Internal Combustion Engines

Lecture-3

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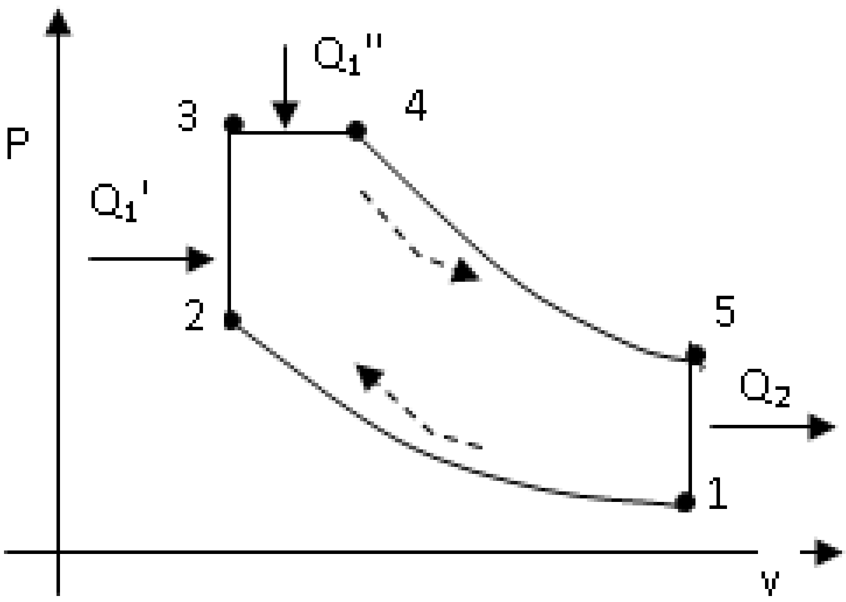
Air Standard Cycles

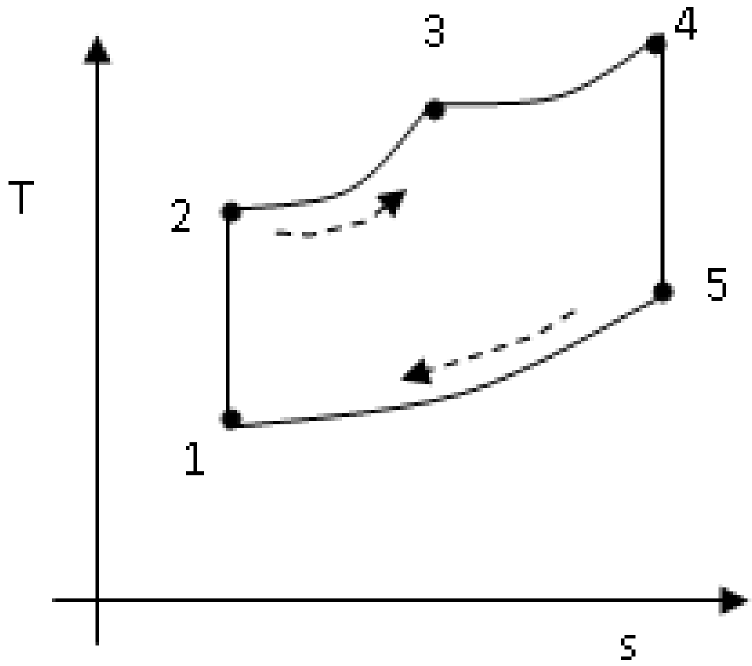
- When the motive fluid of a cycle is air – it is called air standard cycle
- Air standard cycles are considered as the ideal cycle for IC Engines
- It is an ideal cycle and considered as the limit for internal combustion engine operations

Assumptions:

- The mass of air circulated through the system is constant during the process
- Air is behaving like a perfect gas
- Instead of combustion some heat is added to the substance.
- The cycle is completed by rejecting some heat to the surrounding.
- All processes are internally reversible
- Specific heats are constant with respect to temperature.

