B.Tech. DEGREE EXAMINATION, JANUARY 2023.

Third Semester

Electrical and Electronics Engineering

FLUID AND THERMAL MACHINES

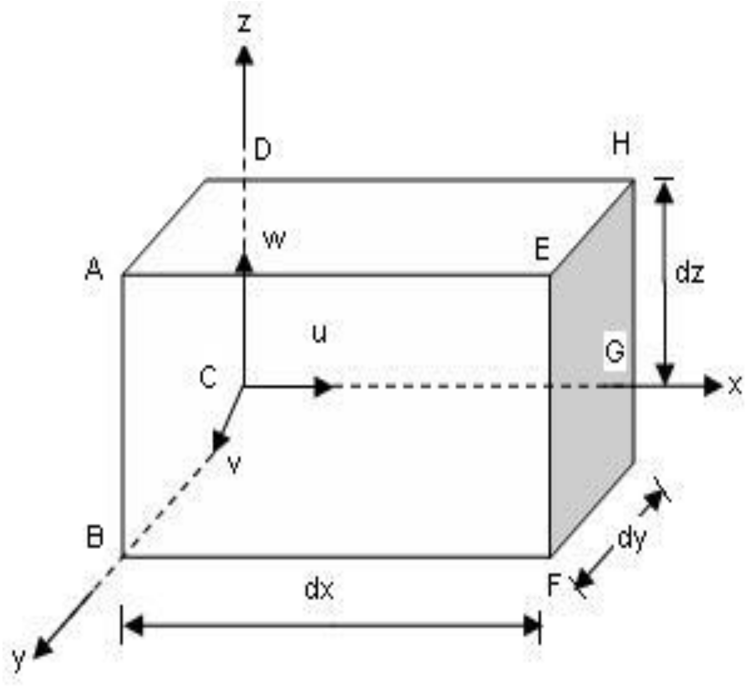
PART A -(10 x 2 = 20 marks)

Answer ALL questions.

1. What is meant by vapor pressure of a fluid?

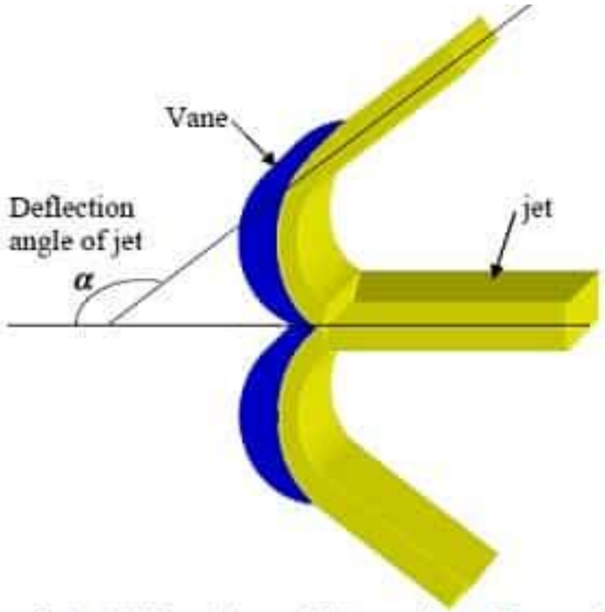
   Vapour pressure is a measure of the tendency of a material to change into the gaseous or vapour state, and it increases with temperature. The temperature at which the vapour pressure at the surface of a liquid becomes equal to the pressure exerted by the surroundings is called the boiling point of the liquid.

2. State the equation of continuity to three Dimensional in compressible flow.

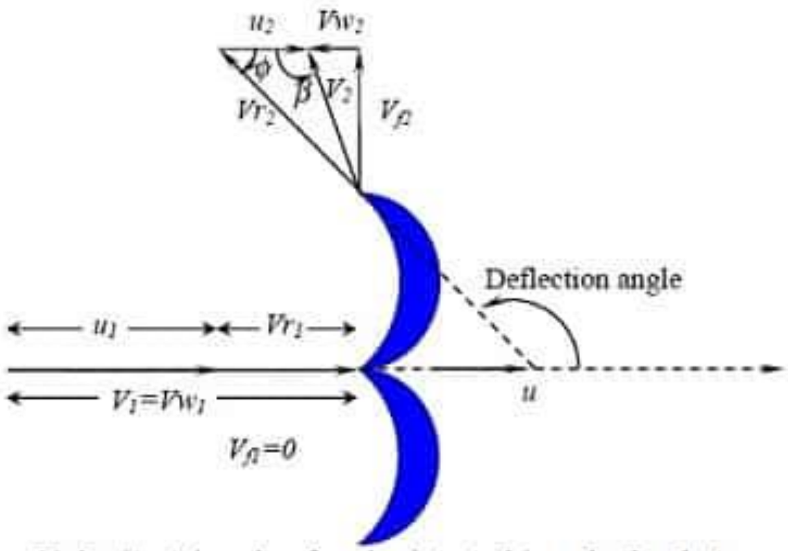


$\partial\rho/\partial t + \partial / \partial x\ (\rho\ u) + \partial / \partial y\ (\rho\ v) + \partial / \partial z\ (\rho\ w) = 0$. Above equation is the continuity equation in Cartesian co-ordinates in its most general form. This equation will be applicable to following types of fluid flow.

3. Draw and Label the velocity triangle diagram for Pelton Wheel turbine.



3 D Picture of a jet striking the splitter and getting split in to two parts and deviating.



Velocity triangles for the jet striking the bucket

4. What are Roto dynamic pumps? Give examples.

Pumps impart energy to the liquids being transferred by mechanical means using moving parts. They can be classified as **rotodynamic** or positive displacement. The most common types of rotodynamic pumps are radial (centrifugal), mixed flow and axial flow (propeller) pumps, including pumps historically referred to as vertical turbine pumps.

5. Give the classification of steam turbines.

The steam turbines are classified based on many factors like exhaust condition, stage design, steam flow, shaft design, types of drive etc.

Based on exhaust condition:

- Condensing
- Non condensing
- Automatic extraction
- Mixed pressure
- Regenerative extraction
- Reheat

Based on stage design:

- Impulse
- Reaction

6. State the principle of impulse turbines.

   Impulse turbine work on the principle of Newton's second law as the resulting change in momentum sets buckets and wheel into rotary motion and thus mechanical energy is made available at the turbine shaft. The fluid jet leaves the runner with a reduced energy.

7. Name four important qualities of SI engine fuels

   Some of the important qualities of gasoline are discussed below.

   ❖ Volatility

   ❖ Starting and warm up

   ❖ Operating Range Performance

   ❖ Crank case dilution

   ❖ Vapour lock characteristics

   ❖ Antiknock quality

   ❖ Gum Deposits

   ❖ Sulphur Contents.

   It is the most important characteristics of a SI engine fuel.

8. Point out the various sources of heat gain of an air-conditioned space.

   Sensible heat gains to the air-conditioned space arise from the following sources: Solar radiation through windows; Solar radiation on the outside surface of the building structure (walls and roofs)

9. Specify the components of Gas turbine power plant.

   A gas turbine unit consists of the following essential parts:

   (a) **Compressor:** The air compressor used in gas turbines is of rotary type mainly axial flow turbines. It draws air from the atmosphere and compressed to the required pressure. This compressed air is then transferred of the air instantaneously.

   (b) **Combustion chamber:** The compressed air from the air compressor is drawn to combustion chamber. The fuel is injected to the air and then ignited in the combustion chamber. It increased the pressure and temperature of the air instantaneously.

