Thermodynamica 1

Lecture 11:

Processtappen

Kringprocessen

- Stirling
- Otto (2 en 4 slags)

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Energy Technology

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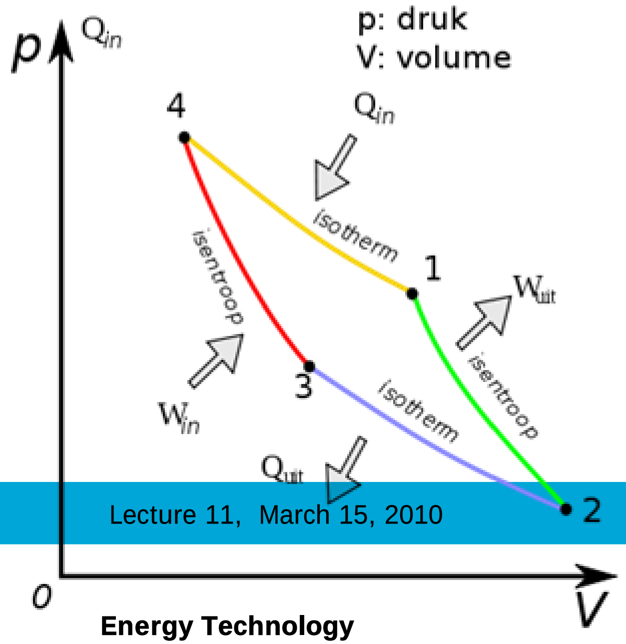
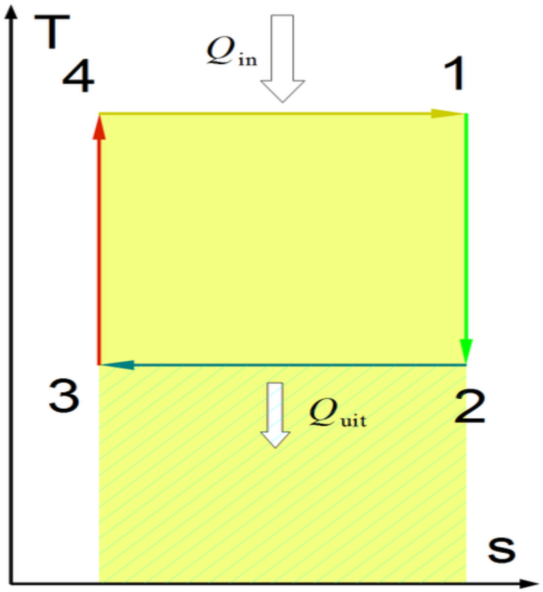
Recap College 10

- Carnot process
- working with the entropy

- Carnot process → 2 isothermal and 2 adiabatic processes

  reversible isentropic=adiabatic





$$\eta_{Carnot} = 1 - \frac{T_3}{T_4} = 1 - \frac{T_c}{T_h}$$

$$\eta_{real} < \eta_{Carnot}$$

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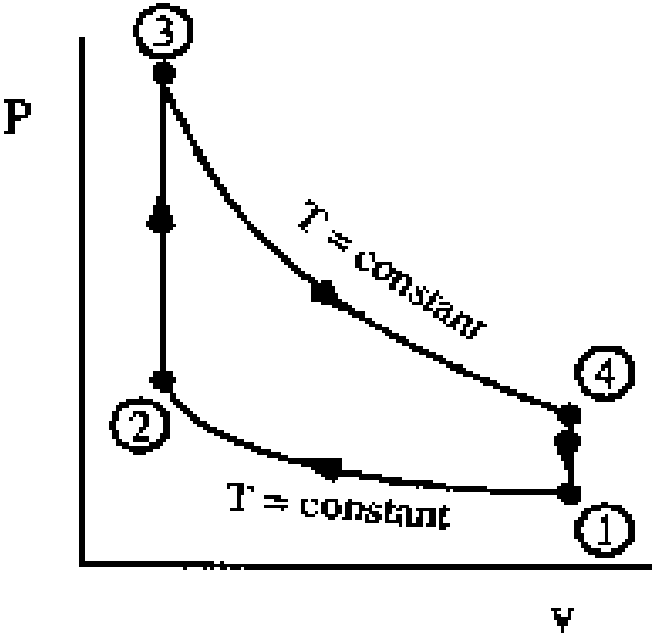
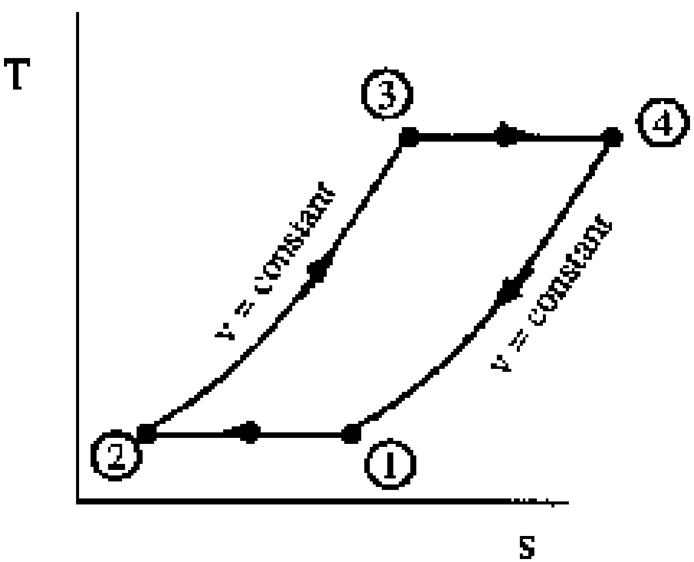
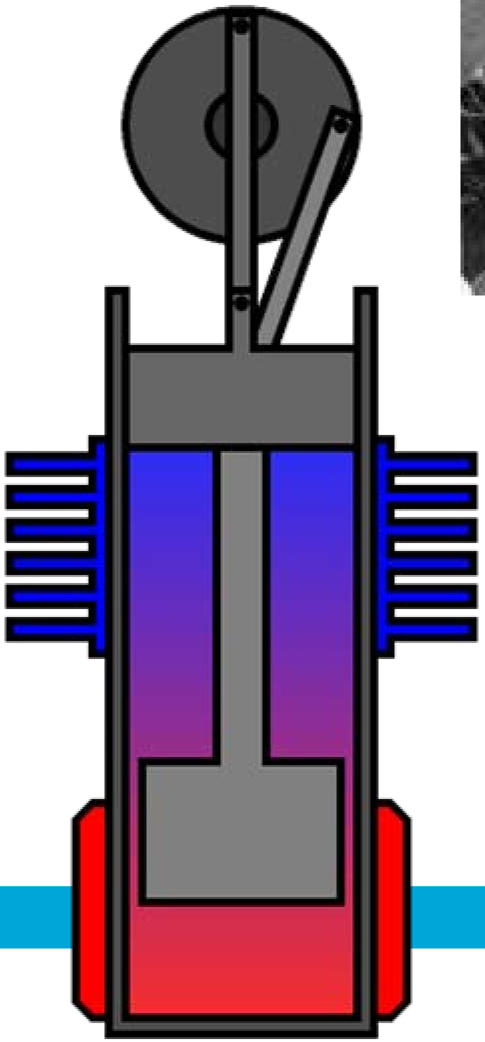
Stirling cycle







