4.4 Air Standard Otto Cycle:

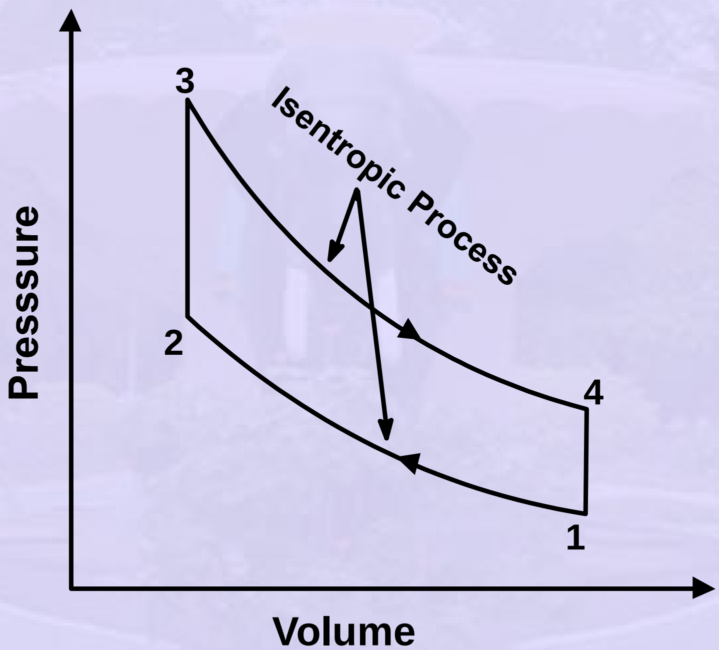
The air-standard-Otto cycle is the idealized cycle for the spark-ignition internal combustion engines. This cycle is shown above on p-v and T-s diagrams. The Otto cycle 1-2-3-4 consists of following four process:

Process 1-2: Reversible adiabatic compression of air.

Process 2-3: Heat addition at constant volume.

Process 3-4: Reversible adiabatic expansion of air.

Process 4-1: Heat rejection at constant volume.



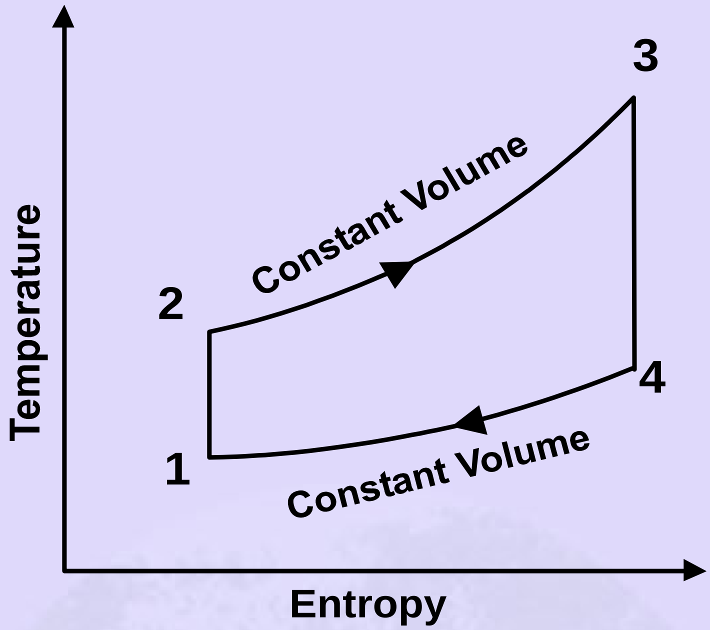


Fig.4.4. Otto cycle on p-v and T-s diagrams

Air Standard Efficiency:

$$\eta_{th} = \frac{\text{Net workdone}}{\text{Net heat added}}$$

Since processes 1-2 and 3-4 are adiabatic processes, the heat transfer during the cycle takes place only during processes 2-3 and 4-1 respectively. Therefore, thermal efficiency can be written as,

$$\eta_{th} = \frac{\text{Heat added - Heat rejected}}{\text{Heat added}}$$

Consider 'm' kg of working fluid,

$$\text{Heat added} = mC_V\left(T_3 - T_2\right)$$
$$\text{Heat Rejected} = mC_V\left(T_4 - T_1\right)$$

$$\eta_{th} = \frac{mC_V\left(T_3 - T_2\right) - mC_V\left(T_4 - T_1\right)}{mC_V\left(T_3 - T_2\right)} = 1 - \frac{T_4 - T_1}{T_3 - T_2}$$

For the reversible adiabatic processes 3-4 and 1-2, we can write,

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{\gamma - 1} \text{ and } \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma - 1}$$

