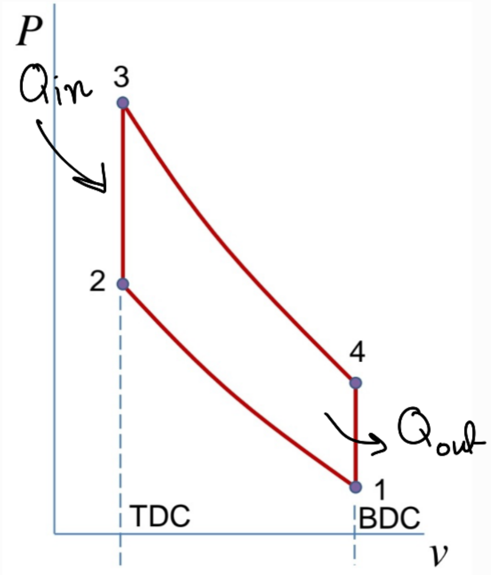
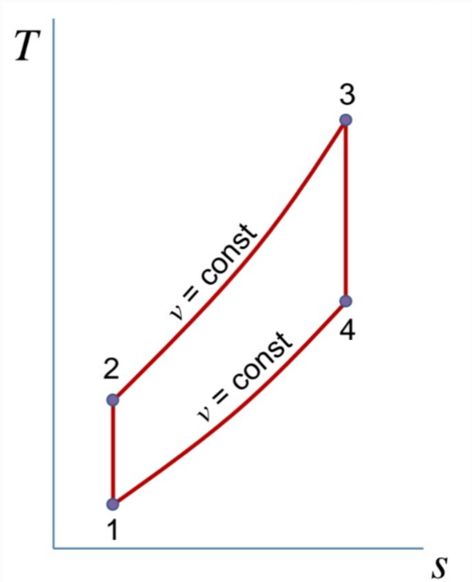
The Otto Cycle





1-2: Isentropic Compression $s_1 = s_2$

$W_{12} = m(u_2 - u_1)$

2-3: Isochoric heat input (combustion)

$v_2 = v_3$

$Q_{23} = m(u_3 - u_2)$

3-4: Isentropic expansion $s_3 = s_4$

$W_{34} = m(u_3 - u_4)$

4-1: Isochoric heat rejection $v_4 = v_1$

$Q_{41} = m(u_4 - u_1)$

Compression Ratio

$r^v = \frac{V_1}{V_2} = \frac{V_4}{V_3}$ (V_1 = swept volume + clearance volume; V_2 = clearance volume)

$\frac{P_2}{P_1} = (r_v)^k$, $\frac{P_4}{P_3} = \left(\frac{1}{r_v}\right)^k$

$\frac{T_4}{T_1} = \frac{T_3}{T_2}$

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

$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{k-1}$

$$\eta_{Th} = 1 - \frac{C_v(T_4 - T_1)}{C_v(T_3 - T_2)} = 1 - \frac{1}{(r_v)^{k-1}}$$

$$MEP = \frac{W_{net}}{\text{Displacement volume/cylinder}}$$

($W_{net} \rightarrow W_{34} - W_{12}$)

Note:

In 2-stroke engines

$r_{eff} = \frac{V_{max}}{V_{min}}$

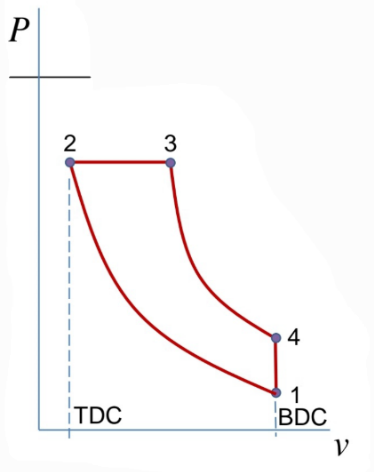
V_{max} = swept volume + clearance volume = eff. stroke × A + V_{min}

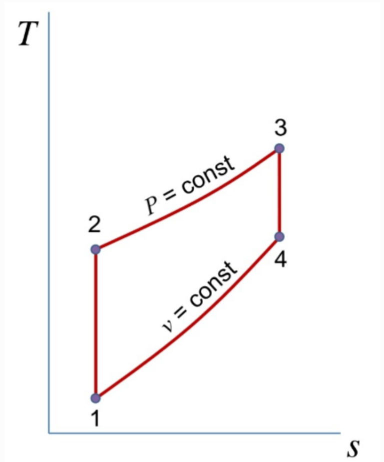
V_{min} = clearance volume

$Q_{23} = m_f \, HV$

HV = Heating value

Diesel Cycle





1-2 : Isentropic Compression $s_1 = s_2$

$W_{12} = m(u_2 - u_1)$

2-3 : Isobaric heat input (combustion)

$P_2 = P_3$

$Q_{23} - W_{23} = m(u_3 - u_2)$

3-4 : Isentropic expansion $s_3 = s_4$

$W_{34} = m(u_3 - u_4)$

4-1 : Isochoric heat rejection $v_4 = v_1$

$Q_{41} = m(u_4 - u_1)$

$MEP = \frac{W_{net}}{\text{Displacement volume/cylinder}}$

Note:

In 2-stroke engines

$r_{eff} = \frac{V_{max}}{V_{min}}$ ← Swept volume = eff. Stroke x A; V_{min} ← Clearance volume

