$S = 2R_{crank}$

A displacement for all cylinders

$V_{displ} = N_{cyc}(V_{max} - V_{min}) = N_{cyc} A_{cyc} S$

The ratio of the largest to the smallest volume is the compression ratio:

$r_v = CR = V_{max} / V_{min}$

→ The net specific work in a complete cycle is used to define a mean effective process

net work per cylinder per cycle:

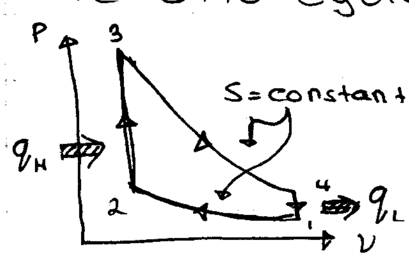
$W_{net} = m w_{net} = P_{meff}(V_{max} - V_{min})$

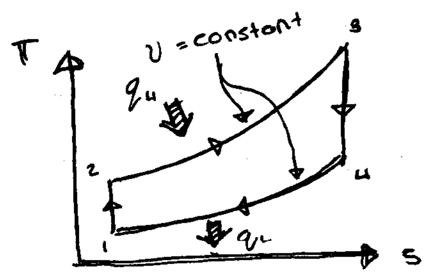
the ratio of work for the whole engine

$\dot{W} = N_{cyc}\, m\, w_{net} \frac{RPM}{60} = P_{meff} V_{displ} \frac{RPM}{60}$

↳ result should be corrected with a factor of (1/2) for a 4-stroke engine.

The Otto Cycle





$q_H = u_3 - u_2$

(constant volume)

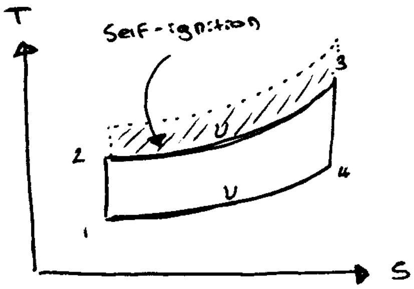
$q_H = C_v(T_3 - T_2)$

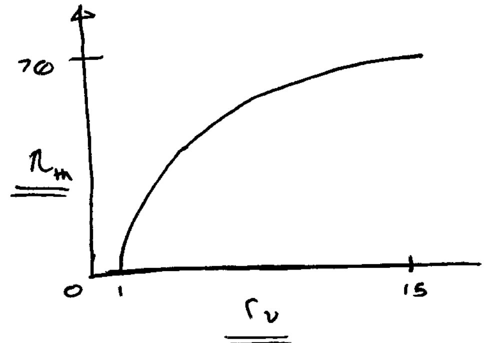
$q_L = u_4 - u_1 = C_v(T_4 - T_1)$

then $\eta_{th} = \frac{q_H - q_L}{q_H} = 1 - q_L/q_H \approx 1 - \frac{C_v(T_3 - T_1)}{C_v(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$

$(T_2/T_1) = (V_1/V_2)^{k-1} = T_3/T_4$

$\eta_{th} = 1 - T_1/T_2 = 1 - (r_v)^{1-k} = 1 - \frac{1}{(r_v^{k-1})}$





→ specific heats of actual gases increase with an increase in temp.

→ 10.7

Example Compression ratio = 10 = v_r = v_1/v_2

$P_1 = 0.1$ MPa , $T_1 = 15°C$

$q_H = 1800$ kJ/kg

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \qquad \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{k}$$

$$T_2 = (10)^{(1.4-1)} \times T_1 = \boxed{723.9\ K} \to T_2$$

$$P_2 = (10)^{1.4} \times P_1 = \boxed{2.512\ MPa} \to P_2$$

$$q_H = q_{2-3} = u_3 - u_2 = C_v(T_3 - T_2)$$

$$1800 = (0.717)(T_3 - 723.9) \Rightarrow \boxed{3234\ K} \to T_3 \text{ (maximum temp.)}$$

$$PV = RT \Rightarrow \frac{P_3}{T_3} = \frac{R}{V} = \frac{P_2}{T_2}, \text{ thus } P_3/P_2 = T_3/T_2 \text{ for c.v. process}$$

IF constant — for ideal gas

$$P_3 = P_2(T_3/T_2) = 2.512\left(\frac{3234}{723.9}\right) = \boxed{11.22\ MPa} \to P_3$$

$$T_3/T_4 = (V_4/V_3)^{k-1} \Rightarrow (10)^{0.4}$$

$$T_4 = T_3/(10^{0.4}) = \boxed{1289.5\ K} \to T_4$$

$$\frac{P_3}{P_4} = \left(\frac{V_4}{V_3}\right)^{(k)} \Rightarrow P_4 = \frac{P_3}{(V_4/V_3)^k} = \frac{11.22}{10^{1.4}} = \boxed{0.4467\ MPa} \to P_4$$

