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Lectures Note

Santosh Paudel

Lect. in Mechanical Dept.
PKAIET Basgash.

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 cylinders. 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 :> It is generally made of cast iron & fitted to the crankshaft. Its function is to provide reciprocating motion to the slide valve.

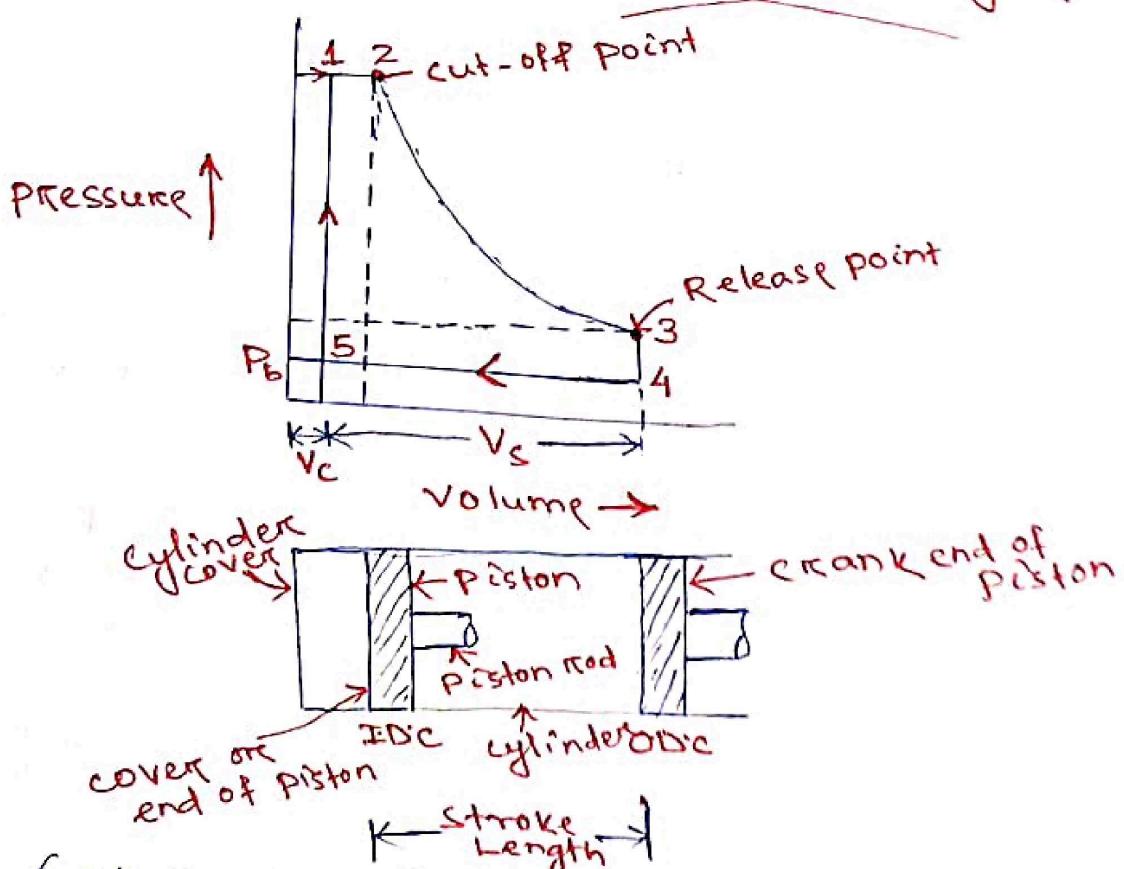
(l) Eccentric rod & valve rod :> The eccentric rod is made of forged steel. Whose one end is fixed to the eccentric & other to the valve rod. Its main function is to convert rotary motion of the crankshaft into to & fro motion of the valve rod.

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

(m) Flywheel :> 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 :> 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.

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

Indicator Diagram of a simple Steam Engine

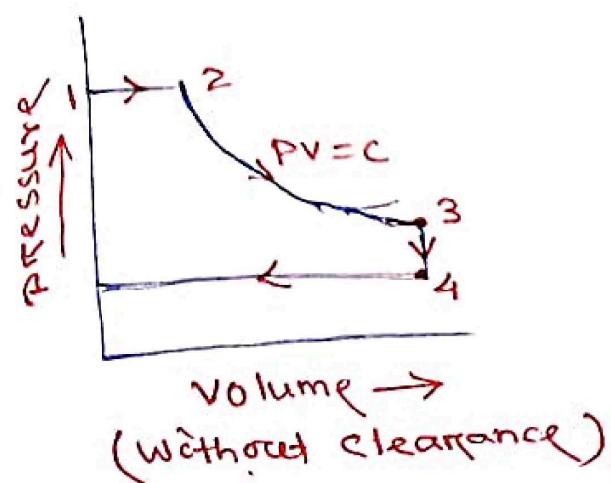
It is the graphical representation of the variation in pressure & volume of steam inside the cylinder. This P-V diagram is developed from that of modified Rankine cycle.

Assumption

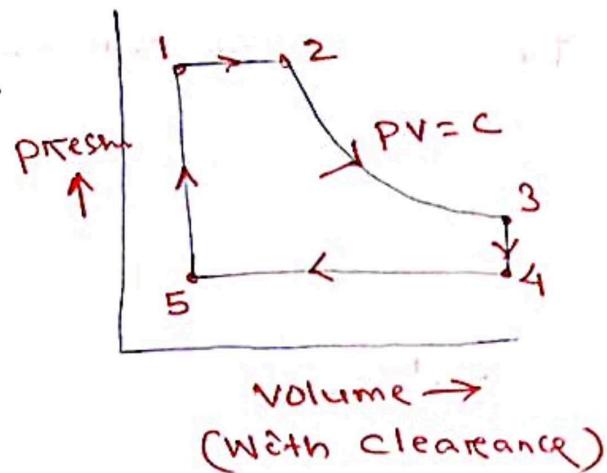
- (i) The opening & closing of steam ports is instantaneous (occurring or done properly)
- (ii) There is no pressure drop due to condensation.
- (iii) There is no wire drawing due to restricted valve opening. (drawn into wire like structure)
- (iv) The steam is admitted at boiler pressure & exhausted 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

