GOVT POLYTECHNIC , BHADRAK

ELEMENTS OF MECHANICAL ENGINEERING

(Th- 03)

(As per the 2019-20 syllabus of the SCTE&VT, Bhubaneswar, Odisha)

Third Semester

Electrical Engg.

Prepared By: *Er S.BISWAL*

ELEMENT OF MECHANICAL ENGINEERING

TOPIC WISE DISTRIBUTION PERIODS

Sl. no.	Topics	No. of periods as per syllabus	No. of periods actually needed	Internal Marks	Sem marks
1	Thermodynamics	06	07	07	03
2	Properties of Steam	05	06	06	04
3	Boilers	10	11	07	03
4	Steam Engines	10	10		09
5	Steam Turbines	06	06		10
6	Condenser	04	05		12
7	I.C Engine	04	04		10
8	Hydrostatics	05	05		09
9	Hydrokinetics	05	06		10
10	Hydraulic Devices and Pneumatics	05	06		10
	Total	60	66	20	80

CHAPTER- 1

THERMODYNAMICS

Learning objectives

Heat and work, first law of thermodynamics
Laws of perfect gases.
Relationship of specific heat of gases at constant volume and constant pressure.

Heat and work, first law of thermodynamics

Heat

The heat is defined as the energy transferred, without transfer of mass, across the boundary of a system because of a temperature difference between the system and the surroundings. It is usually represented by Q and is expressed in Joule (J) or Kilo-Joule (KJ)

Work

Work is defined as the product of the force (F) and the distance moved (X) in the direction the force.
Mathematically, work done, $W= F \times X$,
The unit of work depends upon the unit of force and the distance moved.
In S.I. system of units, the practical unit of work is Newton-metre (N-m). The work of 1N-m is known as Joule such that 1N-m = 1J.

1st law of thermodynamics:

This law may be stated as follow:

(a) The heat and mechanical work are mutually convertible. According to this law, when a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the net work transfer.
In other works, the cyclic integral of heat transfers is equal to the cyclic integral of work transfers, mathematically, $\oint \delta Q = \oint \delta W$
Where symbol "$\oint$" stands for cyclic integral, and δQ , δW represent infinitesimal elements of heat and work transfers respectively.

(b) The energy can neither be created nor destroyed though it can be transferred from one form to another. According to this law, when a system undergoes a change of state, then both heat transfer and work transfer takes place. The net energy transfer is stored within the system and is known as stored energy or total energy of the system. Mathematically $\delta Q - \delta W = dE$

(c) The symbol δ is used for a quantity which is inexact differential and symbol d is used for a quantity which is an exact differential. The quantity E is an extensive property and represents the total energy of the system at a particular state.

1.2 Laws of perfect gases.

The physical properties of a gas are controlled by the following three variables :

1. Pressure exerted by the gas
2. Volume occupied by the gas
3. Temperature of the gas

The behaviour of a perfect gas, undergoing any change in the above-mentioned variables, is governed by the following laws which have been established from experimental results.

1. Boyle's Law
2. Charles's Law
3. Gay-Lussac Law

1. Boyle's Law

This law was formulated by Robert Boyle in 1662. It states, " The absolute pressure of a given mass of a perfect gas varies inversely as its volume, when the temperature remains constant".

Mathematically, $P \propto 1/V$ or $PV = \text{constant}$

2. Charles's Law

This law was formulated by a Frenchman A.c. Charles in about 1787. It states," The volume of a given mass of a perfect varies directly as its absolute temperature, when the absolute pressure remains constant".

Mathematically,

$V \propto T$ or $V/T = \text{constant}$.

3. Gay-Lussac Law

This law states, " The absolute pressure of a given mass of a perfect gas varies directly as its absolute temperature when the volume remains constant".

Mathematically $P \propto T$ or $P/T = \text{constant}$

1.3 Relationship of specific heat of gases at constant volume and constant pressure.

Specific heats of a gas

The specific heat of a substance may be broadly defined as "the amount of heat required to raise the temperature of its unit mass through one degree".

All the liquids and solids have one specific heat only. But a gas can have any number of specific heats (lying between zero and infinity) depending upon the conditions, under which it is heated.

The following two types of specific heats of a gas are important from the subject point of view.

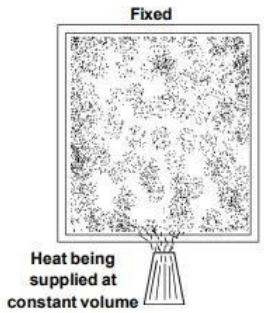
1. Specific heat at constant volume

2. Specific heat at constant pressure

Specific heat at constant volume

It is the amount of heat required one to raise the temperature of a unit mass of gas through one degree when it is heated at a constant volume. It is generally denoted by Cv.

Consider a gas contained in a container with a fixed lid as shown in the figure. Now, if this gas is heated, it will increase the temperature and pressure of the gas in the container. Since the lid of the container is fixed, therefore the volume of gas remains unchanged.



Let m= Mass of the gas

T1 = Initial temperature of the gas

T2 = Final temperature of the gas

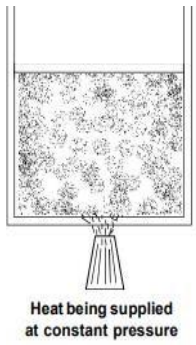
Total heat supplied to the gas at constant volume Q1-2= mass x supplied heat at constant volume x rise in temperature = mCv (T2 – T2).

It may be noted that whenever a gas is heated at constant volume, no work is done by the gas. The whole heat energy is utilised in increasing the temperature and pressure of the gas.

Specific heat at constant pressure

It is the amount of heat required to raise the temperature of a unit mass of a gas through one degree, when it is heated at constant pressure. It is generally denoted by Cp.

Consider a gas contained in a container with a movable lid as shown in figure. Now if this gas is heated, it will increase the temperature and pressure of the gas in container. Since the lid of the container is movable, therefore it will move upwards in order to counter balance the tendency for pressure to rise



Let m= Mass of the gas

T1 = Initial temperature of the gas

V1 = Initial volume of the gas T2,

V2 = Corresponding values for the final condition of the gas

∴ Total heat supplied to the gas, at constant pressure. Q1-2= Mass x Sp. heat at constant pressure x rise in temperature = mCp (T2 – T1).

Whenever a gas is heated at a constant pressure, the heat supplied to the gas is utilised for the following two purposes.

1. To raise the temperature of the gas. The heat remains within the body of the gas and represents the increase in initial energy. $dU = mC_v (T_2 – T_1)$.

2. To do some external work during expansion. Mathematically, work done by the gas $W_{1-2} = P(V_2-V_1) = mR (T_2 – T_1)$.

Relationship between specific heats

Consider a gas enclosed in a container and being heated, at a constant pressure, from the initial state 1 to the final state 2.

m= Mass of the gas

T_1= Initial temperature of the gas

T_2= Final temperature of the gas

V_1 = Initial volume of the gas

V_2 = Final volume of the gas

C_p = Specific heat at constant pressure

C_v = Specific heat at constant volume

P= Constant pressure

We know that heat supplied to the gas at constant pressure $Q_{1-2} = mC_p (T_2 – T_1)$

A part of this heat is utilised in doing the external work, and the rest remains within the gas and is used in increasing the internal energy of the gas.

$\therefore$ Heat utilised for external work $W_{1-2} = P(V_2-V_1)$.................................. (i)

And increase in internal energy $dU = mC_v (T_2 – T_1)$..................................(ii)

We known that $Q_{1-2} = W_{1-2}+dU$. .... (iii)

$\therefore mC_p (T_2 – T_1) = P(V_2 -V_1)+mC_v(T_2 – T_1)$.. (iv)

Using characteristic gas equation (i.e. $Pv=mRT$),

we have $PV_1 = mRT_1$.................(for initial condition)

$PV_2 = mRT_2$................(for final condition)

$\therefore P(V_2 -V_1) = mR(T_2 – T_1)$

Now substituting the value of $P(V_2-V_1)$ in equation .... (v)

$mC_p(T_2 – T_1) = mR(T_2 – T_1) + mC_v(T_2 – T_1)$

$\therefore C_p = R + C_v$ or $C_p – C_v = R$...(vi)

The above equation may be rewritten as $C_p – C_v = R$

⇨ $C_v (\gamma – 1) = R$ (since $C_p /C_v = \gamma$)... (vii)

⇨ $C_V = \frac{R}{\gamma - 1}$ .... (vii)

The equation (v) gives an important result as it proves that characteristic constant of a gas (R) is equal to the difference of its two specific heats i.e. (Cp – Cv).

Problem 1:- A 3000 J of heat is added to a system and 2500 J of work is done by the system. What is the change in internal energy of the system.

Given:- heat (Q) =3000 J, Work (W) = 2500J, internal energy (dU) =?

Solution:- by applying 1st law of thermodynamics , dU = Q-W = 3000J -2500J = 500 J

So, the change in internal energy of the system is 500 J

Problem 2: A closed vessel contains 2 kg of carbon dioxide at temperature 20ºC and pressure bar .Heat is supplied to the vessel till the gas acquires a pressure of 1.4 bar. Calculate

i. Final temperature
ii. Work done on or by the gas
iii. Heat added
iv. Change in internal energy

Take sp.heat of gas at constant volume as 0.657 KJ/Kg K

Solution:-

Given:- m =2 kg,T1 =20 ºC = 20+ 273 =293K

P1 = 0.7 bar ,P2 = 1.4 bar

Let T2 = final temperature

Since the gas is heated in a closed vessel, therefore the volume of gas will remain constant.

We know that $\frac{P1}{T1} = \frac{P2}{T2}$

⇨ T2 = $\frac{P2 * T1}{P1} = \frac{1.4 * 293}{0.7}$= 586 K = 586K- 273K = 313 ºC(Ans)

ii. since there is no change in volume ,therefore workdone on or by the gas is zero.

iii. heat added at constant volume,

Q_{1-2} = mCv(T2 – T1) = 2 x 0.657 x (586-293) = 385 KJ

Let dU = Change in internal energy

We know that , Q1-2= W1-2+dU

⇨ Q1-2= 0 + dU

⇨ Q1-2= dU = 385 KJ

SHORT QUESTIONS WITH ANSWERS

1. Define heat and state its unit? 2017 (W)

Ans :- The heat is defined as the energy transferred, without transfer of mass, across the boundary of a system because of a temperature difference between the system and the surroundings. It is usually represented by Q and is expressed in Joule (J) or Kilo-Joule (KJ)

2. Define work and state its unit? 2017 (W)

Ans:- Work is defined as the product of the force (F) and the distance moved (X) in the direction the force.

Mathematically, work done, $W= F\times X$,

In S.I. system of units, of work is Newton-metre (N-m).

3. Define perfect Gas? 2018 (W)

Ans:- A perfect gas is that gas which obeys all gas laws under all condition of pressure and temperature. It is also called as Ideal gas.

4. State first law of thermodynamics? 2018 (W),2020 (w)

Ans:- According to this law, when a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the net work transfer.

In other works, the cyclic integral of heat transfers is equal to the cyclic integral of work transfers, mathematically, $\int \delta Q = \int \delta W$

5. State Boyle's law? 2019 S

Ans:- This law was formulated by Robert Boyle in 1662. It states, " The absolute pressure of a given mass of a perfect gas varies inversely as its volume, when the temperature remains constant".

Mathematically, $P \propto 1/V$ or $PV = \text{constant}$

POSSIBLE LONG QUESTIONS

1. Derive the relation $C_p - C_v = R$.{ 2019(S) (W)}
   Hints:- refer article no 1.3
2. What is pressure and list out pressure measuring devices? 2019(S)
3. Describe the different laws of perfect gas.
   Hints :- refer article no 1.2
4. 2000J of heat is added to a system and 2500 J of work is done on the system. What is the change in internal energy of the system.
   Hints:- refer problem no 1
   W = -2500 J

CHAPTER No-02

PROPOTIES OF STEAM

Learning objectives

Introduction: -

Use steam table for solution of simple problems

explain total heat of dry, wet and superheated steam

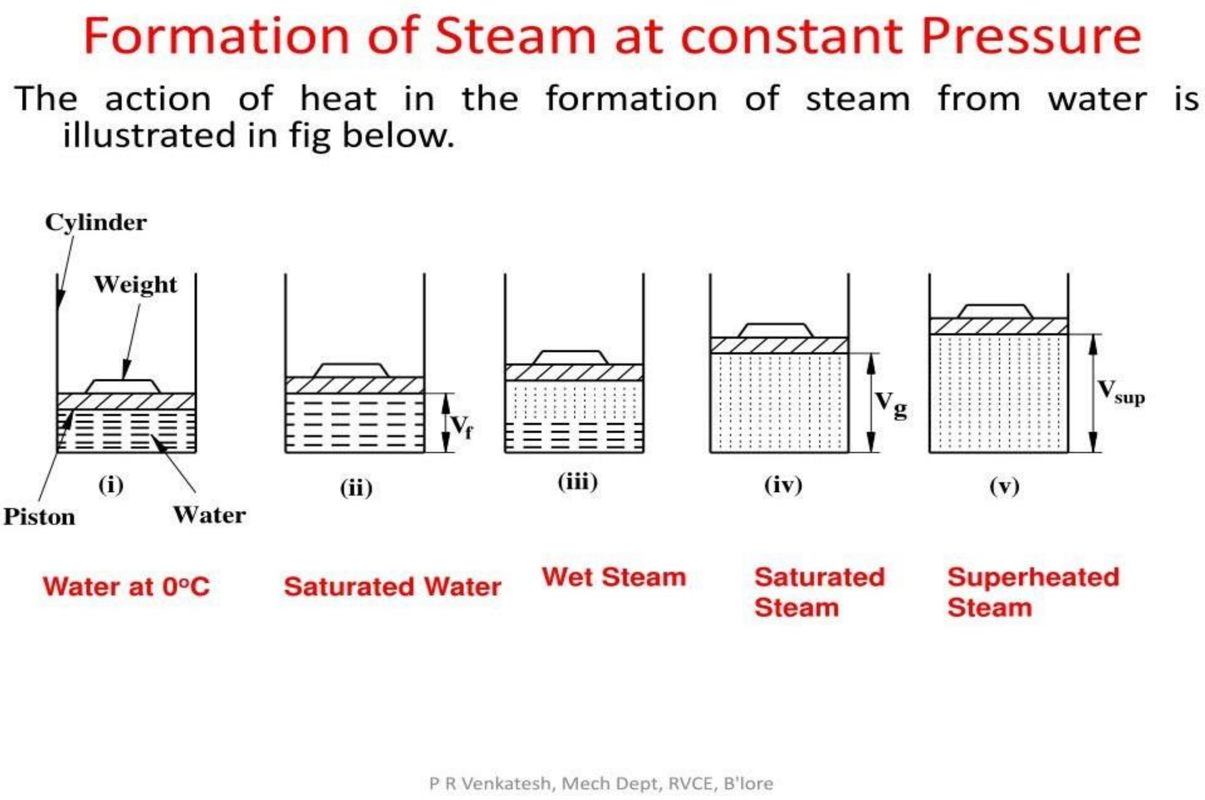
Introduction: -

Steam is a vapour of water, and is invisible when pure and dry. It is used as the working substance in operation of steam engines and steam turbines. Steam does not obey laws of perfect gases until it is perfectly dry. When the dry vapour is heated further, it becomes superheated vapour which becomes superheated vapour which behaves, more or less, like a perfect gas.

Use steam table for solution of simple problems

explain total heat of dry, wet and superheated steam

Formation of steam at a constant pressure from water:-



Important terms for steam:-

1. Wet steam:- when the steam contains moisture or particles of water in suspension, it is said to be wet steam. It means that the evaporation of water is not complete, and the whole of the latent heat has not been absorbed.
2. Dry saturated steam:- when the wet steam is further heated ,and it does not contain any suspended particles of water, it is known as dry saturated steam. The dry saturated steam has absorbed its full latent heat and behaves practically, in the same way as a perfect gas.
3. Superheated steam:- When the dry steam is further heated at a constant pressure this rising its temperature, it is said to be superheated steam since the pressure is constant, therefore the volume of superheated steam increases.
4. Dryness fraction:-The term dryness fraction is related with wet steam. It is defined as the ratio of the mass of actual dry steam to the mass of same quantity of wet steam. It is usually expressed by the symbol 'x'.
   Mathematically, $x=\frac{m_g}{m_g+m_f}$

   m_g = mass of actual dry steam

   m_f = mass of wet steam. = $m_g + m_f$

5. Sensible heat of water:- it is the amount of heat absorbed by 1 kg of water, when heated at a constant pressure , from the freezing point (0^0**c)** to the temperature of formation of steam, i.e saturation temperature (t). the sensible heat is also known liquid heat.
   The specific heat of water at constant pressure is 4.2 kj/kg k. therefore heat absorbed by 1kg of water from 0^0c to t ^{0}c or sensible heat
   = mass x sp.heat x rise in temperature= 1 x 4.2 {(t+273)-(0+273)} =4.2t kJ/kgk
6. Latent heat of vaporization:- it is the amount of heat absorbed to evaporate 1 kg of water at its boiling point or saturation temperature without change of temperature. It is denoted by h_{fg} and its value depends upon the pressure. Latent heat of steam is 2257 KJ/Kg at atmospheric pressure.
7. Enthalpy or total heat of steam:- it is amount of heat absorbed by water from freezing point to saturation temperature plus the heat absorbed during evaporation.
   Enthalpy or total heat of steam: = sensible heat + latent heat
   - Enthalpy of wet steam:- $h = h_f + xh_{fg}$, x= dryness fraction of steam
   - Enthalpy of wet steam:- $h = hg = h_f + h_{fg}$,x =1 for dry steam
   - Enthalpy of superheated steam:- $h_{sup} = h_f + h_{fg}+Cp(t_{sup}-t)$,

     Where Cp = specific heat at constant pressure

     t_{sup}= temperature of superheated steam

     $(t_{sup}-t)$ =called degree of superheat

8. <u>Specific volume of steam:-</u> it is the volume occupied by the steam per unit mass at a given temperature and pressure and is expressed in m3/kg.
   - Specific volume of 1 kg wet steam, $v = x\, v_g$ m3/kg
   - Specific volume of 1 kg dry steam, $v = v_g$ m3/kg
   - Specific volume of 1 kg dry steam, $v = \frac{V_{g*}\, t_{sup}}{t}$ m3/kg

- -40^0C of ice is converted 250^0c of steam.

250^0c steam

t

100^0c steam

t

100^0c water

t

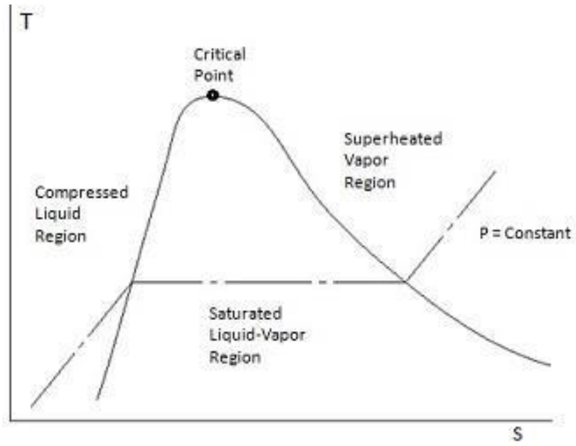
0^0c water

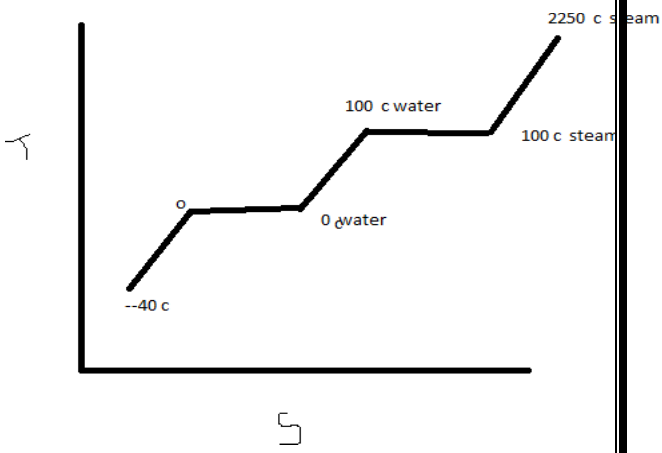
t

0^0c ice

t

-40^0c ice





Steam table and their uses

The properties of dry saturated steam like its temperature of formation (saturation temperature), sensible heat, latent heat of vaporization, enthalpy or total heat, specific volume, entropy etc., vary with pressure and can be found by experiments only. These properties have been carefully determined and made available in a tabular form known as steam tables.

Fig

Steam table format

Absolute Pressure in bar (*P*)	Saturation Temperature in ^{0}C (*t*)	Specific Volume in m^3/kg		Specific Enthalpy in kJ/kg			Specific Entropy in kJ/kg.k		
		Water (v_f)	Steam (v_g)	Water (h_f)	Evaporation (h_{fg})	Steam (h_g)	Water (s_f)	Evaporation (s_{fg})	Steam (s_g)

Problem-01:- Determine the quantity of heat required to produce 1 Kg of steam at a pressure of 6 bar and a temperature of 25 °C. Find the following

(a) When the steam is wet having dryness fraction 0.9
(b) When the steam is dry saturated.
(c) When it is superheated at a constant pressure at 250 degree Celsius. Take CP =2.3.kJ/kg k.

Data given: P= 6 bar, t_w =25 °C ,x = 0.9 , t_{sup} =250 °C ,C_p = 2.3 kJ/kg k
Solution:- From steam tables, corresponding to a pressure of 6 bar, we find that h_f = 670.4 KJ/Kg, h_{fg} = 2085 KJ/Kg, and t =158.8 °C

- **when the steam is wet:-**

Enthalpy of 1kg of wet steam, h = h_f + xh_{fg} = 670.4 +0.9x 2085 =2546.9 KJ
since the water is at a temperature of 25°C , therefore
heat already in water = 4.2x25 =105 KJ
so, heat actually required = 2546.9 -105 =2441.9 KJ (Ans)

- **when the steam is dry saturated:-**

Enthalpy of 1kg of dry saturated steam, h = h_f + h_{fg} = 670.4 + 2085 =2755.4 KJ
so, heat actually required = 2755.4 -105 =2650.4 KJ (Ans)

- **when the steam is superheated:-**

Enthalpy of 1kg of dry superheated steam, h_{sup} = h_{fg}+Cp(t_{sup}-t)

= 2755.4+ 2.3(250-158.8) =2965.16 KJ
so, heat actually required = 2965.16 -105 =2860.16 KJ (Ans)

Problem-02: -Steam enters in engine at a pressure of 12 bar with A 67°C superheat. It is exhausted at a pressure of 0.15 bar and 0.95 dry. Find the drop in enthalpy of the steam.