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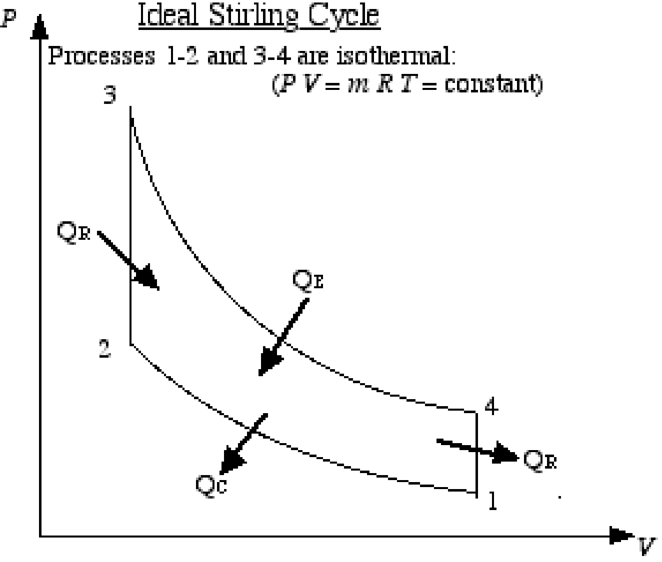

Efficiency Stirling cycle

$$\eta = \frac{W}{Q_{in}} = 1 - \frac{Q_{uit}}{Q_{in}} = 1 - \frac{Q_{12} + Q_{41}}{Q_{23} + Q_{34}} = 1 - \frac{RT_1 \ln(v_1 / v_2) + c_v (T_4 - T_1)}{c_v (T_2 - T_3) + RT_3 \ln(v_3 / v_4)}$$

$$T_4 - T_1 = T_3 - T_2 \quad \text{(1 - 2 en 3 - 4 zijn isothermen)}$$

$$v_2 / v_1 = v_3 / v_4$$

$$\eta = 1 - \frac{T_1 + \dfrac{c_v (T_4 - T_1)}{R \ln(v_1 / v_2)}}{T_3 + \dfrac{c_v (T_3 - T_2)}{R \ln(v_3 / v_4)}} = 1 - \frac{T_1 + p}{T_3 + p} = 1 - \frac{T_c + p}{T_h + p}$$

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Stirling met regenerator

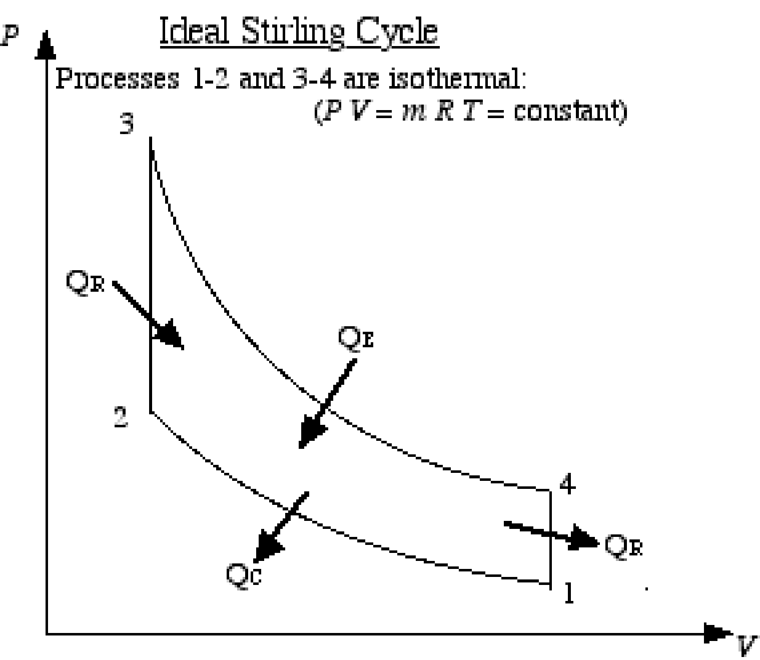
Q_{41} wordt via regenrator weer aan het systeem toegevoerd $\rightarrow Q_{23}$

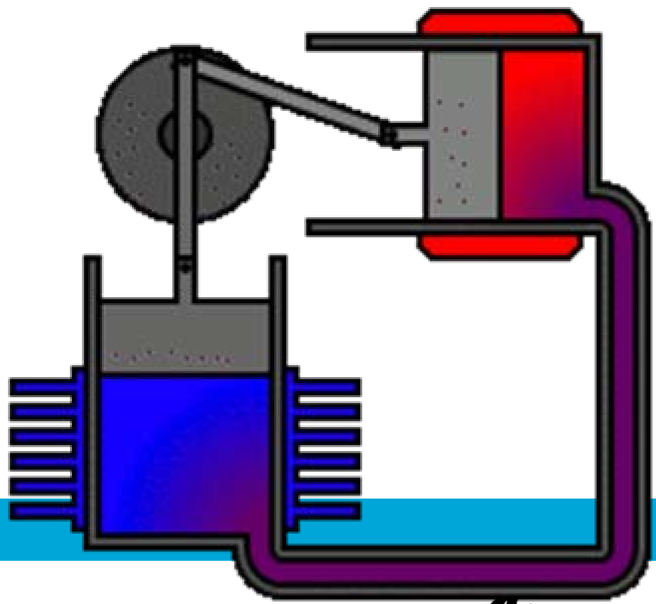
$$\eta = \frac{W}{Q_{in}} = 1 - \frac{|Q_{uit}|}{Q_{in}} = 1 - \frac{|Q_{12}|}{Q_{34}} = 1 - \frac{R T_1 \, |\ln(v_2/v_1)|}{R T_3 \ln(v_4/v_3)}$$