(c) **Turbine:** The high pressure and temperature air is expanded in the turbine. Turbine is also of rotary type. During the expansion, the heat energy in the gas is converted into mechanical energy. This mechanical energy is again converted in to electrical energy by using generator.

10. Select the main advantage of inter cooling in multi-stage reciprocating compressors?

- The work done per kg of air is reduced in multistage compression with inter cooler
- as compared to single stage compression for the same delivery pressure.
- It improves the volumetric efficiency for the given pressure ratio.
- The size of the cylinders (i.e., high pressure and low pressure) may be adjusted to suit
- the volume and the pressure of the air.
- It reduces the leakage loss considerably.
- It gives more uniform torque and hence a smaller size flywheel is required.
- It provides effective lubrication because of lower operating temperature.
- It reduces the cost of the compressor.

PART B-(5 x 11 = 55 marks)

Answer ALL questions.

11. The space between two square flat parallel plates is filled with oil. Each side of the plate is 60 cm. The thickness of the oil film is 12.5 mm. The upper plate, which moves at 2.5 m/s requires a force of 98.1 N to maintain the speed. Determine the dynamic viscosity of the oil and the kinematic viscosity of the oil in stokes if the specific gravity of the oil is 0.95.

(11) Given Data:-

Side of the Plate = 60 cm = 0.6 m

thickness of the oil film = 12.5 mm = 0.0125 m

velocity (u) = 2.5 m/s

force (N) = 98.1 N

Specific gravity of the oil = 0.95

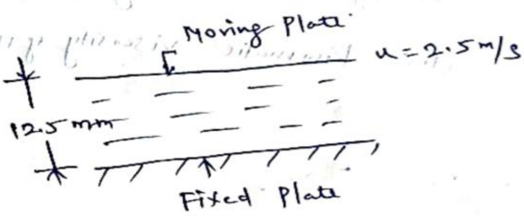
To find:

(i) Dynamic viscosity of the oil

(ii) Kinematic viscosity of the oil.

Soln:-

$\tau = \mu \cdot \frac{du}{dy}$.



We know that

$\tau = F/A$.

$\tau = \frac{98.1}{0.6 \times 0.6} = 272.5 \, N/m^2$

$du = 2.5 - 0 = 2.5 \, m/s$

$\tau = \mu \times \frac{du}{dy}$

$272.5 = \mu \times \frac{2.5}{0.0125}$

$\mu = 1.3625 \, Ns/m^2$

$\boxed{\mu = 0.136 \text{ poise}}$

(ii) Specific gravity $= \frac{\rho_{liquid}}{\rho_{water}}$.

$0.95 = \frac{\rho_{liquid}}{1000}$.

$\boxed{\rho_{liquid} = 950 \, kg/m^2}$

$$\nu = \frac{\mu}{\rho_{liquid}}$$

$$\nu = \frac{1.3625}{950.}$$

$$\nu = 0.00143 \ m^2/s.$$

$$\boxed{\nu = 1.43 \times 10^{-3} \ m^2/s}$$

Result:

i) Dynamic viscosity of the oil is $(\mu) = 0.136$ Poise.

(ii) Kinematic viscosity of the oil is $(\nu) = 1.43 \times 10^{-3} \ m^2/s$

12. A 30 cm x 15 cm venturimeter is provided in a vertical pipe line carrying oil of specific gravity 0.9, the flow being upwards. The difference in elevation of the throat section and entrance section of the venturimeter is 30 cm. The differential U-tube mercury manometer shows a gauge deflection of 25 cm. Calculate (a) The discharge of the oil. (b) The pressure difference between the entrance section and the throat section. Take Cd = 0.98 and specific gravity of mercury as 13.6.

12. Given Data:

Entrance Diameter of venturimeter $= D_1 = 30\ cm = 0.3m$

Outer Diameter of Venturimeter $= D_2 = 15\ cm = 0.15m$

Pipe Diameter $= D = 30\ cm = 0.3m$

Specific Gravity of oil $= \gamma = 0.9$

Height $= z_1 - z_2 = 30\ cm = 0.3m$

Gauge deflection $= x = 25\ cm = 0.25m$

Discharge Coefficient $= k = 0.98$

Specific gravity of Mercury $= \gamma' = 13.6$.

To find:

(a) Discharge of the oil.

(b) Pressure difference b/w the entrance section and the throat section.

Soln;

Considering the definition of piezometric head using the difference in manometer level.

$$h = x\left(\frac{\gamma'}{\gamma} - 1\right)$$

$$= 0.25\left(\frac{13.6}{0.9} - 1\right)$$

$$\boxed{h = 3.52m}$$

Now, the Cross Sectional area of entrance of Venturimeter

$$A_1 = \pi/4\,(D_1)^2 = \frac{\pi}{4} \times 0.3^2$$

$$\boxed{A_1 = 0.07069m^2}$$

The Diameter at throat of Venturimeter is

$$A_2 = \pi/4\,(D_2)^2 = \pi/4\,(0.15)^2\ ;\ \boxed{A_2 = 0.01767m^2}$$

Then the discharge of oil is equal to.

$$Q_{oil} = k\left(\frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh}\right)$$

$$= 0.98\left(\frac{0.07069 \times 0.01767}{\sqrt{0.07069^2 - 0.01767^2}} \times \sqrt{2 \times 9.81 \times 3.52}\right)$$

$$\boxed{Q_{oil} = 0.15158\ m^3/s}$$

(b) The density of the oil is

$$\rho_o = \nu \times \rho_{water}$$

$$\rho_o = 0.9 \times 1000$$

$$\rho_o = 900\ kg/m^3$$

Applying the Bernoulli's equation.

$$h = \left(\frac{P_1 - P_2}{\rho_o g}\right) + (Z_1 - Z_2)$$

$$3.52 = \left(\frac{P_1 - P_2}{900 \times 9.81}\right) + 0.3$$

$$\boxed{P_1 - P_2 = 28.42\ kPa.}$$

13. Derive an expression for maximum hydraulic efficiency in an impulse turbine and Compare radial flow and axial flow turbo machines.

What is Hydraulic Turbines? Write its Classifications?

The hydraulic turbine is a prime mover that uses the energy of flowing water and converts is into the mechanical energy in the form of rotation of the runner. (A prime mover is a machine which uses the raw energy of a substance and converts it into the mechanical energy.) Since the fluid medium is water, these turbines are also known as the „water turbines". Hydraulic turbines coupled with hydro – generators form the so – called „hydro units" which are widely used now days for generating electrical power.

Classification of Turbines

Hydraulic turbines may be classified in the following ways:

i) According to the type of energy at inlet.

   a) Impulse turbine   b) Reaction turbine.

ii) According to the direction of flow through runners.

   a) Tangential flow   b) Radial flow   c) Axial flow   d) Mixed flow turbines.

iii) According to the head and quantity of water

   a) High head turbines – which work under high heads (above 250m) but with less quantity of water. Example: Pelton wheel

   b) Medium head turbines – work under medium heads (60m to 250m)-they require relatively large quantity of water. Example: Francis turbines

   c) Low head turbines – work under heads less than 60m – they require a very large quantity of water. Example: Kaplan turbine

iv) According to position of shaft

   a) Horizontal turbines – These turbines have horizontal shafts.

   Example: Pelton wheel

   b) Vertical turbines – These turbines have vertical shafts.

   Example: Francis and Kaplan turbines.

Explain Head and Efficiencies of Hydraulic Turbines.