Data given:- P_1= 12 bar, t_{sup}- t_{sat} = 67 °C, P_2 = 0.15 bar, x = 0.95

From steam tables, corresponding to a pressure of12 bar, we find that

h_f = 798.4 kJ/kg

h_{fg} = 1984.3 kj/ kg

Solution: Enthalpy of 1kg of superheated steam, $h_{sup} = h_f + h_{fg} + Cp(t_{sup} - t)$

= 798.4+ 1984.3+2x 67 =2916.7 KJ.............................(taking Cp= 2 KJ/kg K)

From steam tables, corresponding to a pressure of0.15bar, we find that

h_f = 226 kJ/kg

h_{fg} = 2373.2 kJ/ kg

Enthalpy of 1kg of wet steam, $h = h_f + xh_{fg}$ = 226 +0.95x 2373.3 =2480.63KJ

Drop in enthalpy of the steam = h_{sup}-h = 2916.7 - 2480.63KJ =436.07KJ (Ans)

Problem – 03:- Determine the volume of 1 kg of superheated steam at a pressure of 20 bar at a temperature of 300 degree Celsius.

Data given:-p =20 bar, t_{sup} = 300 ℃ =300+273 =573 K

Let V_{sup}= volume of 1 kg of superheated steam.

From steam tables, corresponding to a pressure of 20 bar, we find that

t =212.4℃ = 212.4+273 = 485K, Vg = 0.1 m3/kg

Solution :

The superheated steam obeys Charle's law.

⇨ $\frac{Vg}{t} = \frac{Vsup}{tsup}$

⇨ $Vsup = \frac{Vg}{t} * tsup = \frac{0.1}{485.4} * 573$ = 0.118 m3 (ans)

SHORT QUESTIONS WITH ANSWERS

1. What is sensible heat of water?

Ans:-It is the amount of heat absorbed by 1 kg of water, when heated at a constant pressure , from the freezing point (0^0**c)** to the temperature of formation of steam, i.e saturation temperature (t). the sensible heat is also known liquid heat.

The specific heat of water at constant pressure is 4.2 kj/kg k. therefore heat absorbed by 1kg of water from 0^0c to t ^{0}c or sensible heat

= mass x sp.heat x rise in temperature= 1 x 4.2 {(t+273)-(0+273)} =4.2t kJ/kgk.

2. What is a dryness fraction? 2017(W) ,2018 (W)

Ans- It is defined as the ratio of the mass of actual dry steam to the mass of same quantity of wet steam. It is usually expressed by the symbol 'x'.

Mathematically, $x = \frac{m_g}{m_g + m_f}$

m_g = mass of actual dry steam

m_f = mass of wet steam. = $m_g + m_f$

3. Define total heat of wet steam? 2008(W)

Ans- it may be defined as the quantity of heat required to convert 1 kg of water at 0°c at constant pressure into which stream it is represented by h.

$h = h_f + xh_{fg}$

4. What is the degree of superheat?

Ans- it is the difference between the temperature of superheated steam and saturation temperature corresponding to the given (t_{sup}-t).

5. Define steam and it's uses? 2019(W) ,2019 (S)

Ans- steam is water in gas phase. This may occur due to evaporation or due to boiling, where heat is applied until water reaches the enthalpy of vaporization. Steam is used in running turbines, for humidifying, for storing food etc.

6. What is meant by saturation temp and saturation pressure? 2014

Ans- the temperature at which the liquid start boiling is called saturation temperature or boiling point. The pressure corresponding to saturation temperature is called saturation pressure.

POSSIBLE LONG QUESTIONS

1. Find the total heat for 5 kg of stream at 3.2 bar when
   i. Steam is0. 92wet
   ii. Dry and saturated
   iii. Superheated to a temp 320°c [2012 W]

2. Steam is being generated in a boiler under a pressure of 10 bar. Find the total heat of 100kg of steam when
   i. Steam is dry saturated
   ii. When x=0•92 [2011 W]

3. Determine the conditions of steam from the following data:
   a) Pressure is 10 bar and temperature 200°C,
   b) Pressure is 12 bar and enthalpy of 2600 kJ/kg.

   Solution: a)P = 10 bar, T= 200°C From steam tables, at pressure of 10 bar,
   Tsat= 179.88°C
   Since the saturation temperature {179.88 °C} is less than given steam temperature of [200°C], therefore the steam is superheated.
   ∴Degree of superheat = T- Tsat = 20.12 °C

CHAPTER 3

BOILER

Learning objectives

Introduction: -

Classifications or Types of Boilers:

Construction And Working Of Cochran And Babcock And Wilcox Boiler

Boiler mountings and accessories:

Introduction: -

- A steam boiler or steam generator is a closed vessel in which water is heated, vaporized and converted into steam at a pressure higher than atmospheric pressure.
- A Boiler is the biggest and most critical part of a thermal power plant.
- Applications of Boiler:
  - Operating steam engines.
  - Operating steam turbines.
  - Operating reciprocating pumps.
  - Industrial process works in chemical engineering.
  - For producing hot water required to be supplied to room in very cold areas.
  - In thermal power stations.

3.1 Classifications or Types of Boilers:

There are large number of boiler designs, but they may be classified according to the following ways:

1. According to the circulation of gases:
   a) Fire-tube boiler
   b) Water-tube boiler
2. According to Circulation of water:
   a) Free circulation
   b) Forced circulation
3. According to the number of tubes used:

a) Single tube boiler
b) Multi-tube boiler

4. According to the nature of use:

a) Stationary boilers
b) locomotive boilers
c) Marine boilers.

5. According to the nature of the fuels used:

a) Fuel-fired
b) Gas fired
c) Liquid fuel fired
d) Electrically fired
e) Nuclear fired

6. According to the pressure of the boiler:

a) High-pressure boiler
b) Medium-pressure boiler
c) Low-pressure boiler

7. According to the position of the axis of the boiler shell:

a) Vertical boiler
b) Horizontal boiler

3.2 Construction And Working Of Cochran And Babcock And Wilcox Boiler

COCHRAN BOILER

Cochran boiler is a fire tube boiler (Fire inside the boiler and water surrounding to them) in which coal or gases as a working fluid is used, for generating the steam and that steam further used for several purposes.

Construction:

Cochran Boiler consists of the following important Parts:

1. Grate
2. Fire door
3. Ash Pit
4. Flue gases
5. Combustion Chamber
6. Smoke Box

7. Chimney
8. Water level Indicator
9. Man Hole
10. Pressure gauge
11. Safety Valve
12. Steam stop valve
13. anti-Priming Pipe
14. A blow of valve

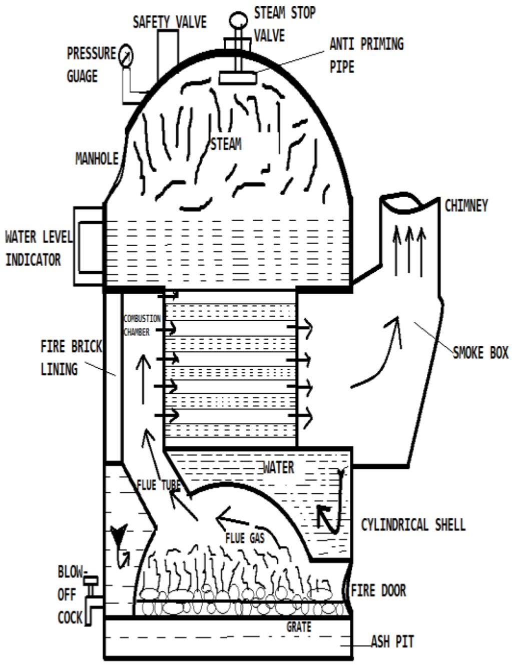


FIG: COCHRAN BOILER

1. Grate: It is the door for placing the fuel.

2. Fire door: The fire is provided through the fire door to start burning of fuel inside the boiler.

3. Ash Pit: Here, ashes are accumulated under the fire. The Ashpit is located below the grate.

4. Flue gases: When the burning of fuel starts, it produces flue gases which is already heated and used for heating the water.

5. Combustion Chamber: Here burning of fuel takes place having huge amount of heat. This heat sends to the fire tube for heating the surrounded water.

6. Smoke Box: The smokebox is basically used for storing and releasing the smokes to the chimney during the working process of the boiler.

7. Chimney: When the flue gas is completely utilised and it remains only smoke, the smoke further comes to the smokebox and Smokebox send smoke to the chimney. Here smoke is released to the atmosphere.

8. Water level Indicator: It is a measuring instrument. It measures the level of water and gives the detail of the water level.

9. Man Hole: It is a very important side of the boiler. When things get damaged and not working, then a boiler specialist enters through the Man Hole and fixes the damaged parts.

10. Pressure gauge: We use this instrument in several places. The works are to measure the pressure of the steam of the boiler.

11. Safety Valve: It is to prevent an increase in steam pressure. When the pressure increases above design pressure, the valve opens and discharges the steam to the atmosphere and,

    When this pressure falls just below the design pressure, the valve closes automatically. Usually, the valve is spring controlled.

12. Steam stop valve: The steam stop valve regulates the supply of steam outside.

13. A blow of valve: Water contains some impurities like mud, sand, and salt. Due to the heating of water, these impurities deposited to the ground that creates a problem and it has to be removed. So the Blow-off-valve is used for removing these things.

Working

- Working of the Cochran boiler is from the grate the fuel gases or coal are used and that is inserted.
- From the firing door, the fire is provided to start the burning of fuel.
- The burning of fuel generates the hot flue gases and it comes to the combustion chamber. Here almost temperature is maximum.
- We know this is a fire tube boiler. In the tube, hot flue gases passing and water is surrounded.
- So the hot flue gases are passing through tubes. The hotness of the fire tube starts heating the surrounded water. The water starts evaporating and at some point it becomes steam.
- Now the steam comes at the top of the boiler.
- With the use of an Anti-priming pipe, the complete steam is extracted from the boiler and here the steam stop valve is placed which works is to transfer the steam to other laces such as the turbine and so on.
- When the fuel is burned completely and it becomes ash it comes down to the ash pit and the smoke is released to the chimney and to the atmosphere.

BABCOCK AND WILCOX BOILER

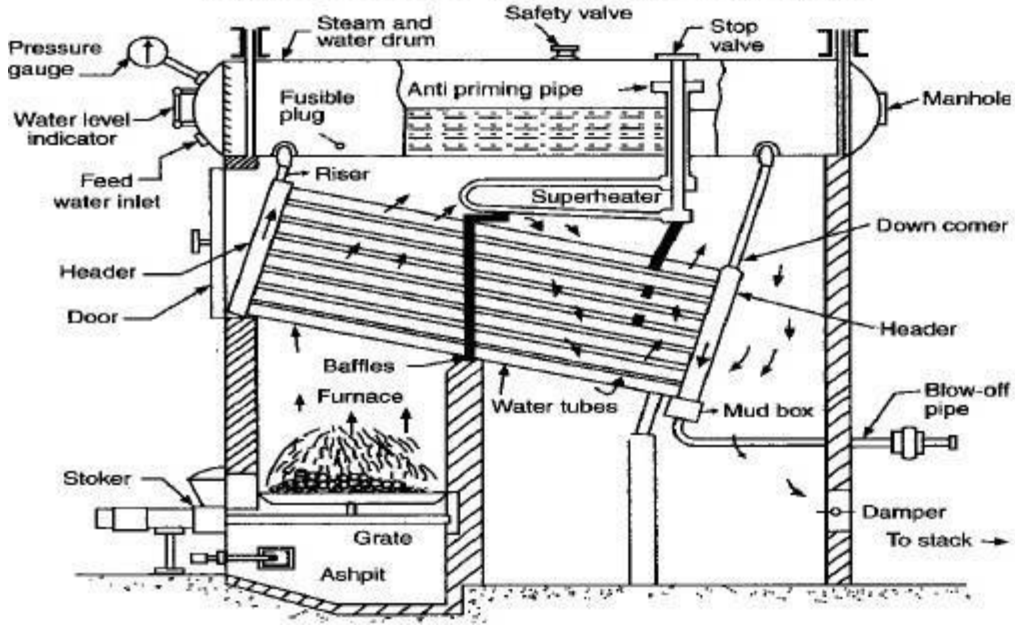
Babcock and Wilcox Boiler is a water tube boiler which is a multi-tubular, high pressure and externally fired water tube boiler used to generate a large amount of steam.

Construction:

The important parts of Babcock and Wilcox Boiler is as follows.

1. Steam and water drum (boiler shell)
2. Uptake-header and Down Take Header
3. Water tubes
4. Superheater
5. Grate
6. Furnace
7. Baffles
8. Mud box
9. Inspection doors
10. Water Level Indicator

BABCOCK & WILCOX BOILERS



1 Boiler Shell: It consists of one or more steel plates bent into a cylindrical form and riveted or welded together. The shell and ends are closed with the endplates.
2. Uptake-header and Down Take Header: Boiler shell and water tubes are connected by the two tubes. Out of them, one is Up Take header and the other is Down Take Header.

- Uptake Header: The steam from the water tubes to the drum flow by means of UpTake Header.
- Down Take Header: The water flows from the drum to the water tubes by means of down take header.

3. Water Tubes: The angle of inclination of the water tubes to the horizontal is about 15 degrees. In this boiler, water will flow from the drum by means of tubes only.
4. Superheater: It increases the temperature of saturated steam.
5. Grate: It is the platform in the furnace upon which fuel is burnt.
6. Furnace: It is a chamber formed by the space above the grate and below the boiler shell in which combustion takes place. It is also called a firebox.
7. Baffles: The baffles are provided to deflect the hot flue gases so that the water tubes experience more amount of heat.
8. Mud Box: All the impurities which are present in the boiler are deposited at the bottom and are stored in the mud box.
9. Inspection doors: They are provided for cleaning and inspection of the boiler.
10. Water Level Indicator: It is the indicator, which shows the level of water in the shell.

Working:

- The entire boiler except for the furnace, are hung by means of metallic slings or straps or wrought iron girders supported on pillars.
- This arrangement enables the drum and the tube to expand or contract freely.
- The angle of inclination of the water tubes to the horizontal is about 15 degrees.
- A feed valve is provided to fill the drum and the inclined tubes with the water level of which is indicated by the water level indicator.
- Through the fire door, the fuel is supplied to the fire grate and it is burnt. The hot gases are forced to move upwards between the tubes by the baffle plates.
- The system consists of a Down Take Header (DTH) and Uptake Header (UTH) which consists of holes in which a series of Inclined water tubes are fixed.
- The water from the drum flows through the inclined tubes via down-take header and goes back into the shell in the form of steam and water mixture via UTH (Up Take Header).
- The steam is collected in the steam space of the drum.
- The steam enters through the APP (Anti-Priming Pipe) and flows in the ST(Superheater Tubes), where it converts from Wet steam to Dry saturated steam and it is taken out from MSV(Main Stop Valve) and feed to the turbine.
- At the lowest point of the boiler, the mud and dirt collect which is pumped out through Blow-off Cock.

Boiler mountings and accessories:

Boiler mountings

Boiler mountings are those mechanical appliances which are considered essential for operating a boiler smoothly and safely which are usually mounted on the surface of a boiler**.**

The followings are the important mountings of a boiler:

1. Water level indicator
2. Pressure gauge
3. Safety valve
4. Fusible plug
5. Steam stop valve
6. Blowoff valve or blowdown valve
7. Feed check valve

1. Water level indicator:

It is an important fitting, which indicates the water level inside the boiler to an observer. It is a safety device upon which the correct working of the boiler depends. This fitting may be seen in front of the boiler, and are generally two in number. A water level indicator, mostly employed in the steam boiler is shown in Fig.3.3. It consists of the cocks and a glass tube. Steam cock C1 Keeps the glass tube in connection with the steam space. Water cook C2 Puts the glass tube in connection with the water in the boiler. Drain cock C3 is used at frequent intervals to ascertain that the steam and water cocks are clear. In the working of a steam boiler and for the proper functioning of the water level indicator, the steam and water cocks are opened and the drain cock is closed.

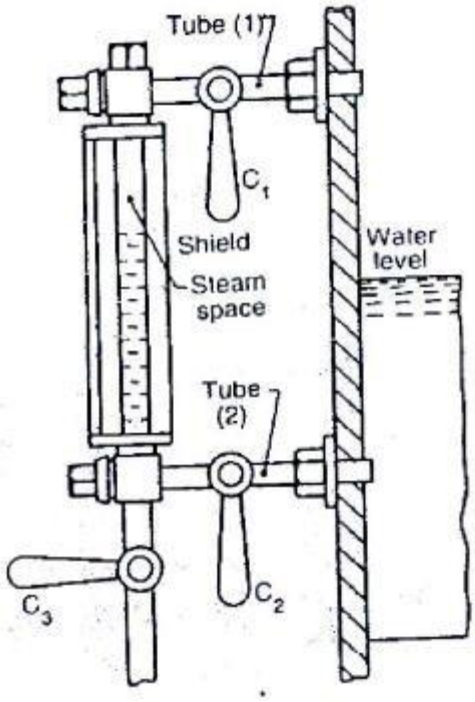
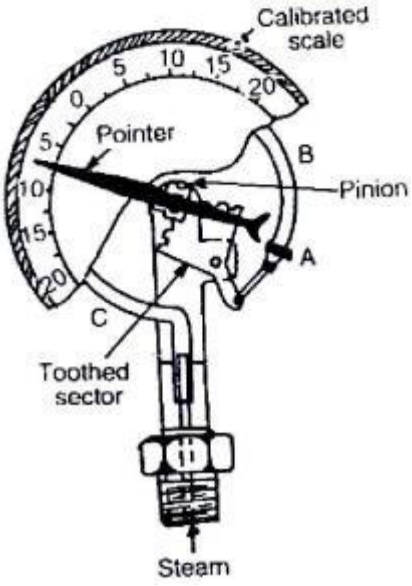


Fig. 3.3 Water level indicator

2. Pressure gauge

A pressure gauge is used to measure the pressure of the steam inside the steam boiler. It is fixed in front of the steam boiler. The pressure gauges generally used are of bourden type. A bourden pressure gauge, in its simplest form, consists of an elliptical elastic tube ABC bent into an arc of a circle, as shown in Fig. This bent up tube is called bourden's tube. One end of the tube gauge is fixed and connected to the steam space in the boiler. The other end is connected to a sector through a link. The steam, under pressure, flows into the tube. As a result of this increase pressure, the bourden's tube tends to straighten itself. Since the tube is encased in a circular curve, therefore it tends to become circular instead of straight. With the help of a simple pinion and sector arrangement, the elastic deformation of the bourdens tube rotates the pointer. This pointer moves over a calibrated scale, which directly gives the gauge pressure.



3. Safety valves

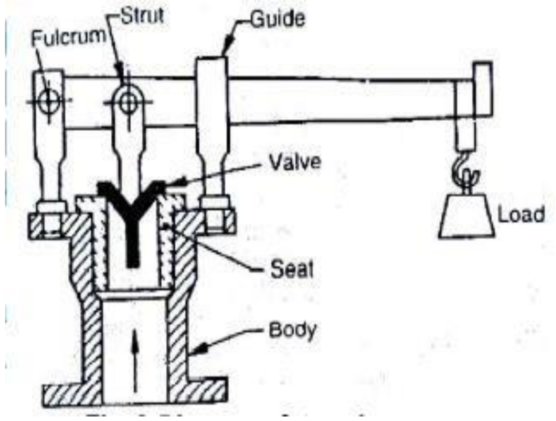
These are the devices to the steam chest for preventing explosions due to excessive internal pressure of steam. In brief, the function of a safety valve is to blow off the steam when the pressure of steam inside the boiler exceeds the working pressure.

The following are the four types of safety valves :

(i) Lever safety valve,
(ii) Dead weight safety valve

(iii) High steam and low water safety valve
(iv) Spring loaded safety valve.

(i) Lever safety valve



A lever safety valve used on steam boiler is shown Fig. It serves the purpose of maintaining constant safe pressure inside the steam boiler. If the pressure inside the boiler exceeds the designed limit, the valve lifts from its seat and blows off the steam pressure automatically

(ii) Dead weight safety valve

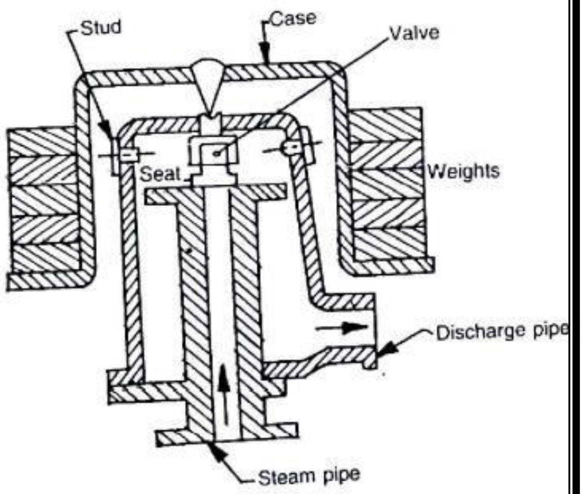


Fig. 3.6 Dead weight safety valve

The valve is made of gun metal, and rests on its gun metal seat. It is fixed to the top of a steel pipe. This pipe is bolted to the mountings block, riveted to the top of the shell. Both the valve and the pipe are covered by a case which contains weights. These weights keep the valve on its seat under normal working pressure. The case hangs freely over the valve to which it is secured by means of a nut. When the pressure of steam exceeds the normal pressure, the valve as well as the case (along with the weights) are lifted up from its seat. This enables the steam to escape through the discharge pipe, which carries the steam outside the boiler house

(iii) High steam and low water safety valve

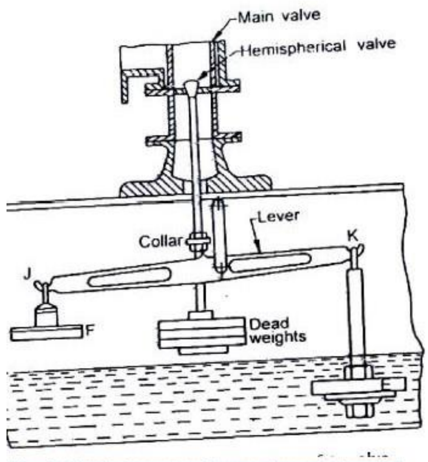


Fig. 3.7 High steam and low water safety valve

It is combination of two valves, one of which is the lever safety valve which blows off steam when the working pressure of steam exceeds. The second valve operates blowing off the steam when the water level becomes too low. It consists of a main valve (known as lever safety valve) and rests on its seat. In the centre of the main valve, a seat for a hemispherical valve is formed for low water operation. This valve is loaded directly by the dead weights attached to the valve by a long rod. There is a lever J.K, which has its fulcrum at K. the lever has weight E suspended at the K. when it is fully immersed in water, it is balanced by a weight F at the other end J of the lever. Fig. 3.6 When the water level falls, the weight E comes out of water and the weight F will not be sufficient to balance weight E. Therefore, weight E comes down. There are two projections on the lever to the left of the fulcrum which comes in contact with a collar attached to the rod. When weight E comes down, the hemispherical valve is lifted up and the steam escapes with a loud noise, which warns the operator. A drain pipe is provided to carry water, which is deposited in the valve casing.