$T_4 - T_1 = T_3 - T_2$ (1-2 en 3-4 zijn isothermen)

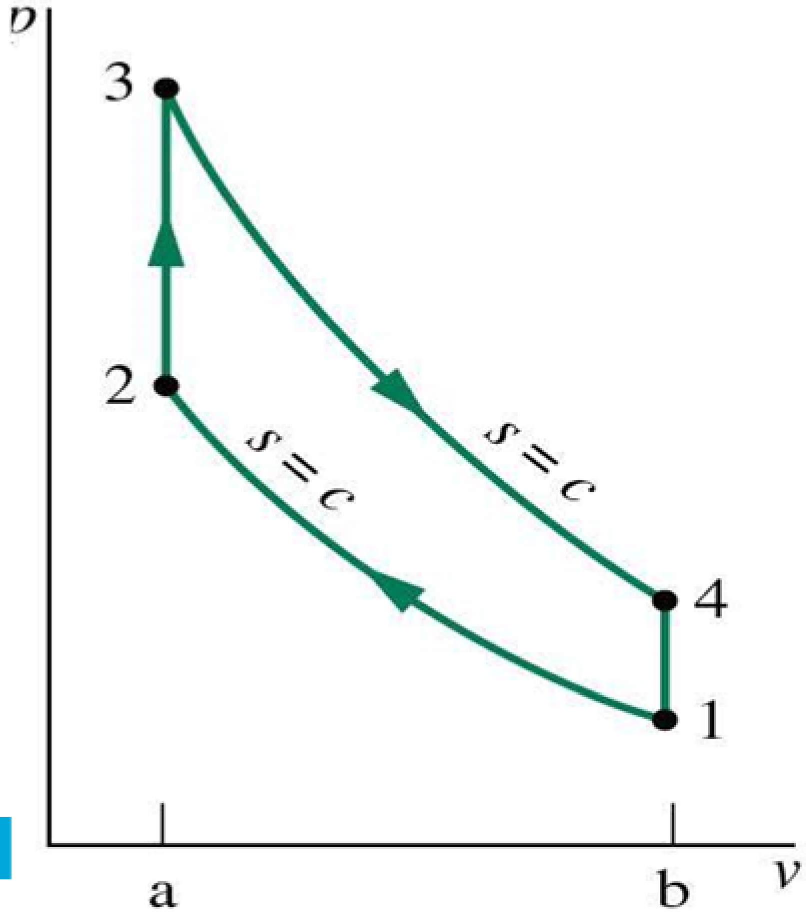
$v_2 / v_1 = v_3 / v_4$

$$\eta = 1 - \frac{T_1}{T_3} = 1 - \frac{T_c}{T_h} \Rightarrow$$ Met regenerator dus Carnot!

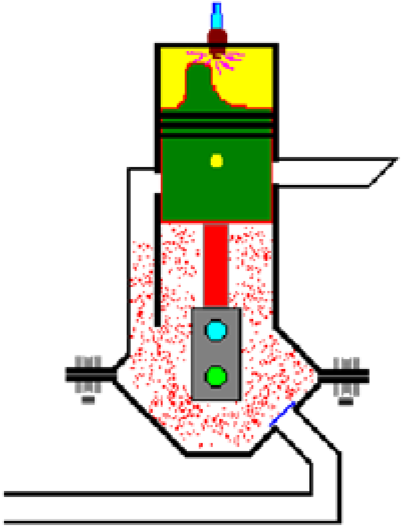




Verbrandingsmotoren bv Otto motor



2 adiabaten en 2 isochoren,
dus geen Carnot machine
en Carnot cyclus!



Standaardlucht aannames (air standard):

- Werkmedium: lucht als ideaal gas
- Kringproces is gesloten
- Deelprocessen zijn inwendig reversibel
- Warmtetoevoer i.p.v. verbrandingsprocessen
- Warmteafvoer i.p.v. uitdrijfproces

$$dh = c_p dT$$

$$h_2 - h_1 = \int_1^2 c_p dT; \quad c_p = c_p(T)$$

$$h_2 - h_1 = \int_1^2 c_p dT \neq c_p (T_2 - T_1)$$

Gebruik dus tabel A-22

Koude lucht aannames (cold air standard):

- Werkmedium: lucht als ideaal gas, Cp en Cv zijn constant
- Kringproces is gesloten
- Deelprocessen zijn inwendig reversibel
- Warmtetoevoer i.p.v. verbrandingsprocessen
- Warmteafvoer i.p.v. uitdrijfproces

Gebruik dus geen tabel

$$dh = c_p dT$$

$$h_2 - h_1 = \int_1^2 c_p dT = c_p (T_2 - T_1)$$

Ideal gas (cold air standard)

$$\left.\begin{aligned} PV^{\kappa} &= Const \\ P &= mRT/V \end{aligned}\right\rangle TV^{\kappa-1} = Const^{*}$$

$$T_1 V_1^{\kappa-1} = T_2 V_2^{\kappa-1}$$

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right) = \left(\frac{V_1}{V_2}\right)^{\frac{1}{\kappa-1}}$$

$$\left.\begin{aligned} PV^{\kappa} &= Const \\ V &= mRT/P \end{aligned}\right\rangle P^{\kappa-1}T^{\kappa} = Const^{**}$$

$$\frac{P_1}{P_2} = \left(\frac{T_1}{T_2}\right)^{\frac{\kappa}{\kappa-1}}$$

Isentroop process (example 6.9)

$$p_1 = 1bar$$

$$T_1 = 300K$$

$$T_2 = 650K$$

$$p_2 = ?$$

Air Standard: $\frac{p_2}{p_1} = \frac{p_{r2}}{p_{r1}}(T - A22) \Rightarrow \frac{p_2}{p_1} = \frac{21.86}{1.3860}$

$$\Rightarrow p_2 = p_1 \bullet 15.77 = 15.77bar$$

Cold air Standard: $\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{k/(k-1)} \Rightarrow \frac{p_2}{p_1} = \left(\frac{650}{300}\right)^{1.39/.39} = 15.81bar$