1. **Gross head**: The gross (total) head is the difference between the water level at the reservoir (also known as the head race) and the water level at the tail race. It is denoted by H_g.

2. **Net or Effective head**: The head available at the inlet of the turbine is known as net or effective head. It is denoted by H and is given by $H = H_g – h_f - h$

Where h_f = total loss of head between the head race and entrance of the turbine,

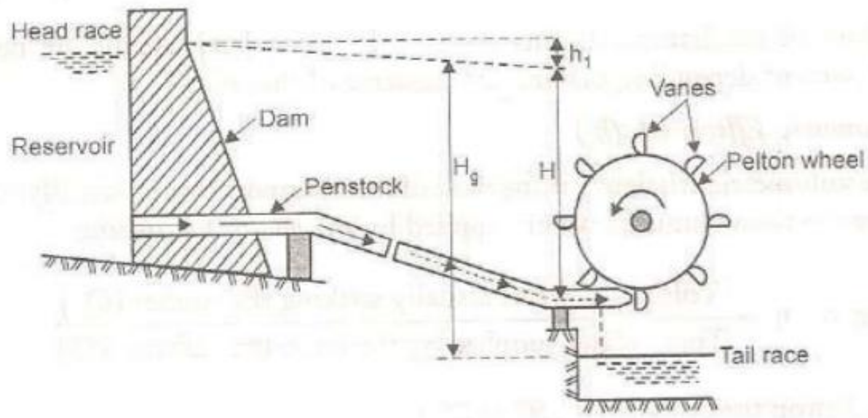
$= 4fLV^2 / 4 \times 2g$

Where L = Length of penstock, D = Diameter of penstock, V = Velocity of flow in penstock, h = Height of nozzle above the tail race.

3. **Efficiencies**: The following are the importance efficiencies of a turbine.

i) Hydraulic efficiency (η_h):

It is defined as the ratio of power developed by the runner to the power supplied by the jet at entrance to the turbine.



Mathematically, η_h = Power developed by the runner / Power supplied at the inlet of Turbine

$= pQ_a (V_w \pm V_{w1}) u / wQ_aH = (w/g) Q_a (V_w \pm V_{w1}) u / wQ_aH$

$= (V_w \pm V_{w1}) u / gH = H_r / H$

Where V_w, W_{w1} = Velocities of whirl at inlet and outlet

respectively u = Tangential velocity of vane

H = Net head on the turbine

Q_a = Actual flow rate to turbine runner (bucket)

The parameter $H = 1/g = (V_w + V_{w1}) u$ represents the energy transfer per unit weight of water and is referred to as the ,,Runner head" of ,,Euler head"

$H - \Delta Hr = H$ = hydraulic losses within the turbine.

ii) **Mechanical Efficiency (η_m):**

It is defined as the ratio of the power obtained from the shaft of the turbine to the power developed by the runner. These two powers differ by the amount of mechanical losses, viz., bearing friction etc.

Mathematically,

η_m = Power developed at the turbine shaft / Power developed by turbine

runner = Shaft power / Bucket power

Values of mechanical efficiency for a Pelton wheel usually lie between 97 to 99 percent depending on size and capacity of the unit.

iii) **Volumetric Efficiency (h_v)**

The volumetric efficiency is the ratio of the volume of water actually striking the runner to the volume of water supplied by the jet to the turbine.

That is, η_r = Volume of water actually striking the runner (Q_a) / Total water supplied by the jet to the turbine (Q)

For Pelton turbines, $\eta_r = 0.97$ to 0.99

iv) **Overall Efficiency (h_o)**

It is defined as the ratio of power available at the turbine shaft to the power supplied by the water jet.

That is,

η_o = Power available at the turbine shaft / Power available from the water jet

= Shaft Power / Water Power = P / wQH

where Q = the total discharge in m^3 / s supplied by the jet

The values of overall efficiency for a Pelton wheel lie between 0.85 to 0.90.

The individual efficiencies may be combined to give

$$\eta_o = \eta_h \times \eta_m \times \eta_v$$

$$= H_r / H \times P / wQ_aH_r \times Q_a / Q = P / wQH$$

which is the same as defined wide equation.

If η_g is the efficiency of a generator, then power output of the hydrounit (turbine + hydrogenerators).

$$= (wQH) \times \eta_o \text{ x } \eta_g$$

The product $\eta o \times \eta g$ is known as hydro-electric plant efficiency.

14. The diameter and stroke length of a single acting reciprocating pump are 150 mm and 300 mm respectively, the pump runs at 50 rpm and lifts 4.21ps of water through a height of 25 m. The delivery pipe is 22 m long and 100 mm in diameter. Identify (a) Theoretical power required to run the pump (b) % of slip and (c) Acceleration head at the beginning and middle of the delivery stroke.

Solution. Given :

Dia. of cylinder, $D = 150 \text{ mm} = 0.15 \text{ m}$

∴ Area, $A = \left(\frac{\pi}{4}\right) \times 0.15^2 = 0.01767 \text{ m}^2$

Stroke, $L = 300 \text{ mm} = 0.3 \text{ m}$

Speed of pump, $N = 50$ r.p.m.

Total height through which water is lifted,

$H = 25$ m

Length of delivery pipe, $l_d = 22$ m

Diameter of delivery pipe, $d_d = 100 \text{ mm} = 0.1 \text{ m}$

Actual discharge, $Q_{act} = 4.2 \text{ litres/s} = \frac{4.2}{1000} \text{ m}^3\text{/s} = 0.0042 \text{ m}^3\text{/s}.$

(i) Theoretical discharge (Q_{th})

Theoretical discharge for a single-acting reciprocating pump is given by equation (20.1), as

$$Q_{th} = \frac{A \times L \times N}{60} = \frac{0.01767 \times 0.3 \times 50}{60} = 0.0044175 \text{ m}^3\text{/s}$$

$$= 0.0044175 \times 1000 \text{ litres/s} = \mathbf{4.4175 \text{ litres/s.}} \text{ Ans.}$$

(ii) Theoretical power (P_t)

Theoretical power is given by, $P_t = \frac{\text{(Theoretical weight of water lifted/s)} \times \text{Total height}}{1000}$

$$= \frac{\rho \times g \times Q_{th} \times H}{1000}$$

$$= \frac{1000 \times 9.81 \times 0.0044175 \times 25}{1000} \qquad (\because Q_{th} = 0.0044175 \text{ m}^3\text{/s})$$

$$= \mathbf{1.0833 \text{ kW. Ans.}}$$

(iii) The percentage slip

The percentage slip is given by,

$$\% \text{ slip} = \left(\frac{Q_{th} - Q_{act}}{Q_{th}}\right) \times 100 = \left(\frac{4.4175 - 4.2}{4.4175}\right) \times 100 = \mathbf{4.92\%.} \text{ Ans.}$$

(iv) Acceleration head at the beginning of delivery stroke.

