Thermodynamic Cycles

Air-standard analysis is a simplification of the real cycle that includes the following assumptions:

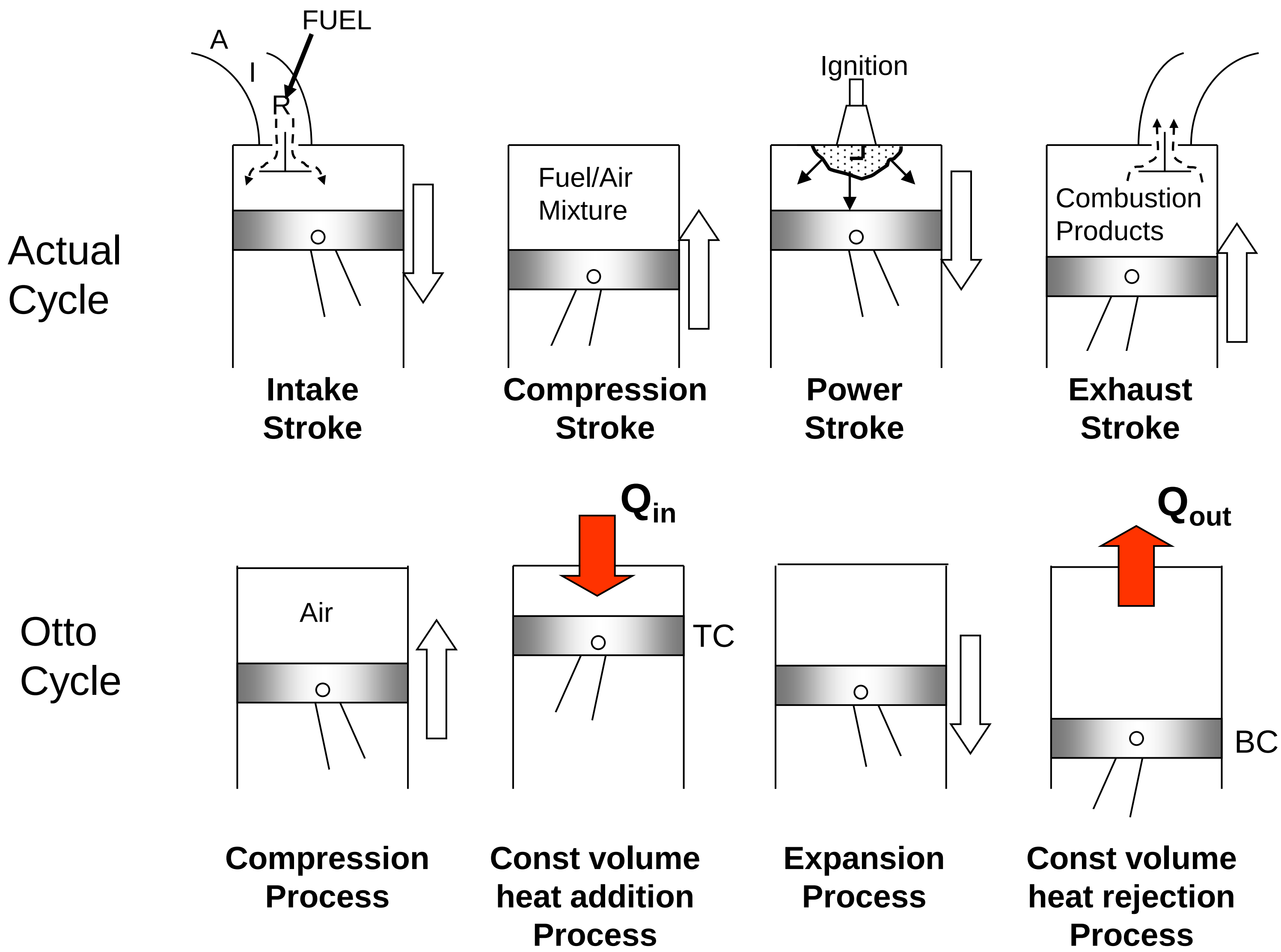
1) Working fluid consists of fixed amount of air (ideal gas)

