GOVERNMENT POLYTECHNIC, NAYAGARH

THERMAL ENGG. -II

4TH SEMESTER, MECHANICAL ENGG.

PREPARED BY- DEVASIS SAHOO

Chapter-01 Performance of IC Engine

Engine:-

Engine is a device or an integral part of a machine in which one form of energy is converted in to the another form for generating the power.

Types of Engine:-

Engine are two types:-

① IC engine
② EC engine

IC engine:-(Internal combustion Engine)

It is the type of engine in which the combustion or the burning of fuel takes place inside the engine cylinder is called IC. engine.

Ex:- Bike engine, car engine, Bus engine, truck engine.

Performance of IC Engine:-

Introduction:-

* An engine is selected for a perticular application on the basis of its power generating and speed rate. Other factors include capital cost and operational cost is required to define the performance of an engine.

* These are :-

① Indicated power
② Brake Power
③ frictional power
④ Mechanical efficiency
⑤ Overall efficiency
⑥ Brake thermal efficiency
⑦ Indicated thermal efficiency
⑧ Air standard efficiency
⑨ Relative efficiency
⑩ Volumemetric efficiency.

① **Indicated Power:-**

* It is the power generating by the working of piston inside the cylinder. The working of piston is due to and fro motion or reciprocating motion.

* It is known as the actual power of the engine.

Mathematically, indicated power

$$I.P = \frac{100 K P_m L A n}{60} KW$$

Where, K = No of cylinder
P_m = mean effective pressure
L = Length or stroke length
A = Area of the piston or cylinder.

n = no of cycle.

*Avg. speed = 2LN

* For 2 stroke $n = N$
* For 4 stroke $n = \frac{N}{2}$

② Brake Power:-

* It is the power generated from the crankshaft
* Brake power

$$B.P = \frac{\text{Workdone}}{\text{time}} \text{ KW}$$

③ Frictional Power:-

$$FP = IP - BP$$

④ Mechanical efficiency:-

Mechanical efficiency of an I.C. engine is defined as it is the ratio between the brake power and indicated power.

Mathematically,

Mechanical efficiency,

$\frac{BP}{IP}$

$$\eta_{mech} = \frac{BP}{IP}$$

⑤ Overall efficiency:-

It is defined as it is the ratio of work obtained at the crankshaft in a given time to the energy supplied by the fuel in same time.

$$\eta_{overall} = \frac{\text{Work obtained at the crank shaft}}{\text{energy supplied by the fuel}}$$

Here,

The workdone at the crankshaft

= Brake Power × 60 kJ.

and

the energy by the burning of fuel = $\frac{Mf \times CV}{60}$

Then

$$\eta_{overall} = \frac{BP \times 60}{\frac{Mf \times CV}{60}}$$

$$= \boxed{\frac{BP \times 3600}{Mf \times CV}}$$

⑥ Breake thermal efficiency:-

* As we know the power of an engine is obtained from the combustion of charge. Thus the overall efficiency of an engine is given by the brake thermal efficiency.

$$\boxed{\eta_{bth} = \frac{BP \times 3600}{mf \times cv}}$$

marks 2

* Specific fuel consumption / brake / power / hour = $\frac{Mf}{BP}$

Scanned with OKEN Scanner

(7) Indicated thermal efficiency:-

* The indicated thermal efficiency is defined as it is the ratio of indicated workout to the energy supply.

$$\eta_{ith} = \frac{\text{Indicated work output}}{\text{Energy supplied.}}$$

$$= \frac{IP \times 60}{\frac{\dot{M}_f \times CV}{60}}$$

$$= \frac{IP \times 3600}{M_f \times CV}$$

* Specific fuel consumption / IP / h

$$= \frac{M_F}{IP}$$

(8) Air standard efficiency :-

* The air standard efficiency of an I.C. engine may also be obtained mathematically from the general expression of efficiency of petrol and diesel engine.

Mathematically expression for petrol engine,

$$(\eta_{air})_{petrol} = 1 - \frac{1}{r^{\gamma - 1}}$$

For diesel engine

$$(\eta_{air})_{diesel} = 1 - \frac{1}{r^{\gamma - 1}} \left[\frac{\rho^{\gamma} - 1}{\gamma - (\rho - 1)} \right]$$

(9) Relative efficiency :-

* It is defined as it is the ratio of indicated thermal efficiency to the air standard efficiency.

Mathematically

$$\eta_{relative} = \frac{\text{Indicated thermal efficiency}}{\text{Air standard efficiency}}$$

$$= \frac{\eta_{ith}}{\eta_{air}}$$

(10) Volumetric efficiency:-

* It is defined as it is the ratio of actual volume of charge during suction stroke at NTP to the swept volume.

Mathematically

$$\eta_{vol} = \frac{\text{Volume of charge admitted at NTP}}{\text{Swept volume}}$$

$$\eta_{vol} = \frac{V_a}{V_s}$$

2 marks

Calorific Value:-

* Calorific value of a fuel is defined as it is the total amount of heat energy liberated when an unit mass of fuel is completely burn is the presence of excess supply of oxygen.

(NTP= Normal temp. and Press... via Standard temp.

IMP Example:- 27.5

Given,

Diameter of piston = 150mm = 150×10^{-3} = 0.15m

Length of the stroke = 400mm = 400×10^{-3} = 0.4m

Effective pressure = 5.5 bar

n = 120

Brake power = 5 kW.

Area = $\frac{\pi}{4} \times (0.15)^2 = 0.017 m^2$

η_{mech} = ?

$$I.P = \frac{100 k P_m L A n}{60} kW$$

$$= \frac{100 \times 1 \times 5.5 \times 0.4 \times 0.017 \times 120}{60}$$

$$= \frac{100 \times 5.5 \times 0.4 \times 0.017 \times 120}{60}$$

= 7.48 kW

$$\therefore \eta_{mech} = \frac{BP}{IP} = \frac{5}{7.48} = 0.668 \times 100 = 66.8\%$$

Example:- 27.1

Given,

Diameter of piston = 100mm = 100×10^{-3} = 0.1m

Indicated power = 4 kW.

Effective pressure = 6.5 bar

Area = $\frac{\pi}{4} \times (0.1)^2 = 7.853 \times 10^{-3} m^2$

For two stroke n = N

$$\therefore I.P = \frac{100 k P_m L A n}{60} kW$$

$$\Rightarrow 4 = \frac{100 \times 1 \times 6.5 \times L \times 7.853 \times 10^{-3} \times N}{60}$$

$$\Rightarrow 4 = \frac{100 \times 6.5 \times L \times 7.853 \times 10^{-3} \times N}{60}$$

$$\Rightarrow 4 = 0.085 LN$$

$\Rightarrow 0.085 LN = 4$

$\Rightarrow LN = \frac{4}{0.085}$

$\Rightarrow LN = 47$

∴ Average speed of the piston =

$2LN$

$\Rightarrow 2 \times 47$

$= 94$ m/s (ANS)

Example:- 27.2:-

Given,

Area of indicated diagram = $420 mm^2$ (a)

Length of indicated diagram = 62 mm (l)

Spring number = 1.1 bar/mm (S)

Diameter of piston = 100mm

$= 100 \times 10^{-3} = 0.1$ mm

Area of piston = $\frac{\pi}{4} \times (0.1)^2$

$= 7.853 \times 10^{-3}$

Length of ~~stoe~~ stroke = 150mm = 150×10^{-3}

$= 0.15$ m

Engine speed = 450 rpm

We know that,

$n = N$

Here, $N = 450$

for, four stroke

$n = \frac{N}{2} = \frac{450}{2} = 225$

∴ Indicated mean effective pressure = ?
∴ Indicated power = ?

(i) Indicated mean effective pressure =

$$P_m = \frac{a \cdot S}{l}$$

$$= \frac{420 \times 1.1}{62} = 7.45 \text{ bar}$$ (ANS)

(ii) Indicated power :-

$$I.P = \frac{100 K P_m L A n'}{60}$$

$$= \frac{100 \times 1 \times 7.45 \times 0.15 \times 7.853 \times 10^{-3} \times 225}{60}$$

$$= \frac{100 \times 7.45 \times 0.15 \times 7.853 \times 10^{-3} \times 225}{60}$$

$$= 3.29 \text{ kW}$$ (ANS)

Example :- 27.6

Given,

No of cylinder = 4

Brake power = 23.5 kW

N = 2500 r.p.m (N = n for two stroke eng)

Mean effective pressure = 8.5 bar

Mechanical efficiency = 85%
= 0.85

Let,

diameter of the cylinder = d

Length of the Stroke = 1.5 d

So, Area = $\frac{\pi}{4}(d^2)$

We know that.

$$\eta_{mech} = \frac{B.P}{I.P}$$

$$\Rightarrow 0.85 = \frac{23.5}{I.P}$$

$$\Rightarrow 0.85 \times I.P = 23.5$$

$$\Rightarrow I.P = \frac{23.5}{0.85} = 27.64 \text{ kW}$$

∴ Indicated Power =

$$I.P = \frac{100\ K P_m L A n}{60}$$

$$\Rightarrow 27.64 = \frac{100 \times 4 \times 8.5 \times 1.5 d \times \frac{\pi}{4} \times (d)^2 \times 2500}{60}$$

$$\Rightarrow 27.64 = \frac{100 \times 4 \times 8.5 \times 1.5 d \times 0.785 \times (d)^2 \times 2500}{60}$$

$$\Rightarrow 27.64 = 166812.5\ d^3$$

$$\Rightarrow 166812.5\ d^3 = 27.64$$

$$\Rightarrow d^3 = \frac{27.64}{166812.5}$$

$$\Rightarrow d^3 = 1.6569 \times 10^{-4}$$

$$\Rightarrow d = \sqrt[3]{1.6569 \times 10^{-4}}$$

$$= 0.054\ m$$

$$= 54\ mm$$

∴ Length $= 1.5 d$

$= 1.5 \times 54 = 81\ mm$ (ANS)

Example 27.8:-

Given,

$m_f = 6.5$ kg/h

Calorific value = 30 000 kJ/kg

BP = 22 kW

Mechanical efficiency = 85% = 0.85

∴ Indicated Power $= \frac{BP}{\eta_{mech}}$

$$= \frac{22}{0.85}$$

$$= 25.88\ kW$$

① Indicated thermal efficiency $= \dfrac{IP \times 3600}{m_f \times C}$

$$= \frac{25.88 \times 3600}{6.5 \times 30000}$$

$= 0.47$ or 48% ⟵ (ANS)

② Brake thermal efficiency $= \dfrac{BP \times 3600}{m_f \times CV}$

$$= \frac{22 \times 3600}{6.5 \times 30000}$$

$= 0.406$ or 40.6% ⟵ (ANS)

③ Specific fuel consumption $= \dfrac{M.f}{B.P}$

~~$\dfrac{0.85}{22} = 0.38$~~

$= \dfrac{6.5}{22} = 0.295$ Kg/B.P/h ⟵ (ANS)

Example :- 27.11 :-

The diameter and stroke length of a single cylinder two stroke gas engine working on the constant volume cycle are 200mm and 300 mm respectively with clearance volume 2.78 L. When the engine is running at 135 rpm. The indicated mean effective pressure was 5.2 bar and the gas consumption $8.8 \ m^3/h$. If the calorific value of the gas used is 16350 K Joule / m^3. Find

① Air standard efficiency.
② Indicated power developed by the engine.
③ Indicated thermal efficiency at the ...