The acceleration head in the delivery pipe is given by equation (20.15) as :

$$h_{ad} = \frac{l_d}{g} \times \frac{A}{a_d} \omega^2 r \times \cos\theta$$

where a_d = Area of delivery pipe $= \frac{\pi}{4} \times (0.1)^2 = 0.007854$

$$\omega = \text{Angular speed} = \frac{2\pi N}{60} = \frac{2\pi \times 50}{60} = 5.236$$

$$r = \text{Crank radius} = \frac{L}{2} = \frac{0.3}{2} = 0.15 \text{ m}$$

$$\therefore \quad h_{ad} = \frac{22}{9.81} \times \frac{0.01767}{0.007854} \times 5.236^2 \times 0.15 \times \cos\theta = 20.75 \times \cos\theta$$

At the beginning of delivery stroke, $\theta = 0°$ and hence $\cos\theta = 1$

$$\therefore \quad h_{ad} = \mathbf{20.75\ m.}\ \textbf{Ans.}$$

(*v*) *Acceleration head at the middle of delivery stroke.*

At the middle of delivery stroke, $\theta = 90°$ and hence $\cos\theta = 0$.

$$\therefore \quad h_{ad} = 20.75 \times 0 = \mathbf{0.}\ \textbf{Ans.}$$

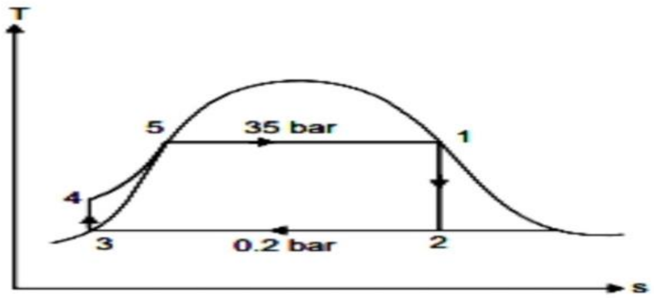
15. In a Rankine Cycle, the steam at inlet to the turbine is saturated at a pressure of 35 bar and the exhaust pressure is 0.2 bar. Determine (a) The pump work (b) The turbine work (c) The condenser heat flow (d) The dryness at the end of expansion. Assume flow rate of 9.5kg/s

Pressure and condition of steam, at inlet to the turbine,

$p_1 = 35$ bar, $x = 1$

Exhaust pressure, $p_2 = 0.2$ bar

Flow rate, $m = 9.5$ kg/s



From steam tables :

At 35 bar :

$h_1 = h_{g1} = 2802$ kJ/kg,

$s_{g1} = 6.1228$ kJ/kg K

At 0.26 bar :

$h_f = 251.5$ kJ/kg,

$h_{fg} = 2358.4$ kJ/kg,

$v_f = 0.001017$ m^3/kg,

$s_f = 0.8321$ kJ/kg K,

$s_{fg} = 7.0773$ kJ/kg K.

(i) The pump work :

Pump work = $(p_4 - p_3)$

$v_f = (35 - 0.2) \times 10^5 \times 0.001017$ J or 3.54 kJ/kg

$$\left[\begin{array}{ll}\text{Also} & h_{f_4} - h_{f_3} = \text{Pump work} = 3.54 \\ \therefore & h_{f_4} = 251.5 + 3.54 = 255.04 \text{ kJ / kg}\end{array}\right]$$

Now power required to drive the pump

= 9.5 × 3.54 kJ/s or 33.63 kW.

(ii) The turbine work :

$s_1 = s_2 = s_{f2} + x_2 \times s_{fg2}$

$6.1228 = 0.8321 + x_2 \times 7.0773$

$$x_2 = \frac{6.1228 - 0.8321}{7.0773} = 0.747$$

$h_2 = h_{f2} + x_2\, h_{fg2} = 251.5 + 0.747 \times 2358.4$ = 2013 kJ/kg

Turbine work = $m\,(h_1 - h_2)$ = 9.5 (2802 – 2013) = 7495.5 kW

It may be noted that pump work (33.63 kW) is very small as compared to the turbine work (7495.5 kW).

(iii) The Rankine efficiency :

$$\eta_{\text{rankine}} = \frac{h_1 - h_2}{h_1 - h_{f_2}} = \frac{2802 - 2013}{2802 - 251.5} = \frac{789}{2550.5} = \mathbf{0.3093 \text{ or } 30.93\%.}$$

(iv) The condenser heat flow :

The condenser heat flow = $m\,(h_2 - h_{f3})$ = 9.5 (2013 – 251.5) = 16734.25 kW.

(v) The dryness at the end of expansion, x_2 :

The dryness at the end of expansion,

x_2 = 0.747 or 74.7%.

16. Explain in detail about Condensers and cooling towers.

A closed vessel in which steam is condensed by abstracting the heat and where the pressure is maintained below atmospheric pressure is known as a condenser. The efficiency of the steam plant is considerably increased by the use of a condenser. In large turbine plants, the condensate recovery becomes very important and this is also made possible by the use of condenser. The steam condenser is one of the essential components of all modern steam power plants. Steam condensers are of two types:

1. Surface condenser. 2. Jet condensers

SURFACE CONDENSERS:

In surface condensers there is no direct contact between the steam and cooling water and the condensate can be re-used in the boiler: In such condenser even impure water can be used for cooling purpose whereas the cooling water must be pure in jet condensers. Although the capital cost and the space needed is more in surface condensers but it is justified by the saving in running cost and increase in efficiency of plant achieved by using this condenser. Depending upon the position of condensate extraction pump, flow of condensate and arrangement of tubes the surface condensers may be classified as follows:

Down flow type

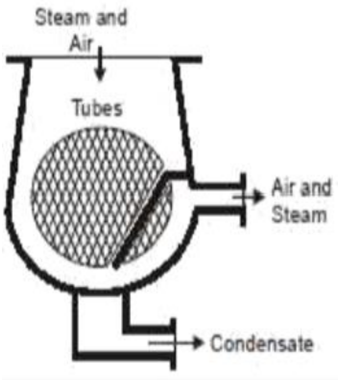


Fig:1

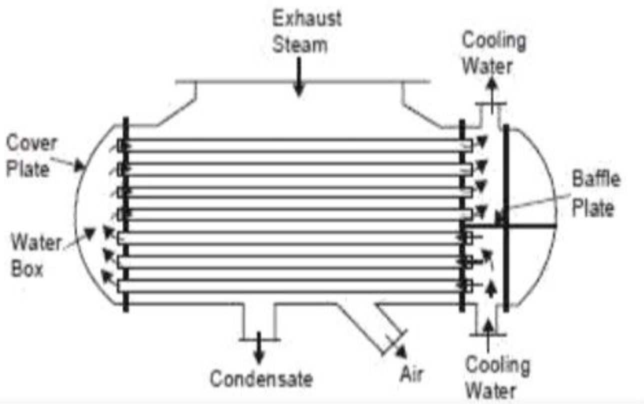
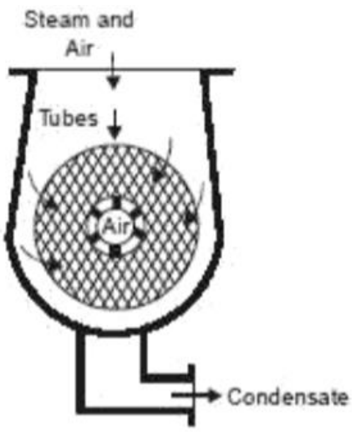


Fig:2

Fig. 1 shows a sectional view of dawn flow condenser. Steam enters at the top and flows downward. The water flowing through the tubes in one direction lower half comes out in the opposite direction in the upper half Fig. 2 shows a longitudinal section of a two pass down-flow condenser.

Central flow condenser

Fig. 3 shows a central flow condenser. In this condenser the steam passages are all around the periphery of the shell. Air is pumped away from the centre of the condenser. The condensate moves radially towards the centre of tube nest. Some of the exhaust steams while moving towards the centre meets the undercooled condensate and pre-heats it thus reduce undercooling.