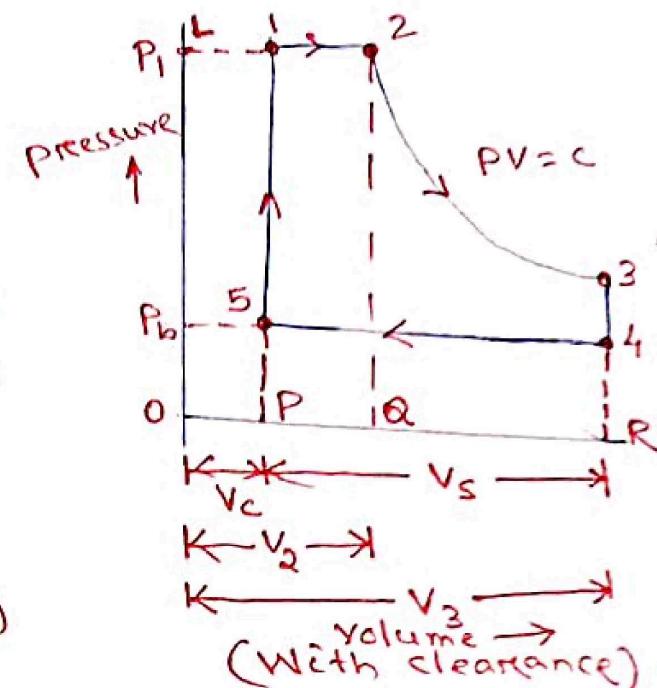
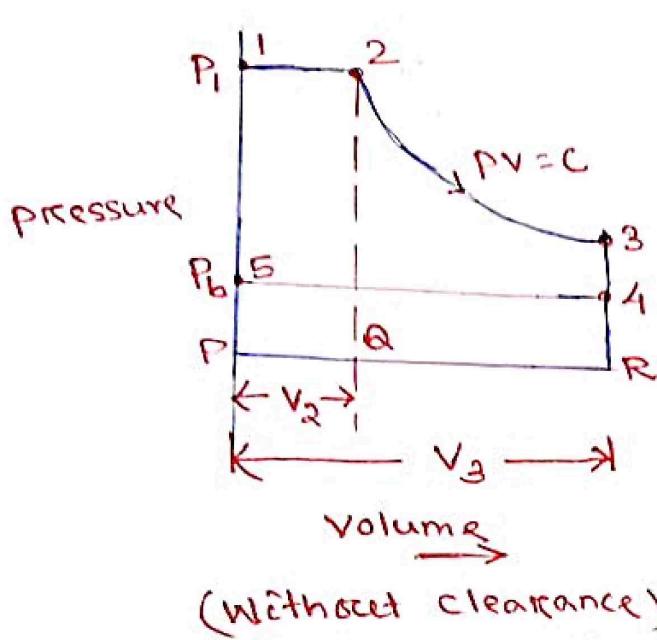


Processes

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

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

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 b/w 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 $P_1 = 8.4 \text{ bar}, v_2 = 0.35 v_3, P_b = 1.25 \text{ bar}$
 $K = 0.75$

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

Theoretical mean effective pressure

$$\begin{aligned} P_m &= \frac{P_1}{\pi} (1 + 2.3 \log \pi) - P_b \\ &= \frac{8.4}{2.86} (1 + 2.3 \log (2.86)) - 1.25 \\ &= 4.77 \text{ bar} \end{aligned}$$

\therefore Actual mean effective pressure

$$\begin{aligned} P_a &= P_m \times K = 4.77 \times 0.75 \\ &= 3.58 \text{ bar} \end{aligned}$$

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 power are developed

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

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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.

