9.10 OTTO CYCLE

This cycle was proposed by Beau de Roches and the first engine operating on this cycle was put forward by a German engineer Mr. Otto. This is why it is named as Otto cycle. It is a theoretical cycle on which most of the internal combustion engine works.

The $p-V$ and $T-s$ diagram of the Otto cycle is shown in the Fig. 18.

The cycle consists of two adiabatic and two constant volume processes. In this cycle Heat in supplied at constant volume process so Otto cycle is also known as "constant volume cycle."

For simplicity, air is assumed to be the working fluid in the cylinder. Heat is supplied to the working fluid at constant volume process 2 – 3 and heat is rejected at constant volume process 4 – 1.

Commencing with point (1), the engine cylinder is full of air at volume V_1. Let the pressure and temperature be p_1 and T_1 respectively.

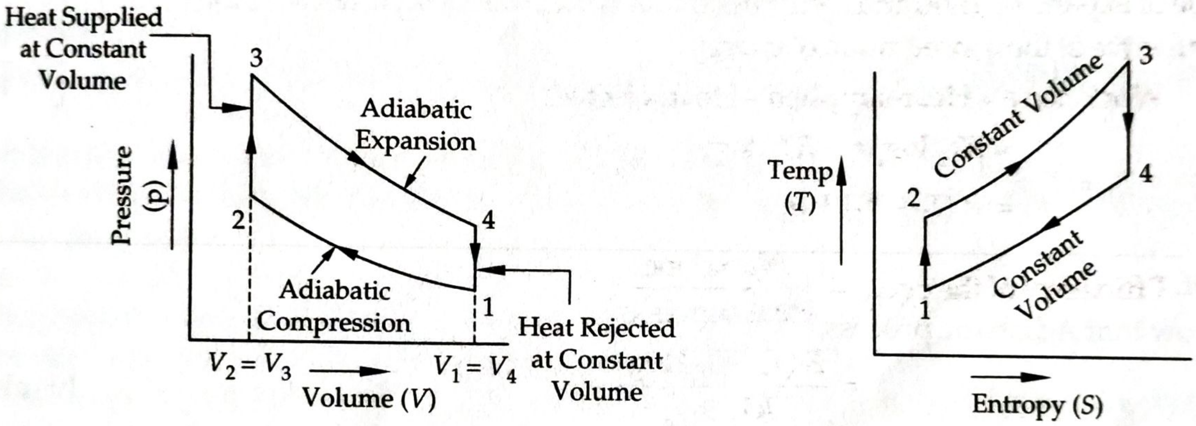

Fig. 18 Otto Cycle

The air at point (1) is compressed adiabatically, to point (2). Let the pressure, volume and temperature of air at point (2) becomes p_2, V_2 and T_2 respectively. At point (2), the air is compressed to the clearance volume.

Now the hot body is brought in contact with the end of the cylinder. Heat is supplied to the air at constant volume. This causes the Pressure and temperature to rise to p_3 and T_3 respectively. At point (3), hot body is removed, and the air is allowed to expand adiabatically to point (4). During expansion, work is done on the piston. Let the conditions of at point (4), be p_4, V_4 and T_4.

At point (4), the cold body is brought in contact with the end of the cylinder. Heat is rejected to the cold body at constant volume. The air is reduced to its original conditions at point (1). This completes the cycle.

Let

c_v = Specific heat of air at constant volume. Considering one kg of air.

Heat supplied = Heat absorbed during constant volume process 2 – 3.

$= c_v (T_3 - T_2)$

Heat Rejected = Heat rejected during constant volume process 4 – 1.

$= c_v (T_4 - T_1)$

∴ Work done = Heat supplied – Heat rejected

$c_v (T_3 - T_2) - c_v (T_4 - T_1)$

$$\therefore \quad \text{Efficiency of the cycle} = \frac{\text{Work done}}{\text{Heat supplied}}$$

$$= \frac{c_v (T_3 - T_2) - c_v (T_4 - T_1)}{c_v (T_3 - T_2)}$$

$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2} \quad \ldots \text{(i)}$$

Expression of efficiency may also be written in terms of compression ratio.