ADVANTAGES AND DISADVANTAGES OF A SURFACE CONDENSER

The various advantages of a surface condenser are as follows:

1. The condensate can be used as boiler feed water.
2. Cooling water of even poor quality can be used because the cooling water does not come in direct contact with steam.
3. High vacuum (about 73.5 cm of Hg) can be obtained in the surface condenser. This increases the thermal efficiency of the plant.

The various disadvantages of' the surface condensers are as follows:

1. The capital cost is more.
2. The maintenance cost and running cost of this condenser is high.
3. It is bulky and requires more space.

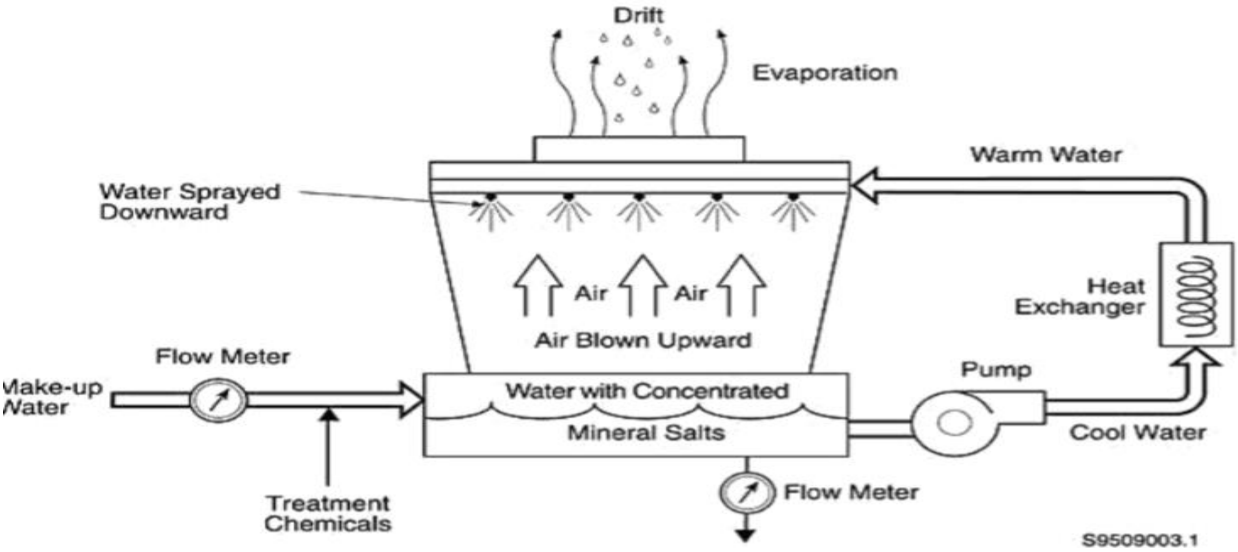
JET CONDENSERS

In jet condensers the exhaust steam and cooling water come in direct contact with each other. The temperature of cooling water and the condensate is same when leaving the condensers. Elements of the jet condenser are as follows:

1. Nozzles or distributors for the condensing water.
2. Steam inlet.
3. Mixing chambers: They may be (*a*) parallel flow type (*b*) counter flow type depending on whether the steam and water move in the same direction before condensation or whether the flows are opposite.
4. Hot well. In jet condensers the condensing water is called injection water

cooling towers.

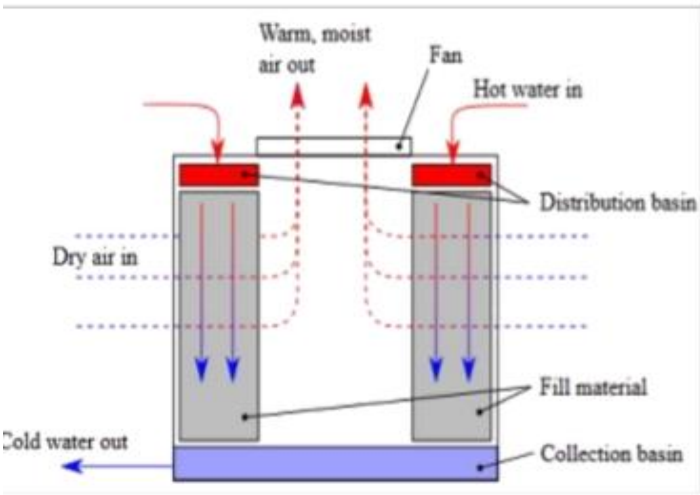
A cooling tower is equipment used to reduce the temperature of a water stream by extracting heat from water and emitting it to the atmosphere. Cooling towers make use of evaporation whereby some of the water is evaporated into a moving air stream and subsequently discharged into the atmosphere. As a result, the remainder of the water is cooled down significantly (Figure). Cooling towers are able to lower the water temperatures more than devices that use only air to reject heat, like the radiator in a car, and are therefore more cost-effective and energy efficient.



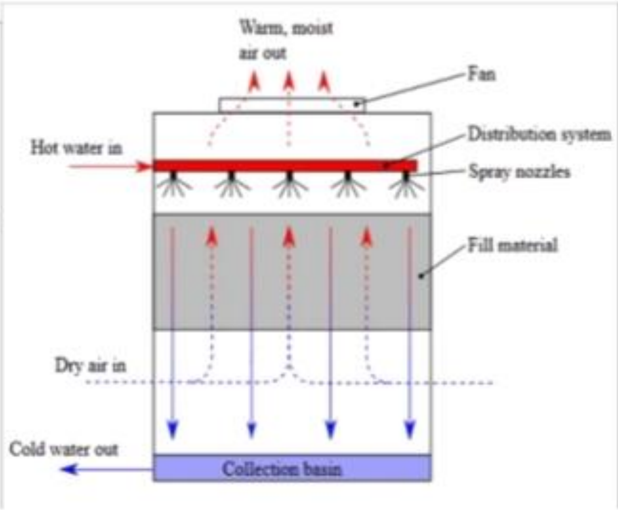
Natural draft cooling tower

The natural draft or hyperbolic cooling tower makes use of the difference in temperature between the ambient air and the hotter air inside the tower. As hot air moves upwards through the tower (because hot air rises), fresh cool air is drawn into the tower through an air inlet at the bottom. Due to the layout of the tower, no fan is required and there is almost no circulation of hot air that could affect the performance. Concrete is used for the tower shell with a height of up to 200 m. These cooling towers are mostly only for large heat duties because large concrete structures are expensive. There are two main types of natural draft towers:

Cross flow tower: air is drawn across the falling water and the fill is located outside the tower **Counter flow tower**: air is drawn up through the falling water and the fill is therefore located inside the tower, although design depends on specific site conditions



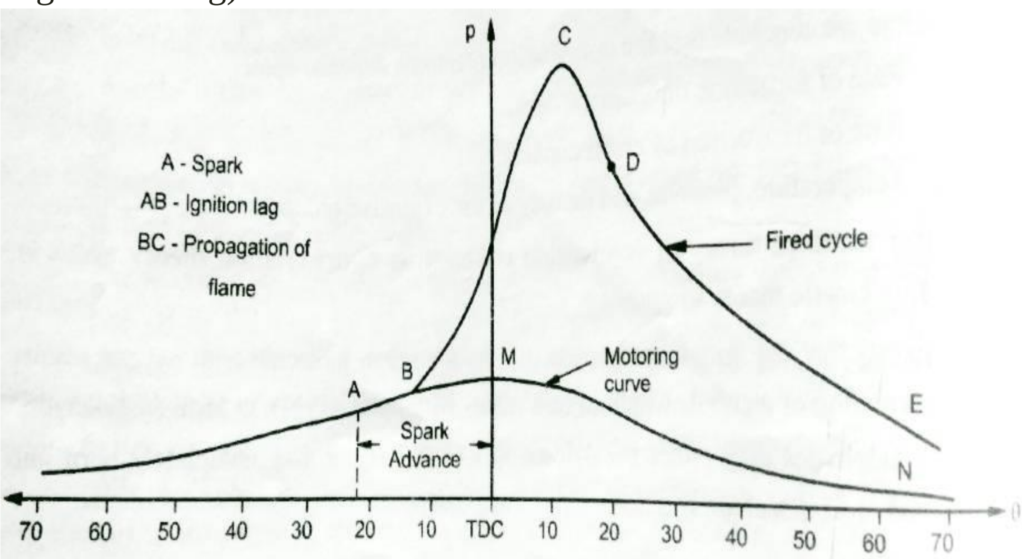
Cross flow natural draft cooling tower



Counter flow natural draft cooling tower

17. (A) Explain in detail about the various stages of combustion in SI engines.

