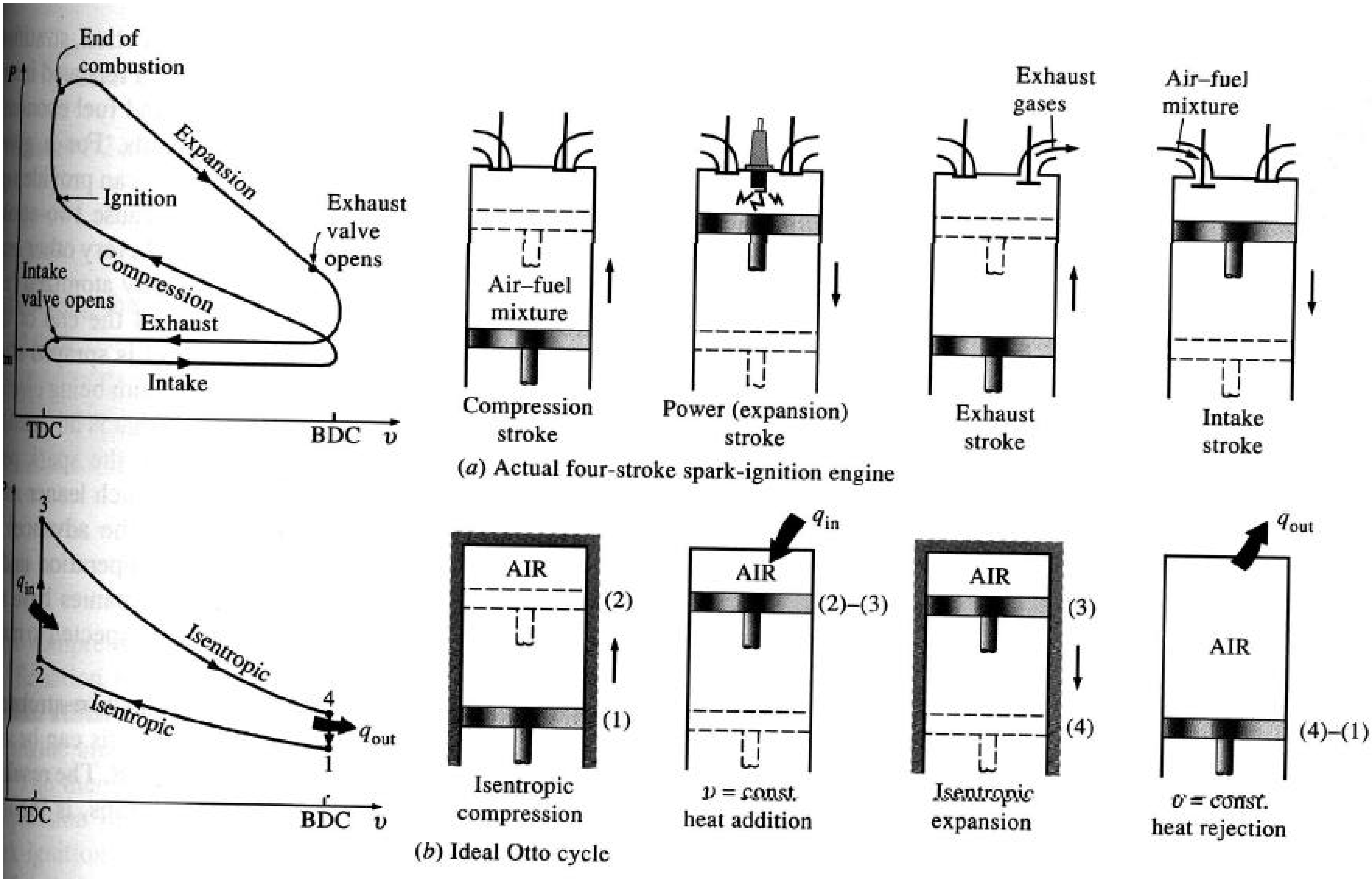
Gas Power Cycle - Internal Combustion Engine