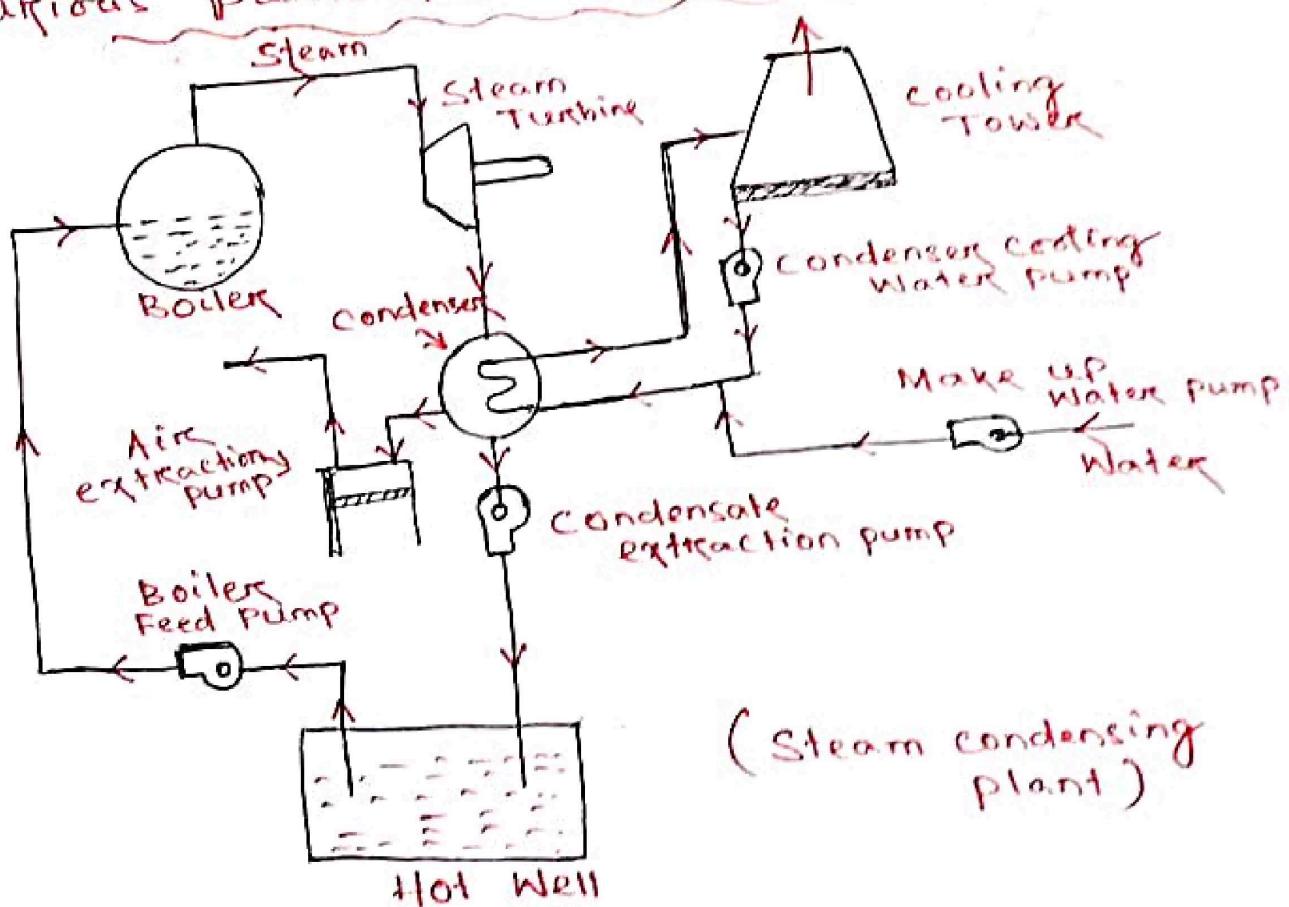
It have two objects:-

- (i) To maintain a low pressure, so as to obtain the maxⁿ possible energy from steam & thus secure a high efficiency.
- (ii) To ~~suppl~~ 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: 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: It is a pump, which remove condensed steam from the Condenser to the hot well.
- (c) Hot Well: It is a sump between the Condenser & boiler, which receives condensed steam from condensate pump.
- (d) Boiler feed pump: It is a pump, which pumps the condensate steam from the hot well to the boiler.
- (e) Air extraction pump: It is a pump which removes air from condenser.
- (f) Cooling Tower: It is a tower used for cooling the water which is discharged from the condenser.
- (g) Cooling Water pump: 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

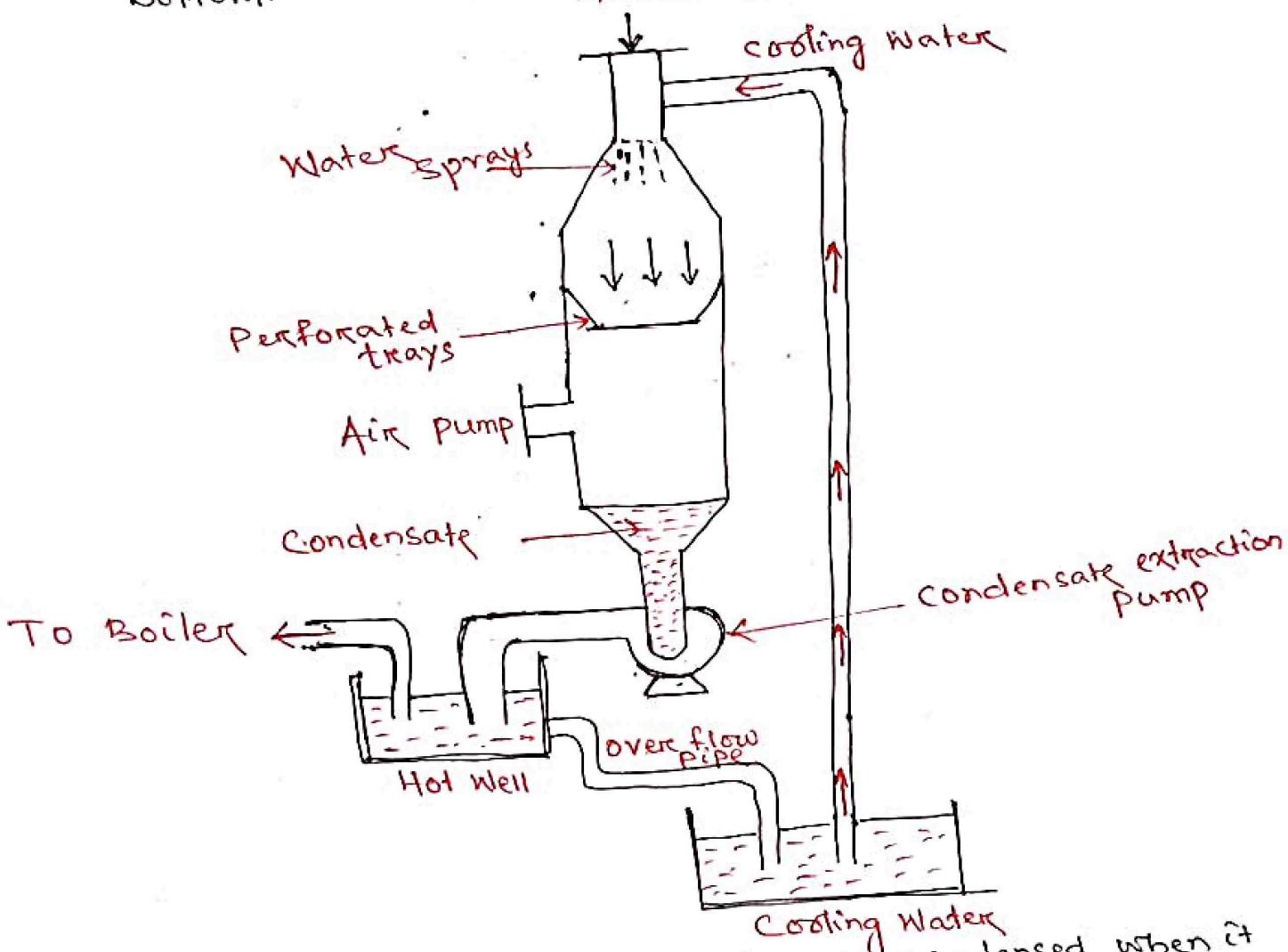
- * Jet condenser is a mixing type condenser where exhaust steam is condensed mixed with cooling water.
- * In jet condenser, high power is required for condensation.

