS

1.	**How does humidity affect human comfort? [AU, Nov/Dec-2003,2005]** **How does humidity affect human comfort? [Anna Univ. Apr'03 & Nov'15]**
	If the humidity is above a certain level, water vapour from human body moisture cannot be absorbed by the atmospheric air. It results in discomfort because of sweating.
2.	**What do you mean by the infiltration in heat loaded calculation? [AU, Nov/Dec-2003, 2005]**
	In an air conditioning system, the heat that is coming into the system by the door opening cracks in buildings, cracks abd gaps in the windows are known as infiltration.
3.	**Define RSHF and RTH. [Anna Univ, Apr'03, Apr'08 & May'14]**
	RSHF (Room Sensible Heat Factor) is the ratio of Room Sensible Heat (RSH) to the Room Total Heat (RTH) ie., $RSHF = \frac{RSH}{RTH} = \frac{RSH}{RSH + RLH}$ RTH (Room Total Heat) is the sum of Room Sensible Heat and Room latent Heat. i.e. $RTH = RSH + RLH$
4.	**Define the term GSHF (Gross or Grand Sensible Heat factor) [AU, Apr'08 & May'15]**
	GSHF (Gross or Grand Sensible Heat factor) is the ratio of total sensible heat (TSH) to the grand total heat (GTH). ie., $GSHF = \frac{TSH}{GTH} = \frac{TSH}{TLH + TSH}$
5.	**Which thermodynamic cycle is used in air conditioning of airplanes using air as a refrigerant? [AU, May / June – 2009]**
	Reversed Brayton cycle
6.	**What are the components used in winter air conditioning system?[AU, Nov / Dec – 2009]**
	❖ Damper ❖ Filter ❖ Preheater ❖ Humidifier ❖ Reheat coil

	❖ Fan
7.	**Which thermodynamic cycle is used in air conditioning of air planes using air as refrigerant? [Anna Univ.June'09]**
	Air cycle refrigeration with reverse Brayton cycle (Gas turbine cycle) is mainly used as an air-conditioning system in airplanes due to the reason of readily available compressed air.
8.	**Distinguish summer and winter air conditioning [Anna Univ. Nov'15]**

Summer air conditioning	Winter air conditioning
Heat is removed from the air by humidification process.	Heat is added to the air by dehumidification process.
Dry space will be cooler than humid space at the same temperature.	Humid space will be cooler than dry space at the same temperature.
Moisture will evaporate quickly from skin.	Moisture will not evaporate on skin.

9.	**What is meant by refrigeration and air conditioning? [Anna Univ. Nov'10]**
	Refrigeration is the process of providing and maintaining the temperature in space below atmospheric temperature. Air conditioning is the process of supplying sufficient volume of clean air containing a specific amount of water vapour and maintaining the predetermined atmospheric condition with a selected enclosure.
10.	**List out the basic elements of an air conditioning system [Anna Univ May'16]**
	❖ Compressor ❖ Condenser coil ❖ Fan ❖ Evaporator coil ❖ Air handling unit ❖ Air filters ❖ Drainage system and pan
11.	**How are air-conditioning systems classified?**

	I. Based on construction of components: ❖ Unitary system ❖ Central system ❖ Package system ❖ Split units. II. Based on fluid flow methods: ❖ Direct expansion (DX) system ❖ Chilled water (DX) system ❖ Chilled water air washer system.
12.	**What are the various sources of heat gain of an air-conditioned space?**
	❖ Solar gain through glass planes. ❖ Solar gain through roof and walls. ❖ Heat gain from occupants. ❖ Heat gain from appliances and lights ❖ Duct leakage. ❖ Infiltration ❖ Vapour transmission.
13.	**Define the term Effective sensible heat factor (ESHF) [Anna Univ, Apr'08 & May'15]**
	Effective sensible heat factor (ESHF) is the ratio of effective room sensible heat to the effective room total heat. ie. ESHF = ERSH / RTH
14.	**What are the requirements of comfort A/C?**
	❖ Supply of O_2 and removal of CO_2. ❖ Removal of heat of occupants. ❖ Removal of moisture of occupants ❖ Good air distribution ❖ Maintaining air purity.
15.	**Define effective temperature (ET)**
	Effective temperature is defined as that temperature of saturated air at which the subject would experience the same feeling of comfort as experienced in the actual unsaturated environment.
16.	**What factors affect effective temperature?**

