

Elements of Mechanical Engineering

EME

By,

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Th3. Elements of Mechanical Engineering

(Common to Electrical and EEE)

Name of the Course: Diploma in Electrical Engineering			
Course code:		Semester	3rd
Total Period:	60	Examination :	3 hrs
Theory periods:	4P/week	Internal Assessment:	20
Maximum marks:	100	End Semester Examination ::	80

A. Rationale:

This subject has been introduced with a view to provide adequate understanding of properties of steam, thermodynamic laws, Boilers, Turbines, Condensers to the students of electrical engineering since these form the basic and fundamental aspect for drive mechanisms used in generation of electricity

B. Objectives:

On completion of the course content the students will be able to:

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1. Explain the principle of working of Boilers, Turbines and condensers.
2. State the different types of boilers and Turbines and their uses.
3. Explain the properties of steam.
4. State and explain thermodynamic laws.

C. TOPIC WISE DISTRIBUTION OF PERIODS

SI No.	Topic	Periods
1.	THERMODYNAICS	06
2.	PROPERTIES OF STEAM	05
3.	BOILERS	10
4.	STEAM ENGINES	10
5.	STEAM TURBINES	06
6.	CONDENSER	04
7.	I.C. ENGINE	04
8.	HYDROSTATICS	05
9.	HYDROKINETICS	05
10.	HYDRAULIC DEVICES AND PNEUMATICS	05
TOTAL		60

D. Course Content :

1. **THERMODYNAICS:**
 - 1.1 State Unit of Heat and work, 1st law of thermodynamics.
 - 1.2 State Laws of perfect gases
 - 1.3 Determine relationship of specific heat of gases at constant volume and constant pressure.
2. **PROPERTIES OF STEAM:**
 - 2.1 Use steam table for solution of simple problem - 20
 - 2.2 Explain total heat of wet, dry and super heated steam - 20
3. **BOILERS:**
 - 3.1 State types of Boilers - 32

3rd Semester Electrical

- 3 . 2 Describe Cochran, Babcock Wilcox boiler
3 . 3 Describe Mountings and accessories
- ✓ 4. STEAM ENGINES:
4.1 Explain the principle of Simple steam engine
4.2 Draw Indicator diagram
4.3 Calculate Mean effective pressure, IHP and BHP and mechanical efficiency.
4.4 Solve Simple problem.
- ✓ 5. STEAM TURBINES:
5.1 State Types
5.2 Differentiate between Impulse and reaction Turbine
- ✓ 6. CONDENSER:
6.1 Explain the function of condenser
6.2 State their types
- ✓ 7. I.C. ENGINE:
7.1 Explain working of two stroke and 4 stroke petrol and Diesel engines.
7.2 Differentiate between them
8. HYDROSTATICS:
8.1 Describe properties of fluid
8.2 Determine pressure at a point, pressure measuring Instruments
9. HYDROKINETICS:
9.1 Deduce equation of continuity of flow
9.2 Explain energy of flowing liquid
9.3 State and explain Bernoulli's theorem
10. HYDRAULIC DEVICES AND PNEUMATICS:
10.1 Intensifier — 10^{51}
10.2 Hydraulic lift — 10^{52}
10.3 Accumulator — 10^{53}
10.4 Hydraulic ram — 10^{54}

Syllabus coverage up to Internal assessment

Chapters: 1, 2, 3, and 4.

Learning Resources:			
Sl.No	Title of the Book	Name of Authors	Name of the publisher
1	Thermal Engineering	R. S. Khurmi ✓	S Chand
2	Hydraulics & Hydraulic M/Cs	A. R. Basu	Dhanpat Rai & Co
3	Thermal Engineering	A. S. Sarad	Satyaprakashan
4	Hydraulics & Hydraulic M/Cs	R. K. Bansal ✓	Laxmi Publishers

Simple Steam Engines

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- * A Steam engine is a heat engine that performs mechanical work using steam as its working fluid.
- * The steam engine uses the force produced by the steam pressure to push a piston back. The pushing force can be transformed by a connecting rod & flywheel into rotational force for work.
- * These engines operate on the principle of first law of thermodynamics (i.e. heat & work are mutually convertible.)

Classification

(a) According to number of working stroke:→

- (i) Single acting steam engine
- (ii) Double acting steam engine

When steam is admitted on one side of the piston & one working stroke is produced during each revolution of the crankshaft, then it is known as single acting steam engine.

When the steam is admitted on both sides of the piston & two working strokes are produced during each revolution of the crankshaft, it is known as double acting steam engine.

(b) According to the position of cylinder:→

- (i) Horizontal steam engine
- (ii) Vertical steam engine

When the axis of the cylinder is horizontal, then it is known as horizontal steam engine.

When the axis of the cylinder is vertical, it is called vertical steam engine. It requires less floor area than horizontal steam engine.

(c) According to the speed of crankshaft:→

- (i) Slow Speed Steam engine:→ Speed of the crankshaft is less than 100 rpm
- (ii) Medium Speed Steam engine:→ Speed of the crankshaft is between 100 rpm to 250 rpm
- (iii) High Speed Steam engine:→ Speed of the crankshaft is above 250 rpm

(d) According to the type of exhaust:→

(i) Condensing Steam engine:→ When steam after doing work in the cylinder passes into a condenser which condenses the steam into water less than the atmospheric pressure, is known as condensing steam engine.

(ii) Non-condensing Steam engine:→ When the steam after doing work in the cylinder is exhausted into the atmosphere, it is known as non-condensing steam engine.

(e) According to the expansion of the steam in the engine cylinder

(i) Simple Steam engine:→ When the expansion of steam is carried out in a single cylinder & the exhausted into the atmosphere, it is said to be simple steam engine.

(ii) Compound Steam engine:→ When the expansion of the steam is completed in two or more cylinders, the engine is called a compound steam engine.

(f) According to the method of governing employed

(i) Throttling Steam engine:→ When the engine speed is controlled by means of a throttle valve in the steam pipe which regulates the pressure of steam to the engine, it is called throttling steam engine.

(ii) Automatic Cut-off Steam engine:→ When the speed is controlled by controlling the steam pressure with an automatic cut-off governor, it is called an automatic cut-off steam engine.

Important parts of Steam Engine

- (a) Frame: It is a heavy cast iron part, which supports all the stationary as well as moving parts & holds them in proper position.
- (b) Cylinder: It is a cast iron cylindrical hollow vessel in which the piston moves to & fro under the steam pressure. The both ends of the cylinder are closed & steam tight.
- (c) Steam Chest: It is casted as an integral part of the cylinder. It supplies steam to the cylinder with the movement of D-slide valve.
- (d) D-Slide Valve: It moves in the steam chest & its function is to exhaust steam from the cylinder at proper movement.
- (e) Inlet & exhaust ports: These are holes provided in the body of the cylinder for the movement of steam. The steam admitted through inlet port & exhausted through exhaust port.
- (f) Piston: It is a cylindrical disc, moving to & fro in the cylinder because of the steam pressure. Its function is to convert heat energy of the steam into mechanical work.
- (g) Piston Rod: It is a circular rod, which is connected to the piston on one side & crosshead to the other end. Its main function is to transfer motion from the piston to the cross-head.
- (h) Cross-head: It is a link betn the piston rod & connecting rod. Its function is to guide motion of the piston rod & to prevent it from bending.
- (i) Connecting Rod: It is made of forged steel, whose one end is connected to the cross-head & the other end to the crank. Its main function is to convert reciprocating motion of piston into rotary motion of the crank.
- (j) Crankshaft: It is the main shaft of the engine having a crank. The crank works on the lever principle & produces rotary motion of the shaft.

(K) Eccentric: \Rightarrow It is generally made of cast iron & fitted to the crankshaft. Its function is to provide reciprocating motion to the slide valve.

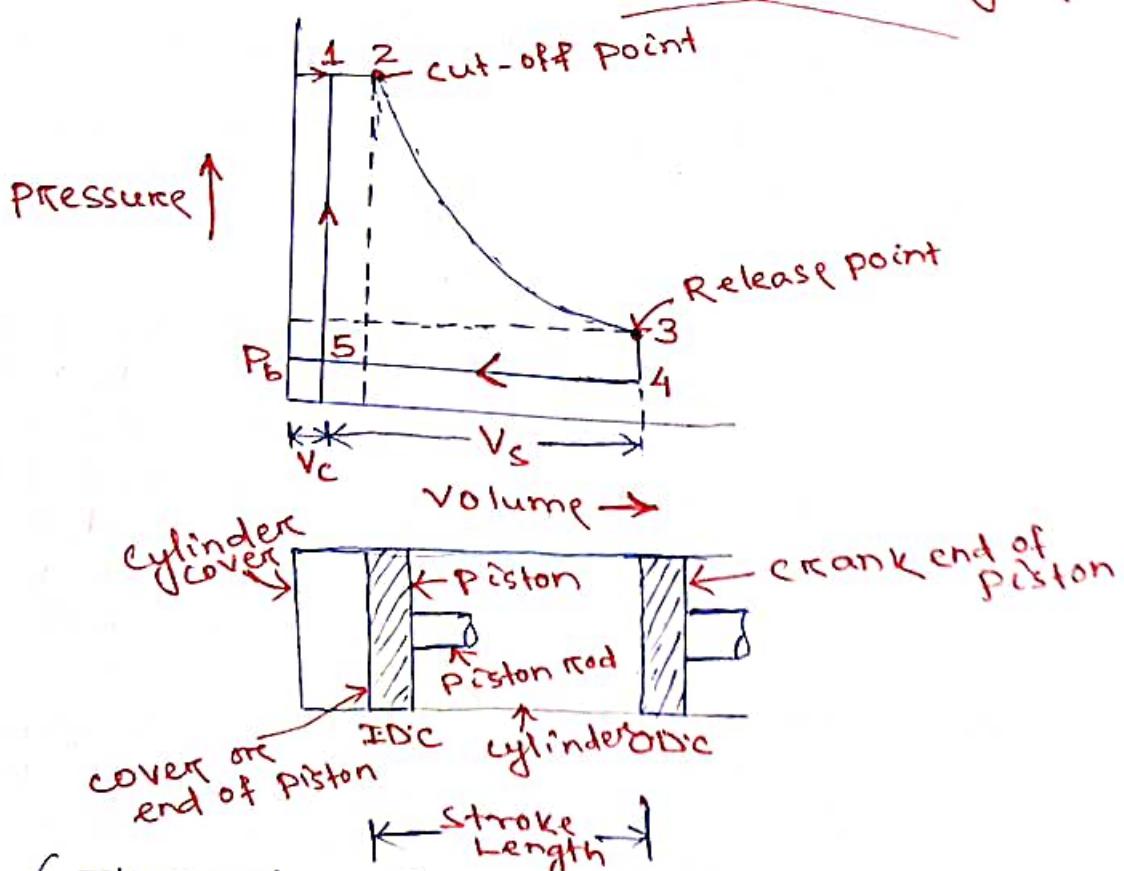
(L) Eccentric rod & valve rod: \Rightarrow The eccentric rod is made of forged steel. Whose one end is fixed to the eccentric & other to the valve rod. Its main function is to convert rotary motion of the crankshaft into to & fro motion of the valve rod.

The valve rod connects the eccentric & D-slide valve.

(M) Flywheel: \Rightarrow It is a heavy cast iron wheel mounted on the crankshaft. Its function is to prevent the fluctuation of engine. It also prevents the jerks to the crankshaft.

(N) Governor: \Rightarrow It is a device to keep the engine speed more or less uniform at all load conditions. (i.e. controls the mean speed of the engine)

Important Terms used in Steam Engines



(Theoretical indicator diagram for a simple steam engine)

(a) BORE : \rightarrow The internal diameter of the cylinder of the engine is known as Bore.

(b) Dead Centres: \rightarrow The extreme positions of the piston inside the cylinder during its motion are known as dead centres.

There are two dead centres

(i) Inner dead centre (I.D.C)

(ii) Outer dead centre (O.D.C)

In horizontal engine, the inner most position of the ~~piston~~ piston (towards the cylinder cover end) is known as inner dead centre.

The outermost position of the piston (towards the crank end) is called outer dead centre.

(c) Clearance Volume: \rightarrow The volume of space between the cylinder cover & the piston, when the piston is at I.D.C position is called Clearance Volume. It is usually represented in percentage of stroke volume.

(d) STROKE VOLUME: \rightarrow (Vs) / Swept Volume

The volume swept by the piston when it moves from I.D.C to O.D.C, is known as stroke volume (Vs). It is also known as piston displacement.

Mathematically

$$V_s = \frac{\pi}{4} \times D^2 \times L$$

Where D = Bore or internal dia. of cylinder
L = Length of the stroke.

(e) Cut-off Volume: \rightarrow The point or the volume where the cut-off of steam takes place is called the point of cut-off or cut-off volume.

(f) Average piston Speed: \rightarrow The distance travelled by the piston per unit time is known as average piston speed

Mathematically

Average piston speed

$$= LN \text{ m/min} \text{ (For single acting steam engine)}$$

$$= 2LN \text{ m/min} \text{ (For double acting steam engine)}$$

Where L = Length of stroke in metres

N = Speed in r.p.m.

(g) Mean effective pressure \rightarrow The average pressure (P_m)

on the piston during the working stroke is called mean effective pressure.

Mathematically $P_m = \frac{\text{Workdone/cycle}}{\text{Stroke volume}}$

Indicator Diagram of a simple Steam Engine

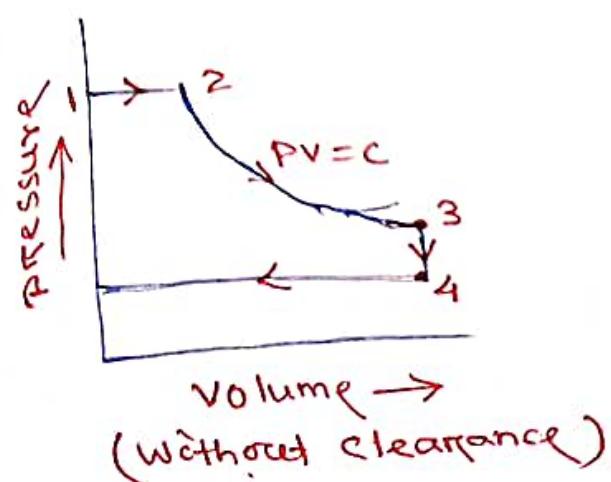
It is the graphical representation of the variation in pressure & volume of steam inside the cylinder. This P-V diagram is developed from that of modified Rankine cycle.

Assumption

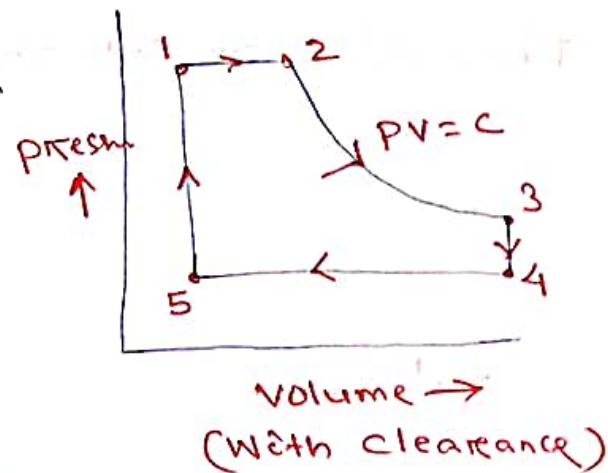
- (i) The opening & closing of steam ports is instantaneous (occurring or done properly)
- (ii) There is no pressure drop due to condensation.
- (iii) There is no Wise drawing due to restricted valve opening. (drawn into wise like structure)
- (iv) The steam is admitted at boiler pressure & exhausted at condenser pressure.
- (v) The expansion of the steam is hyperbolic (i.e $PV = C$)

Theoretical or Hypothetical Indicator Diagram

There is no steam in the cylinder (i.e zero volume of steam at point 1)



There is some steam in the cylinder at Point-1

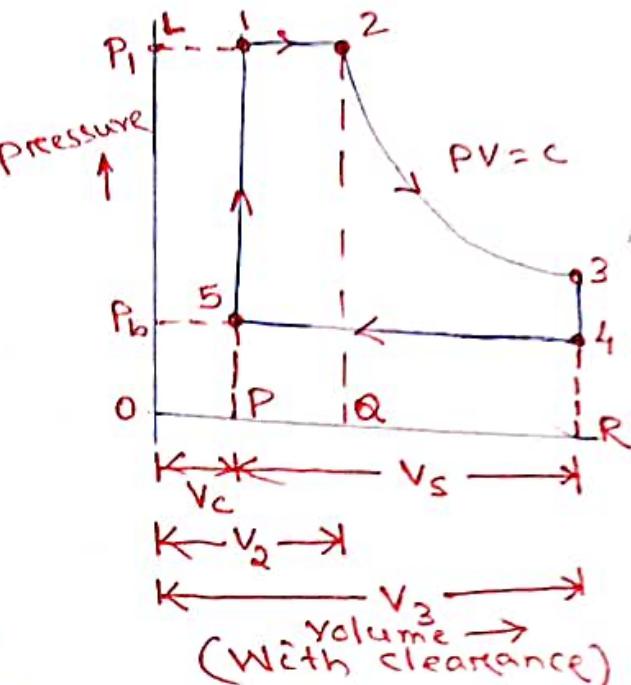
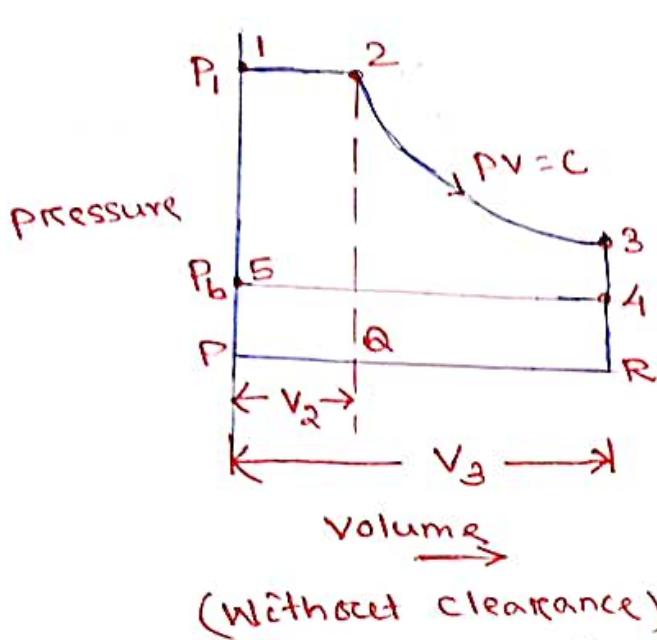


Processes

- (i) PROCESS 1-2: At point 1, the steam is admitted into the cylinder through 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. This point is known as cut-off point.
- (ii) 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 $PV=C$).
- (iii) PROCESS 3-4: At point 3, the exhaust port opens & steam released from cylinder to the exhaust. As a result pressure in the cylinder falls suddenly. The point 3 is known as release point.
- (iv) 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 & the inlet port open. The steam pressure at point 4 is called back pressure.
- (v) PROCESS 5-1: At point 5, the inlet port is opened & some steam suddenly enters into the cylinder which increase the pressure of steam. This process continues till the original position is restored.

Theoretical or Hypothetical Mean effective Pressure:-

The theoretical mean effective pressure may be determined by considering theoretical indicator diagram without clearance & with clearance.



Considering theoretical indicator diagram without clearance \Rightarrow

Let P_1 = Initial pressure or boiler pressure (Point 1)

P_b = Back pressure or condenser pressure
(at point 4 or 5)

V_2 = Volume of steam in cylinder at point of cut-off (Volume at point 2)

V_3 = Stroke Volume or swept volume or piston displacement volume.

Theoretical Workdone per cycle

$$= \text{Area of figure } 123451$$

$$= \text{Area } 12(QP) + \text{Area } 23(RQ) - \text{Area } 45(PR)$$

$$= P_1 V_2 + 2 \cdot 3 P_1 V_2 \log\left(\frac{V_3}{V_2}\right) - P_b V_3$$

Theoretical mean effective pressure

$$P_m = \frac{\text{Workdone/cycle}}{\text{Stroke Volume}}$$

$$= \frac{P_1 V_2 + 2 \cdot 3 P_1 V_2 \log\left(\frac{V_3}{V_2}\right) - P_b V_3}{V_3}$$

$$= P_1 \times \frac{V_2}{V_3} + 2 \cdot 3 P_1 \times \frac{V_2}{V_3} \log\left(\frac{V_3}{V_2}\right) - P_b$$

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$$\pi = \text{Expansion ratio} = \frac{V_3}{V_2}$$

$$P_m = \frac{P_1}{\pi} (1 + 2.3 \log \pi) - P_b$$

Problem

(1) A steam engine cylinder receives steam at a pressure of 11.5 bar & 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.

Soln $P_1 = 11.5 \text{ bar}, V_2 = 0.5 V_3, P_b = 0.15 \text{ bar}$

$$\text{Expansion ratio } \pi = \frac{V_3}{V_2} = \frac{V_3}{0.5 V_3} = 2$$

Theoretical mean effective pressure

$$\begin{aligned} P_m &= \frac{P_1}{\pi} (1 + 2.3 \log \pi) - P_b \\ &= \frac{11.5}{2} (1 + 2.3 \log 2) - 0.15 \\ &= 9.58 \text{ bar (Ans.)} \end{aligned}$$

Diagram factor (K)

The Ratio of the actual mean effective pressure (P_a) to the theoretical mean effective pressure (P_m) is known as diagram factor (K).

