N.S.PUR, CUTTACK

GURUKRUPA TECHNICAL SCHOOL

Narasinghpur, Cuttack

Lecture Notes

On

THERMAL ENGINEERING-2

4Th Semester

DEPARTMENT OF

MECHANICAL ENGINEERING

Prepared by:

Lect. Aruna ku. Samal

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Aire Compressor

Air compressor :-

Aire compressore is a machine which is used to increase the presscere of aire by reducing.

Function of compressor

It is a machine to compress the air and to raise pressure. It sucks air from the atmosphere, compresses it and then delivers the same under a high pressure to a storage vessel from the storage vessel. It may be conveyed by the pipe line to a place. the supply of compressed air is required.

Industrial use of compressed aire

It is used for :-

-> Operating neumatic drills, road drills.
-> It is used for starting and super charging of internal of combustion engine.
-> Operation of lifts, dams, pumps etc.
-> Used for running mining machine
-> Spraying of fuel into diesel engines, push spray, paints, glass blowing etc.
-> For construction industries compressed air is used for doing structural work better and faster air operated drills. wrenches and ribeting hammer are used in aircraft industries.

Classification of Air compressor

(1) According to working
(a) Reciprocating compressor
(b) Rotary compressor.

(2) According to Action
(a) Single acting compressor
(b) Double acting compressor

(3) According to number of stages-
(a) single stage
(b) Multi stage

(4) According to number of cylinder
(a) Single cylinder
(b) Multi cylinder

(5) According to pressure
(a) low pressure (blowiers) or centrifugal displacement
(b) Midium pressure (Single stage)
(c) High pressure (Multi stage)

Parts of reciprocating air compressor

A single stage reciprocating air compressor consists of a piston which reciprocates in a cylinder, driven through a connecting rod and crank mounted in a crank case there are inlet and delivery valves mounted in the head of the cylinder. These valves are usually of the pressure differential teme

→ They will operated as the result of the difference of pressure across the valve.

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Working

The piston moves downward in the cylinder during suction stroke. The pressure inside the cylinder falls below atmospheric due to this pressure difference the inlet valve gets open and air is sucked into the cylinder at inlet pressure. During the stroke the delivery valve will remain closed. After completion of suction stroke piston moves upward in delivery stroke the pressure inside the cylinder goes on increasing up to discharge pressure at this stage discharge valve gets open and air is delivered to the receiver.

At the end of delivery stroke, a small quantity of air at high pressure is left in the clearance space as the piston moves downward the air left in the clearance space expands tills it pressure falls below atmospheric at this stage the inlet valve gets open and fresh air is soaked into the cylinder again

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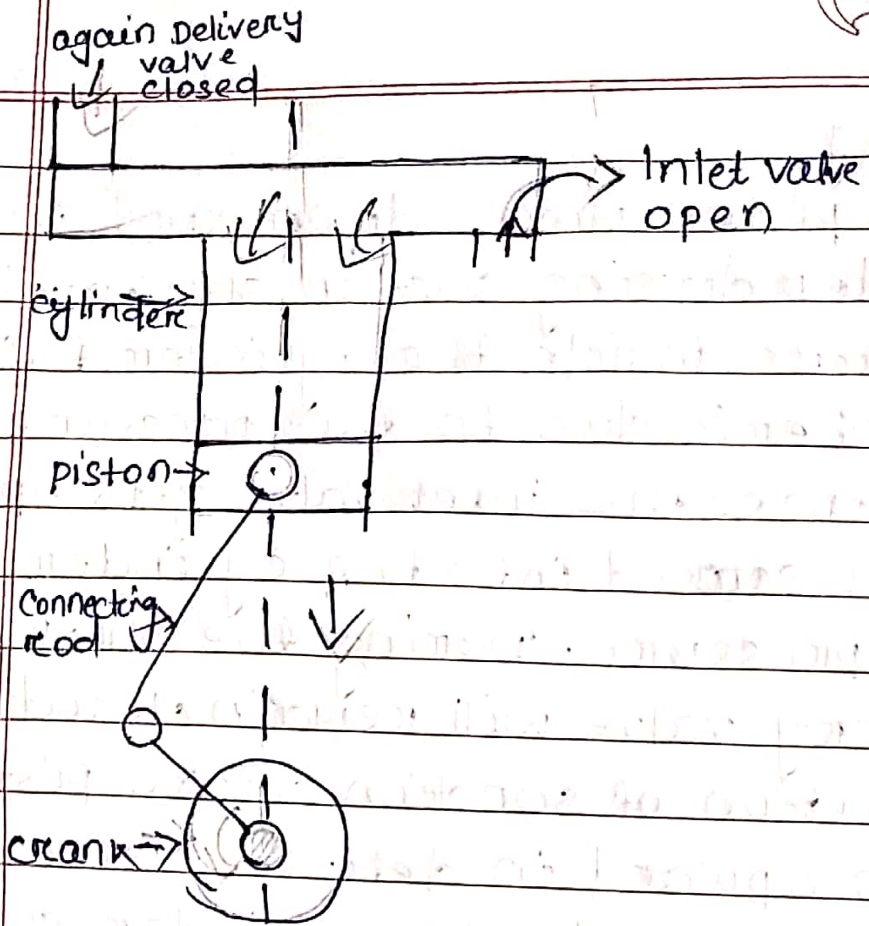
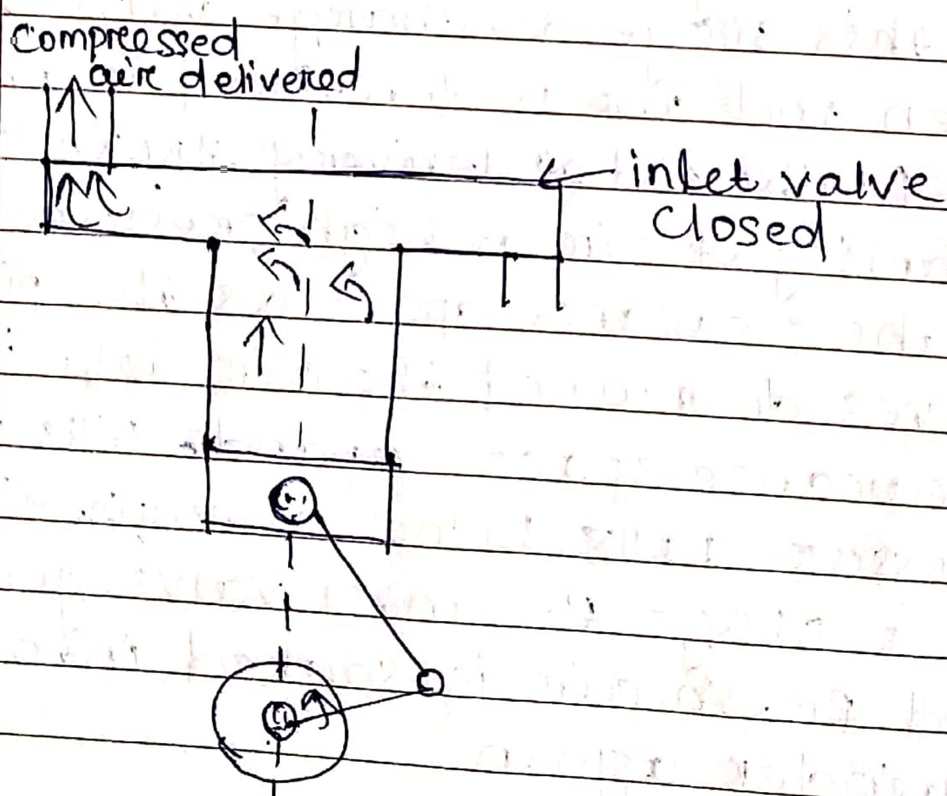


Suction stroke



(Delivery stroke)

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Terminology of reciprocating compressor

compression ratio (pressure ratio)

This is the ratio of the absolute discharge pressure to the absolute inlet pressure.

