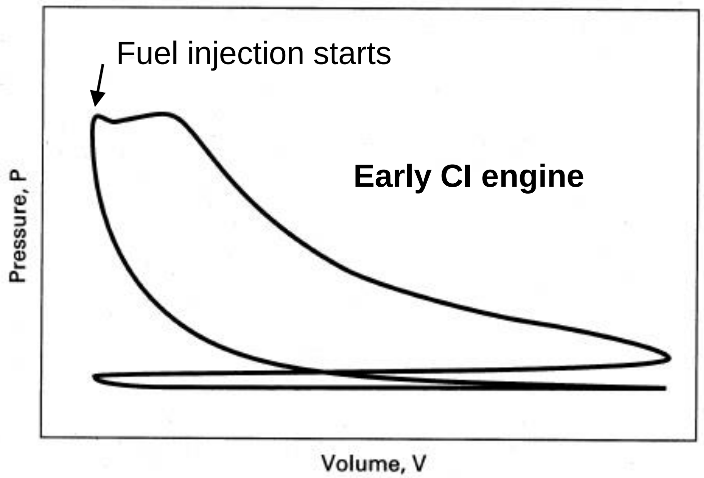
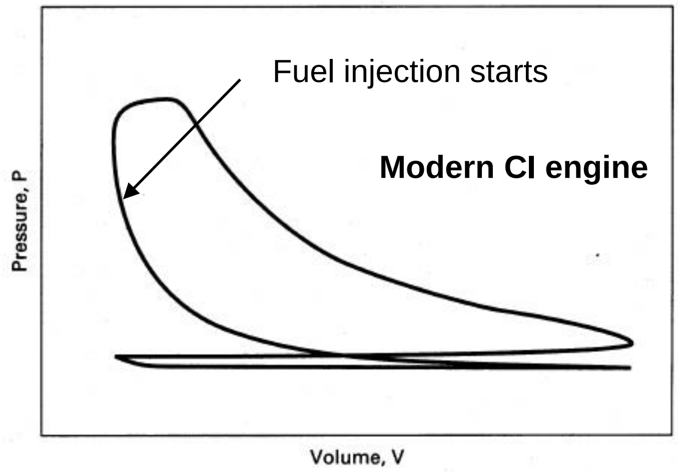
Thermodynamic Cycles for CI engines

- In early CI engines the fuel was injected when the piston reached TC and thus combustion lasted well into the expansion stroke.

- In modern engines the fuel is injected before TC (about 20º)

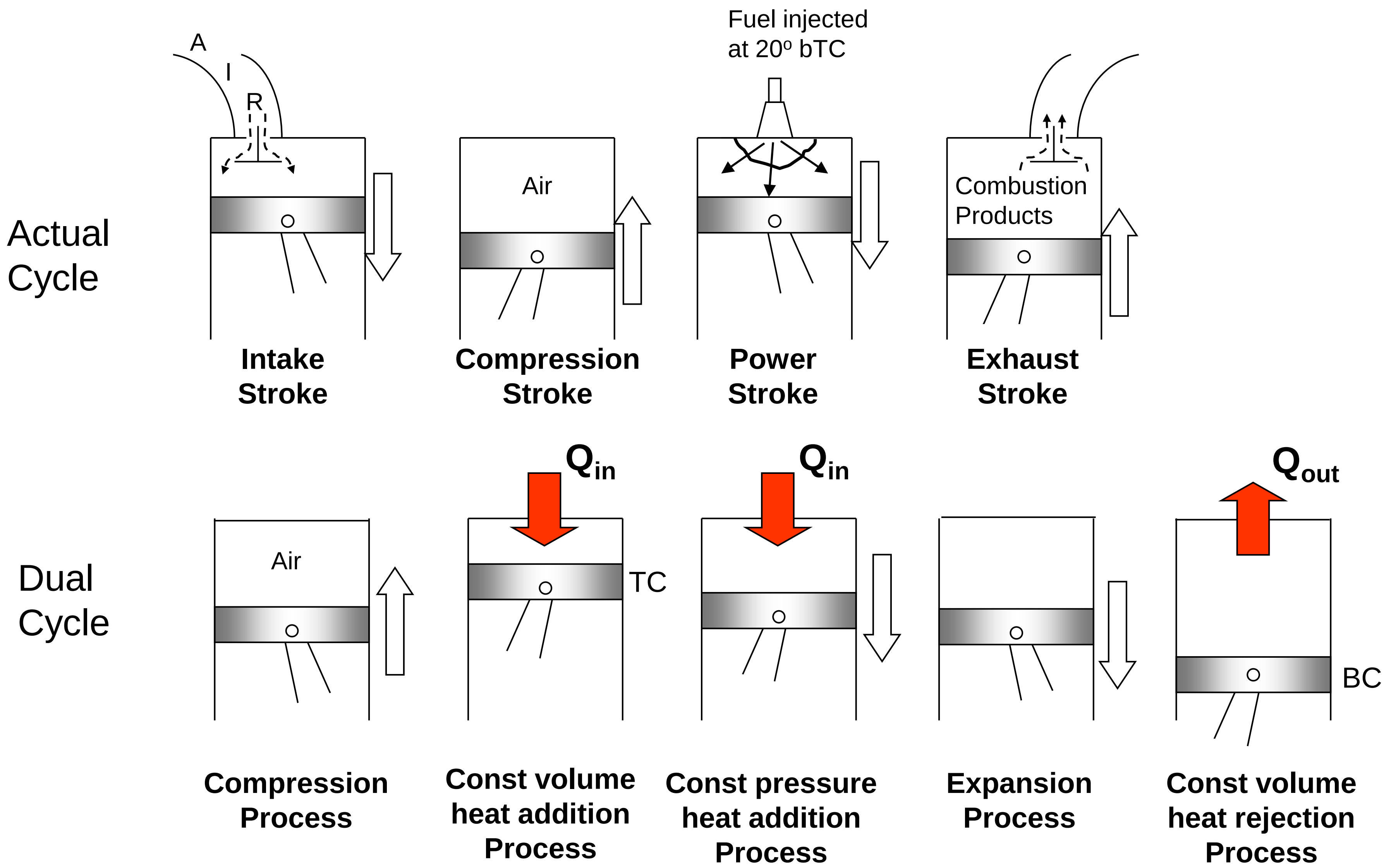




- The combustion process in the early CI engines is best approximated by a constant pressure heat addition process → **Diesel Cycle**

