Thermodynamica 1

Otto, Diesel & dual cycle

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lecture 12

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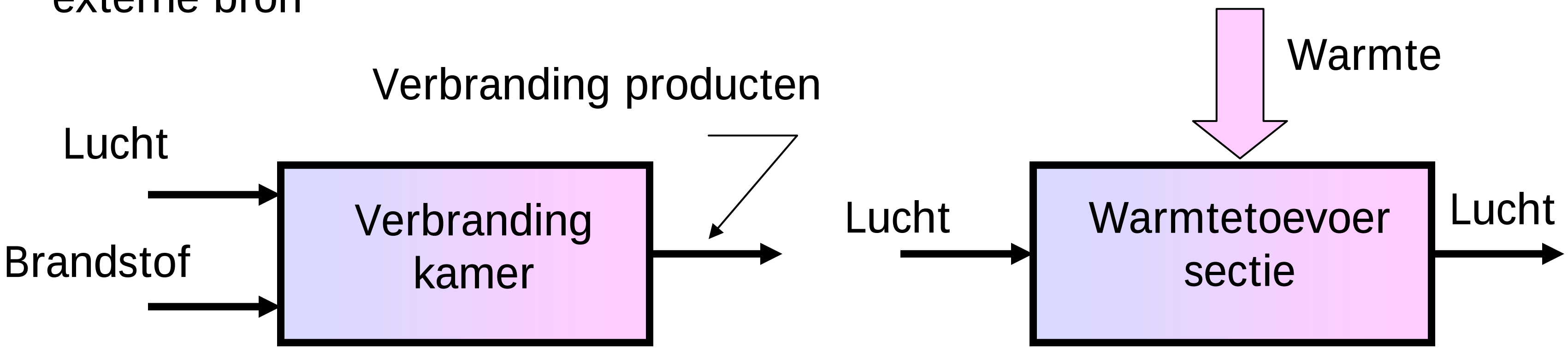
Standaard-lucht aannames / Koude-lucht standaard

Standaard lucht aannames

- Werkmedium is lucht met ideaal gas gedrag
- Kringproces is gesloten
- Deel processen zijn inwendig reversibel
- Verbrandingsprocessen worden vervangen door warmte toevoer vanuit een externe bron



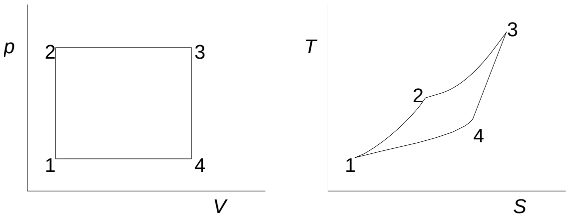
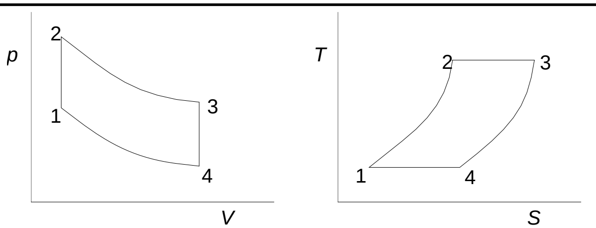
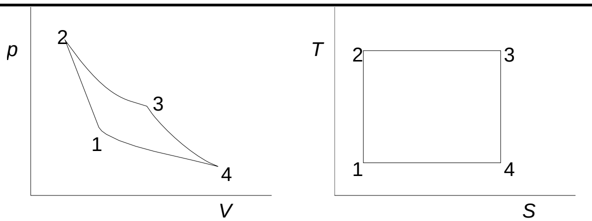
- Uitdrijfproces wordt vervangen door warmteafvoer proces waardoor werkmedium in oorspronkelijke toestand terugkomt

Koude-lucht standaard aannames

- Soortelijke warmte (c_p, c_v) constant bij kamer temperatuur (25ºC)

then $k = \frac{c_p}{c_v}$ also constant

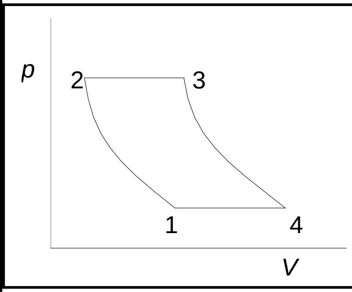
Cycle processes

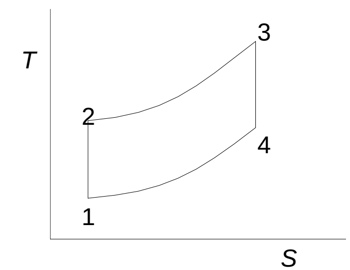
Historisch	***p*** *=const*	***V*** *=const*	***T*** *=const*	***dQ*** *=0*	
Papin 1690	*p*	*V*			
Stirling (Robert) James 1815		*V*	*T*		
Carnot 1824 (Diesel, 1893/7)			*T*	*dQ*	

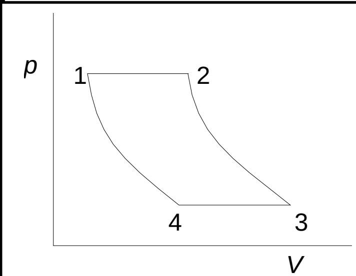
TUDelft

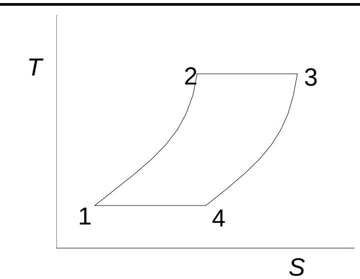
Cycle processes

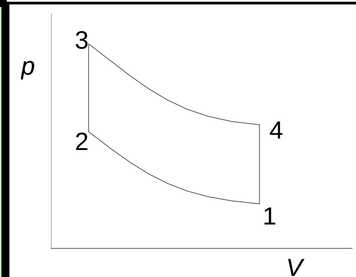
Historisch	*p* =const	*V* =const	*T* =const	*dQ* =0
Ericsson 1833 **Joule 1852** **Brayton 1867**	*p*			*dQ*
Ericsson **1853**	*p*		*T*	
Otto 1867 **(Barsanti - Mat-teucci 1854)**		*V*		*dQ*

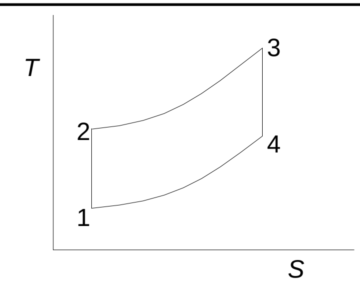








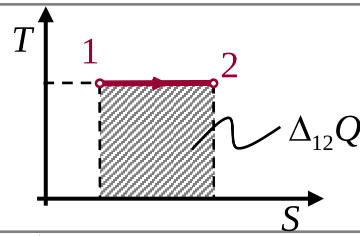
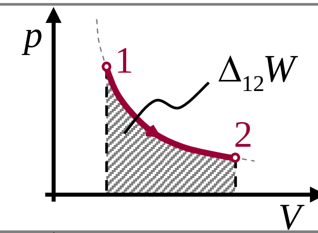
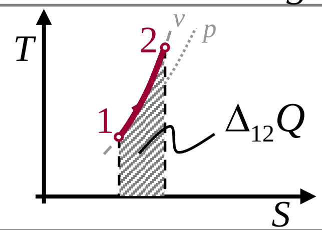
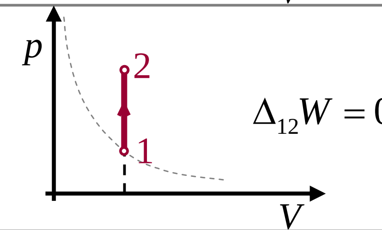
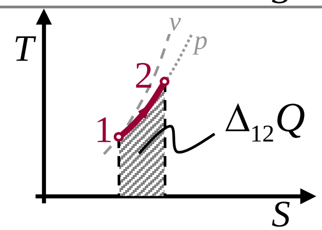
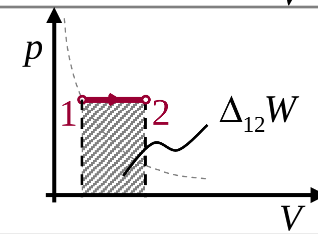
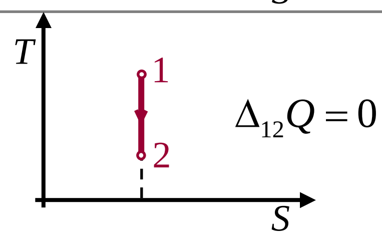
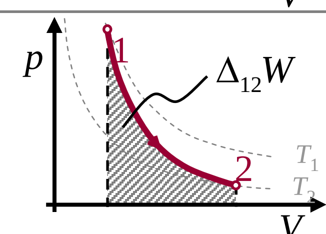
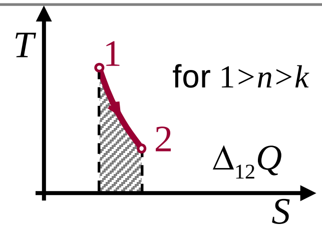
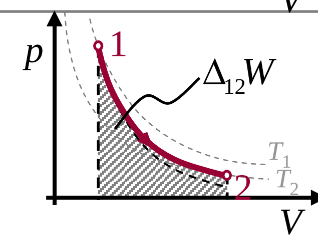