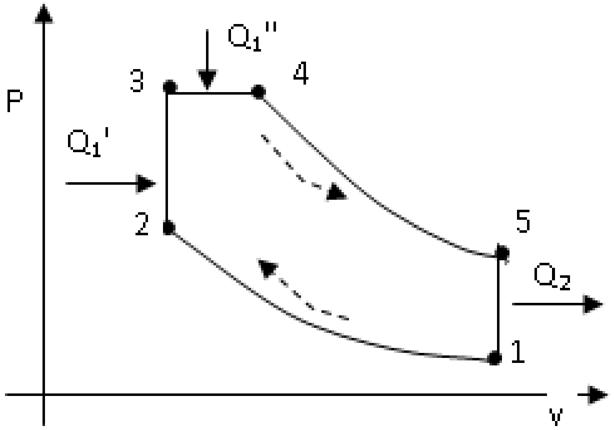
Dual Combustion Cycle





- In this cycle heat addition is in two steps –first at constant volume and secondly at constant pressure.
- is the heat addition at constant volume and is the heat addition at constant pressure. Q_2 is the amount of heat rejected to low temperature sink at constant volume.

Parameters



$$\text{Compression ratio} = r = \frac{v_1}{v_2}$$

$$\Pr essure\,\text{ratio} = \lambda = \frac{P_3}{P_2}$$

$$Cut\ off\ \ ratio = r_c = \frac{v_4}{v_3}$$

$$The\,Thermal\,\text{efficiency} = \eta_{th} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1^{'} + Q_1^{''}}$$

$$Now\,Q_1^{'} = C_V\left(T_3 - T_2\right)$$

$$Q_1^{''} = C_P\left(T_4 - T_3\right)$$

$$Q_2 = C_V\left(T_5 - T_1\right)$$

$$\therefore\ \eta_{th} = 1 - \frac{T_5 - T_1}{\left(T_3 - T_2\right) + \gamma\left(T_4 - T_3\right)} \quad \left[As\,\gamma = \frac{C_P}{C_V}\right]$$

Relation of State Points

At point 2

$$\frac{v_1}{v_2} = r$$

$$P_1 v_1^{\gamma} = P_2 v_2^{\gamma}$$

$$\therefore \frac{P_2}{P_1} = \left(\frac{v_1}{v_2}\right)^{\gamma} = r^{\gamma}$$

$$T_1 v_1^{(\gamma-1)} = T_2 v_2^{(\gamma-1)}$$

$$\therefore \frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1} = r^{(\gamma-1)}$$

At point 3

$$v_3 = v_2 = {v_1}/{r}$$

$$\frac{T_3}{T_2} = \frac{P_3}{P_2} = \lambda$$

$$\frac{P_3}{P_2} = \lambda$$

$$\therefore T_3 = T_2 \lambda$$

$$T_3 = T_1 r^{(\gamma-1)} \lambda$$

$$P_3 = P_2 \lambda = P_1 r^{\gamma} \lambda$$

At point 4

$$P_4 = P_3 = P_1 r^{\gamma} \lambda$$

$$\frac{v_4}{v_3} = r_c$$

$$\frac{T_4}{T_3} = \frac{v_4}{v_3} = r_c$$

$$\therefore v_4 = v_3 r_c = \frac{v_1 r_c}{r}$$

$$\therefore T_4 = T_3 r_c = T_1 r_c r^{(\gamma-1)} \lambda$$

At point 5

$$v_5 = v_1$$

$$P_5 = P_4 \left(\frac{v_4}{v_5}\right)^{\gamma} = P_1 r^{\gamma} \lambda \left(\frac{v_1 r_c}{v_1 r}\right)^{\gamma}$$

$$= P_1 \lambda r_c^{\gamma}$$

$$\frac{T_5}{T_4} = \left(\frac{v_4}{v_5}\right)^{\gamma-1} = \left(\frac{v_4}{v_1}\right)^{\gamma-1}$$

$$\left[{rc}/{r} = \left(\frac{V_4}{V_3}\right) \Big/ \left(\frac{V_1}{V_3}\right) = {V_4}/{V_1} \right]$$