Free air delivered (FAD)

It is the volume of air delivered under the condition of temp and pressure existing at the compressor intake. That is volume of air delivered are surrounding air temp and pressure.

→ In the absence of a any given air conditions these are generally taken as 1.01325 bar absolute 15°c

capacity :-

It is the volume of air delivered by compressor expressed in m3/minute.

Theoritical power

This is the power required to compress adiabatically the air delivered by a compressor through the specified pressure range without any energy loss.

Brake power -

It is the actual power input required by a compressor.

compressor efficiency

This is the ratio of the theoritical power to the brake power.

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volumetric efficiency —

This is the ratio of the capacity of compressor to the ~~position~~ piston displacement of the compressor.

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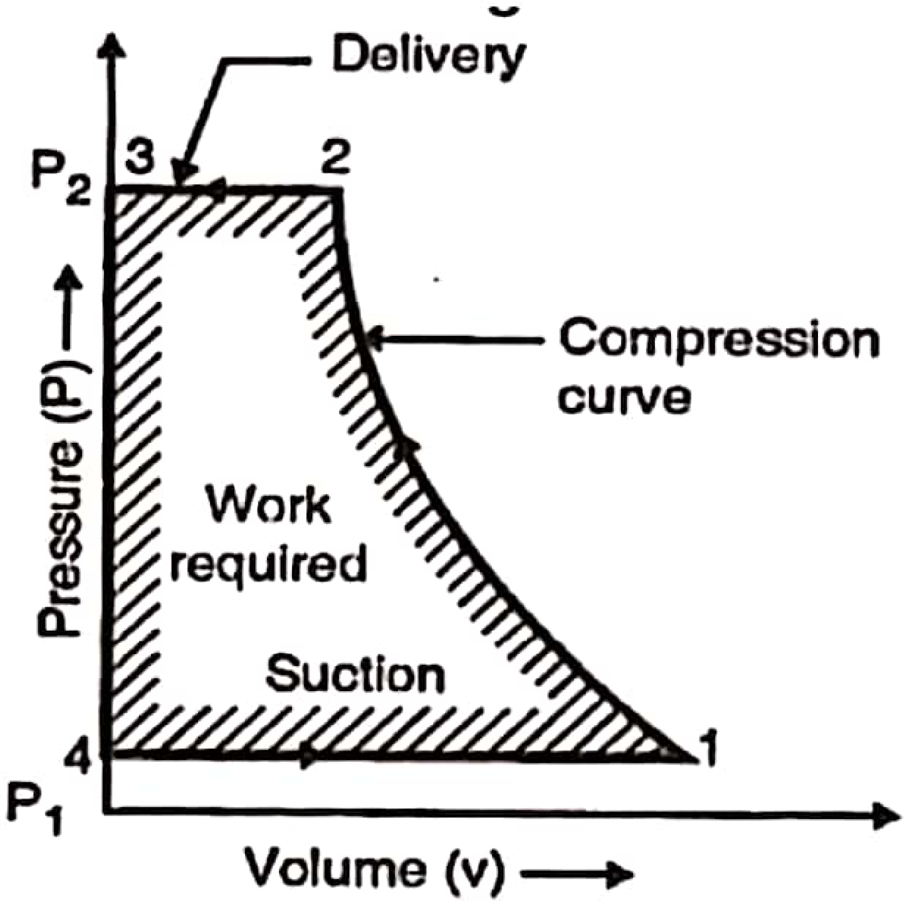
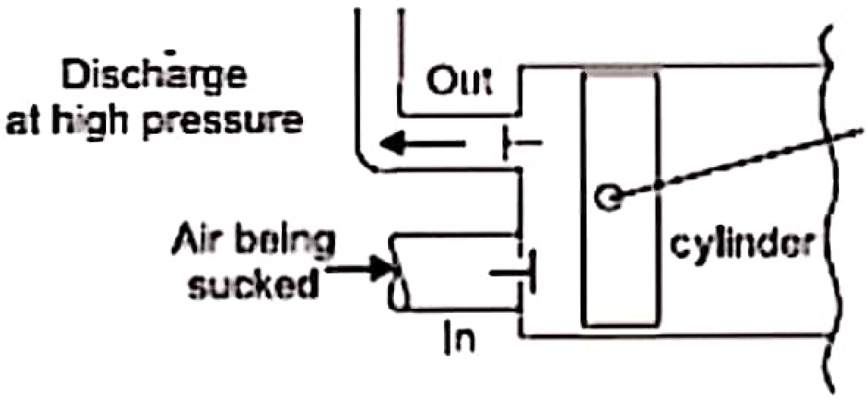
Single stage reciprocating compressor with PV diagram





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The above figure shows the P-V diagram for single stage reciprocating air compressor without clearance.

During the suction stroke the air is drawn into the cylinder along line 4-1 at constant pressure P1 which is slightly below the atmosphere.

At point 1, the piston completes the suction stroke and starts its compression stroke. At this time, all the valves are closed; the air inside the cylinder is compressed along the curve 1-2.

At point 2, the pressure P2 is reached which is slightly higher than the receiver pressure. At this point discharge valve opens delivery of compressed air takes place along line 2-3 at constant pressure P2.

The piston has now reached at top of cylinder and again starts its suction stroke & the pressure in the cylinder will be lowered again P1 & the cycle of operations will be repeated. The net work done required is represented by area 1-2-3-4.

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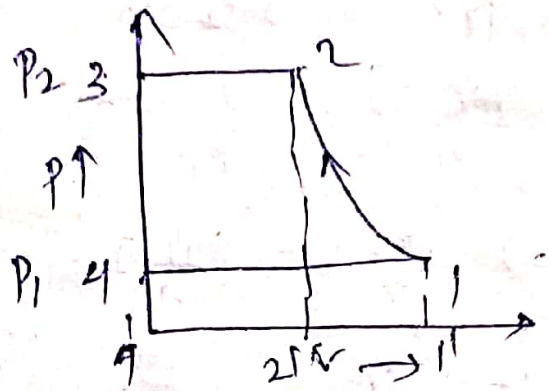
AIR COMPRESSOR

workdone for a single acting single stage reciprocating compressor negative clearance.



let P_1 = pressure of air at the begining of compressor

P_2 = pressure of air at the end of compressor

T_1 = Absolute temperature of air at the begining compressor.

T_2 = Absolute temperature of air at the end of compressor.

V_1 = Volume of air at the begining of compressor

V_2 = Volume of air at the end of compressor.