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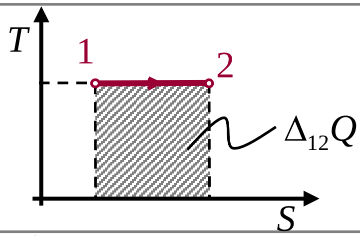
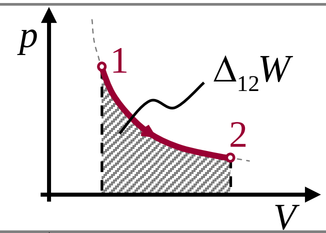
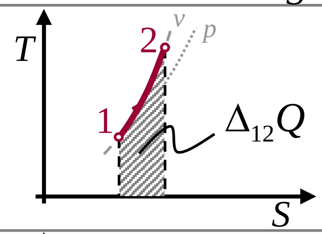
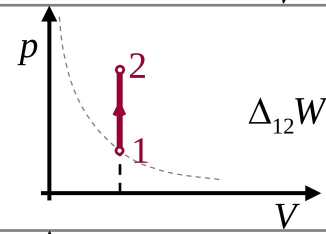
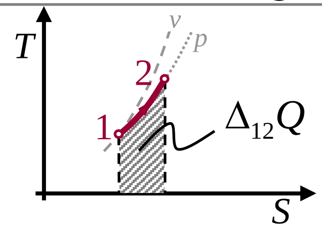
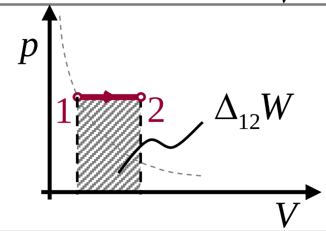
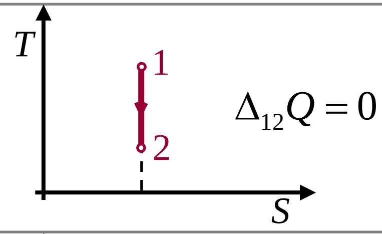
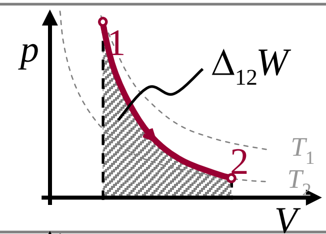
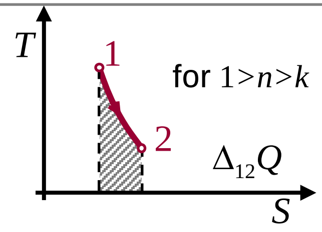
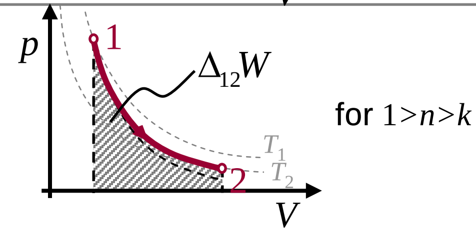
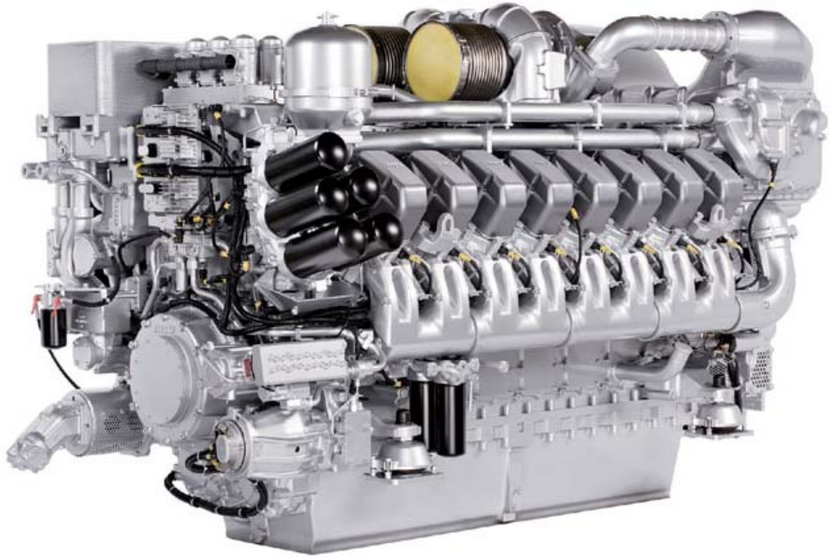
Recap: reversible process steps in closed systems

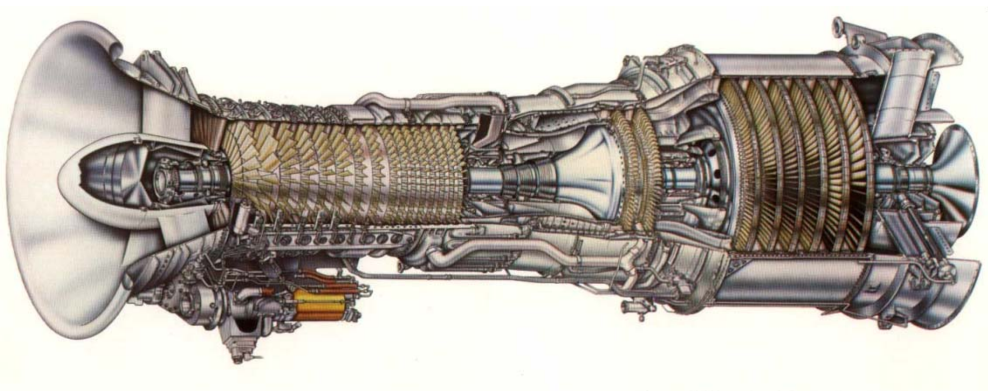
	$\Delta_{12}Q$	$\Delta_{12}W = m\int_{v_1}^{v_2} p\,dv$
isotherm *(T=const.)*	ideal gas $-RT\ln\frac{p_2}{p_1} = +RT\ln\frac{v_2}{v_1}$	ideal gas $\Delta_{12}W = \Delta_{12}Q$
isochor *(v=const.)*	$m\int_{T_1}^{T_2} c_v\,dT = m(u_2 - u_1)$	0
isobar *(p=const.)*	$m\int_{T_1}^{T_2} c_p\,dT = m(h_2 - h_1)$	$m\,p_1(v_2 - v_1)$
adiabatic *(dQ=0)*	0	$-m(u_2 - u_1)$
polytropic *(pv^n=const.)*	$m(u_2 - u_1) - \Delta_{12}W$	$-\frac{m}{n-1}(p_2v_2 - p_1v_1)$