2) Combustion process represented by heat transfer into and out of the cylinder from an external source

3) Differences between intake and exhaust processes not considered (i.e. no pumping work)

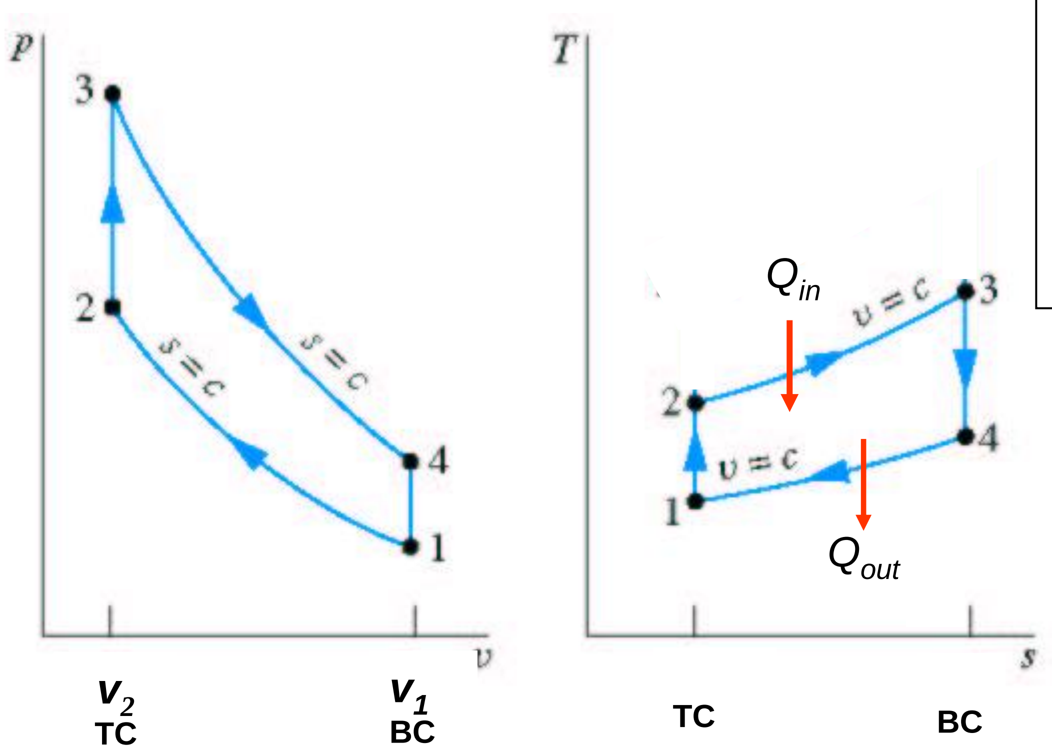
4) Engine friction and heat losses not considered

SI Engine Cycle vs Air Standard Otto Cycle



Air-Standard Otto cycle

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

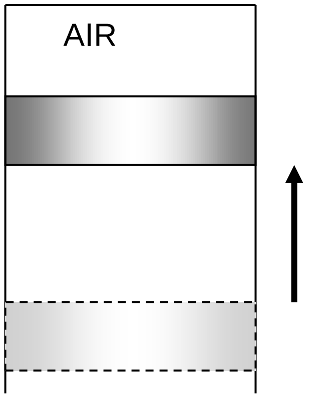


Compression ratio:

$$r = \frac{v_1}{v_2} = \frac{v_4}{v_3}$$

First Law Analysis of Otto Cycle

1→2 Isentropic Compression



$$(u_2 - u_1) = \frac{\cancel{Q}}{m} - (-\frac{W_{in}}{m})$$

$$\boxed{\frac{W_{in}}{m} = (u_2 - u_1)}$$

$$\boxed{\frac{v_{r_2}}{v_{r_1}} = \frac{v_2}{v_1} = \frac{1}{r}}$$

$$R = \frac{P_2 v_2}{T_2} = \frac{P_1 v_1}{T_1} \rightarrow \boxed{\frac{P_2}{P_1} = \frac{T_2}{T_1} \cdot \frac{v_1}{v_2}}$$