Ans: Given,

Diametore of the cylinder = 200 mm = 0.2 m

Length of the cylinder = 300 mm = 0.3 m

Clearance Volume = 2.78 l

$N = \frac{135}{2}$ R.P.M

K = 1

m_f = 8.8 m^3/h

P_m = 5.2 bare

Calorific value = 16350 KJ/m^3

$$\text{Area} = \frac{\pi}{4} \times (d)^2$$

$$= \frac{\pi}{4} \times (0.2)^2 = 0.03141 m^2$$

① Indicated Power = $\frac{100 \, K P_m L A n}{60}$ KW

$$= \frac{100 \times 1 \times 5.2 \times 0.3 \times 0.03141 \times 135}{60}$$

$$= 11.02491 \text{ KW} \text{ — (ANS)}$$

② Indicated thermal efficiency = $\frac{IP \times 3600}{m_f \times C}$

$$= \frac{11.02491 \times 3600}{8.8 \times 16350}$$

$$= 0.275$$

$$= 27.5\% \text{ — (ANS)}$$

Introduction:-

* An air compressor is a machine or a device which is used to compress the air and raised its initial pressure.
* The compressor in other words is defined as a device which converts the power in to potential energy stored in the pressurised air.
* The air compressor sucks ~~sues~~ air from the atmosphere compress it and then delivery the same under a high pressure to a storage ~~ter~~ vessel.

Industrial Application:-

* The compressor is used for many purpose such as operating numatic drills and in gas turbine plants.
* It is also utilized in operation of lifts and verity of ~~oter~~ other devices.

Classification:-

* The air compressor mainly classified in many ways such as:-

① According to working:-

(i) Reciprocating air compressor.

(ii) Rotary air compressor.

② According to Action:-

(i) Single acting air compressor.
(ii) Double acting air compressor.

③ According to number of Stages:-

(i) Single stage air compressor.
(ii) Multi stage air compressor.

Technical terms of resiprocating air compressor

① **Bore:-** It is the diameter of cylinder and is called as bore. It is denoted as 'D'.

② **Stroke:-**

* It is the length travelled by the piston from TDC to BDC. or vice versa in the engine cylinder.

* It is termed as stroke length and is denoted as 'L'.

③ **Inlet Pressure:-**

* It is the compressor pressure of air available at the inlet of a compressor.

* It is also called as suction pressure.

④ **Discharge Pressure:-** It is the pressure of air available at the outlet of a compressurce. It is also called as exhaust pressure.

(5) **Compression Ratio:-** It is the ratio of discharge pressure to the inlet pressure. It is also known as pressure ratio.

(6) **Compression Capacity:-** It is the volume of air delivered by the compressor after compression and it is expressed in m^3/min or m^3/sec.

(7) **Free air delivery:-** It is the actual volume of air delivered by a compressor when reduced to a normal temperature and pressure condition. The capacity of a compressor is generally given by in terms of free air delivery.

(8) **Swept Volume:-** It is the volume of air sucked by compressor during its suction stroke.

Mathematically

Swept volume is given by

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

(9) **Mean effective Pressure:-**

* As a matter of fact in air compressor the compressor piston keeps unchanging with the moment the piston in the cylinder.

* The mean effective pressure of the compressor is found out mathematically by dividing the workdone to the swept volume.

(10) Volumetric efficiency:- It is the ratio of volume of free air / stroke to the swept volume of the piston.

Working Principle and operation of reciprocating air compressor:-

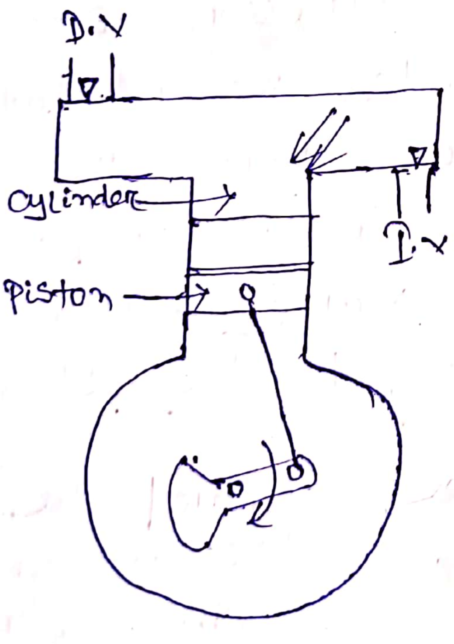
* A single stage reciprocating air compressor in its simplest form consist of a cylinder, piston, inlet and discharge valves.

* In reciprocating air compressor when the piston moves downwards the pressure inside the cylinder falls below the atmospheric level. Due to this pressure difference the inlet valve gets opened and air is sucked in to the cylinder.

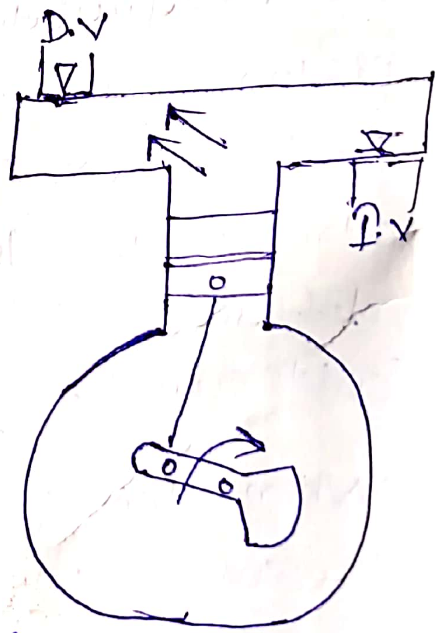
* When the piston moves upward the pressure inside the cylinder goes on increasing till it reaches the discharge pressure. At this stage the discharge valve gets opened and air is delivered to the storage container.

* At the end of the delivery stroke a small quantity of air at high pressure is left in the clearance space.

* As the piston starts its suction stroke the air contained in the clearance space expands and its pressure falls below the atmospheric pressure, at this stage the inlet valve gets open as a result of which fresh air is sucked in to the cylinder and the cycle is repeated.



(Suction Stroke)



(Delivery Stroke)

Workdone by a single stage reciprocating air compressor :-

* We have already discussed that in a reciprocating air compressor the air is first sucked compressed and then delivered. So there are three different operations of the compressor.

* Thus we see that work is done on the piston during the suction of air. Similarly work is done by the piston during compression as well as delivery of the air.

* A little consideration will show, that the work by a reciprocating air compressor is mathematically = The workdone by the compressor during suction.

Here,
We shall discuss the following two important cases of workdone.

1. When there is no clearance volume in the cylinder.

2. When there is some clearance volume. in the cylinder.

Workdone by a single stage reciprocating air compressor without clearance volume :-

Consider a single stage reciprocating air compressor without clearance volume delivery air from one side of the piston only.

Let,

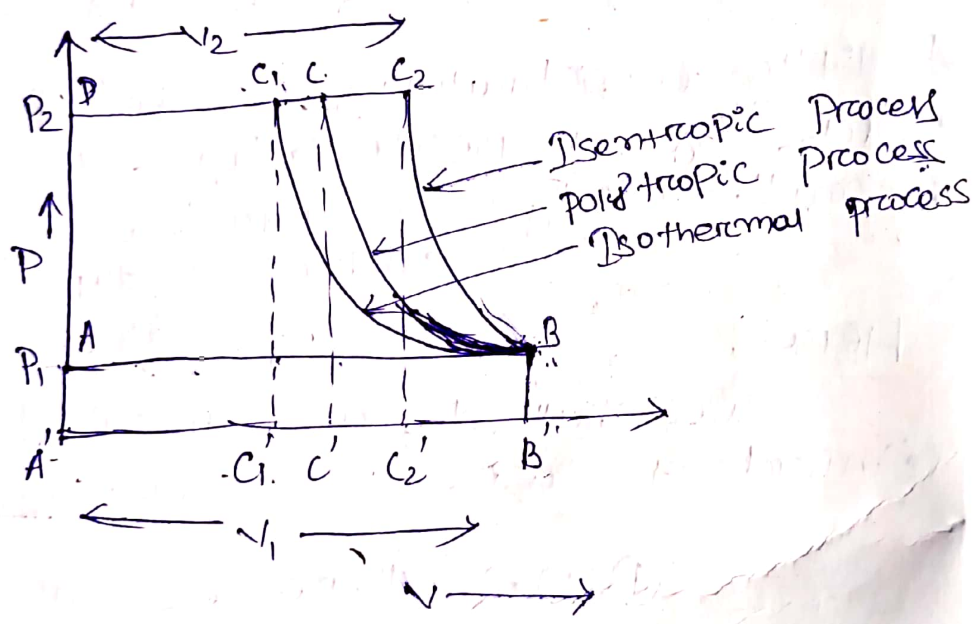
P_1 = Initial Pressure of air

V_1 = Initial volume of air

T_1 = Initial temperature of air.

P_2, V_2, T_2 = Corresponding values for the final condition.

r_1 = Pressure ratio (P_2/P_1).



P-V diagram without clearance volume.

Work done = Area under ABC_1DA

= Area $A'DC_1C_1'$ + Area $C_1'C_1BB'$ − Area $A'ABB'$

$$= P_2V_2 + 2.3\,P_2V_2 \log\left(\frac{V_1}{V_2}\right) - P_1V_1$$

In Iso-thermal Process

$PV = \text{Constant}$

$P_1V_1 = P_2V_2$

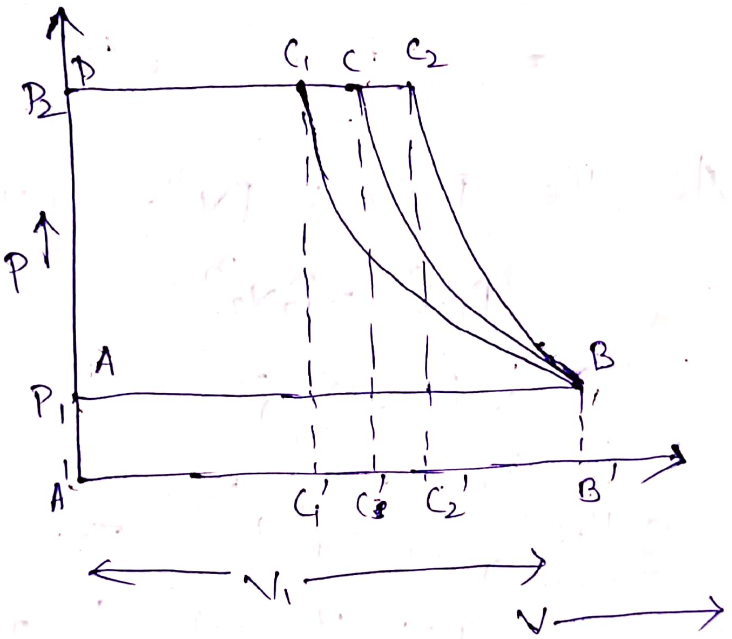
$\text{workdone} = P_1V_1 + 2.3 P_1V_1 \log\left(\frac{P_2}{P_1}\right) - P_1V_1$

$= 2.3 P_1V_1 \log r$

$W = 2.3\, mRT_1 \log r$

$PV = mRT$

$P_1V_1 = mRT_1$



Work done by Poly-tropic Process $PV^n = \text{Const.}$

Workdone = Area under ABCDA

= Area A'DCC' + Area C'CBB' − Area A'ABB'

$= P_2V_2 + \frac{P_2V_2 - P_1V_1}{n-1} - P_1V_1$

$$W = \frac{n-1\,(P_2V_2) + P_2V_2 - P_1V_1 - \{(n-1)(P_1V_1)\}}{n-1}$$

$$= \frac{nP_2V_2 - P_2V_2 + P_2V_2 - P_1V_1 - (nP_1V_1 - P_1V_1)}{n-1}$$

$$= \frac{nP_2V_2 - P_2V_2 + P_2V_2 - P_1V_1 - nP_1V_1 + P_1V_1}{n-1}$$

$$= \frac{nP_2V_2 - nP_1V_1}{n-1}$$

$$= \frac{n}{n-1} P_1V_1 \left(\frac{P_2V_2}{P_1V_1} - 1 \right)$$

$$= \frac{n}{n-1} P_1V_1 \left(\frac{P_2}{P_1} \times \frac{V_2}{V_1} - 1 \right) \quad \text{--- (1)}$$