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workdone upon air within the cycle the during cycle is given by.

$$W = \text{area } 2-3-4'-2'-2 + \text{area } 1-2-2'-1'-1 - \text{area } 1-4-4'-1'-1$$

$$= \text{area } 1-2-3-4-1$$

The compression process is polytropic so $W =$

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

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

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

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

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

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

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

For polytropic process 1-2

$$P_1V_1^n = P_2V_2^n$$

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

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

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

from eqn (i)

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

$$= \left(\frac{n}{n-1}\right)(P_1V_1)\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] \quad \text{---} \quad (ii)$$

If compression is adiabatic

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

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for isothermal process

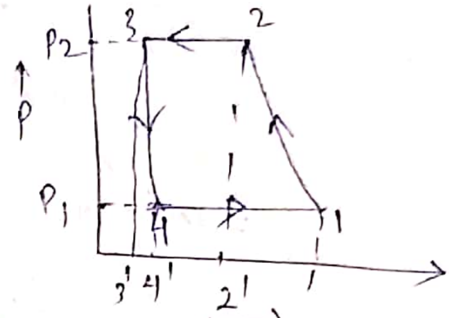
$$P_2V_2 + 2.3 P_1V_1 \log \frac{V_1}{V_2} - P_1V_1$$

for isothermal $P_1V_1 = P_2V_2$

$$W = 2.3 \log \frac{V_1}{V_2} = 2.3 \log \frac{P_2}{P_1}$$

workdone for a single acting single stage reciprocating compressor with clearance :-

W = area 1-2-3-4-1 = area 2-3-3'-2'-2 + area 1-2-2'-1'-1 - area 3-3'-4'-4-3 - area 1-4-4'-1'-1



$$= P_2(V_2 - V_3) + \left(\frac{P_2V_2 - P_1V_1}{n-1}\right) - \left(\frac{P_3V_3 - P_4V_4}{n-1}\right) - P_1(V_1 - V_4)$$

$$= \frac{(P_2V_2 - P_2V_3)(n-1) + (P_2V_2 - P_1V_1) - P_3V_3 + P_4V_4 - P_1V_1 + P_1V_4(n-1)}{(n-1)}$$

$$= P_2V_2n + P_2V_3 - P_2V_2 + P_1V_1 - P_3V_3 + P_4V_4 + P_1V_1n - P_1V_4$$

$$= P_2V_2 - P_2V_3 + \frac{P_2V_2}{n-1} - \frac{P_1V_1}{n-1} - \frac{P_3V_3}{n-1} + \frac{P_4V_4}{n-1} - P_1V_1 + P_1V_4$$

$$= P_2V_2 + \frac{P_2V_2}{n-1} - P_1V_1 - \frac{P_1V_1}{n-1} - P_2V_3 - \frac{P_3V_3}{n-1} + P_1V_4 + \frac{P_4V_4}{n-1}$$

$$= \left(P_2V_2 + \frac{P_2V_2}{n-1}\right) - \left(P_1V_1 + \frac{P_1V_1}{n-1}\right) - \left(P_2V_3 + \frac{P_3V_3}{n-1}\right) + \left(P_1V_4 + \frac{P_4V_4}{n-1}\right)$$

$$= \left[\frac{(P_2V_2)(n-1) + P_2V_2}{n-1}\right] - \left[\frac{(n-1)P_1V_1 + P_1V_1}{n-1}\right] - \left[\frac{P_2V_3(n-1) + P_3V_3}{n-1}\right] + \left[\frac{P_1V_4(n-1) + P_4V_4}{n-1}\right]$$

$$= \frac{n}{n-1}(P_2V_2) - \frac{n}{n-1}(P_1V_1) - \frac{n}{n-1}(P_2V_3) + \frac{n}{n-1}(P_1V_4)$$

$$= \frac{n}{n-1}(P_2V_2 - P_1V_1) - \frac{n}{n-1}(P_2V_3 - P_1V_4)$$

$$= \left(\frac{n}{n-1}\right)(P_2V_2 - P_1V_1) - \frac{n}{n-1}(P_3V_3 - P_4V_4)$$

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$\Rightarrow \frac{n}{n-1} \times P_1 V_1 \times \left(\frac{P_2 V_2}{P_1 V_1} - 1 \right) - \frac{n}{n-1} \times P_4 V_4 \times \left(\frac{P_3 V_3}{P_4 V_4} - 1 \right)$

we know that process 1-2

$$P_1 V_1^n = P_2 V_2^n$$

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

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

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

for 3-4

$$\frac{V_3}{V_4} = \left(\frac{P_4}{P_3}\right)^{1/n} = \left(\frac{P_3}{P_4}\right)^{-1/n} = \left(\frac{P_2}{P_1}\right)^{-1/n}$$

$$W = \frac{n}{n-1} \times P_1 V_1 \times \left(\frac{P_2 V_2}{P_1 V_1} - 1 \right) - \frac{n}{n-1} \times P_4 V_4 \times \left(\frac{P_3 V_3}{P_4 V_4} - 1 \right)$$

$$= \frac{n}{n-1} \times P_1 V_1 \times \left[\frac{P_2}{P_1} \times \left(\frac{P_2}{P_1}\right)^{-1/n} - 1 \right] - \frac{n}{n-1} \times P_4 V_4 \times \left[\frac{P_2}{P_1} \times \left(\frac{P_2}{P_1}\right)^{-1/n} - 1 \right]$$

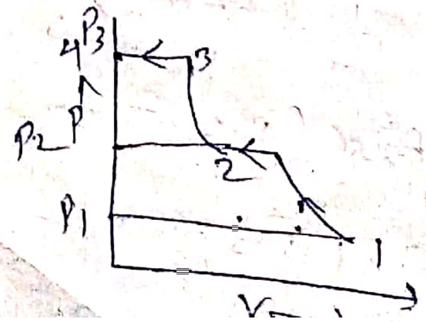
$$= \frac{n}{n-1} \times P_1 V_1 \times \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right] - \frac{n}{n-1} \times P_4 V_4 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

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

$$P_1 V_1 = m R T_1$$

$$= \frac{n}{n-1} \times m R T_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1 \right]$$

2 stage



$w = w_1 + w_2$

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Performance of IC engine

Indicated power (IP)

It is the total power developed by combustion of fuel in the combustion chamber

$$IP = \frac{P_m L A n}{60} \text{ watt} \quad \text{(for single cylinder)}$$

P_m = Actual mean effective pressure as obtain from indicated diagram in bar

L = Length of stroke in meter

A = Area of piston in meter^2

n = no of working strokes per minute = N = N/2

n = N (for 2 stroke cycle engine)

n = N/2 (for 4 stroke cycle engine)

$$Ip = \frac{K P_m L A n}{60} \text{ (for multi cylinder engine)}$$

K = no. of cylinder

$$Ip = \frac{P_m L A n}{60} \Rightarrow \frac{P_m \times 10^5 \times L A n}{60} \text{ W}$$

$$= \frac{P_m \times 10^2 \times 10^3 L A n}{60} \text{ W.}$$

$$IP = \frac{100 P_m L A n}{60} \text{ KW}$$

Break power B.P

The power develop by an engine at the output shaft is called the break power.

$$B.P = \frac{2\pi N T}{60 \times 1000} \text{ KW}$$

N = speed in R.P.M

T = Torque in Newton x meter

Frictional Power - F.P

The difference between IP and B.P. is called frictional power. This power is lossed due to engine friction.

Mechanical efficiency

It is the ratio of break power to the indicated power

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

Mean effective pressure

It is defined as hypothetical pressure which is thought to be acting in the pistone through out the power stroke.

(ii) If it is based on IP it is called indicated mean effective pressure (I.m.e.p)

(iii) If it is based on B.P it is called break mean effective pressure (B.M.e.p)

Specific output

It is defined as the break output per unit of pistone displacement.

$$S_{out} = \frac{BP}{A \times L}$$

Break power

The break power of an IC engine is usually measured by means of proney break mechanism or rope break mechanism.