Mathematically

$$K = \frac{P_a}{P_m}$$

$$P_a = P_m \times K$$

The average value of K lies between 0.65 to 0.9.

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

Soln $P_i = 8.4 \text{ bar}, v_2 = 0.35 v_3, P_b = 1.25 \text{ bar}$
 $K = 0.75$

$$\text{Expansion ratio } \pi = \frac{v_3}{v_2} = \frac{0.35 v_3}{0.35 v_3} = 2.86$$

Theoretical mean effective pressure

$$\begin{aligned} P_m &= \frac{P_i}{\pi} (1 + 2.3 \log \pi) - P_b \\ &= \frac{8.4}{2.86} (1 + 2.3 \log (2.86)) - 1.25 \\ &= 4.77 \text{ bar} \end{aligned}$$

∴ Actual mean effective pressure

$$P_a = P_m \times K = 4.77 \times 0.75 = 3.58 \text{ bar}$$

Power developed by a steam engine

→ It is defined as the rate of doing work.
 It is the measure of performance of a steam engine.

Mathematically,

$$\text{Power } P = \frac{\text{Work done}}{\text{Time Taken}}$$

In steam engine two types of powers are developed

- (i) Indicated power
- (ii) Brake power

(i) Indicated power (I.P.)

The actual power developed in the engine cylinder, is known as indicated power.

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

A = Area of cylinder or piston in m^2

$$= \frac{\pi}{4} \times D^2 \quad D = \text{dia.}$$

L = Length of the stroke in m

N = Speed of crank shaft in R.P.M.

Mathematically

$$I.P. = \frac{P_a L A N}{60} \text{ W} \quad (\text{For single acting})$$

$$= \frac{2 P_a L A N}{60} \text{ W} \quad (\text{For double acting})$$

When actual mean effective pressure is given

$$= \frac{100 P_a L A N}{60} \text{ KW} \quad (\text{For single acting})$$

$$= \frac{200 P_a L A N}{60} \text{ KW} \quad (\text{For double acting})$$

Q: A double acting single cylinder has 200mm stroke, 160mm dia. It runs at 250 rpm & the cut-off is 25% of the stroke. The pressure at cut-off is 15 bar & exhaust is at 0.3 bar for a diagram factor of 0.75. Estimate the indicated power in KW.

Soln $L = 200\text{mm} = 0.2\text{m}, D = 160\text{mm} = 0.16\text{m}, N = 250 \text{ rpm}$

$$V_2 = 25\% \text{ of stroke} = 0.25 V_3, P_i = 15 \text{ bar};$$

$$P_b = 0.3 \text{ bar}, K = 0.75$$

$$\text{Expansion ratio } R = \frac{V_3}{V_2} = \frac{V_3}{0.25 V_3} = 4$$

Theoretical mean effective pressure

$$P_m = \frac{P_i}{R} (1 + 2.3 \log R) - P_b = \frac{15}{4} (1 + 2.3 \log 4) - 0.3 \\ = 8.64 \text{ bar}$$

Actual mean effective pressure

$$P_a = P_m \times K = 8.64 \times 0.75 \\ = 6.48 \text{ bar}$$

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

$$= \frac{\pi}{4} \times (0.16)^2 = 0.02 \text{ m}^2$$

$$I.P. = \frac{200 P_a L A N}{60} = \frac{200 \times 6.48 \times 0.2 \times 0.02 \times 250}{60} \\ = 21.6 \text{ KW}$$

(ii) Brake power

The power available at crankshaft of an engine is called power output or brake power.

$$B.P = I.P - F.P$$

F.P = Frictional power

The power lost in friction is called frictional power

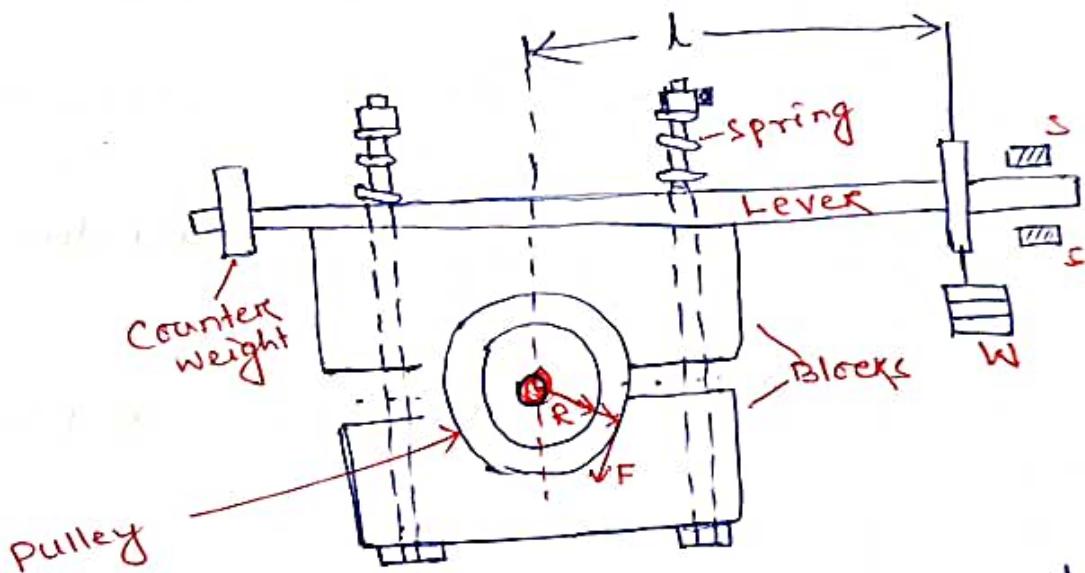
$$I.P = B.P + F.P$$

Measurement of Brake Power

The brake power is measured by an apparatus known as dynamometer.

Two types : (a) Pitoty brake dynamometer
 (b) Rope brake dynamometer

(a) Pitoty brake dynamometer



- * It consists of two wooden blocks placed around a pulley fixed to the shaft of an engine. The blocks are clamped by means of two bolts & nuts.
- * A helical spring is provided between the nut & upper block to adjust the pressure on pulley to control its speed.
- * The upper block has a long lever attached to it & carries a weight 'W' at its outer end. A counterweight is placed at the other end of the lever which balances the brake.
- * Two stops 'S', 'S' are provided to limit the motion of the lever.

Let W = weight of the outer end of the lever in Newton.

λ = Horizontal distance of the weight W from the centre of pulley in meters.

F = frictional resistance between the blocks & the pulley in Newton.

R = Radius of pulley in meter

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

Torque on the shaft or frictional resistance

$$T = W \cdot \lambda = F \cdot R \text{ N-m}$$

$$\text{Work done in one revolution} = \text{Torque} \times \text{Angle turned in radian}$$

$$= T \times 2\pi$$

$$\text{Work done/minute} = T \times 2\pi N$$

Brake power of engine

$$B.P = \frac{\text{Work done/min}}{60} = \frac{2\pi NT}{60} = \frac{2\pi N \times W \cdot \lambda}{60} \text{ Watts}$$

Problem

The following observations were recorded during the trial of a pony brake dynamometer.

Weight hung from the lever = 100N

Distance bet weight & pulley = 1.2m

Shaft speed = 150 r.p.m, find the brake power of the engine.

Soln $W = 100N, \lambda = 1.2m, N = 150 \text{ r.p.m}$

Brake power of the engine

$$B.P = \frac{W \cdot \lambda \times 2\pi N}{60} = \frac{100 \times 1.2 \times 2\pi \times 150}{60}$$

$$= 1885 \text{ W}$$

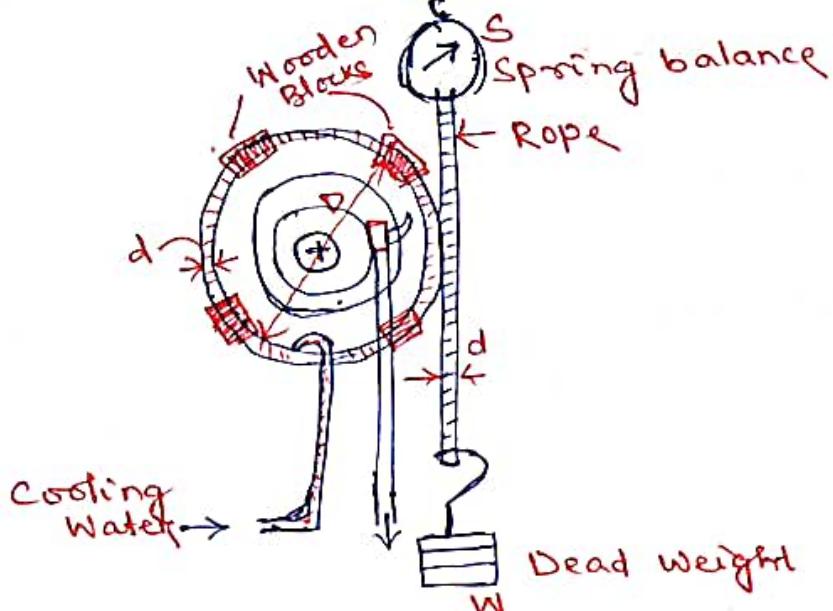
$$= 1.885 \text{ KW}$$

(b) ROPE BRAKE DYNAMOMETER

* It consists of one, two or more ropes wound around the flywheel, fixed rigidly to the shaft of an engine.

* The upper end of the ropes is attached to a spring balance while the lower end of the rope is kept in position by applying a dead weight.

* In order to prevent the slipping of the rope over the flywheel, wooden blocks are placed at intervals around the circumference of the flywheel.



Let W = Dead load in Newton

S = Spring balance reading in Newtons

D = Dia. of the wheel in meter

d = " of ROPE in meter

N = Speed of the engine shaft in R.P.M.

$$\text{Brake Power } B.P = \frac{(W-S) \pi (D+d) N}{60} \text{ watts}$$

If dia. of rope & (d) is neglected

$$B.P = \frac{(W-S) \pi D N}{60} \text{ watts}$$

problem

The following data were recorded in laboratory experiment with the ROPE brake

Dia. of flywheel = 1.2m, Dia. of ROPE = 12.5mm

Eng. speed = 200 rpm, Dead load on brake = 600N

Spring balance reading = 150N, calculate the brake power.

$$D = 1.2\text{m}, d = 12.5\text{mm} = 0.0125\text{m}, N = 200\text{R.P.M}$$

$$W = 600\text{N}, S = 150\text{N}$$

$$B.P = \frac{(W-S) \pi (D+d) N}{60} = \frac{(600-150) \pi (1.2 + 0.0125) 200}{60}$$

$$= 5715 \text{ W}$$

$$= 5.715 \text{ KW}$$

Performance of Steam Engine

Efficiencies of Steam Engine

(i) Mechanical efficiency (η_m) : It is the ratio of the brake power to the indicated power.

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

(ii) Overall efficiency (η_o) : The ratio of work obtained at the crank shaft in a given time to the energy supplied by fuel during the same time.

Let m_f = Mass of fuel burnt in kg/hr

C = Calorific value of fuel in kJ/kg

∴ \rightarrow The amount of energy produced by the complete combustion of a material or fuel.

\rightarrow It is the amount of heat released during its combustion

B.P = Brake Power

Overall efficiency

$$\eta_o = \frac{B.P \times 3600}{m_f \times C}$$

(iii) Indicated thermal efficiency

It is defined as the ratio of heat equivalent of indicated power to the energy in the steam supplied per minute.

$$\text{Indicated thermal efficiency} = \frac{I.P \times 60}{m_s(h_i - h_{fb})}$$

where I.P = Indicated Power

m_s = Mass of steam used in kg/min

h_i = Enthalpy or total heat steam supplied at admission pressure P_i in kJ/kg

h_{fb} = Enthalpy or heat at back pressure P_b in kJ/kg

(iv) Brake thermal efficiency

It is the ratio of the heat equivalent of brake power to the energy in the steam supplied per minute.

Mathematically

$$\text{Brake thermal efficiency} = \frac{B.P \times 60}{m_s (h_i - h_{fb})}$$

(v) Relative efficiency (η)

It is also known as efficiency ratio.

It is the ratio of thermal efficiency to the Rankine efficiency.

Mathematically

$$\text{Relative efficiency} = \frac{\text{Thermal efficiency}}{\text{Rankine efficiency}}$$

Q: Estimate the brake power of simple steam engine having 250mm piston diameter & 40mm piston rod dia. with 250mm stroke length operating at 300 rpm. The initial & back pressure of steam is 8.5 bar & 1.2 bar respectively. Assume 90% mechanical efficiency, cut-off at 25% of the forward stroke. & 0.75 ~~factor~~ diagram factor. Neglect clearance & compression.

Given

$$D = 250 \text{ mm} = 0.25 \text{ m}$$

$$d = 40 \text{ mm} = 0.04 \text{ m}$$

$$L = 250 \text{ mm} = 0.25 \text{ m}$$

$$N = 300 \text{ rpm}$$

$$P_i = 8.5 \text{ bar}$$

$$P_b = 1.2 \text{ bar}$$

$$\eta_m = 90\% = 0.9$$

$$V_2 = 0.25 V_3, K = 0.75$$

$$\text{Expansion ratio } \pi = \frac{V_3}{V_2} = \frac{V_3}{0.25 V_3} = \frac{1}{0.25} = 4$$

Theoretical mean effective pressure (P_m)

$$\begin{aligned} P_m &= \frac{P_i}{\pi} \times [1 + 2.3 \log(\pi)] - P_b \\ &= \frac{8.5}{4} (1 + 2.3 \log(4)) - 1.2 \\ &= 3.8675 \text{ bar} \end{aligned}$$

Actual mean effective pressure

$$P_a = P_m \times K = 3.8675 \times 0.75 = 4.191 \text{ bar}$$

$$\text{Area of piston } A = \frac{\pi}{4} \times D^2 = \frac{\pi}{4} \times (0.25)^2 = 0.0491 \text{ m}^2$$

$$\text{Area of piston rod } a = \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (0.04)^2 = 0.00126 \text{ m}^2$$

Indicated power

$$I.P = \frac{100 P_a L (2A - a) N}{60}$$

$$= \frac{100 \times 4.191 \times 0.25 (2 \times 0.0491 - 0.00126)}{60 \times 360}$$

$$= 50.78 \text{ kW}$$

$$\text{Mechanical efficiency } \eta_m = \frac{B.P}{I.P}$$

$$\Rightarrow B.P = \eta_m \times I.P = 0.9 \times 50.78$$

$$= 45.702 \text{ kW}$$

Impulse turbine

Impulse turbines are defined as turbines in which high-velocity jets of water or steam collide with the blades of the turbine to rotates the turbine & produce electricity using this winding.

Reaction turbine

Reaction turbines are the types of turbines that develops torque by reacting to the pressure or mass of a gas or fluid. The operation of reaction turbines is described by Newton's third law of motion. The reaction turbine is rarely used in actual practice.

Difference bet'n impulse & Reaction Turbine

Impulse turbine

(i) The steam completely expands in the nozzle & its pressure remains constant during its flow through the blade passages.

(ii) The relative velocity of steam passing over the blade remains constant in the absence of friction.

(iii) Blades are symmetrical.

(iv) The pressure on both ends of the moving blade is same.

(v) For the same power developed as pressure drop is more, the number of stages required are less.

(vi) The blade efficiency curve is less flat.

(vii) The steam velocity is very high & therefore the speed of turbine is high.

(viii) Occupies less space per unit power.

Reaction turbine

(i) The steam expands partially in the nozzle & further expansion takes place in the rotor blades.

(ii) The relative velocity of steam passing over the blade increases as the steam expands while passing over the blade.

(iii) Blade are not symmetrical.

(iv) The pressure on both ends of the moving blade is different.

(v) For the same power developed as pressure drop is small, the number of stages required are more.

(vi) The blade efficiency curve is more flat.

(vii) The steam velocity is not very high & therefore the speed of turbine is low.

(viii) Occupies more space per unit power.

Impulse turbine

Impulse turbines are defined as turbines in which high-velocity jets of water or steam collide with the blades of the turbine to rotate the turbine & produce electricity using this winding.

Reaction turbine

Reaction turbines are the types of turbines that develops torque by reacting to the pressure or mass of a gas or fluid. The operation of reaction turbines is described by Newton's third law of motion. The reaction turbine is rarely used in actual practice.

Difference bet' impulse & Reaction Turbine

Impulse turbine

(i) The steam completely expands in the nozzle & its pressure remains constant during its flow through the blade passage.

(ii) The relative velocity of steam passing over the blade remains constant in the absence of friction.

(iii) Blades are symmetrical.

(iv) The pressure on both ends of the moving blade is same.

(v) For the same power developed as pressure drop is more, the number of stages required are less.

(vi) The blade efficiency curve is less flat.

(vii) The steam velocity is very high & therefore the speed of turbine is high.

(viii) Occupies less space per unit power.

Reaction turbine

(i) The steam expands partially in the nozzle & further expansion takes place in the rotor blades.

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(vii) The steam velocity is not very high & therefore the speed of turbine is low.

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Steam condenser

A Steam condenser is a closed vessel into which the steam is exhausted & condensed after doing work in an engine cylinder or turbine.

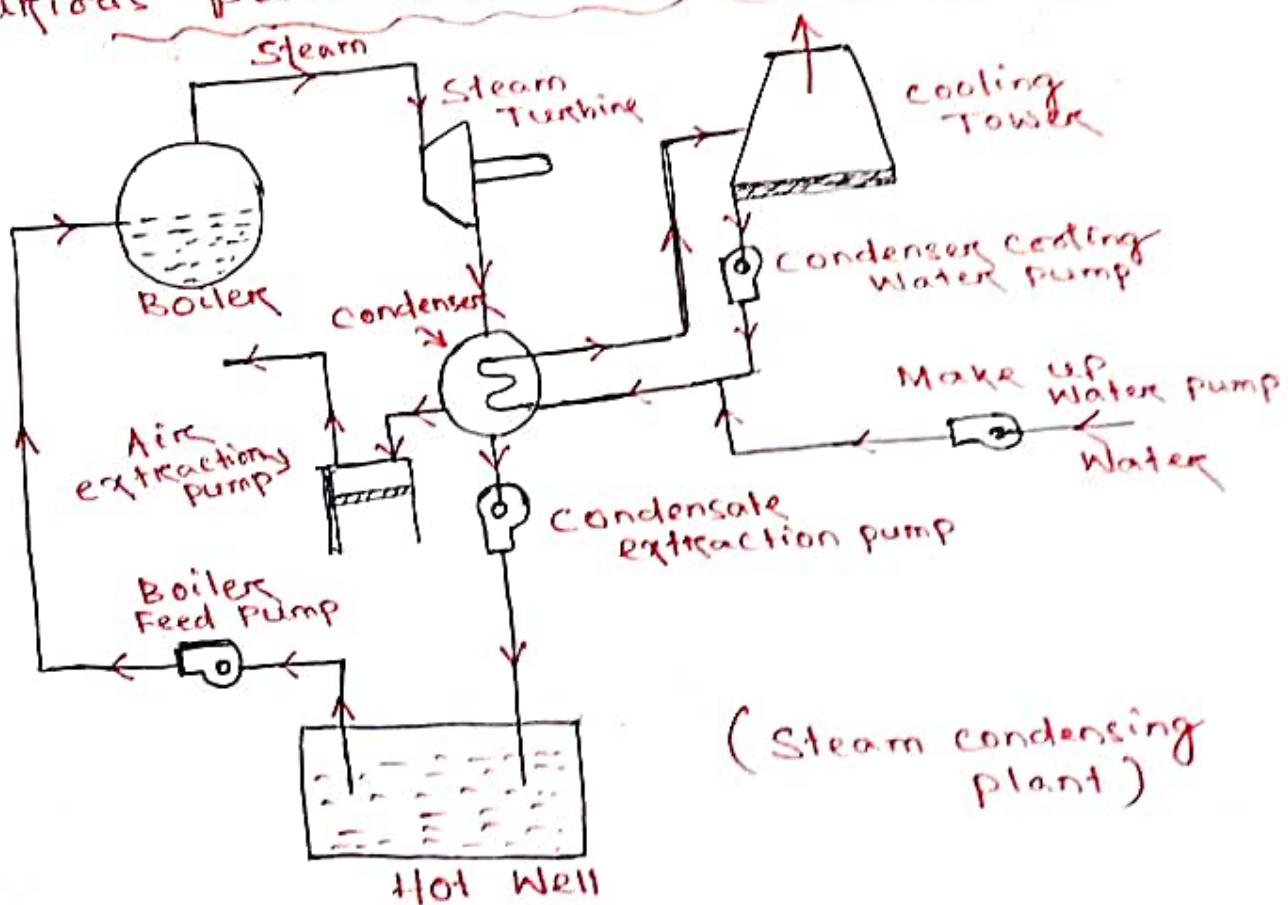
It have two objects:-

- (i) To maintain a low pressure, so as to obtain the max^m possible energy from steam & thus secure a high efficiency.
- (ii) To ~~app~~ supply pure feed water to the hot well, whence it is pumped back to the boiler.

Advantages of condenser (of a steam power plant)

- (i) It increases expansion ratio of steam & thus increases efficiency of the plant.
- (ii) It reduces back pressure, thus more work can be obtained.
- (iii) It reduces temp. of the exhaust steam, thus more work can be obtained.
- (iv) The temp. of condensed steam is higher than that of fresh water. Therefore the amount of heat supplied per Kg of steam is reduced.