(iv) Spring loaded safety valve.

A spring-loaded safety valve is mainly used for locomotives and marine boilers. It is loaded with spring instead of weights in compression. It consists of a cast iron body connected to the top of a boiler. It has two separate valves of the same size. These valves have their seatings in the upper ends of two hallow valve chests. These valve chests are united by a bridge and a base. The base is bolted to a mounting block on the top of a boiler over the fire box. The valves are held down by means of a spring and a lever. The lever has two pivots E and F. The upper end of the spring is hooked to the arm H, while the lower end of the shackle, which is secured to the bridge by a nut By pulling or raising the lever, the driver can release the pressure from either valve separately.

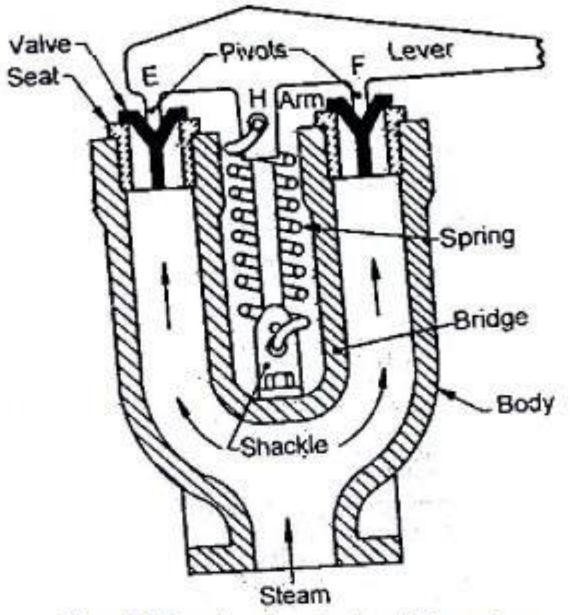


Fig. 3.8 Spring loaded safety valve

5. Steam Stop valve

It is the largest valve on the steam boiler. It is, usually, fitted to the highest part of the shell by means of a flange as shown in Fig. 3.9. The principal functions of a stop valve are:

1. To control the flow of steam from the boiler to the main stream pipe.
2. To shut off the steam completely when required.

The body of the stop valve is made of cast iron or cast steel. The spindle passes through a gland and stuffing box. The spindle is rotated by means of a hand wheel. The upper portion of the spindle is screwed and made to pass through a nut in across head carried by two pillars. The pillars are screwed in the cover of the body. The boiler pressure acts under the valve, so that the valve must be closed against the pressure. The valve is, generally, fastened to the spindle which lifts it up. A non-return valve is, sometimes, fitted near the stop valve to prevent the accidental admission of steam from other boilers. This happens when a number of boilers are connected to the same pipe, and when one is empty and under repair

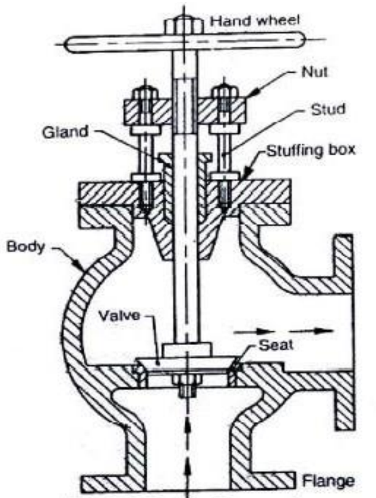


Fig. 3.9 Steam Stop valve

Boiler Accessories

These are the devices which are used as integral parts of a boiler, and help in running efficiently. Though there are many types of boiler accessories, yet the following are important from the subject point of view :

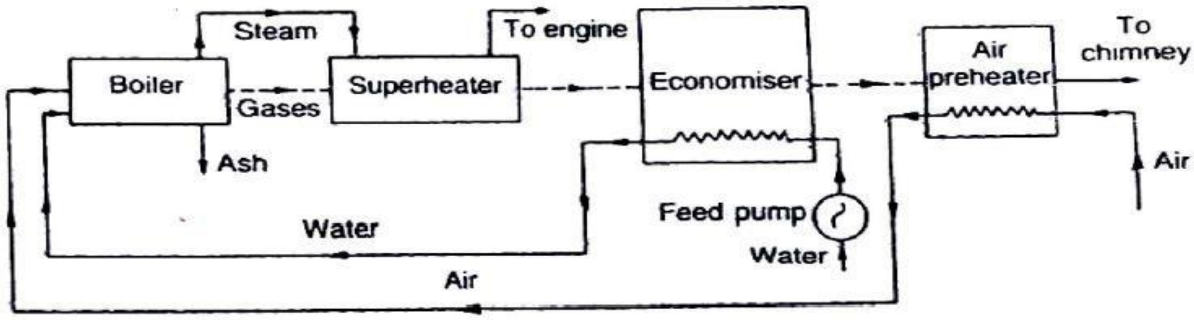
1. Feed pump

2. Superheater

3. Economiser and

4. Air Preheater

Fig. 3.13. shows the schematic diagram of a boiler plant with the above-mentioned accessories



1. Feed Pump

We know that water, in a boiler, is continuously converted into steam, which is used by the engine. Thus we need a feed pump to deliver water to the boiler.

The pressure of steam inside a boiler is high. So the pressure of feed water has to be increased

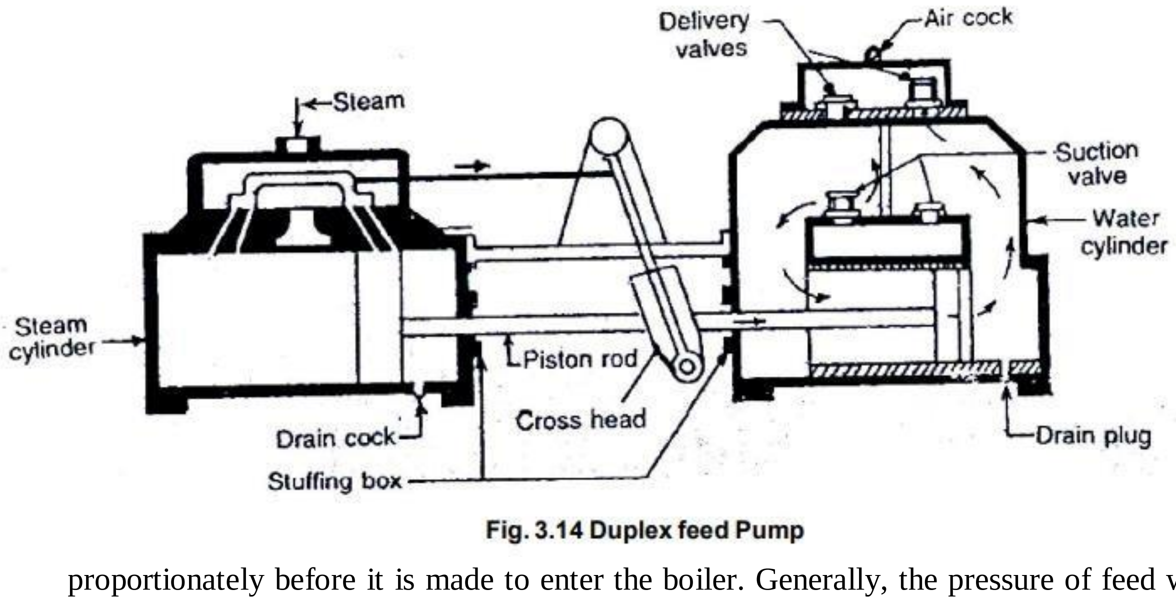


Fig. 3.14 Duplex feed Pump

proportionately before it is made to enter the boiler. Generally, the pressure of feed water is 20% more than that in the boiler.

A feed pump may be of centrifugal type or reciprocating type. But a double acting reciprocating pump is commonly used as a feed pump these days. The reciprocating pumps are run by the steam from the same boiler in which water is to be fed. These pumps may be classified as simplex, duplex and triplex pumps according to the number of pump cylinders. The common type of pump used is a duplex feed pump, as shown in Fig. 3.14. This pump has two sets of suction and delivery valves for forward and backward stroke. The two pumps work alternately so as to ensure continuous supply of feed water.

2. Superheater

A superheater is an important device of a steam generating unit. Its purpose is to increase the temperature of saturated steam without raising its pressure. It is generally an integral part of a boiler, and is placed in the path of hot flue gases from the furnace. The heat, given up by these flue gases, is used in superheating the steam.

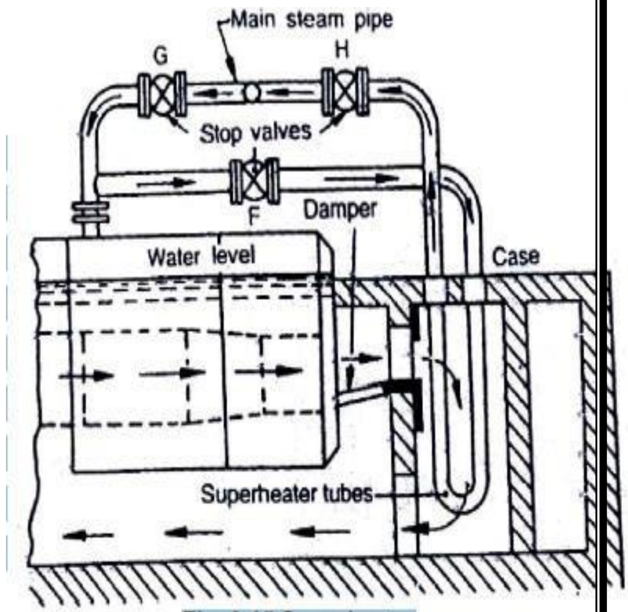


Fig. 3.15 Superheater

A Sudgen's superheater commonly employed with Lancashire boilers is shown in Fig. 3.15. It consists of two mild steel boxes or heaters from which hangs a group of solid drawn tubes bent to U form. The ends of these tubes are expanded into the headers.

The steam enters at one end of the rear header and leaves at the opposite end of the front header. The superheater is in action when the damper is in a position as shown in the figure. If the damper is in vertical position, the gases pass directly into the bottom flue without passing over the superheater tubes. In this way, the superheater is out of action. By placing the damper in intermediate position, some of the gases will pass over the superheater tubes and the remainder will pass directly to the bottom flue. It is thus obvious, that required degree of heat for superheating may be obtained by altering the position of the damper. It may be noted that when the superheater is in action, the stop valves G and H are opened and F is closed. When the steam is taken directly from the boiler, the valves G and H are closed and F is open.

3. Economiser

An economiser is a device used to heat feed water by utilising the heat in the exhaust flue gases before leaving through the chimney. As the name indicates, the economiser improves the economy of the steam boiler. A well-known type of economiser is Greens economiser. It is extensively used for stationary boilers, especially those of Lancashire type. It consists of a large number of vertical pipes or tubes placed in an enlargement of the flue gases between the boiler and chimney as shown in Fig. 3.16. These tubes are 2.75 meters long, 114 mm in external diameter and 11.5 mm thick and are made of cast iron.

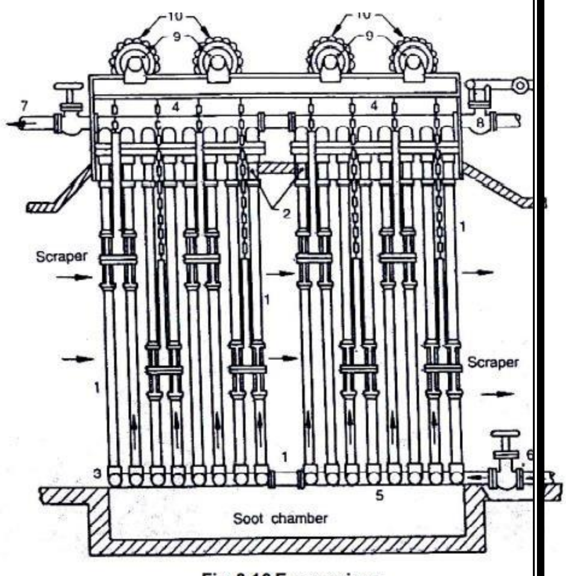


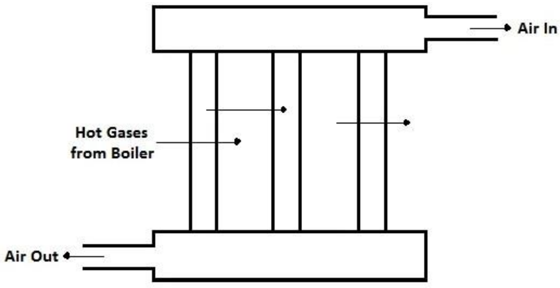
Fig. 3.16 Economiser

The feed water is pumped into the economiser at (6) and enters the pipe (5). It then passes into the bottom boxes (3) and then into the top boxes (2) through the tubes (1). It is now led by the pipe (4) to the pipe (7) and then to the boiler.

It is essential that the vertical tubes may be kept free from deposits of soot, which greatly affect efficiencies of the economiser. Each tube is provided with scraper for this purpose.

4. Air Preheater

An air preheater is used to recover heat from the exhaust flue gases. It is installed between the economiser and the chimney. The air required for the purpose of combustion is drawn through the air preheater where its temperature is raised. It is then passed through ducts to the furnace. The air is passed through the tubes of the heater internally while the hot flue gases are passed over the outside of the tubes. The following advantages are obtained by using an air preheater:



Air Pre-heater

1. The preheated air gives higher furnace temperature which results in more heat transfer to the water and thus increases the evaporative capacity per kg of fuel.

2. There is an increase of about 2% in the boiler efficiency for each 35-40° C rise in temperature of air.

3. It results in better combustion with less soot, smoke and ash. It enables a low-grade fuel to be burnt with less excess air.

POSSIBLE SHORT QUESTIONS

1. What is a Boiler? 2019 (S)

Ans: - A steam boiler or steam generator is a closed vessel in which water is heated, vaporized and converted into steam at a pressure higher than atmospheric pressure.

A Boiler is the biggest and most critical part of a thermal power plant.

2. What is boiler mountings? 2019 (W), 2020(W)

Ans: - Boiler mountings are those mechanical appliances which are considered essential for operating a boiler smoothly and safely which are usually mounted on the surface of a boiler.

Example: - Water level indicator, Pressure gauge, Safety valve etc.

3. Name two accessories of boiler? 2018(W)

Ans: - the two accessories of boiler are feed pump and economiser.

4. Write the difference between mounting and accessories? 2020(W)

Ans: - Boiler Mountings

- Boiler mountings are components used for ensuring the safety of boiler operation.
- These are generally mounted on the surface of the boiler.
- Control fluid parameters at the inside of the boiler shell.

- The mountings are an essential part of a boiler, without which boiler operation is impossible.

Examples: Pressure gauges, Water level indicator, Safety valves, Stop valve, Fusible plug, Blow-off cock, etc.

Boiler Accessories

- Accessories are the auxiliary items required for proper operation of boiler and improve the Boiler efficiency of it.
- These are integral parts of the boiler, but not mounted on it.
- Control fluid parameters at outside of the boiler.
- These are not essential parts of the boiler, without which boiler can operate through at lower efficiency.

Examples: Superheater, Feed pump, Injector, Economizer, Steam Separator, Air preheater**, etc**.

5. Define grate? 2019(S)

Ans: - A furnace grate is provided in a steam boiler furnace for supporting the solid fuel in the furnace. Grate is so designed that it can also allow air to admit air in the solid fuel for combustion

POSSIBLE LONG QUESTIONS

1. State the classification of boiler? 2019(W)
2. With a neat sketch explain the construction and working of Cochran Boiler? 2017(w),2019 (S)
3. With a neat sketch explain the construction and working of Babcock-Wilcox Boiler? 2012(w)
4. What do you mean by Boiler mountings and accessories? List out them and explain one from each ? 2019(S)

…………………………………………………………………………………………..

CHAPTER 4

STEAM ENGINE

Learning objectives

Introduction

Explain The Principle Of Simple Steam Engine: -

Indicator Diagram of a Simple Steam Engine

Mean Effective Pressure, IHP, BHP and Mechanical Efficiency.

4.0 Introduction

In all steam engines, the steam is used as the working substance. These engines operate on the principle of first law of thermodynamics, i.e. heat and work are mutually convertible. In a reciprocating steam engine, as the heat energy in the steam is converted into mechanical work by the reciprocating (to and fro) motion of the piston, it is also called reciprocating steam engine. Moreover, as the combustion of the fuel takes place outside the engine cylinder, it is also called an external combustion engine.

4.1 Explain the Principle of Simple Steam Engine: -

Important Parts of a Steam Engine

All the parts of a steam engine may be broadly divided into two group's i.e. stationary parts and moving parts. The following are important from the subject point of view :

1. Frame- It is a heavy cast iron part, which supports all the stationary as well as moving parts and holds them in proper position.

2. Cylinder- It is also a cast iron cylindrical hollow vessel, in which the piston moves.

3. Steam chest- It supplies steam to the cylinder with the movement of D-slide valve.

4. D-slide valve- It moves in the steam chest with simple harmonic motion. Its function is to exhaust steam from the cylinder at proper movement.

5. Inlet and exhaust ports- These are holes provided in the body of the cylinder for the movement of steam.

6. Piston - It is a cylindrical disc, moving to and fro, in the cylinder because of the steam pressure to convert heat energy of the steam into mechanical work.

7. Piston rod - It is a circular rod, which is connected to the piston on one side and cross head to the other. Its main function is to transfer motion from the piston to the cross-head.

8. Cross head - It is a link between the piston rod and connecting rod. Its function is to guide motion of the piston rod and to prevent it from bending.

9. Connecting rod- It is made of forged steel, whose one end is connected to the cross head and the other to the crank. Its function is to convert reciprocating motion of the piston into rotary motion of the crank.

10. Cranks shaft- It is the main shaft of the engine having a crank.

11. Eccentric - It is generally made of cast iron, and is fitted to the crank shaft. Its function is to provide reciprocating motion to the slide valve.

12. Eccentric rod and valve rod- The eccentric rod is made of forged steel, whose one end is fixed to the eccentric and other to the valve rod. Its function is to convert rotary motion of the crankshaft into to and fro motion of the valve rod.

13. Flywheel- It is a heavy cast iron wheel, mounted on the crank shaft. Its function is to prevent the fluctuation of engine. It also prevents the jerks to the crankshaft.

14. Governor- It is a device to keep the engine speed, more or less, uniform at all load conditions. It is done either by controlling the quantity or pressure of the steam supplied to the engine.

Working of a Single Cylinder Double Acting Horizontal Reciprocating Steam Engine

The superheated steam at a high pressure (about 20 atmospheres) from the boiler is led into the steam chest. After that the steam makes its way into the cylinder through any of the ports ‘a’ or ‘b’ depending upon the position of the D-slide valve. When port ‘a’ is open, the steam rushes to the left side of the piston and forces it to the right. At this stage, the slide valve covers the exhaust port and the other steam port ‘b’. Since the pressure of steam is greater on the left side than that on right side, the piston moves to the right.

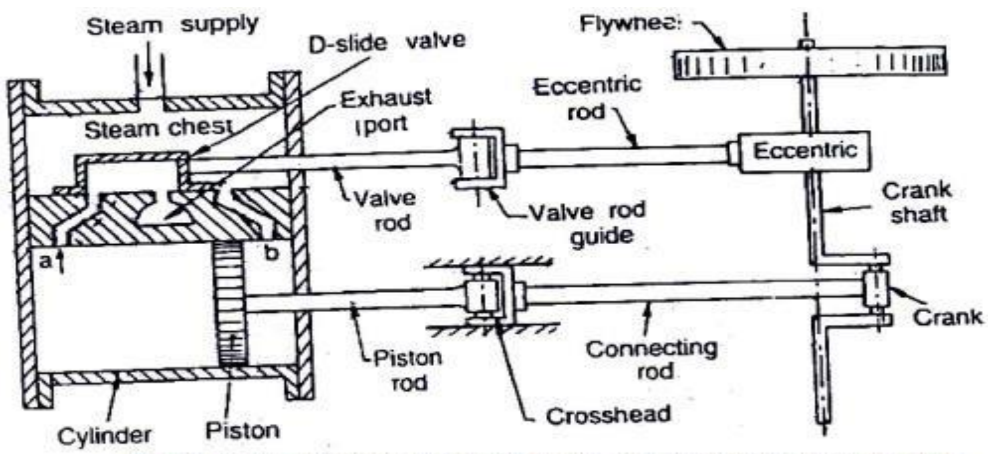


Fig. 4.1 Single cylinder, double acting horizontal reciprocating steam engine

When the piston reaches near the end of the cylinder, it closes the steam port ‘a’ and exhaust port. The steam port ‘b’ is now open, and the steam rushes to the right side of the piston. This forces the piston to the left and at the same time the exhaust steam goes out through the exhaust pipe, and thus completes the cycle of operation. The same process is repeated in other cycles of operation, and as such the engine works.

Important Terms used in Steam Engines

1. Bore- The internal diameter of the cylinder of the engine is known as bore.

2. Dead centre’s- The extreme positions of the piston inside the cylinder during its motion are known as dead centre’s. There are two dead centre’s, i.e. (a) Inner dead centre (I.D.C.), and (b) Outer dead centre (O.D.C.). In a horizontal engine, the inner most position of the piston (towards the cylinder cover end) is known as inner dead centre, whereas the outer most position of the piston towards the crank end is called outer dead centre.