① Proney break case

Break power = $\frac{Wl \times 2\pi N}{60}$ W

Wl = Torque

W = Break load on newton

l = length of arm in meter

N = speed of the engine

(2) Rope break case

$B.P = \frac{(W-S)\pi DN}{60}$ W (without considering diameter of rope)

$= \frac{(W-S)\pi(D+d)N}{60}$ W (considering diameter of rope)

W = Dead Load in newton

S = spring balance reading in newton

D = Diameter of break drawn in meter

d = Diameter of rope in meter

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

Overall efficiency

It is the ratio of work obtain at the crankshaft in a given time to the energy supplied by fuel during the same time

Overall efficiency $= \frac{B.P \times 60}{\left(\frac{m.P \times C}{60}\right)}$

$\eta_{o} = \frac{BP \times 3600}{mf \times C}$

Work obtained at the crank shaft per minute = BP × 60 kJ

Energy supplied by the fuel per minute = $\frac{m_f \times C}{60}$ kJ

m_f = Mass of fuel consumed in kg per hour

C = Calorific value of fuel in $\frac{kJ}{kg}$

Specific fuel consumption

It is the mass of fuel consumed per killowatt developed per hour

$$S.f.C = \frac{\dot{m}_f}{BP} \text{ kg/kw hour}$$

Thermal efficiency

It is the ratio of indicated workdone to energy supplied by the fuel.

Indicated thermal efficiency

It is based in indicated power

$$\eta_{th}(I.P) = \frac{I.P}{\dot{m}_f \times C}$$

$$= \frac{J/S}{\frac{kg}{S} \times J/kg}$$

Break thermal efficiency

It is based on break power.

$$\eta_{th}(B.P) = \frac{B.P}{\dot{m}_f \times C}$$

$\dot{m}_f$ = Mass of fuel used in kg per second

C = calorific value of fuel in $\frac{kJ}{kg}$

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Air-fuel ratio

Air-fuel ratio is the mass ratio of air to a solid, liquid or gaseous fuel presene in a combustion process.

The stoichiometric mixture for a gasoline engine is the ideal ratio of air to fuel that burns all fuel with no excess air. For ~~example~~ gasoline fuel, the stoichiometric air-fuel mixture is about 14.7 : 1 i.e for every one gram of fuel, 14.7 grams of air are required.

Calorific value – Total amount of heat liberated when unit mass or unit volume of a fuel is completely burnt in pressure of excess supply of oxygen.

Gross calorific value or higher calorific value –

The amount of heat evolved when unit mass or unit volume of a fuel in completely burnt in excess supply of O_2 and the biproducts of combustion are allowed to cool at room temperature

Net calorific value or lower calorific value (L.C.V)

The amount of heat evolved when unit mass or unit volume of a fuel in burnt completely in excess supply of O_2 and the biproducts of combustion in allowed to escape in the atmosphere.

L.C.V = H.C.V - Latent heat of vaporisation.

We know that 2 gms of H_2 gives 18 gms of H_2O

here 1 parts by wt of H_2 will give 9 parts of H_2O

∴ L.C.V. = H.C.V - [Mass of H percent / Mass of fuel] × 9 × latent heat of stream

If we repeat H as percentage then

$$L.C.V = H.C.V - \frac{H}{100} \times 9 \times 587$$

or

$$L.C.V = H.C.V - 0.09H \times 587$$

cal/gram

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Heat transfer:-

It can be defind as the transmission of energy from one region to another as a result of temperature differance there are 3 modes of heat transfer, such as :-

1. condecction
2. convection
3. Radiation.

conduction:-

It is the transfer of heat to the one body are between several body with in physical contact in absence of fluid motion.

→ in this case heat is transfer form one molecule to another which remain fixed in their position.

convection:-

convection is the mode of heat transfer which generally occurs between a solid surface and the surrounding fluid due to temperature difference associated with macroscopic.

→ convection may be of two types such as

1. Free convection.
2. Forced convection.

Free convection / Natural :-

→ when ever the flow of fluid over a hot or cold surfaces takes place due to the temperature difference only the heat transfer between the solid surface and fluid is said to be takes place by natural or free convection.

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→ The force acting on the fluid to produce its motion is called buoyancy force.

→ Thus force producing the flow is directly proportional to the temperature difference.

Ex:-

Heat transfer from the condenser of a domestic refrigerator to the surrounding air takes place by natural convection.

Forced convection:-

→ When the fluid flows on a hot or cold surface under external pressure the flow is called forced flow.

→ Heat transfer under such conditions is known as forced convection.

→ The force required to cause the motion of the fluid is due to a fan or blower and it is independent of the temperature difference causing the heat flow.

→ Resisting force is due to the inertia of the fluid.

Ex

It is used in many engineering heat transfer equipments.

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Radiation :-

→ It is the transfer of heat through space or metals by means of other than conduction or convection.

→ In this case transfer of heat from a hot body to cold body takes place by wave motion.

→ It can be takes place the vaccume.

Thermal conductivity :- (K)

→ K is a thermophysical property of a material which tells about the ability of the material to allow the heat energy to get conducted through the material more rapidly or quickly.

→ insulators have very low thermal conductivity there by prevent the conduction heat transfer rate.

Radiation properties :-

→ The radiation energy received by a body is distributed as follows :

① some of radiation energy may be observed by the body.

② Some of radiation energy may be reflected by the body.

③ The remaining radiation energy may be transmitted by the body. Thus total incident radiation energy is the sum of radiation energy ~~absorptivity~~, observed, reflected and transmitted by the body.

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Fourier's law of heat conduction:

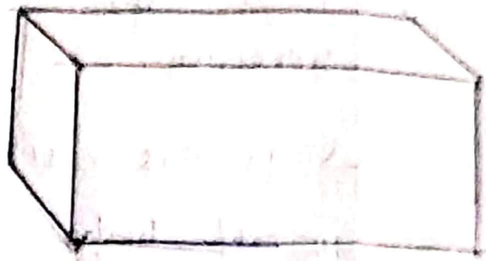
This law can be represented by fourier equation or conduction that is.

$$Q \propto A$$

$$Q \propto \frac{dT}{dx}$$

$$Q \propto A . \frac{dT}{dx}$$

$$Q = k. A. \frac{dT}{dx}.$$



Where k = Thermal conductivity.

Q = Amount of heat flow through the body in a unit time.

A = surface area of heat flow,

dT = Temperature difference in the two faces of the body.

dx = thickness of the body through which the heat flows it is taken along the direction of heat flow,

k = constant proportionality known as thermal conductivity.

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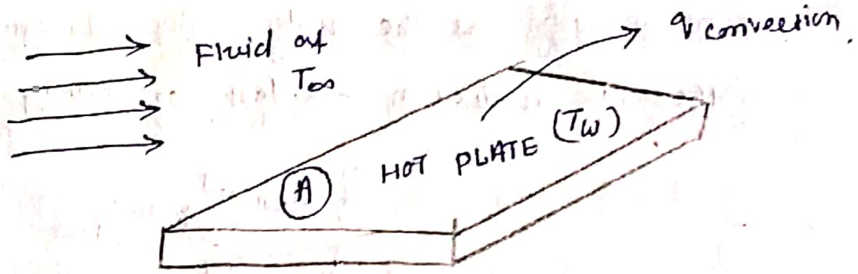
Newtons law of cooling :-



This law states that the rate of heat transfer by convection between a solid body and a surrounding fluid is directly proportional to the temperature difference between them and is also directly proportional to the area of contact of area of exposure between them.

$$q_{convection} \propto (T_w - T_\infty)$$

$$\propto A$$

$$q_{conv} = hA(T_w - T_\infty) \text{ watt}$$

h = convection heat transfer co-efficient.