Recap: reversible process steps in closed systems

	$\Delta_{12}Q$	$\Delta_{12}W$
isotherm *(T=const.)*		
isochor *(v=const.)*		 $\Delta_{12}W = 0$
isobar *(p=const.)*		
adiabatic *(dQ=0)*		
polytropic *(pv^n=const.)*		

Common combustion engines

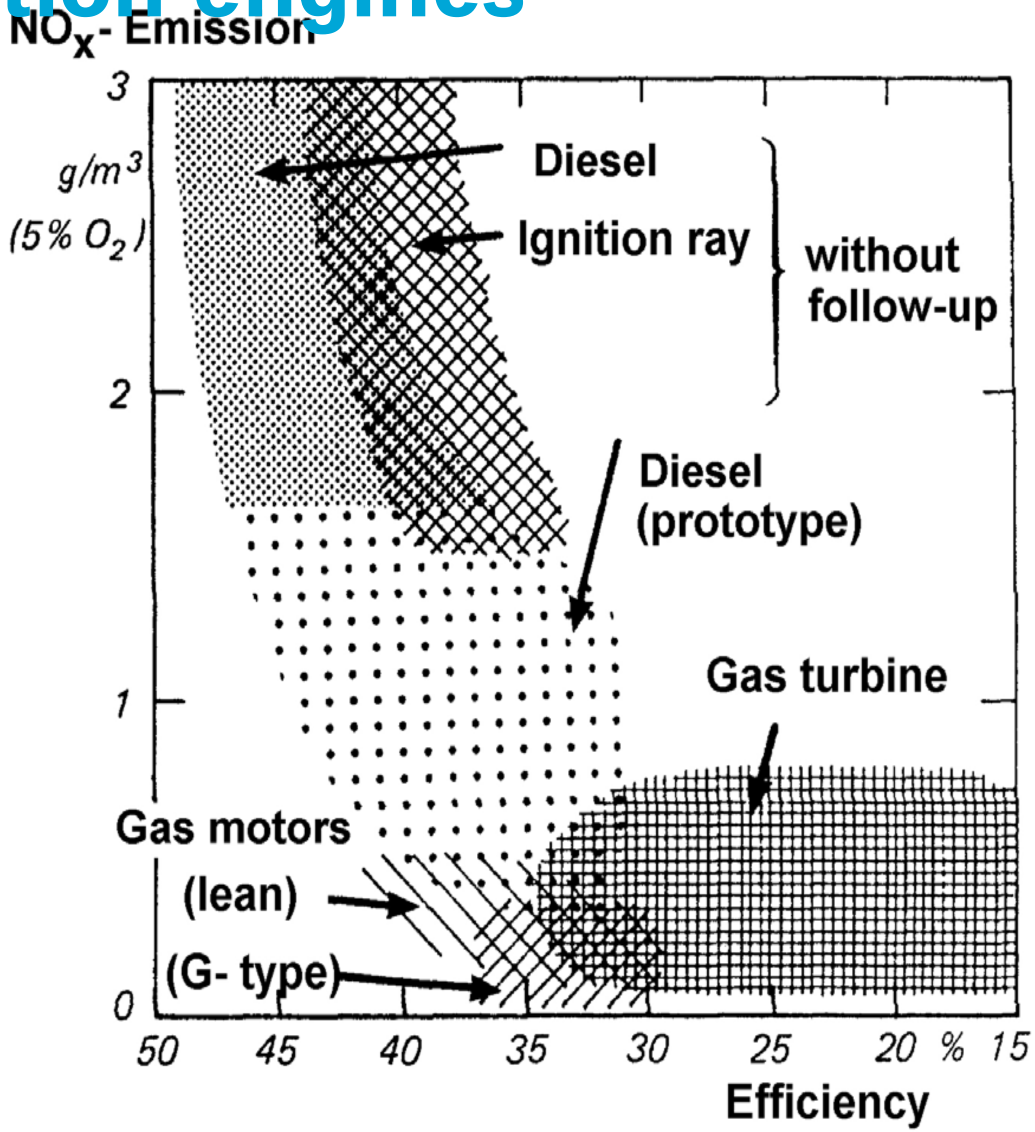




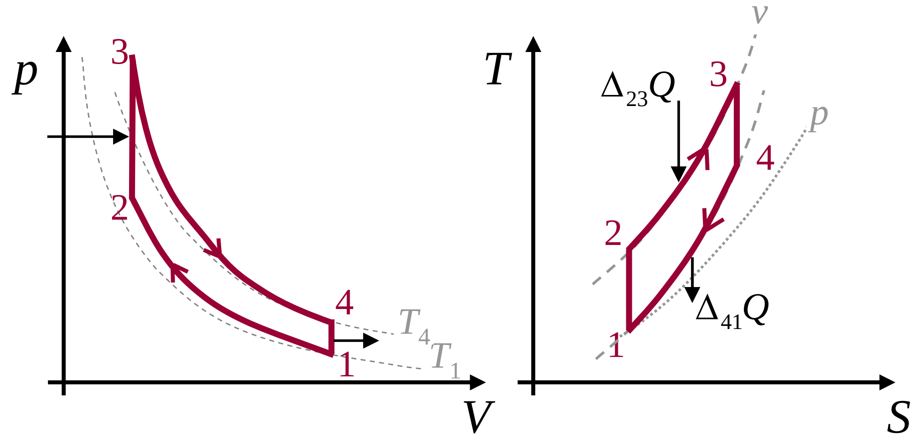
General Electric LM2500 Gas Turbine

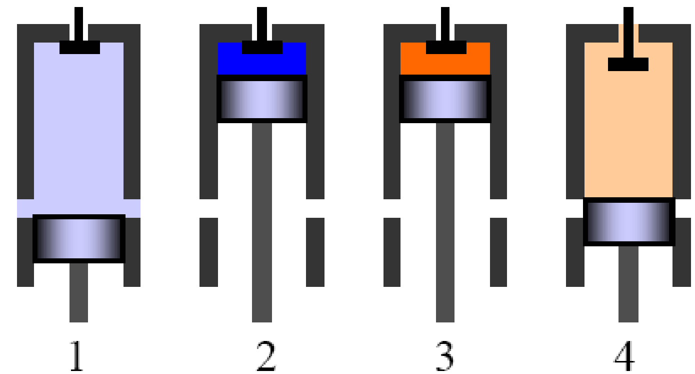
- Otto
- Diesel
- Gasturbine

NOx- emission and efficiency of combustion engines



Recap: Otto cycle





internally reversible processes

1-2 adiabatic compression of the air as the piston moves from bottom dead center to top dead center $\Delta_{12}Q = 0$ $\Delta_{12}W = -m(u_2 - u_1)$

2-3 isochoric heating of air from external source – to mimic the ignition and oxidation of fuel-air mixture $\Delta_{23}Q = m(u_3 - u_2)$ $\Delta_{23}W = 0$

3-4 power stroke: adiabatic expansion $\Delta_{34}Q = 0$ $\Delta_{34}W = -m(u_4 - u_3)$

4-1 isochoric heat transfer to external reservoir – to mimic the release of hot exhaust $\Delta_{41}Q = m(u_1 - u_4)$ $\Delta_{41}W = 0$

Efficiency Otto cycle (cold air standard)

thermal efficiency $\eta^{rev} = \dfrac{\Delta^{cyc}W}{\Delta_{23}Q} = \dfrac{\Delta_{12}W + \Delta_{34}W}{\Delta_{23}Q} = \dfrac{-(u_2 - u_1) - (u_4 - u_3)}{(u_3 - u_2)} = 1 - \dfrac{u_4 - u_1}{u_3 - u_2}$