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.

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

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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.

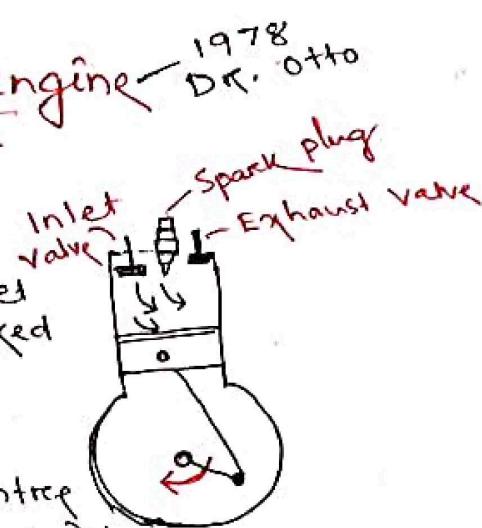
Four-Stroke cycle Petrol Engine

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.).

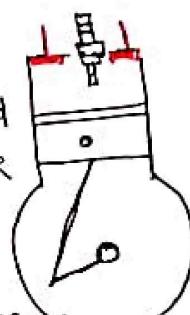


(ii) Compression stroke

In this stroke

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

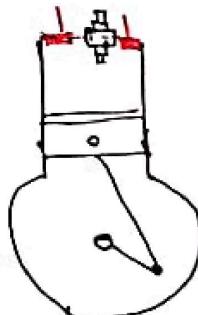
Due to compression, the pressure & temp. of charge increases.
This complete one revolution of crank shaft.



(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.

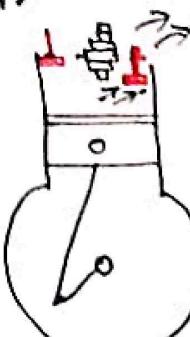


Due to this expansion, some of the heat energy produced, & it transformed into mechanical work.
During working stroke, piston moves from T.D.C to B.D.C & both the valve are closed.

(IV) Exhaust stroke

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

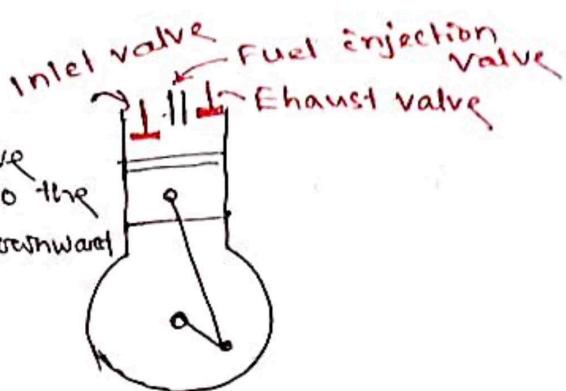
* This movement of the piston pushes out the products of combustion from the engine cylinder & are exhausted through the exhaust valve into the atmosphere.
This complete the cycle.



Four Stroke Diesel Engine

(i) Suction Stroke:

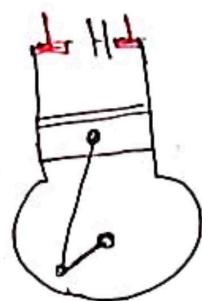
In this stroke, the inlet valve opens & pure air is sucked into the cylinder as the piston moves downward from T.D.C. to B.D.C.



(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.

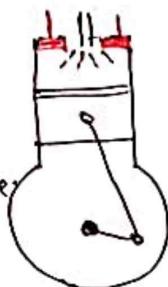
As a result of compression pressure & temp. of air increases. This complete one revolution of the crank shaft.



(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.

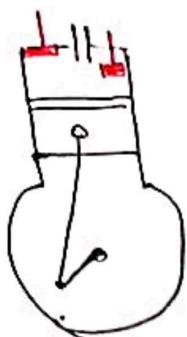
It suddenly increases the pressure & temp. of the fuel of combustion. The hot burnt gases expand due to high speed of the piston. During expansion stroke, some of heat energy is converted into mechanical work. During this stroke, both the valves are closed & piston moves T.D.C to B.D.C.



(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.



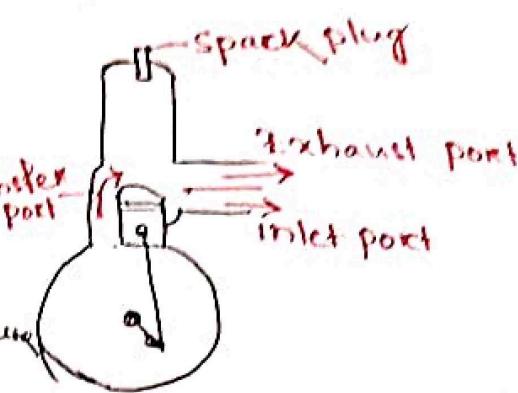
This completes the cycle & the engine cylinder is ready to suck the fresh air again.

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 flows 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

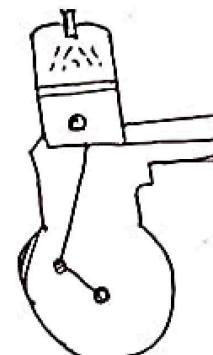
compressed as the piston moves upwards. Here inlet port is open & fresh fuel-air mixture enters into the crank case.



(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.

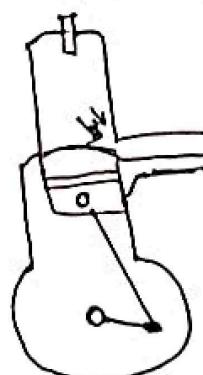


During expansion, some of the heat energy is transformed into mechanical work.

(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.