Stefan - Boltzman's Law of radiation :-

The law states that the radiation energy emitted from the surface of a black body per unit time per unit area is directly proportional to the 4th power of the absolute temperature of the black body

$$E_b \propto T^4 \quad (T \text{ in kelvin only})$$

$$E_b = \sigma T_4 \ \frac{\text{Joule}}{\text{sec } m^2} = \frac{\text{watt}}{m^2}$$

σ = Stefan - Boltzman constant.

$\sigma = 5.67 \times 10^{-8}$ watt / $m^2 K^4$

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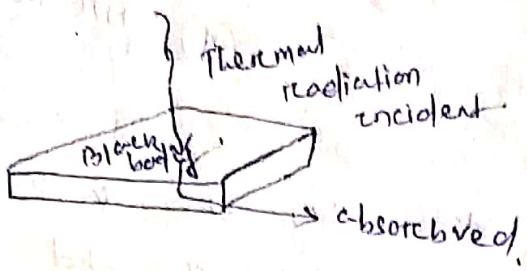
Black body :-

Black body is the body which absorbs all the thermal radiation incident or falling or upon the body.



Black body → Perfect absorbed
→ Ideal - emitter
→ Diffusive in nature.

→ A thermally black body absorbing all the incident thermal radiation falling upon it may not appear black in colour to the human eye.

EX :- Ice and snow,

Absorptivity :- (α)

It is the ratio of the radiation heat observed by the body to the total radiation heat received by the body.

Reflectivity (β)

It is the ratio of the radiation heat reflected by the body to the total radiation heat received by the body.

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Transmissibility :- (γ)

It is the ratio of the radiation heat transmitted by the body to the total radiation heat received by the body.

so $\alpha + \beta + \gamma = 1$

Krichoffs law :-

According to this law the absorptivity and the emisibility of a body are same. when the body in thermal equilibrium with its sorrounding.

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BOILER

Boiler defination

A boiler is a closed vessel in which fluid (generally water) is heated. The fluid does not necessarily boil.

The heated or vaporized fluid exits the boiler for use in various process or heating applications.

Classification and types of boiler:-

Low pressure Boilers:

1. Cochran Boiler
2. Locomotive Boiler.
3. Lanchashire Boiler
4. Cornish Boiler.
5. Scotch marine Boiler.

High pressure Boilers

1. Babcock - wilcox Boiler } Natural circulation
2. Stirling Boiler, } Natural Draught
3. La-mont Boiler } Forced circulation
4. Benson Boiler } Artificial Draught
5. Loeffler Boiler. }

1. Cochran Boiler:- Efficient boiler.

→ vertical (Less floor area) with horizontal fire tubes.

→ multi tubular (62.5 mm external diameter and 165 in numbers)

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→ Diameter of flue tubes is 0.6 times that of shell.

→ Chimney is used.

→ The shell and fire box are both hemisphere.

2. Locomotive Boiler :

Horizontal

multitubular

→ Chimney is used

→ Artificial draught is used by steam jet.

→ Its diameter is 1.5 m and length is 4 m.

3. Lanchashire Boiler :-

Horizontal

→ multitubular (It has two internal flue tubes having diameter about 0.4 times that of shell.

→ Working pressure and power required are moderate.

4. Cornish Boiler :

Horizontal

→ single tube boiler

→ The diameter of flue tube may be about 0.6 times that of shell.

5. Scotch marine Boiler : compact boiler.

→ Horizontal

→ single ended or double ended boiler

→ Fire tubes ~~suck~~ are horizontal

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High pressure Boiler :-

1. Babcock and Wilcox Boiler :-

→ water tubes are inclined with two headers at 22° angle.

→ Horizontal Boiler.

→ stationary Boiler.

2. Stirling Boiler :-

It has 3 drums.

→ 2 Boiler drums and 1 mud drum.

3. La-mont Boiler :-

Forced circulation maintained by centrifugal pump driven by steam turbine.

4. Benson Boiler :-

NO boiler drum is used and recirculation is not occur so it is also called once through boiler.

Note :-

1. Low Pressure boiler → Fire tube boiler.
   → Internally Fired boiler.

2. High pressure boiler → water tube boiler.
   → Externally fired boiler.

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Note:-

3. Boiler is made by steel

4. The efficiency of well maintained boiler is 90%.

5. The efficiency of thermal power plant is 90%.

6. The steam in the boiler is always wet or dry.

Important terms of boiler:-

1. Cylindrical shell:-

It is shell in which different parts of the boiler are enclosed and on which the different mountings are fitted.

2. Grate:-

It is platform in the furnace on which fuel is burnt.

3. Furnace (Fire box)

It is a chamber formed by the space above the boiler shell in which combustion take place.

→ It is also called a fire box.

→ This chamber contains hot gases produced by combustion of fuel.

4. Fire hole:-

It is the hole through which coal is added to the furnace.

5. Ash pit (ash pan)

It is the area in which the ash of burnt coal is collected

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6. Smoke Chamber (Smoke box)

The waste gases are collected here and then releases to the chimney and then to atmosphere.

7. man hole:-

It is a hole provided on the boiler shell so that a workman go inside the boiler for inspection, cleaning and maintenance.

8. Hand holes:-

It is a hole provided on the shell to give easy access for the purpose of cleaning the water tubes or some other internal parts of boiler. They are also fitted with covers.

9. Mud box:-

It collects all impurities present in the water. It is at the bottom of barrel or shell.

→ This impurities are removed time to time by help of blow off cock.

10. Steam collecting pipe (Anti-Priming pipe)

When the steam leaving the boiler, it contains certain amount of water. Anti-priming pipe is used to separate water particles from the steam and to collect dry steam from boiler.

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Boiler Draught :-

Boiler draught is the pressure difference between the atmosphere and the pressure inside the boiler.

→ The draught is necessary to force air through the fuel grate to help in proper combustion of fuel and to remove the products of combustion.

1. Induced draught :-

This is produced by the help of an induced draught fan, it is installed before the chimney and it maintains negative pressure inside the furnace.

→ The disadvantage is the air ingression inside the furnace due to improper sealing, thus leading to losses.

2. Forced draught :-

It is produced by the help of a forced draught fan installed before the furnace, air blown inside the furnace.

→ Thus producing positive pressure inside furnace, disadvantage is that hot flue gases will tend to leak into atmosphere and flames come out from the inspection holes in the furnace.

Balanced draught :-

It has both induced draught as well as forced draught fan and the draught or pressure difference produced is balanced or almost equal to atmospheric pressure,

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Boiler mountings:-

→ These are fittings, which are necessarily mounted on the boiler itself and mandatorily required for the safe and proper operation of boiler.

→ Boiler mountings are → water level indicator
→ Pressure gauge
→ spring loaded safety valve
→ Fusible plug → Blow - off - cock
→ Feed - check - valve

Water level indicator:- Its function is fitted outside the boiler shell to indicate the water level in the boiler through a glass tube.

→ Its working of water level indicator or water gauge is very simple. When the cocks are opened, boiling water and steam from the boiler shell flow into the hard glass tube and maintain the same level as the boiler which is visible to operator.

Pressure gauge:-

→ A pressure gauge is used to indicate the pressure of steam in the boiler.

→ It is generally mounted on the front top of the boiler.

→ It is of two types (1) Bourdon tube pressure gauge.
(2) Diaphragm type pressure gauge.

→ Its function spring loaded safety valve is a safety mounting fitted on the boiler shell ~~to~~ and is essentially required on the boiler shell to safeguard the boiler against high pressure.

→ It is a vital part of boiler and always be in good working condition to protect the boiler from bursting.

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Lancashire Boiler :-

It is a horizontal type and stationary fire tube boiler.

→ This is an internally fired boiler because the furnace is to present inside the boiler.