Various parts of a steam condensing plant



- (a) Condenser: \rightarrow It is a closed vessel in which steam is condensed means it condense the steam into pure water. So that it may be reused in the steam boiler as boiler feed water.
- (b) Condensate pump: \rightarrow It is a pump, which remove condensed steam from the Condenser to the hot well.
- (c) Hot Well: \rightarrow It is a sump between the Condenser & boiler, which receives condensed steam from condensate pump.
- (d) Boiler feed pump: \rightarrow It is a pump, which pumps the condensate steam from the hot well to the boiler.
- (e) Air extraction pump: \rightarrow It is a pump which removes air from condenser.
- (f) Cooling Tower: \rightarrow It is a tower used for cooling the water which is discharged from the condenser.
- (g) Cooling Water pump: \rightarrow It is a pump, which circulates the cooling water through the Condenser.

Classification of Condenser

(a) Jet condenser (Mixing type condenser)

(b) Surface Condenser (Non-mixing type condenser)

(a) Jet condenser

* Jet condenser is a mixing type condenser where exhaust steam is condensed mixed with cooling water.

* In jet condenser, high power is required for condensation.

It are of 4 types:-

(i) Parallel flow jet condenser

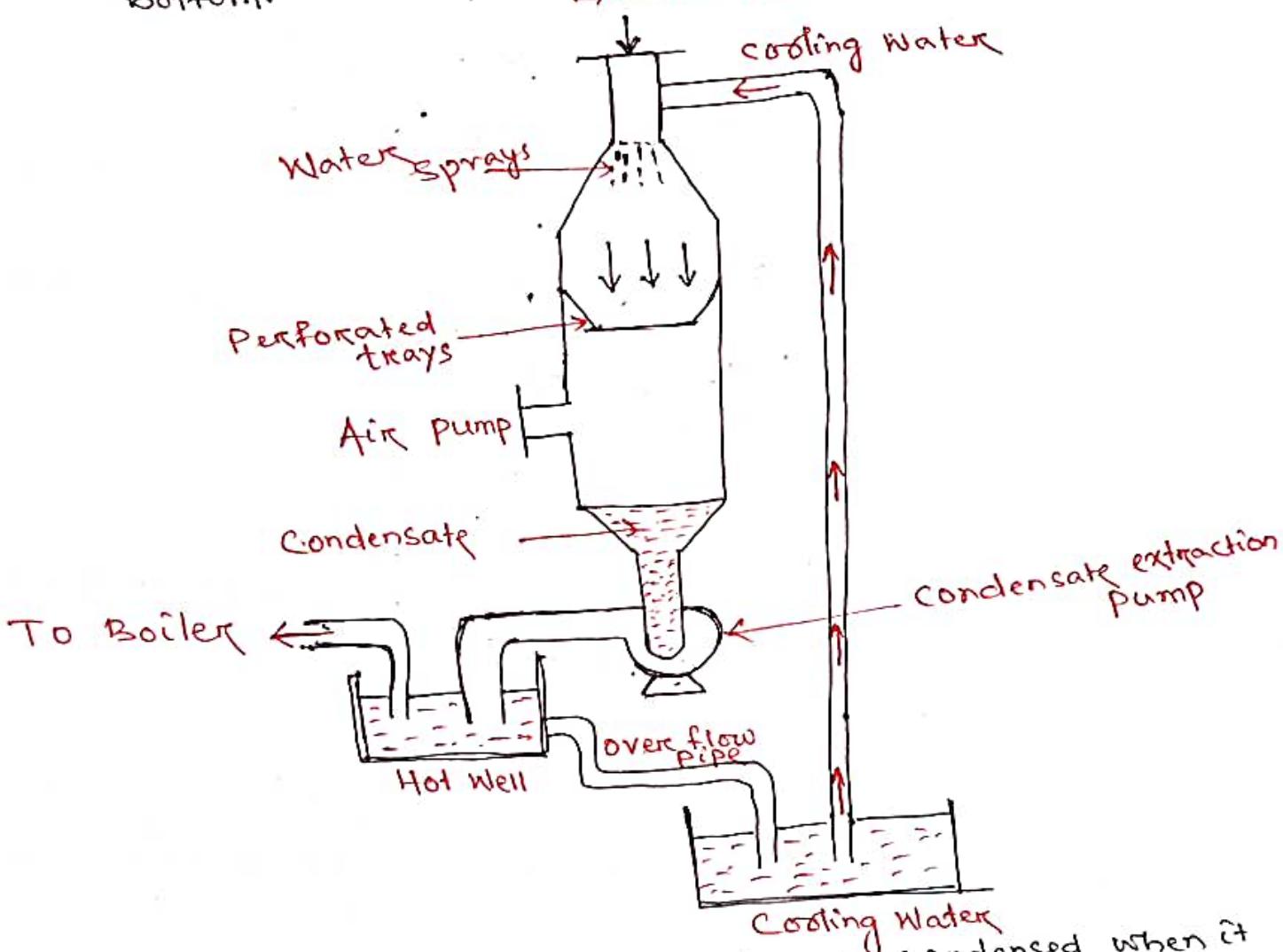
(ii) Counterflow jet condenser

(iii) Barometric or high level jet condenser

(iv) Ejector condenser

(i) parallel flow Condenser

In parallel flow condenser, both the steam & Water enter at the top, & the mixture is removed from the bottom.



The exhaust steam is ~~condensate~~ condensed when it mixes up with Water. The Condensed Steam, cooling Water & air flow downwards & are removed by two separate pump known as condensate pump & Air pump.

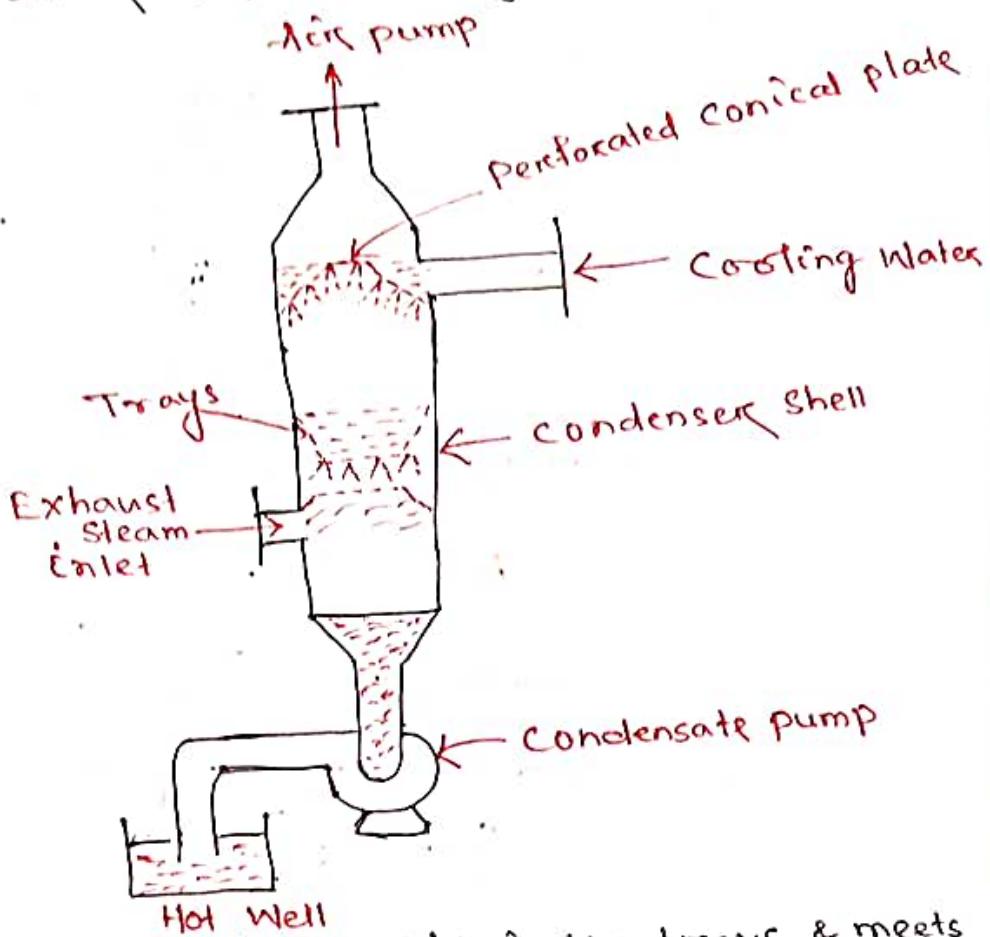
The condensate pump delivers the condensed steam to the hot well, from where extra Water flow to the cooling Water tank through an overflow pipe.

(ii) Counterflow or Low Level jet Condenser

→ The exhaust steam enters at the bottom, flows upwards & meets the down coming cooling water.

The vacuum is created by the air pump, placed at the top of the Condenser Shell.

This draws the supply of cooling water, which falls in a large number of jets, through perforated conical plate



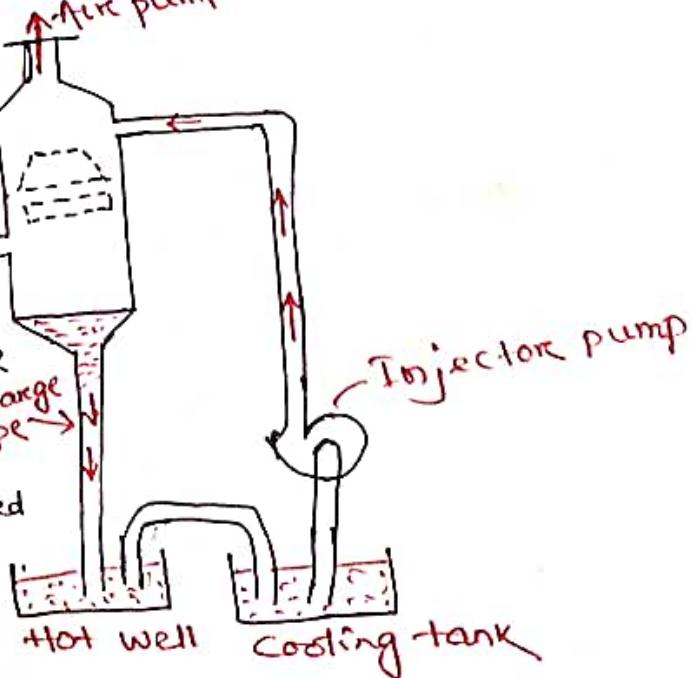
The falling water is caught in the trays & meets the exhaust steam entering at the bottom. The rapid condensation occurs, & condensate & cooling water go through a vertical pipe to the condensate pump, which delivers it to the hot well.

(iii) Barometric or High level jet condenser

These condensers are provided at high level ~~jet~~ ~~condenser~~ with a long vertical discharge pipe

In high level jet condenser
exhaust steam enters at the bottom flows upwards & meets the down coming cooling water.

The vacuum is created by the air pump, placed at the top of the condenser shell.



The condensate & cooling water go through a vertical pipe to the hot well without any pump. The extra water from the hot well flows to the cooling water tank through an overflow pipe.

(iv) Ejector Condenser

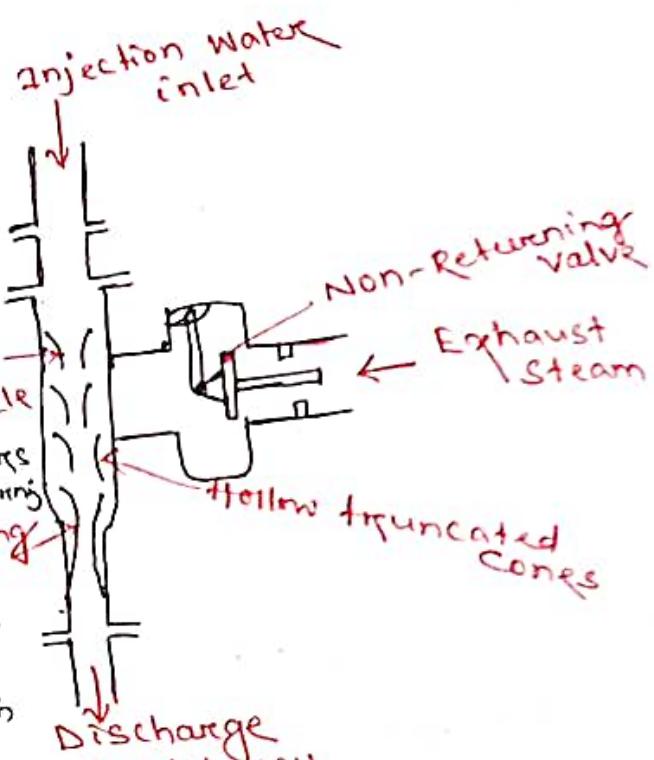
In ejector condenser, the steam & water mix up while passing through a series of metal cones.

Water enters at the top through a number of guide cones.

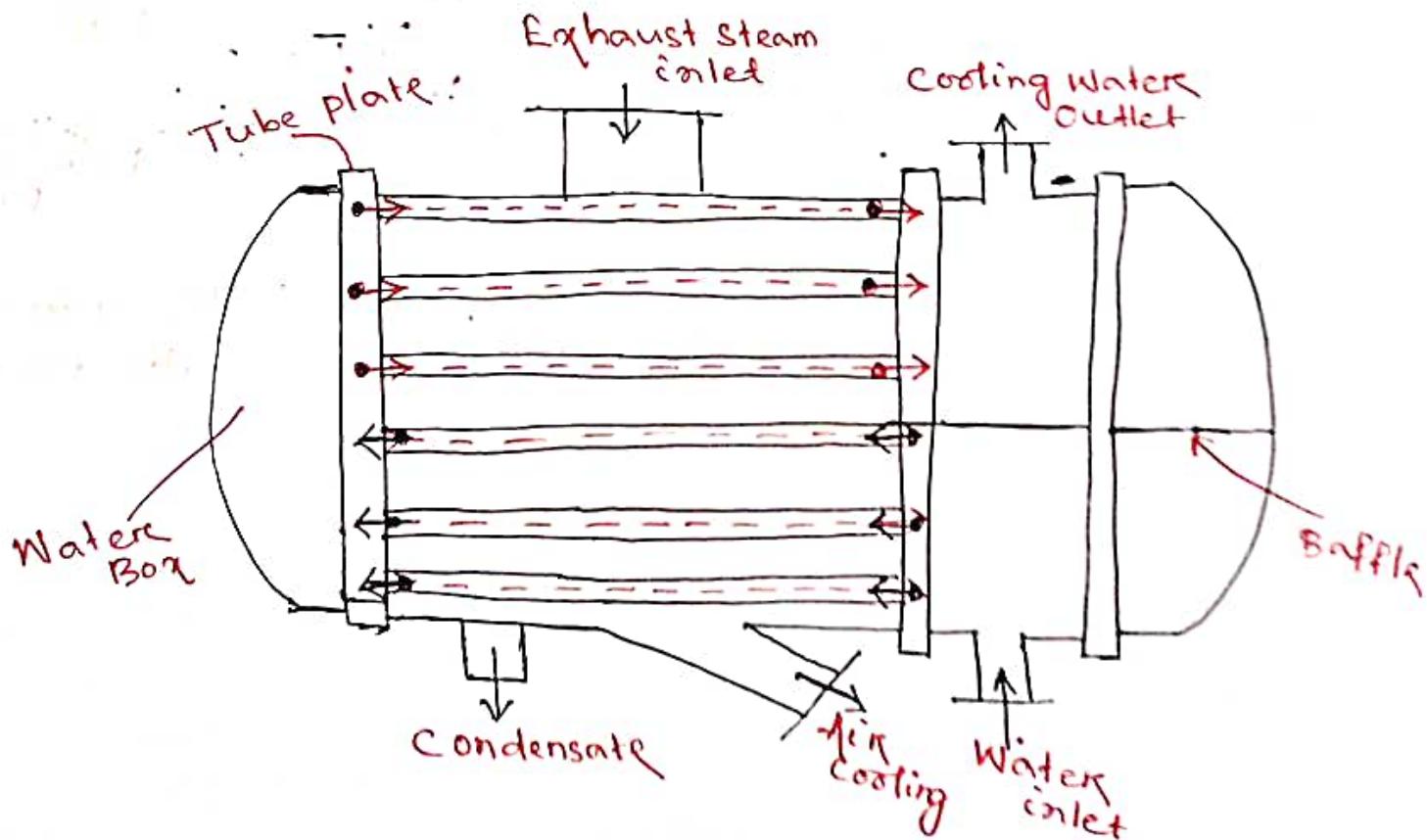
The exhaust steam enters the condenser through non-returning valve arrangement.

The steam & air passes through the hollow truncated cones. After it passes through the diverging cones.

The condensate & cooling water is then discharged to the hot well.



(b) Surface Condenser



- * It is consist of a horizontal cast iron cylindrical vessel ~~filled~~ packed with tubes, through which the cooling water flows.
- * The water tubes pass horizontally through the main condensing space for the steam.
- * The steam enters at the top & flow downwards over the tubes. The cooling water flows in one direction through the lower half of the tubes & returns in opposite direction through the upper half.

Types

It may be classified on the basis of the direction of flow of the condensate.

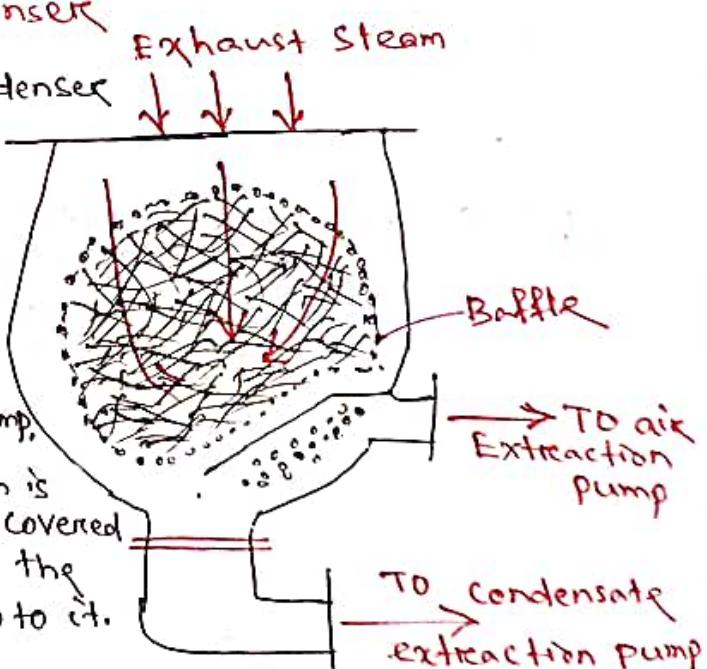
- (a) Down flow Surface Condenser
- (b) Central flow Surface Condenser
- (c) Regenerative Surface Condenser
- (d) Evaporative Condenser

(a) Down flow Surface Condenser

In down flow surface condenser the exhaust steam enters at the top & flow downwards over the tubes by the help of extraction pump.

The condensate collected at the bottom & then pumped by extraction pump.

The 'dry air' pump, which is provided near the bottom, is covered by baffle, so as to prevent the entry of condensed steam into it.



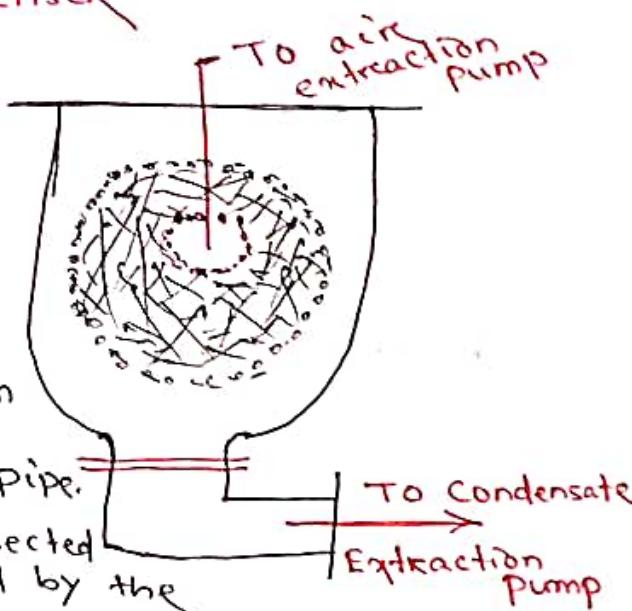
(b) Central flow Surface Condenser

In Central flow Surface Condenser

the exhaust steam enters at the top & flow downwards. The suction pipe of the air extraction pump is placed in the centre of the tube.

This causes the steam to flow radially inwards over the tubes towards the suction pipe.

The condensate is collected at the bottom & then pumped by the extraction pump.