In SI engines or Spark Ignition engines, air and fuel mixture in a proportional ratio is supplied to the combustion chamber with the help of carburetor. This air-fuel mixture in the combustion chamber is ignited using a spark plug which provides a high-intensity spark. This spark initiates the combustion process in the combustion chamber. The full combustion of the air-fuel mixture depends on the rate of heat transfer between the first flame and surrounding area of mixture, pressure, and temperature. To understand the combustion phenomenon in SI engines, Recardo carried out an experiment using a quartz cylinder and high-speed photography. In the below figure, you can see the curve ABMN which is a motoring curve (When the engine is not firing) and the curve ABCD which is a combustion curve (When the engine is firing).



Stages of combustion in SI engine:

On the basis of Recardo experiment, there are three stages of combustion in SI engine as given below:

1. Preparation phase
2. Flame propagation phase
3. After burning

1. Preparation Phase

The preparation phase is also called a period of ignition lag. This is the first stage in the combustion stages in SI engines. According to the experiment, there is some time interval between the first spark given to the mixture (at point A) and the first flame appears out of the mixture. This time interval is known as ignition lag and it is represented on the above map as period AB. Due to this combustion, there is a clear rise in cylinder pressure. This ignition lag represents the preflame reaction. According to the chain reaction theory of combustion, in preflame reactions chain carriers are produced.

During the AB period, the angle changed by the crank between points A and B is known as the ignition delay angle.This first phase or preparation phase in stages of combustion in SI engines depends upon the different factors such as the temperature of fuel, pressure, molecular structure of fuel, density and air-fuel ratio in the combustion chamber.

2. Flame Propagation Phase

When the first flame appears after the spark at point B, this flame travels surrounding and burns the fuel in different layers. This fuel burning rate and flame speed are noticeably low and there is a small but steady pressure rise in the combustion chamber. This burning of air and fuel in the combustion chamber continues further and it causes a continuous rise in pressure and temperature. It releases heat energy in the combustion chamber which is transferred from burned to unburned charge. The speed of flame propagation is becoming very high in the range of 15 to 35 m/s. Differentiating between the first and second phase i.e. Preparation phase and flame propagation phase is quite a difficult task. But you can distinguish between these two phases by observing ($P - \theta$) diagram given above. The second phase i.e. flame propagation phase starts when the pressure in the combustion chamber starts rising at point B and the phase ends when the highest pressure is achieved in the cylinder at point C on ($P - \theta$) diagram. Curve BC on the diagram represents the rate of pressure rise. The rate of heat transfer to the cylinder walls is very low at the beginning of the flame propagation phase. This stage is one the most important stage in the stages of combustion in SI engine.

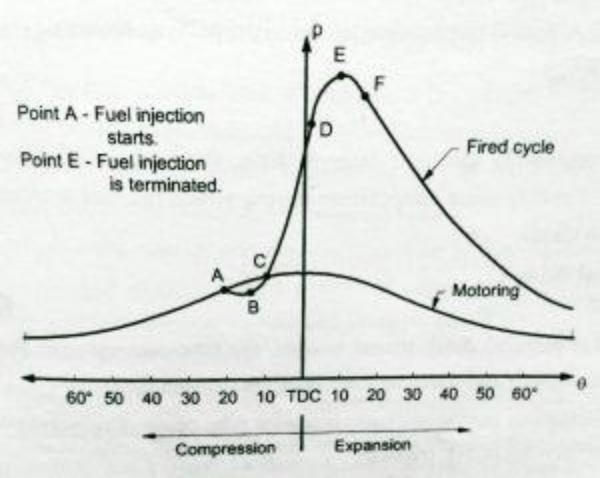
3. After Burning

We attained point C in the second stage of the combustion. But, it does not represent the completion of the combustion of the mixture. Because of the continuous burning of the remaining fuels in the cylinder and reassociation of dissociated gases in the combustion chamber.

During the expansion stroke, the combustion of air and fuel mixture continues after point C. This phase is called after burning. After burning represents the third stage of combustion in SI engine up to point D on (P – θ) diagram.
During after burning phase, flame velocity reduces to a certain level. This was the last phase of the stages of combustion in SI engine.

(b) Discuss in detail about the four stages of combustion in CI engines.

Combustion is a process of the rapid chemical reaction between fuel and the air. This process results in the generation of heat and light. In IC Engine, there are different stages of combustion for different engines. In this post, we are going to focus on stages of combustion in CI engine. Stages of combustion in SI engine are completely different than the CI engines.
In CI or compression ignition engine, in the compression stroke, only air is compressed at very high pressure and temperature. The compression ratio used is in the range of 12 to 120.The temperature of the air becomes higher than the temperature of the fuel which is diesel in the CI engine. Then diesel fuel is injected in the combustion chamber under very high pressure about 120 to 210 bar. The temperature of this fuel is around 20° to 35° before TDC (Top Dead Center).



Stages of Combustion in CI engine:

1. Ignition Delay Period
2. Period of Uncontrolled Combustion
3. Period of Controlled Combustion
4. After Burning

Ignition Delay Period

At this first stage of combustion in the CI engine, the fuel from the injection system sprayed in the combustion chamber in the form of a jet. Due to atomization and vaporization, this fuel disintegrates at the core which is surrounded by a spray of air and fuel particles.In this vaporization process, the fuel gets heat from the compressed and hot surrounding air. It causes some pressure drop in the cylinder. You can see this pressure drop (curve AB) in the above figure.

After completion of the vaporization process, the *preflame reaction* of the mixture in the combustion chamber starts. During the preflame reaction, pressure into the cylinder starts increasing with the release of energy at a slow rate.

This preflame reaction starts slowly and then speeds up until the ignition of the fuel takes place. You can see this process at point C on the diagram.

This time interval between the starting of the fuel injection and the beginning of the combustion is called the **delay period**. This delay period can further be divided into two parts – Physical delay and chemical delay.
The period between the time of injection of the fuel and its achievement of self-ignition temperature during vaporization is called physical delay. When physical delay completes, the time interval up to the fuel ignites and the flame of the combustion appears is called chemical delay.

Period of Uncontrolled Combustion
This is the second stage of combustion in the CI engine. After the above-mentioned delay period is over, the air and fuel mixture will auto-ignite as they have achieved their self-ignition temperature.