This boiler generates low-pressure steam and it is a natural circulation boiler.

→ It has high thermal efficiency of about 80 to 90 %.
It is mostly used in locomotive engines and marines etc.

Components used :-

Safety valve, pressure gauge, Feed check valve, water level indicator, Fire door, Fusible plug, Ash pit, Economizer, Air preheater, Super heater.

Construction and Working Principle of Lancashire Boiler :-

Construction :-

It consist a large drum of diameter up to 4-6 meter and length up to 9-10 meter. This drum consist two fire tube of diameter up to 40 % of the diameter of shell,

→ Flue gases passes through the fire tubes and side and bottom space. The water level inside the drum is always above the side channels of flue gases, so more heat transfer to the water.

→ The drum is half filled with water and the upper half space for steam. The furnace is located at one end of the fire tubes inside the boiler.

→ The low brick is situated at the grates which does not allow to un-burned fuel and ash to flow in fire tubes.

Working :-

The Lancashire boiler is a shell and tube type heat exchanger. The fuel is burn at the grate. The water is pumped in to the shell through the economizer which increases the temperature of water.

Now the shell is half filled with water. The fire tube is fully immersed in to the water.

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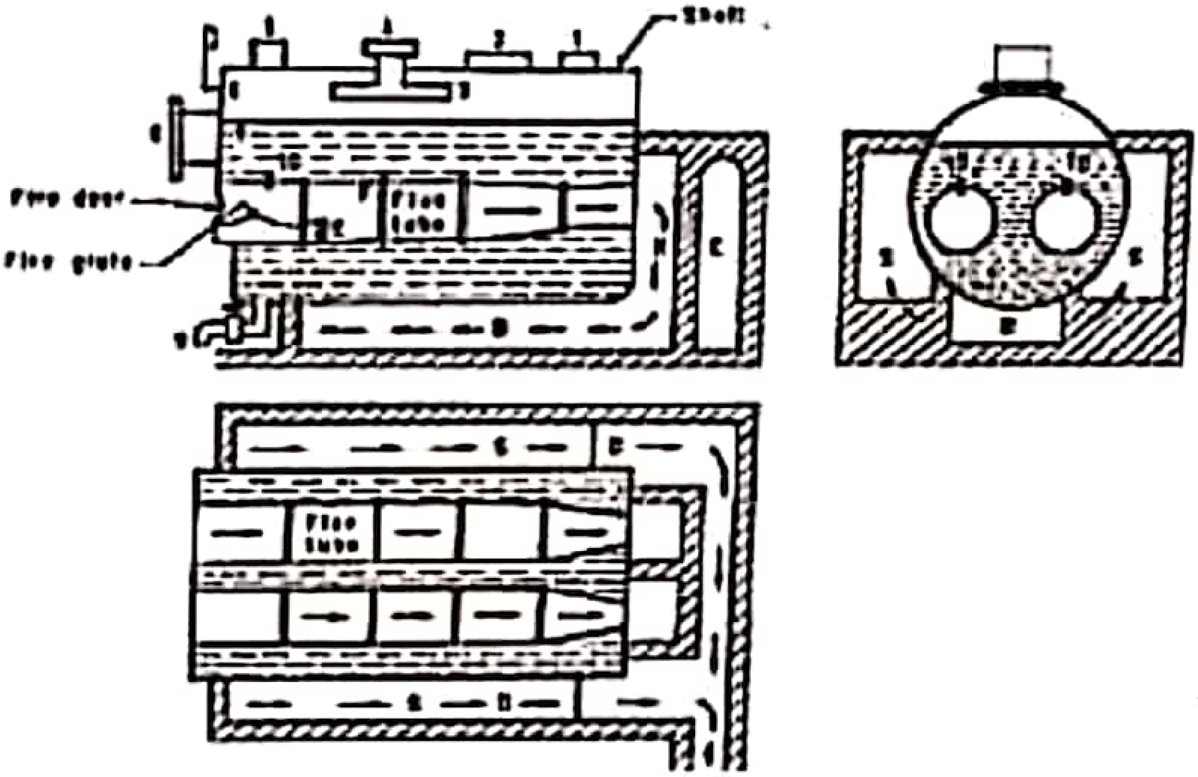
Lancashire boiler.



1. Safety valve
2. Man hole
3. Steam pipe
4. Steam stop va
5. Safety valve
6. Pressure gaug
7. Feed check va
8. Water gauge
9. Blowoff valve
10. Fusible plug

B: Bottom central channel D: Dampers S: side channels

C: Chimney E: Fire grate F :Flue tube K: Main channel

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→ The Fuel is charged at the grate which produces flue gases. These flue gases first passes through the fire tube from one end to another,

→ This fire tubes transfer 80-90% of total heat to the water. The backward flue gases passes from the bottom passage where it is transfer 6-8% of heat to water.

→ The brick is the lower conductor of heat, so work as heat insulators. The steam produces in drum shell. it taken from the upper side.

→ where it flows through superheater if required.

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BABCOCK AND WILCOX BOILER

It is a horizontal type drum axis, natural circulation, stationary, high pressure, solid fuel – fired water tube boiler.

Components used:- welded steel drum, up-take and downtake header, water tubes inclined at about 15° Angle, Externally Fired furnace, mountings and Accessories.

Construction and working principle of babcock and wilcox boiler:-
It is an inclined water tube boiler. In this type of boiler, all tubes usually stay straight and attached with a header. All tubes tilted with a concrete wall which usually presents the upper side of furnaces and it also attached with a steam drum, on the steam drum safety valve, manhole and super heater system present. Steam flow pipe stays attached to the super heater,

-> First water is filled in the water drum through feed pump. The drum is half filled with water and the upper half of the steam, 1st Flue is fired at the grate.

-> The flue gases generate by burning of fuel. These gases start flowing from one end to another end of boiler.

-> The flue gases passes by the water tubes and exchange heat with water, The baffles are provided in the way, which deflects the flues gases before escaping from the chimney. Due to this deflection, the flue gases pass more than one time through water tubes, which cause more heat transfer,

-> The water flows from the drum to the water tube through down take header.

-> The water tube nearer to the furnace heated more than the other so the density of water decreases in this tube which causes the flow of steam from tube to drum through uptake header, At the same time the water from the drum enters into the tubes through downtake header.

-> The circulation of water from drum to tubes and again tubes to drum is natural, due to density difference.

-> The steam ~~ope~~ separates in the drum at the upper half. This is saturated steam. This steam sends to the super heater through steam pipe. The steam is heated again by the flue gases in the super heater and taken out for process work.

-> The flue gases send to the atmosphere from the super heater.

