Otto-, Diesel-, Brayton- & Stirling-Cycles

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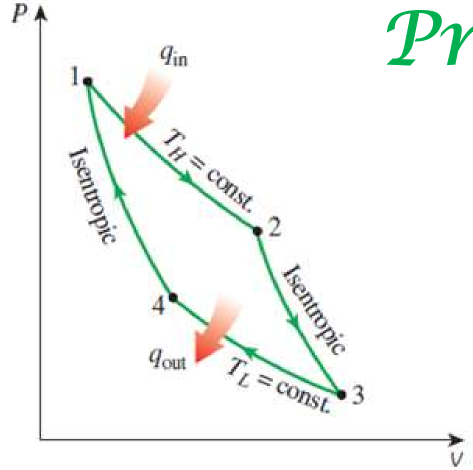
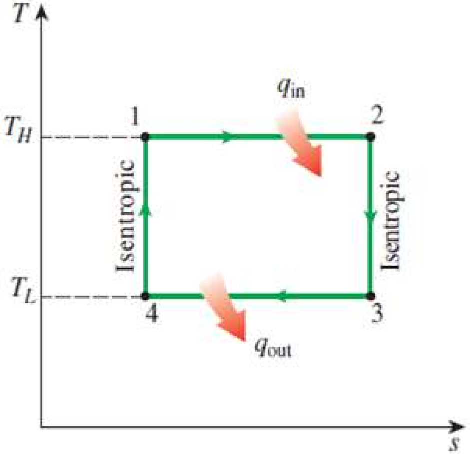
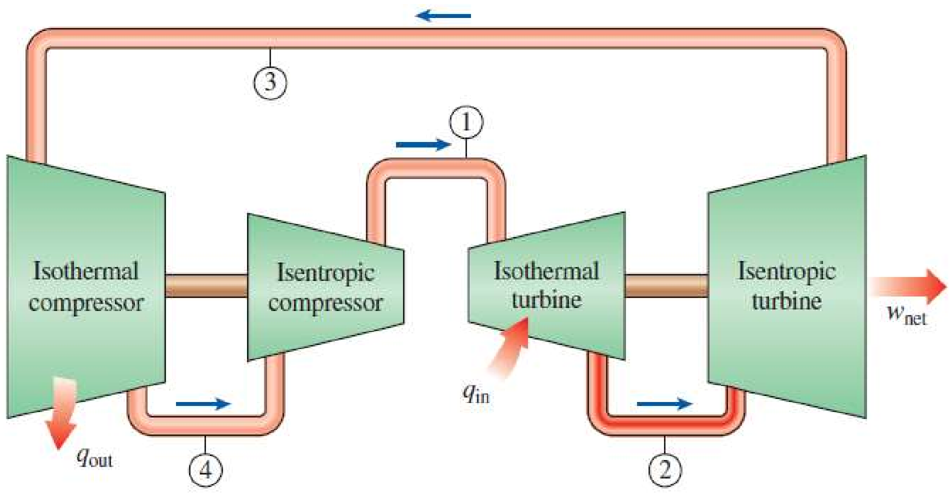
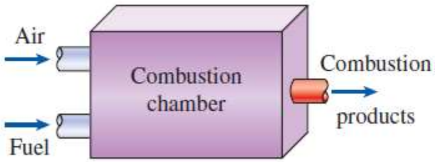
Previously: Gas power cycles