3. Clearance volume- The volume of space between the cylinder cover and the piston, when the piston is at I.D.C. position is called clearance volume .It is usually represented as a percentage of stroke volume.

4. Stroke volume or swept volume- The volume swept by the piston when it moves from I.D.C. to O.D.C., is known as stroke volume or swept volume V_s. It is also known as piston displacement. Mathematically,

stroke volume or swept volume = $V_S = \frac{\pi}{4} \times D^2 \times L$

where D = Bore or internal diameter of the cylinder, and L = Length of the stroke.

1. Cut-off volume- Theoretically, the steam from the boiler enters the clearance space and pushes the piston outward doing external work. At some point during outward movement of the piston, the supply of steam is stopped. The point or the volume where the cut-off of steam takes place is called the point of cut-off or cut-off volume.

4.2 Indicator Diagram of a Simple Steam Engine

It is a graphical representation of the variation in pressure and volume of steam inside the cylinder or p-v diagram.

The theoretical or hypothetical indicator diagram without clearance and with clearance is shown in Fig. 4.3.

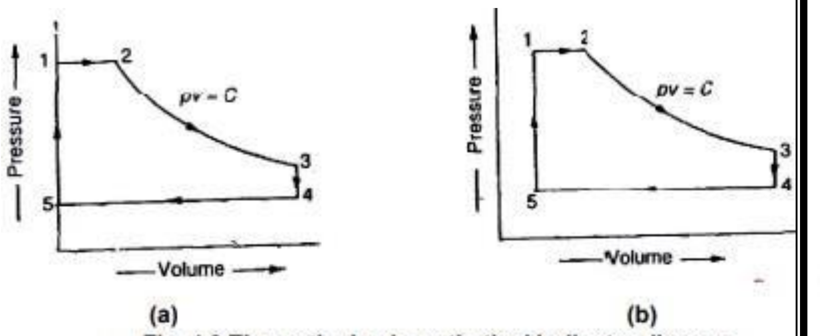


Fig. 4.3 Theoretical or hypothetical indicator diagram

The sequence of processes is given below :

1. Process 1-2 - At point 1, the steam is admitted into the cylinder through the inlet port. As the piston moves towards right, therefore the steam is admitted at constant pressure. Since the supply of steam is cut off at point 2, therefore this point is known as cut-off point.

2. Process 2-3- At point 2, expansion of steam, in the cylinder, starts with movement of the piston till it reaches the dead end. This expansion takes place hyperbolically (i.e. PV=C) and pressure falls considerably .

3. Process 3-4- At point 3, the exhaust port opens and steam is released from the cylinder to the exhaust. As a result of steam exhaust, pressure in the cylinder falls suddenly (without change in volume). The point 3 is known as release point.

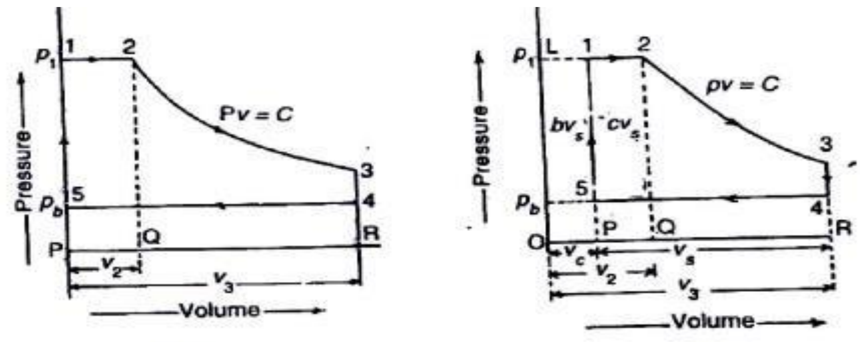
4. Process 4-5- At point 4, return journey of the piston starts. Now the used steam is exhausted at constant pressure, till the exhaust port is closed, and the inlet port is open. The steam pressure at point 4 is called back pressure.

5. Process 5-1- At point 5, the inlet port is opened and some steam suddenly enters into the cylinder, which increases the pressure of steam (without change in volume). This process continues till the original position is restored.

4.3 Mean Effective Pressure, IHP, BHP and Mechanical Efficiency.

Mean Effective Pressure

The theoretical or hypothetical mean effective pressure may be determined as discussed below, by considering the theoretical indicator diagram without clearance and with clearance as shown in Fig. 4.4 (a) and (b) respectively



(a) (b)
Fig. 4.4. Theoretical or hypothetical indicator diagram.

Considering the theoretical or hypothetical indicator diagram without clearance The theoretical or hypothetical indicator diagram without clearance is shown in Fig. 4.4 (a).

Let P_1 = Initial or admission pressure of steam (i.e. pressure at point 1) or boiler pressure,

P_b = Back pressure (i.e. pressure at point 4 or 5) or condenser pressure,

V_2 = Volume of steam in the cylinder at the point of cut-off (i.e. volume at point 2),

V_3 = Stroke volume or swept volume or piston displacement volume. It is the volume of steam in the cylinder at the end of stroke (i.e. volume at point 3 or 4)

We know that theoretical or hypothetical work done per cycle = Area of figure 123451 = Area 12 QP + Area 23 RQ - Area 45PR

$= P_1 V_2 + 2.3 P_1 V_2 \log (V_3 / V_2) - P_b V_3$

∴ Theoretical or hypothetical **mean effective pressure**

$$= \frac{\text{Work doneper cycle}}{\text{Storke volume}} = \frac{P1\ V2 + 2.3P1V2\ \log(V3/V2) - PbV3}{V3}$$

$$= P_1 \times \frac{V2}{V3} + 2.3P_1 \times \frac{V2}{V3} \times \log\left(\frac{V3}{V2}\right) - P_b$$

$$= \frac{P1}{r}(1 + 2.3 \log r) - P_b$$

Where ,r = $\frac{V3}{V_2}$ = called expansion ratio

Power developed by a Simple Steam Engine.

The term ‘power’ may be defined as the rate of doing work. It is thus the measure of performance of a steam engine.

Mathematically,

power developed by an engine= $\frac{\text{Work done}}{\text{Timetaken}}$

In S.I system of units, the unit of power is watt (briefly written as W) which is equal to 1 N-m/s or 1 J/s.

In case of steam engines, the following two terms are commonly used for the power developed.

1. Indicated power, and 2. Brake power

Indicated power

The actual power generated in the engine cylinder is called power input or indicated power (briefly written as I.P). Since the instrument used to draw the P-V diagram (from which work done during the stroke is obtained), is known as indicator, that is why this power is called indicated power.

Now consider a simple steam engine, whose indicated power is required to be found out

Let P_a = Actual mean effective pressure in N/m^2

A = Area of the cylinder or piston in m^2

L = Length of the stroke in metres, and

N = Speed of the crankshaft in revolution per minute (r.p.m)

We know that force on the piston = Pressure x Area = P_a x A (in N)

and work done per stroke = P_a x A x L, N-m

∴ Work done per minute = Pa x A x L x N ... (For single acting)

= 2x Pa x A x L x N ... (For double acting)

and indicated power, IP = $\frac{Pa \times A \times L \times N}{60}$ W...(For single acting)

= $\frac{2 \times Pa \times A \times L \times N}{60}$ W... (For double acting)

When the actual mean effective pressure is given in bar, then

indicated power, IP = $\frac{Pa \times 10^5 \; A \times L \times N}{60}$ W...(For single acting)

= $\frac{2 \times Pa \times 10^5 \times A \times L \times N}{60}$ W... (For double acting)

Brake power

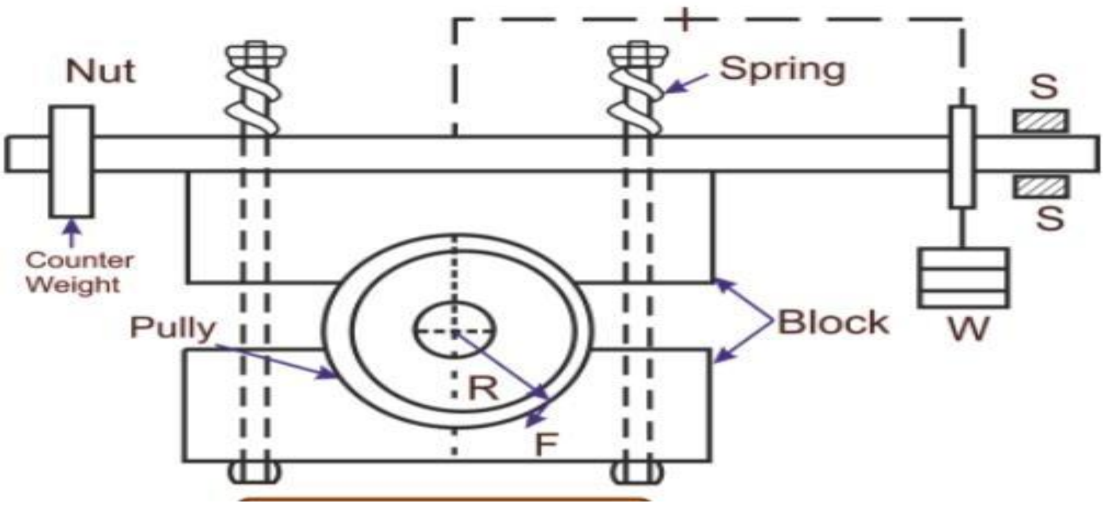
The power available at the crankshaft of an engine is called power output or brake power (briefly written as B.P). It has been observed that the power generated by the engine cylinder is not available at the crankshaft for doing useful work. This happens because some of the power is utilised in overcoming the internal friction of the moving parts of the engine. This power lost in friction is known as frictional power (briefly written as F.P).Thus,

B.P = I.P -F.P

Generally, break power at the steam engine is measured by dynamometer. There are many types of dynamometers available in the market. But absorption type dynamometer is used to measure the break power of the engine. Absorption type dynamometer are two types.

1. Prony break dynamometer
2. Rope break dynamometer

Prony Brake Dynamometer: -



It is a absorption type dynamometer. It consists of two wooden blocks placed around a pulley fixed to the shaft of an engine whose power is required to be measure. The blocks are clamped by means of nuts and bolts. A helical spring is provided between the nut and the upper block to adjust the pressure on the pully to control the speed. A long lever is attached to the upper block and it carries a weight 'W' at the outer end. A counter weight is placed at the opposite side of the lever to balance the unbalanced break power of the engine. Two stops 'S', S is used to limit the motion of the lever.

When the brake is in operation, the lever is located with a load suppose 'W' see in the diagram and the nuts are tightened until shaft runs at a constant speed and the lever is in horizontal position. This condition weight 'W' must balance between the blocks and the pully.
Let,

W = Weight at the outer end of the lever in newtons.

l =Horizontal distance of the weight W from the centre of the pully in meters.

F = Fractional resistance between the blocks and the pully in newtons,

R = Radius of the pully in meters, and

N = Speed of the shaft in r.p.m.

We know that the moment of the frictional resistance or torque on the shaft,

$T = Wl = FR$ N-m

Work done in one revolution = torque x Angle turned in radians = $T \times 2\pi$ N-m

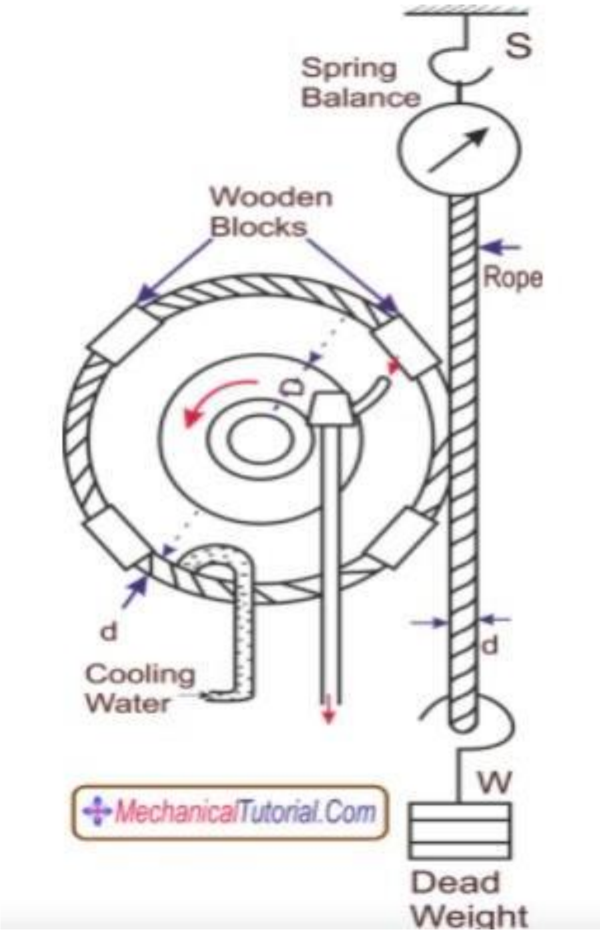
∴ work done per minute = $T \times 2\pi N$ N-m

We know that brake power of the engine,

B.P = $\frac{workdone\ per\ minute}{60} = \frac{T \times 2\pi N}{60} = \frac{l \times 2\pi N}{60}$ watts

Rope Brake Dynamometer: -

It is absorption type dynamometer for measuring B.P of engine. It has a rope winding pully fixed with engine shaft. Upper and lower end of rope is attached with spring balance and dead weight respectively. Wooden block are placed around the circumference of the flywheel to prevent slipping of rope.



Let, W = dead load, N

S = spring balance reading, N

D = diameter of the wheel, m

d = diameter of rope, m

N = speed of engine shaft in r.p.m

∴ Net load on the brake = (W-S) ,N

Distance moved in one revolution =π(D+d) , m

∴ work done per revolution = (W-S) x π(D+d) ,N.m

Work done per minute = (W-S) x π(D+d) N , N.m

∴ Brake power of the engine, B.P $= \frac{work\ done\ per\ minute}{60} = \frac{(W-S) \times \pi(D+d)\ N}{60}$, watts

If the diameter of the rope (d) is neglected, then B.P of the engine, B.P $= \frac{(W-S) \times \pi D\ N}{60}$,watts

Mechanical Efficiency

It is the ratio of brake power (B.P) to the indicated power (I.P).

Mathematically, mechanical efficiency $\eta_m = \frac{B.P}{I.P}$

1.4. Solved simple problems: -

Numerical 1: -

A steam engine cylinder receives steam at a pressure of 11.5 bar and cut-off takes place at half of the stroke. Find the theoretical mean effective pressure, if the back pressure of the steam is 0.15 bar. Neglect clearance.

Solution Given P1 = 11.5 bar; $V_2 = 0.5\ V_3$; P_b=0.15 bar

We know that expansion ratio,

$$r = \frac{V_3}{V_2} = \frac{V_3}{0.5V_3} = 2$$

We know that theoretical mean effective pressure,

$$P_m = \frac{P_1}{r}(1 + 2.3logr) - P_b = \frac{11.5}{2}(1 + 2.3log2) - 0.15 = 9.58 \text{ bar (Ans)}$$

Numerical 2: -

The steam is supplied at a pressure of 8.4 bar and cut-off occurs at 0.35 of the strokes. The back pressure is 1.25 bar. If the diagram factor is 0.75, determine the actual mean effective pressure. Neglect clearance.

Solution

Given Data

P1 = 8.4 bar; v2 = 0.35 v3 ; Pb=1.25 bar; K = 0.75

We know that expansion ratio,

$$r = \frac{V_3}{V_2} = \frac{V_3}{0.35V_3} = 2.86$$

We know that theoretical mean effective pressure,

$$P_m = \frac{P_1}{r}(1 + 2.3logr) - P_b = \frac{8.4}{2.86}(1 + 2.3log2.86) - 1.25 = 4.77 \text{ bar}$$

∴ Actual mean effective pressure, $P_a = P_m$ x K = 4.47 x 0.75 =3.58 (Ans)

Numerical 3: -

A double acting single cylinder has 200mm stroke, 160mm diameter. It runs at 250 r.p.m and the cut-off is 25% of the stroke. The pressure at cut-off is 15 bar and exhaust is at 0.3 bar for a diagram factor of 0.75. Estimate the indicated power in kW.

Solution

Given Data:- L = 200mm = 0.2m; D = 160mm = 0.16m; N = 250 r.p.m; v2 = 25% of stroke = 0.25 v3; P1 = 15 bar; Pb =0.3bar; K = 0.75

We know that expansion ratio

$$r = \frac{V_3}{V_2} = \frac{V_3}{0.25V_3} = 4$$

We know that theoretical mean effective pressure,

$$P_m = \frac{P_1}{r}(1 + 2.3logr) - P_b = \frac{15}{4}(1 + 2.3log4) - 0.3 = 8.64 \text{ bar}$$

∴ Actual mean effective pressure, $P_a = P_m$ x K = 8.64 x 0.75 =6.48 bar

Area of the cylinder, $A = \frac{\pi}{4} \times D^2 = \frac{\pi}{4} \times 0.16^2 = 0.02\ m^2$

Indicated power , I.P $= \frac{2\text{x Pa x}10^5\text{X A X L X N}}{60} = \frac{2\text{x } 6.48 \text{ x}10^5\text{x } 0.02 \text{ x } 0.2 \text{ x } 250}{60} =$ 21600 watt = 21.6 KW

Numerical 4: -

During a test on a single acting non condensing, single cylinder steam engine, the following observations were recorded:

Bore= 225mm; stroke =600 mm; speed = 100r.p.m; effective brake diameter = 2.75m; net load on the brake =1650N; area of indicator diagram = 2500 mm2; length of indicator diagram = 100mm,spring strength = 530 bar/m

Determine :1. Indicated power;2. Brake power; and 3. Mechanical efficiency.

Solution: - Given: D=225 mm= 0.225m; L =600mm =0.6m; N =100 r.p.m; D_1 =2.75m; (W-S) = 1650N, a_1 = 2500mm^2= 2500 x 10^{-6} m^2; b = 100mm = 0.1m; s = 530 bar/m.

We know that actual mean effective pressure,

$$P_a = \frac{area\ of\ the\ indicator\ diagram \times spring\ length}{length\ of\ indicator\ diagram} = \frac{a_1 \times s}{b} = \frac{2500 \times 10-6}{0.1} = 13.25\text{bar}$$

Area of cylinder, $A = \frac{\pi}{4} \times D^2 = \frac{\pi}{4} \times 0.225^2 = 0.04\text{m}^2$

1. Indicated power, $I.P = \frac{Pa \times 10^5\ A \times L \times N}{60} = \frac{13.25 \times 10^5 \times 0.04 \times 0.6 \times 100}{60} = 53000$ Watt

2. Brake power, $B.P = \frac{(W-S) \times \pi D\ N}{60} = \frac{(1650-S) \times \pi \times 2.75 \times 100}{60} = 23760$ watt

3. mechanical efficiency, $\eta_m = \frac{B.P}{I.P} = \frac{23760}{53000} = 0.448$ or 44.8 %

POSSIBLE SHORT QUESTIONS

1. Define mechanical efficiency of a steam engine? 2012,2017, (W)

Ans: - It is the ratio of the Brake power to the indicated power.

So, $\eta_m = \frac{B.P}{I.P}$

2. Define mean effective pressure. (2009,2017,2018,2019)

Ans: - the average pressure on the piston during the working stroke is called mean effective pressure.

∴ Theoretical or hypothetical mean effective pressure (P_m) $= \frac{\text{Work doneper cycle}}{\text{Storke volume}} = \frac{P_1}{r}(1 + 2.3 logr) - P_b$

Where, $r = \frac{V3}{V_2}$ = called expansion ratio

3. State classification of steam engine. (2014)

Ans: - steam engines are classified as follows

i. Vertical steam engine

ii. Horizontal steam engine

iii. Simple steam engine

iv. Compound steam engine

4. What is diagram factor ?

Ans: - Diagram factor(K) is the ratio of the area of actual indicator diagram to the area of theoretical or hypothetical indicator diagram. The average value of diagram factor lies between 0.65 to 0.9

$$K = \frac{\text{area of actual indicator diagram}}{\text{area of theoretical or hypothetical indicator diagram}}$$

5. What is D – slide valve? (2020w)

   Ans: - It is a rectilinear valve used to control the admission of steam into and emission of exhaust from the cylinder of a steam engine.

   The function of D- slide valve in a steam engine is to exhaust steam from the cylinder at proper moment.

POSSIBLE LONG QUESTIONS

1. Draw the actual indicator diagram of steam engine. (2017 W)

2. During a test on a single acting non condensing, single cylinder steam engine, the following observations were recorded:

   Bore= 200 mm; stroke =600 mm; speed = 150r.p.m; effective brake diameter = 2.5m; net load on the brake =1600N; area of indicator diagram = 2400 mm2; length of indicator diagram = 100mm, spring strength = 550 bar/m. Determine :1. Indicated power;2. Brake power; and 3. Mechanical efficiency. (2019S)

3. Determine the diameter and stroke of a double acting steam engine developing 180 KW under the following condition. Initial pressure 7 bar, back pressure 1.12 bar, crank speed 100rpm, mean speed 125 m/min, diagram factor 0.8 and cut-off takes place at 0.4 of stroke. (2020 w)

CHAPTER- 5

STEAM TURBINES

Learning objectives

5.0 Introduction

5.1Types Of Turbines

5.2 Comparison between Impulse Turbine and Reaction Turbine

5.0 Introduction: -

Steam turbine may be defined as a device which converts heat energy of the steam to mechanical energy which finally converted into electrical energy.

5.1.Types Of Turbines: -

The steam turbines may be classified into the following types

1. According to the mode of steam action

   (i) Impulse turbine, and

   (ii) Reaction turbine

2. According to the direction of steam flow

   (i) Axial flow turbine, and

   (ii) Radial flow turbine.

3. According to the exhaust condition of steam

   (i) Condensing turbine, and

   (ii) Non- Condensing turbine

4. According to the pressure of steam

   (i) High pressure turbine,

   (ii) Medium pressure turbine, and

   (iii) Low pressure turbine

5. According to the number of stages

   (i) Single stage turbine, and

(ii) Multi stage turbine

Impulse turbine

In this type of turbine, the superheated steam is projected at high velocity from fixed nozzles in the casing. When the steam strikes the blades (sometimes called buckets), it causes the turbine shaft to rotate. The high pressure and intermediate pressure stages of a steam turbine are usually impulse turbines. The entire pressure drops of steam take place in stationary nozzles only. Though the theoretical impulse blades have zero pressure drop in the moving blades, practically, for the flow to take place across the moving blades, there must be a small pressure drop across the moving blades also.