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

$$T_5 = T_1 r^{(\gamma-1)} \lambda r_c \frac{r_c^{(\gamma-1)}}{r^{(\gamma-1)}}$$

$$= T_1 r_c^{\gamma} \lambda$$

Efficiencies

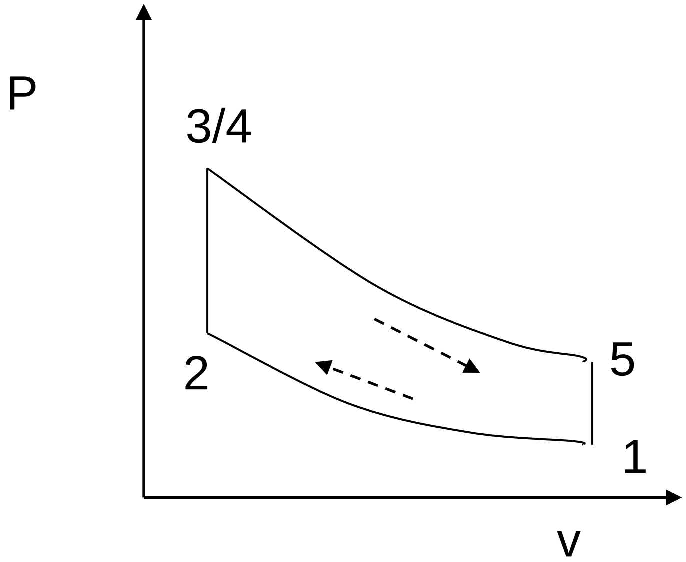
Substituting the obtained values of the temperatures, we get

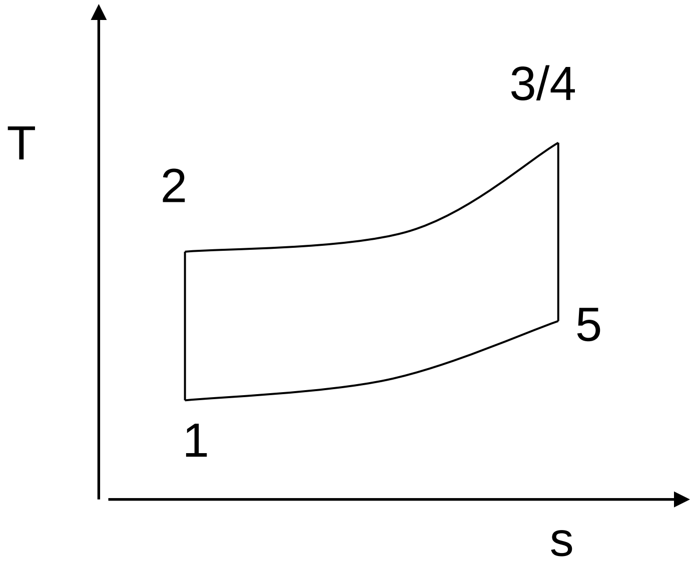
$$\eta_{th} = 1 - \frac{T_1 \lambda r_c{}^{\gamma} - T_1}{\left(T_1 r^{(\gamma-1)} \lambda - T_1 r^{(\gamma-1)}\right) + \gamma\left(T_1 r^{(\gamma-1)} \lambda\, r_c - T_1 r^{(\gamma-1)} \lambda\right)}$$

$$= 1 - \frac{\lambda r_c{}^{\gamma} - 1}{\left[r^{(\gamma-1)} \lambda - r^{(\gamma-1)}\right] + \gamma\left[r^{(\gamma-1)} \lambda\, r_c - r^{(\gamma-1)} \lambda\right]}$$

$$\eta_{th} = 1 - \frac{\lambda r_c{}^{\gamma} - 1}{r^{(\gamma-1)}\left[(\lambda - 1) + \lambda\gamma(r_c - 1)\right]}$$