Recap: reversible process steps in closed systems

	$\Delta_{12}Q$	$\Delta_{12}W = m\int_{v_1}^{v_2} p\,dv$
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.)*		
isobar *(p=const.)*		
adiabatic *(dQ=0)*		
polytropic *(pv^n=const.)*		 for $1>n>k$

Ideal gas (cold air standard)

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

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

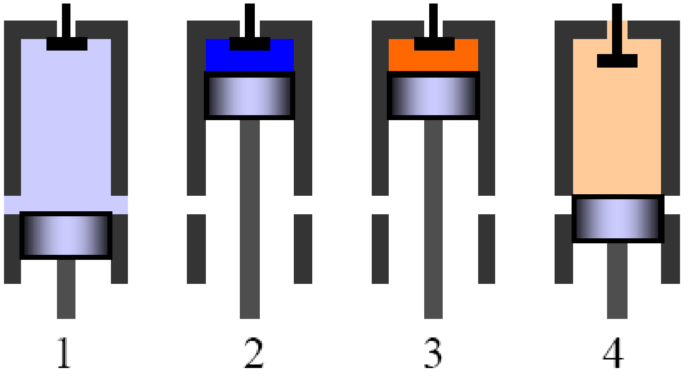
$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right) = \left(\frac{V_1}{V_2}\right)^{\frac{1}{\kappa-1}}$$

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

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

Otto motor

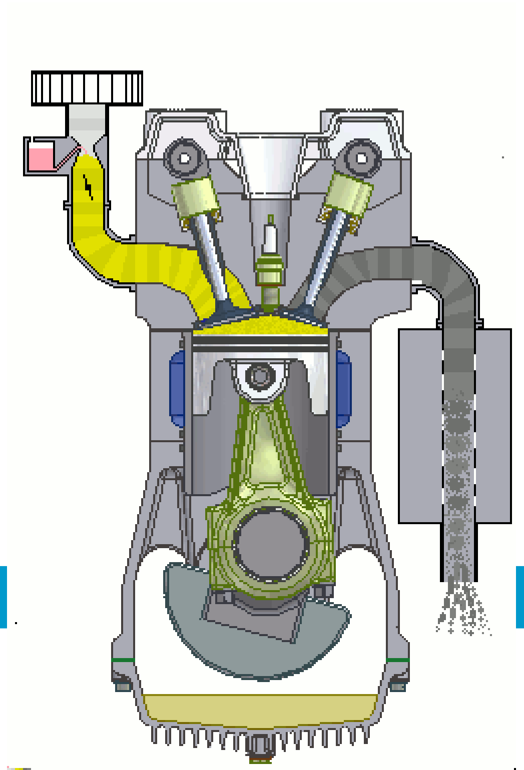
$$\eta^{rev} = 1 - \frac{1}{r^{k-1}}; \text{ met } r = V_1 / V_2$$



Rendement hangt alleen af van de compressie verhouding

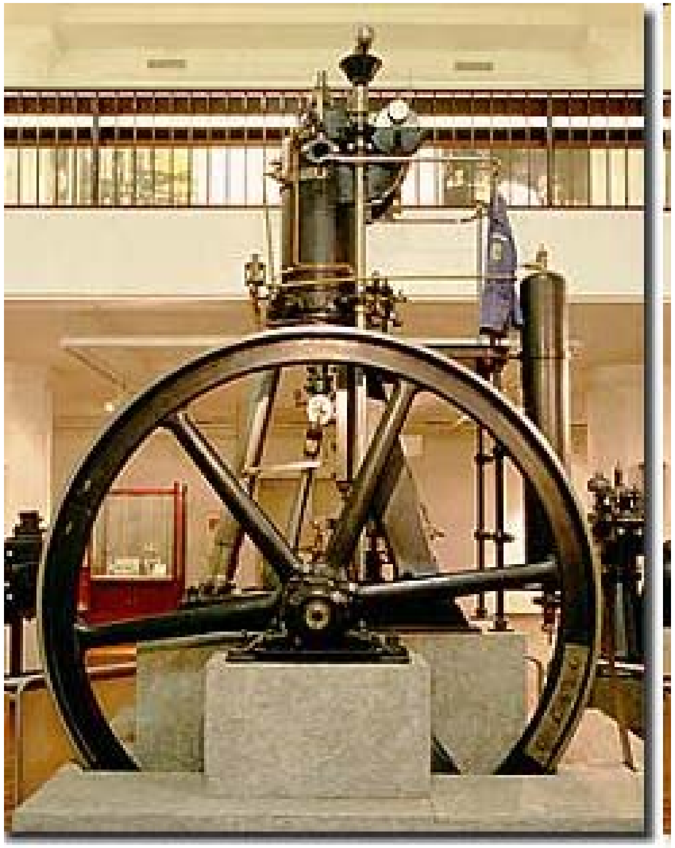
Brandstof wordt samen met lucht gecomprimeerd

Beperkende factor is de vroegtijdige ontbranding "knock"



Diesel

Rudolf Diesel



Werkspoor diesel 1951

Cilinderboring (diameter doorsnee)	390mm
Slag (op- en neergaande beweging)	680mm
Aantal cilinders	10
Omwentelingen per minuut (maximaal)	275
Vermogen in epk (bij vol vermogen)	2100 pk /1500 kW

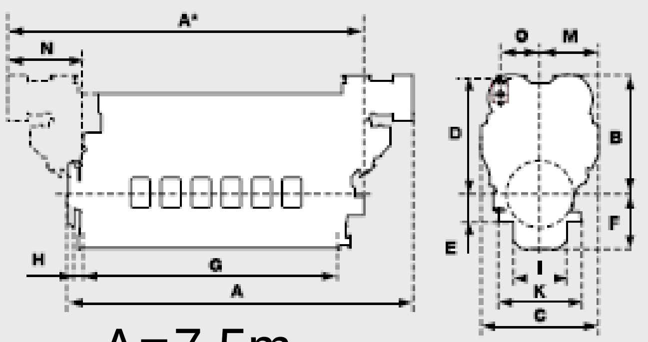
Moderne diesel

WÄRTSILÄ 38

Marine engines	
Cylinder bore	380 mm
Piston stroke	475 mm
Cylinder output	725 kW/cyl
Engine speed	600 rpm
Mean effective pressure	26.9 bar