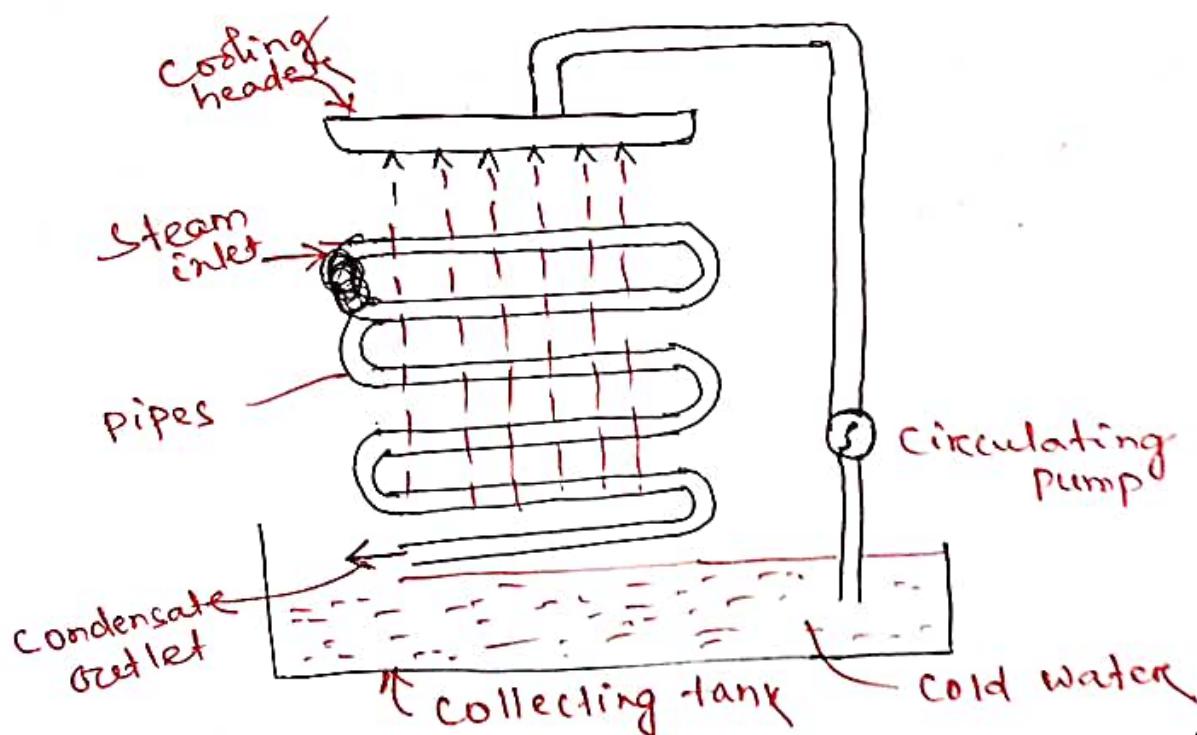


(c) Regenerative Surface Condenser

In Regenerative Surface condenser,

the condensate is heated by a regenerative method. The Condensate after leaving the tubes is passed through the exhaust steam from the turbine.

(d) Evaporative Condenser



The exhaust steam enters at the top of a series of pipes outside of which cold water is falling. At the same time, a current of air circulates over the water film, causing rapid evaporation of some cooling water.

As a result of this, the steam circulating inside the pipe is condensed. The remaining cooling water is collected & is reused.

The evaporative condensers are provided when the circulating water is to be used again & again.

Difference bet' jet condenser & Surface condenser

Jet Condenser

- (i) Cooling water & steam are mixed up.
- (ii) Less suitable for high capacity plant
- (iii) Condensate is wasted.
- (iv) It requires less quantity of circulating water.
- (v) The condensing plant is economical & simple
- (vi) Maintenance cost is low.
- (vii) More power is required for air & water pump.

Surface Condenser

- (i) Cooling water & steam are not mixed-up.
- (ii) More suitable for high capacity plant.
- (iii) Condensate is reused.
- (iv) It requires large quantity of circulating water.
- (v) The condensing plant is costly & complicated
- (vi) Maintenance cost is high.
- (vii) Less power is required for air & water pump.

I.C. Engine

The internal combustion engines are those engines in which the combustion of fuel takes place inside the engine cylinder.

These are petrol, diesel & gas engines.

Difference bet' steam engine & I.C. engine.

Steam Engine

- (i) Combustion of fuel takes place outside the cylinder (i.e. in a boiler)
- (ii) These engines are smooth & silent running.
- (iii) The working pressure & temp. inside the engine cylinder is low.
- (iv) A steam engine requires boiler & other components to transfer energy.
- (v) Steam engines have efficiency about ~~50%~~ 15% to 20%.

I.C. Engine

- (i) Combustion of fuel takes place inside the engine cylinder.
- (ii) These engines are very noisy.
- (iii) The working pressure & temp. inside the engine cylinder is very high.
- (iv) In I.C. engine does not require a boiler or other components to transfer energy.
- (v) I.C. engines have efficiency about 35% to 40%.

Classification of I.C. engine

- (1) According to the type of fuel used
 - (a) Petrol engine
 - (b) Diesel engine
 - (c) Gas engine
- (2) According to the method of igniting the fuel.
 - (a) Spark ignition engine (S.I. engine)
 - (b) Compression ignition engine (C.I. engine)
- (3) According to the number of strokes per cycle
 - (a) Four-stroke engine
 - (b) Two-stroke engine
- (4) According to the cycle of operation
 - (a) Otto cycle engine (constant volume cycle)
 - (b) Diesel cycle engine (constant pressure cycle)
 - (c) Dual Combustion cycle (semi-diesel cycle)

(5) According to the speed of engine

- (a) Slow speed engine
- (b) Medium speed engine
- (c) High speed engine

(6) According to the cooling system used

- (a) Air-cooled engine
- (b) Water-cooled engine
- (c) Evaporative cooling engine

(7) According to the method of fuel injection

- (a) Carburetor engine
- (b) Air injection engine
- (c) Airless or solid injection engine

(8) According to the number of cylinders

- (a) Single cylinder engine
- (b) Multi-cylinder engine

(9) According to the arrangement of cylinders

- (a) Vertical engines
- (b) Horizontal engines
- (c) Radial engines
- (d) In-line multi-cylinder engine
- (e) V-type multi-cylinder engine
- (f) Opposite-cylinder engine
- (g) Opposite piston engine

(10) According to the valve mechanism

- (a) Overhead valve engine
- (b) Side valve engine

.....

TWO STROKE engine

* Working cycle is completed in two strokes of the piston or one revolution of the crank shaft.

* Suction & compression processes in one stroke (inward stroke)

Expansion & exhaust processes in second stroke (outward stroke)

Four-stroke engine

* Working cycle is completed in four strokes of the piston or two revolution of the crankshaft.

* Suction, compression, expansion, exhaust processes completed in each stroke.

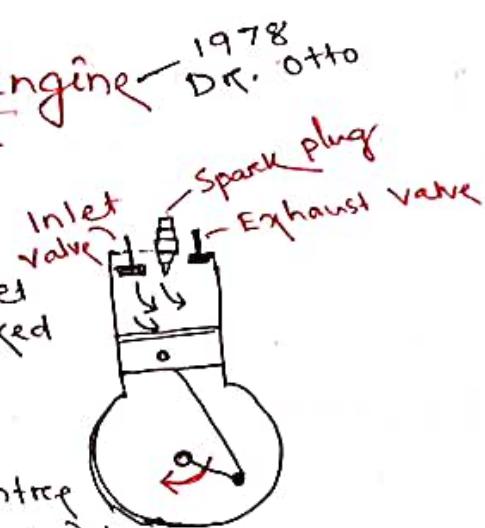
Four-Stroke cycle Petrol Engine

It is based on Otto cycle.

(i) Suction Stroke →

In Suction stroke the inlet valve opens & charge is sucked into the cylinder.

The piston moves downward from top dead centre (T.D.C.). It continues till the piston reaches its bottom dead centre (B.D.C.).

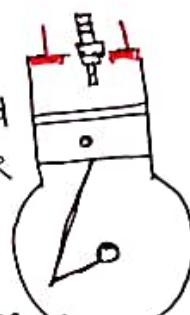


(ii) Compression Stroke

In this stroke

Both inlet & exhaust valve closed & the charge is compressed as the piston moves from B.D.C to T.D.C

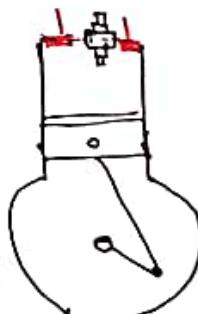
Due to compression, the pressure & temp. of charge increases.
This complete one revolution of crank shaft.



(III) Expansion or Working Stroke

The charge ignited with the help of Spark plug. Due to the rise in pressure, the piston is pushed down with great force.

The hot burnt gases expand due to high speed of the piston.

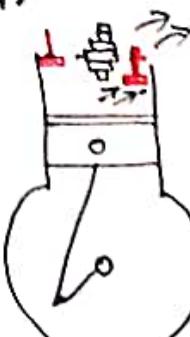


Due to this expansion, some of the heat energy produced, & it transformed into mechanical work.
During working stroke, piston moves from T.D.C to B.D.C & both the valve are closed.

(IV) Exhaust Stroke

* The exhaust valve is open as the piston moves from B.D.C to T.D.C.

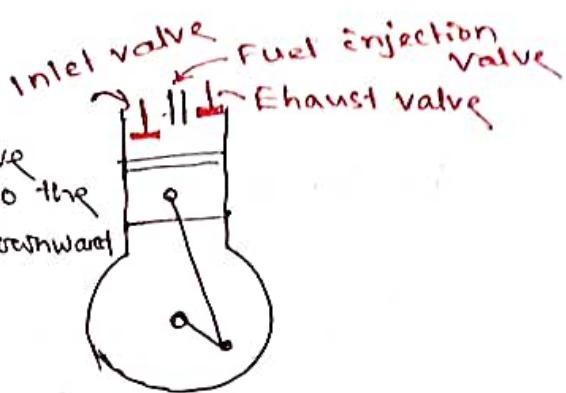
* This movement of the piston pushes out the products of combustion from the engine cylinder & are exhausted through the exhaust valve into the atmosphere.
This complete the cycle.



Four Stroke Diesel Engine

(i) Suction Stroke:

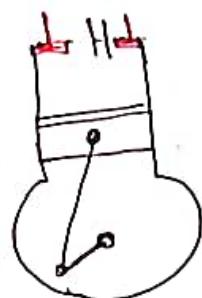
In this stroke, the inlet valve opens & pure air is sucked into the cylinder as the piston moves downward from T.D.C. to B.D.C.



(ii) compression stroke:

In this stroke both valves are closed & air is compressed as the piston moves upward from B.D.C to T.D.C.

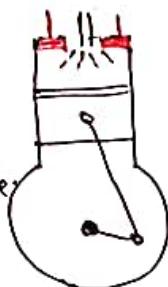
As a result of compression pressure & temp. of air increases. This complete one revolution of the ~~crank~~ Crank Shaft.



(iii) Expansion or Working Stroke

Before the piston reaches the T.D.C., fuel is injected in the form of very fine spray into the engine cylinder through fuel injection valve.

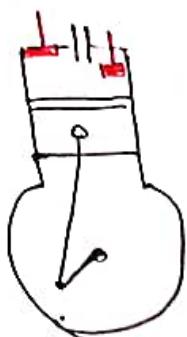
It suddenly increases the pressure & temp. of the fuel of combustion. The hot burnt gases expand due to high speed of the piston. During expansion stroke, some of heat energy ~~burning~~ is converted into mechanical work. During this stroke, both the valves are closed & piston moves T.D.C to B.D.C.



(iv) Exhaust Stroke

In this stroke, the exhaust valve is open as the piston moves from B.D.C to T.D.C.

This movement of piston pushes out the products of combustion from the engine cylinder to the atmosphere through exhaust valve.



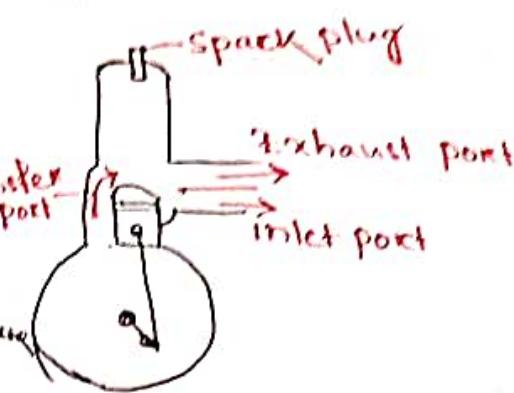
This completes the cycle & the engine cylinder is ready to suck the fresh air again.

TWO STROKE Petrol Engine

(i) Suction Stage:

In this stage, the piston going down TDC to BDC, uncovers both the transfer port & exhaust port.

The fresh fuel-air mixture allows into the engine cylinder.



(ii) Compression Stage:

In this stage, the piston while moving up, first covers the transfer port & then exhaust port.

After that, fuel is

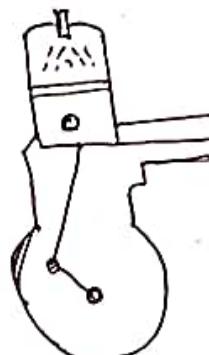
compressed as the piston moves upwards. Here inlet port is open & fresh fuel-air mixture enters into the crank case.



(iii) Expansion Stage:

Before the piston reaches the TDC in compression stroke the charge is ignited with the help of spark plug.

It suddenly increases the pressure & temp. of the combustion, the piston pushed downwards with a great force. As a result the burnt gases expand.

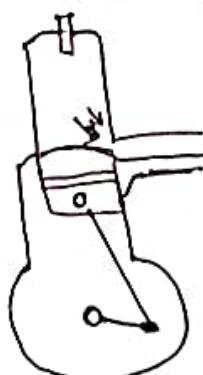


During expansion, some of the heat energy is transformed into mechanical work.

(iv) Exhaust Stage:

In this stage, exhaust port is opened as the piston moves downwards.

The combustion from the engine cylinder are exhausted through the exhaust port into the atmosphere.

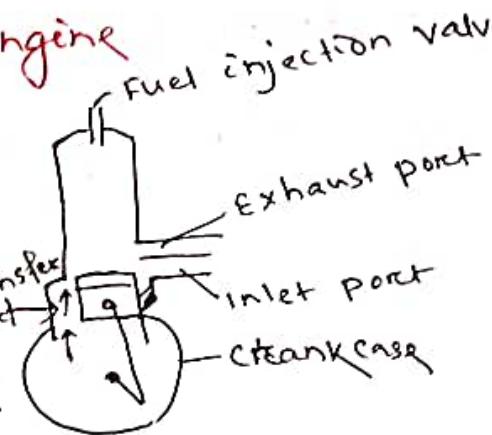


This completes the cycle & the engine cylinder is ready to suck the charge again.

TWO STROKE CYCLE DIESEL ENGINE

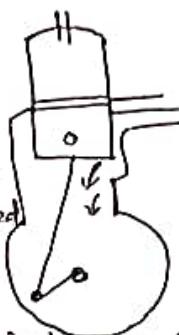
(i) Suction Stage

In this stage, piston moves towards BDC uncovers the transfer port & then exhaust port. The fresh air flows into the engine cylinder from the crankcase.



(ii) Compression Stage

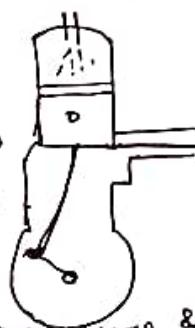
In this stage, while the piston moving up, first cover the transfer port & then exhaust port. Air is compressed as the piston moves upward.



In this stage, the inlet port open & fresh air enters into the crankcase.

(iii) Expansion Stage:-

Before the piston reaches the TDC, during compression stage, the fuel is injected in the form of very fine spray into the engine cylinder through the ~~inlet~~ fuel injection valve.

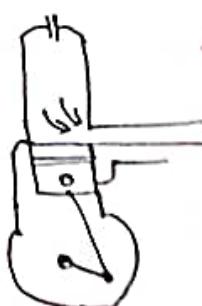


It suddenly increase the pressure & temp. of the combustion. Due to increased pressure, the piston is pushed with a great force.

The hot burnt gases expand due to high speed of piston. During the expansion, some of heat energy is transferred into mechanical work.

(iv) Exhaust Stage

In this stage, the exhaust port is opened & the piston moves downwards.



The combustion from the engine cylinder are exhausted through the exhaust port into atmosphere.

This completes the cycle & the engine cylinder is ready to suck the air again.

Difference betⁿ 2-stroke & 4-stroke engine

TWO STROKE engine

- (i) It has one revolution of the crankshaft during one power stroke.
- (ii) It generates high torque.
- (iii) It uses ports for fuel's outlet & inlet.
- (iv) It's engines result in lesser thermal efficiency.
- (v) It generates more smoke & shows less efficiency.
- (vi) Requires more lubricating oil as some oil burns with the fuel.
- (vii) Engines are cheaper & are simple for manufacturing.
- (viii) Engines are basically lighter & are noisy.
- (ix) Produces more heat, so it requires greater cooling & lubrication.

Four-stroke engine

- (i) It has two revolution of crankshaft during one power stroke.
- (ii) It generates less torque.
- (iii) It uses valves for fuel's outlet & inlet.
- (iv) It's engines result in higher thermal efficiency.
- (v) It generates less smoke & shows more efficiency.
- (vi) It requires less lubricating oil.
- (vii) Engines are expensive due to lubrication & valves & are ~~more~~ difficult to manufacture.
- (viii) Engines are basically heavier because its flywheel is heavy & are less noisy.
- (ix) Generates less heat.

Fluid Mechanics

It is defined as the branch of engineering science which deals with the study of behaviour of the fluids (i.e liquid or gases) at rest as well as in motion.

- ✓ The study of fluid at rest is called fluid statics
- ✓ The study of fluids in motion, ~~not considering~~ without considering pressure forces, is called fluid kinematics
- ✓ The study of fluids in motion, by considering the pressure forces, is called fluid dynamics.

Properties of fluid

(a) Density or Mass density : It is defined as the ratio of the mass of fluid to its volume. It is denoted by ρ .

Mathematically,

$$\rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}$$

Unit :- kg/m^3

Density of water = 1000 kg/m^3

(b) Specific weight or Weight density

It is defined as the ratio of both the weight of the fluid to its volume. It is denoted by w .

Mathematically,

$$w = \frac{\text{Weight of fluid}}{\text{Volume of fluid}} = \frac{(\text{Mass of fluid} \times \text{Acceleration due to gravity})}{\text{Volume of fluid}}$$

$$= \frac{\text{Mass of fluid} \times g}{\text{Volume of fluid}}$$

$$= \rho \times g$$

$$\Rightarrow w = \rho g$$

$$\therefore \rho = \frac{\text{Mass of fluid}}{\text{Volume of fluid}}$$

Unit :- N/m^3

Specific weight or weight density (w) for water is $9.81 \times 1000 \text{ N/m}^3$

(C) Specific volume: \rightarrow It is defined as the ratio betⁿ the volume of fluid to the mass of fluid.

Mathematically,

$$\text{Specific volume} = \frac{\text{Volume of fluid}}{\text{Mass of fluid}} = \frac{1}{\frac{\text{Mass of fluid}}{\text{Volume of fluid}}} = \frac{1}{\rho}$$

Unit:- m^3/kg

It is the reciprocal of mass density, is commonly applied to gases.

(d) Specific gravity (S)

It is defined as the ratio betⁿ the density of a fluid to the density of standard fluid.

For liquid, the standard fluid taken is water & for gases, the standard fluid taken is air.

Mathematically,

$$S (\text{for liquid}) = \frac{\text{Weight density of liquid}}{\text{Weight density of water}}$$

$$S (\text{for gas}) = \frac{\text{Weight density of gas}}{\text{Weight density of air}}$$

Weight density of liquid = $S \times \text{Weight density of water}$
 $= S \times 1000 \times 9.81 \text{ N/m}^3$

Density of liquid = $S \times \text{Density of water}$
 $= S \times 1000 \text{ kg/m}^3$

Example

Specific gravity of mercury is 13.6
Hence, density of mercury = $13.6 \times 1000 \text{ kg/m}^3$

Problems

(1) Calculate the specific weight, density & specific gravity of one litre of a liquid which weighs 7 N.

Soln

$$\text{Volume} = 1 \text{ litre} = \frac{1}{1000} \text{ m}^3 \quad (1 \text{ m} = 1000 \text{ cm})$$

$$\text{Weight} = 7 \text{ N}$$

$$(i) \text{ Specific Weight } w = \frac{\text{Weight}}{\text{Volume}} = \frac{7}{\frac{1}{1000}} = 7000 \text{ N/m}^3$$

$$(ii) \text{ Density } \rho = \frac{w}{g} = \frac{7000}{9.81} = 713.5 \text{ kg/m}^3$$

$$(iii) \text{ Specific gravity} = \frac{\text{density of liquid}}{\text{density of water}} = \frac{713.5}{1000} = 0.7135$$

(2) Calculate the density, specific weight & weight of one litre of Petrol of specific gravity = 0.7

Soln

$$\text{Volume} = 1 \text{ litre} = 1 \times 1000 \text{ cm}^3 = \frac{1000}{10^6} \text{ m}^3$$

$$\text{Sp. gravity} = 0.7$$

$$= \frac{1}{1000} \text{ m}^3 = 0.001 \text{ m}^3$$

$$(i) \text{ Density } \rho = s \times 1000 \text{ kg/m}^3 = 0.7 \times 1000 = 700 \text{ kg/m}^3$$

$$(ii) \text{ Sp. Weight } w = \rho \times g = 700 \times 9.81 = 6867 \text{ N/m}^3$$

Weight

$$\text{Sp. Weight } w = \frac{\text{Weight}}{\text{Volume}}$$

$$\Rightarrow w = \frac{\text{Weight}}{0.001}$$

$$\Rightarrow 6867 = \frac{\text{Weight}}{0.001}$$

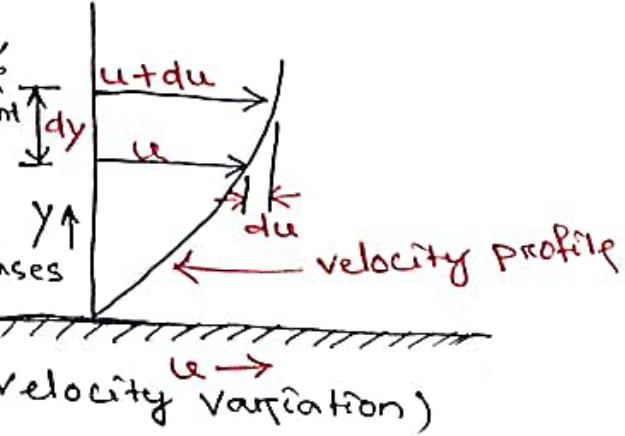
$$\Rightarrow \text{Weight} = 6867 \times 0.001 = 6.867 \text{ N}$$

Viscosity

It is defined as the property of a fluid which offers resistance to the movement of one layer of fluid over another adjacent layer of the fluid.