In impulse turbines, the steam expands through the nozzle, where most of the pressure potential energy is converted to kinetic energy. The high-velocity steam from fixed nozzles impacts the blades changes its direction, which in turn applies a force. The resulting impulse drives the blades forward, causing the rotor to turn. The main feature of these turbines is that the pressure drop per single stage can be quite large, allowing for large blades and a smaller number of stages.

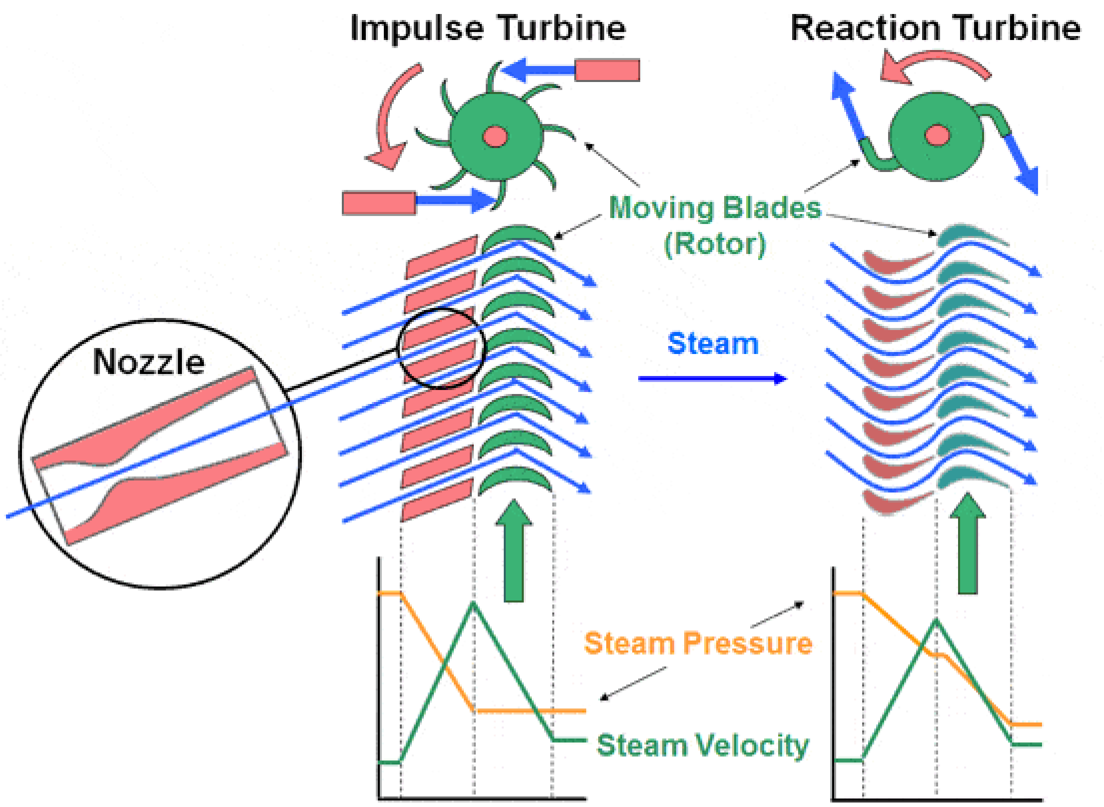
Reaction Turbine

In reaction turbines, the steam expands through the fixed nozzle, where the pressure potential energy is converted to kinetic energy. The high-velocity steam from fixed nozzles impacts the blades (nozzles), changes their direction, and undergoes further expansion. The change in its direction and the steam acceleration applies a force. The resulting impulse drives the blades forward, causing the rotor to turn. There is no net change in steam velocity across the stage but with a decrease in both pressure and temperature, reflecting the work performed in the driving of the rotor. In this type of turbine, the pressure drops take place in a number of stages, because the pressure drop in a single stage is limited.

The main feature of this type of turbine is that in contrast to the impulse turbine, the pressure drop per stage is lower, so the blades become smaller, and the number of stages increases. On the other hand, reaction turbines are usually more efficient, i.e. they have higher "isentropic turbine efficiency". The reaction turbine was invented by Sir Charles Parsons and is known as the Parsons turbine.

In the case of steam turbines, such as would be used for electricity generation, a reaction turbine would require approximately double the number of blade rows as an impulse turbine, for the same degree of thermal energy conversion. Whilst this makes the reaction turbine much longer and heavier, the overall efficiency of a reaction turbine is slightly higher than the equivalent impulse turbine for the same thermal energy conversion.

Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery. The rotor blades are usually designed like an impulse blade at the rot and like a reaction blade at the tip.



5.1 Comparison between Impulse Turbine and Reaction Turbine

Following are the few points of comparison between an impulse turbine and a reaction turbine.

Impulse turbine	Reaction Turbine
1. The steam flows through the nozzles and impinges on the moving blades.	1. The steam flows first through guide mechanism and then through the moving blades.
2. The steam impinges on the buckets with kinetic energy.	2. The steam glides over the moving vanes with pressure and kinetic energy.
3. The steam may or may not be admitted over the whole circumference.	3. The steam must be admitted over the whole circumference.
4. The steam pressure remains constant during its flow through the moving blades.	4. The steam pressure is reduced during its flow through the moving blades.
5. The relative velocity of steam while gliding over the blades remains constant (assuming no friction)	5. The relative velocity of steam while gliding over the moving blades increase (assuming no friction)
6. The blades are symmetrical.	6. The blades are not symmetrical.
7. The number of stages required are less for the same power developed.	7. The number of stages required are more for the same power developed
8. Example- Pelton wheel turbine	8. Example- Francis Turbine, Kaplan Turbine

Possible Short Questions with answers

1. Give the classification of steam turbines. (2019 S)

Ans- The steam turbines may be classified into the following types

1. According to the mode of steam action
   - (i) Impulse turbine, and
   - (ii) Reaction turbine
2. According to the direction of steam flow
   - (i) Axial flow turbine, and
   - (ii) Radial flow turbine.
3. According to the exhaust condition of steam
   - (i) Condensing turbine, and
   - (ii) Non- Condensing turbine

2. What is difference between steam turbine and steam engine? (2019 W)

Ans-

steam turbine	steam engine
1. It uses steam for generating electricity.	It uses steam for generating mechanical power for running vehicles.
2. It converts heat energy to mechanical energy and then to electrical energy	It converts heat energy to mechanical energy and then to rotational motion
3. It has veins and guide blades.	It has cylinder, piston, crank etc.

3. Define impulse turbine with example. (2018 W)

   Ans- Impulse Turbine: - It is a type of steam turbine in which there is no pressure drop across moving blades. Steam energy is transferred to the rotor entirely by the steam jets striking the moving blades. Since there is no pressure drop, negligible thrust is produced.
   Example- Pelton wheel turbine.

4. Define reaction turbine with example. (2019 W)

   Ans- Reaction Turbine: - It is a type of steam turbine in which steam expands in both the stationary and moving blades. Moving blades also act as nozzles. High axial thrust is produced.
   Example- Francis Turbine, Kaplan Turbine

5. Define steam turbine. (2010 W)

   Ans- Steam turbine may be defined as a device which converts heat energy of the steam to mechanical energy which finally converted into electrical energy.

Possible Long Questions

1. Give the difference/compare between Impulse and Reaction turbines. (2009 W,2011 W,2012W,2014,2016W,2019S,2017 W)
   Hints: -refer article no.5.2
2. Give difference between steam turbine and steam engine.(2010,2014)
3. Give a detail classification of steam turbine.
   Hints- refer article no- 5.1

CHAPTER- 6

CONDENSER

Learning objectives

Introduction

Explain The function of condenser

State their types.

Introduction: -

Condenser is a device in which steam is condensed to water at a pressure less than atmosphere. Condensation is done by removing heat from exhaust steam using circulating cooling water. During condensation the working substance changes its phase from vapour to liquid and rejects latent heat.

Function of condenser: -

1. The main function of condenser is to convert gaseous form of exhaust steam into liquid form at a pressure of below atmosphere.
2. create a vacuum by condensing steam.
3. Remove dissolved non – condensable gases from the condensate.
4. Providing a leak tight barrier between the high-grade condensate contained within the shell and the untreated cooling water.
5. Providing leak tight barrier against air ingress, preventing excess back pressure on the turbine.

Types of condensers: -

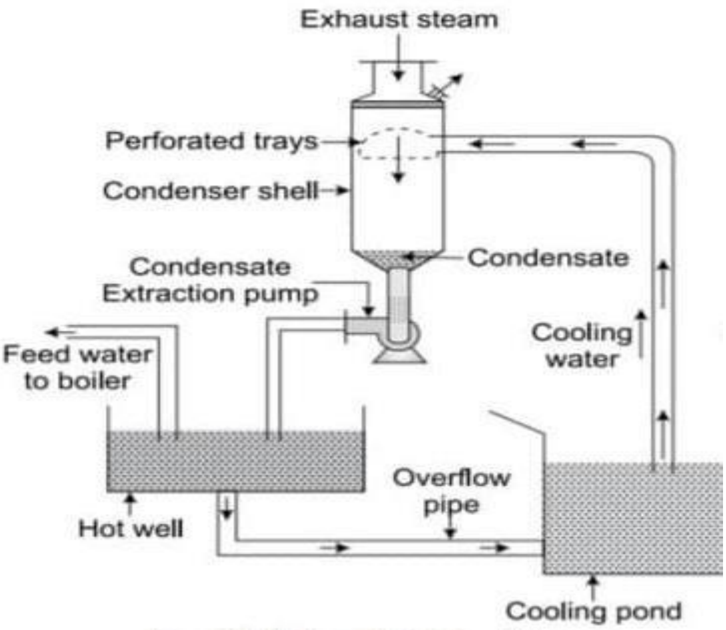
The steam condensers are classified as follows:

1. *Jet condensers (mixing type condensers)*
   - *a.* Parallel flow jet condenser
   - *b.* Counter flow jet condenser (low level)
   - *c.* Barometric or high-level jet condenser
   - *d.* Ejector condenser

2. *Surface condensers (non mixing type condensers)*
   - *a.* Down flow surface condenser
   - *b.* Central flow surface condenser
   - *c.* Regenerative surface condenser
   - *d.* Evaporative condenser

Parallel flow jet condenser

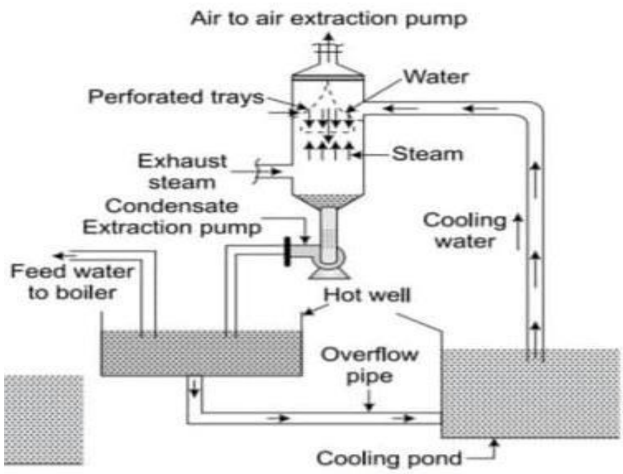
In parallel flow jet condensers, both the steam and water enter at the top, and the mixture is removed from the bottom. The exhaust steam is condensed when it mixes up with water. The condensate, cooling water and air flow downwards and are removed by two separate pumps known as air pump and condensate pump. Sometimes, a single pump known as wet air pump, is also used to remove both air and condensate. But the former gives a greater vacuum. The condensate pump delivers the condensate to the hot well, from where surplus water flows to the cooling water tank through an overflow pipe.



Parallel Flow Jet Condenser

Counter flow or low-level jet condenser

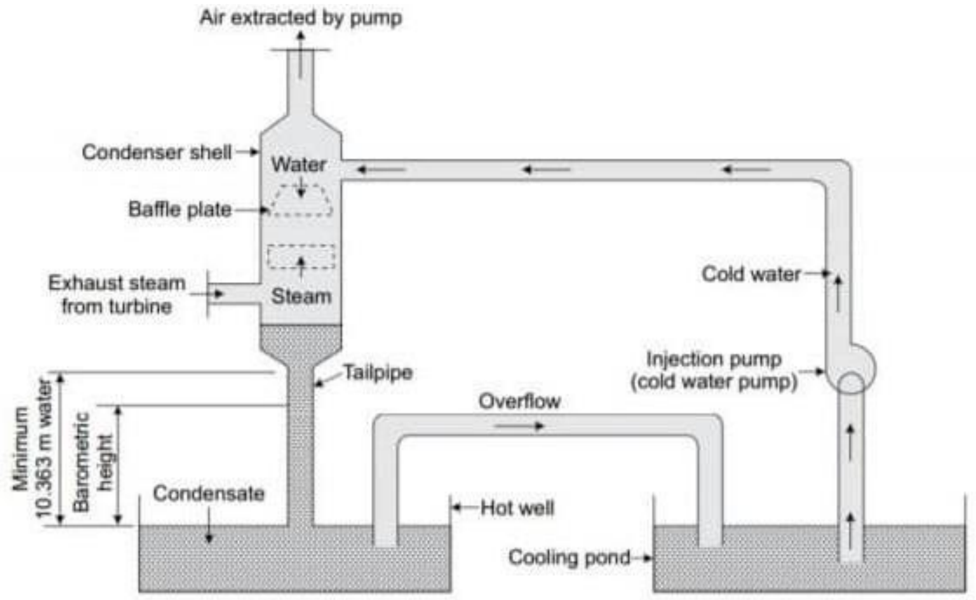
In counter flow or low-level jet condenser, the exhaust steam enters from bottom and mixes with the down coming cooling water as shown in Figure. The air pump mounted at the top of the condenser shell creates vacuum as it sucks air. This draws the supply of cooling water which falls from a large number of jets through perforated conical plate.
The water then falls in the trays and flows through second series of jets and mixes with the exhaust steam entering at the bottom. This cause rapid condensation after which the condensate and the cooling water are delivered to the hot well by the condensate extraction pump.



Counter Flow Jet Condenser

Barometric or high level jet condenser

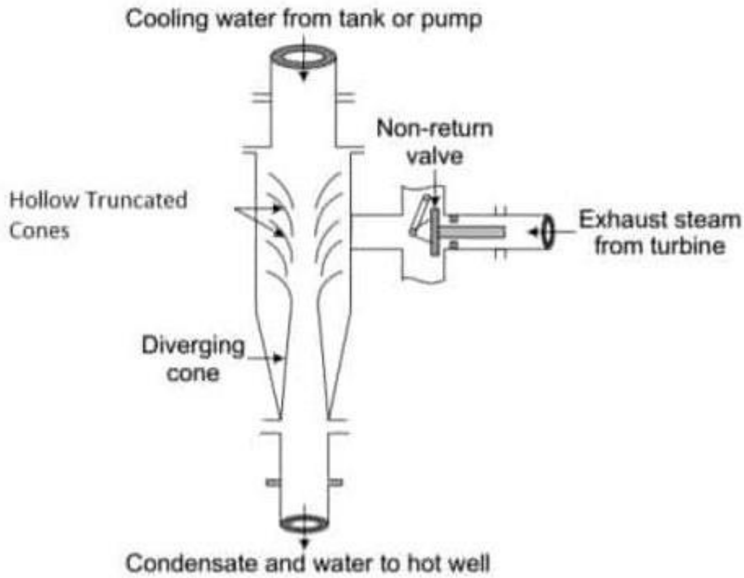
This type of condenser is provided at a high level as shown in Figure having a long tail pipe. The exhaust steam enters from the bottom and flows upwards. This steam then mixes with cooling water which falls from the top through various baffles. The vacuum is created by the air pump placed at the top of the condenser shell. The condensate and the cooling water flows downwards through a vertical tail pipe to the hot well without the aid of any pump. The surplus water from the hot well flows to the cooling pond through an overflow pipe.



Barometric or High Level Jet Condenser

Ejector condenser

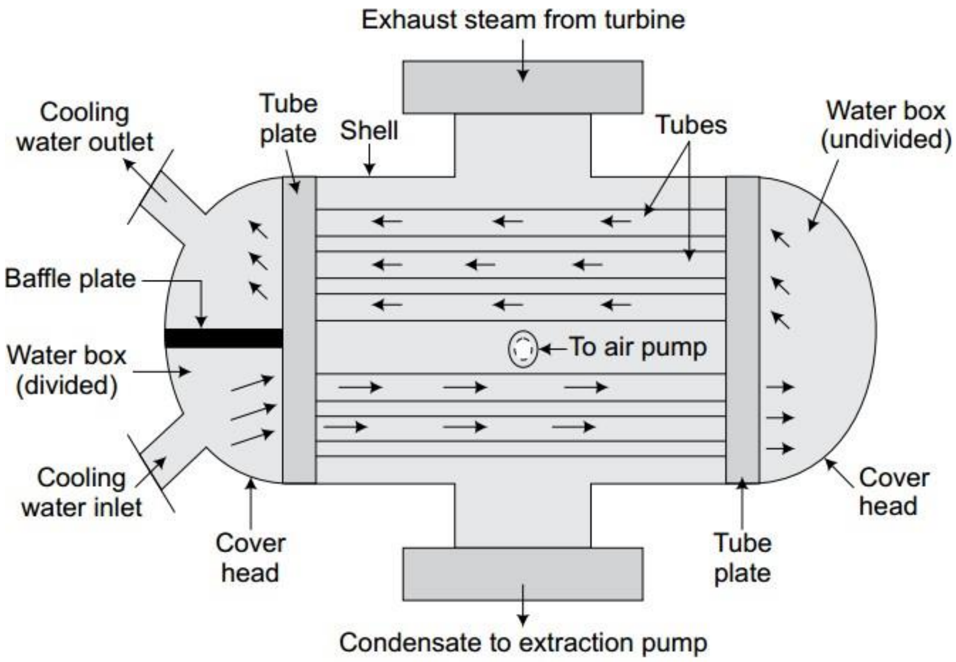
In ejector condenser, the steam and water mix-up while passing through a series of metal cones as shown in Figure 4. Water enters from the top through a number of guide cones. The exhaust steam enters the condenser through a non-return valve. The steam and air then pass through the hollow truncated cones. After that it passes through the diverging cone where its kinetic energy is partly transformed into pressure energy. The condensate and the cooling water are then discharged to the hot well. The high exit pressure in the diverging cone allows discharged of water automatically into the hot well at atmospheric pressure



Ejector Condenser

Surface condenser

In surface condenser, the condensate does not mix up with the cooling water. So the whole condensate can be reused in the boiler. This type of condenser is used where is only limited quantity of fresh water is available like ships. A sectional view of a two-pass surface condenser is shown in Figure . It consists of a horizontal cylindrical vessel made of cast iron packed with tubes for cooling water. The cooling water flows in one direction through the lower half of the tubes and in opposite direction through the upper half. The water tubes are fixed into vertical perforated type plates at the ends so that leakage of water should not occur into the central condensing space. The steam enters from top end. The extraction pump at the bottom sucks the condensate resulting in the downwards flow of steam over the water tubes.



Surface Condenser

Types of Surface Condensers

The surface condensers may be further classified on the basis of the direction of flow of the condensate, the arrangement of tubing system and the position of the extraction pump, into the following four types:

1. Down flow surface condenser

2. Central flow surface condenser

3. Regenerative surface condenser and

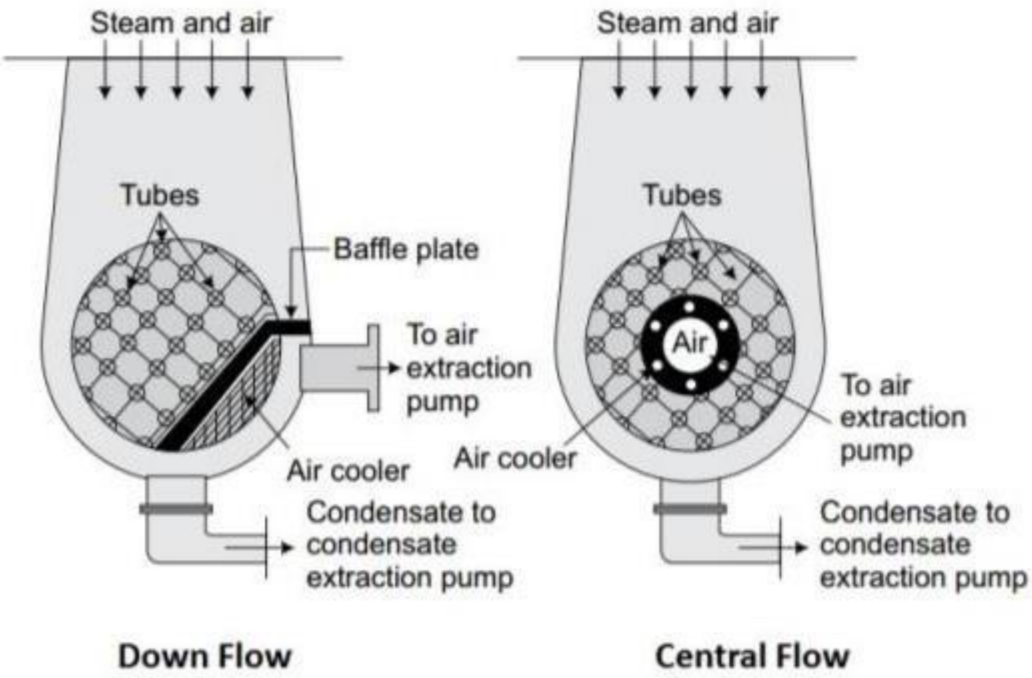
4. Evaporative condenser

Down flow surface condenser

In down flow surface condenser, the steam enters from the top as shown in Figure . The exhaust steam is forced to flow downwards over the water tubes due to suction of the extraction pump at the bottom. The suction pipe of the dry air pump is provided near the bottom and is covered by a baffle so that the condensed steam does not enter into it. As the steam flow perpendicular to the direction of flow of cooling water, it is also called cross flow surface condenser.