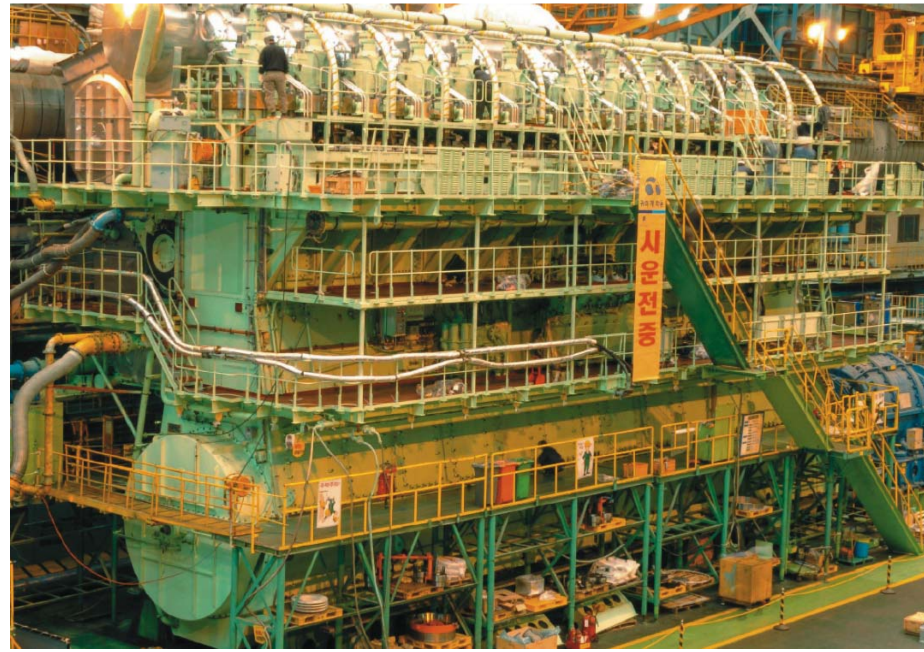
Rated power: Propulsion engines

Engine type	kW
6L38	4 350
8L38	5 800
9L38	6 525
12V38	8 700
16V38	11 600



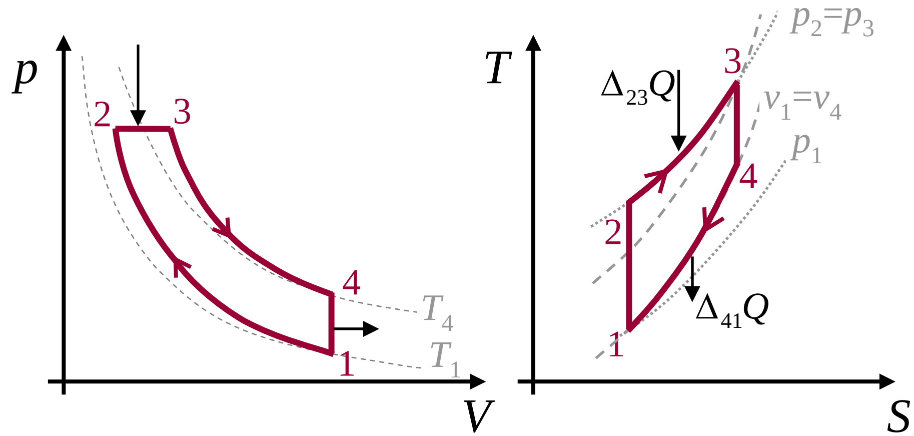
A=7.5m

B+F=4.3m



Length:	89 feet (27 meter)
Height:	44 feet (13 meter)
Maximum power:	**108,920 hp at 102 rpm**
	80MW

Diesel process



De lucht wordt gecomprimeerd en de temperatuur neemt daardoor toe. Als de cylinder op het hoogste punt is wordt brandstof ingespoten die dan spontaan gaat ontbranden. Door de constructie heeft de motor geen “knock”

internally reversible processes

1-2 adiabatic compression of the air as the piston moves from bottom dead center to top dead center

$$\Delta_{12}Q = 0 \qquad \Delta_{12}W = -m\left(u_2 - u_1\right)$$

2-3 first part of power stroke: isobaric heating of air from external source – to mimic ignition and oxidation of fuel-air mixture

$$\Delta_{23}Q = m\left(h_3 - h_2\right) \qquad \Delta_{23}W = p_2\left(V_3 - V_2\right)$$

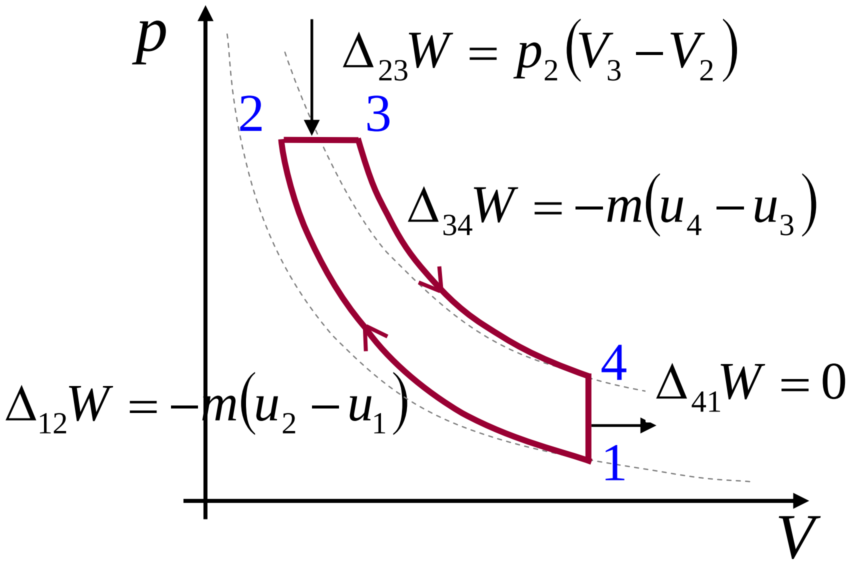
3-4 second part of power stroke: adiabatic expansion

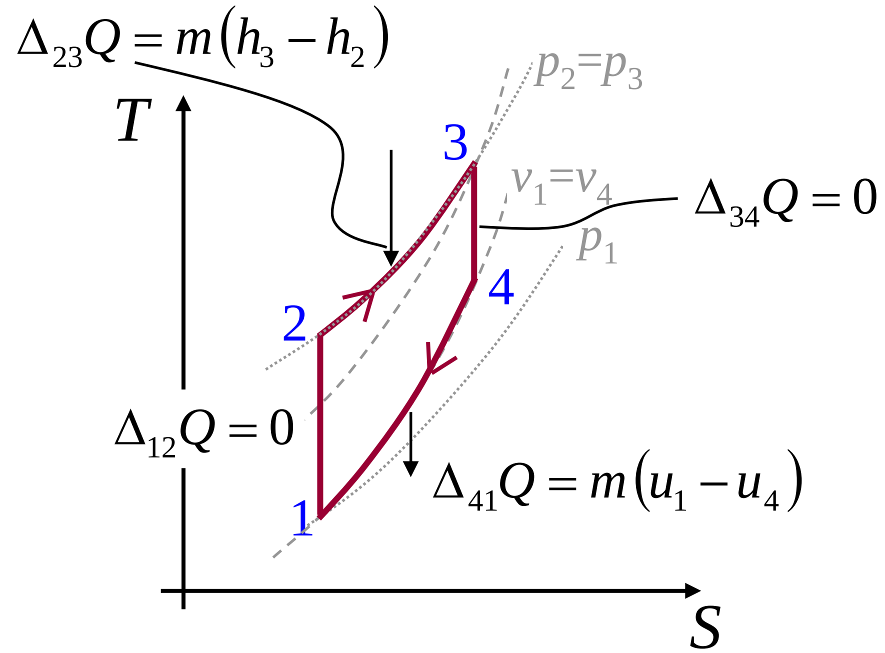
$$\Delta_{34}Q = 0 \qquad \Delta_{34}W = -m\left(u_4 - u_3\right)$$