As the process $PV^n = \text{Const}$.

$$P_1V_1^n = P_2V_2^n$$

$$\Rightarrow \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n$$

Putting the value in eqn (1)

$$\Rightarrow \frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{1/n} \quad \text{--- (2)}$$

$$W = \frac{n}{n-1} P_1V_1 \left\{ \left(\frac{P_2}{P_1}\right) \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} - 1 \right\}$$

$$= \frac{n}{n-1} P_1V_1 \left\{ \left(\frac{P_1}{P_2}\right)^{-1} \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}} - 1 \right\}$$

$$= \frac{n}{n-1} P_1V_1 \left\{ \left(\frac{P_1}{P_2}\right)^{-1+\frac{1}{n}} - 1 \right\}$$

$$= \frac{n}{n-1} P_1V_1 \left\{ \left(\frac{P_1}{P_2}\right)^{\frac{-n+1}{n}} - 1 \right\}$$

$$= \frac{n}{n-1} P_1V_1 \left\{ \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right\}$$

$$= \frac{n}{n-1} mRT_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

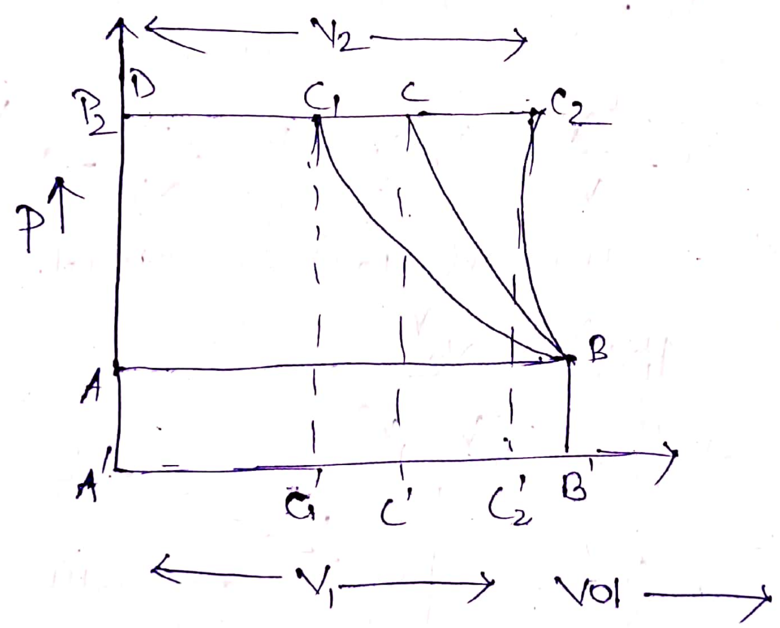
$$= \frac{n}{n-1} mRT_1 \left(\frac{T_2}{T_1} - 1 \right)$$

$$= \frac{n}{n-1} mRT_1 \left(\frac{T_2 - T_1}{T_1} \right)$$

$$= \frac{n}{n-1} mRT_1 \left(\frac{T_2}{T_1} - \frac{T_1}{T_1} \right)$$

$$= \frac{n}{n-1} mR \left(\frac{T_2}{T_1} \times T_1 - 1 \times T_1 \right)$$

$$\Rightarrow \boxed{W = \frac{n}{n-1} mR (T_2 - T_1)}$$



Workdone by isentropic process $PV^{\gamma} = \text{Const.}$

Workdone = Area under ABC_2D

= Area $A'DC_2C_2'$ + Area $C_2'C_2BB'$ − Area $A'ABB'$

$$= P_2V_2 + \frac{P_2V_2 - P_1V_1}{\gamma - 1} - P_1V_1$$

$$\Rightarrow W = \frac{(\gamma-1)P_2V_2 + P_2V_2 - P_1V_1 - \{(\gamma-1)P_1V_1\}}{\gamma-1}$$

$$\Rightarrow W = \frac{\gamma P_2V_2 - P_2V_2 + P_2V_2 - P_1V_1 - (\gamma P_1V_1 - P_1V_1)}{\gamma-1}$$

$$\Rightarrow W = \frac{\gamma P_2V_2 - P_2V_2 + P_2V_2 - P_1V_1 - \gamma P_1V_1 + P_1V_1}{\gamma-1}$$

$$\Rightarrow W = \frac{\gamma P_2V_2 - \gamma P_1V_1}{\gamma-1}$$

$$\Rightarrow W = \frac{\gamma(P_2V_2 - P_1V_1)}{\gamma-1}$$

$$\Rightarrow W = \frac{\gamma}{\gamma-1} P_1V_1 \left(\frac{P_2V_2}{P_1V_1} - 1\right)$$

$$\Rightarrow W = \frac{\gamma}{\gamma-1} P_1V_1 \left(\frac{P_2}{P_1} \times \frac{V_2}{V_1} - 1\right) \quad \text{--- (1)}$$

As the process PV^γ = Constant.

$$P_1V_1^\gamma = P_2V_2^\gamma$$

$$\Rightarrow \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma$$

$$\Rightarrow \frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}} \quad \text{--- (II)}$$

Putting the value in eqn (1)

$$W = \frac{\gamma}{\gamma-1} P_1V_1 \left(\frac{P_2}{P_1} \times \frac{V_2}{V_1} - 1\right)$$

$$\Rightarrow W = \frac{\gamma}{\gamma-1} P_1V_1 \left\{\frac{P_2}{P_1} \times \left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}} - 1\right\}$$

$$\Rightarrow W = \frac{\gamma}{\gamma-1} P_1V_1 \left\{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\}$$

$$\Rightarrow W = \frac{\gamma}{\gamma-1} MRT_1 \left\{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\}$$

$$\Rightarrow \boxed{W = \frac{\gamma}{\gamma-1} MRT_1 \left(\frac{T_2}{T_1} - 1\right)}$$

(γ = 1.4 const)

Scanned with OKEN Scanner

Power required to drive a single stage reciprocating air compressor:-

We have already to obtained in the last article the expressions for the workdone per cycle during isothermal polytropic and isentropic compression.

The power required to drive the compressor may to obtained from the following relation.

$$\text{Power} = \frac{W \times N_w}{60} \text{ watts.}$$

N = rpm

$N_w = N$ (single acting compressor)

$N_w = 2N$ (For double acting compressor).

① Isothermal Power $= \dfrac{\text{Isothermal work}(W) \times N_w}{60}$ watts.

② Isentropic Power $= \dfrac{\text{Isentropic work}(W) \times N_w}{60}$ watts

③ Indicated Power $= \dfrac{\text{Polytropic work}(W) \times N_w}{60}$ watts.

* The indicated power is also known as AIR Power of the compressor.

① $W_{isothermal} = 2.3\, P_1 V_1 \log\left(\frac{V_1}{V_2}\right) / 2.3\, P_1 V_1 \log\left(\frac{P_2}{P_1}\right) /$
$2.3\, P_1 V_1 \log r \;/\; 2.3\, mRT_1 \log r.$

② $W_{polytropic} = \frac{n}{n-1}\, mRT_1 \left\{\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right\} / \frac{n}{n-1}\, mRT_2 \left\{1 - \left(\frac{P_1}{P_2}\right)^{\frac{n-1}{2}}\right\}$

③ $W_{isentropic} = \frac{\gamma}{\gamma-1} mRT_1 \left\{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\} \Big/ \frac{\gamma}{\gamma-1} mRT_2 \left\{1-\left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}\right\}$

or

$\frac{\gamma}{\gamma-1} mRT_2\left(1-\frac{T_1}{T_2}\right)$

Example 28.1:-

A single stage reciprocating air compressor is required to compress 1 kg of air from 1 bar to 4 bar. The initial temperature is 27°c. Compare the work requirement in the following cases:

① Isothermal compression
② Compression with $Pv^{1.2}$ = constant
③ Isentropic compression.

Ans:-

Given,

$P_1 = 1$

$P_2 = 4$

$T_1 = 27°c = 27+273 = 300\,K$

$m = 1\,kg$

① Isothermal Compression:-

$2.3\, mRT_1 \log r$

$= 2.3 \times 1 \times 287 \times 300 \log\left(\frac{P_2}{P_1}\right)$

$= 2.3 \times 287 \times 300 \log\left(\frac{4}{1}\right)$

$= 2.3 \times 287 \times 300 \times \log(4)$

$= 119225.9401$

$= 119.22\ KJ$

② Polytropic :-

$$\frac{n}{n-1} mRT_1 \left\{\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right\}$$

$$= \frac{1.2}{1.2-1} \times 1 \times 287 \times 300 \left\{\left(\frac{4}{1}\right)^{\frac{1.2-1}{1.2}} - 1\right\}$$

$$= \frac{1.2}{1.2-1} \times 287 \times 300 \left\{(4)^{\frac{1.2-1}{1.2}} - 1\right\}$$

$= 134275.2144 = 134.27\ KJ$

③ Isentropic Compression :-

$$\frac{\gamma}{\gamma-1} mRT_1 \left\{\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\}$$

$$= \frac{1.4}{1.4-1} \times 1 \times 287 \times 300 \left\{\left(\frac{4}{1}\right)^{\frac{1.4-1}{1.4}} - 1\right\}$$

$$= \frac{1.4}{1.4-1} \times 287 \times 300 \left\{(4)^{\frac{1.4-1}{1.4}} - 1\right\}$$

$= 146454.379$

$= 146.47\ KJ$ (ANS)

Example 28.2:-

Determine the size of the cylinder for a double acting air compressor of 40 kW indicated Power, in which air is drawn in at 1 bar and 15°C and compressed according to the law $PV^{1.2}$ = const. to 6 bar. The Compressor runs at 100 r.p.m with average Piston speed of 152.5 m/min. Neglect clearance.

Ans:- Given,

Indicated power = 40 kW = 40×10^3 W

P_1 = 1 bar = 1×10^5

P_2 = 6 bar

T_1 = 15°C = 15 + 273 = 288 K

N = 100 r.p.m

~~Averaga~~

Average Piston speed = 152.5 m/min.

Let,

D = Diameter of cylinder

L = Length of the Stroke

We know that,

$2LN = 152.5$

$\Rightarrow 2 \times L \times 100 = 152.5$

$\Rightarrow L \times 200 = 152.5$

$\Rightarrow L = 152.5/200 = 0.7625$ m

Volume =

$$V_1 = \frac{\pi}{4} \times D^2 \times L$$

$$= \frac{\pi}{4} \times D^2 \times 0.7625$$

$$= 0.6 D^2$$

∴ Polytropic :-

$$W = \frac{n}{n-1} \times P_1 V_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

$$= \frac{1.2}{1.2-1} \times 1 \times 10^5 \times 0.6 D^2 \left\{ \left(\frac{6}{1} \right)^{\frac{1.2-1}{1.2}} - 1 \right\}$$

$$= 125310 D^2$$

For double acting compressor

$$N_w = 2N$$

$$= 2 \times 100 = 200$$

We know,

$$\text{Indicated Power} = \frac{\text{Polytropic work} \times N_w}{60}$$

$$\Rightarrow 4 \times 10^3 = \frac{125310 D^2 \times 200}{60}$$

$$\Rightarrow 40 \times 10^3 \times 60 = 125310 D^2 \times 200$$

$$\Rightarrow 2400000 = 125310 D^2 \times 200$$

$$\Rightarrow 125310 D^2 \times 200 = 2400000$$

$$\Rightarrow 125310 D^2 = \frac{2400000}{200} = 12000$$

$$\Rightarrow 125310 D^2 = 12000$$

$$\Rightarrow D^2 = \frac{12000}{125310} = 0.0957$$

$$\Rightarrow D = \sqrt{9.576 \times 10^{-3}} = 0.097 \text{ m}$$

Example :- 28.3 :-

A single acting reciprocating air compressor has cylinder diameter and stroke of 200 mm and 300 mm respectively. The compressor sucks air at 1 bar and 27°C and delivers at 8 bar while running at 100 r.p.m. Find 1. Indicated Power of compressor, 2. Mass of air delivered by the compressor per minute and 3. Temp. of the air delivered by the compressor. The compression follows the law $PV^{1.25} = C$. Take R as 287 J/kg K.