Poisson relation

$TV^{k-1} = const.$

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

$k = \dfrac{c_p}{c_v}$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{k-1} = \left(\frac{V_1}{V_2}\right)^{k-1} = \frac{T_2}{T_1} \quad \Rightarrow \quad \frac{T_3}{T_2} = \frac{T_4}{T_1}$$

$V_1 = V_4,\; V_2 = V_3$

$$\eta^{rev} = 1 - \frac{c_v(T_4 - T_1)}{c_v(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)} = 1 - \frac{T_1}{T_2}$$

$$= 1 - \frac{T_4}{T_3}$$

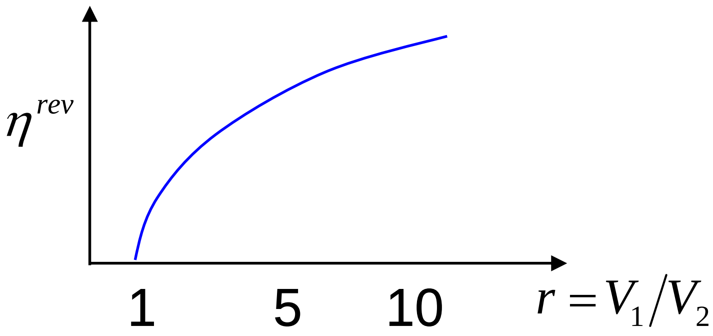
Efficiency Otto cycle (cold air standard)

thermal efficiency $$\eta^{rev} = 1 - \frac{C_v(T_4 - T_1)}{C_v(T_3 - T_2)} = .. = 1 - \frac{T_1}{T_2}$$

with compression ratio $$r = \frac{V_1}{V_2} \rightarrow pV^k = const \rightarrow \frac{V_1}{V_2} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{k-1}}$$

$$TV^{k-1} = const.$$

$$\boxed{\eta^{rev} = 1 - \frac{1}{r^{k-1}}}$$



$$\eta^{rev} = 1 - \frac{1}{r^{k-1}}$$

The efficiency monotonically increases with the compression ratio

$\rightarrow$ in practice, high compression ratios leads to high temperatures, resulting

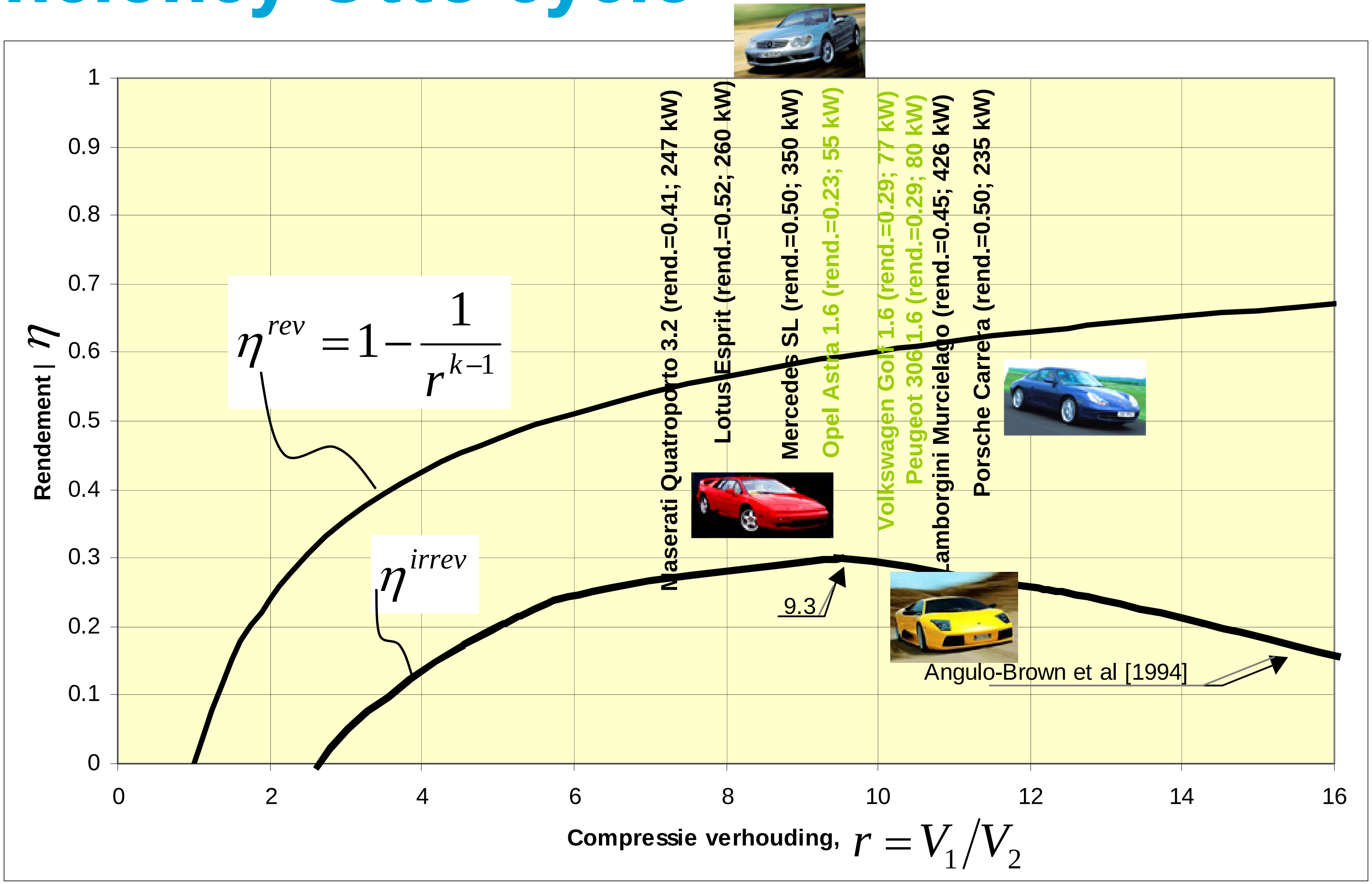
{1} in NO_x emissions (oxidation of air-nitrogen, severe at $T > 1600\ K$)