4-1 isochoric heat transfer to external reservoir – to mimic the release of hot exhaust and uptake of fresh (cool) fuel-air mixture

$$\Delta_{41}Q = m\left(u_1 - u_4\right) \qquad \Delta_{41}W = 0$$

Diesel process (s,p,s,v)





the ratio V_3/V_2 is called cut-off ratio r_c, with $r_c := \frac{V_3}{V_2} \Leftrightarrow r_c = \frac{T_3}{T_2}$

ideal gas with $p_2=p_3$

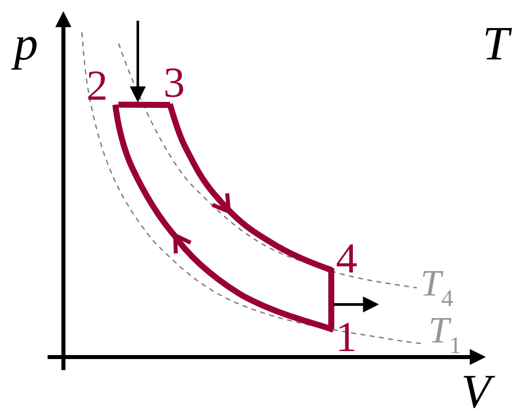
$$\frac{T_2}{V_2} = \frac{p_2}{mR} = \frac{T_3}{V_3}$$

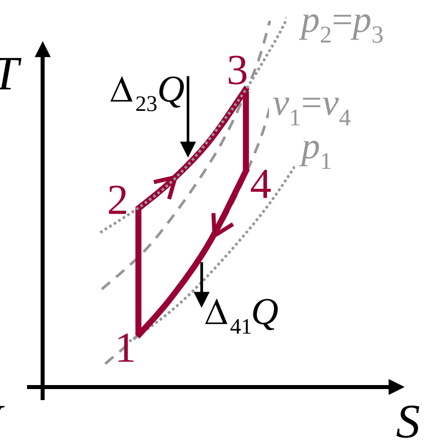
the ratio V_1/V_2 is the compression ratio r, with $r := \frac{V_1}{V_2}$

Efficiency of the Diesel engine (s,p,s,v)

$$\eta^{rev} = \frac{W^{cyc}}{\Delta_{23}Q} = \frac{\Delta_{12}W + \Delta_{34}W + \Delta_{23}W}{\Delta_{23}Q}$$

$$\eta^{rev} = \frac{\Delta_{23}Q + \Delta_{41}Q}{\Delta_{23}Q} = 1 + \frac{\Delta_{41}Q}{\Delta_{23}Q} = 1 + \frac{u_1 - u_4}{h_3 - h_2}$$





cold air standard

$$\eta^{rev} = 1 + \frac{c_v\left(T_1 - T_4\right)}{c_p\left(T_3 - T_2\right)} = 1 + \frac{1}{k}\frac{T_1 - T_4}{T_3 - T_2}$$

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

with

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{k-1} = \frac{1}{r^{k-1}} \qquad \frac{T_3}{T_2} = \frac{V_3}{V_2} = r_c$$

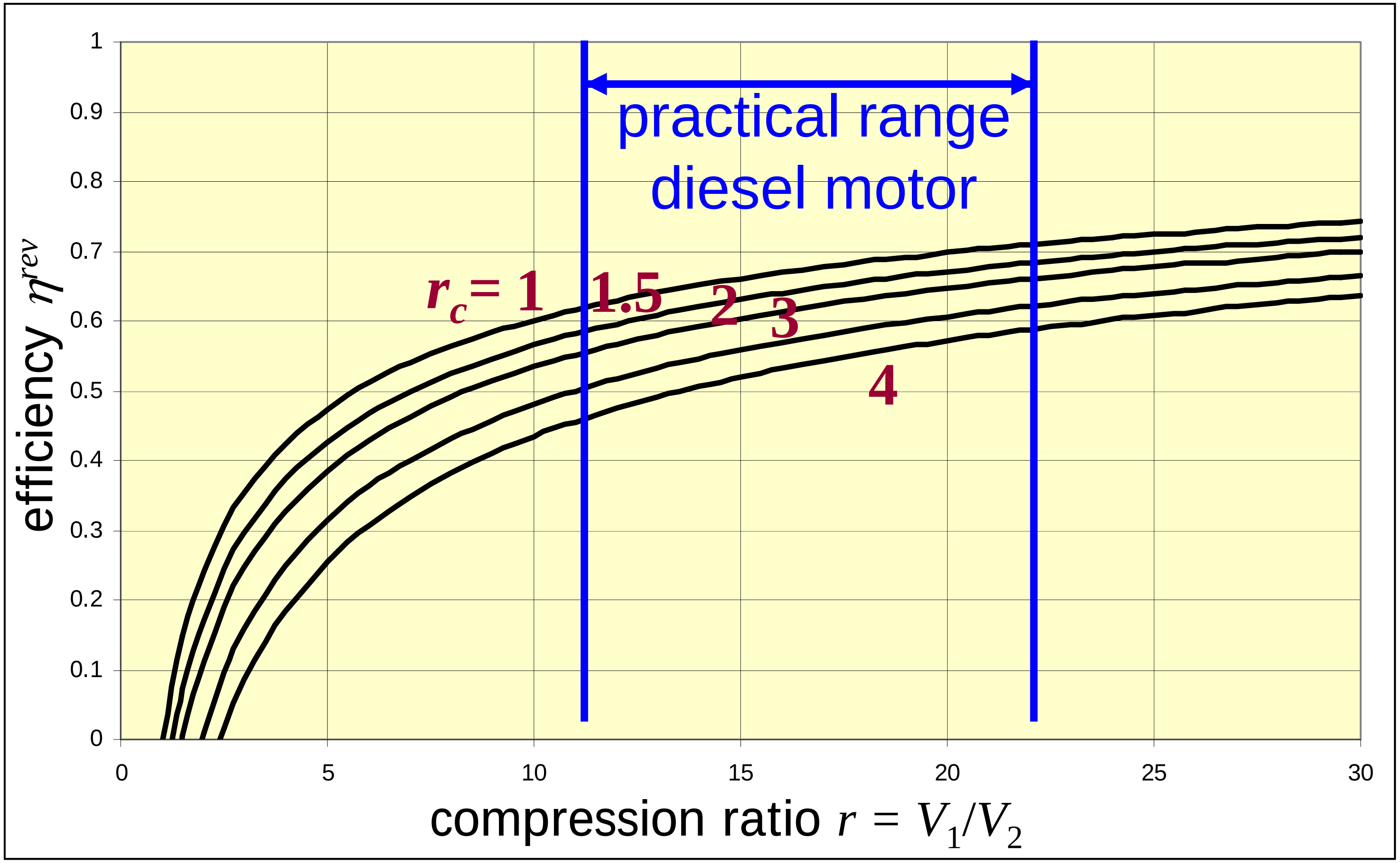
$$\frac{p_4}{p_3} = \left(\frac{V_3}{V_4}\right)^k \qquad \frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^k \Rightarrow \frac{p_4}{p_1} = \left(\frac{V_3}{V_2}\right)^k = r_c^k$$

with $p_2 = p_3$
and $V_1 = V_4$

$$\frac{T_4}{T_1} = \frac{p_4}{p_1}$$

$$\eta^{rev} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k\left(r_c - 1\right)}\right]$$