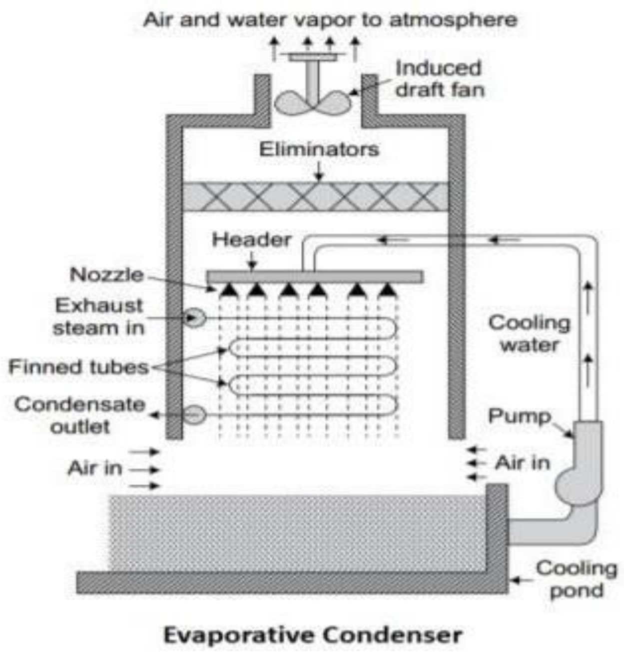
Central flow surface condenser

In this type of surface condenser, the suction pipe of the air extraction pump is placed in the centre of the tube nest as shown in Figure . The exhaust steam from turbine enters from the top and flows radially inwards over the tubes. The condensate is collected at the bottom. The advantage of central flow type surface condenser over the down flow type is that the steam flows over the whole periphery of the water tubes as the steam flows radially inwards.



Evaporative condenser

In evaporative condenser the steam flows enter the gilled pipes and flows backwards and forwards in a vertical plane as shown in Figure 8. The water pump sprays water on the pipes which condenses the steam. The main advantage of this type of condenser is that the quantity of cooling water needed to condense the steam can be reduced by causing the circulating water to evaporate which decrease the temperature. The remaining water is collected in the cooling pond.



Regenerative surface condenser

In regenerative surface condensers, the condensate is heated by a regenerative method. The condensate after leaving the tubes is passed through the exhaust steam from the engine or turbine. It thus, raises its temperature for use as feed water for the boiler.

POSSIBLE SHORT QUESTIONS

1. what is a condenser? (2011 W)
   Ans: - Condenser is a device in which steam is condensed to water at a pressure less than atmosphere. Condensation is done by removing heat from exhaust steam using circulating cooling water. During condensation the working substance changes its phase from vapour to liquid and rejects latent heat.

2. What is the function of a condenser? (2010,2017,2019)
   i. The main function of condenser is to convert gaseous form of exhaust steam into liquid form at a pressure of below atmosphere.
   ii. create a vacuum by condensing steam.
   iii. Remove dissolved non – condensable gases from the condensate.

3. What is the use of condenser? (2009)
   Ans: - In thermal power plants, a steam condenser is a device in which the exhaust steam from the steam turbine is condensed by means of cooling water.
   The purpose of a steam condenser is to condense the steam into pure water so that it can be used in the steam generator or boiler as feed and obtain maximum efficiency.

POSSIBLE LONG QUESTIONS

1. Describe the working of a surface condenser with a neat sketch? (2016 W)
   Ans: - refer article no.6.2

2. Compare between jet condenser and surface condenser? (2018 W)
   Ans:-

JET CONDENSER	SURFACE CONDENSER
1. Steam and water comes in direct contact.	1. Steam and water do not comes in direct contact.
2. Condensate is due to mixing of coolant.	2. Condensate is due to heat transfer by conduction and convection.
3. It is cheap. Does not affect plant efficiency.	3. It is costly. Improves plant efficiency.
4. Maintenance cost is low.	4. Maintenance cost is high.
5. Vacuum is created up to 600mm of Hg.	5. Vacuum is created up to 730mm of Hg.
6. The condensing plant is simple	6. The condensing plant is complicated.

3. What is a surface condenser? What are the advantages and disadvantages over jet condenser? (2020W)

Hints: - refer article no.6.2 for surface condenser.

<u>The Advantages And Disadvantages Over Jet Condenser</u>
<u>Advantages: -</u>

- There is a high vacuum obtained compared to the jet.
- Water used for cooling is reused without any treatment.
- For high-capacity plants, it is More advantageous.
- In this Condensate losses can be eliminated.
- It required power for air pump is low.

<u>Disadvantages</u>

- It requires more space than the jet condenser.
- The cost of maintenance is high.
- In this not much effective in steam and cooling water than the jet.
- This is a complex plant.

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CHAPTER- 7

I.C ENGINE

Learning objectives

Introduction

Explain Working Of Two Stroke And Four Stroke Petrol And Diesel Engine.

Difference between them.

7.0 Introduction: -

An internal combustion engine (ICE or IC engine) is a heat engine in which the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an I.C engine, the expansion of the high-temperature and high-pressure gases produced by combustion applies direct force to pistons, turbine blades, a rotor, or a nozzle which moves the component over a distance, transforming chemical energy into useful kinetic energy and is used to propel, move or power whatever the engine is attached to.

The first commercially successful I.C engine was created by Étienne Lenoir around 1860 and the first modern I.C engine was created in 1876 by Nicolaus Otto.

Types of I.C engine: -

I.C engine may be classified as followings

1. According to Number Of Strokes Per Cycle:
    a) Four-Stroke Cycle Engine
    b) Two-Stroke Cycle Engine
    c) Six Stroke Cycle Engine
2. According to Nature Of Thermodynamic Cycle:
    a) Otto Cycle Engine
    b) Diesel Cycle Engine
    c) Dual Cycle Engine
3. According to Types Of Fuel Used
    a) Petrol Or Gasoline Engine
    b) Diesel Engine
    c) Bi-Fuel Engine
4. According to Method Of Ignition
    a) Spark Ignition Engine
    b) Compression Ignition Engine
5. According to Number Of Cylinders
    a) Single-Cylinder Engine
    b) Multi Cylinder Engine
6. According to Arrangement Of Cylinder
    a) Horizontally Opposed Engine:

b) Vertical Engine
c) V-Type Engine:
d) Radial Engine

7. According to Cooling System
a) Air Cooled Engine
b) Water Cooled Engine
c) Oil Cooled Engine

7.1 Explain Working Of Two Stroke And Four Stroke Petrol And Diesel Engine.: -

TWO STROKE PETROL ENGINE.: -

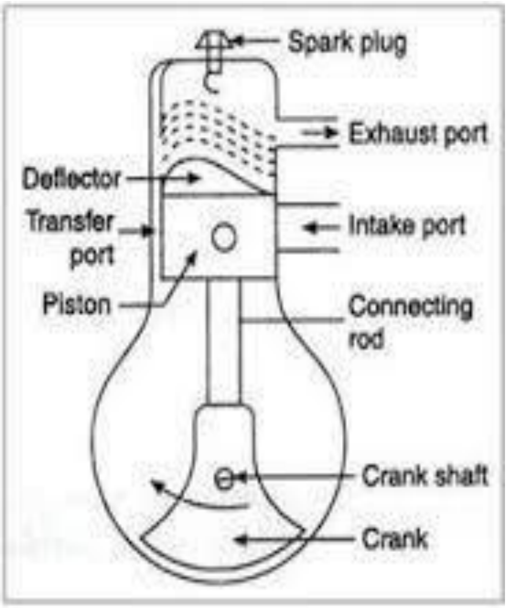
In a 2-stroke petrol engine the four stages i.e suction, compression, expansion and exhaust takes place in two strokes of the piston. It means that there is one working stroke after every revolution of the crank shaft. A two-stroke engine has ports instead of valves. Four stages of a two-stroke petrol engine are described below:

1. Suction and compression stage: -

- Piston moves upward from BDC to TDC.
- Both transfer port and exhaust port closed.
- Fresh air-fuel mixture enters into the cylinder through inlet port.
- Compression of previous air fuel mixture take place.

2. Expansion and exhaust Stage: -

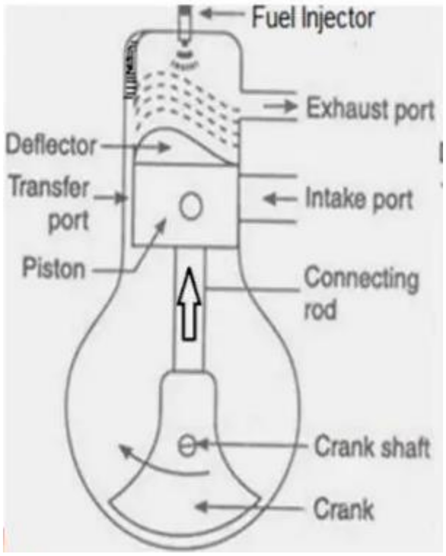
- Air fuel mixture are ignited by the help of a spark plug.
- large number of gases are produced due to burning of air fuel mixture, which exert force on the piston which moves TDC to BDC.
- Both the transfer port and exhaust ports are opened.
- Combustion gases removed through exhaust port and fresh air-fuel charge rushed into the combustion chamber through transfer port.
- This completes the cycle.



TWO STROKE DIESEL ENGINE.: -

In a 2-stroke diesel engine the four stages i.e suction, compression, expansion and exhaust takes place during two strokes of the piston. It means that there is one working stroke after every revolution of the crank shaft. A two-stroke engine has ports instead of valves. It has fuel injector instead of spark plug. Four stages of a two-stroke diesel engine are described below:

1. Suction and compression stage: -



- Piston moves upward from BDC to TDC.
- Both transfer port and exhaust port closed.
- Fresh air sucked into the cylinder through inlet port.
- Compression of previous sucked air take place.

2. Expansion and exhaust Stage: -

- Diesel is sprayed into the compressed air by a fuel injector and ignition takes place.
- large amount of gases are produced, which exert force on the piston moving it from TDC to BDC.
- Both the transfer port and exhaust ports are opened.
- Combustion gases removed through exhaust port and fresh air rushed into the combustion chamber through transfer port.
- This completes the cycle.

FOUR STROKE PETROL ENGINE.: -

4-stroke engines deliver a good balance of power, reliability and efficiency. When it comes to emissions, 4-strokes separate each event mechanically, which reduces unburned fuel emissions. It also separates oil from fuel, which significantly reduces carbon monoxide emissions. This combination of desirable traits has earned the 4-stroke the top spot in passenger vehicles today.

In order to effectively power equipment, 4-stroke PETROL engines complete and repeat the following steps:

Intake stroke

- Piston moves from TDC to BDC.
- Intake valve is open and the exhaust valve is closed.
- Downward piston motion creates a vacuum (negative air pressure) that draws air/fuel mixture into the engine via the open intake valve.

Compression stroke

- Piston moves up the cylinder bore from BDC to TDC.

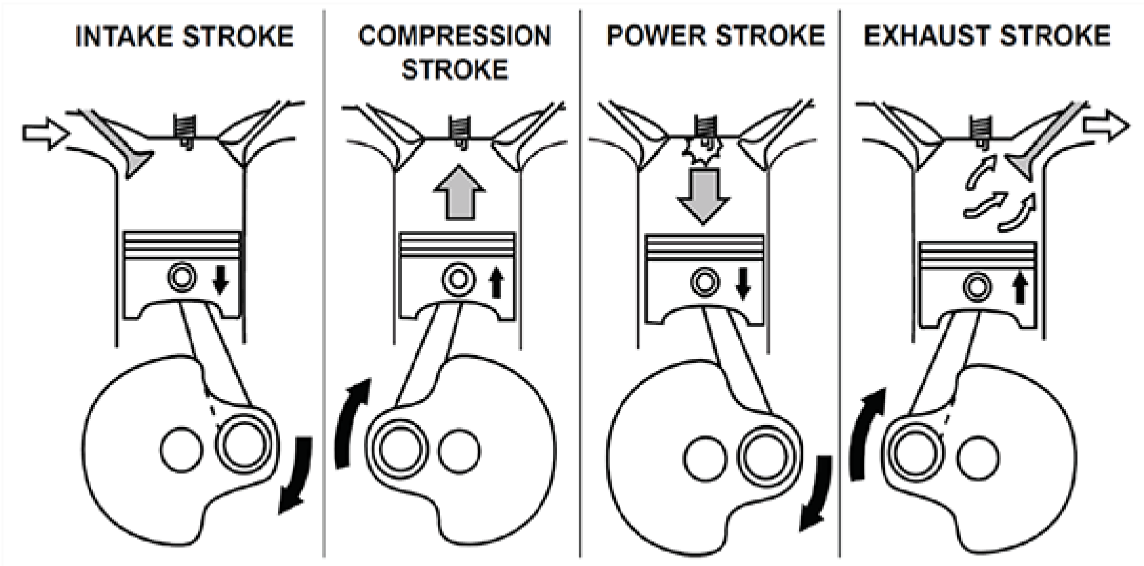
- Both the intake and exhaust valves are closed.
- Upward piston motion compresses air/fuel mixture in the combustion chamber.

Power stroke

- At the end of the compression stroke, the spark plug fires and ignites the compressed air/fuel mixture. This ignition/explosion forces the piston back down the cylinder bore and rotates the crankshaft, propelling the vehicle forward.
- Piston moves down the cylinder bore from TDC to BDC.
- Both the intake and exhaust valve are closed.

Exhaust stroke

- Piston moves up the cylinder bore from BDC to TDC. The momentum caused by the power stroke is what continues the crankshaft movement and the other 3 strokes consecutively.
- Intake valve is closed, the exhaust valve is open
- This final stroke forces the spent gasses/exhaust out of the cylinder. The cycle in now complete and the piston is ready to begin the intake stroke.



FOUR STROKE DIESEL ENGINE.: -

The working of the diesel engine is different than the petrol or SI engine. A diesel engine works on the base of the diesel cycle. In order to effectively power equipment, 4-stroke DIESEL engines complete and repeat the following steps:

Intake stroke

- Piston moves from TDC to BDC.
- Intake valve is open and the exhaust valve is closed.

- Downward piston motion creates a vacuum (negative air pressure) that draws air into the engine via the open intake valve.

Compression stroke

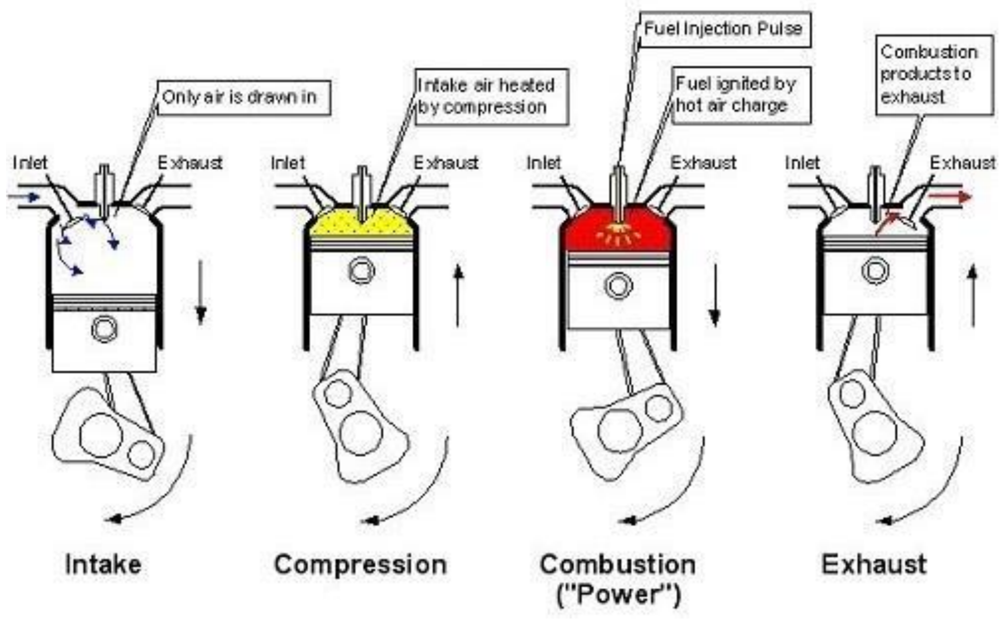
- Piston moves up the cylinder bore from BDC to TDC.
- Both the intake and exhaust valves are closed.
- Upward piston motion compresses air in the combustion chamber.

Power stroke

- At the end of the compression stroke, fuel is injected into the combustion chamber through fuel injector, which mixes with compressed air.
- Due to high compression of air, the fuel-air mixture ignites.
- This ignition/explosion forces the piston back down the cylinder bore and rotates the crankshaft, propelling the vehicle forward.
- Piston moves down the cylinder bore from TDC to BDC.
- Both the intake and exhaust valve are closed.

Exhaust stroke

- Piston moves up the cylinder bore from BDC to TDC. The momentum caused by the power stroke is what continues the crankshaft movement and the other 3 strokes consecutively.
- Intake valve is closed, the exhaust valve is open
- This final stroke forces the spent gasses/exhaust out of the cylinder. The cycle in now complete and the piston is ready to begin the intake stroke.



7.2 Difference between petrol and diesel engine: -

Petrol engine	Diesel engine
1. Works on otto cycle	1. Works on diesel cycle
2. Air fuel mixture is admitted during suction stroke.	2. Fuel is injected at the end of compression stroke.
3. Spark ignition	3. Compression ignition
4. Low compression ratios (6-10)	4. high compression ratios (10-20)
5. Lower engine efficiency	5. higher engine efficiency
6. low engine vibration and noise	6. high engine vibration and noise
7. used in light duty application	7. used in heavy duty application

4-stroke engine	2-stroke engine
1. It has one power stroke for every two revolutions of the crankshaft.	1. It has one power stroke for each revolution of the crankshaft.
2. A heavy flywheel is required.	2. A lighter flywheel is required.
3. Engine is heavy.	3. Engine is light.
4. Engine design is complicated.	4. Engine design is simple.
5. Cost is high.	5. Cost is less.
6. Less mechanical efficiency due to more friction in many parts.	6. More mechanical efficiency due to less friction on a few parts.
7. More output due to full fresh charge intake and full burnt gas exhaust.	7. Less output due to mixing of fresh charge with the hot burnt gases.
8. The engine runs cooler. It means that Temperature runs on lower temperatures.	8. Engine runs hotter. It means that the engine temperature is higher as compared with two stroke engines.
9. The engine may be air-cooled or water-cooled.	9. The engine is air-cooled.
10. Less fuel consumption and complete burning of fuel.	10. More fuel consumption and a small amount of fresh charge is mixed with exhaust gases.
11. The engine requires more space.	11. The engine requires less space.
12. Complicated lubricating system.	12. Simple lubricating system.

POSSIBLE SHORT QUESTIONS WITH ANSWERS

1. What is S.I engine? (2012 W)

Ans:- A spark-ignition engine (SI engine) is an internal combustion engine, generally a petrol engine, where the combustion process of the air-fuel mixture is ignited by a spark from a spark plug.

2. Define mechanical efficiency?

Ans: - Mechanical Efficiency- It is the ratio of the power available at the engine crankshaft (BHP) to the power developed in the engine cylinder (IHP).
Mathematically,
Mechanical Efficiency=$\frac{BHP}{IHP} \times 100\%$

3. Define stroke length. (2017 w)

Ans: - Stroke means displacement of the piston inside the cylinder. One complete travel of the piston from TDC to BDC and vice versa in a vertical engine is one stroke of the piston.
The distance travelled by the piston from TDC to BDC (in a vertical engine) and from crank end to cover end (in a horizontal engine) is called stroke length.
TDC —Top dead centre.
BDC —Bottom dead centre.

4. Give a difference between valve and port? (2009W)

Ans: - Ports are simple opening for facilitating inlet or outlet of air-fuel mixture and exhaust gases, while valves are the combination of ports and mechanisms for its opening and closing often connected to a rocker arm and timing cam shaft in engines.

5. Name the operations of an I.C engine cycle. (2008 W)

Ans:- An internal-combustion engine goes through four strokes: intake, compression, combustion (power), and exhaust. As the piston moves during each stroke, it turns the crankshaft.

POSSIBLE LONG QUESTIONS

1. Difference between petrol and diesel engine? (2012W,2018W)
2. Difference between 2-stroke and 4-stroke cycle engine? (2019W,2020W)
3. Explain the working of 2-stroke petrol engine with neat sketch? (2017W,2019W)

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CHAPTER- 8

HYDROSTATICS

Learning objectives

Introduction

properties of fluid.

determine pressure at a point, pressure measuring instrument.

Introduction: -

A fluid is any material that can flow and take the shape of its container. A fluid can flow because its particles easily move past each other. Examples of fluids are-

Liquids: - like water and blood

Gases: - like oxygen

Properties of Fluids:

There are five properties of fluids and those are:

1. Density or Mass Density
2. Weight Density or Specific Weight
3. Specific Volume
4. Specific Gravity
5. Viscosity

1. Density or Mass Density:

- It is defined as the ratio of mass of a fluid to its volume.
- Density is called a Mass per unit volume of a fluid. This is denoted by symbol ρ (rho) and the unit of mass density is (kg/m3).
- Mathematically, Density, ρ (rho) $= \frac{\text{Mass of Fluid}}{\text{Volume of Fluid}} = \frac{M}{V}$
- The density of liquid may be constant but the density of gases changes with the variation of temperature and pressure. The Density of water is 1000 kg/m3 or we can say 1 g/cm3.