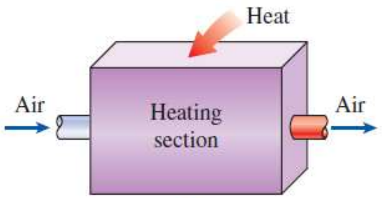




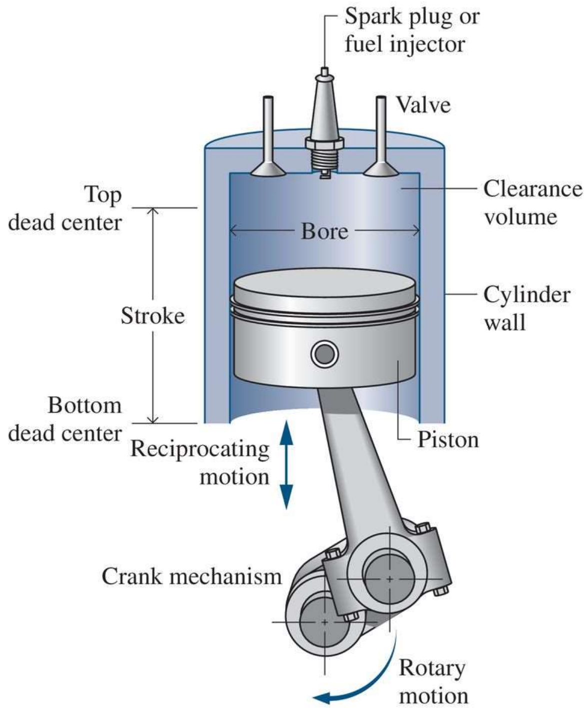


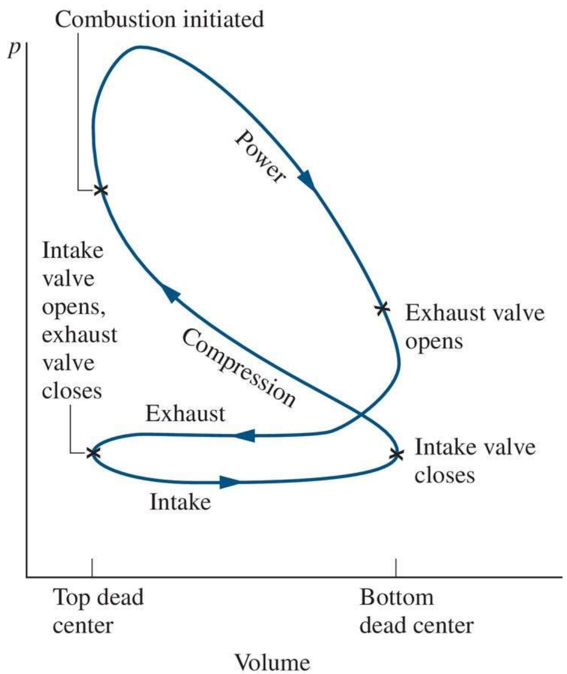


(*a*) Actual



(*b*) Ideal





TD: Cengel & Boles; Moran, Shapiro, Boettner & Bailey

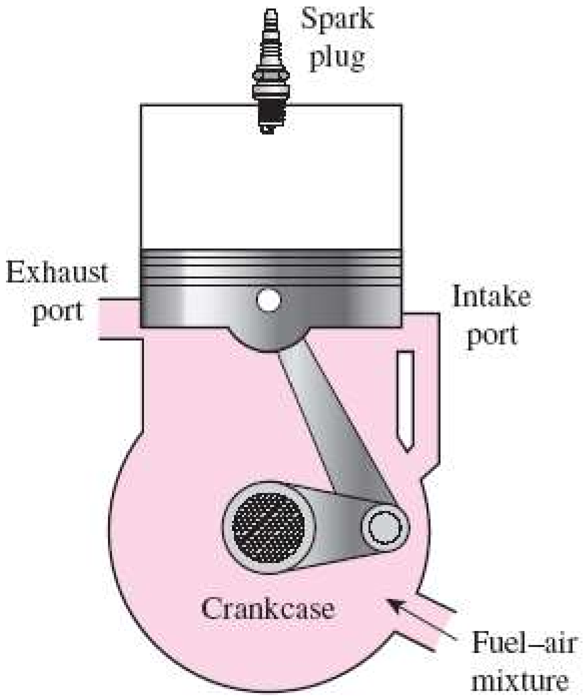
Two-Stroke Otto Cycle

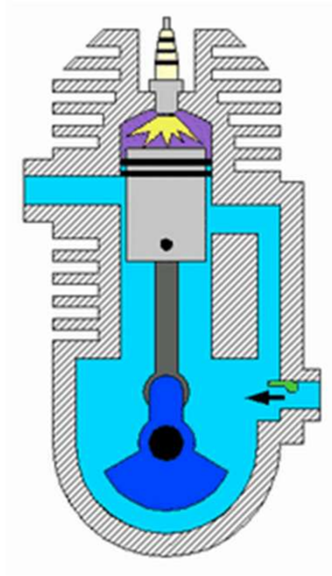
Four-stroke cycle

1 cycle = 4 stroke = 2 revolution

Two-stroke cycle