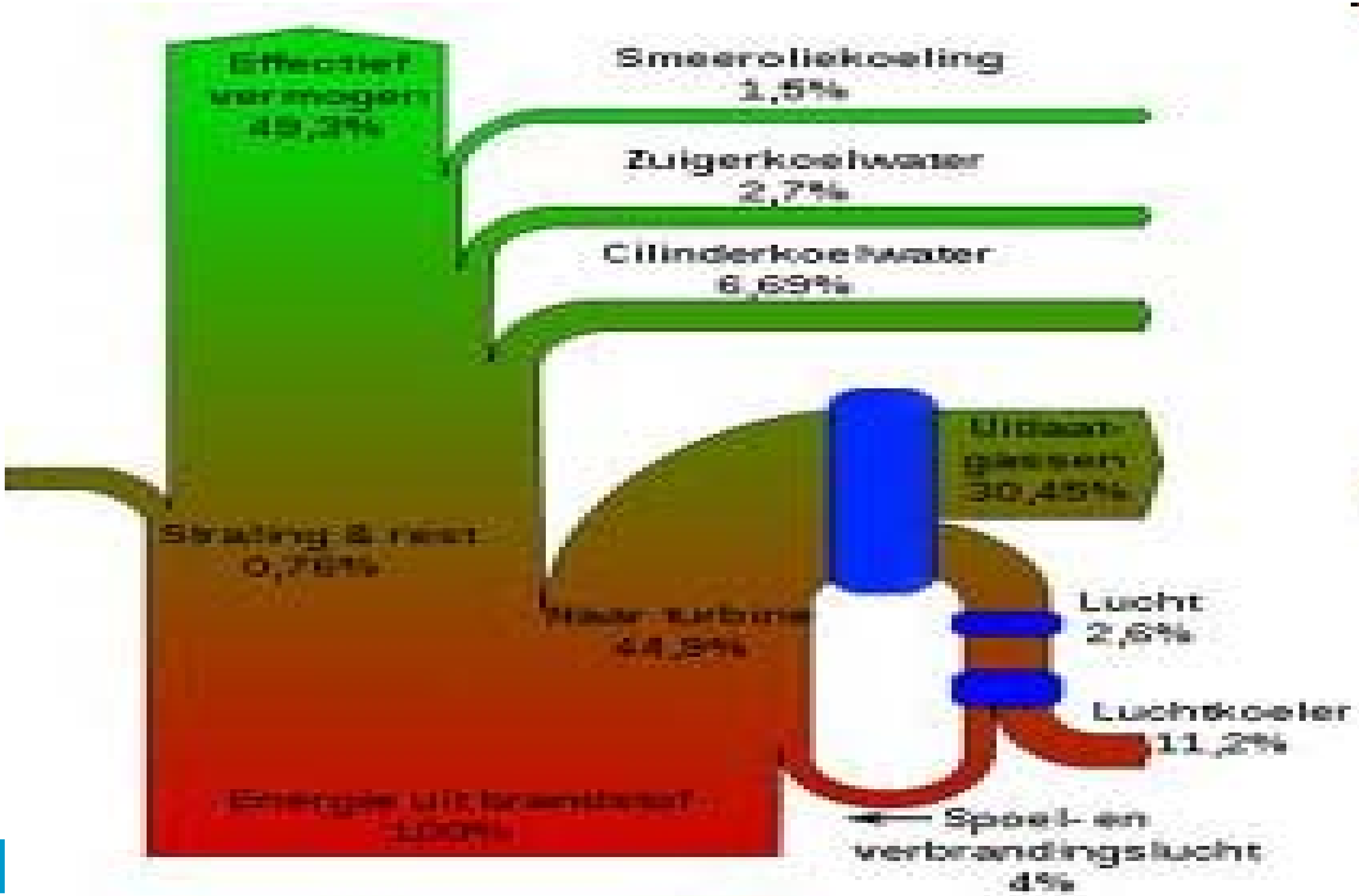
Efficiency of the Diesel engine



$$\eta^{rev} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^{\ k} - 1}{k(r_c - 1)}\right]$$

$\Rightarrow$ for a given compression ratio r, the efficiency of Diesel is lower than Otto (because the square bracket is >1). But higher compression ratios are realized for Diesel engines.

Diesel waar blijft de rest?



TU Delft

Diesel motor (opgave 9.17)

De slagvolume van een inwendige verbrandingsmotor is $5.60\ liter$. De processen in de verschillende cilinders van de motor worden gemodelleerd als een standaard-lucht Diesel kringproces met een “cutoff ratio” van 2.4. De luchttoestand bij start van de compressie fase is p_1=$95\ kPa$, T_1=$300K$, en V_1=$6.0\ liter$

a) Bereken de netto arbeid per cyclus, in kJ

b) Het vermogen geleverd door de motor, in kW, als 1500 cycli worden uitgevoerd per minuut

c) Het thermisch rendement

Diesel motor (opgave 9.17)

- Standard air
- Cold air standard

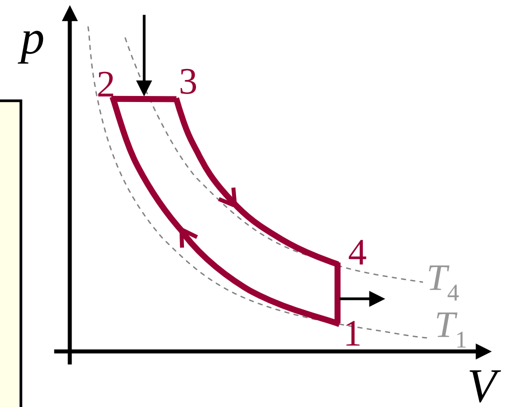
$$h_2 - h_1 = \int_1^2 C_p dT$$

$$\text{Cold air standard} \Rightarrow C_p = const \Rightarrow \underline{h_2 - h_1} = C_p \int_1^2 dT = \underline{C_p (T_2 - T_1)}$$

$$\text{Air standard} \Rightarrow \mathrm{C_p} = f(T) \Rightarrow h_2 - h_1 = \int_1^2 C_p dT \Rightarrow \text{Tabel A22}$$

Entropy op soortgelijke wijze

Diesel motor (opgave 9.17)



berekenpad 1

netto arbeid per cyclus

$$\Delta^{cyc}W = \Delta_{12}W + \Delta_{23}W + \Delta_{34}W$$

$$\Delta_{12}W = -m\left(u_2 - u_1\right)$$

$$\Delta_{23}W = p_2\left(V_3 - V_2\right)$$

$$\Delta_{34}W = -m\left(u_4 - u_3\right)$$

thermisch rendement

$$\Delta_{23}Q = m\left(h_3 - h_2\right)$$

$$\eta^{therm} = \frac{\Delta^{cyc}W}{\Delta_{23}Q}$$

berekenpad 2

netto arbeid per cyclus

$$\Delta^{cyc}W = \Delta^{cyc}Q$$

$$\Delta^{cyc}W = \Delta_{23}Q + \Delta_{41}Q$$

$$\Delta_{23}Q = m\left(h_3 - h_2\right)$$

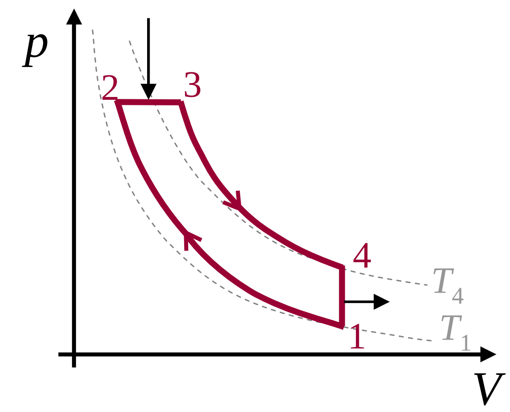
$$\Delta_{41}Q = m\left(u_1 - u_4\right)$$

thermisch rendement

$$\eta^{therm} = \frac{\Delta^{cyc}W}{\Delta_{23}Q}$$

Diesel motor (opgave 9.17)