When two layers of a fluid, a distance dy apart, move one over the other adjacent layer at different velocities u & $u + du$.

The top layer causes a shear stress on the adjacent lower layer while the lower layer causes a shear stress on the adjacent top layer.



This shear stress is proportional to the rate of change of velocity with respect to y .

Mathematically $\tau \propto \frac{du}{dy}$

$$\Rightarrow \boxed{\tau = \mu \frac{du}{dy}}$$

μ = co-efficient of viscosity

OR
viscosity = $\frac{\tau}{(du/dy)}$

$\frac{du}{dy}$ = Rate of Shear Strain
OR Shear deformation
OR Velocity gradient.

Unit : $\rightarrow N\text{-s}/\text{m}^2$ (SI unit)

OR poise ($1 \text{ poise} = \frac{1}{10} \text{ Ns}/\text{m}^2$)

Fluid Pressure at a point

Let Consider a small area dA . Let dF is the force acting on the area dA in the normal direction. Then the ratio $\frac{dF}{dA}$ is known as the intensity of pressure or pressure. It is denoted by p .

Mathematically
pressure at a point in
a fluid at rest is

$$\boxed{p = \frac{dF}{dA}}$$

If the force F is uniformly distributed over the area A , then the pressure at any point is

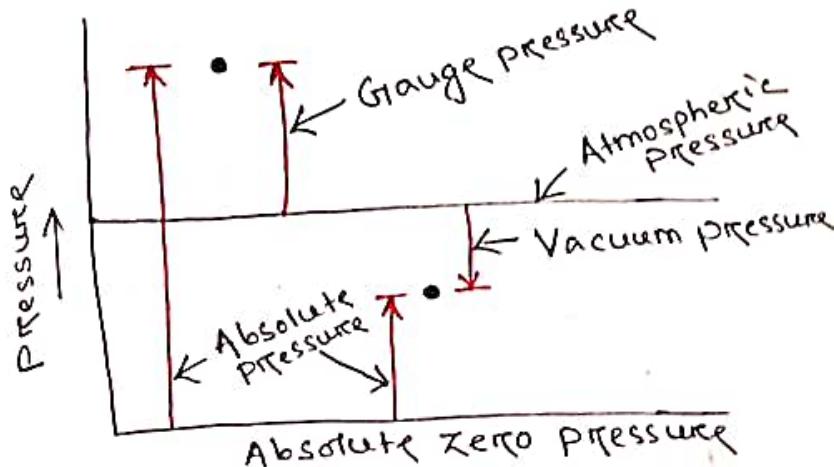
$$\boxed{p = \frac{F}{A}}$$

Unit :- N/m^2 , N/mm^2 , Pascal, bar

$$1 \text{ bar} = 10^5 \text{ N/m}^2$$

Absolute, Gauge, Atmospheric & Vacuum Pressure:

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Absolute Pressure

It is defined as the pressure which is measured with the reference to absolute vacuum pressure.

$$\text{Absolute pre} = \text{Atmospheric pre} + \text{Gauge pre}$$

Gauge pressure

It is defined as the pressure which is measured with the help of pressure measuring instrument, in which the atmospheric pressure is taken as datum.

Vacuum pressure

It is defined as the pressure below the atmospheric pressure.

$$\text{Vacuum pre} = \text{Atmospheric pre} - \text{Absolute pre}$$

Measurement of pressure

The pressure of fluid is measured by two devices

i.e. Manometers

or Mechanical Gauges

(a) Manometers :→ It is a device used for measuring the pressure at a fluid by balancing the column of fluid by the same or another column of the fluid.

Two types:- (i) Simple manometer
(ii) Differential manometer

(i) Simple Manometer

A simple manometer consists of a glass tube having one of its ends connected to a point where pressure is to be measured & other end open to atmosphere.

The various simple manometers are

* Piezometer

* U-tube manometer

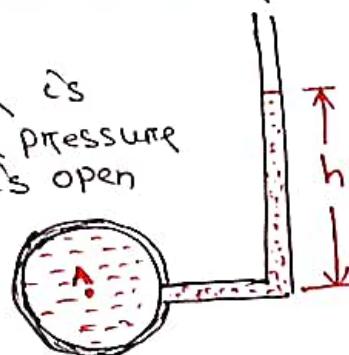
* Single column manometer

* Piezometer

It is the simplest form of manometer used for measuring gauge pressure.

One end of this manometer is connected to the point where the pressure is to be measured & other end is open to the atmosphere.

If a point 'A', the height of liquid say water is h in Piezometer tube, then the pressure at A = $\rho \times g \times h \text{ N/m}^2$



* U-tube manometer

It is consist of glass tube bent in U-shape, one end of which is connected to a point at which pressure is to be measured & other end remains open to the atmosphere.

The tube generally contain mercury or any other liquid (whose specific gravity is greater than the specific gravity of liquid) whose pressure is to be measured.

(a) For Gauge pressure:

Let B is the point at which pressure is to be measured. i.e P

The datum line is A-A.

Let h_1 = Height of light liquid above the datum line.

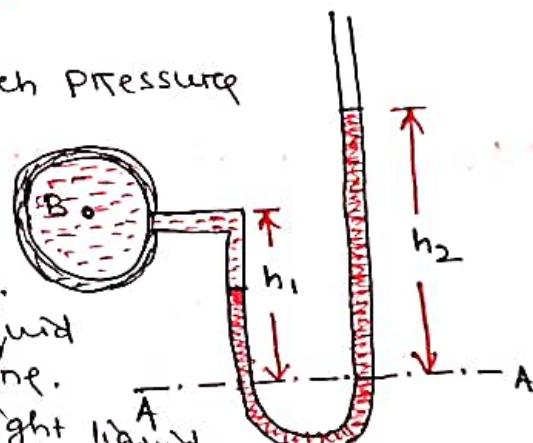
h_2 = Height of heavy liquid above the datum line.

S_1 = Specific gravity of light liquid.

S_2 = " " " heavy liquid.

f_1 = Density of light liquid = $1000 \times S_1$

f_2 = " " " heavy liquid = $1000 \times S_2$



Pressure above the horizontal datum line A-A, in the left column & in the right column should be same.

Pressure above A-A in the left column = $P + f_1 \times g \times h_1$

" " " in the right column = $f_2 \times g \times h_2$

Hence equating both eqns $P + f_1 \times g \times h_1 = f_2 \times g \times h_2$

$$\Rightarrow P = (f_2 g h_2 - f_1 g h_1)$$

(b) For vacuum pressure?

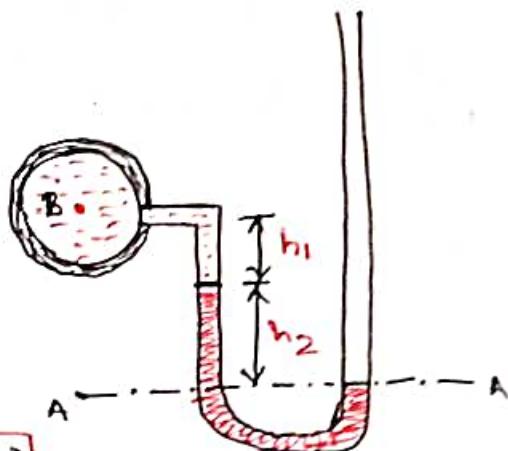
Pressure above A-A in the left column = $P + \rho_2 gh_2 + \rho_1 gh_1$

Pressure above A-A in the right column = 0

Hence equating both eqn's

$$P + \rho_2 gh_2 + \rho_1 gh_1 = 0$$

$$\Rightarrow P = -(\rho_2 gh_2 + \rho_1 gh_1)$$



problems

- (1) The right limb of a single U-tube manometer containing mercury is open to the atmosphere while left limb is connected to a pipe in which a fluid of sp. gravity 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 the fluid in the pipe, if the difference of mercury level in the two limbs is 20 cm.

Soln

$$\text{Sp. gravity of fluid } s_1 = 0.9$$

$$\begin{aligned} \text{Density of fluid } \rho_1 &= s_1 \times 1000 \\ &= 0.9 \times 1000 \\ &= 900 \text{ kg/m}^3 \end{aligned}$$

$$\text{Sp. gravity of mercury } s_2 = 13.6$$

$$\text{Density of Mercury } \rho_2 = s_2 \times 1000$$

$$\begin{aligned} &= 13.6 \times 1000 \\ &= 13600 \text{ kg/m}^3 \end{aligned}$$

$$\text{Difference of mercury level } h_2 = 20 \text{ cm} = 0.2 \text{ m}$$

$$\text{Height of fluid from A-A } h_1 = 20 - 12 = 8 \text{ cm} = 0.08 \text{ m}$$

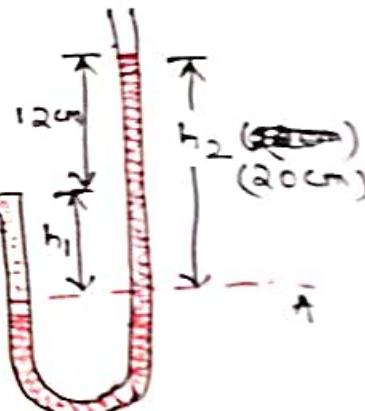
$$\text{Pressure } P = \rho_2 gh_2 - \rho_1 gh_1$$

$$= (13600 \times 9.81 \times 0.2) - (900 \times 9.81 \times 0.08)$$

$$= 26683 - 706$$

$$= 25977 \text{ N/m}^2$$

$$= 2.5977 \text{ N/cm}^2$$



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(2) A simple U-tube manometer containing mercury is connected to a pipe at which a fluid of sp. gravity 0.8 & 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 40cm & the height of fluid in the left from the centre of pipe is 15cm below.

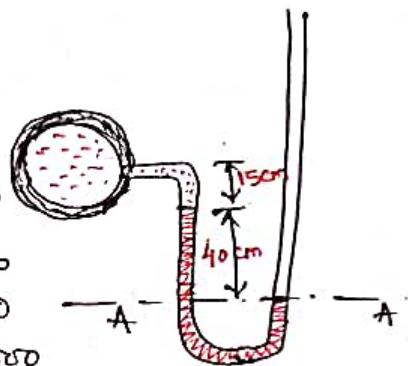
Soln

$$\text{Sp. gravity of fluid } S_1 = 0.8$$

$$\begin{aligned} \text{Density of fluid } f_1 &= S_1 \times 1000 \\ &= 0.8 \times 1000 \\ &= 800 \text{ kg/m}^3 \end{aligned}$$

$$\text{Sp. gravity of mercury } S_2 = 13.6$$

$$\begin{aligned} \text{Density of mercury } f_2 &= S_2 \times 1000 \\ &= 13.6 \times 1000 \\ &= 13600 \text{ kg/m}^3 \end{aligned}$$



$$\text{Difference of mercury level } h_2 = 40 \text{ cm} = 0.4 \text{ m}$$

$$\text{Height of liquid in left limb } h_1 = 15 \text{ cm} = 0.15 \text{ m}$$

$$\text{Pressure } P = -[f_2 g h_2 + f_1 g h_1]$$

$$\begin{aligned} &= -[13600 \times 9.81 \times 0.4 + 800 \times 9.81 \times 0.15] \\ &= -54543.6 \text{ N/m}^2 \\ &= -5.454 \text{ N/cm}^2 \end{aligned}$$

Hydrokinetics

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Rate of Flow or Discharge (Q)

It is defined as the quantity of a fluid flowing per second through a section of a pipe.

$$\text{Discharge } Q = A \times v \quad \text{m}^3/\text{s}$$

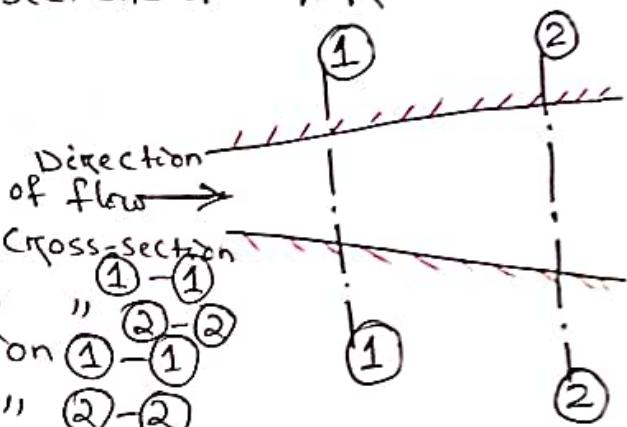
A = Cross-Sectional area of a Pipe

$V = \text{Avg. velocity of fluid}$

Continuity Equation

The equation based on the principle of conservation of mass is called continuity equation.

Consider two cross-sections of a pipe



Let V_1 = Average velocity at $\frac{\text{of flow}}{\text{cross-section}}$

$$v_2 = \frac{v}{2} \text{ at cross-section } ①-①$$

f_1 = Density at section "1-1" ②-2

$$f_2 = 11 \quad " \quad " \quad " \quad ②-2$$

$$A_1 = \text{Area at section } ①-①$$

$$\text{Rate of discharge at Sec 1-1} = f_1 A_1 V_1$$

$$" \quad " \quad " \quad \text{Sec } 2-2 = f_2 A_2 v_2$$

According to law of conservation of mass

$$\text{Rate of discharge at sec 1-1} = \text{Rate of discharge at sec 2-2}$$

$$f_1 A_1 v_1 = f_2 A_2 v_2$$

If $\varphi_1 = \varphi_2$

This eqn is known as continuity equation

Then continuity equ'n reduce to

$$A_1 v_1 = A_2 v_2$$

Problems

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- (1) The diameter of a pipe at the section 1 & 2 are 10 cm & 15 cm respectively. Find the discharge through the pipe if the velocity of water flowing through the pipe at section 1 is 5 m/s. Determine also the velocity at section 2.

Soln

$$D_1 = 10 \text{ cm} = 0.1 \text{ m}$$

$$D_2 = 15 \text{ cm} = 0.15 \text{ m}$$

$$V_1 = 5 \text{ m/s}$$

Area at section 1

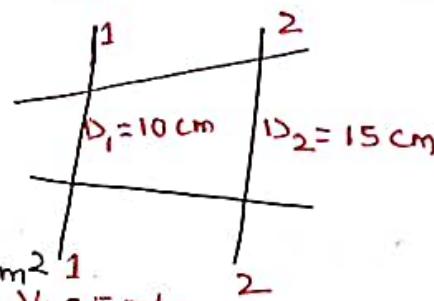
$$A_1 = \frac{\pi}{4} \times (D_1)^2 = \frac{\pi}{4} \times (0.1)^2 = 0.007854 \text{ m}^2$$

Area at section 2

$$A_2 = \frac{\pi}{4} \times (D_2)^2 = \frac{\pi}{4} \times (0.15)^2 = 0.01767 \text{ m}^2$$

$$\text{Rate of discharge } Q = A_1 V_1 = 0.007854 \times 5$$

$$= 0.03927 \text{ m}^3/\text{s} \quad \underline{\text{Ans}}$$



- (2) A 30 cm dia. pipe, branches into two pipes of diameters 20 cm & 15 cm respectively. If velocity in the 30 cm dia. pipe is 2.5 m/s. Find the discharge in the pipe. Also determine velocity in 15 cm pipe if the velocity in 20 cm dia. pipe is 2 m/s.

Soln

$$D_1 = 30 \text{ cm} = 0.3 \text{ m}, D_2 = 20 \text{ cm} = 0.2 \text{ m}, D_3 = 15 \text{ cm} = 0.15 \text{ m}$$

$$A_1 = \frac{\pi}{4} \times D_1^2 = \frac{\pi}{4} \times (0.3)^2 = 0.07068 \text{ m}^2$$

$$A_2 = \frac{\pi}{4} \times D_2^2 = \frac{\pi}{4} \times (0.2)^2 = 0.0314 \text{ m}^2 \rightarrow V_1 = 2.5 \text{ m/s}$$

$$A_3 = \frac{\pi}{4} \times D_3^2 = \frac{\pi}{4} \times (0.15)^2 = 0.01767 \text{ m}^2 \quad D_1 = 30 \text{ cm}$$

Discharge in the pipe (Q_1)

$$Q_1 = A_1 V_1 = 0.07068 \times 2.5 = 0.1767 \text{ m}^3/\text{s} \quad \underline{\text{Ans}}$$

velocity at section - 3 (V_3)

$$Q_2 = A_2 V_2 = 0.0314 \times 2 = 0.0628 \text{ m}^3/\text{s}$$

Continuity eqn $Q_1 = Q_2 + Q_3$

$$\Rightarrow 0.1767 = 0.0628 + Q_3$$

$$\Rightarrow Q_3 = 0.1139 \text{ m}^3/\text{s}$$

$$\text{Again } Q_3 = A_3 V_3 \Rightarrow V_3 = \frac{Q_3}{A_3} = \frac{0.1139}{0.01767} = 6.44 \text{ m/s} \quad \underline{\text{Ans}}$$

Energy of Flowing Liquid

A liquid in motion possesses pressure energy, kinetic energy & potential energy.

Pressure Energy:→ It is the energy possessed by the liquid by virtue of its pressure.

$$\boxed{P.E = \rho g h}$$

ρ = density of liquid

g = Acceleration due to gravity

h = Height of liquid

Kinetic energy:→ It is the energy possessed by the liquid by virtue of its motion.

$$\boxed{K.E = \frac{1}{2} m v^2}$$

m = mass of liquid

v = velocity of liquid

Potential energy:→ It is the energy possessed by the liquid by virtue of its height above the ground level.

$$\boxed{P.E = mgh}$$

m = Mass of liquid

g = Acceleration due to gravity

h = Height of liquid.

Total Energy:-

Total energy = Pressure energy + Kinetic energy
+ Potential energy

$$\boxed{T.E = P.E + \frac{1}{2} m v^2 + mgh}$$

Bernoulli's Theorem

It State that the sum of pressure energy per unit volume, kinetic energy per unit volume & potential energy per unit volume of a in compressible, non-viscous fluid in a streamlined irrotational flow remains constant.

Mathematically

$$\boxed{\frac{P}{\rho g} + \frac{V^2}{2g} + Z = \text{constant}}$$

Where

$\frac{P}{\rho g}$ = Pressure energy or pressure head

$\frac{V^2}{2g}$ = Kinetic energy or kinetic head

Z = Potential energy or potential head
or datum head.

Bernoulli's Equation from Euler's equation

Euler's equn is

$$\frac{dp}{\rho} + gdz + vdv = \text{constant}$$

Integrating above equn

$$\int \frac{dp}{\rho} + g \int dz + \int v dv = \text{constant}$$

$$\Rightarrow \frac{P}{\rho} + gz + \frac{V^2}{2} = \text{constant}$$

Dividing g in above equn

$$\Rightarrow \frac{P}{\rho g} + \frac{gz}{g} + \frac{V^2}{2g} = \text{constant}$$

$$\Rightarrow \boxed{\frac{P}{\rho g} + \frac{V^2}{2g} + z = \text{constant}}$$

Assumptions

- (i) The fluid is ideal i.e viscosity is zero.
- (ii) The flow is steady.
- (iii) The flow is incompressible.
- (iv) The flow is irrotational.

Problems

- (1) Water is flowing through a pipe having diameters 20cm & 10cm at Section-1 & Section-2 respectively. The rate of flow through the pipe is 35 litre/sec. The section 1 is 6m above datum & section 2 is 4m above datum. If the pressure at section-1 is 39.24 N/cm^2 . Find the intensity of pressure at section-2.