1 cycle = 2 stroke = 1 revolution

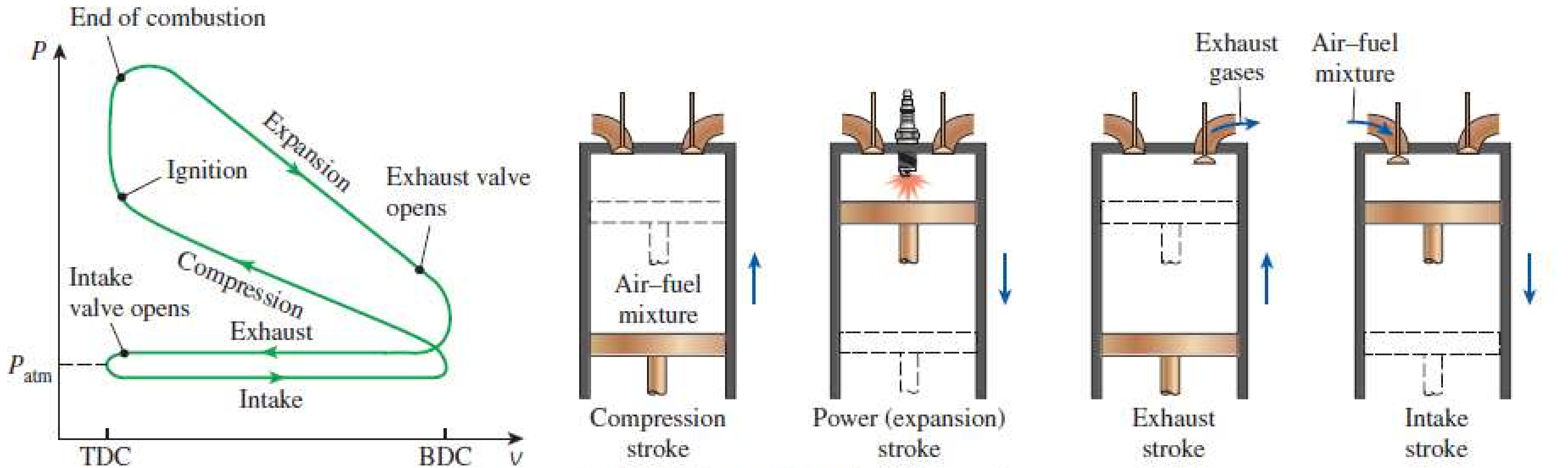




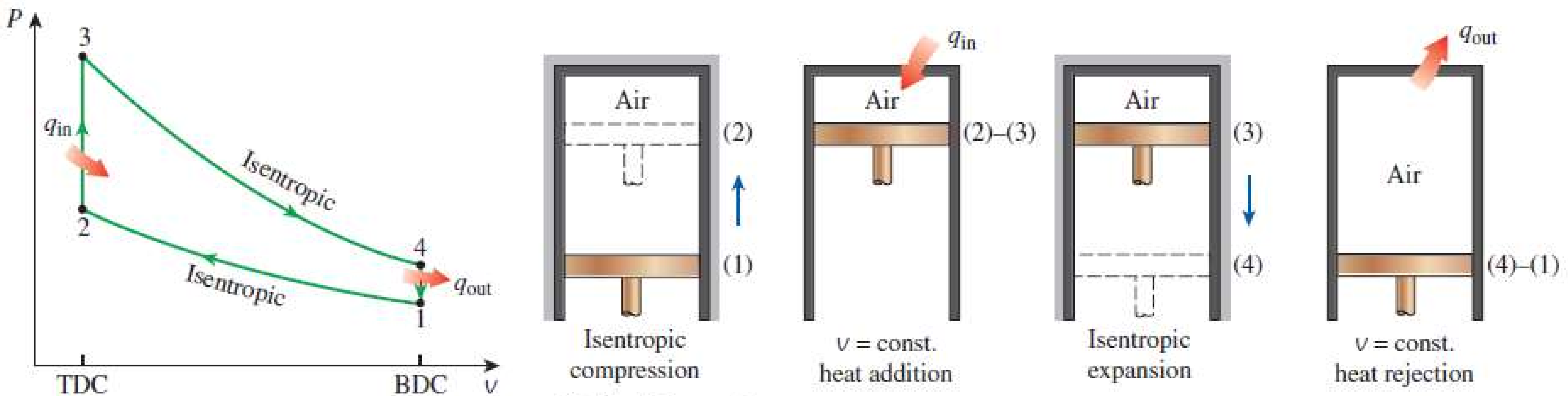
https://en.wikipedia.org/wiki/Two-stroke_engineTD: Cengel & Boles

Otto Cycle & Spark-ignition engine (4-stroke)

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet}$$



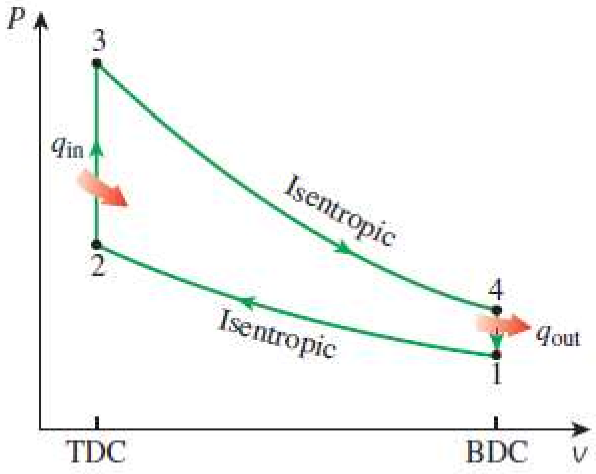
(*a*) Actual four-stroke spark-ignition engine