2. Weight Density or Specific Weight:

- It is defined as the ratio of the weight of the fluid to its volume.
- Weight density is called Weight per unit volume of a fluid. This is denoted by symbol 'w 'and the unit of mass density is (N/m3). Mathematically,
- $w = \frac{\text{Weight of Fluid}}{\text{Volume of fluid}} = \frac{W}{V} = \frac{mg}{V} = \frac{\text{Mass of fluid} \times \text{Acceleration due to gravity}}{\text{Volume of fluid}} = \frac{m}{V} \times g = \rho g$
- The value of weight density or specific weight for water is 9.81 x 1000, N/m3

3. Specific Volume: It is defined as the ratio of the volume of fluid to the mass of fluid. or

- The volume of a fluid occupied by a unit mass or volume per unit mass of a fluid is called Specific volume. It is denoted by v.
- The unit of Specific volume is **m³/kg** and This is commonly applied to Gases.
- Mathematically, specific volume, $v = \frac{\text{Volume of Fluid}}{\text{mass of fluid}} = \frac{V}{m} = \frac{1}{\boldsymbol{\rho}}$

4. <u>Specific Gravity</u>:

- It is defined as the ratio of the Density or weight density of a fluid to density or weight density of a standard fluid.
- for liquid the water is standard fluid and for gases, the Standard fluid is taken as Air.
- The specific gravity is called Relative Density. This is denoted by the symbol 'S' and this is dimensionless because the upper unit and lower units get cancelled.
- Mathematically, $\boldsymbol{S}\ (\boldsymbol{liquid}) = \frac{\text{Density or } \boldsymbol{Weight\ Density\ of\ liquid}}{\text{Density or } \boldsymbol{Weight\ Density\ of\ water}}$

$$S\ \textbf{(Gases)} = \frac{\text{Density or } \boldsymbol{Weight\ Density\ of}\ gases}{\text{Density or } \boldsymbol{Weight\ Density\ of}\ air}$$

5. <u>Viscosity</u>:

- Viscosity is a measure of a fluid's resistance to flow.
- Mathematically,

$$F = \mu A \frac{u}{y}$$

Where, F = force,
μ =viscosity of the fluid.
A = Area of each plate.
$\frac{u}{y}$ =rate of shear deformation

- Viscosity does not change as the amount of matter changes; therefore, it is an intensive property.
- The viscosity of liquids decreases rapidly with an increase in temperature, and the viscosity of gases increases with an increase in temperature.
- The SI unit of viscosity is newton-second per square metre (N s m-2) or pascal-second (Pa s.)

Pressure at a point in a Fluid:

Pressure at a point in a liquid means a force exerted perpendicularly by the liquid on unit area around that point in the liquid. In figure shown some liquid is kept in a vessel.

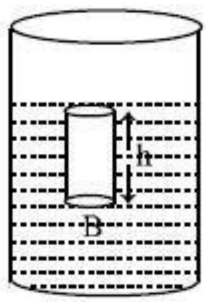
Let the area of the base of the vessel =A

density of the liquid = ρ

depth of the liquid = h

acceleration due to gravity = g

We know, pressure $= \frac{\text{force}}{\text{area}}$



= mass of the liquid x g

= volume of the liquid x density x g

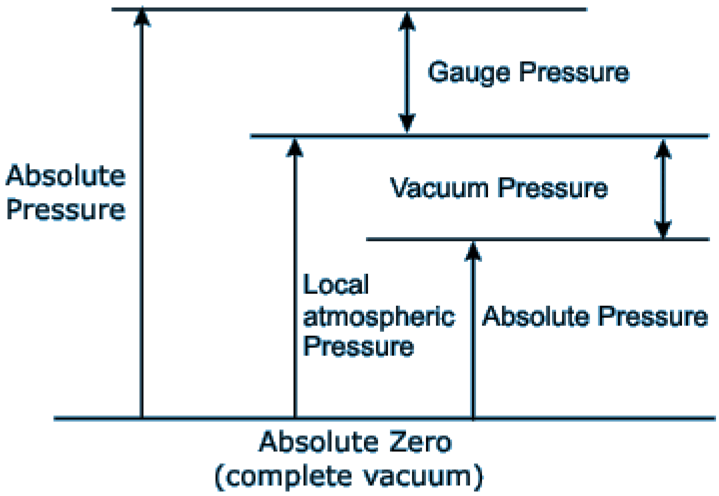
= area of the base x depth x density x g

= Ah ρ g

Pressure, P = $\frac{Ah\,\rho g}{A}$

or, Pressure, P= ρhg

Absolute pressure, Gauge pressure and Vacuum pressure: -



Absolute pressure: When pressure is measured with reference to absolute vacuum pressure then it is called absolute pressure. At this pressure, the molecular momentum is zero.

Gauge pressure: This is the pressure measured by of pressure measuring instrument, in which atmospheric pressure is taken as datum (reference). The atmospheric pressure is taken as zero in this system. The instrument used to measure this pressure is known as Pressure gauge. The pressure always used to indicate the pressure above atmospheric pressure.

Vacuum pressure: Measurement of pressure below the atmospheric pressure, in which atmospheric pressure taken as reference. This is also known as negative pressure or suction pressure. The instrument used to measure vacuum pressure is known as Vacuum gauge.

Relation between Absolute pressure and Gauge pressure

Absolute pressure (Pab) = atmospheric pressure (Patm) + Gauge pressure (Pgauge)
Vacuum pressure = atmospheric pressure (Patm) - Absolute pressure (Pab)

The pressure of fluid is measured by the following devices:

1. Manometers
2. Mechanical gauges

<u>Manometers:</u> -Manometers are defined as the devices used for measuring the pressure at a point in a fluid by balancing the column of fluid by the same or another column of the fluid by the same or another column of fluid. They are classified as: a) simple manometers and b) differential manometers.

<u>Mechanical gauges</u>: - Pressure gauges or Mechanical gauges these are the devices used for measuring the pressure by balancing the column of fluid by spring or dead weight.

Types of Pressure Gauges

a) Diaphragm pressure gauge
b) Bourdon tube pressure gauge
c) Bellows pressure gauge
d) Dead-weight pressure gauge

Simple manometers: a simple manometers consists of a glass tube having one of its ends connected to a point where pressure is to be measured and other end remains open to atmosphere. Common type of simple manometers are:

1. Piezometer
2. U – tube manometer, and
3. Single column Manometer.

Piezometer: - it is the simplest form of manometer used for measuring gauge pressures. One end of this manometer is connected to the point where the pressure is to be measured and another end is open to the atmosphere. The rise of liquid gives the pressure head at that point. If at a point A, the height of liquid say water is h in piezometer tube, then pressure at A = ρ.g.h, N/m^2.

U -tube manometer: -

It consists of glass tube bent in U shape, one end of which is connected to a point at which pressure is to be measured.

a) **For gauge pressure:-** let B is the point where pressure is to be measured, whose value is p. the datum line is A-A.
   Let h_1 = height of liquid above the datum line.

   h_2 = height of heavy liquid above datum line.

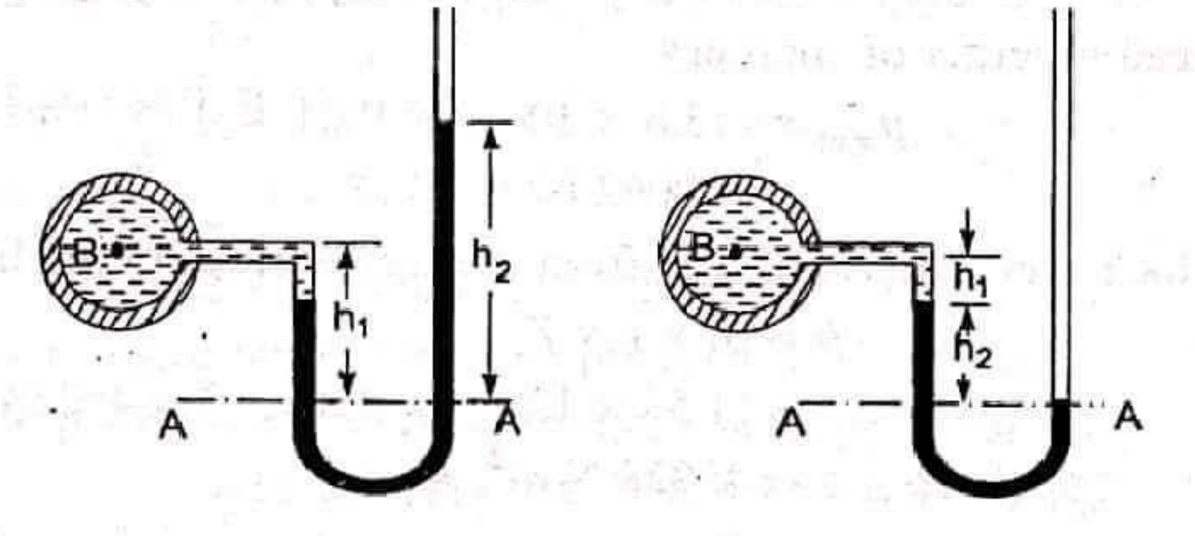
S_1= Specific gravity of light liquid.

S_2 = specific gravity of heavy liquid

ρ_1 = density of light liquid = 1000 x S_1

ρ_2 = density of light liquid = 1000 x S_2

As the pressure is the same for the horizontal surface. Hence pressure above the horizontal datum line A-A in the left column and in the right column of U -tube manometer should be same.



(a) For gauge pressure (b) For vacuum pressure

Pressure above A-A in the left column = P + ρ_1 g h_1

Pressure above A-A in the right column = ρ_2 g h_2

Hence equating the two pressures P + ρ_1 g h_1= ρ_2 g h_2

⇨ **P = (ρ_2 g h_2 - ρ_1 g h_1)**

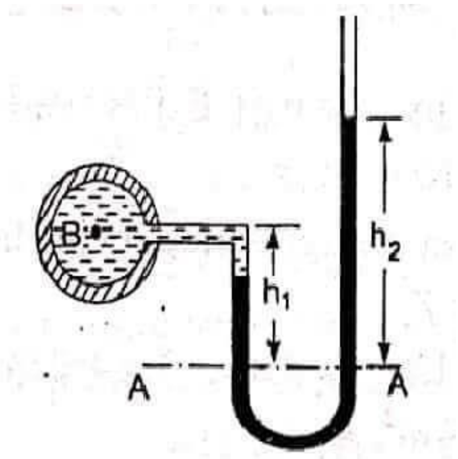
b) **For vacuum pressure: -** for measuring vacuum pressure, the level of the heavy liquid in the manometer will be shown as below
Then, pressure above A-A in the left column = ρ_1 g h_1+ ρ_2 g h_2+ P

Pressure above A-A in the right column = 0

⇨ ρ_1 g h_1+ ρ_2 g h_2+ P =0
⇨ ***P* = - (ρ_1 g h_1+ ρ_2 g h_2)**

Problem 1
The right limb of a simple U tube manometer containing mercury is open to the atmosphere while left limb is connected to a pipe in which a fluid of sp.gr. 0.9 is flowing. The centre of the pipe is 12 cm below the level of mercury in the right limb. Find the pressure of fluid in the pipe if the difference of mercury level in the two limbs is 20 cm.
Solution:-
S1 = 0.9
Density of fluid, ρ_1 =S1 x 1000 =0.9 x 1000 = 900 Kg/m^3
Sp.gr.of mercury, S2 = 13.6
Density of mercury, ρ_2 = 13.6 x 1000 kg/m^3
Difference of mercury level, h2 = 20 cm = 0.2 m
Height of fluid from A-A, h1 =20-12 = 8cm = 0.08 m

Let P = pressure of fluid in pipe
Equating the pressure above A-A, we get



$P + \rho_1 \, g \, h_1 = \rho_2 \, g \, h_2$

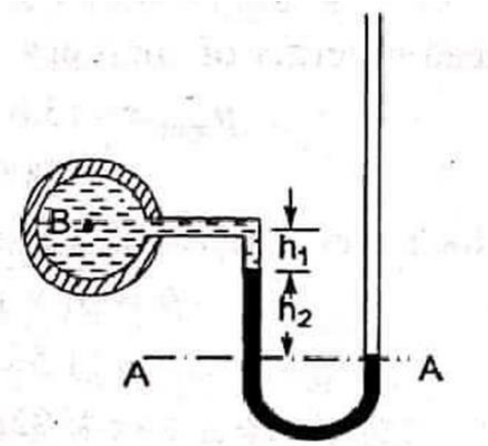
P + 900 x 9.81 x 0.08 = 13.6 x 1000 x 9.81 x 0.2

P = 13.6 x 1000 x 9.81 x 0.2 – 900 x 9.81 x 0.08

P = 26683-706 = 25977 N/m^2 = 2.597 N/cm^2 (Ans)

Problem 2: -

A simple U -tube manometer containing mercury is connected to a pipe in which a fluid of sp.gr 0.8 and having vacuum pressure is flowing. The other end of the manometer is open to atmosphere. Find the vacuum pressure in pipe, if the difference of mercury level in the two limbs is 40 cm and the height of fluid in the left from the centre of pipe is 15 cm below.



Solution: -
Sp.gr.of fluid, S1 = 0.8
Sp.gr.of mercury, S2 = 13.6
Density of fluid, ρ_1 = 800
Density of mercury, ρ_2 = 13.6 x 1000
Difference of mercury level, h2 = 40cm = 0.4 m.
Height of liquid in left limb, h1 = 15 cm = 0.05m.
Let the pressure in pipe = P
Equating pressure above datum line A-A , we get

- ⇨ P = - ($\rho_1 \, g \, h_1 + \rho_2 \, g \, h_2$) **= - [**13.6 x 1000 x9.81x 0.4 + 800 x 9.81x 0.15]
- ⇨ P = -[53366.4 + 1177.2]
- ⇨ P = -54543.6 N/m2
- ⇨ P = - 5.454 N/cm2 (Ans)

POSSIBLE SHORT QUESTIONS WITH ANSWERS

1. What is the difference between pascal and bar? (2018 W)
   Ans: - both bar and pascals are units of fluid pressure but bar is greater than pascal.
   1 bar = 10^5 N/m2
2. Define density and write down the relationship between density and weight density? (2018 W)

   Ans: It is defined as the ratio of mass of a fluid to its volume.

   Density is called a Mass per unit volume of a fluid. This is denoted by symbol ρ (rho) and the unit of mass density is (kg/m3).

   Mathematically, Density, ρ (rho) = $\frac{\text{Mass of Fluid}}{\text{Volume of Fluid}} = \frac{M}{V}$

$$S\,(liquid) = \frac{\text{Density or } \boldsymbol{Weight\ Density\ of\ liquid}}{\text{Density or } \boldsymbol{Weight\ Density\ of\ water}}$$

3. Write down the pressure measuring instruments? (2017W)

Ans: The pressure of fluid is measured by the following devices:

1. Manometers
2. Mechanical gauges

4. Define specific gravity? (2019S)

- Ans: It is defined as the ratio of the Density or weight density of a fluid to density or weight density of a standard fluid.
- for liquid the water is standard fluid and for gases, the Standard fluid is taken as Air.
- The specific gravity is called Relative Density. This is denoted by the symbol '*S*' and this is dimensionless because the upper unit and lower units get cancelled.
- Mathematically, $S\,(liquid) = \frac{\text{Density or } \boldsymbol{Weight\ Density\ of\ liquid}}{\text{Density or } \boldsymbol{Weight\ Density\ of\ water}}$

$$S\ \textbf{(Gases)} = \frac{\text{Density or } \boldsymbol{Weight\ Density\ of}\ gases}{\text{Density or } \boldsymbol{Weight\ Density\ of}\ air}$$

5. Define Newtonian fluid? (2020W)

Ans: A Newtonian fluid's viscosity remains constant, no matter the amount of shear applied for a constant temperature. These fluids have a linear relationship between viscosity and shear stress.

Examples:

- Water
- Mineral oil
- Gasoline
- Alcohol

POSSIBLE LONG QUESTIONS

1. Define the terms density, viscosity, sp. Weight, viscosity and their units? (2019S)
   Hints: refer article 8.1
2. Calculate the specific weight, density and specific gravity of 1 Ltr. Of a liquid which weights 7 N.(2018 W)
   Hints :- refer article no 8.1
3. The right limb of a simple U tube manometer containing mercury is open to the atmosphere while left limb is connected to a pipe in which a fluid of sp.gr. 0.85 is flowing. The centre of the pipe is 10 cm below the level of mercury in the right limb. Find the pressure of fluid in the pipe if the difference of mercury level in the two limbs is 16 cm.(2020 W)
   Hints :-Refer problem 1

CHAPTER 9

HYDROKINETICS

Learning objectives

Introduction

equation of continuity of flow.

explain energy of flowing fluid

state and explain Bernoulli's equation

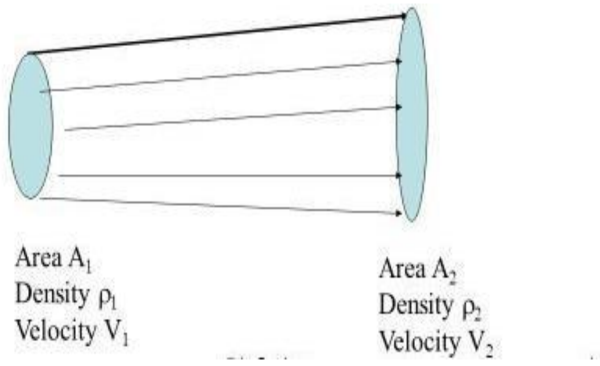
Introduction

It is the branch of science concerned with the mechanical behaviour and properties of fluids in motion. Hydrokinetics definition, the branch of hydrodynamics that deals with the laws governing liquids or gases in motion. The concept of hydrokinetic energy is a part of the control strategy of a tidal power plant and is a fundamental principle of tidal turbines. The basic ideology applied to the pulling of hydrokinetic energy from the rated value of tidal currents at different tidal ranges is the same as those for wind and hydro energy systems. The power delivered in a moving fluid is a function of the mass flow rate, which is a measure of the mass of fluid passing a point in the system per unit time; it is working as the active element of the system.

Equation Of Continuity Of Flow

The equation based on the principle of conservation of mass is called continuity equation. Thus for a fluid flowing through the pipe at all the cross section , the quantity of fluid per second is constant.

Consider two cross-sections of a pipe as shown in fig.



Let V1 = average velocity at cross section 1-1

ρ1 = density at section 1-1

A1 = area of pipe at section 1-1

V2, ρ2 ,A2 are corresponding valves at section ,2-2

Then ,rate of flow at section 1-1 = V1 $\boldsymbol{\rho 1}$ A1

rate of flow at section 2-2 = V2 $\boldsymbol{\rho 2}$ A2

according to law of conservation of mass

Rate of flow at section 1-1 = rate of flow at section 2-2

- ⇨ $V_1 \rho_1 A_1 = V_2 \rho_2 A_2$, called the continuity equation for compressible fluid.
- ⇨ $V_1 A_1 = V_2 A_2$, called the continuity equation for compressible fluid.

Energies Of Flowing Fluid;

There are three types of energies or head as follows

1. Pressure energy or pressure head- is the energy possessed by a liquid particle by virtue of its existing pressure. Pressure energy or pressure head is denoted by $p/\rho g$.

2. Kinetic energy- It is the energy possessed by a liquid particle by virtue of its motion or velocity.

K.E is also known as kinetic head or velocity head. Kinetic energy or kinetic head is measured as $v^2/2g$

3. Potential energy- It is the energy possessed by a liquid particle by virtue of its position with respect to a datum. Potential energy or potential head is denoted by z.

TOTAL ENERGY- Total energy of a liquid particle in motion is the sum of its pressure energy , kinetic energy and potential energy.

Total energy head $H=p/\rho g+v^2/2g+z$

State and Prove Bernoulli's Equation: -

Bernoulli's equation states that ,"In an ideal incompressible fluid when the flow is steady and continuous the sum of pressure energy, kinetic energy and potential energy is constant along a stream line."

Mathematically, $p/\rho g + v^2/2g+z$ is constant.

Where $p/\rho g$=pressure energy

$v^2/2g$=kinetic energy

z=datum energy

Proof:-

Consider an ideal incompressible liquid flowing through a non-uniform pipe as shown in the figure.

Let us consider two sections 1-1 & 2-2 and assume that the pipe is running full and there is continuity of flow between the two sections.

Let p_1=pressure at 1-1

V_1=velocity of liquid at 1-1

Z_1=height of 1-1 above the datum

A_1=area of pipe at 1-1

And P_2,V_2,Z_2,A_2 are corresponding values at 2-2.

Let the liquid between two sections 1-1 & 2-2 move to 1'-1' & 2'-2' through very small length dl1& dl2 as shown in the figure.

This movement of liquid between 1-1 & 2-2 is equivalent to the movement of the liquid between 1-1 and between 1'-1' and between 2-2 & between 2'-2'.

Let W=weight of the liquid between 1-1 & 1'-1'

As the flow is continuous $W= \rho g A_1 \times dl_1 = \rho g A_2 \times dl_2$

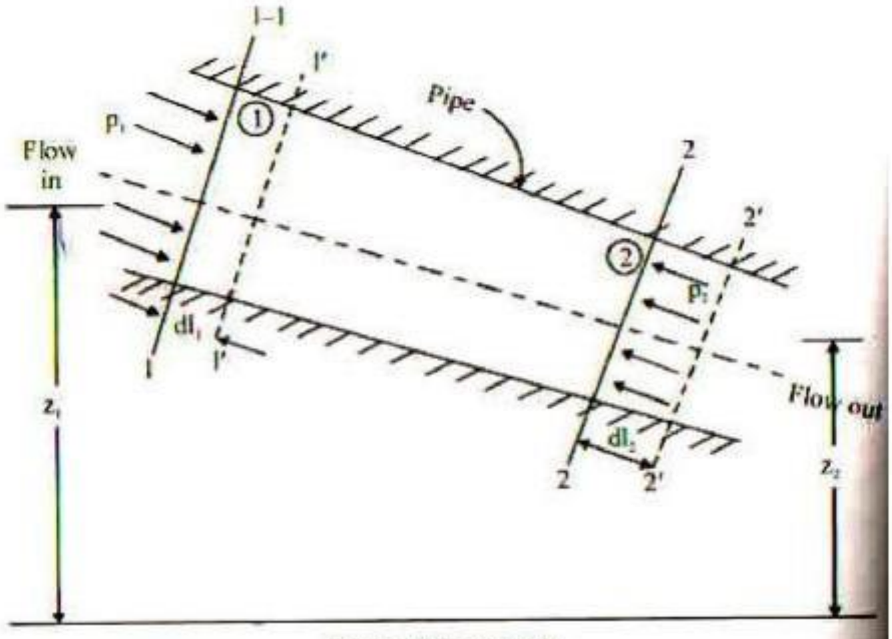
Or, $A_1 \times dl_1 = W/\rho g$

Or, $A_2 \times dl_2 = W/\rho g$

Or ,$A_1 \times dl1 = A_2 \times dl_2$

Workdone by pressure force at 1-1 moving the liquid to 1'-1' =force × distance=$\rho 1 A_1 \times dl1$

Similarly workdone by the pressure force at 2-2 in moving the liquid to 2'-2'=$\rho 2A2 \times dl2$



Bernoulli's equation

Total work done by the pressure =$\rho_1 A1 \times dl1 - \rho 2A2 \times dl2$ ($A1 \times dl1 = A2 \times dl2$) = $A1 \times dl1(p1-p2)$

$=w/\rho g(p1-p2)$

Loss of potential energy =w(z1-z2)

Gain in kinetic energy=w(v2 2 /2g-v1 2 /2g) =w/2g(v2 2 -v1 2)

Also loss of potential energy +work done by pressure = gain in kinetic energy

Since w(z1-z2)+w/ρg(p1-p2)=W/2g(v2 2 -v1 2)

Or z1-z2+(p1/ρg-p2/ρg)=(v2 2 /2g-v1 2 /2g)

Or $p_1/\rho g+v_1{}^2/2g+z_1=p_2/\rho g+v_2{}^2/2g+z_2$

This proves Bernoulli's Equation.