Sol:

AT Section-1

$$D_1 = 20 \text{ cm} = 0.2 \text{ m}$$

$$A_1 = \frac{\pi}{4} \times D_1^2 = \frac{\pi}{4} \times (0.2)^2 = 0.0314 \text{ m}^2$$

$$P_1 = 39.24 \text{ N/cm}^2 \\ = 39.24 \times 10^4 \text{ N/m}^2$$

$$z_1 = 6 \text{ m}$$

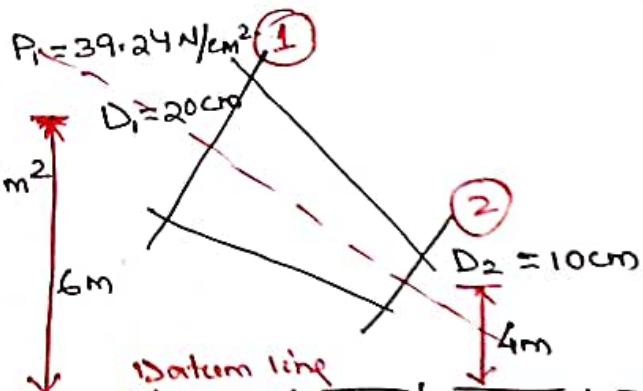
AT Section-2

$$D_2 = 10 \text{ cm} = 0.1 \text{ m}$$

$$A_2 = \frac{\pi}{4} \times (D_2)^2 = \frac{\pi}{4} \times (0.1)^2 = 0.00785 \text{ m}^2$$

$$z_2 = 4 \text{ m}$$

$$P_2 = ?$$



$$\text{Rate of flow } Q = 35 \text{ lt/s} = \frac{35}{1000} = 0.035 \text{ m}^3/\text{s}$$

$$\text{Now } Q = A_1 V_1 = A_2 V_2$$

$$\Rightarrow V_1 = \frac{Q}{A_1} = \frac{0.035}{0.0314} = 1.114 \text{ m/s}$$

$$\Rightarrow V_2 = \frac{Q}{A_2} = \frac{0.035}{0.00785} = 4.456 \text{ m/s}$$

Applying Bernoulli's eqn in section 1 & 2

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$\Rightarrow \frac{39.24 \times 10^4}{1000 \times 9.81} + \frac{(1.114)^2}{2 \times 9.81} + 6 = \frac{P_2}{1000 \times 9.81} + \frac{(4.456)^2}{2g} + 4$$

$$\Rightarrow 40 + 0.063 + 6 = \frac{P_2}{9810} + 1.012 + 4$$

$$\Rightarrow 46.063 = \frac{P_2}{9810} + 5.012$$

$$\Rightarrow \frac{P_2}{9810} = 46.063 - 5.012 = 41.051$$

$$\Rightarrow P_2 = \frac{41.051 \times 9810}{10^4} \text{ N/cm}^2 = 40.27 \text{ N/cm}^2$$

(2) Water is flowing through a pipe having diameter 300mm & 200mm at the bottom & upper respectively. The intensity of pressure at the bottom end is 24.525 N/cm² & the pressure at the upper end is 9.81 N/cm². Determine the difference in datum head if the rate of flow through the pipe is 40 lt/s.

SOL $D_1 = 300 \text{ mm} = 0.3 \text{ m}$

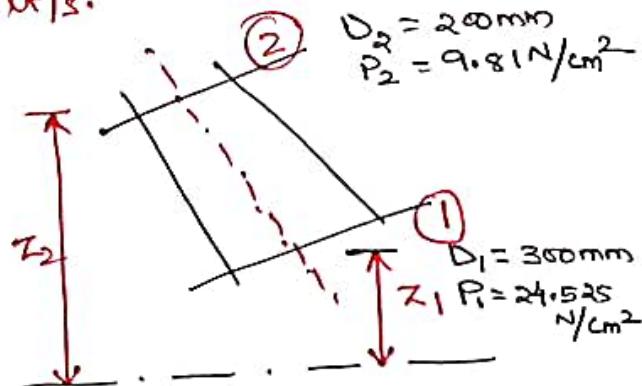
$$P_1 = 24.525 \text{ N/cm}^2 = 24.525 \times 10^4 \text{ N/m}^2$$

$$D_2 = 200 \text{ mm} = 0.2 \text{ m}$$

$$P_2 = 9.81 \text{ N/cm}^2 = 9.81 \times 10^4 \text{ N/m}^2$$

$$\text{Rate of flow } Q = 40 \text{ lt/s} = \frac{40}{1000} \text{ m}^3/\text{s}$$

$$= 0.04 \text{ m}^3/\text{s}$$



$$Q = A_1 V_1 = A_2 V_2$$

$$A_1 = \frac{\pi}{4} \times D_1^2 = \frac{\pi}{4} \times (0.3)^2 = ? \text{ m}^2$$

$$A_2 = \frac{\pi}{4} \times D_2^2 = \frac{\pi}{4} \times (0.2)^2 = ? \text{ m}^2$$

$$V_1 = \frac{0.4}{A_1}, V_2 = \frac{0.4}{A_2} = 1.274 \text{ m/s}$$

$$= 0.5658 \text{ m/s}$$

Applying Bernoulli's eqn

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$\Rightarrow z_2 - z_1 = ? \text{ m}$$

Hydraulic Devices & Pneumatics

Intensifier

The device, which is used to increase the intensity of pressure of water by means of hydraulic energy, is called hydraulic intensifier.

Construction:-

- * It is consist of fixed ram through which the water, under a high pressure, flows to the machine.
- * A hollow inverted sliding cylinder, containing water under high pressure, is mounted over the fixed ram.
- * The inverted sliding cylinder is surrounded by another fixed inverted cylinder which contains water from the main supply at a low pressure.

Operation

- * A large quantity of water at low pressure from supply enters the inverted fixed cylinder. ~~The water in the sliding cylinder~~ The weight of this water pressure the sliding cylinder downward direction.
- The water in the sliding cylinder gets compressed due to the downward movement of the ~~the~~ sliding cylinder & its pressure is thus increased.
- The high pressure water is forced out of the sliding cylinder through the fixed ram to the machine.

HYDRAULIC INTENSIFIER

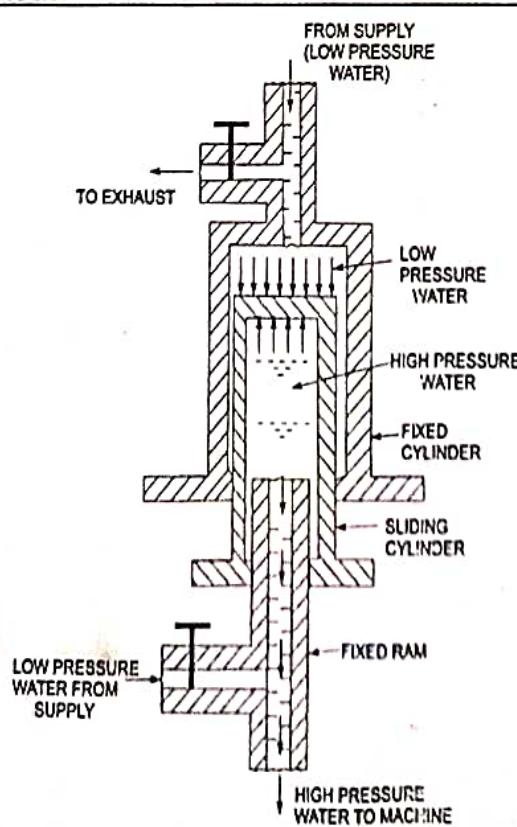


Fig. 21.6 The hydraulic intensifier.

Let P = Intensity of pressure of water supply to the fixed cylinder or Low pressure water.

P^* = Intensity of pressure of water in the sliding cylinder or High pressure water

A = External area of the Sliding cylinder

a = Area of the end of the fixed ram

✓ Force exerted by low pressure = $P \times A$
(downward direction)

✓ Force exerted by high pressure = $P^* \times a$
(Upward direction)

Equating upward & downward forces

$$P \times A = P^* \times a$$

$$P^* = \frac{P \times A}{a}$$

Problem

The dia. of fixed ram & fixed cylinder of an intensifier are 8 cm & 20 cm respectively. If the pressure of the water supplied to the fixed cylinder is 300 N/cm^2 , find the pressure of the water flowing through the fixed ram.

Sol) Diameter of fixed ram $d = 8 \text{ cm}$

$$\text{Area of fixed ram } a = \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (8)^2 = 16\pi \text{ cm}^2$$

Dia. of fixed cylinder $D = 20 \text{ cm}$

$$\text{Area of fixed cylinder } A = \frac{\pi}{4} \times (D)^2 = \frac{\pi}{4} \times (20)^2 = 100\pi \text{ cm}^2$$

Intensity of Supply Pressure $P = 300 \text{ N/cm}^2$

Intensity of pressure through fixed ram

$$P^* = \frac{P \times A}{a} = \frac{300 \times 100\pi}{16\pi} = 1875 \text{ N/cm}^2$$

Hydraulic Lift

The hydraulic lift is a device used for carrying passenger & goods from one floor to another in multi-storeyed building.

Two types, (a) Direct acting hydraulic lift
(b) Suspended hydraulic lift

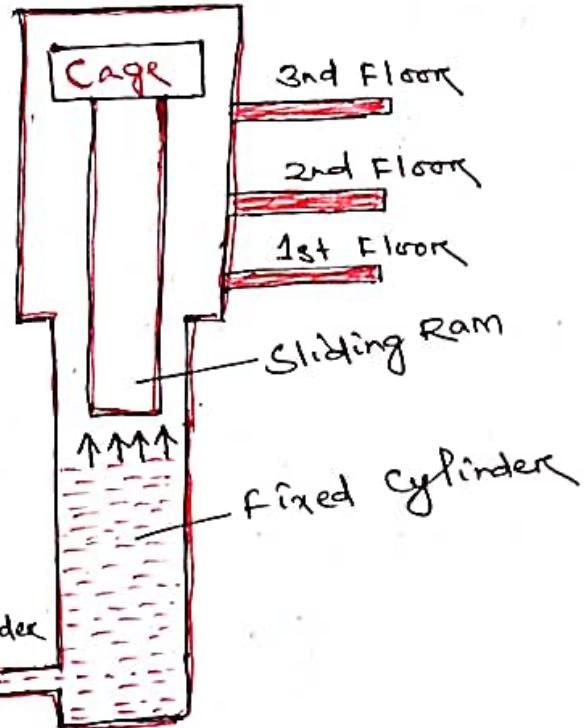
(a) Direct acting Hydraulic lift

* It is consist of a ram sliding in fixed cylinder.

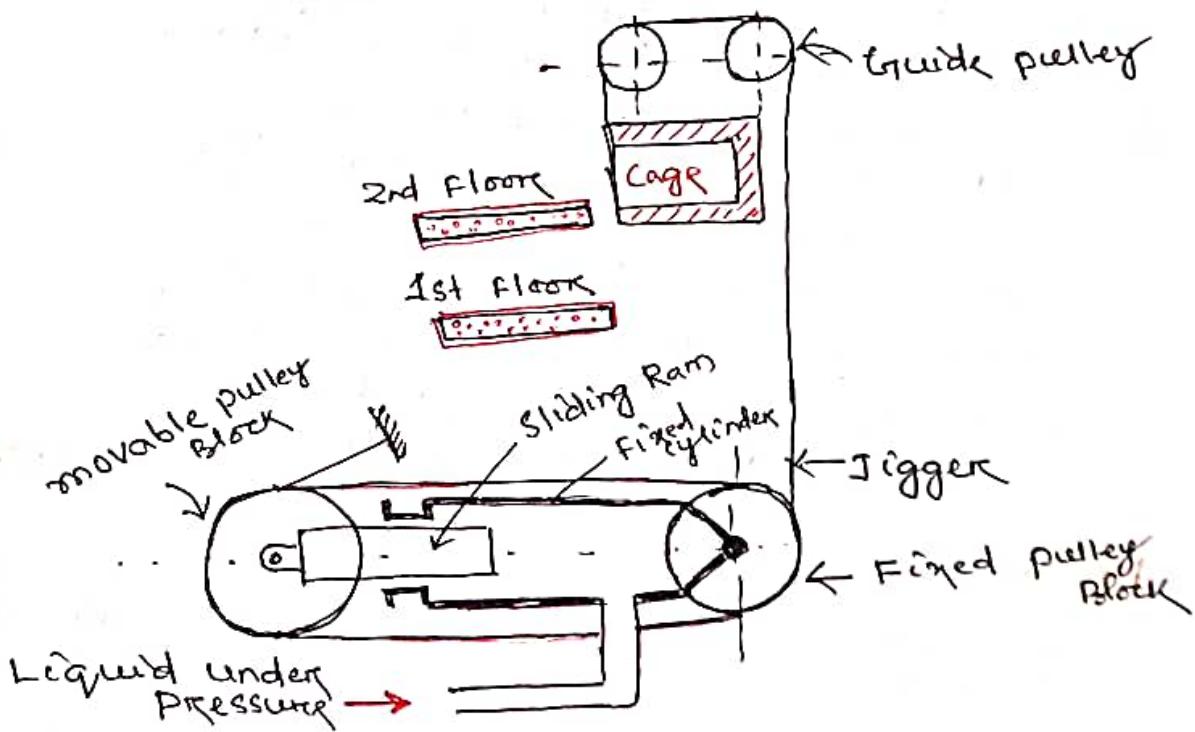
* At the top of the cage (where person or goods carry) is fitted.

* The liquid under pressure flows into the fixed cylinder. This liquid exerts force on the sliding ram, which moves vertically up, & thus raises the cage to the required height.

The cage is moved in the downward direction, by removing the liquid from the fixed cylinder.



(b) Suspended Hydraulic lift



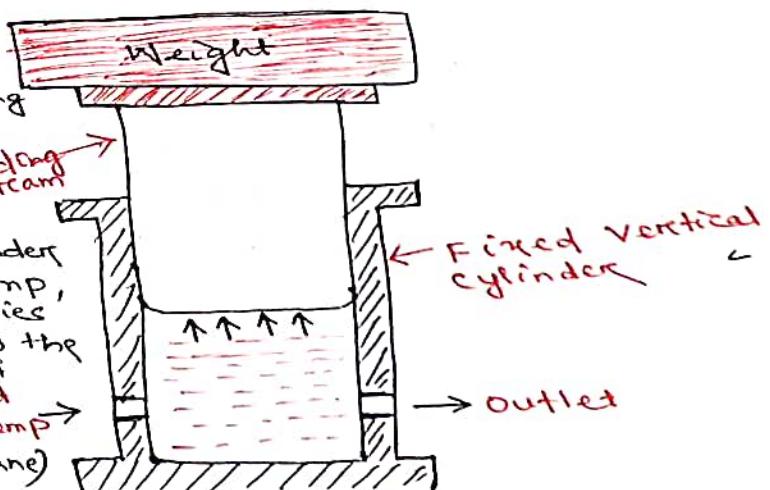
- * It is modified form of direct acting hydraulic lift. It is consist of a cage which is suspended from a wire rope.
- * A jigger consisting of a fixed cylinder, a sliding ram & set of two pulley blocks. One pulley block is movable & other is fixed one.
- * The end of the sliding ram is connected to the movable pulley block.

- * A wire rope, which one end is fixed & the other end is taken round all the pulleys of the movable & fixed blocks & finally over the guide pulleys.
- * When water under high pressure admitted into the fixed cylinder of the jigger, the sliding ram is forced to move towards left.
- * As one end of the sliding ram is connected to the movable pulley block & hence the movable pulley & block move towards the left, thus increasing the distance between two pulley blocks.
- * The wire rope connected to the cage is pulled & the cage is lifted.
- * For lowering the cage, water from the fixed cylinder is taken out. The sliding ram moves towards right & hence movable pulley blocks also moves towards right. This decrease the distance between two pulley blocks & the cage is lowered due to increased length of the rope.

Accumulator

- * It is a device used for storing the energy of a liquid in the form of pressure energy.
- * In case of hydraulic lift or the hydraulic crane, a large amount of energy is required when lift or crane is moving upward. This energy is supplied from hydraulic accumulator.

- * It consists of a fixed vertical cylinder containing sliding ram. A heavy weight is placed on the ram.
- * The inlet of the cylinder is connected to the pump, which continuously supplies water under pressure to the cylinder. The outlet of the system cylinder is connected to the machine (lift or crane) from pump.



- * When the Ram is at the uppermost position, the cylinder is full of water & accumulator has stored the maximum amount of pressure energy. When the machine requires a large amount of energy, the hydraulic accumulator will supply this energy & ram will move in the downward direction.

Capacity of Accumulator

It is defined as the max^m amount of energy stored in the accumulator.

Let A = Area of Sliding Ram

L = Stroke or Lift of Ram

p = Intensity of Water Pressure supplied by the pump.

W = Weight Placed at the Ram

$$= p \times A$$

$$\text{Workdone in lifting Ram} = W \times \text{Lift of Ram}$$

$$= W \times L$$

$$= p \times A \times L$$

The workdone in lifting Ram is also the energy stored in the accumulator & also is equal to the capacity of accumulator.

Problem

Determine the length of stroke for an accumulator having a displacement of 115 litres. The dia. of the plunger is 350 mm.

Given

$$\text{Displacement} = 115 \text{ lts} = 0.115 \text{ m}^3$$

$$\text{Volume of accumulator} = 0.115 \text{ m}^3$$

$$\text{Dia. of plunger } D = 350 \text{ mm} = 0.35 \text{ m}$$

$$\text{Area of plunger } A = \frac{\pi}{4} \times D^2 = \frac{\pi}{4} \times (0.35)^2 \text{ m}^2$$

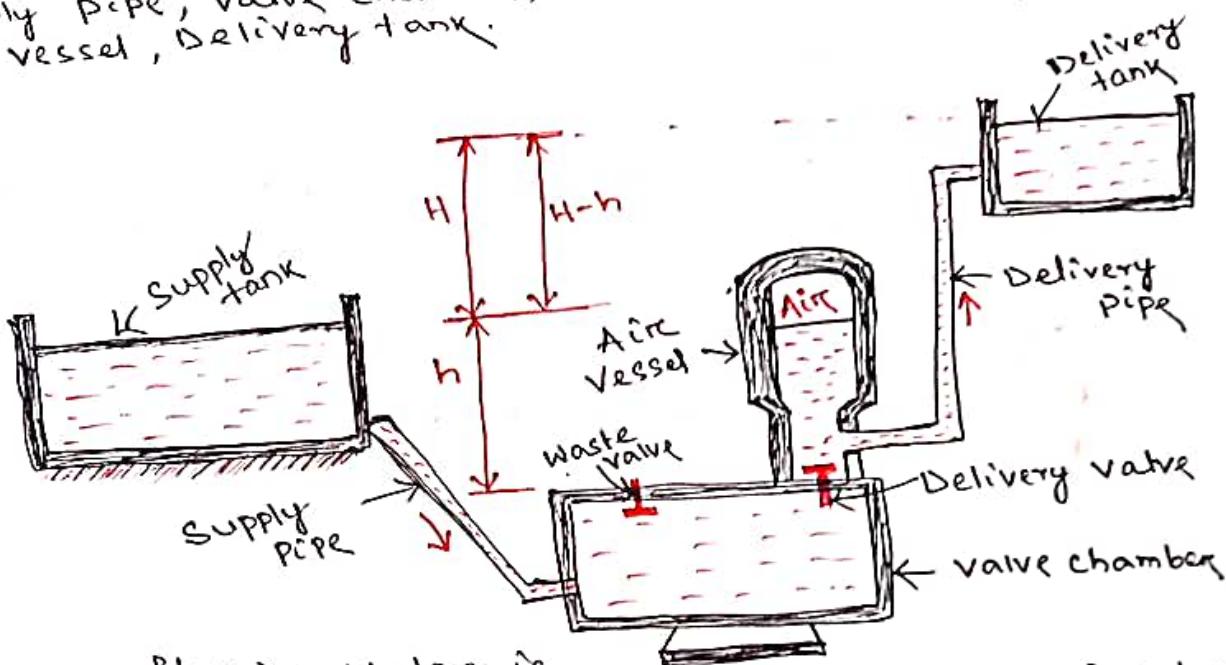
$$\text{Volume} = \frac{\pi}{4} D^2 \times L$$

$$\Rightarrow 0.115 = \frac{\pi}{4} \times (0.35)^2 \times L$$

$$\Rightarrow L = 1.195 \text{ m}$$

Hydraulic Ram

- * It is a device which raises small quantity of water without any external power to higher level from large quantity of water available at lower level.
- * It works on the principle of water hammer or inertia force of water in a pipe line.
- * The main parts of hydraulic ram are:- Supply tank, Supply pipe, Valve chamber, Waste valve, Delivery valve, Air vessel, Delivery tank.



- * When a flowing water is suddenly brought to rest the change in momentum of water masses causes a sudden rise in pressure. The rise in pressure is utilized to raise a small quantity of water to higher level.
- * Initially the waste valve is open & waste delivery valve is closed. The water from supply tank starts to flow under the force of gravity until it forces the waste valve to closed.
- * After the closing of delivery valve, it causes a water hammer that raises the pressure in chamber. This high pressure opens the delivery valve & water enters into the air vessel, which compresses the air in the air vessel.
- * The pressure in the air vessel increases & closes the delivery valve, now water from air vessel is forced to flow through delivery pipe.
- * Slowly pressure in the valve chamber decreases & waste valve again opens allowing the water to flow through it.
- * Now, under this condition, flow through the Supply pipe begins again. The cycle is repeated.

Advantages

- * Simple design
- * Low repair cost
- * Negligible running cost
- * NO electricity consumption
- * It works continuously & therefore gives regular supply.
- * Long life
- * Reliable

Disadvantages

- * Large amount of water wasted through waste valve
- * Noisy
- * Limited use.

Application

- * TO lift the drinking water from lower to higher level.
- * Useful in hilly area

Steam Boiler

A Steam generator OR Boiler is a closed vessel made of Steel. Its function is to transfer the heat by the combustion of fuel to generate steam.

The steam produced may be supplied to steam engines & turbines

Types of Boiler

(i) According to the contents in the tube:-

- (a) Fire tube boiler
- (b) Water tube boiler

(a) Fire tube

→ The flames & hot gases produced by the combustion of fuel, pass through the tubes which are surrounded by water. The heat is conducted through the walls of the tubes from the hot gases to the surrounding water.

Examples:- Simple vertical boiler, Cochran boiler, Lancashire boiler, Cornish boiler, Scotch marine boiler, Locomotive boiler, & Velcon boiler

→ The water is contained inside the tubes, which are surrounded by flames & hot gases from outside.

Examples:→ Babcock & Wilcox boiler, Stirling boiler, La-Mont boiler, Benson boiler, Yarrow boiler, Loeffler boiler.

(ii) According to the position of the furnace:-

- (a) Internally fired steam boiler
- (b) Externally fired steam boiler

→ The furnace is located inside the boiler shell. & most of the fire tube steam boilers are internally fired.