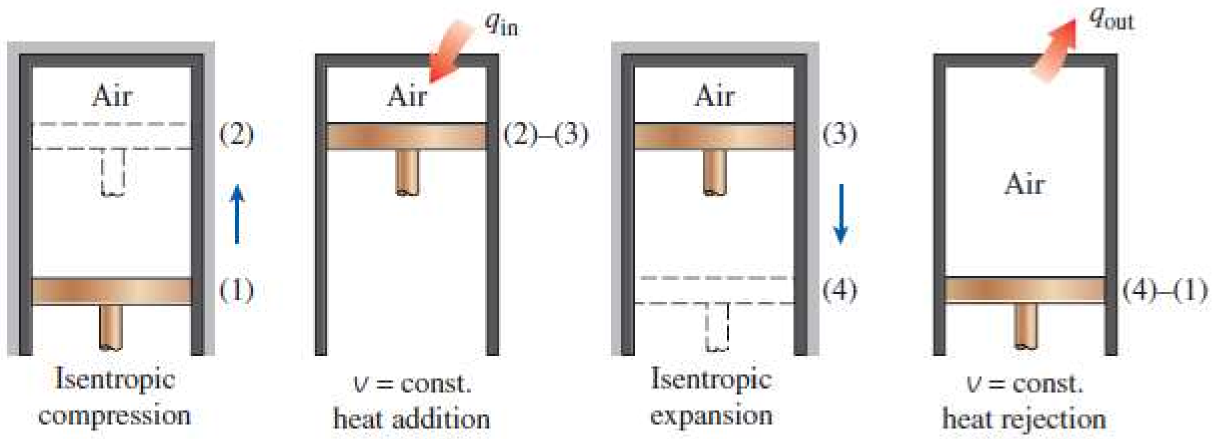


(*b*) Ideal Otto cycle

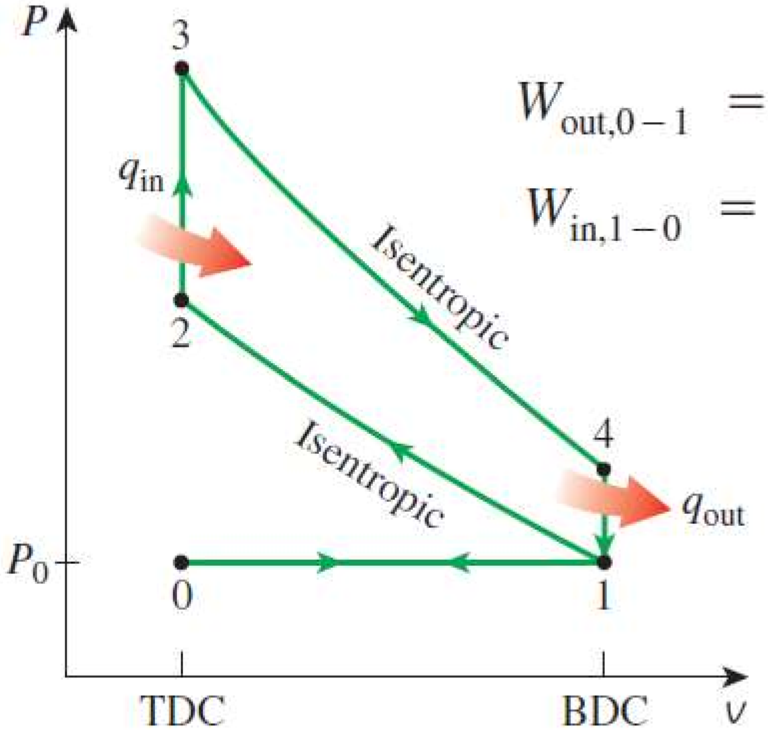
TD: Cengel & Boles

Ideal Otto Cycle engine



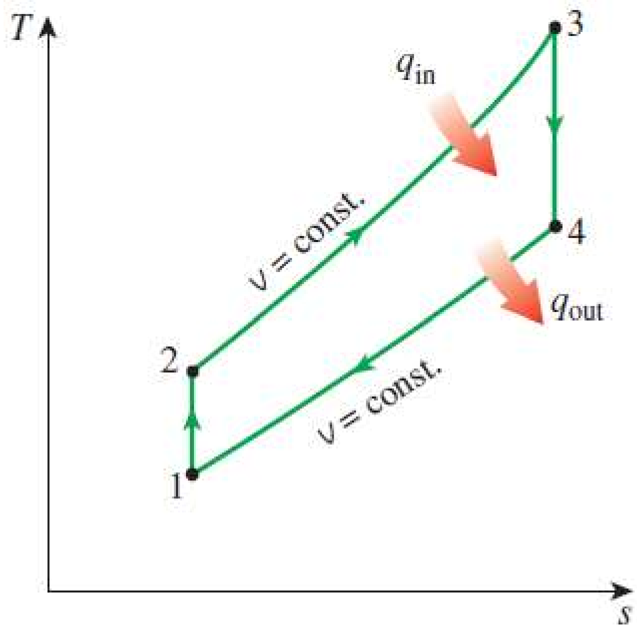


(*b*) Ideal Otto cycle



$$W_{out,0-1} = P_0(v_1 - v_0)$$

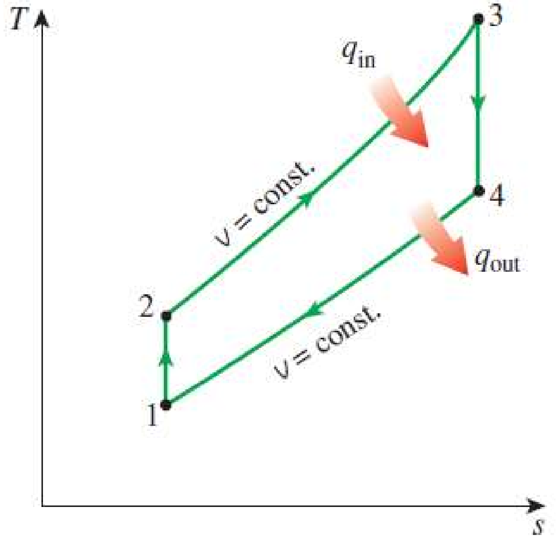
$$W_{in,1-0} = P_0(v_1 - v_0)$$

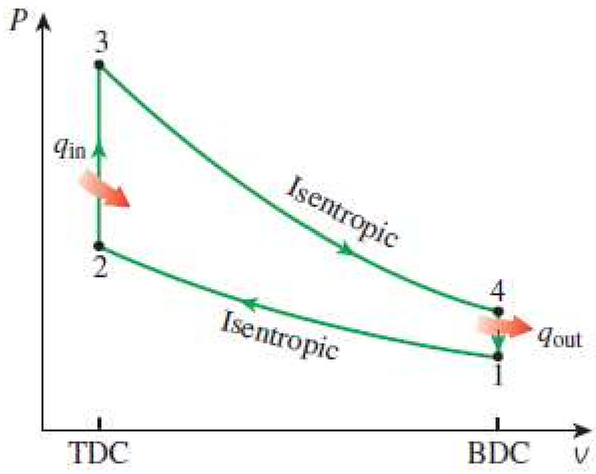


TD: Cengel & Boles

Analysis of Otto Cycle

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