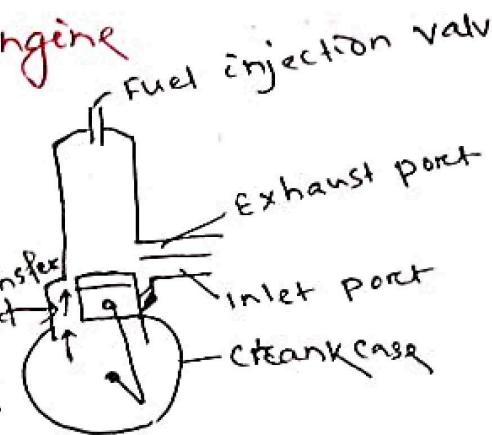


This completes the cycle & the engine cylinder is ready to suck the charge again.

TWO STROKE CYCLE DIESEL ENGINE

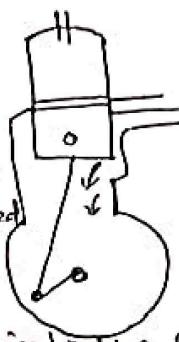
(i) Suction Stage

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



(ii) Compression Stage

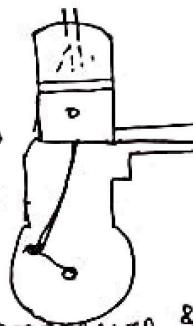
In this stage, while the piston moving up, first cover the transfer port & then exhaust port. Air is compressed as the piston moves upward.



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.

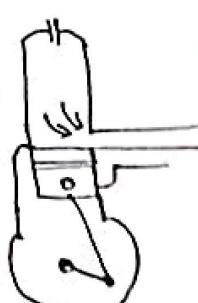


It suddenly increase the pressure & temp. of the combustion. Due to increased pressure, the piston is pushed with a great force.

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

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

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

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

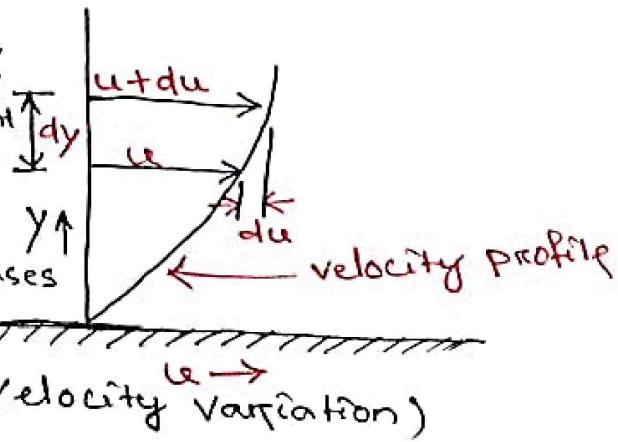
$$\Rightarrow \text{Weight} = 6867 \times 0.001 = 6.867 \text{ N}$$

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 : $N\text{-s}/\text{m}^2$ (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

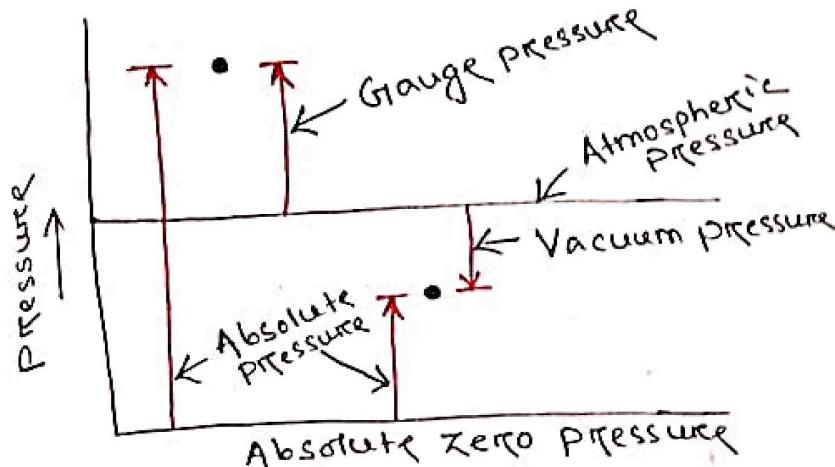
$$\boxed{p = \frac{dF}{dA}}$$

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 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 (a) Manometers

(b) 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

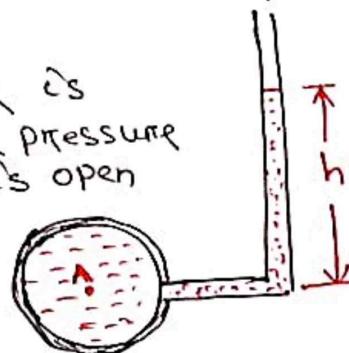
- * Single column manometer

* 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.

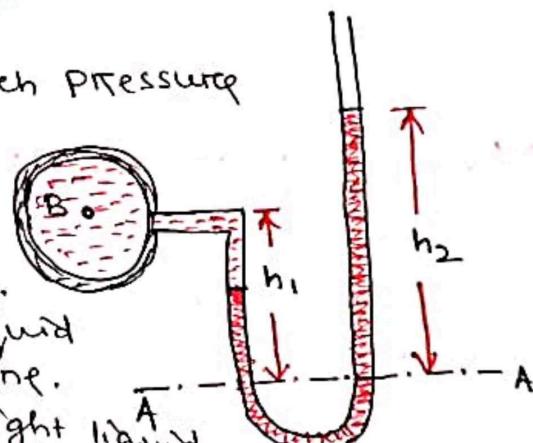
h_2 = Height of heavy liquid above the datum line.

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?

