NOTE

# Thermal Engg-II

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Chapter-1

# Performance of IC engine

Mechanical efficiency :- It is the ratio of brake power to indicated power.

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

Frictional power $(F.P) = I.P - B.P$

Indicated thermal efficiency :-

It is the ratio of the heat equivalent to one KW hour to the heat in the fuel per I.P hour.

$$\eta_t = \frac{I.P \times 3600}{m_f \times C}$$

Relative efficiency :-

It is the ratio of indicated thermal efficiency to the air standard efficiency.

Brake thermal efficiency :-

It is the ratio of the heat equivalent to one KW hour to the heat in fuel per B.P hour.

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

Overall efficiency :- It is the ratio of work obtained at the crankshaft in a given time to the energy supplied by the fuel during the same time.

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

Mean effective pressure :-

Mean effective pressure of the working medium can be found out from the area of the actual indicator diagram recorded by engine indicator in the same way as in case of steam engine.

Specific fuel consumption :-

It is the ratio of fuel consumption per unit time to the power devloped by engine.

Air fuel ratio :-

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

## Calorific Value of fuels :-

The calorific value or heat value of a solid or liquid fuel may be defined as the amount of heat given out by the complete combustion of 1 Kg of fuel. It is expressed in KJ/kg of fuel.

For gaseous fuel it is expressed in $KJ/m^3$ at a specified temperature and pressure.

# Air Compressors — Chapter-2

Compressor :- It is a machine to compress the air and to raise its pressure.

Air compressor 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 pipe to a place where it required.

## Classification :-

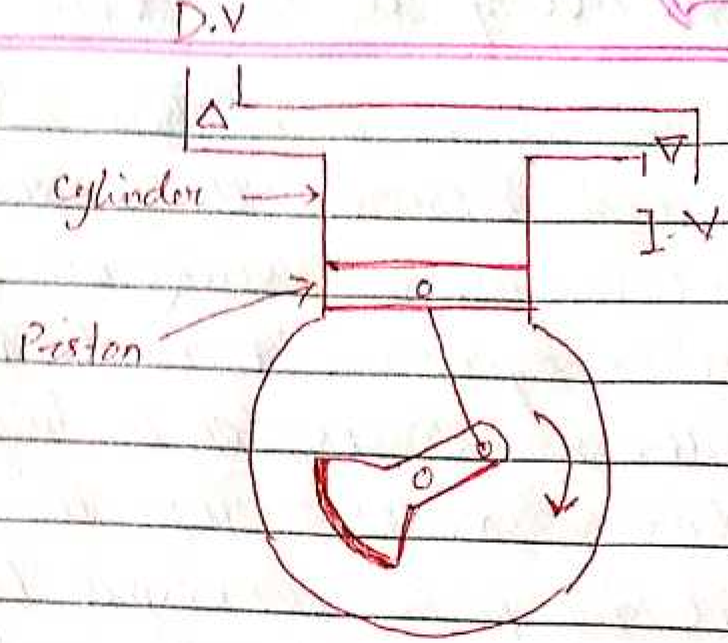
① According to working.
ⓐ Reciprocating ⓑ Rotary

② According to action
ⓐ Single acting ⓑ Double acting

③ According to number of stages
ⓐ Single stage ⓑ Multi stage

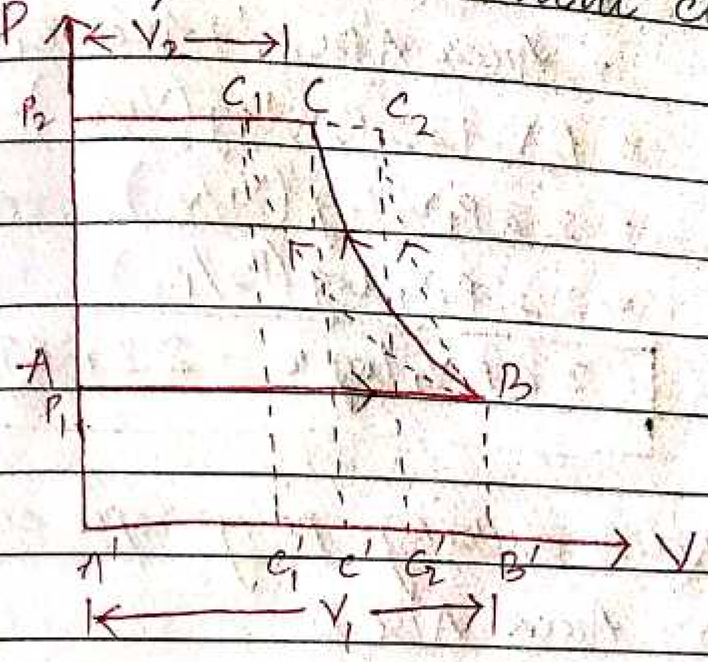
## Working of single stage Reciprocating air compressor :-