	❖ Climatic and seasonal differences ❖ Clothing ❖ Age and sex ❖ Activity ❖ Stay duration ❖ Air velocity
17.	**What are the general comfort conditions during summer and winter?**
	Summer: Inside temperature $24^0 \pm 1^0C$ RH 50 – 60% Air movements 4.5 – 7.5 m/min **Winter:** Inside temperature $20^0 \pm 1^0C$ RH 35 – 40% RH
18.	**Enumerate the components of cooling load estimate. [Anna Univ. May'11 & May'12]**
	a) Heat flow through the exteriors walls, ceilings, floors, doors and windows. b) Heat by solar radiation. c) Heat received from the occupants. Heat received by infiltrated air etc., adds to the amount of heat into the room and hence, it may be considered as a 'load'. The a/c system should be capable of handling this heat load. In this context, the heat load estimation is assumed as important one and it has to be accurately arrived at.
19.	**What is Air Conditioner?**
	Air Conditioner continuously draws the air from the space to be cooled & cools it by the principle of refrigeration and discharge it back to the same indoor space that need to be cooled.
20.	**What is Sensible Heat Ratio (SHR)?**
	The Sensible Heat Ratio (SHR) expresses the ratio between the sensible heat load and the total heat load.
21.	**Explain the classification of Air Conditioning Systems**

	The air conditioning system may be broadly classified as follows: 1. According to the purpose a) Comfort air conditioning system. b) Industrial air conditioning system. 2. According to a season of the year a) Winter air conditioning system. b) Summer air conditioning system. Year-round air conditioning system. 3. According to the arrangement of equipment a) The unitary air conditioning system b) Central air conditioning system.
22.	**Explain Comfort Air Conditioning system**
	In comfort air conditioning, the air is brought to the required dry bulb temperature and relative humidity for human health, comfort and efficiency. If sufficient data of the required is not available, then it is assumed to be 21°C dry bulb temperature and 50% relative humidity. Ex. In homes, offices, shops, restaurants, theatres, hospitals, schools etc. are using air-conditioning systems to give comfort to people.
23.	**Explain Industrial Air Conditioning System**
	In the industrial air conditioning system, the inside dry bulb temperature and relative humidity of the air is kept constant for working of the machine and for the manufacturing process. Textile mills, Paper mills, Machine part manufacturing plants, Tool room, Photographic etc. are using this type of air-conditioning systems.
24.	**Explain Unitary Air Conditioning System**
	In unitary air conditioning system, the assembled air conditioner is installed in or adjacent to the space to be conditioned. Unitary systems, the common type of one room conditioners, sit in a window or wall opening, with interior controls. ❖ Interior air is cooled as a fan blows it over the evaporator. ❖ The exterior air is heated as a second fan blows it over the conditioner. ❖ In this process, heat is supplied from the room and discharge to the

	environment. ❖ A large house or building may have several such units, permitting each room to be cooled separately.
25.	**List the types of unitary air conditioning system**
	❖ Window unit unitary air conditioning system ❖ Vertical packed units or PTAC systems unitary air conditioning system
26.	**Explain Window Unit unitary air conditioning system**
	This type of conditioners has a small capacity of 1TR to 3TR and is mentioned through a window or wall. They are employed to condition the air of one room only. If the room is bigger in size, then two or more units are used.
27.	**Explain Vertical Packed Units or PTAC systems unitary air conditioning system**
	❖ This type of air conditioner is bigger in the capacity of 5 to 20TR and is adjacent to the space to be conditioned. This unit is very useful for conditioning the air of a restaurant, bank or small office. PTAC systems are also known as wall split air conditioning systems or ductless systems. ❖ These PTAC systems which are widely used in hotels have two separate units, the evaporative unit on the interior and the condensing unit on the exterior, with tubing passes through the wall and connect them together. This minimizes the interior system footprint and allows each room to be adjacent independently. ❖ PTAC system may be adapted to provide heating in cold weather, either directly by using an electric strip, gas or other heaters, or by reversing the refrigerant flow to heat the interior and draw heat from the exterior air, converting the air into a heat pump. ❖ While room air conditioning provides maximum flexibility when cooling rooms it is generally more expensive than a central air conditioning system.
28.	**Explain Central Air Conditioning System**
	It is a most important type of air conditioning system, it uses when the required cooling capacity 25TR or more. It uses when the air flow is more than 300 m^3/min or different zones in a building are to be air-conditioned.
29.	**List the Application of Air-Conditioning**