Otto Cycle





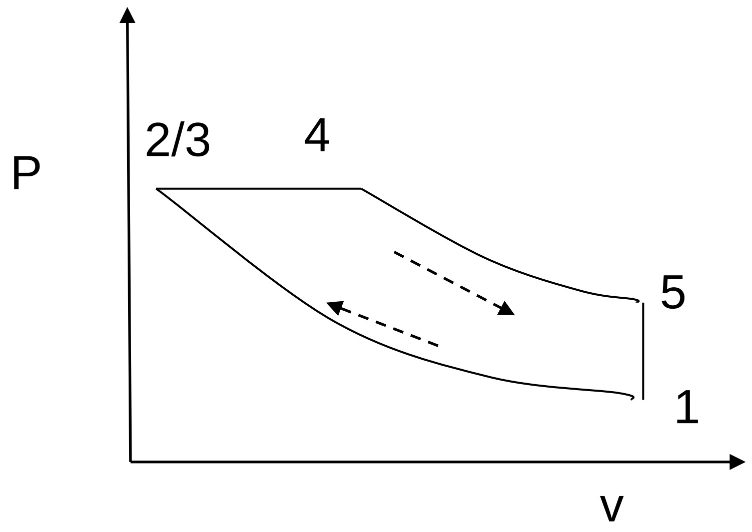
In Otto cycle, there is only constant volume heat addition. So points 3 and 4 are at the same location.

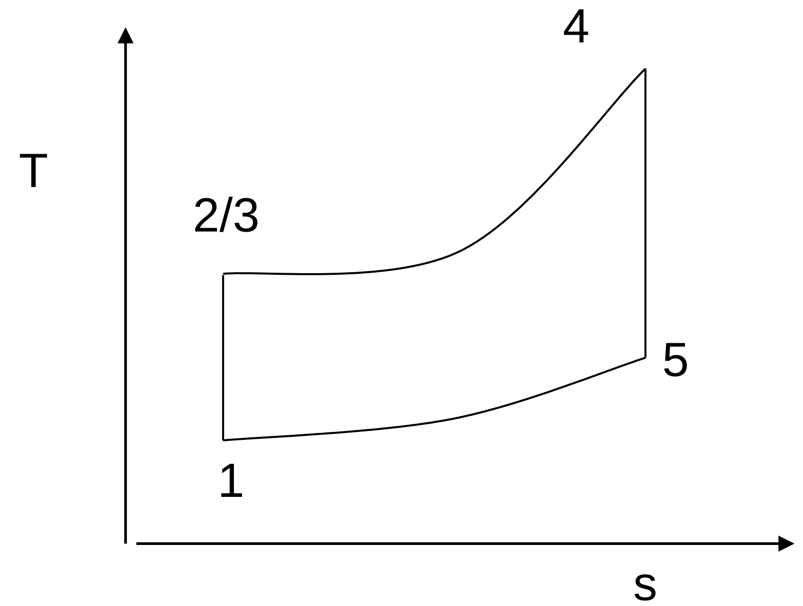
$$\text{For Otto Cycle } r_c = \frac{v_4}{v_3} = 1$$

$$\therefore \ \eta_{th} = 1 - \frac{\lambda - 1}{r^{(\gamma-1)}\left[(\lambda - 1) + \gamma\lambda(1-1)\right]}$$

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

Diesel Cycle





In Diesel cycle, there is only constant pressure heat addition. So points 2 and 3 are at the same location.

For Diesel Cycle λ=1

$$\eta_{th} = 1 - \frac{r_c^{\gamma} - 1}{r^{(\gamma-1)}.\gamma.(r_c - 1)}$$

- Derive the expression of efficiencies of Otto and Diesel cycles from first principle

Thank You