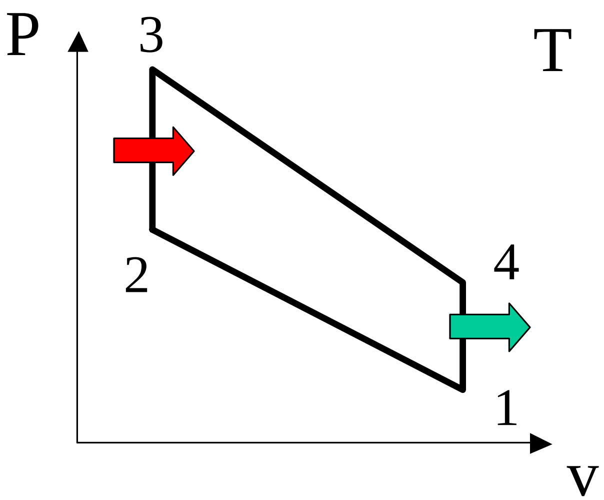


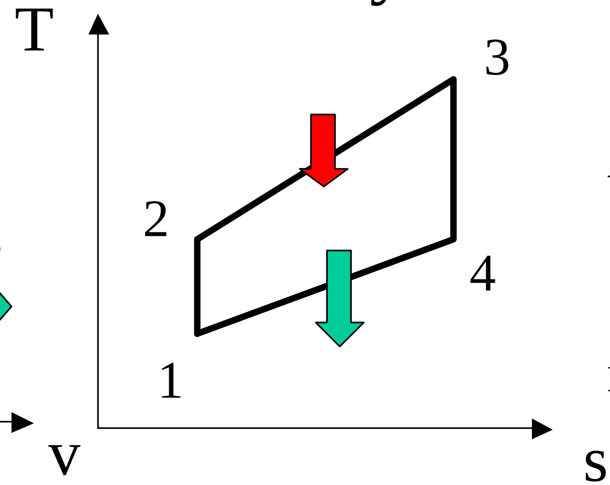
(*a*) Actual four-stroke spark-ignition engine

(*b*) Ideal Otto cycle

Otto Cycle

Otto Cycle





- 1-2 isentropic compression
- 2-3 constant volume heat transfer
- 3-4 isentropic expansion
- 4-1 constant volume heat rejection

Thermal efficiency of the system:

$$h = \frac{\mathrm{W_{cycle}}}{\mathrm{Q_{in}}} = \frac{W_{34} + W_{12}}{Q_{23}} = \frac{m[(u_3 - u_4) + (u_1 - u_2)]}{m(u_3 - u_2)} = 1 - \frac{(u_4 - u_1)}{(u_3 - u_2)}$$

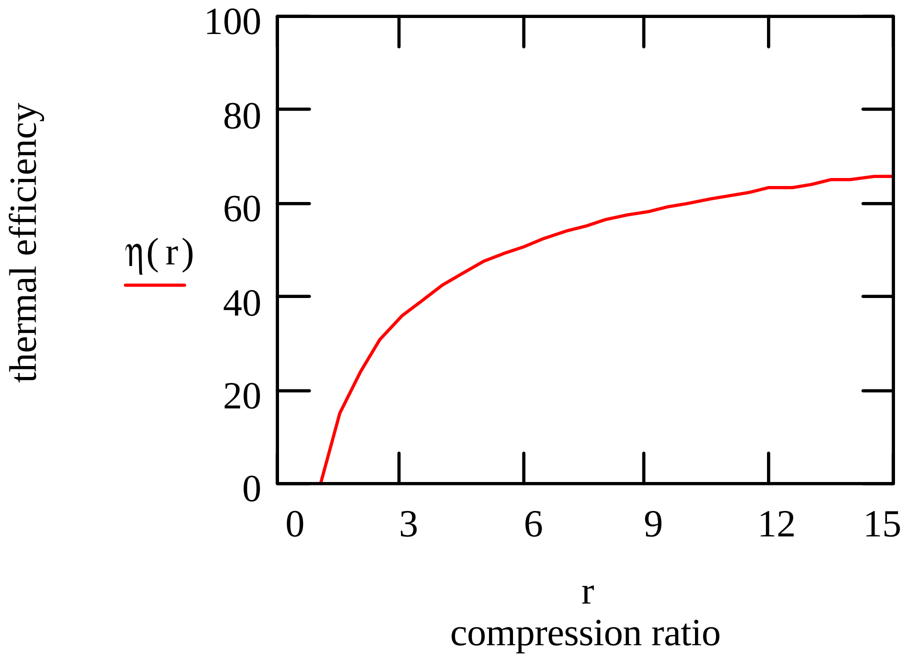
For an ideal gas, u=C$_\mathrm{v}T$, $h = 1 - \frac{(u_4 - u_1)}{(u_3 - u_2)} = 1 - \frac{C_v(T_4 - T_1)}{C_v(T_3 - T_2)} = 1 - \frac{T_1}{T_2}\left(\frac{T_4/T_1 - 1}{T_3/T_2 - 1}\right)$

Since $T_4/T_1 = T_3/T_2$ (why?)

$h = 1 - \frac{T_1}{T_2}$. From isentropic compression relation for an ideal gas

$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{g-1} = \frac{1}{r^{g-1}}$, where r=$\left(\frac{V_1}{V_2}\right)$ is the volume compression ratio, $g = \frac{\mathrm{c_p}}{\mathrm{c_v}}$

Otto Cycle-2



Thermal efficiency of an Otto cycle,

$$h = 1 - \frac{1}{r^{g-1}}$$

Typical value of r for a real engine: between 7 and 10

- The higher the compression ratio, the higher the thermal efficiency.
- Higher r will led to engine knock (spontaneous ignition) problem.