	❖ Using air-conditioner is common in food cooking and processing areas. Used in hospital operating theatres to provide comfortable conditions to patients. And many more industries like Textile, Printing, Photographic and much more. ❖ Air-conditioning system used as the commercial purpose for a human being. Example, in Theatres, Departmental store-room etc. ❖ Many of transport vehicles use air-conditioning systems such as cars, trains, aircraft, ships etc. This provides a comfortable condition for the passengers. ❖ The air-conditioning system used in Television-centres, Computer centres and museum for a special purpose.
30.	**Define Human comfort**
	Human comfort is that condition of mind, which expresses satisfaction with the thermal environment.
31.	**Explain Physiological Hazards Resulting from Heat**
	Following are some of the physiological hazards which may result due to the rise in body temperature: **1. Heat exhaustion:** It is due to the failure of normal blood circulation. The symptoms of heat exhaustion include fatigue, headache, dizziness, vomiting and abnormal mental reactions such as irritability. Severe heat exhaustion may cause fainting. It does not cause permanent injury to the body and recovery is usually rapid when the person is removed to a cool place. **2. Heat cramp:** It results from loss of salt due to an excessive rate of body perspiration. It causes severe pain in the calf and thigh muscles. The heat cramp may be largely avoided by using salt tablets. **3. Heat stroke:** It is the most serious hazard. When a man is exposed to excessive heat and work, the body temperature may rise rapidly to 40.5°C (105°F) or higher. At such elevated temperatures, sweating ceases and the man may enter a coma, with death imminent. A person experiencing a heat stroke may have permanent damage to the brain. The heat stroke may be avoided by taking sufficient water at frequent intervals. It has been found that a man doing hard work in the sun requires about one litre of water per hour.
32	**What are the Factors Affecting Human Comfort**

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	1. Effective temperature, 2. Heat production and regulation in human body 3. Heat and moisture losses from the human body 4. Moisture content of air 5. Quality and quantity of air 6. Air motion 7. Hot and cold surfaces, and 8. Air stratification
33.	**Define Effective Temperature**
	It is defined as that index which correlates the combined effects of air temperature, relative humidity and air velocity on the human body. The numerical value of effective temperature is made equal to the temperature of still *(i.e.* 5 to 8 m/min air velocity) saturated air, which produces the same sensation of warmth or coolness as produced under the given conditions.
34.	**What are the Factors Affecting Optimum Effective Temperature**
	The important factors which affect the optimum effective temperature are as follows : **1. Climatic and seasonal differences:** It is a known fact that the people living in colder climates feel comfortable at lower effective temperatures than those living in warmer regions. There is a relationship between the optimum indoor effective temperature and the optimum outdoor temperature, which changes with seasons. In winter, the optimum effective temperature is 19°C whereas in summer this temperature is 22°C. **2. Clothing**: It is another important factor which affects the optimum effective temperature. It may be noted that the person with light clothing need less optimum temperature than a person with heavy clothing. **3. Age and Sex:** Women of all ages require higher effective temperature (about 0.5°C) than men. Similar is the case with young and old people. The children also need higher effective temperature than adults. Thus, the maternity halls are always kept at an effective temperature of 2 to 3°C higher than the effective temperature used for adults. **4. Duration of stay:**