$$\eta_{th} = 1 - \frac{1}{r_v^{k-1}} = 1 - \frac{1}{10^{0.4}} = 0.602 \text{ or } \boxed{60.2\ \%}$$

$$mep = \frac{w_{net}}{(V_1 - V_2)}$$

$$w_{net} = q_H - q_L \to w_{net} = \boxed{1083.5\ kJ/kg} \to w_{net}$$

$$q_L = u_4 - u_1 = C_v(T_4 - T_1) = 0.717(1287.5 - 288.2)$$

$$\boxed{= 716.5\ kJ/kg} \to q_L$$

$$Pv = RT \longrightarrow v_1 = \frac{RT_1}{P_1} = \frac{(0.287)(288.2)}{(100)} = \boxed{0.827\ m^3/kg}$$

$$v_2 = \frac{RT_2}{P_1} = \frac{(0.287)(725.9)}{(2.512\times10^3)} = \boxed{0.0827\ m^3/kg}$$

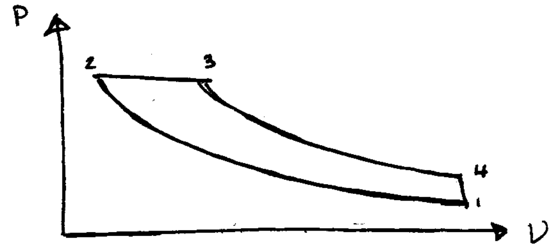
$$\longrightarrow \text{or} \quad v_1/v_2 = V_1/V_2 = 10$$

or...

$$\text{then} \quad v_2 = v_1/10 = \boxed{0.827\ m^3/kg}$$

$$mep = \frac{1083.5}{(0.827 - 0.0827)} = \boxed{1456\ kPa}$$

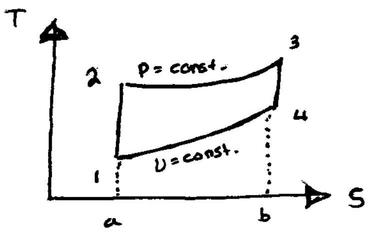
The Diesel Cycle (compression ignition engine)



$$q_H = u_3 - u_2 + w_{2-3}$$

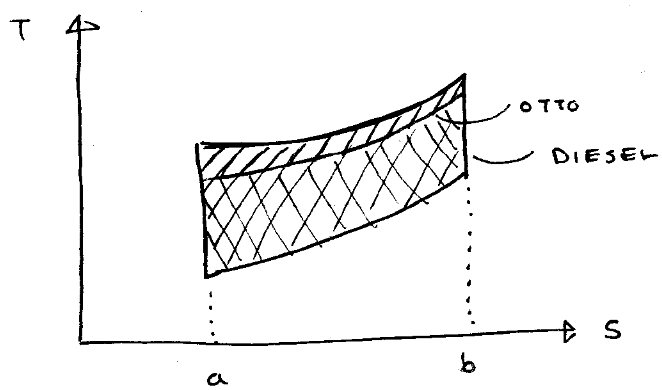
$$\Rightarrow u_3 - u_2 + P_2(v_3 - v_2)$$

$$\Rightarrow h_3 - h_2$$



$$\eta_{th} = 1 - q_L/q_H = 1 - \frac{C_v(T_4 - T_1)}{C_p(T_3 - T_2)}$$

$$= 1 - \frac{T_1(T_4/T_1 - 1)}{k\,T_2(T_3/T_2 - 1)}$$

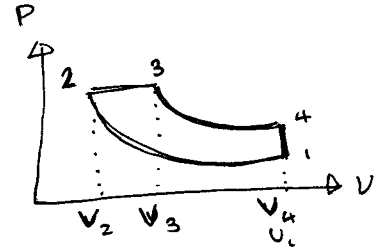


$$\underline{\eta_{di} > \eta_{otto}}$$

THERMO

1

Nov. 8/18



→ 10.8

$\boxed{\text{Example}}$

$P_1 = 0.1$ MPa

$T_1 = 288$ K

$T_2/T_1 = (V_1/V_2)^{k-1} \Rightarrow T_2 = T_1(20)^{0.4} = 955.2$ K

$P_2/P_1 = (V_1/V_2)^k \Rightarrow P_2 = P_1(20)^{1.4} = 6.629$ MPa

$q_H = 1800$ kJ/kg $= h_3 - h_2 = C_p(T_3 - T_2)$

$T_3 = q_H/C_p + T_2 = 1800/1.004 + 955.2 = 2748$ K

$P_3 = P_2 = 6.629$ MPa (Diesel Cycle)

$T_4/T_3 = (V_3/V_4)^{k-1}$ $\quad PV = mRT \rightarrow \frac{V_2}{T_2} = \frac{mR}{P} = \frac{V_3}{T_3}$