$$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$$

$$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$

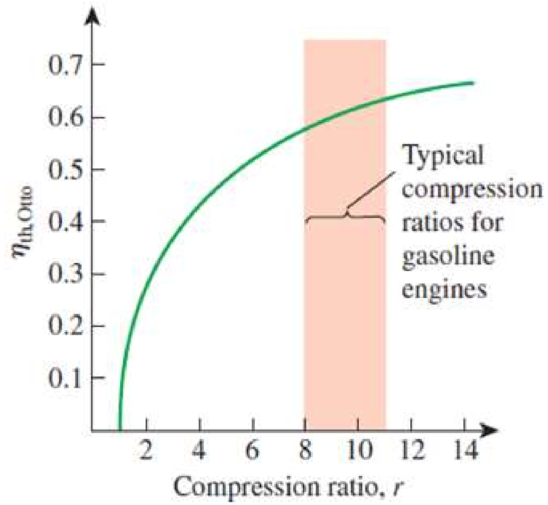
$$\eta_{th,Otto} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

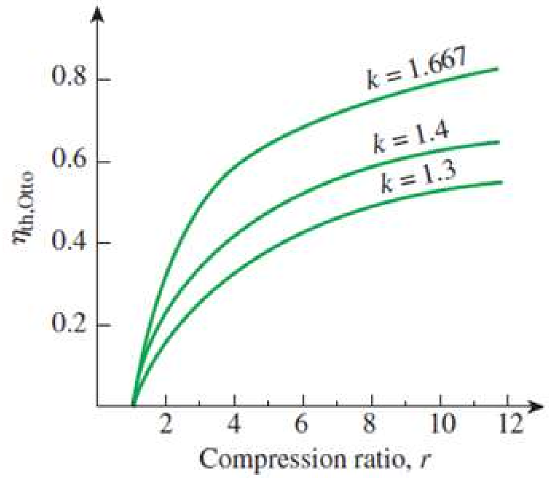
Isoentropic gas results for 1→2 & 3→ 4

$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{k-1} = \left(\frac{v_3}{v_4}\right)^{k-1} = \frac{T_4}{T_3}$$