Ans Given,

$P_1 = 1 \text{ bar} = 1 \times 10^5 \text{ N/m}^2$

$P_2 = 8 \text{ bar}$

Diameter of cylinder = 200 mm = 0.2 m

Length of the stroke = 300 mm = 0.3 m

$T_1 = 27^\circ C = 27 + 273 = 300 K$

$N = 100$ r.p.m.

$R = 287$ J/kg K.

$n = 1.25$, $V_1 = \frac{\pi}{4} \times D^2 \times L$

$= \frac{\pi}{4} \times (0.2)^2 \times 0.3 = 9.424 \times 10^{-3} m^3$

Polytropic air compression :-

$$W = \frac{n}{n-1} \times P_1 V_1 \left\{ \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right\}$$

$$= \frac{1.25}{1.25-1} \times 1 \times 10^5 \times 9.424 \times 10^{-3} \left\{ \left(\frac{8}{1} \right)^{\frac{1.25-1}{1.25}} - 1 \right\}$$

$$= 2430.05 \text{ N-m}$$

$N_w = N$ (For single acting compressor)

$\Rightarrow N_w = 100$

$\therefore$ I.P. $= \frac{W \times N_w}{60} = \frac{2430.05 \times 100}{60}$

$= 4050.08$ W —(ANS)

$\therefore$ Mass of air delivered by the compressor per minute,

$P_1 V_1 = MRT_1$

$\Rightarrow MRT_1 = P_1 V_1$

$\Rightarrow M = \frac{P_1 V_1}{RT_1}$

$\Rightarrow M = \frac{1 \times 10^5 \times 9.424 \times 10^{-3}}{287 \times 300}$

$= 0.01094$ kg per stroke

$\therefore$ Mass per minute $= 0.01094 \times 100 =$

$\therefore$ Temp. of the air delivered by the compressor,

$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

$= \left(\frac{8}{1}\right)^{\frac{1.25-1}{1.25}}$

$= 1.515$

$\therefore \frac{T_2}{T_1} = 1.515$

$\Rightarrow T_2 = 1.515 \times T_1$

$= 1.515 \times 300$

$=$

Workdone by reciprocating Air-Compressor with Clearance volume:-

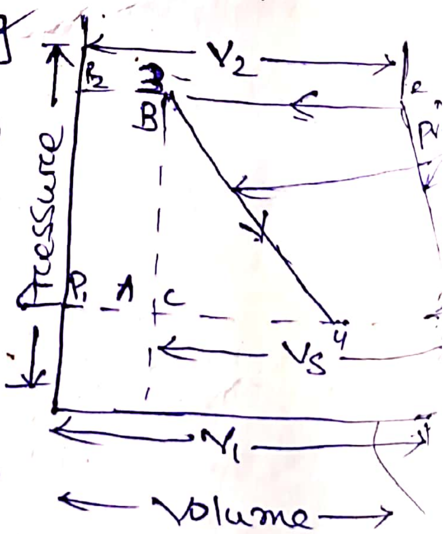
* In the previous articles, we has assumed that there is no clearance volume in the compressor cylinder. In other words, the entire volume of air, in the compressor cylinder, is compressed by the inword stroke of the piston.

* But in actual practice, it is not possible to reduce the clearance volume to zero, for mechanical reasons.

* Moreover, it is not desirable to allow the piston head to come in contact with the cylinder head.

* In addition to this, the passage leading to the inlet and outlet values always contribute to clearance volume. In generally the clearance volume is expressed as some percentage of the piston displacement.

Now consider a reciprocating air compressor with clearance volume, as show in fig.



Let P_1 = Initial pressure of air (before compression)

V_1 = Initial volume of air (before compression)

T_1 = Initial Temperature of air (before compression)

P_2, V_2, T_2 = Corresponding values for the final conditions (i.e. at the delivery points)

r = Pressure ratio (i.e. P_2/P_1)

V_c = Clearance volume (i.e. volume at point 3)

V_s = Stroke volume = $V_1 - V_c$ and

n = Polytropic index for compression and expansion

Workdone area under W = Area 1-2-3-4

= Area A-1-2-B − Area A-4-3-B

$$= \frac{n}{n-1} \times P_1 V_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right] - \frac{n}{n-1} P_1 V_4 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{n}{n-1} \times P_1 (V_1 - V_4) \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$= \frac{n}{n-1} \times mRT_1 \left[\left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

Where $(V_1 - V_4)$ and m is equal to the actual volume and mass of air sucked by the piston per cycle respectively.

Chapter-03 Properties ...

Introduction:-

Steam:-

* It is defined as the vapourization state of water or normally called water vapour.
* Steam is invisible when it is pure and dry.
* It is used as the working fluid for the operation of steam engines and steam turbin...

Types of Steam:-

Steam are of three (3) types:-

(i) Wet steam
(ii) Dry steam
(iii) Dry saturated steam

① Wet Steam:-

* When the steam contains moisture or water particles in suspension, it is said to be wet steam.

* It means that the evapouration of water isn't completely.

② Dry Steam:-
When the wet steam is further heated and It doesn't contain any suspended water particles. It is known as Dry steam.

③ Dry Saturated Steam:-

* When the dry steam is further heated at a constant pressure for raising its temperature, it is said to be dry saturated steam.

* Some time it is also called super heated steam.

* Since the Pressure is constant therefore the volume of super heated steam increases.

Difference between Vapour and Gas.

Vapour	Gas
* Vapour is a mixture of two or more different phases at room temperature. These phases are liquid as gassious phase.	* Gas usually contains a single thermodynamic state at room temperature.
* Vapour has a definite shape when observed under a microshape.	* Gas doesn't have a definite shape when observed under a microscope.
* Vapour isn't a state of matter unlike gasses	* Gases are state of matter.
* A vapour is a substance above its boiling Point temperature.	* A gas is a substance above its critical temperature.
* Ex:- Iodine is a solid under odinary condition. But when it is heated it changes in to its gasious state, in the form of iodine vapour.	* Ex:- Oxygen, nitrogen, Chlorine etc.

Formation of Steam:-

* Steam is known as the water vapour and Steam is also known as the water in gasses Phase.

* It is commonly formed by boiling or evapourating of water under desired temperature.

* Steam that is Saturated or Superheated in the form is invisiable however steam often refers to wet steam is visiable in the form of water droplet.

Some important terms in steam:-

Imp ① Dryness fraction / Quality of wet steam.

* It is the ratio of mass of actual dry steam to the mass of same quantity of wet steam and is generally denoted by 'x'.

Mathematically

$$x = \frac{\text{Actual mass of dry steam}}{\text{Mass of wet steam}}$$

$$= \frac{m_g}{m_f + m_g}$$

Where,

m_g = Mass of dry steam.

m_f = Mass of water particles present is wet steam

② Sensible heat of water:-

It is the amount of heat absorved by 1 kg of water. When heated at a constant pressure from the frizzing point to the temperature of formation of steam that is saturation temperature.

③ Latent heat of vapourization:-

* It is the amount of heat absorved to evapourate 1 kg of water.
* It is denoted by h_{fg} and its value depends upon pressure.
* The Heat of vopourization of water or lattent heat of steam is 2257 KJ/kg at atmospheric pressure.

Enthalpy and total heat of steam:-

* It is the amount of heat energy absorved by water from frizzing point to saturation temperature plus the heat absorved during evaporation.
* Enthalpy or total heat of steam = sensiable heat + Latent heat.
* It is denoted by 'h_g'. And its value for the dry saturated steam may be read directly from steam table.

ⓐ The enthalpy of wet steam is

$h = h_f + x h_{fg}$

(b) The enthalpy of dry steam is

$$h = h_g$$

(c) The enthalpy of super heated steam is

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

Here,
sup = Superheated

Specific Volume of Steam:-

* It is the volume occupied by the steam for unit mass at a given temperature and pressure and in expressed m^3/kg.
* It is the reciprocal of density of steam in kg/m^3.
* It may be noted that the specific volume decreases with increase in pressure.

Specific volume for Wet Steam:-

* Consider 1 kg of wet steam and the dryness fraction 'x'. We know that from the concept here the steam will have x kg of dry steam and $1-x$ kg of water.

* Let,
V_f be the volume of one kg of water then $V_f = xV_g + (1-x)V_f$

* Since,
V_f is very small as compare to the V_g therefore $(1-x)V_f$ will be negligible so, specific volume of wet steam is $\boxed{V_f = xV_g}$.

Specific volume for dry steam:-

* As we know there is no any present of water vapour in dry steam so that the degree of fraction is unit. Therefore

$\boxed{V = V_g}$ $\boxed{m^3/kg = \text{unit}}$

Specific volume for superheated steam:-

* We have already discussed that when the dry saturated steam is further headed under in a constant pressure there is an increase in volume with the raise in temperature.

* Now the superheated steam behaves like a perfect gas. So according to Charl's law.

$$\frac{V}{T} = \text{Constant} \quad (P = \text{Const})$$

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

$$\Rightarrow \boxed{V_{sup} = \frac{V_g}{T} \times T_{sup}}$$

Steam table and its uses:-

* The properties of dry saturated steam like its temperature of formation sensible head, latent heat, enthalpy or total heat, specific volume, entropy etc. varry with pressure and can be found by experiments only.

* These properties ~~having~~ are carefully determine made available in a tabular form known as steam table.

* It may be noted that there is a slight difference in figures quoted by various authors.

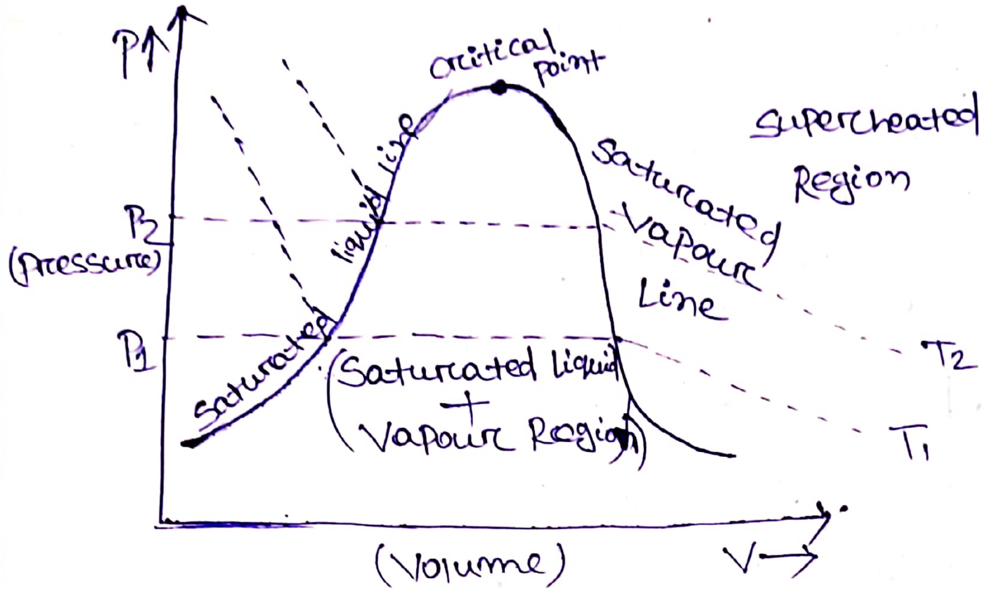
* There are two important steam tables one in terms of absolute pressure and other in terms of temperature.