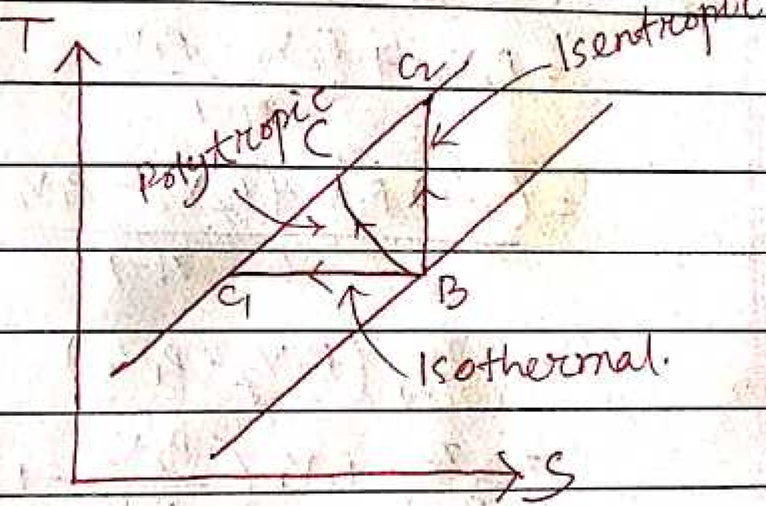
A single stage reciprocating air compressor consists of a cylinder, piston and discharge valves.




When the piston moves downwards the pressure inside the cylinder falls below the atmospheric pressure. Due to the pressure difference the inlet valve gets opened and air sucked into the cylinder. Now when the piston moves upwards, the pressure inside the cylinder goes on increasing till it reaches the discharge pressure. At this stage discharge valve gets opened and air is delivered to the container. At the end of delivery stroke, a small quantity of air at high pressure is left in the clearance space.

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




Let $P_1$ = initial pressure of air (before compression)

$V_1$ = initial volume of air (before $comp^n$)

$T_1$ = initial temperature (before $comp^n$)

$P_2, V_2, T_2$ = corresponding values after $comp^n$.

$r$ = pressure ratio $(P_2/P_1)$

1- Workdone during isothermal Compression:-

$$W = \text{Area } ABC_1D$$
$$= \text{Area } A'DC_1C_1' + \text{Area } C_1BB'C_1' - \text{Area } A'ABB'$$
$$= P_2V_2 + 2.3\,P_2V_2 \log(V_1/V_2) - P_1V_1$$
$$= 2.3\,P_1V_1 \log(V_1/V_2)$$
$$= 2.3\,P_1V_1 \log(P_2/P_1)$$
$$\boxed{= 2.3\,P_1V_1 \log r = 2.3\,mRT_1 \log r}$$

2- Workdone during polytropic compression:-

$$W = \text{Area } ABCD$$
$$= \text{Area } A'DCC' + \text{Area } CBB'C' - \text{Area } A'ABB'$$
$$= P_2V_2 + \frac{P_2V_2 - P_1V_1}{n-1} - P_1V_1$$
$$= \frac{(n-1)P_2V_2 + P_2V_2 - P_1V_1 - (n-1)P_1V_1}{n-1}$$
$$= \frac{n}{n-1}(P_2V_2 - P_1V_1) \quad \text{—(i)}$$
$$= \frac{n}{n-1}P_1V_1\left(\frac{P_2V_2}{P_1V_1} - 1\right) \quad \text{—(ii)}$$

We know polytropic compression

$$P_1V_1^n = P_2V_2^n$$
$$\therefore \frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{1/n}$$
$$\text{or } V_1/V_2 = (P_2/P_1)^{1/n}$$

Substituting the value of $V_2/V_1$ in eq$^n$ (ii)

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

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

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

3- Workdone during isentropic compression:-

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

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

$$= \frac{\gamma}{\gamma-1} mR(T_2 - T_1) = \boxed{m C_p (T_2 - T_1)}$$

Workdone by Reciprocating air compressor with clearance volume:-

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

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

# Properties of Steam :- Chapter 3

**Gas :-** It is a substance that has a single defined thermodynamic state at room temperature.

**Vapour :-** It is a substance that is a mixture of two phases at room temperature namely gaseous and liquid phase.

**Steam :-** Steam is a vapour of water and is invisible when pure and dry.

**Wet steam :-** When the steam contain moisture.

**Dry steam :-** When the wet steam is further heated and does not contain water particles.

**Superheated steam :-** When the dry steam is further heated at a constant pressure thus raising its temperature.

# Steam Generator - Chapter-4

**Boiler :-** It is a closed vessel made of steel. Its function is to transfer the heat produced by the combustion of fuel. to water and ultimately to generate steam.