Improvement of Performance

- Increase the compression ratio

- Increase the engine displacement: more power

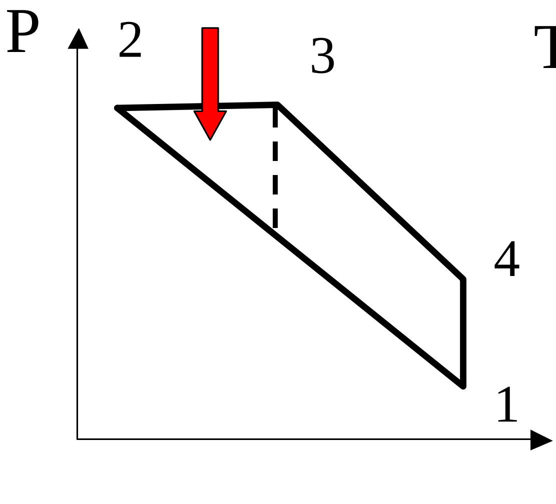
- Compress more air into the cylinder during intake: using supercharger and turbocharger.

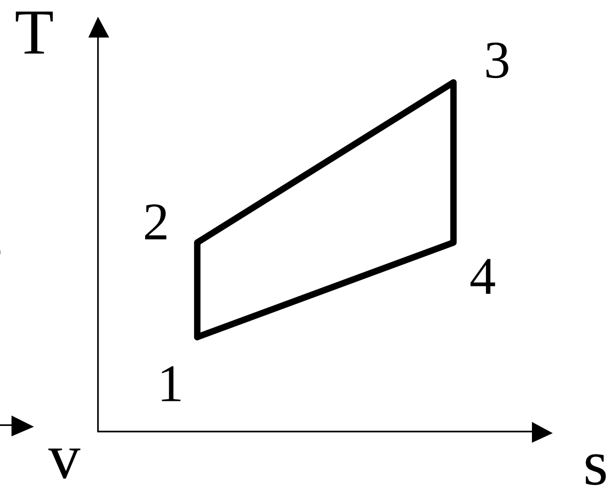
- Cool the air before allowing it to enter the cylinder: cooler air can expand more, thus, increase the work output.

- Reduce resistance during intake and exhaust stages: multiple valve configuration: 4 cylinders/16 valves engine

- Fuel injection: do away with the carburetor and provide precise metering of fuel into the cylinders.

Diesel Cycle





2-3: a constant pressure process (instead of a constant volume process) and is the only difference between an idealized Diesel cycle and an idealized Otto cycle.

- Fuel injection for an extended period during the power stroke and therefore maintaining a relatively constant pressure.
- Diesel cycle has a lower thermal efficiency as compared to an Otto cycle under the same compression ratio.
- In general, Diesel engine has a higher thermal efficiency than spark-ignition engine because the Diesel engine has a much higher compression ratio.
- Compression-ignition: very high compression ratio 10 to 20 or even higher.

Diesel Cycle   Internal Combustion Engine

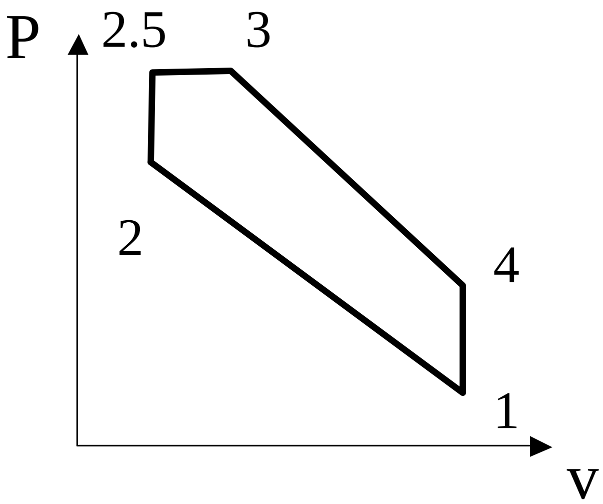
Thermal Efficiency of Diesel Cycle

- Introduce parameter $\beta = V_3/V_2$
- Show that the efficiency of an ideal Diesel cycle is:

$$\eta_{Diesel} = 1 - \frac{1}{r^{\gamma-1}} \frac{\beta^{\gamma} - 1}{[\gamma(\beta - 1)]}$$

- It can also be shown that $\eta_{Otto} > \eta_{Diesel}$ for the same compression ratio. However, Diesel engines can usually operate at higher compression ratio (Why?).
- If the maximum pressure is the same, the Diesel engine has a higher efficiency than the Otto engine.

Dual Cycle



- Some heat is added at constant volume (2 ➔ 2.5)
- The remaining heat is added at constant pressure (2.5 ➔ 3)

- Define $\beta = V_3/V_{2.5}$, $\alpha = P_3/P_2$

Show that: $$h_{\text{dual}} = 1 - \left(\frac{1}{r}\right)^{g-1} \left[\frac{ab^{g} - 1}{(a-1) + ga(b-1)}\right]$$

- It has an efficiency falling between the Otto and Diesel limits.