Ideal gas law : for constant pressure process

$V_3/V_2 = T_3/T_2 \Rightarrow V_3 = V_2(T_3/T_2)$

$V_3/V_2 = 2748/955.2 = 2.8769$

$V_3/V_4 = V_3/V_2 \times \underbrace{V_2/V_4}_{= V_2/V_1} =$

$T_4/T_3 = (V_3/V_4)^{k-1} \Rightarrow \left(\frac{2.8769}{20}\right)^{0.4}$

$\Rightarrow T_4 = 1265$ K

$P_4/P_3 = (V_3/V_4)^k \Rightarrow P_4 = (6.629)\left(\frac{2.8769}{20}\right)^{1.4}$

$\Rightarrow P_4 = 439$ kPa

$q_L = C_v = (T_1 - T_4) = 0.717(288.2 - 12.65)$

$= -700.4$ kJ/kg

$w_{net} = |q_H| - |q_L| = 1800 - 700.4 = 1099.6$ kJ/kg

$\eta_{th} = w_{net}/q_H = 1099.6/1800 = 0.611$ or 61.1%

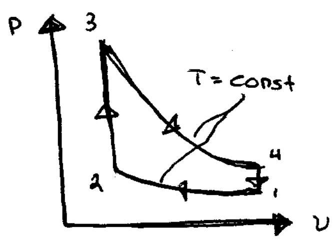
$mep = w_{net}/(v_1 - v_2)$

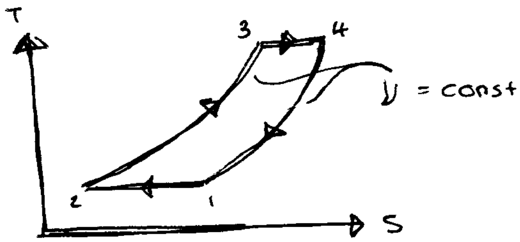
$v_1 = \frac{RT_1}{P_1} = \frac{(0.287)(288)}{(100)} = 0.827$ m³/kg

$v_2 = 0.04135$ m³/kg

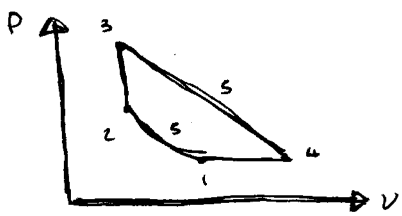
$mep = \frac{1099.6}{(0.827 - 0.04135)} = 1400$ kPa

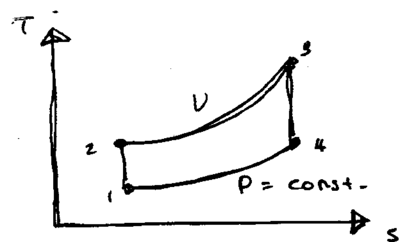
The Stirling Cycle





The Atkinson Cycle





For compression and expansion

$$T_2/T_1 = (v_1/v_2)^{k-1} \quad \text{and} \quad T_4/T_3 = (v_3/v_4)^{k-1}$$

$$P = C \; ; \quad T_4 = (v_4/v_1)\,T_1 \; ; \quad \text{and} \quad q_L = h_4 - h_1$$

$$\eta = \frac{q_H - q_L}{q_H} = 1 - \frac{q_L}{q_H} = 1 - \frac{h_4 - h_1}{u_3 - u_2}$$

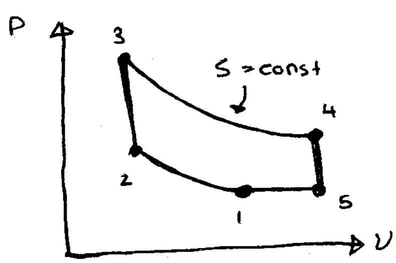
$$\cong 1 - \frac{C_p(T_4 - T_1)}{C_v(T_3 - T_2)} = 1 - k\frac{T_4 - T_1}{T_3 - T_2}$$

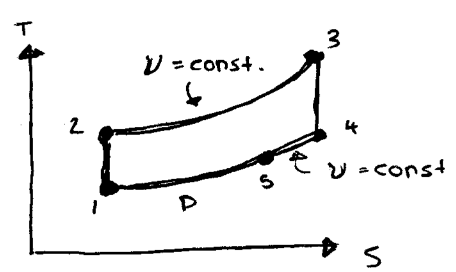
$$T_2 = T_1\,CR_1^{k-1} \; ; \quad T_4 = (v_4/v_1)\,T_1 = \frac{CR}{CR_1}T_1$$

$$\rightarrow \; T_3 = T_4\,CR^{k-1} = (CR/CR_1)\,T_1\,CR^{k-1} = \frac{CR^k}{CR_1}T_1$$

$$\boxed{\eta = 1 - k\frac{\left(\frac{CR}{CR_1}\right) - 1}{\left(\frac{CR^k}{CR_1}\right) - CR_1^{k-1}} = 1 - k\left(\frac{CR - CR_1}{CR^k - CR_1^k}\right)}$$

The Miller Cycle





→ both Atkinson and Miller have higher efficiencies than the Otto Cycle.