Problem 1:

The diameters of a pipe at the sections 1 and 2 are 10cm and 15 cm respectively. Find the discharge through the pipe if the velocity of water flowing through the pipe at section 1 is 5m/s. determine also the velocity at section 2.

Solution: -

At section 1, D_1 = 10cm = 0.1m

$A_1 = \frac{\pi}{4} \times D_1{}^2 = \frac{\pi}{4} \times 0.1^2 = 0.007854\ m2$

V_1 =5 m/s

At section 2, D_2 = 15cm = 0.15m

$A_2 = \frac{\pi}{4} \times D_2{}^2 = \frac{\pi}{4} \times 0.15^2 = 0.01767\ m2$

V_1 =?

Discharge through pipe is given by, Q = A_1 x V_1=$0.007854\ m2$ x 5 m/s = 0.03927 m3/s (Ans)

Using continuity equation we have,

$A_1V_1 = A_2V_2$

Or, $V2 = \frac{A1.V1}{A2} = \frac{0.007854 \times 5}{0.01767}$ = 2.22 m/s (Ans)

Example 2: -

A 30 cm diameter pipe ,conveying water ,branches into two pipes of diameter 20cm and 15 cm respectively. If the average velocity in the 30cm diameter pipe is 2.5 m/s, find the discharge in this pipe. Also determine the velocity in 15 cm pipe if the average velocity in 20 cm diameter pipe is 2 m/s.

Solution :-

Given :- D1 = 30cm = 0.30m

$A1 = \frac{\pi}{4} \times D_1{}^2 = \frac{\pi}{4} \times 0.3^2 = 0.017068\ m2$

V1 =2.5 m/s

D2 = 20cm = 0.20m

$A2 = \frac{\pi}{4} \times D_2{}^2 = \frac{\pi}{4} \times 0.20^2 = 0.0314\ m2$

V2 = 2 m/s

D3 = 15 cm = 0.15m

$A3 = \frac{\pi}{4} \times D_3{}^2 = \frac{\pi}{4} \times 0.15^2 = 0.01767\ m2$

According to continuity equation, Q1 = Q2 + Q3 ....(1)

1) The discharge Q1 in pipe 1 is given by
Q1 = A1. V1 = 0.07068 x 2.5 = 0.1767 m3/s (ans)
2) Q2 = A2.V2 = 0.0314 x 2.0 = 0.0628 m3/s
Substituting the values of Q1 and Q2 in equation 1
=> 0.1767 = 0.0628 + Q3
Q3 = 0.1767 – 0.0628 = 0.1139 m3/s
Q3 = A3 x V3
=> 0.1139 = 0.01767 x V3
=> V3 = $\frac{0.1139}{0.01767}$ = 6.44 m/s (Ans)

POSSIBLE SHORT QUESTIONS WITH ANSWER

1) State Bernoulli’s theorem? (2011W,2008W)

Ans:- Bernoulli’s equation states that ,”In an ideal incompressible fluid when the flow is steady and continuous the sum of pressure energy, kinetic energy and potential energy is constant along a stream line.”

Mathematically, $p/\rho g + v^2/2g + z$ is constant.

Where $p/\rho g$=pressure energy

$v^2/2g$=kinetic energy

z=datum energy

2) What is continuity equation? (2011,2016 W,2018W,2019 S,2020W)

Ans:- It states that “for a fluid flowing through the pipe at all the cross section , the quantity of fluid per second is constant.”

Rate of flow at section 1-1 = rate of flow at section 2-2

⇨ $V1\ \boldsymbol{\rho 1}\ A1 = V2\ \boldsymbol{\rho 2}\ A2$, called the continuity equation for compressible fluid.

⇨ V1 A1 = V2 A2, called the continuity equation for compressible fluid.

POSSIBLE LONG QUESTIONS

1) State and prove Bernoulli’s theorem? (2012W,2018W,2019W)
2) Write short notes on continuity equation? (2012 W,2019 W)
3) A 30 cm pipe, branches into two pipes of diameter of 20cm and 15 cm. if the average velocity in the 30 cm diameter pipe is 2.5 m/s. find the discharge in this pipe. Also

determine the velocity in 15 cm diameter pipe if the average velocity in 20 cm diameter pipe is 2m/s. (2019W)

CHAPTER- 10

HYDRAULIC DEVICES AND PNEUMATICS

Learning objectives

Introduction

Intensifier.

Hydraulic Lift

Accumulator

hydraulic Ram

Introduction: -

In the industry we use three methods for transmitting power from one point to another. Mechanical transmission is through shafts, gears, chains, belts, etc. Electrical transmission is through wires, transformers, etc. Fluid power is through liquids or gas in a confined space. In this chapter, we shall discuss a structure of hydraulic systems and pneumatic systems. We will also discuss the advantages and disadvantages and compare hydraulic, pneumatic, electrical and mechanical systems.

Intensifier: -

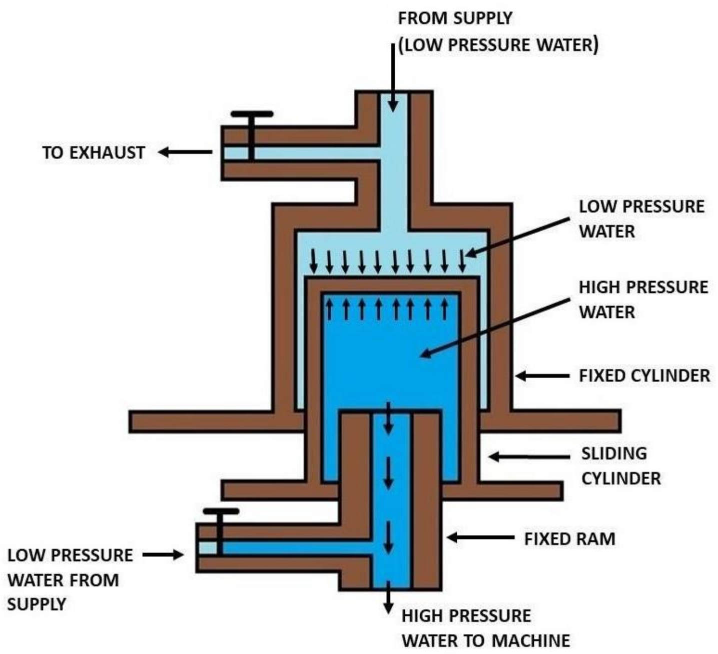
- The hydraulic intensifier is a mechanical device which is used to increase the intensity of pressure of the fluid.
- Some hydraulic machines like hydraulic press, hydraulic ram and hydraulic lift etc. Require high pressure for working but this high pressure can't be obtained by using pump.
- A hydraulic intensifier is mounted in between the pump and these working machines.
- Generally, a normal intensifier can raise the pressure intensity of liquid at 150-160 MN/.

Construction:
A hydraulic intensifier is very simple in construction; it has only three main parts such as:-

1. Fixed Cylinder: It is the outermost body part of the hydraulic intensifier to receive the low-pressure liquid from the main supply.
2. Sliding Cylinder Or Ram: It is the middle part of hydraulic intensifier which slides in between the fixed ram and fixed cylinder. It contains high pressure liquid which is supplied to it through the fixed ram.
3. Fixed Ram: It is the inner most and smallest part of the hydraulic intensifier. It is surrounded by a sliding cylinder. The high-pressure liquid is supplied to the machine through this fixed ram.

Working:

A large quantity of water at a low pressure from the supply enters the inverted fixed cylinder. The weight of this water presses the sliding cylinder in the downward direction. The water inside the inverted sliding cylinder gets compressed due to the downward movement of the sliding cylinder and its pressure thus increases. This high-pressure water is forced out of the sliding cylinder through the fixed ram, to the hydraulic machine.



Applications:

- Hydraulic intensifier is used to supply high intensity pressure where ever need.
- It used where pump is not sufficient to provide high intensity of pressure as per the requirement.
- It is most commonly used in hydraulic press, hydraulic ram, hydraulic cranes and hydraulic lifts etc where high intensity of pressure is required for lift the loads.

Advantages:

- Hydraulic intensifier is a compact device and very easy to operate and control.
- It can be directly attached with the hydraulic machinery, where ever it is needed.
- It is compact as well as energy saving device.
- It is cheaper device.
- It is very easy to operate and control.

Disadvantages:

- leakage of the fluid.
- Sometimes the hydraulic fluid used is may be corrosive.
- leakage fluid can catch fire.
- This system requires high maintenance.

Hydraulic Lift

The hydraulic lift is a device used to lift or bring down passengers and loads from one floor to another in multi-storeyed buildings.
The hydraulic lift are of two types:-

1. Direct Acting Hydraulic Lift
2. Suspended Hydraulic Lift

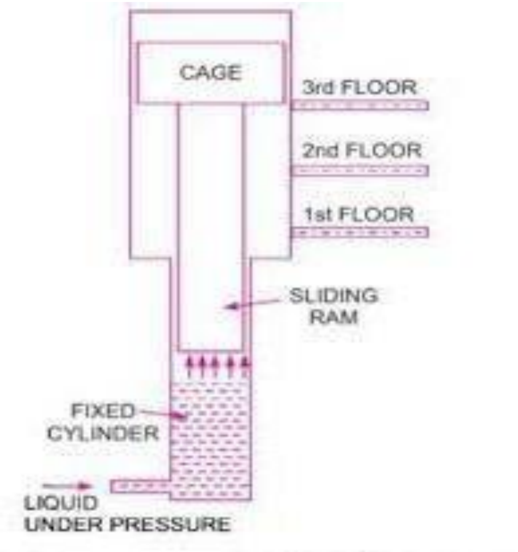
1. DIRECT ACTING HYDRAULIC LIFT

Construction:

Cage: It is fitted on the top of the sliding ram where the load is placed (i.e. lifted load).

Wire rope: It connects the cage to pulley.

Sliding ram: It is fitted in the fixed cylinder which is reciprocate (upward or downward direction) when we applied the pressure (i.e. reaches the floor wise)



Working:

When fluid under pressure is forced into the cylinder, the ram gets a push upward. The platform carries loads or passengers and moves between the guides. At required height, it can be made to stay in level with each floor so that the good or passengers can be transferred.

In direct acting hydraulic lift, stroke of the ram is equal to the lift of the cage.

2. SUSPENDED HYDRAULIC LIFT

Construction:

Cage: It is fitted on the top of the sliding ram where the load is placed (i.e. lifted load).

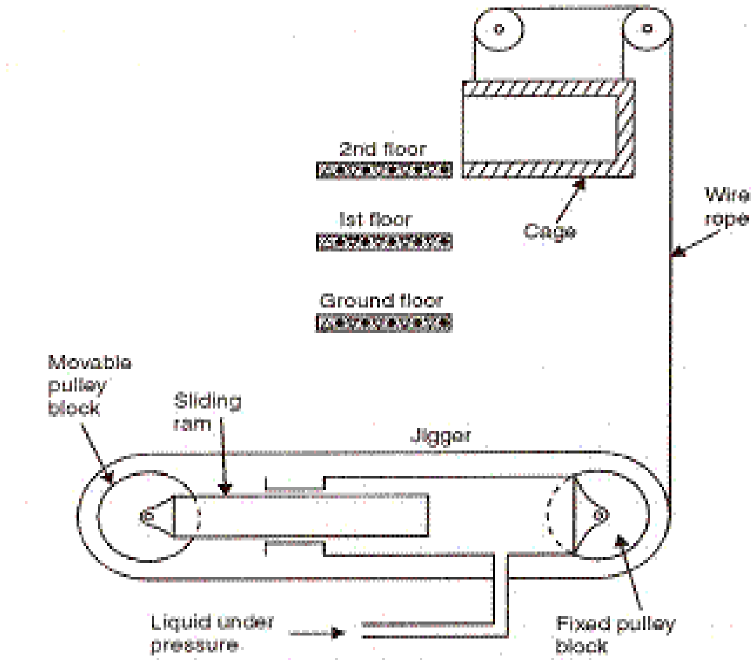
Wire rope: It connects the cage to pulley.

Sliding ram: It is fitted in the fixed cylinder which is reciprocate (upward or downward direction) when we applied the pressure (i.e. reaches the floor wise)

Pulleys: pulleys are connected to the sliding ram and fixed cylinder; where one pulley is fixed and another pulley is movable.

Hydraulic jigger: It consists of a moving ram which slides inside a fixed hydraulic cylinder.

Fixed cylinder-: It is fixed with the wall of the floor, where the sliding ram reciprocate when we apply the pressure.



Working:

When fluid under pressure is forced into the cylinder, the ram gets reciprocate to the movable pulleys. With the help of arrangement of hydraulic jigger; pulley can rotate; with the help of

wire rope the cage is maintain their pressure force with their floor. At required height, it can be made to stay in level with each floor so that the good or passengers can be transferred.
Working period of the lift is ratio of the height of lift to the velocity of lift.
Idle period of lift is the difference of the total time for one operation and the working period of the lift.

Accumulator

Hydraulic accumulator is a mechanical device used in hydraulic applications. It works as an intermediate device between supply lines of hydraulic fluid from pump to required machines like hydraulic lift, hydraulic press, hydraulic cranes etc. It temporarily stores the pressurized hydraulic fluid when operating machine is at ideal condition. Some hydraulic machines require high pressure for a small period of time or we can say that only for required working period so this time hydraulic accumulator comes into the play. It stores the pressurized hydraulic fluid at ideal time and supply to the machine when it is required. Pump continuously supplies the fluid which is not required all the time that's why hydraulic accumulator creates a balance between the demand and supply of hydraulic fluid. For highly loaded working operations high capacity pumps are not required because small pumps can do same job with the application of hydraulic accumulator which is the main advantage of it. The maximum amount of hydraulic energy stored by any hydraulic accumulator is known as the capacity of the accumulator.

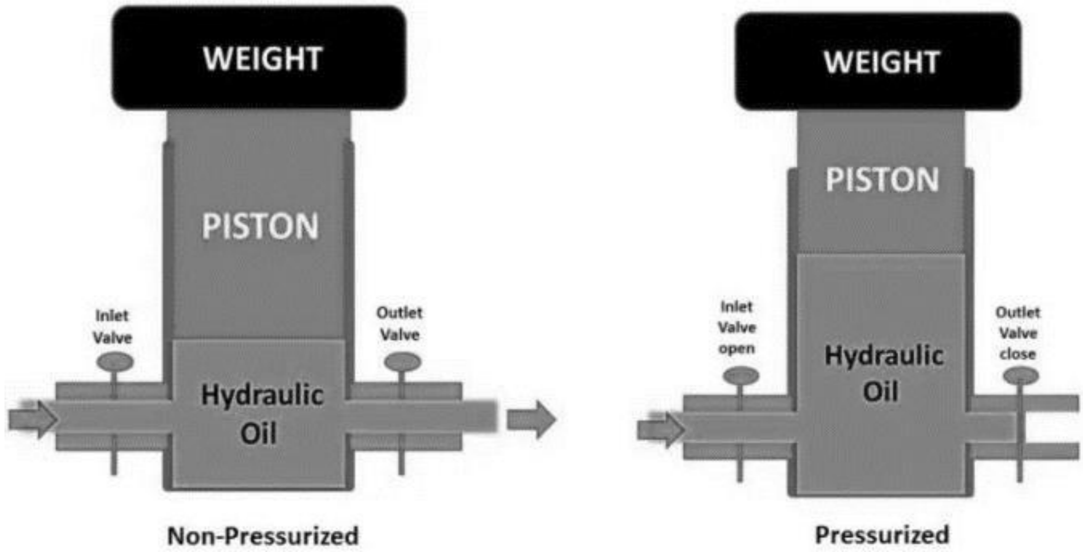
Constructions and working:

A simple hydraulic accumulator consists of a cylinder with inlet and outlet ports for the hydraulic fluid, inlet are attached with the pump where as outlet is connected with the operational machine. Cylinder consists of a ram with reciprocating motion inside the cylinder and having some weight on the top of the ram. The arrangement of the ram and cylinder should be vertical in position.

Pump continuously supplies the hydraulic fluid to the operating machine through the accumulator, when there is no requirement of the fluid the outlet becomes close. This time continuous supply from the pump raises the ram/plunger in the upward position gradually till the extreme end or until the outlet is open. This operation helps to store the hydraulic energy inside the accumulator for a small period of time. As the operating machine require pressurized fluid for the power stroke then the outlet port becomes open and ram with weights on the top starts slides downward gradually which results high pressurized liquid is delivered to the operating machine during its power stroke. This whole operation repeated continuously and helps us to do difficult tasks with small investment of energy in daily life.
Hydraulic accumulator plays important role in the hydraulic applications where high pressure is requires for working operation although the basic principle and working operation explained above but it has some important functions, some of these functions are

1. Stores hydraulic energy: As we studied above the most important function of the any hydraulic accumulator is to store the hydraulic energy and transmit it further when requires. It results a small size pump able to do high capacity tasks which save lot of input power and energy.
2. Reduce vibrations and shocks: It works as intermediate device between the pump and the operating machine so it helps to obtain a smooth and noise free operation while working which results less vibrations and shocks will occurs in the system. The turbulence in the flow coming from the pump is easily settled by the ram/plunger action into the accumulator.

3. Safety device: Hydraulic accumulator works as safety device also because it works as intermediate device so it control any kind of bursting due to high pressure hydraulic fluid in the transmission line.
4. Work as reservoir: Hydraulic accumulator stores the excess energy of the fluid and transmits furth



er when it is required so we can say that it works as a reservoir of hydraulic energy.

Hydraulic Ram

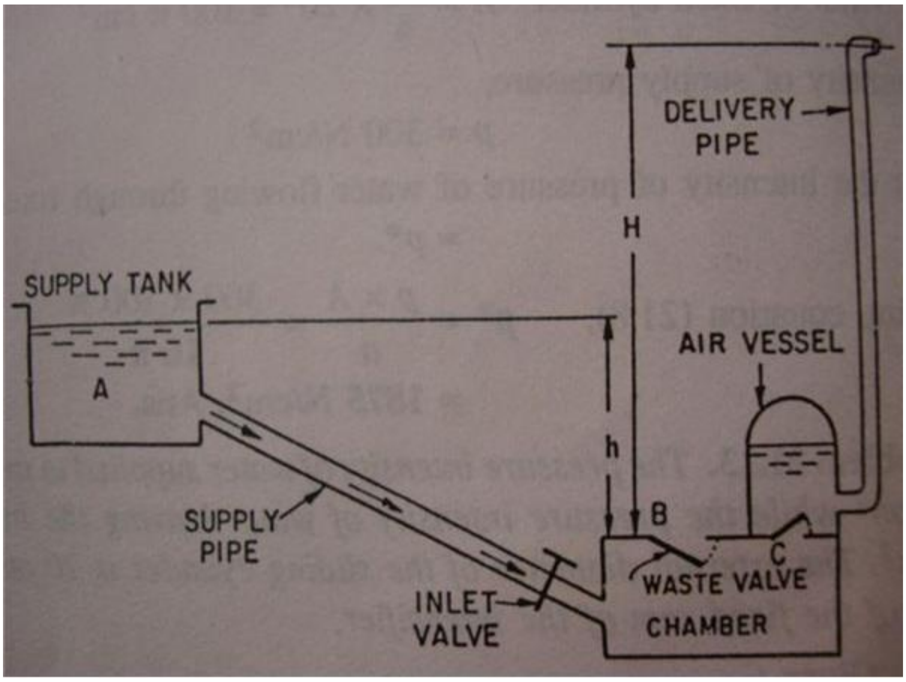
The hydraulic ram is a pump which raises water without any external power for its operation.
One essential requirement for the satisfactory operation of a hydraulic ram is the availability of a large quantity of water with a small positive head or height.
This large quantity of water at a small height is sufficient to lift small quantity of water to a greater height.
It works on the principle of "Water Hammer."

Construction:-

The system has a chamber with two flap valves and an air vessel.
This chamber is connected to the water supply from a supply tank or a water reservoir at a small height.
The supply tank and the pumping chamber are separated by a valve which controls the flow of water.

Working:-

When the inlet valve fitted on the supply line is opened, water starts flowing from the supply tank to the pumping chamber. The chamber has two valves, "B" and "C." Valve "B" is the waste valve and "C" is called the delivery valve. The valve "C" is fitted to an air vessel. As water is flowing from the supply tank, the chamber gets filled up and valve "B" starts to move upwards. A moment comes, when the valve "B" suddenly closes. This sudden closure of valve "B" creates high pressure inside the chamber. This sudden increase in pressure opens "C" which is the delivery valve. Thus the water from the chamber enters the air vessel and compresses the air inside the vessel. The compressed air exerts a force on water which is inside the air vessel. Thus a small quantity of water is raised to a greater height. As the water in the chamber looses momentum, the waste valve "B" gradually opens in downward direction and flow of water from the supply tank starts flowing to the chamber and the cycle will be repeated.



POSSIBLE SHORT QUESTIONS WITH ANSWERS

1. What is the function of hydraulic ram? (2018 W)
   Ans:- The hydraulic ram is a pump which raises water without any external power for its operation.
   large quantity of water at a small height is sufficient to lift small quantity of water to a greater height.
   It works on the principle of "Water Hammer."
2. What is intensifier? (2019 S)
   Ans:- The hydraulic intensifier is a mechanical device which is used to increase the intensity of pressure of the fluid.
   A hydraulic intensifier is mounted in between the pump and these working machines.
   Generally, a normal intensifier can raise the pressure intensity of liquid at 150-160 MN/.
3. State uses of pneumatic systems. (2020W)
   Ans:- pneumatic system uses air that is compressed in order to transmit and control energy.
   It is used in train ,doors ,automatic production system etc.

POSSIBLE LONG QUESTIONS

1. Explain hydraulic accumulator with neat sketch?(2019 S)

2. What is the function of hydraulic lift and describe working of hydraulic lift with neat sketch? (2017W, 2018W, 2019W)