Properties Diagram:-

* Properties diagram are useful in the study of variation of properties of steam during phase, change, process.

P-V Diagram:-

* The overall shape of P-V diagram is shown in below figure.



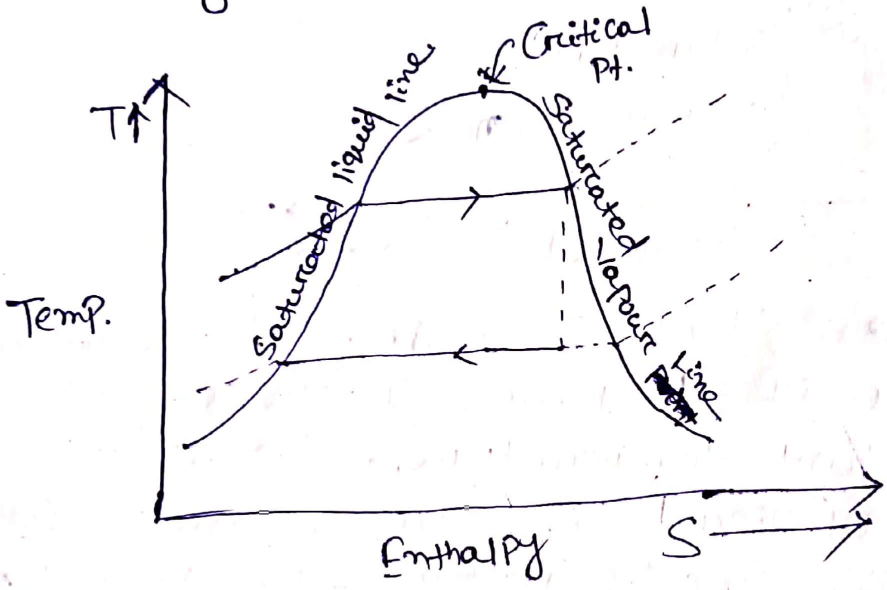
* It is evident from P.V. diagram as pressure of a pure substance decreases at constant temperature, the specific volume of liquid increases marzinally but the specific volume of vapoure increasses considerably.

* The P.V. diagram represents the equillibrium states involving the liquid and vapour phases only.

* These diagrams can also be extended to include the solid phase as well as solid-liquid, solid vapour saturation ~~reasons~~ region. All the three phases of ~~the~~ a pure substance exist along a line called the triple line.

T-S Diagram (Temperature Entropy Diagram):

* The temperature entropy diagram of a Pure substance as shown in figure are the following observation.



* The absolute temperature data is ~~floa~~ ploted along the ordinate and specific entropy is ploted along the abscissa.

* The value of specific entropy at triple point is '0' (zero). and saturated liquid line and saturated vapour line divides the diagram in to three ~~regions~~ regions that is compressed liquid ~~reg~~ region left to the saturated liquid line, superheated vapour ~~region~~ region, right to the saturated line then that two saturated lines meets at the critical point.

* ~~In the compressed liquid region~~

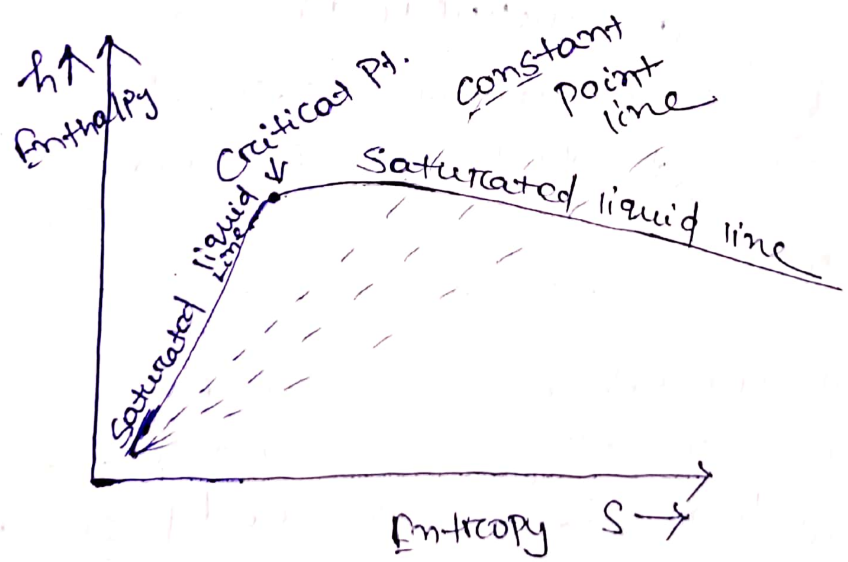
* In the saturated liquid – vapour mixture region the constant pressure line ~~and~~ ~~constant~~ are horizontal and parallel to each other.

H-S Diagram:- (Enthalpy Entropy Diagram)

* The enthalpy entropy Diagram is referred as mollier diagram. It is the most commonly used to obtaine the properties of steam.

* The enthalpy line is plotted against enthalpy.
* The lines of constant temperature are drawn in the superheated region. The H-S diagram ~~des~~ doesn't show the value of specific enthalpy.

* Specific entropy, specific volume for saturated water at pressure which are generally associated with a steam ~~cons~~ condition.



Imp Non flow or flow Process of vapour:-

Non flow process:-

* A non-flow process or system is one that containes a fixed quantity of matter in to which no mattered is allowed to flow in.

* Such a system Can be meet to undoubtably a process by varring its properties. So a the Path Can take verity of forms that Can affect the amount of workdone.

* It other words it is the one in which their is no mass intraction across the system boundaries. During the Process.

* The non-flow processes are

ⓐ Isobaric Process
ⓑ Isochoric Process
ⓒ Isentropic Process
ⓓ Poly tropic process

* Flow Process:-

* A flow process or system in which the matters Crossing the boundaries of the system either at steady or unsteady rate.

* In other wards it is the one in which fluid enters the system and leaves it

after work intractions, which means that such processes occures in the system having open boundary.

Steam Boilers

Introduction:-

A steam generator or boiler, a closed vessel made of steel. Its function is to transfer the heat produced by the combustion of fuel (solid, liquid or gaseous) to water and ultimately to generate steam. The steam produced may be supplied.

1. To an external combustion engine, i.e. steam engines and turbines.
2. At low pressure for industrial process work in cotton mills, sugar factories, breweries, etc and
3. For producing hot water, which can be used for heating installations at much lower pressures.

Classification of steam boilers:-

Though there are many classification of steam boilers, yet the following are important from the subject point of view:

1. According to the Contents in the tube:-

The steam boilers, according to the contents in the tube may be classified as:

(a) Fire tube or smoke tube boiler and

(b) Water tube boiler.

In fire tube steam boilers, the flames and hot gases, produced by the combustion of fuel, pass through the tubes (called multi-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 of fire tube boilers are: Simple vertical boiler, Cochran boiler, Lancashire boiler, Cornish boiler, Scotch marine boiler, Locomotive boiler and Velcon boiler.

In water tube steam boilers, the water is contained inside the tubes (called water tubes) which are surrounded by flames and hot gases from outside. Examples of water tube boilers are: Babcock and Wilcox boiler, Stirling boiler, La-Mont boiler, Benson boiler, Yarrow boiler and Loeffler boiler.

② According to the Position of the furnace:-

The steam boilers, according to the position of the furnace are classified as:

ⓐ Internally fired boilers and
ⓑ Externally fired boilers.

In internally fired steam boilers, the furnace is located inside the boiler shell. Most of the fire tube steam boilers are internally fired.

In externally fired steam boilers, the furnace is arranged underneath in a brick-work setting. Water tube steam boilers are always externally fired.

③ According to the axis of the sheel:-

The steam boilers, according to the axis of the shell, may be classified as:

ⓐ Vertical boilers and
ⓑ Horizontal boilers.

In vertical steam boilers, the axis of the shell is vertical. Simple vertical boiler and Cochran boiler are vertical boilers

In horizontal steam boilers, the axis of the shell is horizontal. Lancashire boiler Locomotive boiler and Babcock and wilco boiler are horizontal boilers.

④ According to the number of tubes:-

The steam boilers, according to the number of tubes, may be classified as:

ⓐ Single tube boilers and
ⓑ Multi tubular boilers.

In single tube steam boilers there is only one fire tube or waste tube. Simple vertical boiler and Cornish boiler are single tube boilers.

In Multitubular steam boilers, there are two or more fire tubes or water tubes. Lancashire boiler, Locomotive boiler, Cochran boiler, Babcock and Wilcox boiler are multitubular boilers.

⑤ <u>According to the method circulation of water and Steam.</u>

The steam boilers, according to the method of circulation of water and steam, may be classified as:

(a) Natural circulation boilers and
(b) Forced circulation boilers.

In natural circulation steam boilers, the circulation of water is by natural convention currents, which are set up during the heating of water. In most of the steam boilers, there is a natural circulation of water.

In forced circulation steam boilers, there is a forced circulation of water by a centrifugal pump driven by some external power. Use of forced circulation is made in high pressure boilers such as La-Mont boiler, Benson boiler, Loeffler boiler and velocon boiler.

STEAM BOILERS

Introduction

A steam generator or boiler, usually, a closed vessel made of steel. Its function is to transfer the heat produced by the combustion of fuel (solid, liquid or gaseous) to water, and ultimately to generate steam. The steam produced may be supplied :

1. To an external combustion engine, i.e. steam engines and turbines.

2. At low pressures for industrial process work in cotton mills, sugar factories, breweries, etc, and

3. For producing hot water, which can be used for heating installations at much lower pressures.

3.1. Classification of steam boilers.

Though there are many classification of steam boilers, yet the following are important from the subject point of view :

1. ***According to the contents in the tube.*** The steam boilers, according to the contents in the tube may be classified as :

(a) Fire tube or smoke tube boiler and

(b) Water tube boiler.

In fire tube steam boilers, the flames and hot gases, produced by the combustion of fuel, pass through the tubes (called multi-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 of fire tube boilers are : Simple vertical boiler, Cochran boiler, Lancashire boiler, Cornish boiler, Scotch marine boiler, Locomotive boiler and Velcon boiler.

In water tube steam boilers, the water is contained inside the tubes (called water tubes) which are surrounded by flames and hot gases from outside. Examples of water tube boilers are : Babcock and Wilcox boiler, Stirling boiler, La-Mont boiler, Benson boiler, Yarrow boiler and Loeffler boiler.

2. ***According to the position of the furnace.*** The steam boilers, according to the position of the furnace are classified as :

(a) Internally fired boilers, and

(b) Externally fired boilers

In internally fired steam boilers, the furnace is located inside the boiler shell. Most of the fire tube steam boilers are internally fired.

In externally fired steam boilers, the furnace is arranged underneath in a brick-work setting. Water tube steam boilers are always externally fired.

3. ***According to the axis of the shell.*** The steam boilers, according to the axis of the shell, may be classified as :

(a) Vertical boilers and

(b) Horizontal boilers.

In vertical steam boilers, the axis of the shell is vertical. Simple vertical boiler and Cochran boiler are vertical boilers.

In horizontal steam boilers, the axis of the shell is horizontal. Lancashire boiler, Locomotive boiler and Babcock and Wilcox boiler are horizontal boilers.

4. ***According to the number of tubes.*** The steam boilers, according to the number of tubes, may be classified as :

(a) Single tube boilers and

(b) Multi tubular boilers

In single tube steam boilers there is only one fire tube or water tube. Simple vertical boiler and Cornish boiler are single tube boilers.