Let $\quad r$ = Compression ratio = Expansion ratio

i.e. $\quad r = \dfrac{V_1}{V_2} = \dfrac{V_4}{V_3}$

Consider the adiabatic compression process 1 – 2.

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \quad \left[\gamma = \frac{c_p}{c_v}\right]$$

$$\frac{T_2}{T_1} = (r)^{\gamma-1} \quad \left[\because \frac{V_1}{V_2} = r\right]$$

$$T_2 = T_1\, r^{\gamma-1} \quad \ldots \text{(ii)}$$

For Ref.

We know that Adiabatic process,

$$p_1 V_1^{\gamma} = p_2 V_2^{\gamma} \quad [\because pV^{\gamma} = C]$$

and, $\quad \dfrac{p_2}{p_1} = \left(\dfrac{V_1}{V_2}\right)^{\gamma} \quad \ldots\text{(i)}$

Gas law, $\quad \dfrac{p_1 V_1}{T_1} = \dfrac{p_2 V_2}{T_2}$

$$\frac{p_2}{p_1} = \frac{T_2 V_1}{T_1 V_2} \quad \ldots\text{(ii)}$$

Equating the Equation (i) and (ii), we get

$$\frac{T_2 V_1}{T_1 V_2} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}\left(\frac{V_2}{V_1}\right)$$

$$= \left(\frac{V_1}{V_2}\right)^{\gamma}\left(\frac{V_1}{V_2}\right)^{-1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

Similarly, considering the adiabatic expansion process 3 – 4.

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} \qquad (\because V_1 = V_4 \text{ and } V_2 = V_3)$$

$$= r^{\gamma-1}$$

$$T_3 = T_4 r^{\gamma-1} \qquad ...(v)$$

Putting the values of T_2 and T_3 from equation (ii) and (iii) in equation (i), we get

$$\eta = 1 - \frac{T_4 - T_1}{T_4 r^{\gamma-1} - T_1 r^{\gamma-1}}$$

$$= 1 - \frac{T_4 - T_1}{r^{\gamma-1}[T_4 - T_1]}$$

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

∴ Air standard efficiency $\boxed{\eta = 1 - \frac{1}{r^{\gamma-1}}}$

Assumption Made

Following assumptions were made to derive the expression for the air standard efficiency of the Otto cycle.

1. Air is assumed to be working fluid in the engine cylinder.
2. The working fluid (air) is assumed to be a perfect gas and follows the relation ship.

$$pV = mRT$$

or $$p = \rho RT$$

3. The compression and the expansion of the working fluid are adiabatic.
4. The adiabatic compression and expansion processes are frictionless.
5. Heat is supplied to the working fluid at constant volume, by bringing a hot body in contact with the end of the cylinder.
6. The heat is rejected at constant volume by bringing the cold body in contact with the cylinder end.
7. It is assumed that there are no heat losses from the system to the surrounding.
8. The cylinder walls are made of non-conducting material.
9. The working fluid has constant specific heats throughout the cycle.
10. Take some physical constants.

$$c_p = 1.005 \text{ kJ/Kg k}$$
$$c_v = 0.717 \text{ kJ/Kg k}$$
$$\gamma = 1.4$$
$$M = 29 \text{ Kg/k mol.}$$

9.11 DIESEL CYCLE

This cycle is very important because the diesel engines are based on this. The first engine working on this cycle was first constructed successfully by Dr. Rudolph Diesel.

The $p-V$ and $T-s$ diagrams of this cycle are shown in Fig. 19.

The cycle consists of two adiabatic processes, one constant pressure process and one constant volume process. For the simplicity, air is assumed to be the working fluid.

In order to calculate the air standard efficiency of cycle, let us consider the engine cylinder to be full of air. The condition of this air is represented by point (1), where the pressure, volume and absolute temperature of the air is p_1, V_1 and T_1 respectively.