$$v_2 = v_3 \text{ and } v_4 = v_1$$

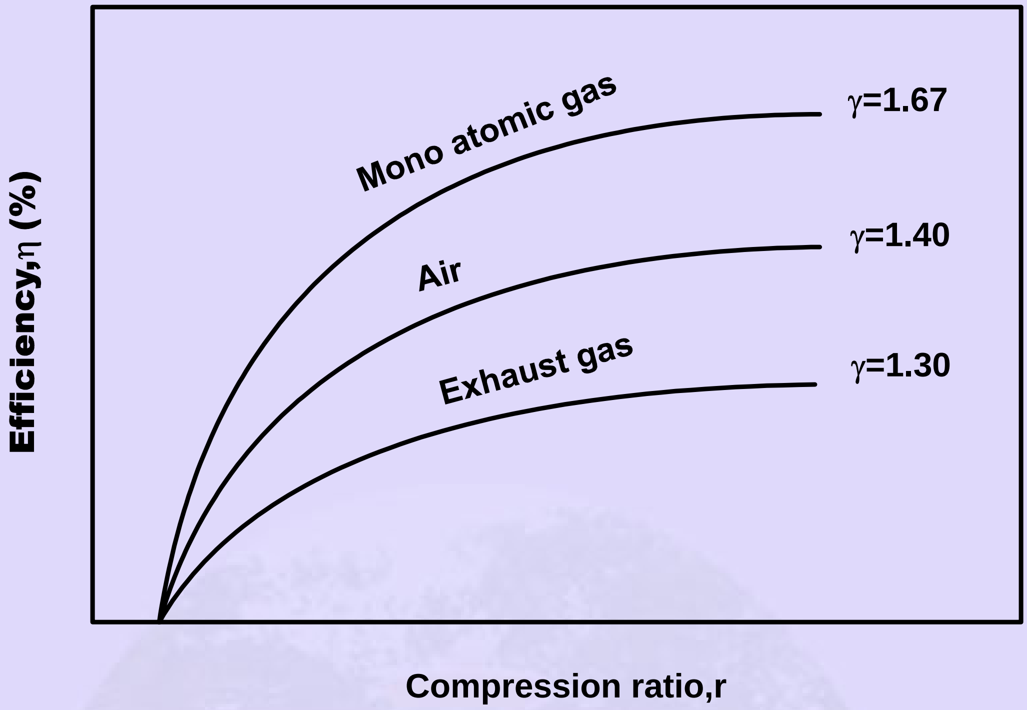
$$\frac{T_4}{T_3} = \frac{T_1}{T_2} = \frac{T_4 - T_1}{T_3 - T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma - 1}$$

$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - \left(\frac{V_2}{V_1}\right)^{\gamma - 1}$$

The ratio $\frac{V_1}{V_2}$ is called as compression ratio, r.

$$\eta_{th} = 1 - \left(\frac{1}{r}\right)^{\gamma - 1}$$

From the above equation, it can be observed that the efficiency of the Otto cycle is mainly the function of compression ratio for the given ratio of C_p and C_v. If we plot the variations of the thermal efficiency with increase in compression ratio for different gases, the curves are obtained as shown in Fig.4.4.1. Beyond certain values of compression ratios, the increase in the thermal efficiency is very small, because the curve tends to be asymptotic. However, practically the compression ratio of petrol engines is restricted to maximum of 9 or 10 due to the phenomenon of knocking at high compression ratios.



Effect of CR and γ on efficiency for Otto cycle.

Fig.4.4.1. Variation of thermal efficiency with compression ratio

Mean Effective Pressure:

Generally, it is defined as the ratio of the net workdone to the displacement volume of the piston.

Let us consider 'm' kg of working substance.

$$\text{Net work done} = m\,C_v\left\{(T_3 - T_2) - (T_4 - T_1)\right\}$$

$$\text{Displacement Volume} = (V_1 - V_2)$$

$$= V_1\left(1 - \frac{1}{r}\right) = \frac{m\,R\,T_1}{P_1}\left(\frac{r-1}{r}\right)$$

$$= \frac{m\,C_v(\gamma - 1)T_1}{P_1}\left\{\frac{r-1}{r}\right\}$$

since, $R = C_v(\gamma - 1)$

$$\text{mep} = \frac{\cancel{m}\,\cancel{C}_v\left[\left(T_3 - T_2\right) - \left(T_4 - T_1\right)\right]}{\dfrac{\cancel{m}\,\cancel{C}_v(\gamma - 1)\,T_1}{P_1}\left\{\left(\dfrac{r - 1}{r}\right)\right\}}$$

$$= \left(\frac{1}{\gamma - 1}\right)\left(\frac{p_1}{T_1}\right)\left(\frac{r}{r - 1}\right)\left\{\left(T_3 - T_2\right) - \left(T_4 - T_1\right)\right\}$$

Now, $\quad T_2 = T_1\left(r\right)^{\gamma-1}$

Let, $\quad r_p = \dfrac{P_3}{P_2} = \dfrac{T_3}{T_2} = \text{Pressure ratio}$

$$T_3 = \frac{P_3}{P_2}T_2 = r_p T_2 = r_p\, r^{\gamma-1}\, T_1 \qquad \text{(for V = C)}$$

So, $\quad T_4 = T_3\left(\dfrac{1}{r}\right)^{\gamma-1} = r_p\, r^{\gamma-1}\, T_1\left(\dfrac{1}{r}\right)^{\gamma-1} = r_p T_1$

$$\text{mep} = \frac{P_1\, r}{(r - 1)\,(\gamma - 1)}\left\{\left(r_p\, r^{\gamma-1} - r^{\gamma-1}\right) - \left(r_p - 1\right)\right\}$$

$$= P_1\, r\left\{\left(\frac{r^{\gamma-1}\left(r_p - 1\right) - \left(r_p - 1\right)}{(\gamma - 1)\,(r - 1)}\right)\right\}$$

$$\text{mep} = P_1\, r\left\{\frac{\left(r^{\gamma-1} - 1\right)\left(r_p - 1\right)}{(r - 1)\,(\gamma - 1)}\right\}$$