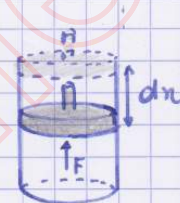
H3 Uitwerking vd energietermen vd Eerste Hoofdwet

Arbeidswisseling

Volume arbeid bij omkeerbare toestandsver.



$F = P.A$

$dW = F.dx$

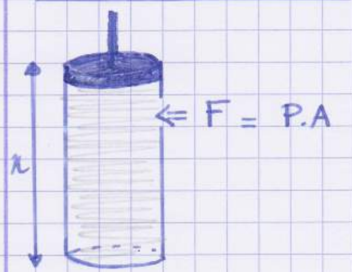
$dW = P.\underbrace{A.dx}_{=dV} \Rightarrow dW = PdV$

$$W_{1\to2} = \int_1^2 dW = \int_1^2 P\,dV$$

Technische arbeid W_t

$$W_t = \underbrace{W_{in}}_{\text{arbeid inlaatstap}} + \underbrace{W}_{\text{volume arbeid}} + \underbrace{W_{uit}}_{\text{arbeid uitlaatstap}}$$

Inlaatstap

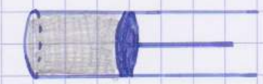


$W_{in} = F \cdot x = P \cdot \underbrace{A \cdot x}_{= V}$

$W_{in} = P_1 V_1 > 0$

(0613) comp (0524) exp

Compressie / Expansie



$W = \int_1^2 P\, dV < 0$ (4213)

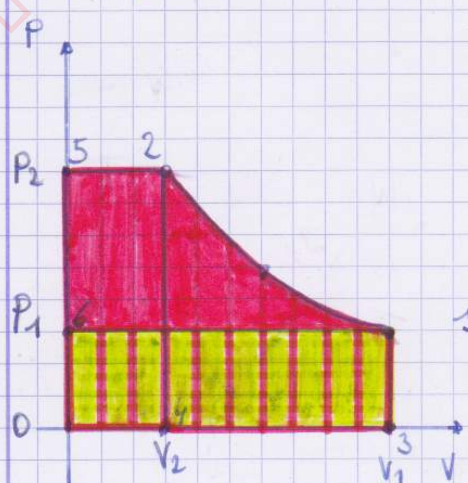
$W = \int_1^2 P\, dV > 0$ (4213)

Uitlaatklep

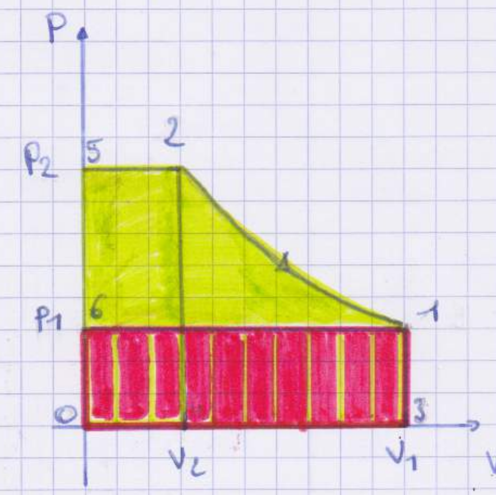
$W_{uit} = -P_2 V_2 < 0$

(0426) comp (0613) exp

Compressie (PV-dia.)



expansie (PV-dia)



$W_{t,1\to 2} = -\int_1^2 V\, dP$

$W_{t,1\to 2} = -\int_1^2 V\, dP$

Isobaar (P = ct.)

$$W_{1\to2} = \int_1^2 P\,dV \qquad W_{1\to2} = P\Delta V$$

$$W_{t,1\to2} = -\int_1^2 V\,dP \qquad W_{t,1\to2} = 0$$

Isochoor (V = ct.)

$$W_{1\to2} = \int_1^2 P\,dV \qquad W_{1\to2} = 0$$

$$W_{t,1\to2} = -\int_1^2 V\,dP \qquad W_{t,1\to2} = V\Delta P$$

Isotherm (T = ct.)