{2} in “knock”, the spontaneous ignition of air-fuel mixture prior to spark plug

{3} incomplete combustion

$\rightarrow$ compression ratios of $r \approx 10$ are therefore common (efficiency <60%)

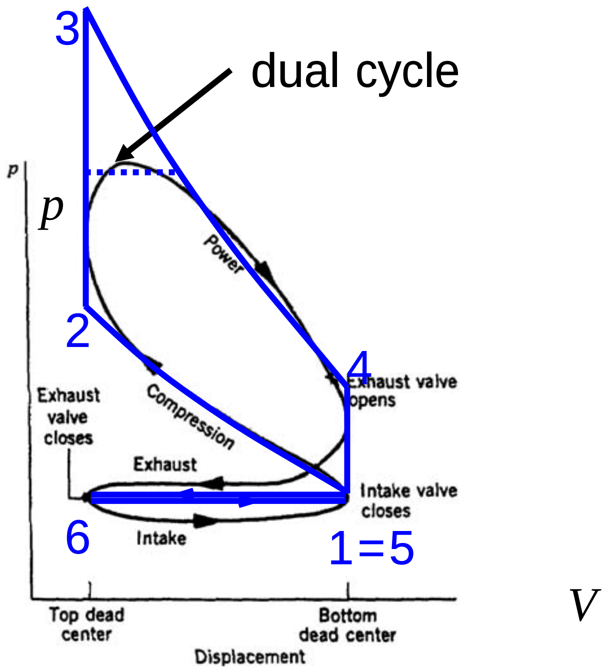
Efficiency Otto cycle

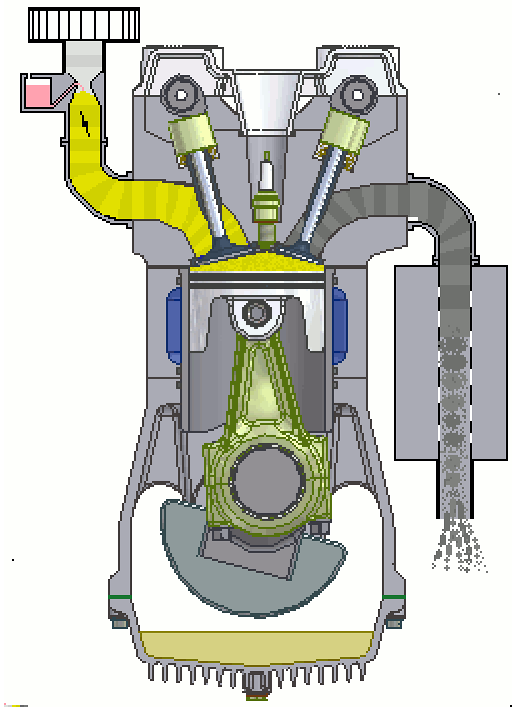


F. Angulo-Brown et al [1994] " Compression ratio of an optimized air standard Otto-cycle model", *Eur. J. Physics*, Vol. 15, pp. 38-42

irreversible processes: heat transfer processes, friction in cylinders and dissipation in cycle, non-isochoric processes

4-stroke Otto cycle





Ideal process steps of 4-stroke Otto cycle

1-2 adiabatic compression of air (1st stroke)

2-3 isochoric heating, to mimic the ignition and oxidation of fuel-air mixture

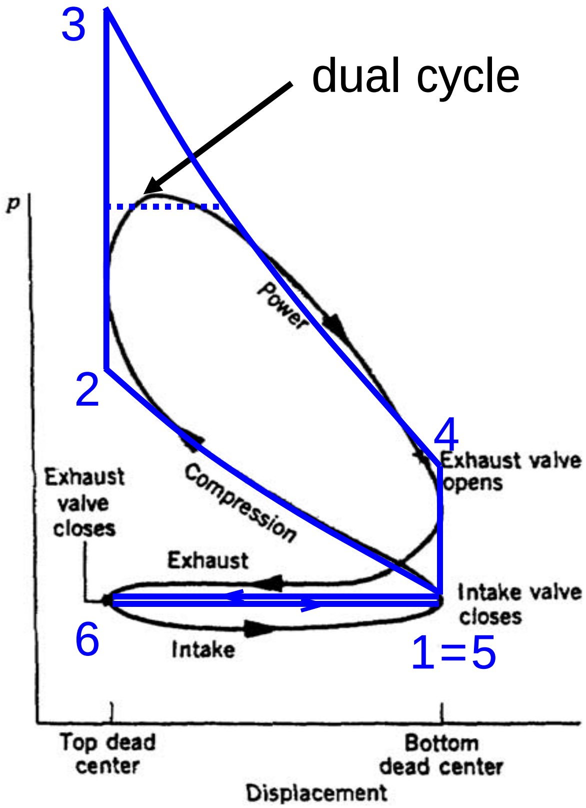
3-4 power stroke: adiabatic expansion (2nd stroke)