**Fire tube boiler :-** In this type of boiler the flames and hot gases produced by the combustion of fuel pass through the tubes which are surrounded by water. The heat is conducted through the walls of the tubes from the hot gases to the surrounding water. Examples of fire tube boiler is cochran boiler.

**Water tube boiler :-** In this type of boiler the water is contained inside the tubes which are surrounded by flames and hot gases from out side. Example - Babcock and Wilcox boiler.

**Cochran boiler :-**

It is a multitubular boiler. The firebox 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. The gases from the smoke box passes to the atmosphere through the chimney. At the bottom of the fire box there is a grate and the coal is fed through the fire hole. ~~If the~~

Boiler draught :-

Draught is the difference of pressure which causes a flow of air to take places from outside atmosphere into the boiler ~~furnace~~ furnace for complete combustion of fuel.

Draught

- Natural
- Artificial

Natural draught :- The draught produced by chimney is called natural draught.

Artificial draught :- The draught produced by any means other than by chimney.

Forced draught :- In this system the supply of air through the fuel in the boiler furnace is ensured by means of a fan placed below the grate.

Induced draught :- Here the air is drawn in through the fuel in the boiler furnace through the grate passage due to pressure difference between boiler furnace and outside atmosphere. The difference in pressure created by means of a fan placed between the boiler and chimney.

Boiler mounting :-

Boiler mounting are those mechanical appliances which are considerd essential for operating a boiler smoothly and safely and which are mounted on the surface of a boiler.

Examples - pressure gauge, safty valve.

## Boiler Accessories :-

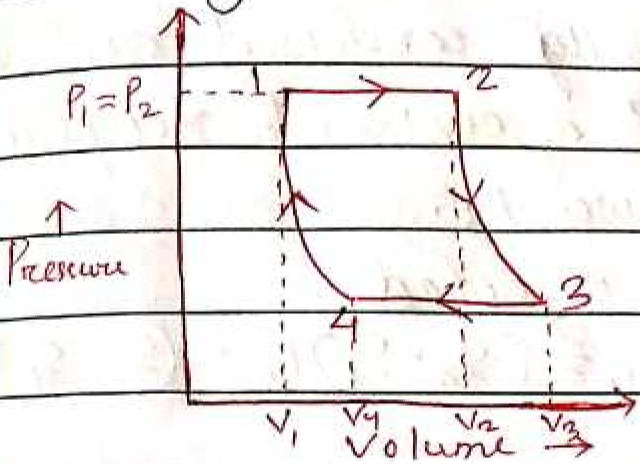
These are the appliances and plants which are installed along with a boiler to improve the operating condition and overall efficiency of the boiler plant.

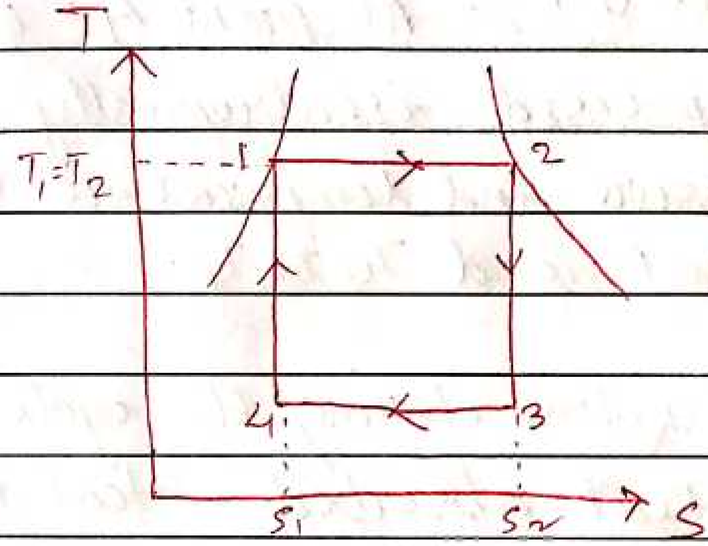
Ex- Economiser, Superheater etc.