The mixture of air and fuel in CI engines is heterogeneous unlike homogeneous in the SI engines. Due to this heterogeneous mixture, flames appear at more than one location where the concentration of the mixture is high

When the flame formed the mixture in the other low concentration starts burning by the propagation of flames or due to auto-ignition, because of the process of heat transfer. The accumulated fuel during the delay is now started burning at an extremely rapid rate. It causes a rise in in-cylinder pressure and temperature. So, the higher the delay period, the higher would be the rate of pressure rise.
During this stage, you can’t control the amount of fuel burning, that’s why this period is called a *period of uncontrolled combustion.* This period is represented by the curve CD in the above figure. Period of Controlled Combustion When the accumulated fuel during the delay period completely burned in the period uncontrolled combustion, the temperature and pressure of the mixture in the cylinder are so high that new injected fuel from the nozzle will burn rapidly due to the presence of sufficient oxygen in the combustion chamber.
That’s the reason we can control the rise of pressure into the cylinder by controlling the fuel injection rate. Therefore, this period of combustion is called a period of controlled combustion.

After Burning
This is the last stage out of the four stages of combustion in CI engine.

Naturally, the combustion process is completed at the point when the maximum pressure is obtained in the combustion chamber at point E as shown in the figure.

Practically, the burning of the fuel in the combustion chamber remains to continue during the expansion stroke. The main reason behind it is the reassociation of dissociated *gases* and unburnt fuel. Therefore, this last phase of combustion is called After Burning .These are the four different stages of combustion in CI engine.

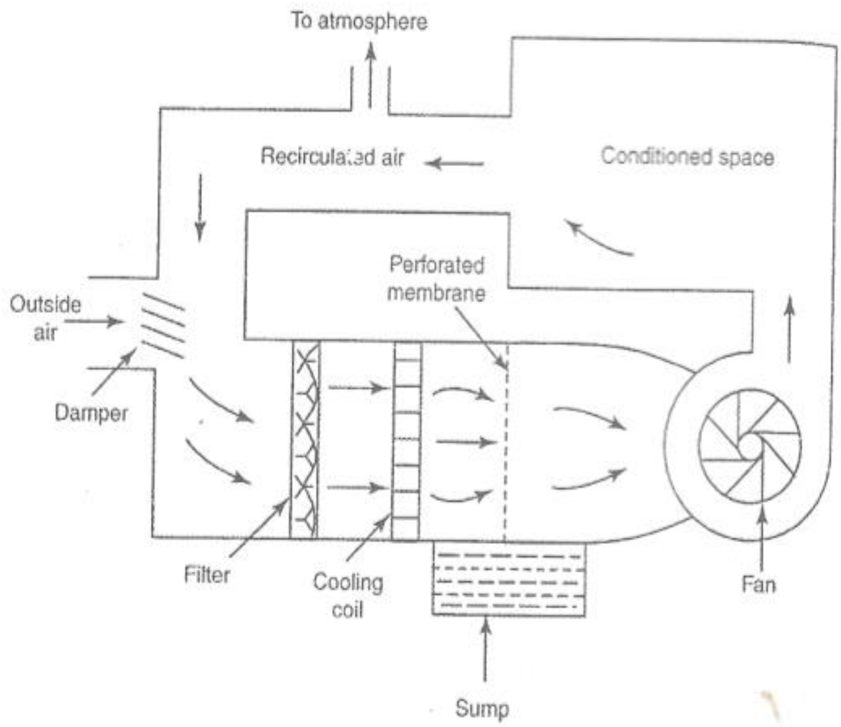
18. Explain air conditioning systems and their application in automobile industries.

Air conditioning is the process of supplying sufficient volume of clean air containing a specific amount of water vapor and maintaining the predetermined atmospheric condition with in an enclosed space. The air conditioning system is broadly classified into two groups.

1. Comfort air conditioning

2. Industrial air conditioning

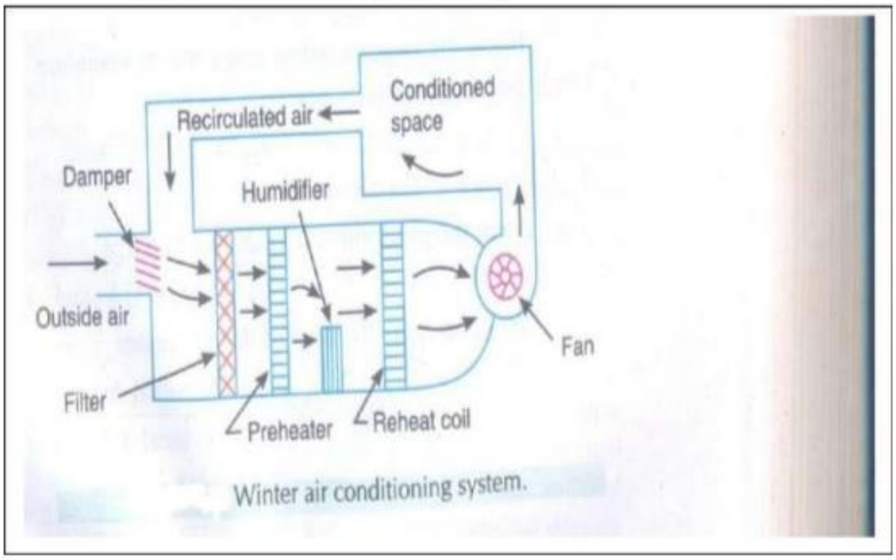
SUMMER AIR CONDITIONING SYSTEM



- The schematic arrangement of a typical summer air conditioning system is shown in fig.
- The air from outside is sucked into the system through the damper and gets mixed with re circulated air.

- The mixed air passes through a filter.
- The filter removes the dust particles and harmful bacteria's from the air and the filtered air is passed through the cooling coil.
- The cooling coil is kept at temperature below the dew point temperature of air. So, it cools the air.
- When the cooled air passes through membrane, moisture in the cooled air gets condensed and collected in a sump.
- Finally the cooled conditioned air is supplied to the space which is to be air conditioned.
- From the conditioned space a part of the used air is exhausted to the atmosphere and the remaining part of the air is again recirculated.

WINTER AIR CONDITONING SYSTEM



Winter air conditioning system.

Winter Air Conditioning System

- The schematic arrangement of a typical winter air conditioning system is shown in fig.
- The air from outside is sucked into the system through the damper and get mixed with recirculated air.
- The mixed air passes through a filter.
- The filter removes the dust particles and harmful bacteria's from the air and the filtered air is passed through pre-heater.
- Pre- heater is used to heat the air for better humidification during winter. After that it passes through a heating coil.
- The heating coil is used to heat the air to the required temperature.
- Finally the conditioned air is supplied to the space which is to be air conditioned.

From the conditioned space a part of the used air is exhausted to the atmosphere and the remaining part of the air is again recirculated.

19. Air enters the compressor of an open cycle constant pressure gas turbine at a pressure of 1 bar and temperature of 20°C. The pressure of the air after compression is 4 bar. The isentropic efficiencies of compressor and turbine are 80% and 85% respectively. The air-fuel ratio used is 90:1. If the flow rate of air is 3 kg/s. Find (a) power developed b) thermal efficiency of the cycle. Assume Cp=1kJ/kgK and y =1.4 of air and gases calorific value of fuel = 41800 kJ/kg.