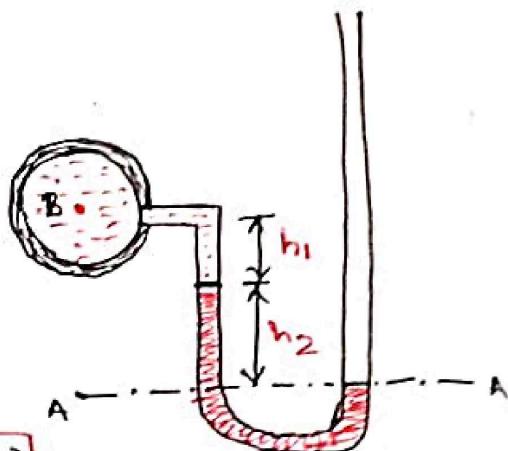
Pressure above A-A in the left column = $P + \rho_2 gh_2 + \rho_1 gh_1$

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

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

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

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

$$\begin{aligned} \text{Density of Mercury } \rho_2 &= s_2 \times 1000 \\ &= 13.6 \times 1000 \\ &= 13600 \text{ kg/m}^3 \end{aligned}$$

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

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

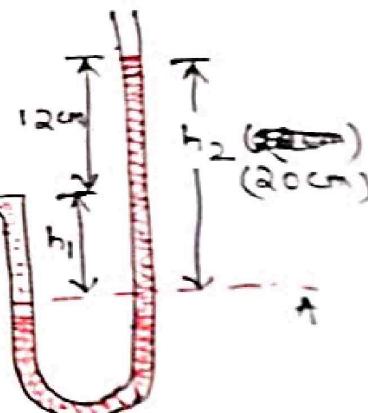
$$\text{Pressure } P = \rho_2 gh_2 - \rho_1 gh_1$$

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

$$= 26683 - 706$$

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

$$= 2.597 \text{ N/cm}^2$$



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.

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

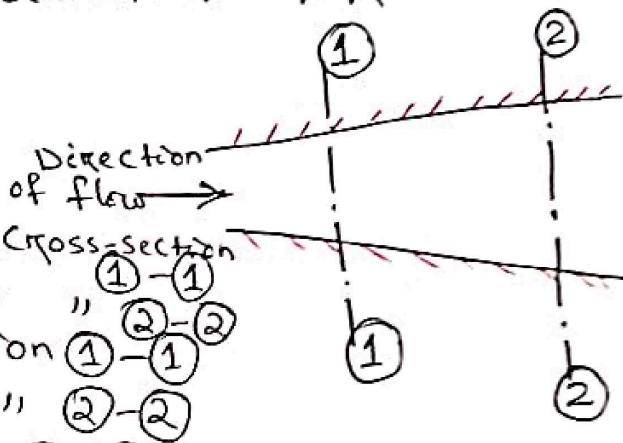
A = Cross-Sectional area of a pipe

V = 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 cross-section

v_2 = " " " "

ρ_1 = Density at section " " " "

ρ_2 = " " " "

A_1 = Area at section 1-1

A_2 = " " 2-2

Rate of discharge at sec 1-1 = $\rho_1 A_1 v_1$

" " " Sec 2-2 = $\rho_2 A_2 v_2$

According to law of conservation of mass

Rate of discharge at sec 1-1 = Rate of discharge at sec 2-2

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

If $\rho_1 = \rho_2$

This eqn is known as continuity equation

Then continuity eqn 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

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

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

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

$$A_1 V_1 = A_2 V_2$$

$$\Rightarrow V_2 = \frac{A_1 V_1}{A_2} = \frac{0.03927}{0.01767} = 2.22 \text{ m/s}$$

- (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)

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

velocity at section - 3 (V_3)

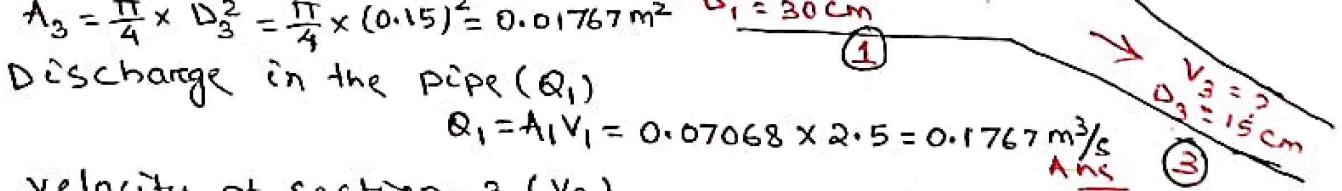
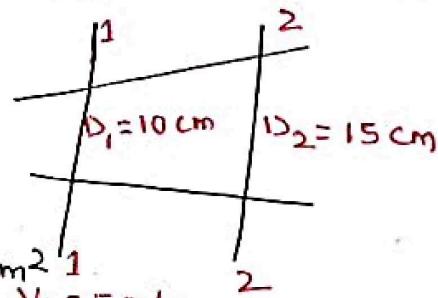
$$Q_2 = A_2 V_2 = 0.0314 \times 2 = 0.0628 \text{ m}^3/\text{s}$$

Continuity eqn $Q_1 = Q_2 + Q_3$

$$\Rightarrow 0.1767 = 0.0628 + Q_3$$

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

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



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.

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

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.

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

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.

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

m = Mass of liquid

g = Acceleration due to gravity

h = Height of liquid.

Total Energy:-

Total energy = Pressure energy + Kinetic energy
+ Potential energy

$$\text{T.E.} = \rho g h + \frac{1}{2} m v^2 + mgh$$

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

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

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

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

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

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

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

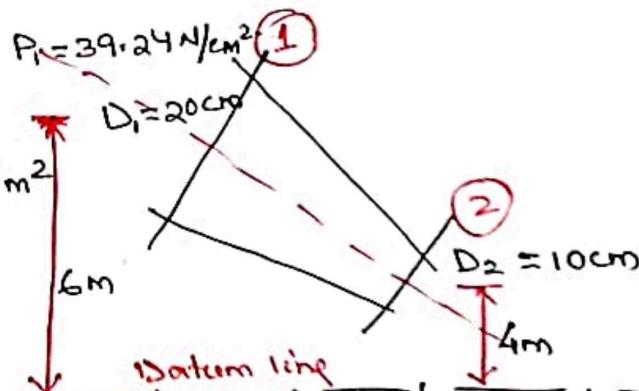
AT Section-2

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

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

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

$$P_2 = ?$$



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

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

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

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

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/cm^2 & the pressure at the upper end is 9.81 N/cm^2 . Determine the difference in datum head if the rate of flow through the pipe is 40 lt/s .