$$r = \frac{V_{max}}{V_{min}}$$

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

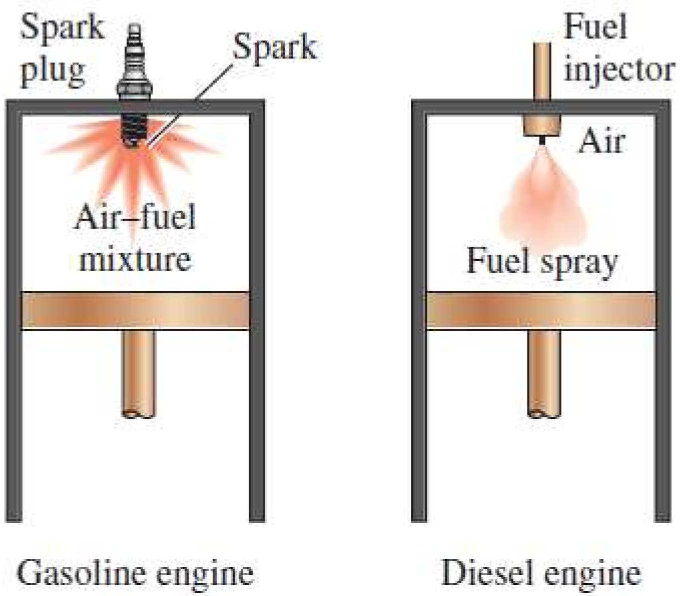




Compression ratio & autoignition/engine knock

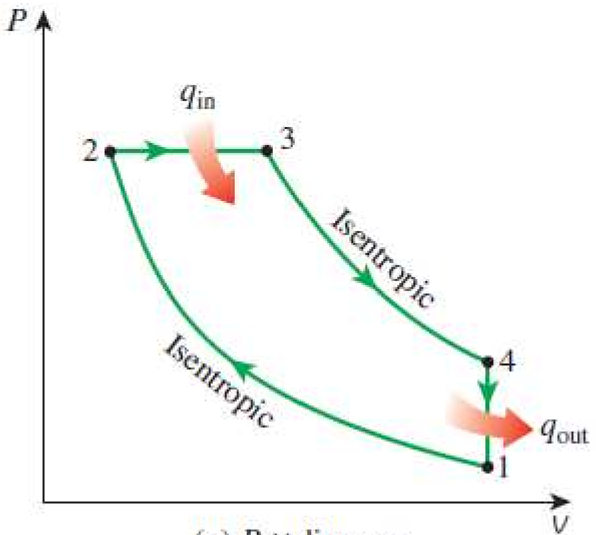
TD: Cengel & Boles

Diesel engine & compression-ignition engines

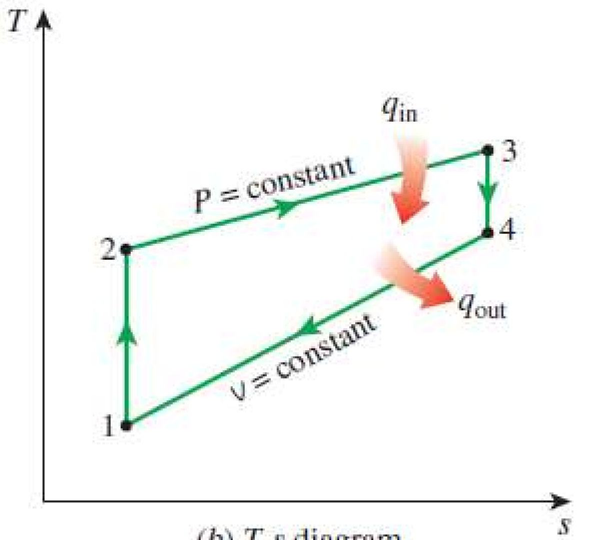


TD: Cengel & Boles

Analysis of Diesel-engines



(a) P-v diagram



(b) T-s diagram

$$q_{in} - w_{b,out} = u_3 - u_2 \rightarrow q_{in} = P_2(v_3 - v_2) + (u_3 - u_2)$$
$$= h_3 - h_2 = c_p(T_3 - T_2)$$
$$-q_{out} = u_1 - u_4 \rightarrow q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$$
$$\eta_{th,Diesel} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{k(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{kT_2(T_3/T_2 - 1)}$$