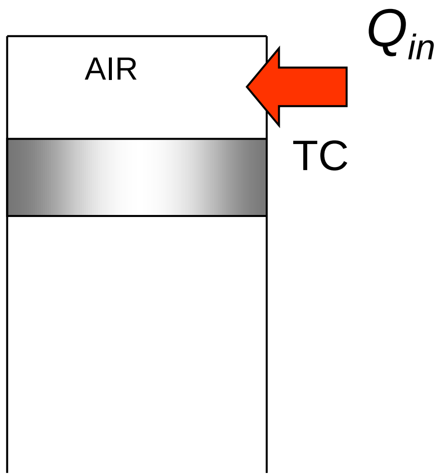
First Law Analysis of Otto Cycle

2→3 <u>Constant Volume Heat Addition</u>

$$(u_3 - u_2) = (+\frac{Q_{in}}{m}) - \frac{\cancel{W}}{m}$$

$$\boxed{\frac{Q_{in}}{m} = (u_3 - u_2)}$$

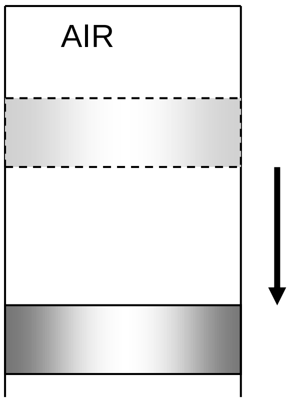
$$v = \frac{P_2}{RT_2} = \frac{P_3}{RT_3} \rightarrow \boxed{\frac{P_3}{P_2} = \frac{T_3}{T_2}}$$



First Law Analysis of Otto Cycle

3 → 4 <u>Isentropic Expansion</u>

$$(u_4 - u_3) = \frac{\not{Q}}{m} - (+\frac{W_{out}}{m})$$



$$\boxed{\frac{W_{out}}{m} = (u_3 - u_4)}$$

$$\boxed{\frac{v_{r_4}}{v_{r_3}} = \frac{v_4}{v_3} = r}$$

$$\frac{P_4 v_4}{T_4} = \frac{P_3 v_3}{T_3} \rightarrow \boxed{\frac{P_4}{P_3} = \frac{T_4}{T_3} \cdot \frac{v_3}{v_4}}$$

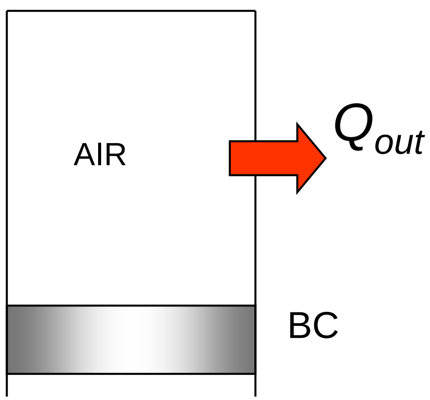
First Law Analysis of Otto Cycle

4 → 1 Constant Volume Heat Removal

$$(u_1 - u_4) = (-\frac{Q_{out}}{m}) - \frac{W}{m}$$

$$\boxed{\frac{Q_{out}}{m} = (u_4 - u_1)}$$

$$v = \frac{P_4}{RT_4} = \frac{P_1}{RT_1} \rightarrow \boxed{\frac{P_4}{T_4} = \frac{P_1}{T_1}}$$



First Law Analysis

Net cycle work:

$$W_{cycle} = W_{out} - W_{in} = m(u_3 - u_4) - m(u_2 - u_1)$$

Cycle thermal efficiency:

$$\eta_{th} = \frac{W_{cycle}}{Q_{in}} = \frac{W_{out} - W_{in}}{Q_{in}} = \frac{(u_3 - u_4) - (u_2 - u_1)}{(u_3 - u_2)}$$

$$\eta_{th} = \frac{(u_3 - u_2) - (u_4 - u_1)}{u_3 - u_2} = 1 - \frac{u_4 - u_1}{u_3 - u_2}$$

Cold Air-Standard Analysis

• For a cold air-standard analysis the specific heats are assumed to be constant evaluated at ambient temperature values ($k = c_p/c_v = 1.4$).