-> This process repeat until sufficient amount of steam generates. This boiler can generate 20 ton steam per hour,

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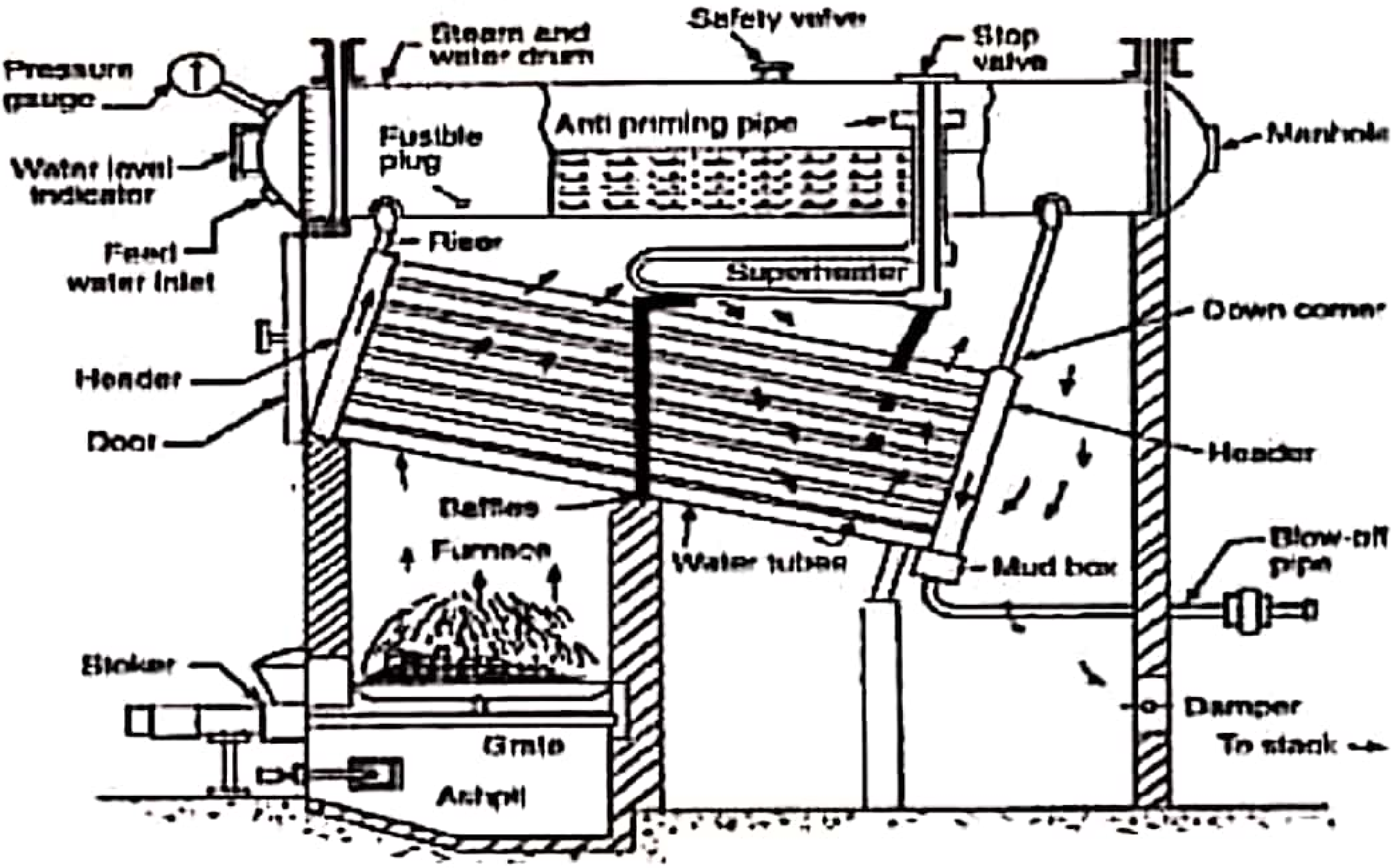
BABCOCK & WILCOX BOILERS



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Comparison of water tube and Fire tube boiler.

~~Water tube boiler~~ Fire tube boiler	Water tube boiler
→ Hot gases inside the tube and water outside the tube.	→ Water inside the tube and hot gases outside the tube.
→ These are operated at low low pressure of 20 bar.	→ The working pressure is high enough up to 250 bar in super critical boilers.
→ The rate of steam generation and quality of steam are very low, therefore, not suitable for power generation.	→ The rate of steam generation and quality of steam are better and suitable for power generation.
→ It requires more floor area for a given output.	→ It requires less floor area of given output.
→ Load fluctuations cannot be handeled.	→ Load fluctuations can be easily handled.
→ These are bulky and difficult to transport.	→ They are light in weight, hence transport is easy.
→ overall efficiency is up to 75%.	→ overall efficiency with an economizer is up to 90%.
→ water doesn't circulate in a definite direction.	→ Direction of water circulated is well defined.
→ It is not suitable for large power plants.	→ It is used for large power plants
→ Examples :- Simple vertical boiler, Cochran boiler, Lancashire boiler, Locomotive boiler, Velcon boiler.	→ Examples :- Babcock and Wilcox boiler, Striling boiler, La-mont boiler, Benson boiler, Yarrow boiler.

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Properties of Steam :-

Difference between gas and vapour :-

gas	vapour
→ A gas is a substance which has not and will not experience a phase change.	→ vapour is ~~formed by~~ a substance which has experienced a phase change.
→ The natural state of matter for a gas is a gas.	→ vapour is formed by a substance which is a solid or a liquid at room temperature that its natural state of matter is either a solid or a liquid.
→ Nitrogen (a gas) at room temperature would still be in a gaseous state, so it is a gas.	→ steam would be a vapour because at room temperature it would be water, which is a liquid.
→ Gas is a state of matter	→ Vapour is not a state of matter
→ while gas is a naturally occuring state of matter.	→ The word vapour suggests a gas that was formed by evaporation of something that is a liquid at room temperature
→ A gas is a substance above its critical temperature.	→ While a vapour is a substance above its boiling point temperature.

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Steam and its Properties :-

→ Steam is the gaseous phase of water. It utilizes heat during the process and carries large quantities of heat later.

→ Hence it could be used as a working substance for heat engines.

→ Steam is generated in boilers at constant pressure.

→ Generally steam may be obtained starting from ice or straight away from the water by adding heat to it.

Steam exists in following states or types

(i) Wet steam (saturated steam)

(2) Dry steam (Dry saturated steam)

(3) Superheated steam

(4) Supersaturated steam. Water, which is one of the pure substance, exists in three phases.

① Solid phase as ice (Freezing of water)

② Liquid phase as water (melting of ice)

③ Gaseous phase as steam

(vaporization of water)

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8.1 VAPOR POWER CYCLE

8.1.1 RANKINE CYCLE – THE IDEAL CYCLE FOR VAPOR POWER CYCLE

Many of the impracticalities associated with the Carnot cycle can be eliminated by superheating the steam in the boiler and condensing it completely in the condenser, as shown schematically on a *T-s* diagram in Fig.8.1. This cycle is called the Rankine cycle, which is the ideal cycle for vapor power plants. The ideal Rankine cycle does not involve any internal irreversibility and consists of the following four processes:

1-2 Isentropic compression in a pump.
2-3 Constant pressure heat addition in a boiler.
3-4 Isentropic expansion in a turbine.
4-1 Constant pressure heat rejection in a condenser.

a) Flow diagram. b) T-s Property diagram.

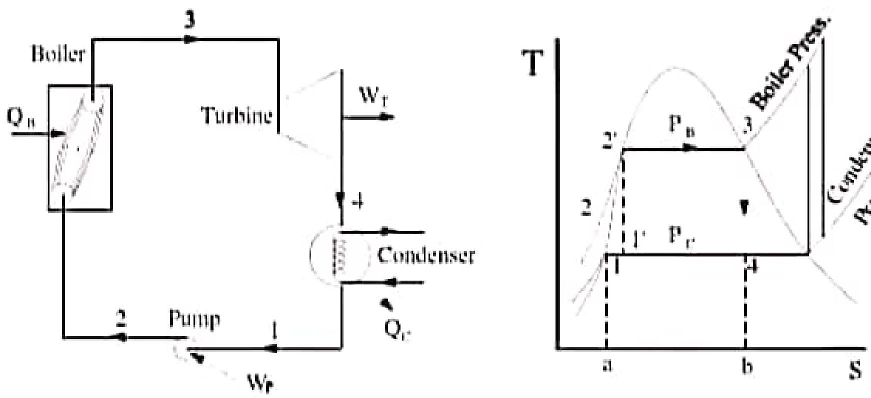

Figure 8.1 Ideal Rankine cycle

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The steam extracted from the turbine at state (6) between the boiler pressure and the condenser pressure is mixed with the water from the condenser. Thus the water pressure at the condenser exit should be increased by a pump in order to mix with the extracted steam. Another pump is required at the exit of the feedwater heater to increase the water pressure to the boiler pressure. Therefore, the feedwater heater requires two pumps for operation as shown in Fig. 8.9.