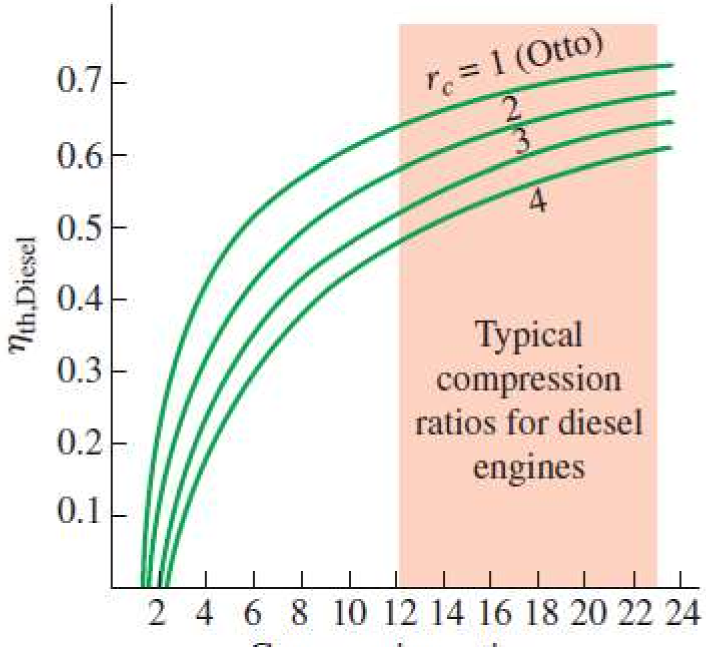
Isoentropic gas results for 1→2 & 3→ 4

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

$$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$$

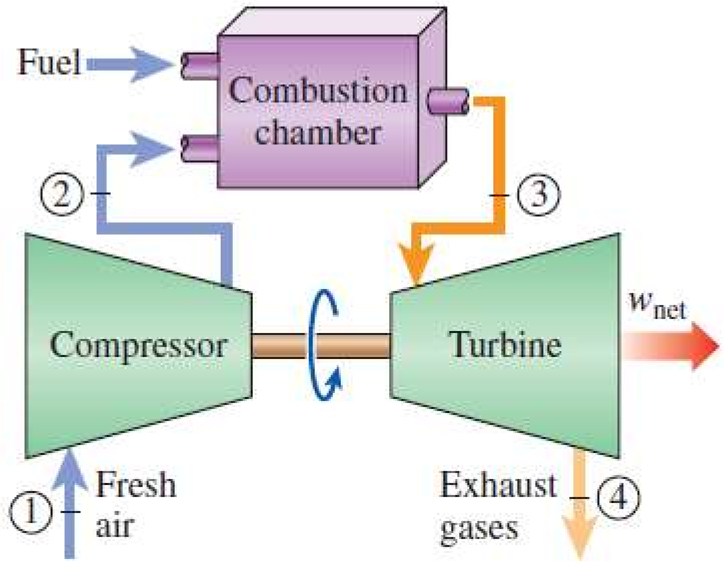
$$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$$

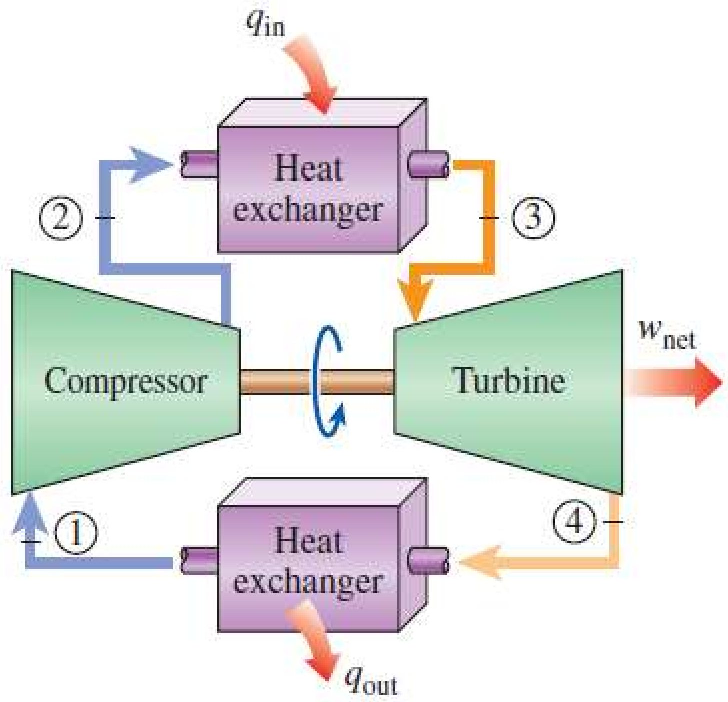
$$\eta_{th,Otto} > \eta_{th,Diesel}$$



TD: Cengel & Boles

Brayton Cycle

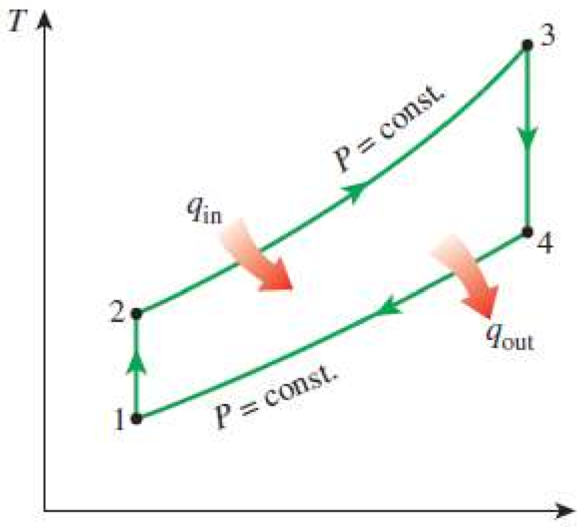




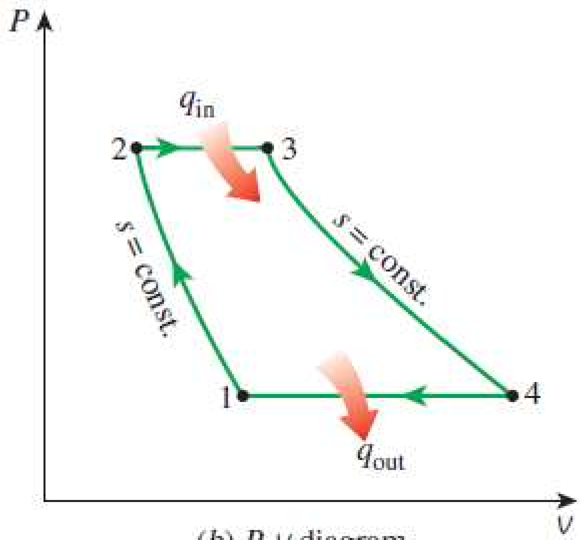
1-2 Isentropic compression (in a compressor)
2-3 Constant-pressure heat addition
3-4 Isentropic expansion (in a turbine)
4-1 Constant-pressure heat rejection