SOL)

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

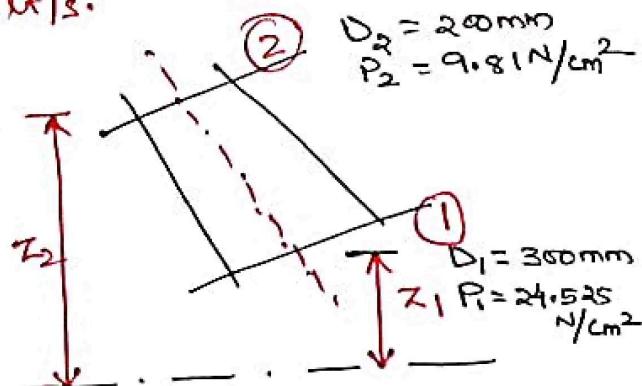
$$P_1 = 24.525 \text{ N/cm}^2 = 24.525 \times 10^4 \text{ N/m}^2$$

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

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

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

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



$$Q = A_1 V_1 = A_2 V_2$$

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

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

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

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

Applying Bernoulli's eqn

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

$$\Rightarrow Z_2 - Z_1 = ? \text{ m}$$

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

→ 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 \downarrow 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.

Ex: Simple vertical boiler

Cornish boiler

→ There are more fire tubes or water tubes.

Ex: 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.
Ex: - 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.

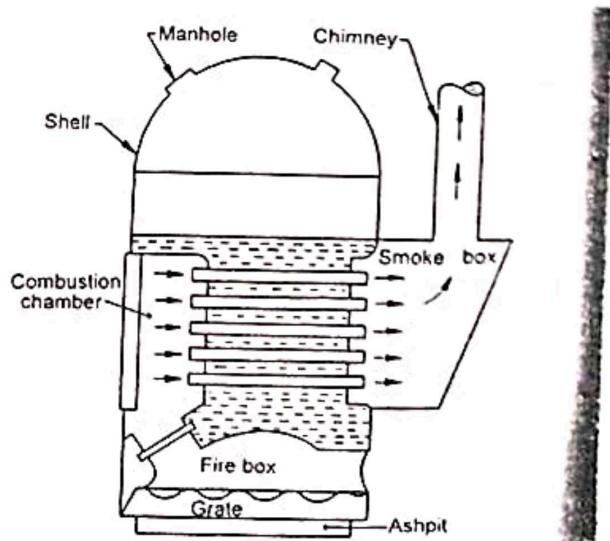


Fig 13.2. Cochran boiler.

- * 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 consists 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

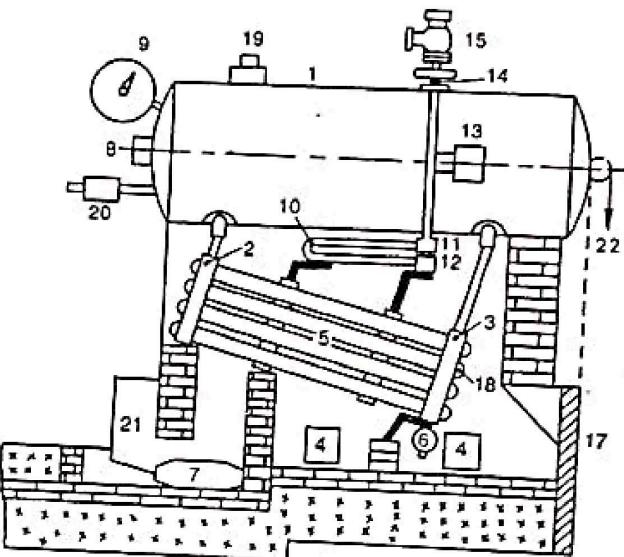


Fig. 13.7. Babcock and Wilcox boiler.

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

* The water tubes are inclined to the horizontal & connects the uptake header to the downtake 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 downtake 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.

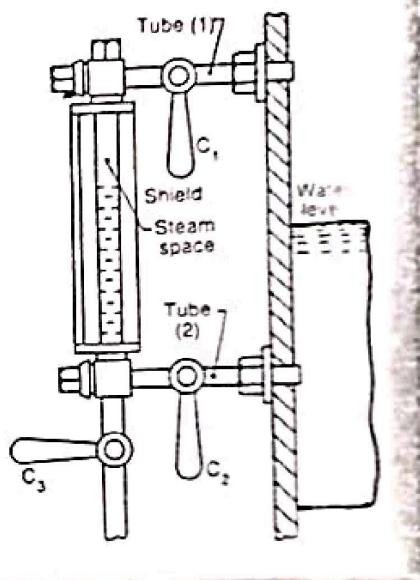
Water cock C₂ → Puts the glass tube in connection with the water in boiler.

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.

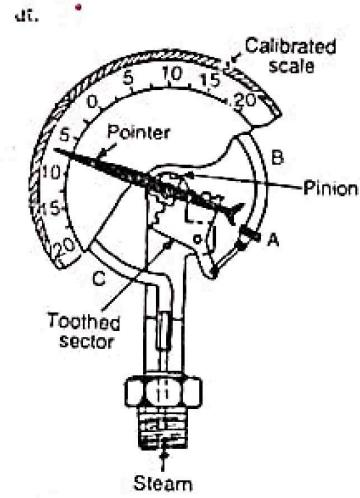


Fig. 14.2. Bourden type pressure gauge.

(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.

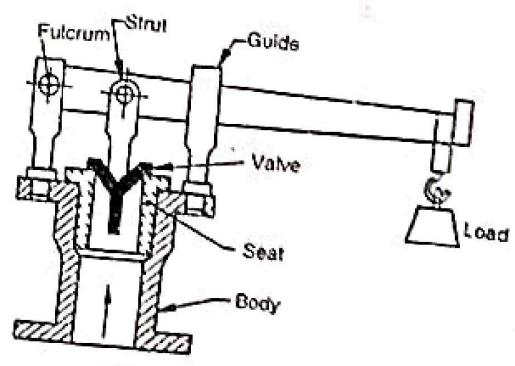


Fig. 14.3. Lever safety valve.

- * 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.