Solution. *Given* : $p_1 = 1$ bar ; $T_1 = 20 + 273 = 293$ K

$p_2 = 4$ bar ; $\eta_{compressor} = 80\%$; $\eta_{turbine} = 85\%$

Air-fuel ratio $= 90 : 1$; Air flow rate, $m_a = 3.0$ kg/s

(*i*) **Power developed, P :**

Refer to Fig. 13.59 (*b*)

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{4}{1}\right)^{\frac{1.4-1}{1.4}} = 1.486$$

$$\therefore \quad T_2 = (20 + 273) \times 1.486 = 435.4 \text{ K}$$

$$\eta_{compressor} = \frac{T_2 - T_1}{T_2' - T_1}$$

$$0.8 = \frac{435.4 - 293}{T_2' - 293}$$

$$\therefore \quad T_2' = \frac{435.4 - 293}{0.8} + 293 = 471 \text{ K}$$

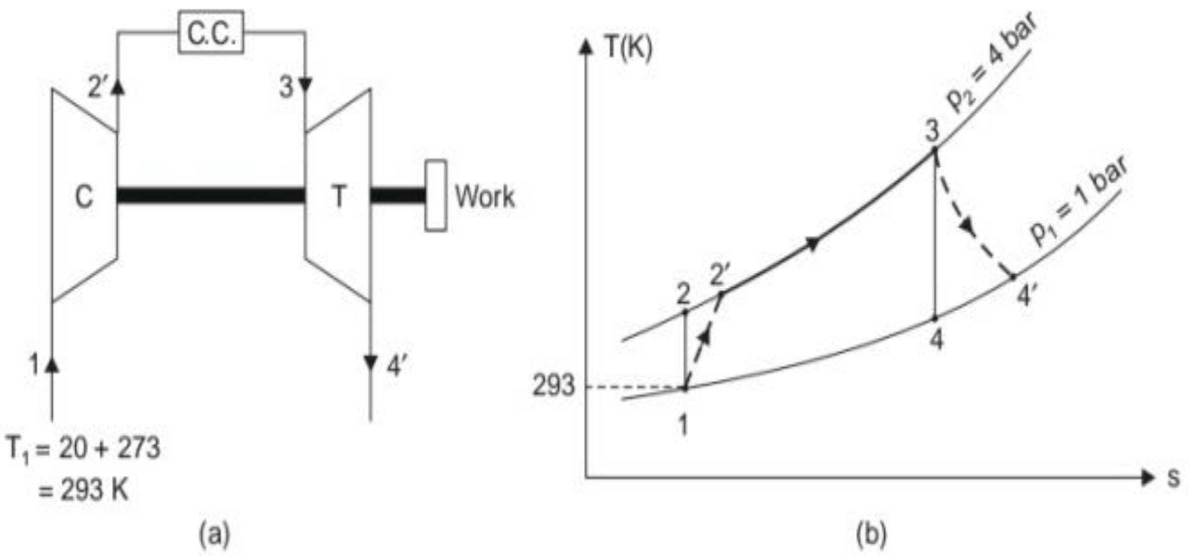


Fig. 13.59

Heat supplied by fuel = Heat taken by burning gases

$$m_f \times C = (m_a + m_f)\, c_p (T_3 - T_2')$$

'here m_a = mass of air, m_f = mass of fuel)

$\therefore$ $$C = \left(\frac{m_a}{m_f} + 1\right) c_p (T_3 - T_2')$$

$\therefore$ $$41800 = (90 + 1) \times 1.0 \times (T_3 - 471)$$

i.e., $$T_3 = \frac{41800}{91} + 471 = 930 \text{ K}$$

Again, $$\frac{T_4}{T_3} = \left(\frac{p_4}{p_3}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{1}{4}\right)^{\frac{0.4}{0.4}} = 0.672$$

$\therefore$ $$T_4 = 930 \times 0.672 = 624.9 \text{ K}$$

$$\eta_{\text{turbine}} = \frac{T_3 - T_4'}{T_3 - T_4}$$

$$0.85 = \frac{930 - T_4'}{930 - 624.9}$$

$\therefore$ $$T_4' = 930 - 0.85\,(930 - 624.9) = 670.6 \text{ K}$$

$$W_{\text{turbine}} = m_g \times c_p \times (T_3 - T_4')$$

(where m_g is the mass of hot gases formed per kg of air)

$\therefore$ $$W_{\text{turbine}} = \left(\frac{90+1}{90}\right) \times 1.0 \times (930 - 670.6)$$

$$= 262.28 \text{ kJ/kg of air.}$$

$$W_{\text{compressor}} = m_a \times c_p \times (T_2' - T_1) = 1 \times 1.0 \times (471 - 293)$$

$$= 178 \text{ kJ/kg of air}$$

$$W_{\text{net}} = W_{\text{turbine}} - W_{\text{compressor}}$$

$$= 262.28 - 178 = 84.28 \text{ kJ/kg of air.}$$

Hence *power developed,* $P = 84.28 \times 3 =$ **252.84 kW/kg of air. (Ans.)**

(*ii*) **Thermal efficiency of cycle, η_{thermal} :**

Heat supplied per kg of air passing through combustion chamber

$$= \frac{1}{90} \times 41800 = 464.44 \text{ kJ/kg of air}$$

20. Explain parts, working principle and working of reciprocating air compressor?

Air compressors may be classified as follows:

1) According to design and principle of operation

a) Reciprocating compressors

b) Rotary compressors

2) According to action

a) Single acting compressors

b) Double acting compressors

3) According to number of stages

a) Single stage compressors

b) Multistage compressors

4) According to pressure limit

a) Low pressure compressor

b) Medium pressure compressors

c) High pressure compressors

5) According to capacity

a) Low capacity compressors (Volume delivered $0.12m^3$/s or less)

b) Medium capacity compressors (volume delivered $0.15m^3$/s to $5m^3$/s)

c) High capacity compressors (Volume delivered is above $5m^3$/s)

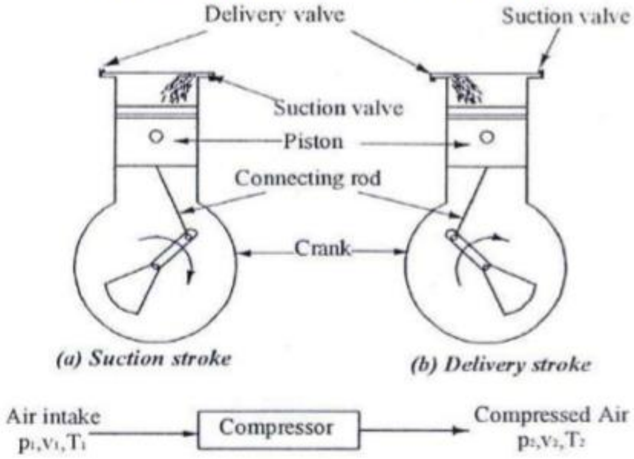
Single stage compressor:

In single stage compressor, the compression of the air from the initial pressure to the final pressure is carried out in one cylinder only.

Multistage compressor:

In multistage compressor, the compression of the air from the initial pressure to the final pressure is carried out in more than one cylinder.

WORKING OF SINGLE STAGE RECIPROCATING AIR COMPRESSOR



Single stage reciprocating air compressor

In a single stage compressor, the compression of air from the initial pressure to final pressure is carried out in one cylinder only. A schematic diagram of single stage, single acting compressor is shown in fig

It consists of a cylinder, piston, connecting rod, crank, and inlet and discharge valves. When the piston moves downward i.e. during suction stroke, the pressure of air inside the cylinder falls below the atmospheric pressure. So the inlet valve opens and the air from atmospheric is sucked into the cylinder until the piston reaches the bottom dead center. During this stroke delivery valve remains closed. When the piston moves upwards both valves are closed. So the pressure inside the cylinder goes on increasing till it reaches required discharge pressure. At this stage, the discharge value opens and the compressed air is delivered through this valve. Thus the cycle is repeated.