TD: Cengel & Boles

Analysis of Brayton Cycle



(a) T-s diagram



(b) P-v diagram

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet}$$

$$q_{in} = h_3 - h_2 = c_p(T_3 - T_2)$$

$$q_{out} = h_4 - h_1 = c_p(T_4 - T_1)$$

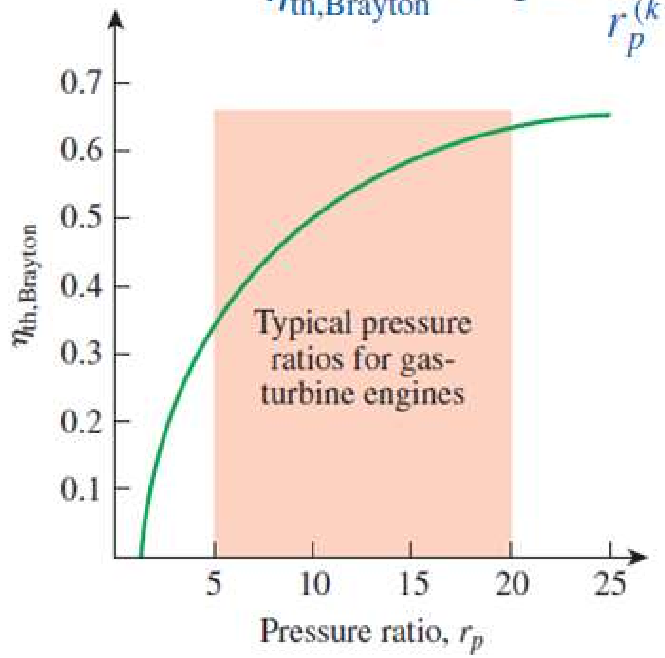
$$\eta_{th,Brayton} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

Isoentropic gas results for 1→2 & 3→ 4

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = \left(\frac{P_3}{P_4}\right)^{(k-1)/k} = \frac{T_3}{T_4}$$

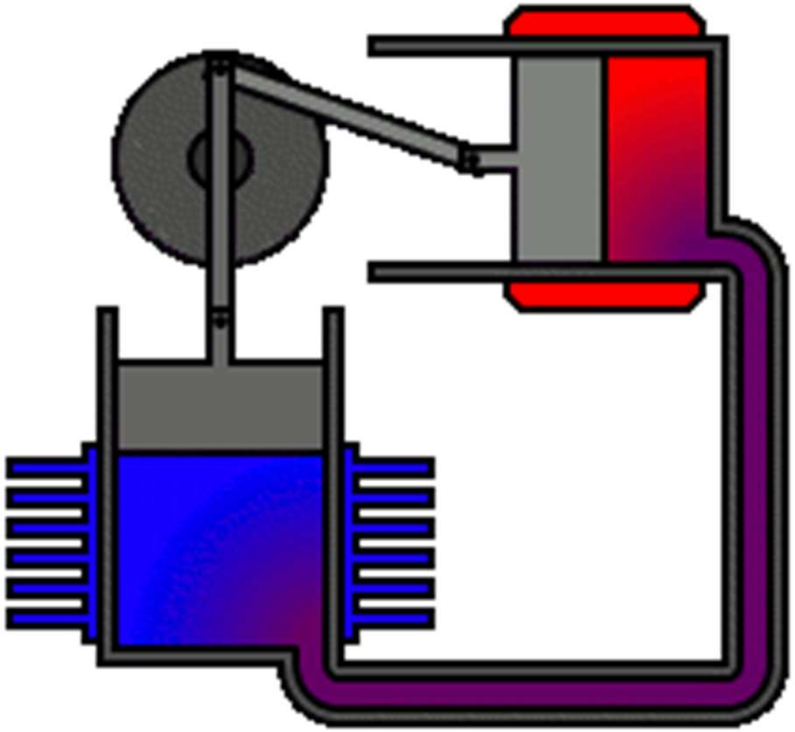
$$r_p = \frac{P_2}{P_1}$$

$$\eta_{th,Brayton} = 1 - \frac{1}{r_p^{(k-1)/k}}$$



TD: Cengel & Boles

Solar Powered Sterling Engine



https://en.wikipedia.org/wiki/Solar-powered_Stirling_engine
https://en.wikipedia.org/wiki/Stirling_engine

What's next?

- Vapor power cycle