4-5 isochoric heat transfer, to mimic opening of exhaust valve

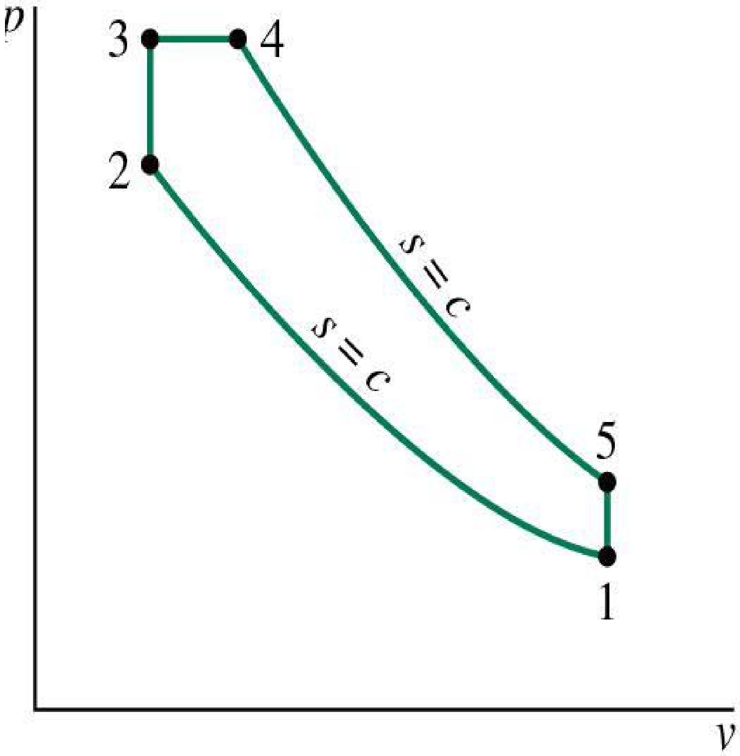
5-6 exhaust stroke (3rd stroke): isobaric displacement of exhaust gas

6-1 intake stroke (4th stroke): isobarically drawing fresh air into the cylinder

Dual cycle



4 stroke



dual cycle

Efficiency of dual cycle

$$\eta = \frac{W}{Q_{in}} = \frac{W_{34} + W_{45} + W_{32}}{Q_{23} + Q_{34}} = 1 - \frac{Q_{out}}{Q_{in}} = 1 - \frac{Q_{51}}{Q_{23} + Q_{34}}$$

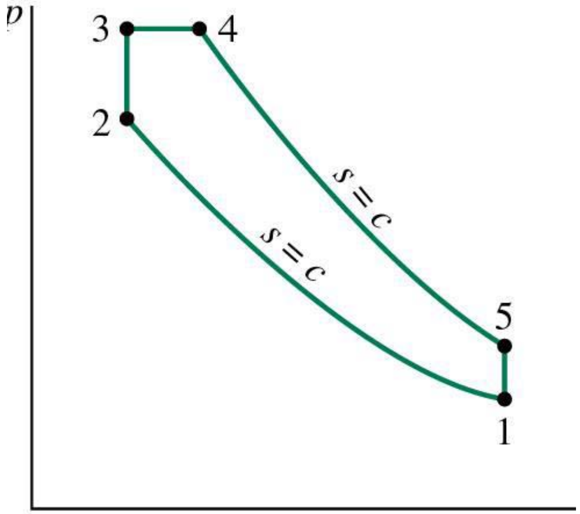
$$Q_{23} = mc_v (T_3 - T_2)$$

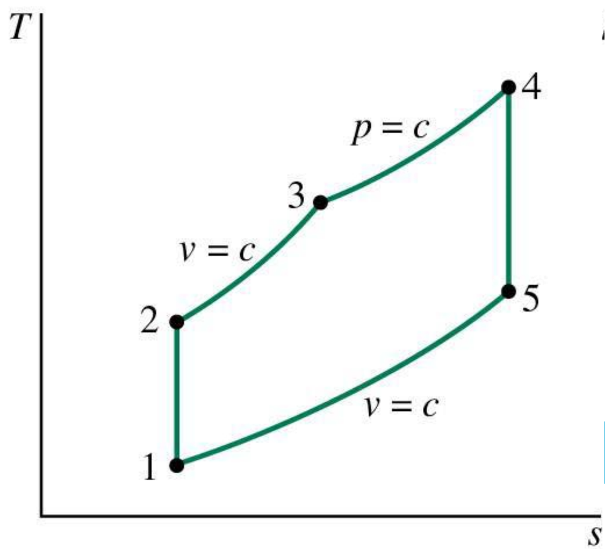
$$Q_{34} = mc_p (T_4 - T_3)$$

$$Q_{51} = mc_v (T_5 - T_1)$$

$$\eta_{4tact} = 1 - \frac{T_5 - T_1}{T_3 - T_2 + k(T_4 - T_3)}$$

$$k = c_p / c_v$$





Tentamen juni 2010

We willen een gasmotor gebruiken om 3MW elektriciteit op te wekken. De compressie verhouding van de gasmotor is 12 en het cilinder volume aan het begin van de arbeidsslag is 2 liter. Er is gegeven dat Cp =1.0KJ/kgK en Cv=0.714KJ/kgK en dat de laagste druk in het systeem gelijk is aan 1 bar

- Schets het p-v en T-s diagram voor de Otto cyclus.
- Bepaal het volume V1, als gegeven is dat T1=300K bepaal dan T2.
- Tijdens het proces 2→3 neemt de druk in de motor toe met een factor 2.5.
- Hoe groot zijn dan T3 en T-4?
- Bepaal de warmte toe en afvoer aan het systeem Q23 en Q41?
- Bepaal de geleverde arbeid en het rendement van de motor