# Steam Power Cycles



## Carnot cycle :-




1- Process 1-2 :- At point 1 saturated water is isothermally converted into dry steam. Heat absorbed at constant Temperature $T_1$ and pressure $P_1$

∴ Heat absorbed

$$q_{1-2} = (S_2 - S_1)T_1 = (S_2 - S_1)T_2$$

2- Process 2-3 :- At point 2 dry steam expands isentropically. Pressure and temperature falls from $P_2$ to $P_3$ and $T_2$ to $T_3$.

3- Process 3-4 :- At point 3 wet steam isothermally condensed and heat is rejected at a constant temperature $T_3$ and pressure $P_3$.

$\therefore$ Heat rejected

$$q_{3-4} = (S_2 - S_1)T_3 = (S_2 - S_1)T_4$$

4- Process 4-1 :- At point 4 wet steam compressed isentropically. The pressure and temperature rises from $P_4$ to $P_1$ and $T_4$ to $T_1$.

$\therefore$ Work done during the cycle

= Heat absorbed - Heat rejected

$$= (S_2 - S_1)T_1 - (S_2 - S_1)T_3 = (S_2 - S_1)(T_1 - T_3)$$

Efficiency $\eta = \dfrac{\text{Work done}}{\text{Heat absorbed}}$

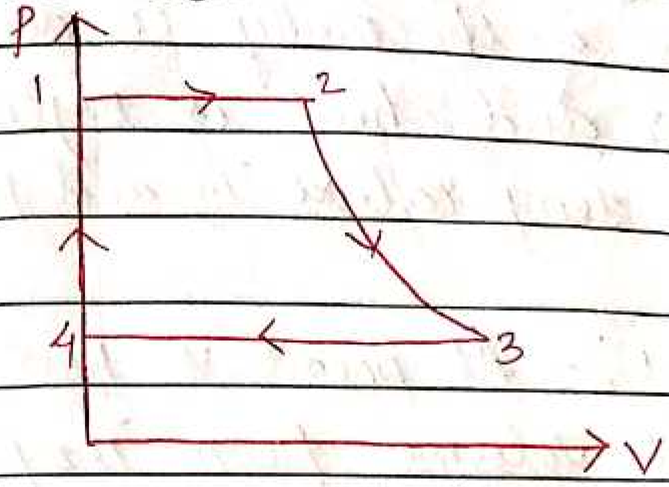
$$= \frac{(S_2 - S_1)(T_1 - T_3)}{(S_2 - S_1)T_1}$$

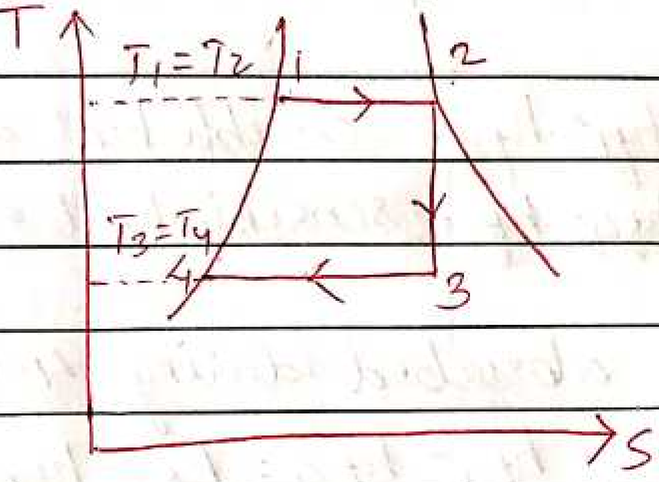
$$= \frac{T_1 - T_3}{T_1} = 1 - \frac{T_3}{T_1}$$

$T_1$ = Highest temperature

$T_3$ = Lowest temperature

## Rankine Cycle :-




**Process 1-2 :-** At point 1 saturated water is isothermally converted into dry saturated steam in boiler and heat absorbed at a constant temperature $T_1$ and pressure $P_1$.

**Process 2-3 :-** At point 2 isentropically dry saturated steam expands. The pressure and temperature falls from $P_2$ to $P_3$ and $T_2$ to $T_3$.

Process 3-4 :- At point 3 the wet steam is now isothermally condensed in a condenser and heat is rejected at constant temperature $T_3$ and pressure $P_3$.

Process 4-1 :- At point 4 heat added at constant volume from Temperature $T_4$ to $T_1$ and pressure rises from $P_4$ to $P_1$.