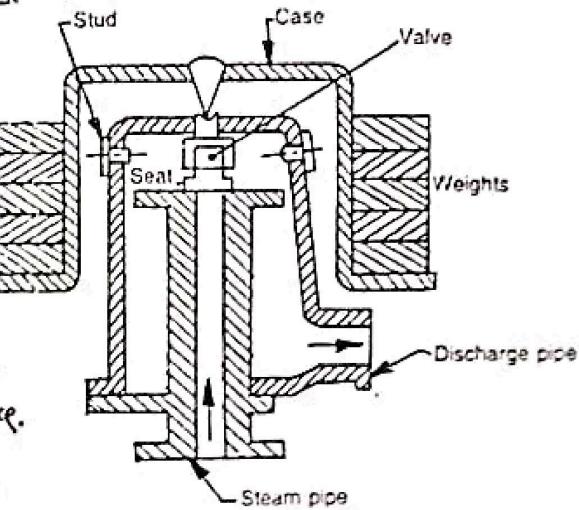


Fig. 14.4 Dead weight safety valve

(iii) High Steam Low Water Safety valve

* These valves 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.

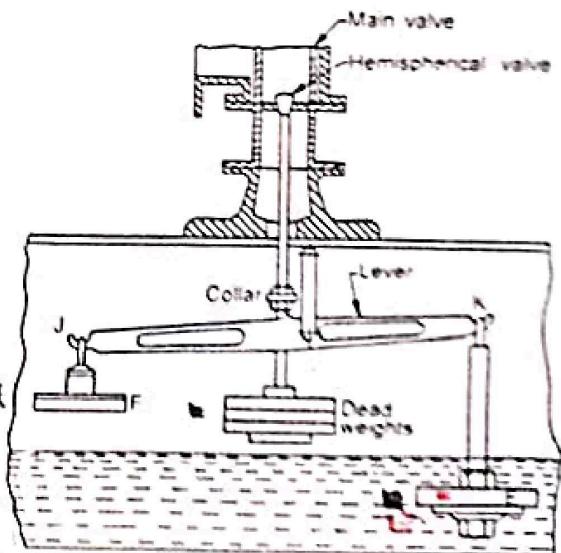
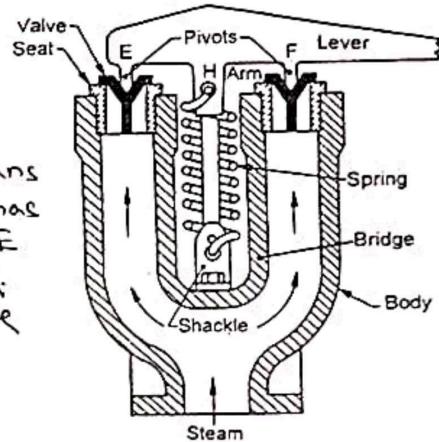


Fig. 14.5 High steam low water safety valve.

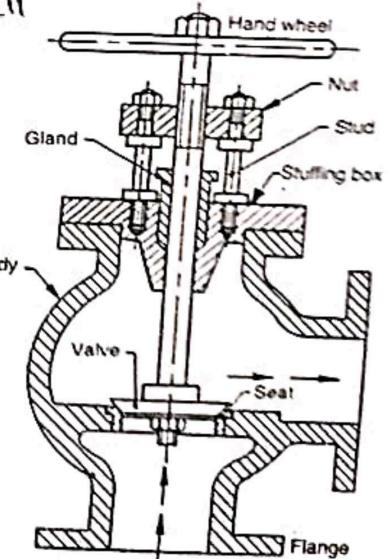
(iv) Spring Loaded Safety Valve

- * 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

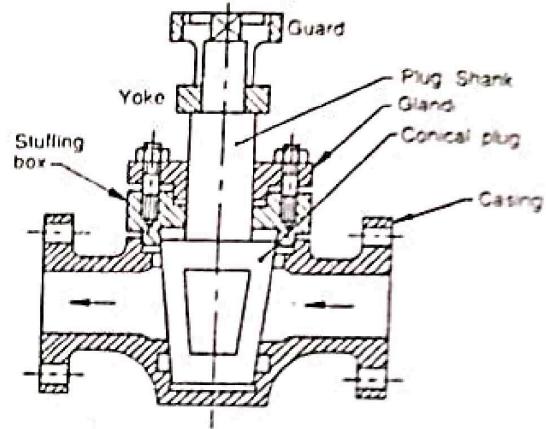
- * It is the largest valve on the steam boiler. It is fitted to the highest part of the shell by means of a flange.
- The function of Stop valve is: →
 - vii To control the flow of steam from the boiler to the main steam pipe.
 - viii To shut off the steam completely when required.
- * It is made of 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

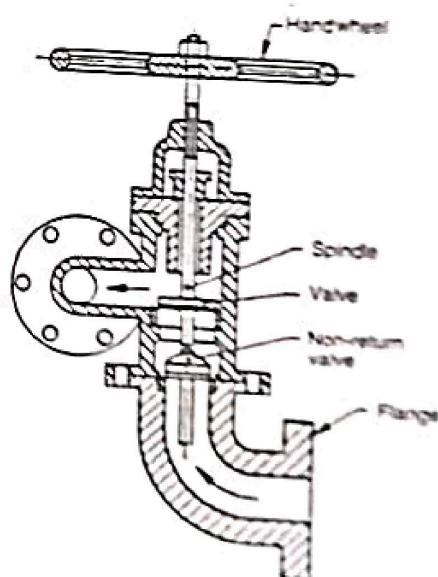
The function of Blow off cock are:-

- (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 guarded fire top box spanner to be used for operating the cock.



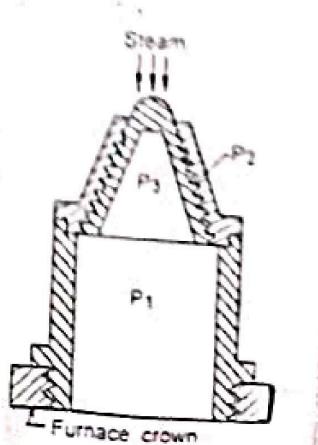
(f) Feed Check valve

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

~~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 "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 .

Sol

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

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

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

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

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

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

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

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: (C_P)

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 ~~water~~ 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

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