In Multitubular steam boilers, there are two or more fire tubes or water tubes. Lancashire boiler, Locomotive boiler, Cochran boiler, Babcock and Wilcox boiler are multitubular boilers.

5. ***According to the method circulation of water and steam.*** The steam boilers, according to the method of circulation of water and steam, may be classified as :

(a) Natural circulation boilers, and

(b) Forced circulation boilers.

In natural circulation steam boilers, the circulation of water is by natural convention currents, which are set up during the heating of water. In most of the steam boilers, there is a natural circulation of water.

In forced circulation steam boilers, there is a forced circulation of water by a centrifugal pump driven by some external power. Use of forced circulation is made in high pressure boilers such as La-Mont boiler, Benson boiler, Loeffler boiler and Velcon boiler.

6. ***According to the use.*** The steam boilers, according the their use, may be classified as

(a) Stationary boilers, and

(b) Mobile boilers

The stationary steam boilers are used in power plants, and in industrial process work. These are called stationary because they do not move from one place to another.

The mobile steam boilers are those which move from one place to another. These boilers are locomotive and marine boilers.

7. ***According to the source of the heat.*** The steam boilers may also be classified according to the source of heat supplied for producing steam. The sources maybe the combustion of solid, liquid or gaseous fuel, hot waste gases as by-products of other chemical processes. electrical energy or nuclear energy etc.

3.2. Cochran Boiler or Vertical Multitubular Boiler

These are various designs of vertical multitubular boilers, A Cochran boiler is considered to be one of the most efficient type of such boilers. It is an improved type of simple vertical boiler.

This boiler consists of an external cylindrical shell and a fire box as shown in Fig.3.1 The shell and fire box are both hemispherical. The hemispherical crown of the boiler shell gives pressure of steam and strength to withstand the pressure of steam inside the boiler. The hemispherical crown of the fire box is also advantageous for resisting intense heat. The fire box and the 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. Then tubes generally have 62.5 mm external diameter and are 165 in number. The gases from the smoke box pass to the atmosphere through a chimney. The combustion chamber is lined with fire bricks on the shell side. A manhole near the top of the crown on the shell is provided for cleaning.

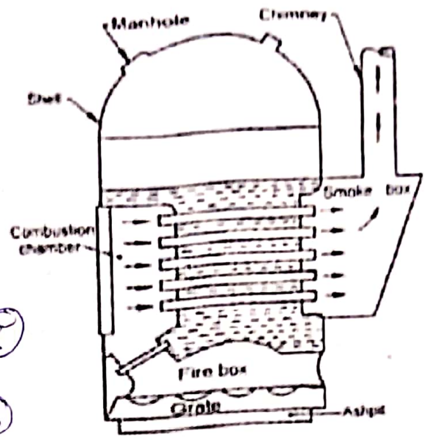


Fig. 3.1 Cochran Boiler

At the bottom of the fire box, there is a grate (in case of coal firing) and the coal is fed through the fire hole. If the boiler is used for oil firing, no grate is provided, but the bottom of the fire box is lined with firebricks. The oil burner is fitted at the fire hole.

3.2.1. Babcock and Wilcox Boiler

It is a straight tube, stationary type water tube boiler, as show in Fig.3.2 It consist of a stem and water drum (1). It is connected by a short tube with uptake header or riser (2) at the back end.

The water tubes (5) (100mm diameter) are inclined to the horizontal and connects the uptake head to the down take header. Each row of the tubes is connected with two headers, and there are plenty of such rows. The headers are curved when viewed in the direction of tubes so that one tube is not in the space of other, and hot gases can pass properly after heating all the tubes. The headers are provided with hand holes in the front of the tubes and are covered with caps (18).

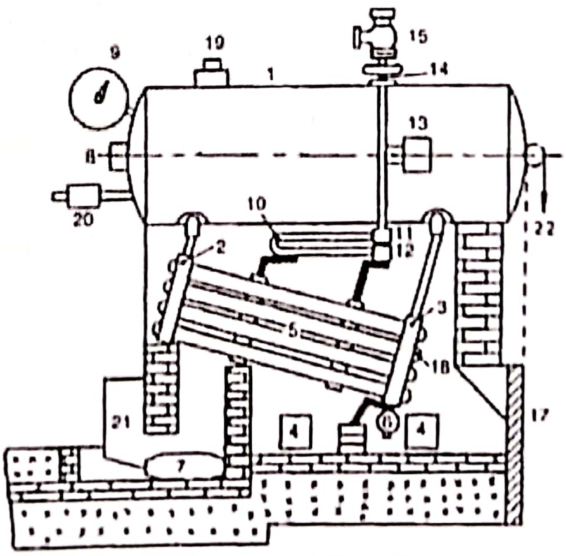


Fig. 3.2 Babcock and Wilcox Boiler

A mud box (6) is provided with each down take header and the mud, that settles down is removed. There is slow moving automatic chain grate on which the coal is fed from the hopper (21). A fire bricks baffle causes hot gases to move upwards and downwards and again upwards before entering shell by a chain (22) which passes over a pulley to the boiler is suspended on steel girders, and surrender on all the four sides by fire brick walls. The doors (4) are provided for a man to enter the boiler for repairing and cleaning. Water circulates from the drum (1) into the header (2) and through the tubes (5) to header (3) and again to the drum. Water continues to circulate like this till it is evaporated. A steam superheater consists of a large number of steel tubes (1) and contains two boxes; one is superheated steam box (11) and other is saturated steam box (12).

The steam generated above the water level in the drum flows in the dry pipe (13) and through the inlet tubes into the superheated steam box (11). It then passes through the tubes (10) into the becomes superheated. The steam, during the passage through tubes (10), gets further heated and through the outlet pipe (14) to the stop valve (15).

The boiler is fitted with usual mountings, such as safely vale (19), feed valve (20), water level indicator (8) and pressure gauge (9).

3.2.2. Comparison between Water and Fire Tube boilers

Following are the few points of comparison between a water tube and a fire tube boiler.

	Water tube boiler	Fire tube boiler
1.	The water circulates inside the tubes which are surrounded by hot gases from the furnace.	The hot gases from the furnance the furnace pass through the tubes which are surrounded by water.
2.	It generates steam at a higher pressure upto 165 bar.	It can generation of steam only up to 24.5 bar.
3.	The rate of generation of steam is high i.e. upto 450 tonnes per hour.	The rate of generation of steam is low, i.e. upto 9 tonnes per hour.
4.	For a given power, the floor area required for the generation of steam is less, i.e. about 5 m^2 per tone per hour of steam generation.	The floor area required is more, i.e. about 8m^2 per tonne per hour of steam generation.
5.	Overall efficiency with economizer is upto 90%.	Its overall efficiency is only 75%.
6.	It can be transported and erected easily as its various parts can be separted.	The transportation and erection is difficult.
7.	It is preferred for widely fluctuating loads.	It can also cope reasonably with sudden increase in load but for a shorter period.
8.	The direction of water circulation is well defined.	The water does not circulate is a definite direction.
9.	The operating cost is high.	The operating cost is less.
10.	The bursting chance are more.	The bursting chances are less.
11.	The bursting does not produce any destruction to the whole boiler.	The bursting produces greater risk to the damage of the property.
12.	It is used for large power plants.	It is not suitable for large plants.

3.3 Boiler Mountings and Accessories

Introduction

Boiler mountings and accessories are reuiqred for the proper and satisfactory functioning of the steam boilers. Now in this chapter, we shall discuss these fittings and appliances which are commonly used these days.

3.3.1. Boiler Mountings

These are the fittings, which are mounted on the boiler for its proper and safe functioning. Though there are many types of boiler mountings, yet the following are important from the subject point of view :

1. Water level indicator
2. Pressure gauge
3. Safety valves
4. Stop valve
5. Blow off cock
6. Feed check valve and
7. Fusible plug

1. Water level Indicator

It is important fitting, which indicates the water level inside the boiler to an observer. It is a safety device upon which the correct working of the boiler depends. This fitting may be seen in front of the boiler, and are generally two in number.

A water level indicator, mostly employed in the steam boiler is shown in Fig.3.3. It consists of the cocks and a glass tube. Steam cock C_1 Keeps the glass tube in connection with the steam space. Water cook C_2 Puts the glass tube in connection with the water in the boiler. Drain cock C_3 is used at frequent intervals to ascertain that the steam and water cocks are clear.

In the working of a steam boiler and for the proper functioning of the water level indicator, the steam and water cocks are opened and the drain cock is closed. In this case, the handles are place in a vertical position as shown in Fig. The rectangular passage at the ends of the glass tube contains two balls.

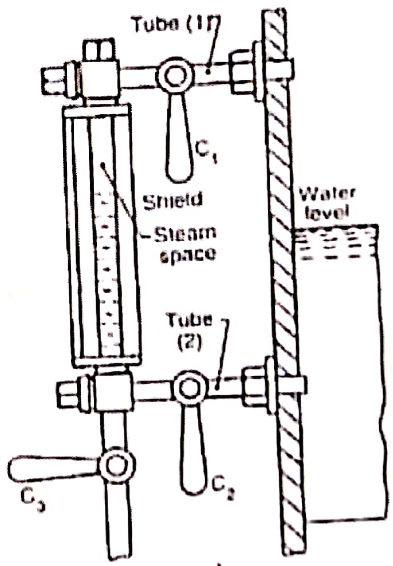


Fig. 3.3 Water level Indicator

In case the glass tube is broken, the two balls are carried along its passages to the ends of the glass tube. It is thus obvious, that water and steam will not escape out. The glass tube can be easily replaced by closing the steam and water cocks and opening the drain cock.

When the steam boiler is not working, the bolts may be removed for cleaning. The glass tube is kept free from leaking by means of conical ring and the gland nut.

2. Pressure gauge

A pressure gauge is used to measure the pressure of the steam inside the steam boiler. It is fixed in front of the steam boiler. The pressure gauges generally used are of bourden type.

A bourden pressure gauge, in its simplest form, consists of an elliptical elastic tube ABC bent into an arc of a circle, as shown in Fig. This bent up tube is called bourden's tube.

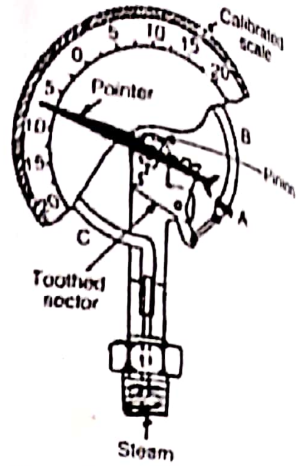


Fig. 3.4 Water level indicator

One end of the tube gauge is fixed and connected to the steam space in the boiler. The other end is connected to a sector through a link. The steam, under pressure, flows into the tube. As a result of this increase pressure, the bourden's tube tends to straighten itself. Since the tube is encased in a circular curve, therefore it tends to become circular instead of straight. With the help of a simple pinion and sector arrangement, the elastic deformation of the bourdens tube rotates the pointer. This pointer moves over a calibrated scale, which directly gives the gauge pressure.

3. Safety valves

These are the devices to the steam chest for preventing explosions due to excessive internal pressure of steam. A steam boiler is, usually, provided with two safety valves. These are directly placed on the boiler. In brief, the function of a safety valve is to blow off the steam when the pressure of steam inside the boiler exceeds the working pressure. The following are the four types of safety valves :

(i) Lever safety valve,

(ii) Dead weight safety valve

(iii) High steam and low water safety valve

(iv) Spring loaded safety valve.

It may be noted that the first three types of the safety valves are usually employed with stationary boilers, but the fourth type is mainly used for locomotive and marine boilers.