#	T / K	p / bar	V / m³	u / kJ/kg	h / kJ/kg
1	**300.**	**0.95**	**$6.0\cdot10^{-3}$**	214.07	
2	843.2		$0.4\cdot10^{-3}$		869.6
3	2024.		$0.96\cdot10^{-3}$		2282.1
4	1146.		$6.0\cdot10^{-3}$	885.6	



rood: in opgave gespecificeerd
zwart: hier berekend
grijs: later berekend

volume

$$V_1 - V_2 = 5.6\cdot10^{-3}\,m^3$$

$$V_1 = 6.0\cdot10^{-3}\,m^3 \quad\Rightarrow\quad \underline{V_2 = 0.4\cdot10^{-3}\,m^3}$$

$$\underline{V_4 = V_1 = 6.0\cdot10^{-3}\,m^3}$$

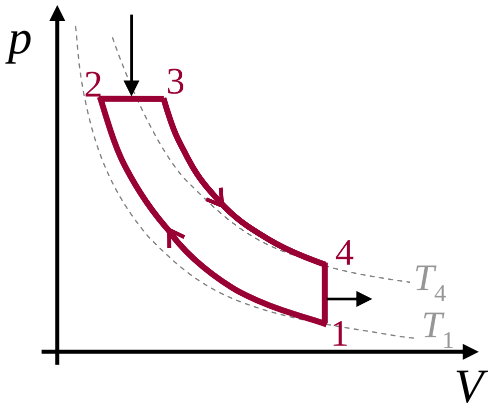
$$r_c = 2.4 \;\Rightarrow\; \frac{V_3}{V_2} = 2.4 \;\Rightarrow\; \underline{V_3 = 2.4\cdot V_2 = 0.96\cdot10^{-3}\,m^3}$$

massa (punt 1)

$$p_1V_1 = mRT_1 \quad\Rightarrow\quad m = \frac{p_1V_1}{RT_1} = \frac{95\,\frac{kJ}{m^3}\cdot 0.006\,m^3}{\dfrac{8.314\,\frac{kJ}{kmol\,K}}{28.97\,\frac{kg}{kmol}}\cdot 300\,K}$$

$$\underline{m = 0.00662\,kg}$$

Diesel motor (opgave 9.17)



temperatuur punt 2

$$\frac{V_2}{V_1} = \frac{v_2}{v_1} = \frac{v_{r2}}{v_{r1}}$$

$$Tabel\ \ A22: \ T_1 = 300K \quad \Rightarrow \quad v_r(T_1 = 300K) = 621.2$$

$$v_r(T_2) = v_r(T_1)\frac{v_2}{v_1} = 621.2\frac{0.4}{6.0} = 41.41$$

$$\Rightarrow \quad T_2 = \underline{\underline{843.2K}}$$

geïnterpoleerd

(Tabel A-22)

$$T_2 = 840\,K + \frac{860K - 840K}{v_r(860K) - v_r(840K)}\left(v_r(T_2) - r_v(840K)\right)$$

$$\Rightarrow \quad h_2 = h(T_2 = 843.2K) = \underline{\underline{869.6\,kJ}}/kg$$

geïnterpoleerd

temperatuur punt 3

$$\frac{V_2}{T_2} = \frac{mR}{p_2} = \frac{mR}{p_3} = \frac{V_3}{T_3}$$

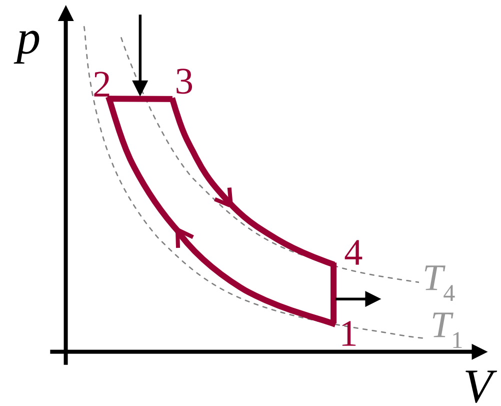
met $p_2 = p_3$

$$T_3 = T_2\frac{V_3}{V_2} = 843.3\,K \cdot 2.4 = 2024.\,K$$

$$\Rightarrow \quad h_3 = h(T_3 = 2024\,K) = \underline{\underline{2282.1kJ}}/kg$$

geïnterpoleerd

Diesel motor (opgave 9.17)



temperatuur punt 4

$$\frac{V_4}{V_3} = \frac{v_r(T_4)}{v_r(T_3)}$$

$$v_r(T_4) = v_r(T_3)\frac{V_4}{V_3} = \underline{\underline{2.670}}\,\frac{6.0}{0.96} = 16.69$$

geïnterpoleerd

$$\Rightarrow \quad T_4 = \underline{\underline{1146.K}}$$

geïnterpoleerd

$$\Rightarrow \quad u_4 = u(T_4 = 1146K) = \underline{\underline{885.6\,kJ/kg}}$$

geïnterpoleerd

netto arbeid per cyclus

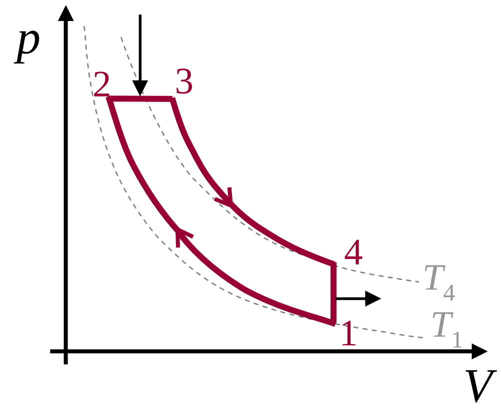
$$W^{cyc} = Q^{cyc}$$

$$W^{cyc} = \Delta_{23}Q + \Delta_{41}Q \qquad \Delta_{23}Q = m(h_3 - h_2) \qquad \Delta_{41}Q = m(u_1 - u_4)$$

$$W^{cyc} = 0.00662\,kg \cdot (2282.1 - 869.6 + 214.07 - 885.6)\frac{kJ}{kg}$$

$$W^{cyc} = 4.91kJ$$

Diesel motor (opgave 9.17)



vermogen motor

$$\dot{W} = W^{cyc} \cdot \frac{cycli}{tijdseenheid}$$

$$\dot{W} = 4.91\,kJ \cdot \frac{1500}{60\,s} = 123\,kW$$

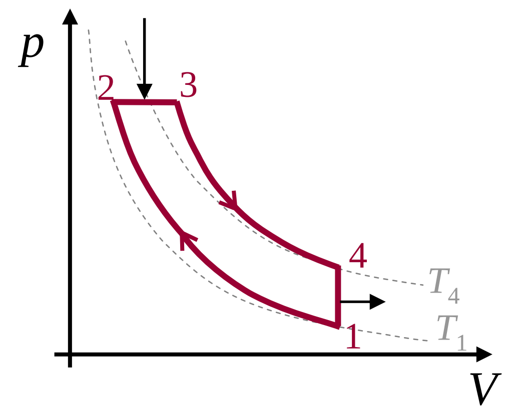
thermisch rendement

$$\eta = \frac{W^{cyc}}{\Delta_{23}Q} = \frac{4.91\,kJ}{0.00662\,kg\left(2282.1-869.6\right)kJ/kg} = \frac{4.91\,kJ}{9.35\,kJ} = 0.525$$

Zelfde opgave met cold air standard

Volume identiek aan air standard

#	T / K	p / bar	V / m³	u / kJ/kg	h / kJ/kg
1	**300.**	**0.95**	**6.0·10⁻³**	214.07	
2	843.2		0.4·10⁻³		869.6
3	2024.		0.96·10⁻³		2282.1
4	1146.		6.0·10⁻³	885.6	



rood: in opgave gespecificeerd
zwart: hier berekend
grijs: later berekend

volume

$$V_1 - V_2 = 5.6 \cdot 10^{-3} m^3$$

$$V_1 = 6.0 \cdot 10^{-3} m^3 \quad \Rightarrow \quad \underline{V_2 = 0.4 \cdot 10^{-3} m^3}$$

$$\underline{V_4 = V_1 = 6.0 \cdot 10^{-3} m^3}$$

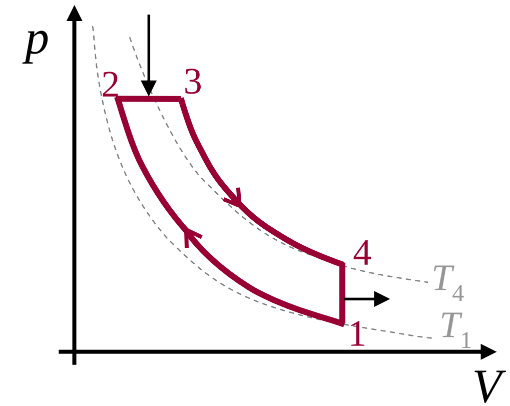
$$r_c = 2.4 \quad \Rightarrow \frac{V_3}{V_2} = 2.4 \quad \Rightarrow \underline{V_3 = 2.4 \cdot V_2 = 0.96 \cdot 10^{-3} m^3}$$

massa (punt 1)

$$p_1 V_1 = m R T_1 \quad \Rightarrow \quad m = \frac{p_1 V_1}{R T_1} = \frac{95 \frac{kJ}{m^3} \cdot 0.006 \, m^3}{\frac{8.314 \frac{kJ}{kmol\,K}}{28.97 \frac{kg}{kmol}} \cdot 300 \, K}$$

$$\underline{m = 0.00662 \, kg}$$

Diesel motor (opgave 9.17)



punt 2 $T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\kappa-1} = 300 * 15^{0.4} = 886K \quad$ (843K)

punt 3 $\frac{V_2}{T_2} = \frac{V_3}{T_3} \Rightarrow T_3 = T_2 \bullet 2.4 = 2127K \quad$ (2024K)

$$\Delta Q_{23} = mc_p(T_3 - T_2) = 0.0066 \bullet 1005 \bullet (2127 - 886) = 8.23kJ$$

punt 4

$$T_4 = T_3 \left(\frac{V_3}{V_4} \right)^{0.4} = 2127(0.96/6)^{0.4} = 1022K \quad (1146K)$$