→ The furnace is cover in a brick-work setting. Water tube steam boilers are always externally fired. (Impact the proper direction to the flow)

(iii) According to the axis of the shell:-

- (a) Vertical boiler

- (b) Horizontal boiler

→ The axis of the shell is vertical. Simple vertical boiler & Cochran boilers are vertical boiler.

→ The axis of the shell is horizontal. Lancashire boiler, Locomotive boiler & Babcock Wilcox boilers are horizontal boiler.

(iv) According to the number of tubes:-

(a) Single tube boiler

(b) Multitubular boiler

→ There is only one fire tube or water tube.

Exp: Simple vertical boiler

Cornish boiler

→ There are more fire tubes or water tubes.

Exp: Lancashire boiler, Locomotive boiler,

Cochran boiler, Babcock & Wilcox boiler.

(v) According to the method of circulation of water & steam:-

(a) Natural circulation boiler

(b) Forced circulation boiler

→ The circulation of water is by natural convection currents, which are set of during the heating of water.

→ There is a forced circulation of water by a centrifugal pump driven by some external power.

(vi) According to the use:-

(a) Stationary boiler

(b) Mobile boiler

→ It is used in power plant & industrial process work. These boiler do not move one place to another.

→ These boilers are move from one place to another.
Exp: - Locomotive boiler, Marine boiler

Cochran Boiler

* It is the most efficient type of multitubular boiler. & improved type of simple vertical boiler.

* It is consist of an external cylindrical shell & fire box.

The shell gives max^m space & strength to withstand the pressure of steam inside the boiler.

* The fire box & combustion chamber is connected through a short pipe.

* The flue gases from the combustion chamber flow to the smoke box through a number of smoke tubes.

* The gases from the smoke box pass to the atmosphere through a chimney.

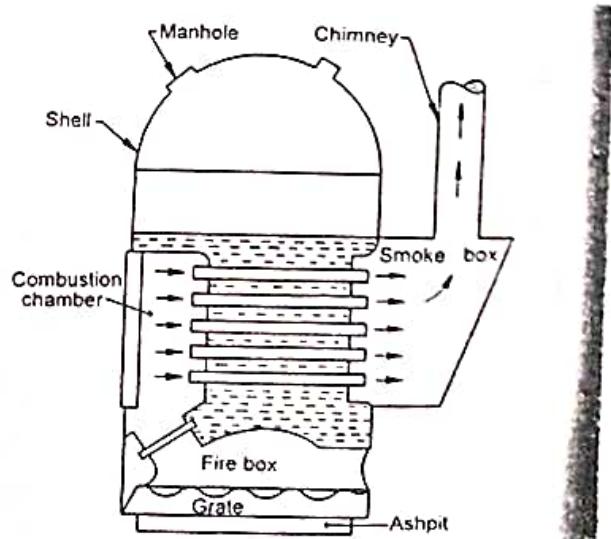


Fig 13.2. Cochran boiler.

- * A manhole near the top of the shell is provided for cleaning.
- * At the bottom of the fire box, there is a grate in case of coal firing. If the boiler is used for oil firing, no grate is provided.

Babcock & Wilcox Boiler

It is a straight tube, stationary type Water tube boiler.

It is consist of :-

1. Water drum
2. Uptake header or Riser
3. Header
4. Doors
5. Tubes
6. Mud box
7. Grate
8. Indicator (Water Level)
9. Pressure gauge
10. Tubes
11. Steam box
12. Steam box
13. Dry pipe
14. outlet pipe
15. Stop valve
16. Dampers
17. Caps

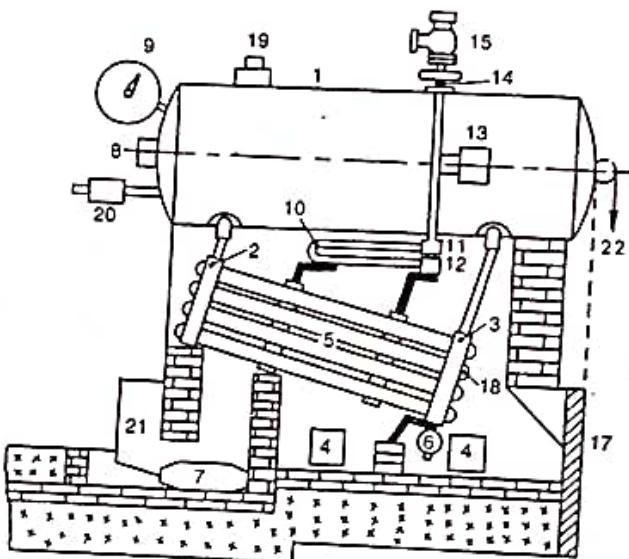


Fig. 13.7. Babcock and Wilcox boiler.

- 19. Safety valve
- 20. Feed valve
- 21. ~~Boiler~~ Hoppers
- 22. Chain

* The Water tubes are inclined to the horizontal & connects the uptake header to the downtime header. Each row of the tubes is connected with two headers & there are plenty of such rows. The headers are provided with hand holes in the front of the tubes & are covered with caps.

* A mud box is provided with each downtime header. There is a slow moving automatic chain grate on which the coal is fed from the hopper.

A fire bricks baffle causes hot gases to move upwards & downwards & again upward before leaving the chimney.

- * The dampers are operated by a chain which passes over a pulley to the front of a boiler to regulate the draught.
- * The doors are provided for a man to enter the boiler for repairing & cleaning. Water circulates from the drum into the header & through the tubes to header & again to the drum.
- * A Steam Superheater consists of a large number of steel tubes & contains two boxes - one is Superheated Steam box & other is Saturated Steam box.
- * The steam generated above the water level in the drum flows in the dry pipe & through the inlet tubes into the Superheated Steam box. It then passes through the tubes into the Saturated Steam box. The steam is now taken through the outlet pipe to the stop valve.
- * The boiler is fitted with usual mountings, such as safety valve, feed valve, water level indicator & pressure gauge.

Advantages

- * This boiler produces steam upto 2000 to 4000 kg/hr.
- * It takes less space as compared to other boilers.
- * Boiler tubes can be easily replaced.
- * In this boiler, the draught loss is low.
- * It can be easily repaired & cleaned.
- * High overall efficiency.

Disadvantages

- * Large maintenance cost.
- * Not suitable for impure water.
- * Continuous feedwater supply is needed to work.

Boiler Mountings & Accessories

Boiler Mountings

These are the fittings, which are mounted on the boiler for its proper & safe functioning.

The various Boiler mountings are :-

- (a) Water Level Indicator
- (b) Pressure gauge
- (c) Safety valve
- (d) Stop valve
- (e) Blow off cock
- (f) Feed check valve
- (g) Fusible plug

(a) Water level indicator

* It is an important fitting, which indicates the water level inside the boiler. It is a safety device.

* This fitting may be seen in front of the boiler, & generally two in number.

* It consists of three cock & a glass tube.

Steam cock C₁ → Keeps the glass tube in connection with the Steam Space.

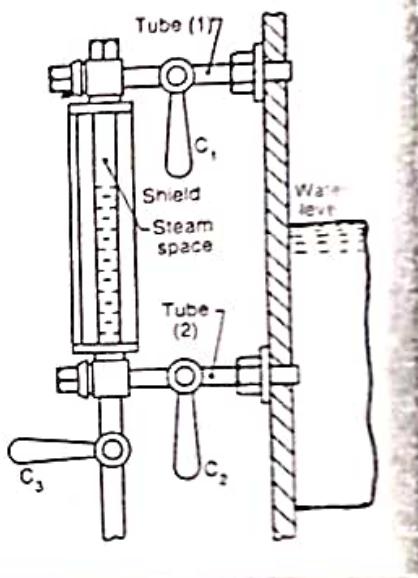
Water cock C₂ → Puts the glass tube in connection with the Water in boiler.

Drain cock C₃ → used to clear steam & water cocks.

* In the working of a steam boiler & for the proper functioning of the water level indicator, the steam & water cocks are opened & the drain cock is closed.

* ~~at the end of the glass tube~~

* The rectangular passage at the end of the glass tube contains two balls. In case of glass tube is broken, the two balls are carried along its passages to the ends of the glass tube.



(b) Pressure Gauge

- * It is used to measure the pressure of the steam inside the steam boiler. It is fixed in front of the steam boiler.
- * The pressure gauge generally used are of Bourden type.
- * It consists of an elliptical elastic tube ABC bent into an arc of a circle.
- * The one end of the tube is 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, the Bourden's tube tends to straighten itself. With the help of a simple pinion & sector arrangement, the elastic deformation of the Bourden's tube rotates the pointer. This pointer moves over a calibrated scale, which directly gives the pressure gauge.

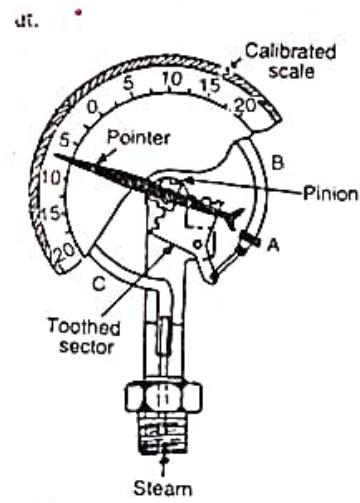


Fig. 14.2. Bourden type pressure gauge.

(c) Safety Valves

- * These are the devices attached to the steam chest for preventing explosions due to excessive internal pressure of steam.
- * A steam boiler is usually provided with two safety valves. These are directly placed on the boiler.
- The various types of safety valves are:—
- (i) Lever Safety valve
- (ii) Dead Weight Safety valve
- (iii) High steam & low water safety valve
- (iv) Spring loaded safety valve

(i) Lever Safety Valve

- * It ~~serves~~ serves the purpose of maintaining constant safe pressure inside the steam boiler.
- * It is consist of a valve body with a flange fixed to the steam boiler. The valve is made of bronze & the bronze valve seat is screwed to the body.
- * The Valve & Seat are made of same material & it reduces rusting. The guide keeps the lever in vertical plane.

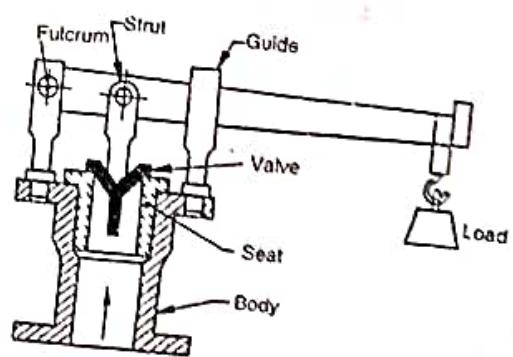


Fig. 14.3. Lever safety valve.

- * The load is properly adjusted at the other end of the lever.
- * When the pressure of steam exceeds the safe limit, the upward thrust of steam raises the valve from its seat. This allows the steam to escape till the pressure falls back to its normal value. The valve then returns back to its original position.

(ii) Dead Weight Safety valve

- * It is used for stationary boilers.

* The valve is made of gun metal, & rests on a gun metal seat. It is fixed to the top of a steel pipe. This pipe is bolted to the mounting blocks, riveted to the top of the shell.

* Both the valve & pipe are covered by a case which contains weight. These weights keep the valve on its seat under normal working pressure.

* When the pressure of steam exceeds the normal pressure, the valve & the case are lifted up from its seat.

* The lift of the valve is controlled by the studs. The main disadvantage of these valves, is the heavy load which these valves carry.

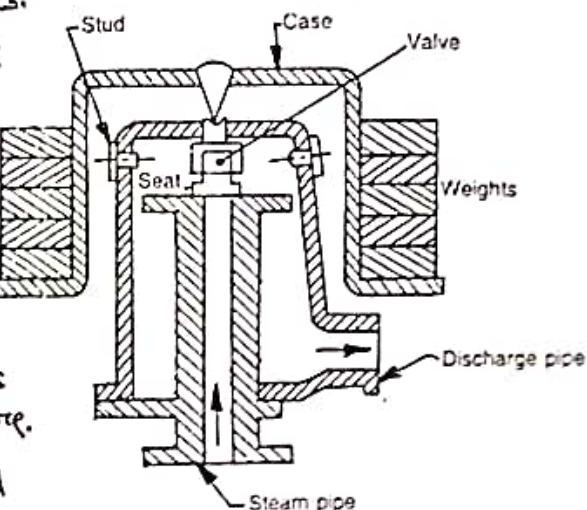


Fig. 14.4 Dead weight safety valve

(iii) High Steam Low Water Safety Valve

* These valves are placed at the top of Cornish & Lancashire boilers only. It is a combination of two valves.

* It consists of a main valve & rest on its seat. 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 & it has a weight E suspended at the end K.

* When the water level falls, the weight comes out of water & the weight F will not be sufficient to balance weight E. Therefore weight E comes down.

* Then, the valve is lifted up & 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.

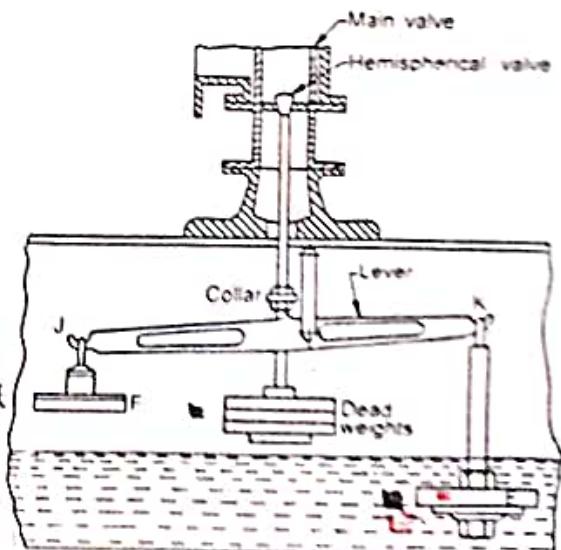
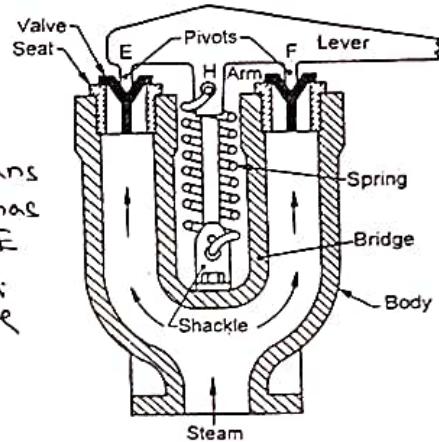


Fig. 14.5 High steam low water safety valve

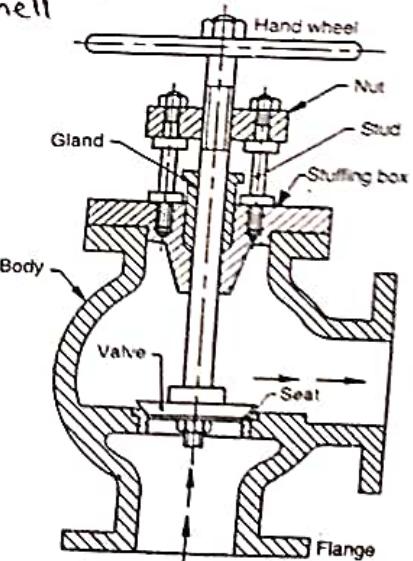
(iv) Spring Loaded Safety Valve

- * It is used for locomotives & marine boilers. It is loaded with spring instead of weight.
- * The spring is made of round or square spring steel rod in helical form.
- * It consists of a cast iron body connected to the top of a boiler. It has two separate valve of ~~two~~^{same} sizes.
- * The valves are held down by means of a spring & lever. The lever has two pivots E & F. The pivot E is joined by a pin to the lever, & the pivot F is forged on the lever.
- * The upper end of the spring is hooked to the arm H. The spring has two safety links, one behind the other, or one on either side of the lever connected by the pin at their ends.
- * The lever has an extension, which projects into the driver's cabin. By pulling or raising the lever, the driver can release the pressure from either valve separately.



(d) Stop valve

- * It is the largest valve on the steam boiler. It is fitted to the highest part of the shell by means of a flange.
- The function of Stop valve is: →
 - vii To control the flow of steam from the boiler to the main steam pipe.
 - viii To shut off the steam completely when required.
- * It is made of Cast iron or cast steel.
- * The spindle passes through a gland & stuffing box. The spindle is rotated by means of a hand wheel.
- * The boiler pressure acts on the valve so that the valve must be closed against the pressure.
- * A non-return valve is sometimes fitted near the Stop valve to prevent the accidental admission of steam from the boiler.



(e) Blow off cock

The function of Blow off cock are:-

(i) To empty the boiler whenever required.

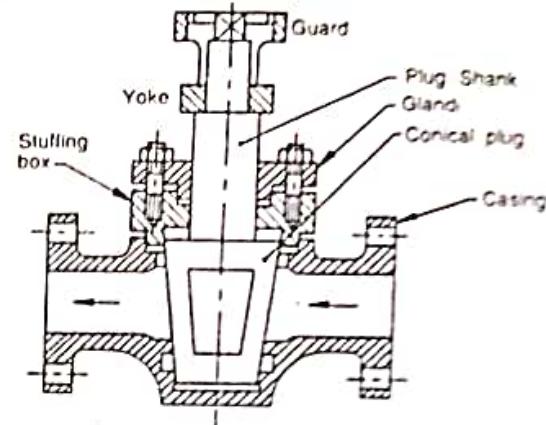
(ii) To discharge the mud, Scale & or sediments which are found at the bottom of the boiler.

* It is fitted to the bottom of a boiler. It is consist of a conical plug fitted to the body or casing.

* The casing is packed with asbestos. The asbestos packing made tight on the packing.

* The shank of plug passes through a gland & stuffing box in the cover.

* There are two vertical slots on the inside of a guard fire the box spanner to be used for operating the cock.



(f) Feed Check valve

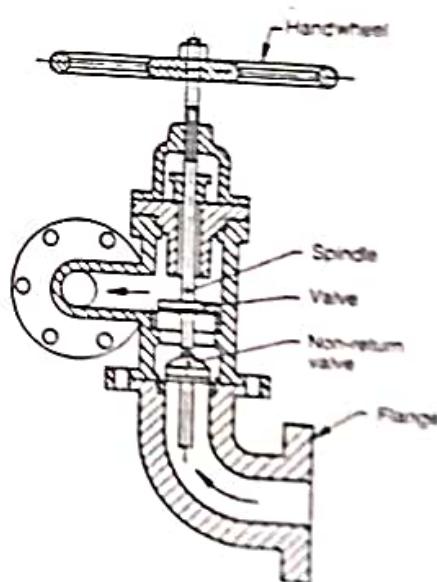
* It is a non-return valve, fitted to a screwed spindle to regulate the lift.

* Its function is to regulate the supply of water, which is pumped into the boiler by the feed pump.

* It is consist of a valve whose lift is controlled by a spindle & hand wheel.

* The body of the valve is made of brass casting.

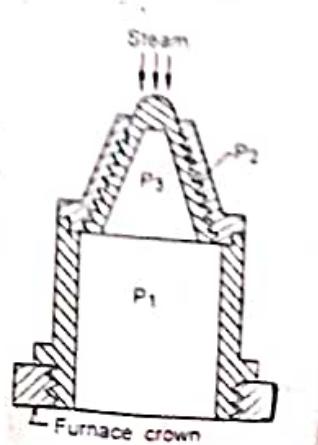
* A flange is bolted to the end of boiler at a point from which perforated pipe leads the feed water. This pipe distributes the water in the boiler uniformly.



(g) Fusible plug

* It is fitted to the crown plate of the furnace or the fire box.

* Its function is to put off the fire in the furnace of the boiler, when the level of water in the boiler falls to an unsafe limit.



- * It consists of a hollow gun metal plug P_1 & is keyed to the furnace crown.
A second hollow gun metal plug P_2 is screwed to the first plug. There is also a 3rd hollow gun metal plug P_3 separated from P_1 by a ring of fusible metal. The P_2 & P_3 are plugged together.
- * There is a contact at the top between P_2 & P_3 so that the fusible metal is completely enclosed.
- * The fusible plugs must be kept in a good condition & replaced annually.

~~Boiler Accessories~~

These are the devices which are used as integral parts of a boiler & help in running efficiently.

There are three types of Boiler accessories:-

- (a) Feed pump
- (d) Air-Preheater
- (b) Superheater
- (c) Economiser

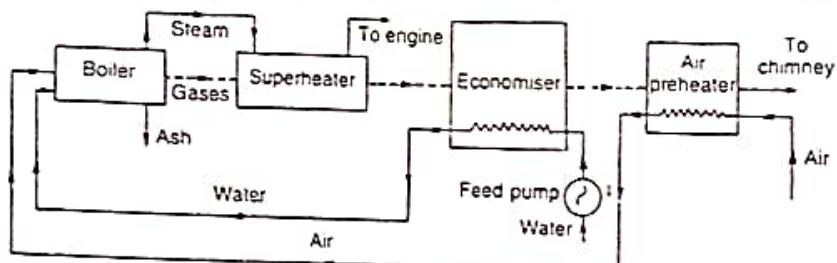


Fig. 14.11. Schematic diagram of a boiler plant.

(a) Feed pump

- * Feed Pump delivers Water to the boiler. & the boiler continuously converted the water into steam, which is used by the engine.
- * 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.