(I) Lever safety valve

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

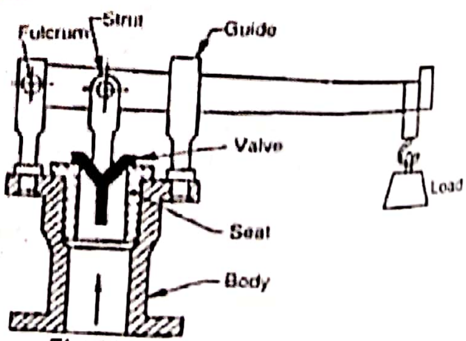


Fig. 3.5 Lever safety valve

A lever safety valve consists of a valve body with a flange fixed to the steam boiler. The bronze valve seat is screwed to the body, and the valve is also made of bronze. It may be noted that by using the valve and seat of the same material, rusting is considerably reduced. The thrust on the valve is transmitted by the strut. The guide keeps the lever in a vertical plane. The load is properly adjusted at the other end of the lever.

(II) **Dead weight safety valve**

A dead weight safely valve, used for stationary boilers, is shown In Fig. 3.6 The valve is made of gun metal, and rests on its gun metal seat. It is fixed to the top of a steel pipe. This pipe is bolted to the mountings block, riveted to the top of the shell. Both the valve and the pipe are covered by a case which contains weights. These weights keep the valve on its seat under normal working pressure. The case hangs freely over the valve to which it is secured by means of a nut.

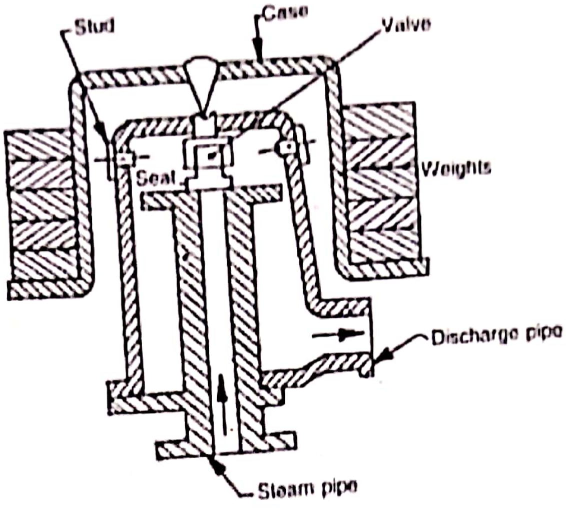


Fig. 3.6 Dead weight safety valve

When the pressure of steam exceeds the normal pressure, the valve as well as the case (along with the weights) are lifted up from its seat. This enables the steam to escape through the discharge pipe, which carries the steam outside the boiler house.

The lift of the valve is controlled by the studs. The head of the studs projects into the interior of the casing. The centre of gravity of the dead weight safety valve is considerably below the valve which ensures that the load hangs vertically.

The dead weight safety valve has the advantage that it cannot be readily tempered because any added weight be equal to the total increases pressure of steam on the valve. The only disadvantage of these valves, is the heavy which these valves carry.

(III) **High steam and low water safety valve**

These valves are placed at the top of Cornish and Lancashire boilers. It is combination of two valves, one of which is the lever safety valve which blows off steam when the working pressure of steam exceeds. The second valve operates blowing off the steam when the water level becomes too low.

A best known combination of high steam low water safety valve is shown in Fig.3.7 It consists of a main valve (known as lever safety valve) and rests on its seat. In the centre of the main valve, a seat for a hemispherical valve is formed for low water operation. This valve is loaded directly by the dead weights attached to the valve by a long rod. There is a lever J.K, which has its fulcrum at K. the lever has weight E suspended at the K. when it is fully immersed in water, it is balanced by a weight F at the other end J of the lever.

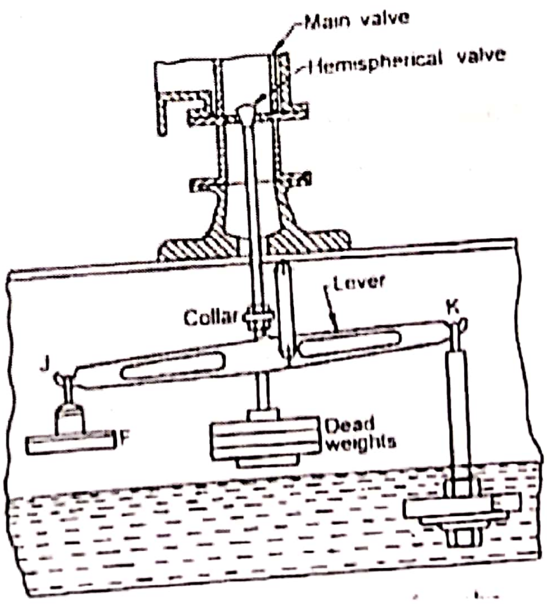


Fig. 3.7 High steam and low water safety valve

When the water level falls, the weight E comes out of water and the weight F will not be sufficient to balance weight E. Therefore weight E comes down. There are two projections on the lever to the left of the fulcrum which comes in contact with a collar attached to the rod. When weight E comes down, the hemispherical valve is lifted up and the steam escapes with a loud noise, which warns the operator. A drain pipe is provided to carry water, which is deposited in the valve casing.

(iv) Spring loaded safety valve.

A spring loaded safety valve is mainly used for locomotives and marine boilers. It is loaded with spring instead of weights. The spring is made of round or square spring steel rod in helical form. The spring may be in tension or compression, as the steam pressure acts along the axis of the spring. In actual practice, the spring is placed in compression.

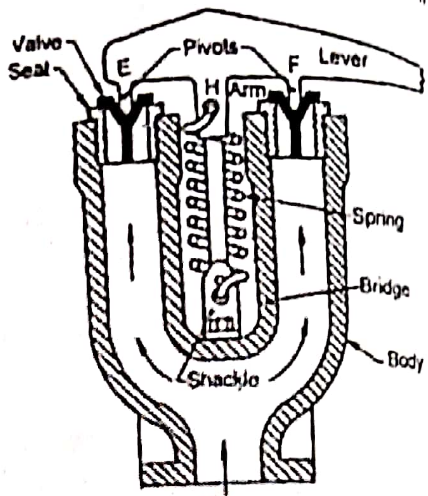


Fig. 3.8 Spring loaded safety valve

A Ramsbottom spring loaded safety valve is shown in Fig. 3.8 It I, usually, fitted to locomotives. It consists of a cast iron body connected to the top of a boiler. It has two separate valves of the same size. These valves have their seating's in the upper ends of two hallow valve chests. These valve chests are united by a bridge and a base. The base is bolted to a mounting block on the top of a boiler over the fire box.

The valves are held down by means of a spring and a lever. The lever has two pivots E and F. the pivot E is joined by a pin to the lever, while the pivot F is forged on the lever. These pivots rest on the centre's of the valves. The upper end of the spring is hooked to the arm H, while the lower end of the shackle, which is secured to the bridge by a nut. The spring has two safety links, one behind the other, or one either side of the lever connected by pins at the ends. The lower pin passes through the shackle while the upper one passes through slot in arm H of the lever. 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.

4. Steam Stop valve

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

1. To control the flow of steam from the boiler to the main stream pipe.

2. To shut off the steam completely when required.

The body of the stop valve is made of cast iron or cast steel. The valve, valve seat and the nut through which the valve spindle works, are made of brass or gun metal.

The spindle passes through a gland and stuffing box. The spindle is rotated by means of a hand wheel. The upper

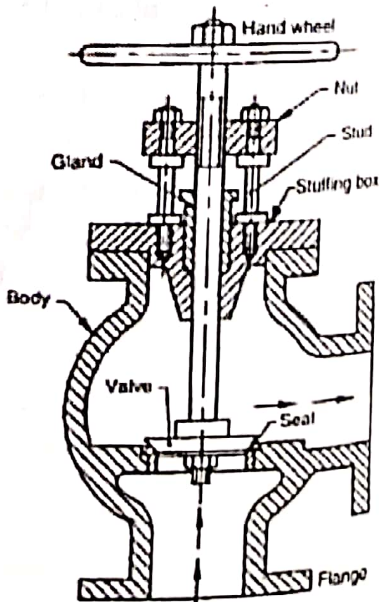


Fig. 3.9 Steam Stop valve

portion of the spindle is screwed and made to pass through a nut in across head carried by two pillars. The pillars are screwed in the cover of the body as shown in the figure. The boiler pressure acts under the valve, so that the valve must be closed against the pressure. The valve is, gen¬erally, fastened to the spindle which lifts it up.

A non-return valve is, sometimes, fitted near the stop valve to prevent the acciden¬tal admission of steam from other boilers. This happens when a number of boilers are con¬nected to the same pipe, and when one is empty and under repair.

5. Blow off cock

The principal functions of a blow-off cock are :

3. To empty the boiler whenever requiled.

4. To discharge the mud, scale or sediments which are accumulated at the bottom of the boiler.

The blow-off cock, as shown in Fig. 3.10, is fitted to the bottom of a boiler drum and consists of a conical plug fitted to the body or casing. The casing is packed, with asbestos packing, in grooves round the top and bottom of the plug. The asbestos packing is made tight and plug bears on the packing. It may be noted that the cocks packed in this way keep the grip better under high pressure and easily operated than unpacked.

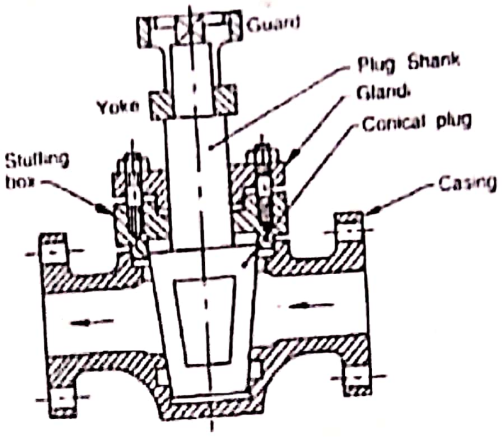


Fig. 3.10 Blow off cock

The shank of plug passes through a gland and stuffing box in the cover. The plug is held down by a yoke and two stud bolts (not shown in the figure). The yoke forms a guard on it. There are two vertical slots on the inside of a guard for the box spanner to be used for operating the cock.

6. 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. This valve must have its spindle lifted before the pump is started. It is fitted to the shell slightly below the normal water level of the boiler.

A feed check valve for marine boilers is shown in Fig. 3.11. It consists of a valve whose lift is controlled by a spindle and hand wheel. The body of the valve is made of brass casting and except spindle, its every part is made of brass. The spindle is made of muntz metal. 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.

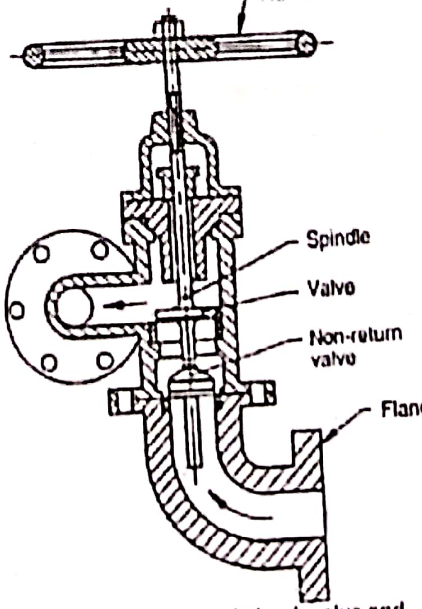


Fig. 3.11 Feed check valve and

7. **Fusible plug**

It is fitted to the crown plate of the furnace or the fire box. Its object 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, and thus avoids the explosion which may take place due to overheating of the furnace plate.