Let $h_{f1} = h_{f2}$ = sensible heat at point 1
$h_{f4} = h_{f3}$ = sensible heat at point 4

∴ Heat absorbed during 4-1

$$= h_{f1} - h_{f4} = h_{f2} - h_{f3}$$

and heat absorbed during complete cycle

$$= h_{fg2} + (h_{f2} - h_{f3})$$

$$= h_{f2} + h_{fg2} - h_{f3} = h_2 - h_{f3} \quad \text{— (i)}$$

(∵ for dry steam $h_2 = h_{f2} + h_{fg2}$)

We know that heat rejected during the cycle $= h_3 - h_{f4} = h_{f3} + x_3 h_{fg3} - h_{f4} = x_3 h_{fg3}$

∴ Workdone during cycle

= Heat absorbed − Heat rejected

$$= (h_2 - h_{f3}) - x_3 h_{fg3}$$

$$= h_2 - (h_{f3} + x_3 h_{fg3}) = h_2 - h_3$$

Efficiency

$$\eta_R = \frac{\text{Work done}}{\text{Heat absorbed}} = \frac{h_2 - h_3}{h_2 - h_{f3}}$$

Heat - The energy in transit is termed as heat.

Heat is a form of energy. The moleculs of a substance are in parallel motion. The mean Kinetic energy per molecule of the substance is proportional to its absolute temperature.

Heat Transfer :-

The transmission of energy from one region to another as a result of temperature gradient.

Heat transfer can takes place by the following three modes:

i) Conduction
ii) Convection
iii) Radiation

i) Conduction :- Conduction is the transfer of heat from one part of a substance to another part of the same substance or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance.

ii) Convection :- Convection is the transfer of heat within a fluid by mixing of one portion of the fluid with ~~medium itself~~ another.

Free or natural convection :-

Free or natural convection occures when the fluid circulates by virtue of the natural differences in densities of hot and cold fluids, the denser portions of the fluid moves downward because of the greater force of gravity, as compared with the force on the less dense.

Forced Convection :-

When the work is done to blow or pump the fluid, it is said to be forced convection.

iii) Radiation :- Radiation is the transfer of heat through space or matter by means other than conduction or convection. ~~It is through~~

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## Fourier's laws of heat conduction :-

The rate of flow of heat through a simple homogeneous solid is directly proportional to the area of the section at right angles to the direction of heat flow and to change of temperature with respect to the length of the path of the heat flow.

Mathematically

$$Q \propto A \cdot \frac{dt}{dx}$$

where Q = Heat flow through a body per unit time.

A = surface area of heat flow

dt = temperature difference of the faces of block

dx = thickness of block.

Thus $Q = -K \cdot A \cdot \frac{dt}{dx}$

where K = constant of proportionality known as Thermal conductivity of body.

The -ve sign indicates the decrease in temperature with increase in thickness.

Thermal Conductivity of the materials :-

$$K = \frac{Q}{A} \cdot \frac{dx}{dt}$$

The value of $K=1$ when $Q=1, A=1$ and $\frac{dt}{dx}=1$

unit of K is W/mK or W/m°C.

Thermal Conductivity of a material is defined as the amount of energy conducted through a body of unit area and unit thickness in unit time when the difference in temperature between the faces causing heat flow is unit temperature differences.

Heat Transfer by convection :-

$$Q = hA(t_s - t_f)$$

where Q = Rate of conductive heat transfer.

A = area exposed to heat transfer.

$t_s$ = Surface temperature

$t_f$ = Fluid temperature

h = Co-efficient of convective heat transfer

The unit of h are

$$h = \frac{Q}{A(t_s - t_f)} = \frac{W}{m^2 °C}$$

The coefficient of convective heat transfer 'h' will be defined as the amount of heat transmitted for a unit temperature difference between the fluid unit area of surface in unit time.

Kirchhoff's law :- It state that the emissivity of the body at a particular temperature is numerically equal to its absorptivity for radient energy from body at the same temperature.

Stefan-Boltzmann law :- The law states that the emissivity power of a blackbody is directly proportional to forth power of its absolute temperature.

i.e. $Q \propto T^4$

Emissivity ($\epsilon$) :- It is defined as the ability of the surface of a body to radiate heat. It is also defined as the ratio of the emissive power of any body to the emissive power of a black body of equal temperature.

Absorptivity :- The property of a body that determines the fraction of incident radiation absorbed by the body

Transmissivity :- It is the fraction of irradiation transmitted through the surface.

Reflectivity :- It is the of irradiation reflected by the surface.

blackbody :- A blackbody is one which neither reflects nor transmits any part of the incident radiation but absorbs all of it.

white body :- All the incident radiation falling on the body are reflected.

Gray body :- It is defined as one whose absorptivity of a surface does not vary with temperature and wavelength of the incident radiation.

Newton's law of cooling :-

Heat transfer from a hot body to a cold body is directly proportional to the surface area and difference of temperature between two bodies.