Compression Ratio

$r_v = \frac{V_1}{V_2} = \frac{V_4}{V_3}$ (V_1 ← swept volume + clearance volume; V_2 ← clearance volume)

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

$T_4 = T_3 / \left(\frac{r_v}{X}\right)^{k-1}$

Cutoff Ratio

$X = \frac{V_3}{V_2}$

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

$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^k$

$\eta_{Th} = 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)} = 1 - \frac{T_4 - T_1}{k(T_3 - T_2)}$

$Q_{23} = m_f \, HV$ ← Heating value

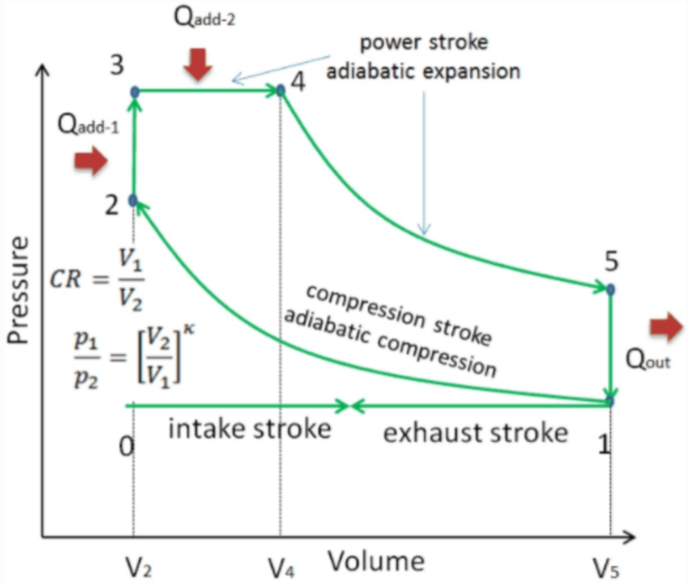
$W_{net} = W_{23} + W_{34} - W_{12}$

$Power = W_{net} \times n \times \frac{N}{2 \times 60}$ (n ← number of cylinders; N ← RPM)

The Dual Cycle

$$Q_{add\text{-}1} = m\,C_v(T_3 - T_2)$$
$$Q_{add\text{-}2} = m\,C_p(T_4 - T_3)$$
$$Q_{add\text{-}Tot} = Q_{add\text{-}1} + Q_{add\text{-}2}$$
$$Q_{out} = m\,C_v(T_5 - T_1)$$

$$\eta_{Th} = 1 - \frac{C_v(T_5 - T_1)}{C_v(T_3 - T_2) + C_p(T_4 - T_3)}$$



Compression ratio

$$r_v = \frac{V_1}{V_2} \quad / \quad A/F = \frac{m_a}{m_f}$$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{K} \quad / \quad \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{K-1} \quad / \quad \frac{T_5}{T_4} = \left(\frac{V_4}{V_5}\right)^{K-1}$$

In General

MEP → Indicative (cylinder)
MEP → Break (Shaft)

$$\text{Brake power} = P_b\,L\,A\,N\,n$$

Piston Area (A)
Stroke length (L)
n: 2 stroke → rev/s; 4 strokes → rev/s

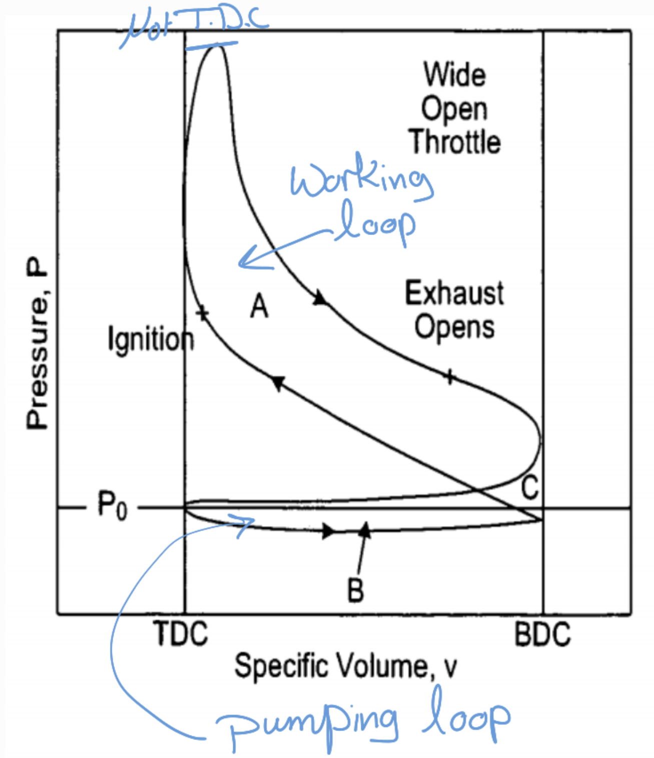
$$SFC = \frac{m_f}{W}$$

W: output Work

The Actual Cycle

It is an open cycle with changing composition
Lower efficiency than standard cycles due to **losses**:

1. Losses due to cp & cv changing
2. Losses due to dissociation ← endothermic reaction that takes away energy
   $CO_2 \longrightarrow O_2 + CO$
3. time losses: burning is not instantaneous / Max Pressure is not at (after) T.D.C and so less work



Engine → Fast / Slo