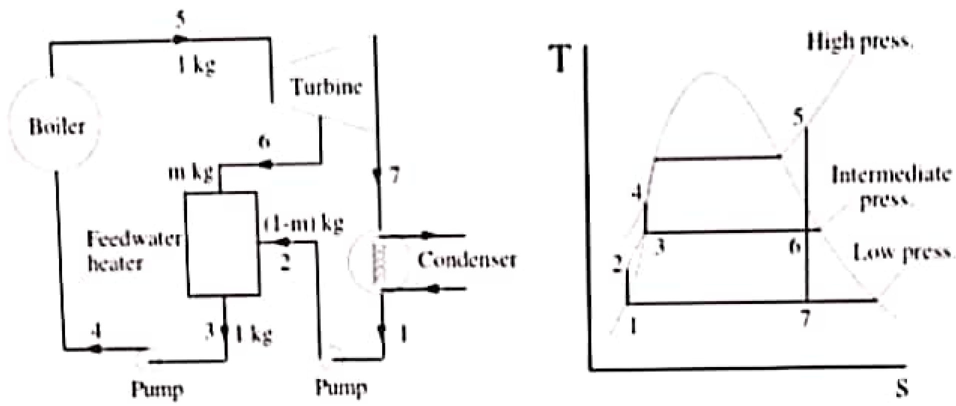

Figure 8.9 Regenerative cycle with open feedwater heater

To apply the first law of thermodynamics in this case, first start with feedwater heater to calculate "m" or state (3) or (6) if "m" is given as small part of the steam extracted from the turbine to an external heat exchanger called feedwater heater. Two types of feedwater heaters are used. The first type is called "open type" feedwater heater where the extracted, bled, steam mixes with the water and the result is hot water at the exit of the heater. The second type is called "closed type", where there is no mixing between the steam and the water. The heat is only transferred from the steam to the water. The regenerative cycle using these two types is presented in the following sections.

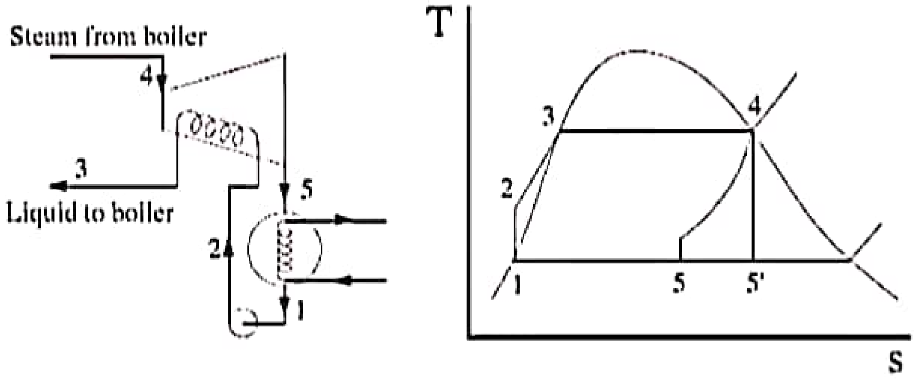

Figure 8.8 Ideal regenerative cycle

8.4.1 REGENERATIVE CYCLE WITH OPEN FEEDWATER HEATER

A regenerative cycle using one open type feedwater heater is shown in Fig. 8.9 below. The ratio between the bled steam to the total steam flow rate is called "m". Then:

$$m=\frac{\text{bled steam flow rate}}{\dot{m}}$$

The flow diagram per 1 kg of total steam flow rate is also shown in Fig. 8.9.

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8.2.2 EFFECT OF BOILER PRESSURE

To study the effect of boiler pressure we should keep the steam temperature at the exit of the boiler, T_3, constant. Then

- $T_3 = T_{3'} = T_{max}$
- Also condenser pressure is kept constant.
- Heat rejection is reduced by the area (4 4` a c).

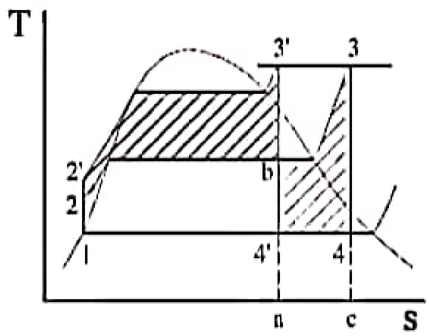

Figure 8.3 Effect of boiler pressure

- As a result of increasing boiler pressure, $\dot{Q}_C$ is decreased.
- If the area (a-b-3-c) = area (2-2`-3`-b). Then $\dot{Q}_B$ is constant and

$\dot{W}_{net}$ increases. This leads to an increase of η_R.

- Also if area (4-4`-3-b) = area (2-2`-3`-b), then $\dot{Q}_B$ decreases and

$\dot{W}_{net}$ kept the same. Thus Rankine efficiency increases. So,
As P_B increases η_R increases.

Note:
Disadvantage of increasing the boiler pressure leads to decrease of the steam quality at the exit of the turbine. This is similar to the pervious effect of reducing condenser pressure.

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8.2.3 EFFECT OF SUPERHEATING

As shown in Fig. 8.4 by increasing T_3 and keeping P_B the same, then

- W_{net} is increased by the area (3 3` 4` 4).
- Q_A is increased by the same area + area (4 4` b` b).
- Heat rejection is increased by the area (4 4` b` b).

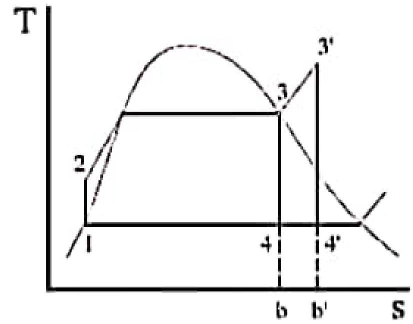

Figure 8.4 Effect of steam superheat

- $\eta_{th,R} = 1 - \dfrac{Q_R}{Q_A}$ since Q_A is increased by a larger ratio

→ η_R will be increased if superheat is used.

- Another advantage is the increase of the steam quality at the exit of the turbine, i.e. less erosion is expected.

Summary:

As shown in Fig.8.5 below η_{th} is increased by:

1- Lowering condenser pressure (less heat rejection for same heat addition).
2- Increasing boiler pressure.

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8.3 THE REHEAT CYCLE

Superheating the steam to high temperature is limited by its effect on the turbine material. So, in order to improve the Rankine cycle efficiency and increase the net power output, the steam is reheated after expansion through some part of the turbine as shown in Fig.8.6. Thus the steam is reheated before complete expansion in the turbine. After reheat the steam is further expanded in the second part of the turbine. This expansion may be occurring in two parts, called stages, of the turbine. The first part of the turbine is called high-pressure stage and the second part is called low-pressure stage.

After expansion from state (3) to state (4) in the turbine the steam is reheated in the boiler building to state (5). The temperature of the steam at state (5) is almost equal or less than T_3:

$$T_5 \leq T_3$$

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