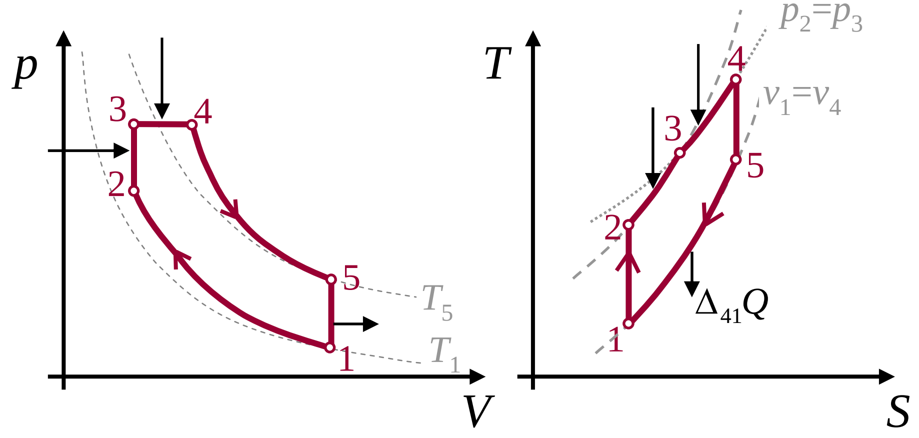
$$\Delta Q_{41} = mc_p(T_1 - T_4) = 0.0066 * 0.718 * (300 - 1022) = 3.42kJ$$

$$W_{cyc} = 8.23 - 3.42 = 4.8kJ$$

$$\eta = 4.8/8.23 = 58.4\%$$

$$\eta^{rev} = 1 - \frac{1}{r^{k-1}} \left[\frac{r_c^{\ k} - 1}{k(r_c - 1)} \right] = 0.584$$

Dual process



the Otto cycle and the Diesel cycle are strongly idealized. The dual process cycle can better approximate real combustion engines

internally reversible processes

1-2	adiabatic compression of the air	$\Delta_{12}Q = 0$	$\Delta_{12}W = -m(u_2 - u_1)$
2-3	1st part of power stroke: isochoric heating	$\Delta_{23}Q = m(u_3 - u_2)$	$\Delta_{23}W = 0$
3-4	2nd part of power stroke: isobaric expansion	$\Delta_{34}Q = m(h_4 - h_3)$	$\Delta_{34}W = p_3(V_4 - V_3)$
4-5	3rd part of power stroke: adiabatic expansion	$\Delta_{45}Q = 0$	$\Delta_{45}W = -m(u_5 - u_4)$
5-1	isochoric heat transfer to external reservoir	$\Delta_{51}Q = m(u_1 - u_5)$	$\Delta_{51}W = 0$

Duaal kringproces (opgave 9.26)

Een standaard lucht duual kringproces heeft een compressieverhouding van 16 en een cutoff ratio van 1.15. Aan het begin van de compressieproces $p_1 = 95\ kPa$ en $T_1 = 300\ K$. De druk wordt 2.2 keer zo groot gedurende het isochoor warmte toevoer proces. Als de massa van lucht $0.04\ kg$ bedraagt, bereken:

a) de toegevoerde warmte gedurende de twee warmte toevoer processen

b) de netto arbeid van het kringproces, in kJ

c) de afgevoerde warmte, in kJ

d) het thermisch rendement

Duaal kringproces (opgave 9.26)

berekenpad ← **nodig** ← **nodig**

a) toegevoerde warmte

$$\Delta^{in}Q = \Delta_{23}Q + \Delta_{34}Q$$

$$\Delta_{23}Q = m(u_3 - u_2) \leftarrow T_2\,,\; T_3$$

$$\Delta_{34}Q = m(h_4 - h_3) \leftarrow T_4$$

b) netto arbeid per cyclus

$$\Delta^{cyc}W = \Delta^{cyc}Q$$

$$\Delta^{cyc}W = \Delta_{23}Q + \Delta_{34}Q + \Delta_{51}Q$$

$$\Delta_{51}Q = m(u_1 - u_5) \leftarrow T_5$$

c) afgevoerde warmte

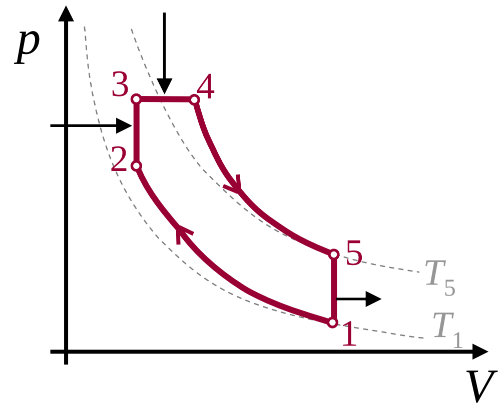
$$\Delta_{51}Q$$

d) thermisch rendement

$$\eta^{therm} = \frac{\Delta^{cyc}W}{\Delta^{in}Q}$$

Duaal kringproces (opgave 9.26)

#	T / K	p / kPa	V / m³	u / kJ/kg	h / kJ/kg
1	**300.**	**95**	0.03625	214.07	
2	862.3		0.002266	643.3	
3	1897.		0.002266	1580.	2124.
4	2182.		0.002606		2480.
5	955.4		0.03625	721.1	



temperature T_1 $T_1 = 300\,K$

pressure p_1 $p_1 = 95\,kPa$

compression ratio $r = 16$

cut-off ratio $r_c = 1.15$

pressure ratio $p_3 = 2.2 \cdot p_2$

mass $m = 0.04\,kg$

$$R = \frac{\overline{R}}{M} = \frac{8.314\,\frac{kJ}{kmol\,K}}{28.97\,\frac{kg}{kmol}} = 0.287\,\frac{kJ}{kg\,K}$$

volume

$$V_1 = \frac{mRT_1}{p_1} = \frac{0.04\,kg \cdot 287\,\frac{J}{kg\,K} \cdot 300\,K}{95 \cdot 10^3\,\frac{J}{m^3}}$$

$$V_1 = 0.03625\,m^3$$

$$r = 16 = \frac{V_1}{V_2} \qquad V_2 = \frac{V_1}{16} = 0.002266\,m^3$$

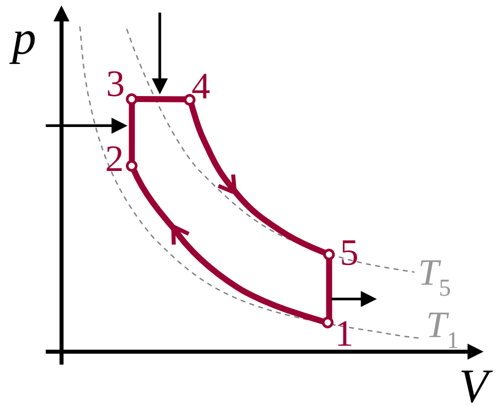
$$V_3 = V_2 = 0.002266\,m^3$$

$$r_c = 1.15 = \frac{V_4}{V_3} \qquad V_4 = 1.15 \cdot V_3 = 0.002606\,m^3$$

$$V_5 = V_1 = 0.03625\,m^3$$

Duaal kringproces (opgave 9.26)