	It has been established that if the stay in a room is shorter (as in the case of persons going to banks), then higher effective temperature is required than that needed for long stay (as in the case of persons working in an office). **5. Kind of activity:** When the activity of the person is heavy such as people working in a factory, dancing hall, then low effective temperature is needed than for the people sitting in cinema hall or auditorium. **6. Density of occupants:** The effect of body radiant heat from person to person particularly in a densely occupied space like auditorium is large enough which require a slight lower effective temperature.
35.	**What are the Factors Affecting Comfort Air Conditioning**
	1. *Temperature of air.* In air conditioning, the control of temperature means the maintenance of any desired temperature within an enclosed space even though the temperature of the outside air is above or below the desired room temperature. This is accomplished either by the addition or removal of heat from the enclosed space as and when demanded. It may be noted that a human being feels comfortable when the air is at 21°C with 56% relative humidity. **2. *Humidity of air.*** The control of humidity of air means the decreasing or increasing of moisture contents of air during summer or winter respectively in order to produce comfortable and healthy conditions. The control of humidity is not only necessary for human comfort but it also increases the efficiency of the workers. In general, for summer air conditioning, the relative humidity should not be less than 60% whereas for winter air conditioning it should not be more than 40%. **3. *Purity of air.*** It is an important factor for the comfort of a human body. It has been noticed that people do not feel comfortable when breathing contaminated air, even if it is within acceptable temperature and humidity ranges. It is thus obvious that proper filtration, cleaning and purification of air is essential to keep it free from dust and other impurities.

	4. *Motion of air.* The motion or circulation of air is another important factor which should be controlled, in order to keep constant temperature throughout the conditioned space. It is, therefore, necessary that there should be equi-distribution of air throughout the space to be air conditioned.
36.	**Explain the Equipments Used in an Air Conditioning System**
	Following are the main equipments or parts used in an air conditioning system : **1. *Circulation fan:*** The main function of this fan is to move air to and from the room. **2. *Air conditioning unit:*** It is a unit which consists of cooling and dehumidifying processes for summer air conditioning or heating and humidification processes for winter air conditioning. **3. *Supply duct:*** It directs the conditioned air from the circulating fan to the space to be air conditioned at proper point. **4. *Supply outlets:*** These are grills which distribute the conditioned air evenly in the room. **5. *Return outlets:*** These are the openings in a room surface which allow the room air to enter the return duct. **6. *Filters:*** The main function of the filters is to remove dust, dirt and other harmful bacteria from the air.
37.	**Define Room Sensible Heat Factor**
	It is defined as the ratio of the room sensible heat to the room total heat. Mathematically room sensible heat factor, $RSHF = \mathrm{RSH}/RTH$ $RSHF = \mathrm{RSH}/(RSH + RLH)$
38.	**Define room apparatus dew point (ADP).**
	In a cooling and dehumidification process, the temperature at which the room sensible heat factor line intersects the saturation curve is called room apparatus dew point (ADP).

39.	**Define Grand Sensible Heat Factor**
	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, $GSHF = \frac{TSH}{GTH} = \frac{TSH}{TSH + TLH} = \frac{RSH + OASH}{(RSH + OASH) + (RLH + OALH)}$ where TSH = Total sensible heat = $RSH + OASH$; TLH = Total latent heat = $RLH + OALH$; GTH = Grand total heat = $TSH + TLH = RSH + RLH + OATH$ $= RSH + RLH + (OASH + OALH)$
40.	**Define Effective Room Sensible Heat Factor**
	It is defined as the ratio of the effective room sensible heat to the effective room total heat. Mathematically, effective room sensible heat factor, $ERSHF = \frac{ERSH}{ERTH} = \frac{ERSH}{ERSH + ERLH}$ where $ERSH$ = Effective room sensible heat = $RSH + OASH \times BPF$ $= RSH + 0.020\,44\, v_1 (t_{d1} - t_{d2})\, BPF$; $ERLH$ = Effective room latent heat = $RLH + OALH \times BPF$ $= RLH + 50\, v_1 (W_1 - W_2)\, BPF$; $ERTH$ = Effective room total heat = $ERSH + ERLH$; BPF = By-pass factor
37.	**Define cooling load**
	The total heat required to be removed from the space in order to bring it at the desired temperature by the air conditioning and refrigeration equipment is known as *cooling load.*
38.	**What is meant by Heat Gain due to Infiltration**
	The infiltration air is the air that enters a conditioned space through window cracks and opening of doors. This is caused by pressure difference on the two sides of the windows and doors and it depends upon the wind velocity and its direction and difference in densities due to the temperature difference between the inside and

	outside air.