~~Steam cylinder in the boiler~~

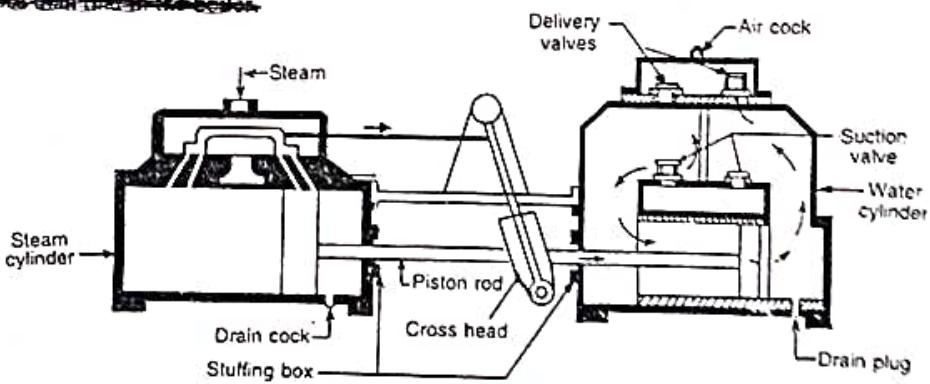


Fig. 14.12. Duplex feed pump.

- * The pumps may be classified as Simplex, duplex & triplex pumps according to the number of cylinder. The common type of pump used is duplex feed pump.

(B) Superheater

- * It 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 an integral part of a boiler & is placed in the path of hot flue gases from the furnace.
- * A Sedgen's Superheater commonly employed with Lancashire boilers.
- * It consists of two mild steel boxes OR heaters from which hangs a group of solid drawn tubes bent to U-form.
- * The steam enters at the one end & leaves at the opposite end.
- * When the superheater is in action, the stop valves G & H are opened & F is closed. When the steam is taken directly from the boiler, the valves G & H are closed & F is open.

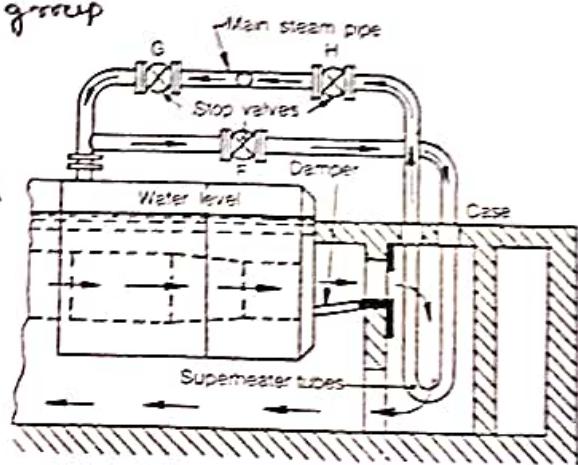
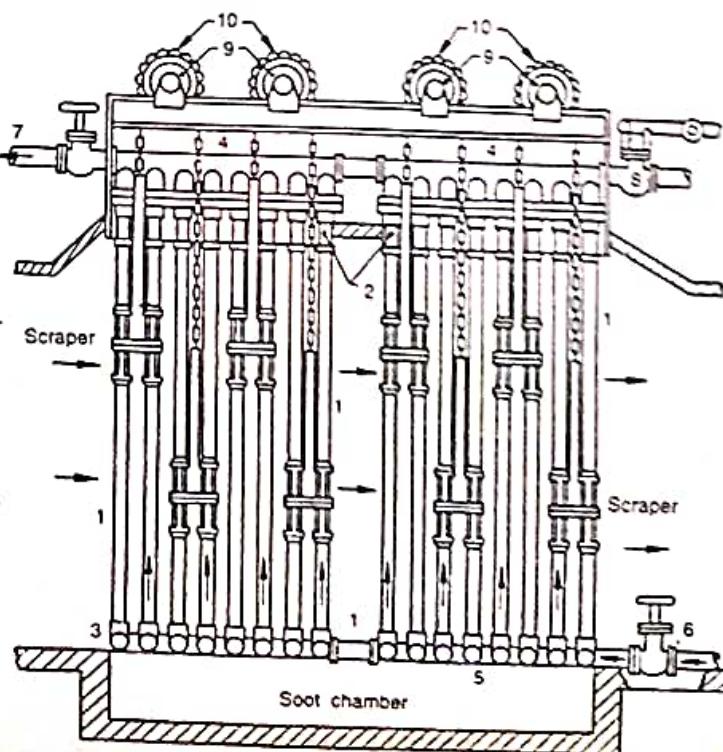


Fig 14.13. Superheater

(C) Economiser

- * It is a device used to heat feed water by utilizing the heat in the exhaust flue gas before leaving through the chimney. The Economiser improves the economy of steam.
- * It consists of a large number of vertical pipes or tubes placed in an enlargement of the flue gases betw the boiler & chimney.
- * Each section consists of six or eight vertical tubes. These tubes are joined to horizontal pipes at the top & bottom.
- * The feed water is pumped into the economiser at (6) & enters the pipe (5). It then passes into the bottom tube (3) & then into the top tube (2) through the tube (1).



It is now pass to the boiler through the pipe 4 & 7.

- * It may be noted that temp. of feed should not be less than 25°C . Otherwise there is a danger of corrosion due to moisture in the flue gases.

Advantages of Economiser

- * 15 to 20% of coal saving.
- * Increases Steam Raising Capacity of boiler.
- * Prevents formation of scale in boiler water tubes.

(d) Air-Preheater

- * It is used to recover heat from the exhaust flue gases.
- * It is installed betⁿ the economiser & the chimney.
- * The air required for the purpose of combustion is drawn through the air preheater where its temp. is raised. It is then passed to the furnace.

Advantages

- * gives higher furnace temperature.
- * Improve ~~boiler~~ boiler efficiency upto 2%.
- * Results in better combustion with less smoke & ash.

Thermodynamics

~~Heat~~ It is the branch of engineering science which deals with the study of ~~energy~~ relations betⁿ heat & other forms of energy & relationships betⁿ all forms of energy.

Heat: It is defined as the energy transferred, without transfer of mass, across the boundary of a system. It is denoted by Q .

Unit:- Joule (J)
Kilo-Joule (kJ)

Work: It is defined as the product of force (F) & the distance moved (x) in the direction of the force.

Mathematically

$$W = F \times x$$

Unit:- Newton-meter (N-m)

First Law of Thermodynamics

(i) The heat & work are mutually convertible.
~~According to this law,~~

When a closed system undergoes a thermodynamic cycle The total heat transfer is equal to the total work transfer.

Mathematically, $\oint \delta Q = \oint \delta W$

The symbol \oint stands for cycle integral (integral around a complete cycle)

δQ = Total heat
 δW = Total Work

(ii) The energy can ~~exist~~ neither be created nor be destroyed, it can only convert from one form to another.

According to this law

When a system undergoes a change of state, then both heat & work transfer takes place.

Mathematically
Total energy
(dE) $\delta Q - \delta W = dE$

Limitations of First Law of Thermodynamics

(i) When a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the net work transfer.

This statement does not ~~sufficiently~~ specify the direction of flow of heat & work (i.e. heat flows from hot body to cold body or cold body to hot body).

It also does not give any condition under which these transfers takes place.

(ii) The heat energy & Mechanical Work are mutually convertible.

The heat energy & mechanical work are not fully mutually convertible. There is a limitation on the conversion of one form of energy into another form.

A machine which violates the first law of thermodynamics is known as perpetual motion machine of the first kind (PMM-I).

→ It is defined as a machine which produces work energy ~~which produces~~ without consuming an equivalent of energy from other source. Such a machine is impossible to obtain in actual practice, because no machine can produce energy of its own without consuming any other form of energy.



Work

Laws of Perfect Gases

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

- * Pressure exerted by the gas
- * Volume occupied by the gas
- * Temperature of the gas

The behaviour of perfect gas is governed by three laws, which is established from experimental results.

(a) Boyle's law

(b) Charles law

(c) Gay-Lussac law

(a) Boyle's Law (Robert Boyle in 1662)

It states ~~it~~ The ~~absolute~~ absolute pressure of a given mass of a perfect gas varies inversely as its volume, when the temp remains constant.

Mathematically

$$P \propto \frac{1}{V}$$

$$\Rightarrow PV = \text{constant}$$

For more forms $P_1V_1 = P_2V_2 = P_3V_3 = \dots = \text{constant}$

(b) Charles' Law (A.C. Charles in 1787)

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

Mathematically, $V \propto T$

$$\Rightarrow \boxed{\frac{V}{T} = \text{constant}}$$

For more forms $\frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3} \dots = \text{constant}$

(c) Gay-Lussac Law

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

Mathematically $P \propto T$

$$\Rightarrow \boxed{\frac{P}{T} = \text{constant}}$$

For more forms $\frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{P_3}{T_3} \dots = \text{constant}$

General Gas Equation

The Boyle's law & Charles law are combined together gives general gas equation.

Boyle's law $P \propto \frac{1}{V}$ or $V \propto \frac{1}{P}$ (T is constant)

Charles law $V \propto T$ (P is constant)

So, $V \propto \frac{1}{P} \propto T$

$$\Rightarrow V \propto \frac{T}{P}$$

$$\Rightarrow PV \propto T$$

$$\Rightarrow \boxed{PV = CT} \quad C = \text{constant}$$

The general gas equn is:-

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = \frac{P_3 V_3}{T_3} = \dots = \text{constant}$$

Problem

- (1) A gas occupies a volume of 0.1 m^3 at a temp. of 20°C & a pressure of 1.5 bar . Find the final temp. of the gas, if it is compressed to a pressure of 7.5 bar & occupies a volume of 0.04 m^3 .

Soln

$$V_1 = 0.1 \text{ m}^3, T_1 = 20^\circ\text{C} = 20 + 273 = 293 \text{ K}$$

$$P_1 = 1.5 \text{ bar} = 1.5 \times 10^5 \text{ N/m}^2$$

$$P_2 = 7.5 \text{ bar} = 7.5 \times 10^5 \text{ N/m}^2$$

$$V_2 = 0.04 \text{ m}^3, T_2 = \text{Final temp. of gas}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\Rightarrow T_2 = \frac{P_2 V_2 T_1}{P_1 V_1} = \frac{7.5 \times 10^5 \times 0.04 \times 293}{1.5 \times 10^5 \times 0.1} = 586 \text{ K}$$

$$= 586 - 273 = 313^\circ \text{C Ans.}$$

Specific Heat

- * It is the amount of heat required to raise the temp. of its unit mass through one degree.
- * A Gas can have numbers of specific heats lying between zero to infinity depending upon the condition under which it is heated.

It can be of two types

- Sp. heat at constant volume
- Sp. heat at constant pressure

Relationship of Specific Heat of Gas at constant Volume: $\rightarrow (C_V)$

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

Let m = mass of the gas

T_1 = Initial temp. of gas

T_2 = Final temp. of gas

Total heat supplied to the gas at constant volume

$$Q_{1-2} = \text{Mass} \times \text{Sp. heat at const. vol.} \times \text{Rise in temp.}$$

$$Q_{1-2} = m C_V (T_2 - T_1)$$

When a gas is heated at constant volume, no work is done by the gas.

Relationship of Sp. heat of gas at constant pressure

It is the amount of heat required to raise the temp. of unit mass of gas through one degree when it is heated at constant pressure. It is denoted by C_P .

Let m = mass of the gas

T_1 = Initial temp. of gas

T_2 = Final temp. of gas

V_1 = Initial volume of gas

V_2 = Final volume of gas

Total heat supplied to the gas at const. pressure

$$Q_{1-2} = \text{Mass} \times \text{Sp. heat at constant volume} \times \text{Rise in temp.}$$

$$Q_{1-2} = m C_P (T_2 - T_1)$$

When a gas is heated at a constant pressure, the heat supplied to the gas is utilised for the two purposes: →

(i) To raise the temp. of gas

$$\text{Increase in internal energy } dU = mc_V(T_2 - T_1)$$

(ii) To do some external work during expansion.

$$\text{Work done by gas } W_{1-2} = mR(T_2 - T_1)$$

Thus, The Sp. heat at const. Pressure is higher than the Sp. heat at const. volume.

$$Q_{1-2} = dU + W_{1-2}$$

~~Properties of Steam~~

- * Steam is a ~~wet~~ vapour of water & is invisible when pure & dry.
- * It is used as the working substance in the operation of steam engines & 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 behaves like a perfect gas.

(i) Wet Steam: → When the steam contain moisture of water in suspension, it is said to be wet steam. It means that the evaporation of water is not complete.

(ii) Dry Saturated Steam: → When the wet steam is further heated & it does not contain any particle of water, it is known as dry saturated steam.

(iii) Superheated Steam: → When the dry steam is further heated at a constant pressure to raising its temperature, it is said to be superheated steam.

Since the pressure is constant, therefore the volume of Superheated steam increases.

(iv) Dryness Fraction or quality of wet steam

It is the ratio of the mass of actual dry steam to the mass of some quantity of wet steam. It is denoted by χ .

Mathematically

$$\chi = \frac{m_d}{m_d + m_f} = \frac{m_d}{m}$$

Where m_g = Mass of actual dry steam

m_f = Mass of water

m = Mass of wet steam

$$= m_g + m_f$$

The value of dryness fraction (γ) for dry steam is 1.
because, the mass of water (m_f) is zero.

(V) Sensible Heat of Water :- (h_f)

It is the amount of heat absorbed by 1kg of water, when heated at a constant pressure, from the freezing point (0°C) to the temp. of formation of steam (Saturation Temp. (t)).

The Specific heat (at constant pressure) of water

$$= 4.2 \text{ kJ/kg K}$$

Sensible heat (h_f) = $4.2t \text{ kJ/kg}$ (Sp. heat of water Saturation temp)

Sensible heat of water = Total head or Specific enthalpy (h_f)

(VI) Latent Heat of Vaporisation :- (h_{fg})

It is the amount of heat absorbed to evaporate 1kg of water at its boiling point or saturation temp (t) without change of temperature.

The Latent heat of steam is 2257 kJ/kg

The value of h_{fg} decreases as the pressure increases & it is zero at critical pressure.

If the steam is wet with a dryness fraction γ , then the head absorbed by it during evaporation is γh_{fg} .

(VII) Enthalpy or Total head of Steam (h_g)

It is the amount of heat absorbed by water from freezing point to saturation temperature, plus the heat absorbed during evaporation.

Enthalpy or Total head of steam

h_g = sensible heat + latent heat

$$h_g = h_f + h_{fg} \quad h_g \text{ is obtained directly from steam table.}$$

(a) Wet Steam :-

Enthalpy of wet steam $h = h_f + \gamma h_{fg}$

γ = dryness fraction of steam.

(b) Dry steam :-

In case of dry steam, $\gamma = 1$

$$h = h_g = h_f + h_{fg}$$

(c) Superheated Steam $\Rightarrow (h_{sup})$

h_{sup} = Total heat for dry steam + Head for Superheated steam

$$h_{sup} = h_f + h_{fg} + C_p(t_{sup} - t)$$

$$h_{sup} = h_g + C_p(t_{sup} - t)$$

Where C_p = Mean specific heat at const. pressure for Superheated steam.

t_{sup} = Temp. of Superheated steam

t = Saturation temp. at const. pressure

The difference $t_{sup} - t$ is known as degree of superheat.

The value of C_p for steam lies b/w 1.67 to 2.5 KJ/kg K

(viii) Specific volume of steam

It is the volume occupied by the steam per unit mass at a given temp. & pressure.

It is expressed in m^3/kg . It is the reciprocal of density of steam in kg/m^3 .

(a) Wet Steam: \Rightarrow Consider 1 kg of wet steam of dryness fraction α . Let V_g be the volume of 1 kg of water.

Specific vol. of wet steam $V = \alpha V_g m^3/kg$

(b) Dry steam: \Rightarrow In case of dry steam, the mass of water in suspension is zero & dryness fraction is 1.

So, Sp. Vol. of dry steam = $V_g m^3/kg$

(c) Superheated steam: \Rightarrow The superheated steam behaves like a perfect gas. According to Charles law:-

$$\frac{V_{sup}}{T_{sup}} = \frac{V_g}{T}$$

$$\Rightarrow V_{sup} = \frac{V_g T_{sup}}{T} \quad \because P = \text{constant}$$

Where, V_{sup} = Sp. Vol. of superheated steam.

V_g = " of dry steam

T_{sup} = Absolute temp. of Superheated steam.

T = Absolute saturation temp.

(1) Determine the quantity of heat required to produce 1kg of steam at a pressure of 6 bar at a temp. of 25°C , under the following conditions:-

- (a) (i) When the steam is wet having a dryness fraction 0.9.
- (ii) when the steam is dry saturated.
- (iii) when it is superheated at a constant pressure at 25°C assuming the mean specific heat of superheated steam to be 2.3 kJ/kg K .

Soln

$$P = 6 \text{ bars}, t_w = 25^{\circ}\text{C}, \chi = 0.9, t_{\text{sup}} = 250^{\circ}\text{C}, c_p = 2.3 \text{ kJ/kg K}$$

From the steam table, when pressure $P = 6 \text{ bar}$

$$\text{Sensible heat } h_f = 670.4 \text{ kJ/kg}$$

$$\text{Latent heat } h_{fg} = 2085 \text{ kJ/kg}$$

$$\text{Saturation temp. } t = 158.8^{\circ}\text{C}$$

(i) When the steam is wet

Enthalpy or Total heat of 1kg of wet steam

$$h = h_f + \chi h_{fg} = 670.4 + 0.9 \times 2085 = 2546.9 \text{ kJ}$$

Water is at a temp. of 25°C

$$\text{Heat in water} = 4.2 \times 25 = 105 \text{ kJ}$$

$$\text{Heat actually required} = 2546.9 - 105 = 2441.9 \text{ kJ Ans}$$

(ii) When the steam dry saturated

Enthalpy or Total heat of 1kg of dry saturated steam

$$h_g = h_f + h_{fg} = 670.4 + 2085 = 2755.4 \text{ kJ}$$

$$\text{Heat actually required} = 2755.4 - 105 = 2650.4 \text{ kJ}$$

(iii) When the steam is Superheated :-

Enthalpy or total heat of 1kg of Superheated steam

$$h_{\text{sup}} = h_g + c_p(t_{\text{sup}} - t)$$

$$= 2755.4 + 2.3(250 - 158.8)$$

$$= 2965.16 \text{ kJ}$$

$$\text{Heat actually required} = 2965.16 - 105 = 2860.16 \text{ kJ}$$

(2) Steam enters an engine at a pressure of 12 bar with a 67°C of Superheat. It is exhausted at a pressure of 0.15 bar & 0.95 dry. Find the drop in Enthalpy of the steam.

Soln

$$P_1 = 12 \text{ bar}, t_{\text{sup}} - t = 67^{\circ}\text{C}, P_2 = 0.15 \text{ bar}, \chi = 0.95$$

From the steam table, when pressure is 12 bar

$$h_f = 798.4 \text{ kJ/kg}, h_{fg} = 1984.3 \text{ kJ/kg}$$

Enthalpy or total heat of 1kg of Superheated steam

$$h_{\text{sup}} = h_f + h_{fg} + c_p(t_{\text{sup}} - t)$$

$$= 798.4 + 1984.3 + 2 \times 67 \quad (c_p = 2 \text{ kJ/kg K})$$

$$= 2916.7 \text{ kJ/kg Ans}$$

Similarly, from the steam table, when the pressure is 0.15 bar

$$h_f = 226 \text{ kJ/kg}, h_{fg} = 2373.2 \text{ kJ/kg}$$

Enthalpy or total heat of 1kg of wet steam

$$h = h_f + x h_{fg}$$

$$= 226 + 0.95 \times 1984.3$$

$$= 2111 \text{ kJ/kg}$$

\therefore Drop in enthalpy of the steam

$$= h_{sup} - h = 2916.7 - 2111$$

$$= 805.7 \text{ kJ/kg Ans}$$

- (3) A steam engine obtains steam from a boiler at a pressure of 15 bar & 0.98 dry. It was observed that the steam loses 21 kJ of heat per kg as it flows through the pipe line, pressure remaining constant. calculate dryness fraction of the steam, at the engine end of the pipeline.

Sol $P = 15 \text{ bar}, x = 0.98, \text{Heat loss} = 21 \text{ kJ/kg}$

From the steam tables, when the pressure is 815 bar

$$h_f = 844.6 \text{ kJ/kg}, h_{fg} = 1945.3 \text{ kJ/kg}$$

Enthalpy of wet steam at the boiler end

$$h_1 = h_f + x h_{fg} = 844.6 + 0.98 \times 1945.3 \\ = 2751 \text{ kJ/kg}$$

Since the steam losses 21 kJ/kg of steam, therefore enthalpy of wet steam at the engine end,

$$h_2 = 2751 - 21 = 2730 \text{ kJ}$$

x_2 = dryness fraction of steam at the engine end.

Since the pressure is constant, therefore h_f & h_{fg} is same: $h_2 = h_f + x_2 h_{fg}$

$$\Rightarrow 2730 = 844.6 + x_2 \times 1945.3$$

$$\Rightarrow x_2 = \frac{2730 - 844.6}{1945.3} = 0.97 \text{ Ans.}$$

$X \longrightarrow X \longrightarrow X$

Steam Tables & Their uses

The properties of dry saturated steam like its Saturation temp., Sensible heat, Latent heat of Vapourisation, Enthalpy or total heat, specific volume, Entropy etc. vary with pressure & can be found by experiments only.

These properties have been determined in a tabular form known as ~~stem~~ Steam tables.

There are two important Steam tables, one in terms of absolute pressure & other in terms of temperature.