A fusible plug consists of a hollow gun metal plug P, as shown in Fig. 3.12. It is screwed to the furnace crown. A second hollow gun metal plug P2 is screwed to the first plug. There is also a third hollow gun metal plug P3 separated from P, by a ring of fusible metal. The inner surface of P2 and outer surface of P3 are grooved so that when the fusible metal is poured into the plug, P2 and P3 are locked together. A hexagonal flange is provided on plug P, to take a spanner for fixing or removing the plug Pr There is a hexagonal flange on plug P2 for fixing or removing it. The fusible metal is protected from fire by the flange on the lower end of plug P2. There is also a contact at the top between P2 and P3 so that the fusible metal is completely enclosed.

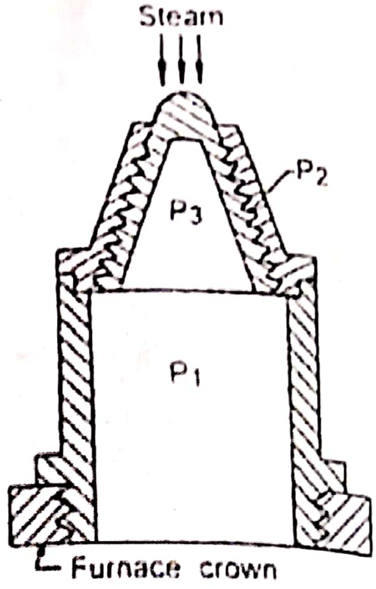


Fig. 3.12 Fusible plug

The fusible plugs must be kept in a good condition and replaced annually. A fusible plug must not be refilled with anything except fusible metal.

3.3.2 Boiler Accessories

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

1. Feed pump
2. Superheater
3. Economiser and
4. Air Preheater

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

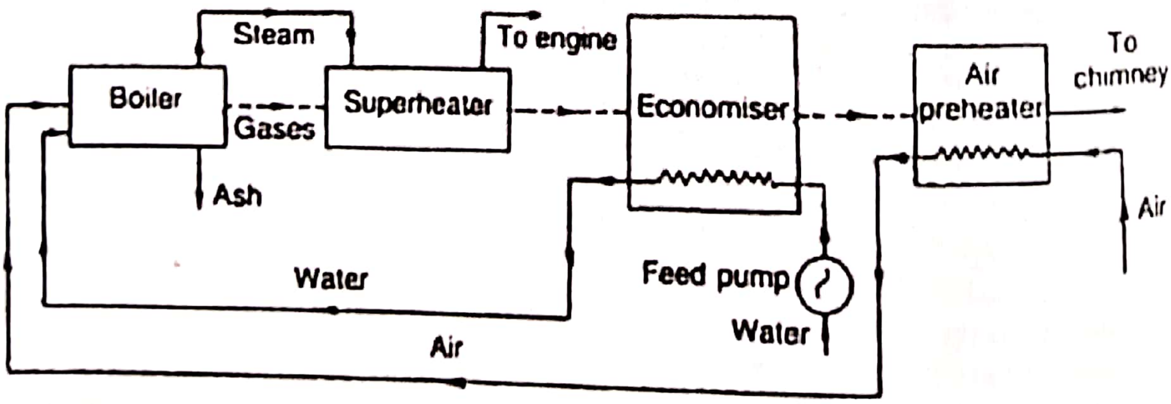


Fig. 3.13 schematic diagram of a boiler plant

1. Feed Pump

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

The pressure of steam inside a boiler is high. So the pressure of feed water has to be increased proportionately before it is made to enter the boiler. Generally, the pressure of feed water is 20% more than that in the boiler.

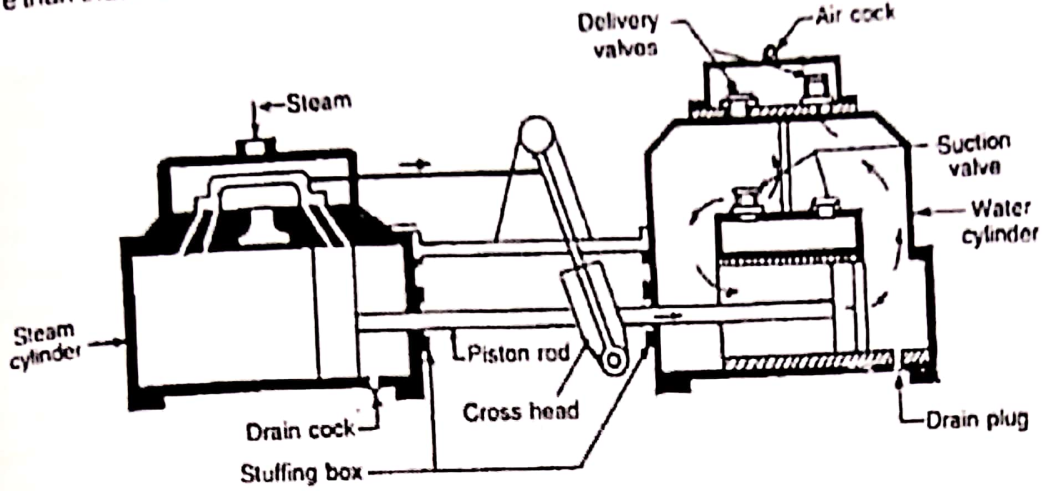


Fig. 3.14 Duplex feed Pump

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

2. Superheater

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

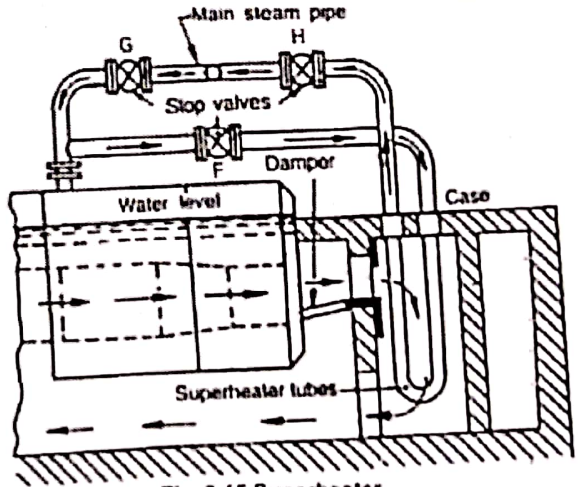


Fig. 3.15 Superheater

A Sudgen's superheater commonly employed with Lancashire boilers is shown in Fig. 3.15. It consists of two mild steel boxes or heaters from which hangs a group of solid drawn tubes bent to U-form. The ends of these tubes are expanded into the headers. The tubes are arranged in groups of four and one pair of headers generally carries ten of these groups or forty tubes in all. The outside of the tubes can be cleaned through the space between the headers. This space is closed by covers.

The steam enters at one end of the rear header and leaves at the opposite end of the front header. The overheating of superheater tubes is prevented by the use of a balanced damper which is operated by the handle. The superheater is in action when the damper is in a position as shown in the figure. If the damper is in vertical position, the gases pass directly into the bottom flue without passing over the superheater tubes. In this way, the superheater is out of action. By placing the damper in intermediate position, some of the gases will pass over the superheater tubes and the remainder will pass directly to the bottom flue. It is thus obvious, that required degree of heat for superheating may be obtained by altering the position of the damper.

It may be noted that when the superheater is in action, the stop valves G and H are opened and F is closed. When the steam is taken directly from the boiler, the valves G and H are closed and F is open.

3. Economiser

An economiser is a device used to heat feed water by utilising the heat in the exhaust flue gases before leaving through the chimney. As the name indicates, the economiser improves the economy of the steam boiler.

A well known type of economiser is Greens economiser. It is extensively used for stationary boilers, especially those of Lancashire type. It consists of a large number of vertical pipes or tubes placed in an enlargement of the flue gases between the boiler and chimney as shown in Fig. 3.16. These tubes are 2.75 meters long, 114 mm in external diameter and 11.5 mm thick and are made of cast iron.

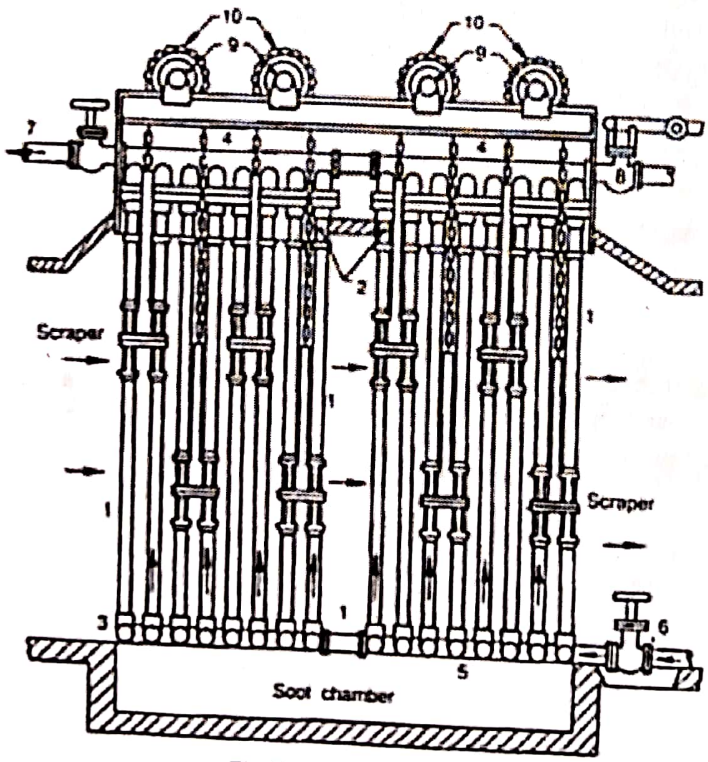


Fig. 3.16 Economiser

The economiser is built-up of transverse section. Each section consists of generally six or eight vertical tubes (1). These tubes are joined to horizontal pipes or boxes (2) and (3) at the top and bottom respectively. The top boxes (2) of the different sections are connected to the pipe (4).

while the bottom boxes are connected to pipe (5). The pipes (4) and (5) are on opposite sides, which are outside the brickwork enclosing the economiser.

The feed water is pumped into the economiser at (6) and enters the pipe (5). It then passes into the bottom boxes (3) and then into the top boxes (2) through the tubes (1). It is now led by the pipe (4) to the pipe (7) and then to the boiler. There is a blow-off cock at the end of the pipe (5) opposite to the feed inlet (6). The purpose of this valve is to remove mud or sediment deposited in the bottom boxes. At the end of pipe (4) (opposite to the feed outlet) there is a safety valve.

It is essential that the vertical tubes may be kept free from deposits of soot, which greatly affect efficiencies of the economiser. Each tube is provided with scraper for this purpose. The scrapers of two adjoining sections of tubes are grouped together, and coupled by rods and chains to the adjacent group of scrapers. The chain passes over a pulley (9) so that one group of scrapers balance the adjacent group. The pulley (9) of each chain is connected to a worm wheel (10) which is driven by a worm on a longitudinal shaft (not shown in the figure). The scrapers automatically reverse when they reach the top or bottom end of the tubes. These are kept in motion continuously when the economiser is in use. The speed of scraper is about 46 m/h.

It may be noted that the temperature of feed should not be less than about 35° C, otherwise there is a danger of corrosion due to the moisture in the flue gases being deposited in cold tubes. Following are the advantages of using an economiser

4. There is about 15 to 20% of coal saving.

5. It increases the steam raising capacity of a boiler because it shortens the time required to convert water into steam.

6. It prevents formation of scale in boiler water tubes, because the scale formed in the economiser tubes, can be cleaned easily.

7. Since the feed water entering the boiler is hot, therefore strains due to unequal expansion are minimised.

4. Air Preheater

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

The following advantages are obtained by using an air preheater:

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

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

3. It results in better combustion with less soot, smoke and ash.

It enables a low grade fuel to be burnt with less excess air.