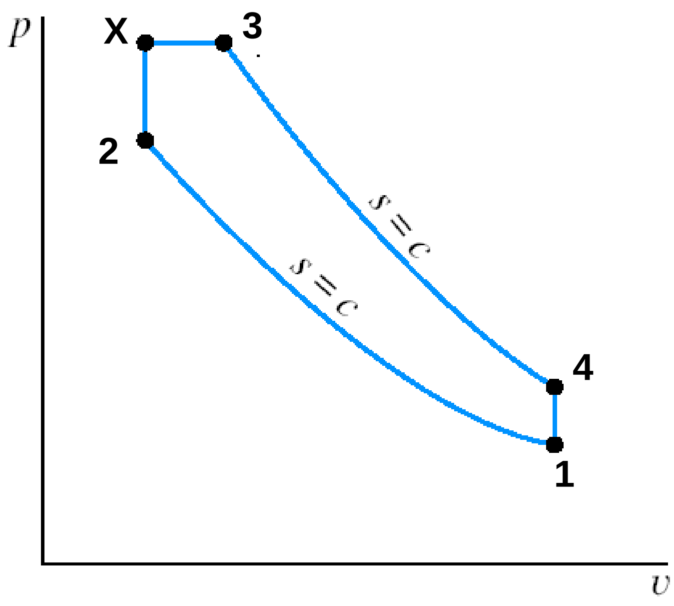
- The combustion process in the modern CI engines is best approximated by a combination of constant volume & constant pressure → **Dual Cycle**

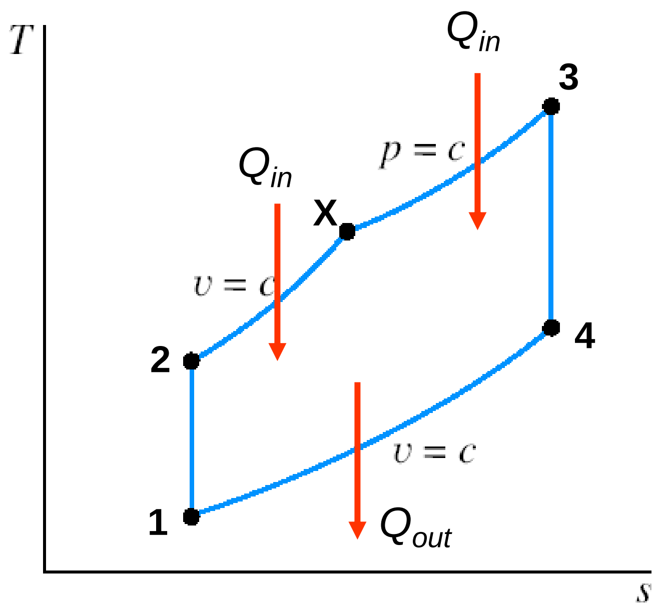
Modern CI Engine Cycle vs Dual Cycle



Dual Cycle

Process 1 → 2 Isentropic compression
Process 2 → X Constant volume heat addition
Process X → 3 Constant pressure heat addition
Process 3 → 4 Isentropic expansion
Process 4 → 1 Constant volume heat rejection





Thermal Efficiency

$$\eta_{\substack{Dual\\cycle}} = 1 - \frac{Q_{out}/m}{Q_{in}/m} = 1 - \frac{u_4 - u_1}{(u_X - u_2) + (h_3 - h_X)}$$

For cold air-standard the above reduces to:

$$\eta_{\substack{Diesel\\const\ c_v}} = 1 - \frac{1}{r^{k-1}}\left[\frac{\alpha r_c^k - 1}{(\alpha - 1) + \alpha k (r_c - 1)}\right]$$

where $r_c = v_3/v_X$ and $\alpha = P_3/P_2$

Note, the Otto cycle ($r_c = 1$) and the Diesel cycle ($\alpha = 1$) are special cases:

$$\eta_{Otto} = 1 - \frac{1}{r^{k-1}}$$

$$\eta_{\substack{Diesel\\const\ c_V}} = 1 - \frac{1}{r^{k-1}}\left[\frac{1}{k} \cdot \frac{\left(r_c^k - 1\right)}{\left(r_c - 1\right)}\right]$$

The use of the Dual cycle requires information about either the fractions of constant volume and constant pressure heat addition (common assumption is to equally split the heat addition), or the maximum pressure P_3.

Transformation of r_c and α into more natural variables yields

$$r_c = 1 - \frac{k-1}{\alpha k}\left[\left(\frac{Q_{in}}{P_1 V_1}\right)\frac{1}{r^{k-1}} - \frac{\alpha - 1}{k-1}\right] \qquad \alpha = \frac{1}{r^k}\frac{P_3}{P_1}$$

For the same inlet conditions P_1, V_1 and the same compression ratio:

$$\eta_{Otto} > \eta_{Dual} > \eta_{Diesel}$$

For the same inlet conditions P_1, V_1 and the same peak pressure (actual design limitation in engines):

$$\eta_{Diesel} > \eta_{Dual} > \eta_{otto}$$