punt 2



$$\frac{V_2}{V_1} = \frac{v_2}{v_1} = \frac{v_r(T_2)}{v_r(T_1)}$$

$$Tabel\ \ A22:\ \ T_1 = 300K \qquad \Rightarrow \ v_r\left(T_1 = 300K\right) = 621.2$$

$$v_r\left(T_2\right) = v_r\left(T_1\right)\frac{V_2}{V_1} = 621.2\frac{1}{16} = 38.83$$

$$\Rightarrow \quad T_2 = \underline{\underline{862.3K}}$$

geïnterpoleerd

(Tabel A-22)

$$T_2 = 860\,K + \frac{880K - 860K}{v_r\left(880K\right) - v_r\left(860K\right)}\left(v_r\left(T_2\right) - v_r\left(860K\right)\right)$$

$$\Rightarrow \quad u_2 = u\left(T_2 = 862.3K\right) = \underline{\underline{643.3\,kJ/kg}}$$

geïnterpoleerd

TU Delft

Duaal kringproces (opgave 9.26)

punt 3

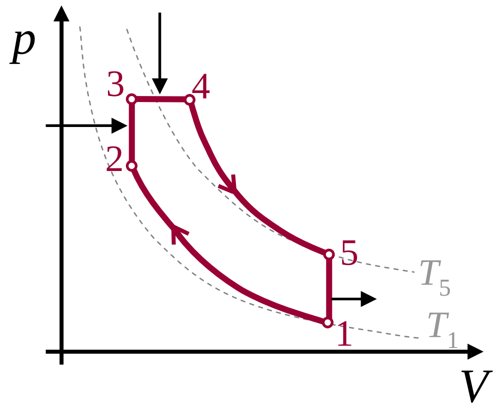
stap 2→3: isochoor (V_3=V_2) met p_3 =2.2 p_2

met $pV = mRT$ is $\frac{p_3}{T_3} = \frac{mR}{V_3} = \frac{mR}{V_2} = \frac{p_2}{T_2}$

$$\Rightarrow \frac{T_3}{T_2} = \frac{p_3}{p_2} = 2.2$$

$$\Rightarrow T_3 = 2.2 \cdot T_2 \qquad = 2.2 \cdot 862.3K$$

$$\Rightarrow T_3 = 1897.K$$



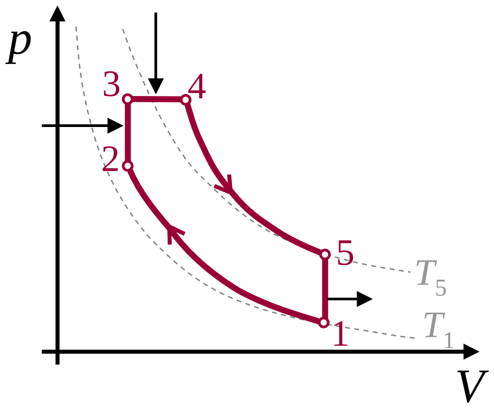
$$\Rightarrow u_3 = u(T_3 = 1897.K) = 1580.kJ/kg$$

geïnterpoleerd

$$\Rightarrow h_3 = h(T_3 = 1897.K) = 2124.kJ/kg$$

geïnterpoleerd

Duaal kringproces (opgave 9.26)



punt 4

stap 3→4: isobaar (p_4=p_3) met V_4=1.15 V_3

met $pV = mRT$ is $\frac{V_4}{T_4} = \frac{mR}{p_4} = \frac{mR}{p_3} = \frac{V_3}{T_3}$

$$\Rightarrow \quad \frac{T_4}{T_3} = \frac{V_4}{V_3} = 1.15$$

$$\Rightarrow \quad T_4 = T_3 \frac{V_4}{V_3} = T_3 \cdot 1.15 = 1897.K \cdot 1.15$$

$$\Rightarrow \quad T_4 = 2182.K$$

$$\Rightarrow \quad h_4 = h(T_4 = 2182.K) = \underline{\underline{2480.kJ}}/kg$$

geïnterpoleerd

TU Delft

Duaal kringproces (opgave 9.26)

punt 5

$$\frac{V_5}{V_4} = \frac{v_5}{v_4} = \frac{v_r(T_5)}{v_r(T_4)}$$

$$T_4 = 2182.K \quad \Rightarrow \quad v_r(T_4 = 2182K) = 2.072$$

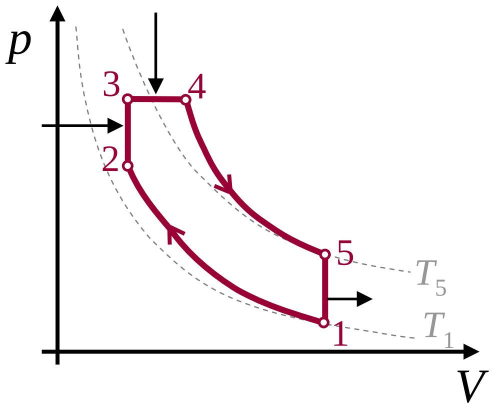
$$v_r(T_5) = v_r(T_4)\frac{V_5}{V_4} = 2.072\frac{0.03625\,m^3}{0.002606\,m^3} = 28.82$$

$$\Rightarrow \quad T_5 = \underline{\underline{955.4\,K}}$$

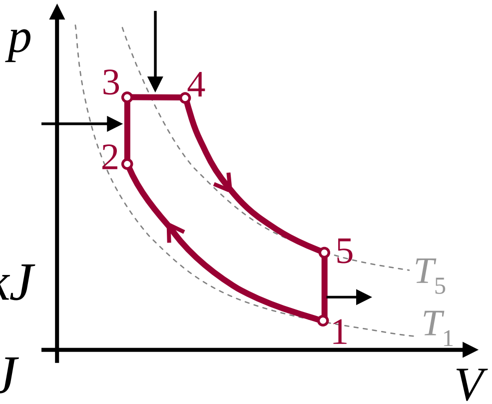
geïnterpoleerd

$$\Rightarrow \quad u_5 = u(T_5 = 955.4K) = \underline{\underline{721.1kJ/kg}}$$

geïnterpoleerd



Duaal kringproces (opgave 9.26)



toegevoerde warmte

$$\Delta^{in}Q = \Delta_{23}Q + \Delta_{34}Q$$

$$\Delta_{23}Q = m\left(u_3 - u_2\right) = 0.04\,kg\left(1580. - 643.3\right)kJ/kg = 37.5\,kJ$$

$$\Delta_{34}Q = m\left(h_4 - h_3\right) = 0.04\,kg\left(2480 - 2124\right)kJ/kg = 14.2\,kJ$$

$$\Delta^{in}Q = 37.5\,kJ + 14.2\,kJ = 51.7\,kJ$$

netto arbeid per cyclus

$$\Delta^{cyc}W = \Delta^{cyc}Q$$

$$\Delta^{cyc}W = \Delta_{23}Q + \Delta_{34}Q + \Delta_{51}Q$$

$$\Delta_{51}Q = m\left(u_1 - u_5\right) = 0.04\,kg\left(214.07 - 721.1\right)kJ/kg = -20.3\,kJ$$

$$\Delta^{cyc}W = \left(37.5 + 14.2 - 20.3\right)kJ = 31.4\,kJ$$

afgevoerde warmte

$$\Delta_{51}Q = -20.3\,kJ$$

thermisch rendement

$$\eta^{therm} = \frac{\Delta^{cyc}W}{\Delta^{in}Q} = \frac{31.3}{51.7} = 0.608$$

Aanwijzigingen voor zelfstudie

- H9.3 en H9.4 nu behandeld. Dit voor de volgende keer goed doorlezen – ook de ‘examples’ in tekst
- Maak enkele van de opgaven 9.13 t/m 9.21 (Diesel kringproces)
- Maak enkele van de opgaven 9.22 t/m 9.27 (lucht duaal kringprocessen)