• For the two isentropic processes in the cycle, assuming ideal gas with constant specific heat using $Pv^k = const.$ $Pv = RT$ yields:

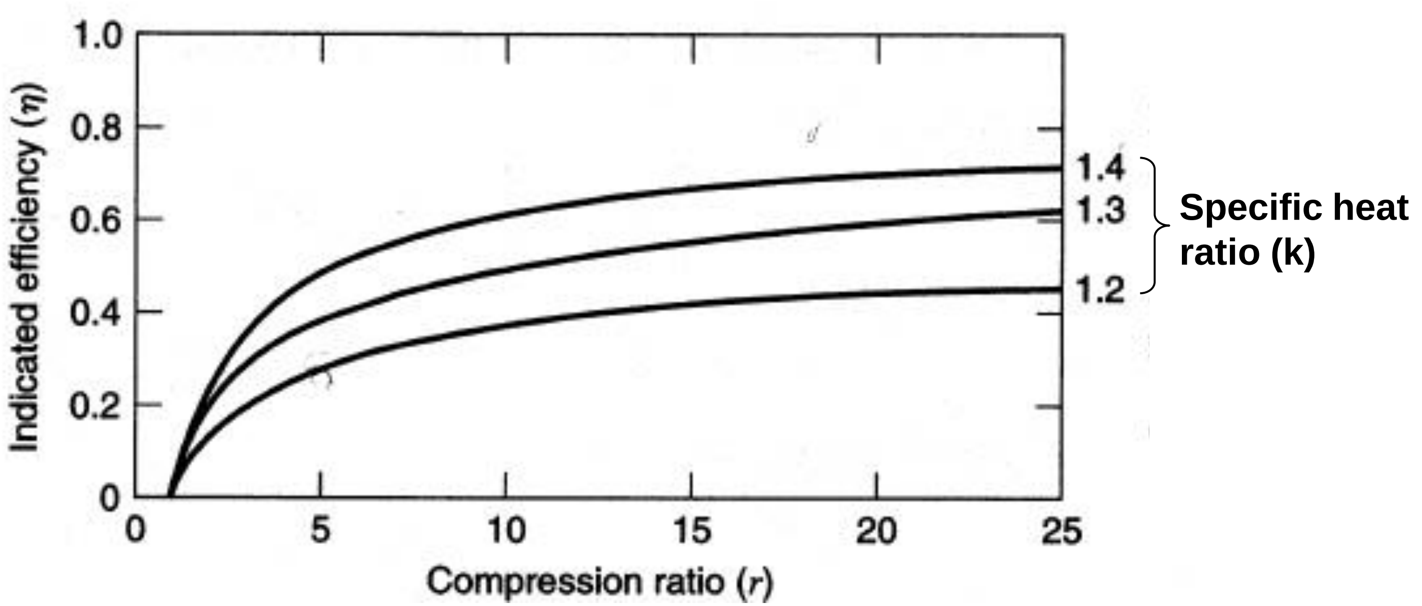
1 → 2 : $$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{k-1} = r^{k-1} \qquad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

3 → 4 : $$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{k-1} = \left(\frac{1}{r}\right)^{k-1} \qquad \frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}}$$

$$\eta_{th_{const\ c_V}} = 1 - \frac{c_v(T_4 - T_1)}{c_v(T_3 - T_2)} = 1 - \frac{T_1}{T_2} = \boxed{1 - \frac{1}{r^{k-1}}}$$

Effect of Specific Heat Ratio

$$\eta_{th}\Big|_{const\ c_V} = 1 - \frac{1}{r^{k-1}}$$



Cylinder temperatures vary between 20K and 2000K where 1.2 < k < 1.4