$$W_{1\to2} = \int_1^2 P\,dV$$

$$= \int_1^2 \frac{P_1V_1}{V}\,dV$$

$$= P_1V_1 \int_1^2 \frac{dV}{V}$$

$$= P_1V_2 \ \ln\left(\frac{V_2}{V_1}\right)$$

$P_1V_1 = mR_gT$

$PV = mR_gT$

$\Rightarrow P = \frac{P_1V_1}{V}$

$\Rightarrow V = \frac{P_1V_1}{P}$

$\frac{V_2}{V_1} = \frac{P_1}{P_2}$

$$W_{1\to2} = P_1V_1 \ln\left(\frac{P_1}{P_2}\right)$$

$$W_{t,1\to2} = -\int_1^2 V\,dP = -\int_1^2 P_1V_1 \frac{dP}{P}$$

$$= -P_1V_1 \ln\left(\frac{P_2}{P_1}\right)$$

$$W_{t,1\to2} = P_1V_1 \ln\left(\frac{P_1}{P_2}\right)$$

$W_{1\to2} = W_{t,1\to2}$ want $W_{in} = -W_{uit}$

Warmtewisseling

$$dQ = m\,c\,dT$$

$$\underbrace{dQ}_{\text{afh. van transformatie}} = \underbrace{dU}_{\text{onafh. v. proces}} + \underbrace{dW}_{\text{afh. v. proces}}$$

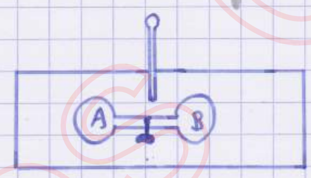
$$\overbrace{m\,c\,dT} = \overbrace{dU} + \overbrace{p\,dV}$$

⇒ De warmte wisseling is dus afh. vd gevolgde weg.

c_p c_v

Inwendige Energie

Wet van Joule



⇒ geen temp. ver. ⇒ $du = dq - dw = 0$
geen arbeid

⇒ $u = f(T)$ (toestandsgrootheid)

De inwendige energie bij ideale gassen

Geen arbeid: isochoor: $dq = du + dw$

⇒ $c_v\,dT = du$

verandering v. d. toestandsgrootheid u

De wet van Mayer voor ideale gassen

Isobaar:
$$dq = du + dw$$
$$c_p\,dT = c_v\,dT + p\,dv$$

met $Pv = R_g T$
$$\downarrow$$
$$\cancel{dPv} + dv\,P = R_g\,dT$$

$$c_p\,dT = c_v\,dT + R_g\,dT$$

$$c_p = c_v + R_g$$

Enthalpie

$$h = u + pv \rightsquigarrow dh = du + d(pv)$$

$$\left.\begin{aligned} du &= c_v\, dT \\ d(pv) &= R_g\, dT \end{aligned}\right\} \rightsquigarrow dh = c_v\, dT + R_g\, dT$$

$$dh = c_v\, dT + (c_p - c_v)\, dT$$

voor $\forall$ mogelijke processen $\Rightarrow$ $dh = c_p\, dT$

$$dh = \underbrace{du + \underbrace{p\,dv}_{dW}}_{dq} + v\,dp$$

$$dh = dq + v\,dp$$

$$dh = dq - dW_t$$

$$\Rightarrow \quad dq = dW_t + dh$$

Besluit:

$$dq = c_v\, dT + p\,dv$$

$$dq = c_p\, dT - v\,dp$$

H4 Polytrope toestandsveranderingen bij ideale gassen

Definitie

soortelijke warmte vh. fluïdum ct. — isobaar c_p / isochoor c_v

Afleiding vd. algemene formule

$$dq = du + dw$$

$$C\,dT = C_v\,dT + P\,dv$$

$$(C - C_v)\,dT = P\,dv$$

$$(C - C_v)\left(\frac{P\,dv + v\,dP}{R_g}\right) = P\,dV$$

$$(C - C_v)(P\,dV + v\,dP) = R_g\,P\,dV$$

$$(C - C_v - R_g)\,P\,dV = -v\,dP(C - C_v)$$

$$(C - C_p)\,P\,dV = -v\,dP(C - C_v)$$

als $P \neq 0$, $v \neq 0$, $C \neq C_v$

$$\left(\frac{C - C_p}{C - C_v}\right)\frac{dV}{V} + \frac{dP}{P} = 0$$

integreren met $n = \frac{C - C_p}{C - C_v}$

$$n \ln v + \ln p = ct.$$

$$\ln(Pv^n) = ct. \Rightarrow Pv^n = ct.$$

$$PV^n = ct.$$

$$n = \frac{C_p - C}{C_v - C} \Rightarrow C = \frac{n C_v - C_p}{n - 1}$$

Isobaar : $n = 0$ $\quad C = C_p$

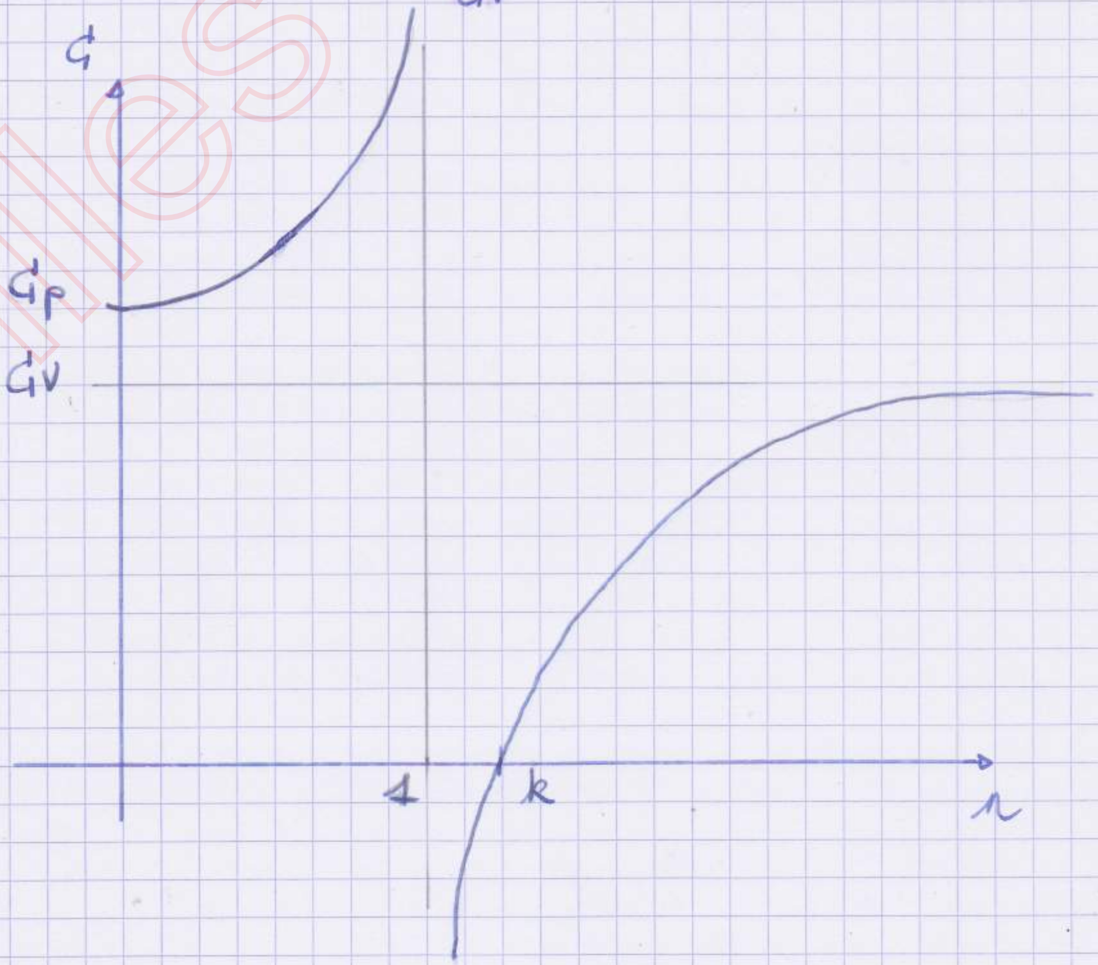
Isochoor : $n \to \infty$ $\quad C = C_v$

Isotherm : $n = 1$ $\quad C = \infty$

$$\lim_{n \underset{<}{\to} 1} \frac{n C_v - C_p \; (<0)}{n - 1 \; (<0)} \quad \downarrow \quad C = +\infty$$

$$\lim_{n \underset{>}{\to} 1} \frac{n C_v - C_p \; (<0)}{n - 1 \; (>0)} \quad \downarrow \quad C = -\infty$$

Isentroop : $n = k = \frac{C_p}{C_v}$ $\quad C = 0$



formules van Poisson

$PV^n = ct.$ met $PV = mRgT$

$$\frac{mRgT}{V} \cdot V^n = ct \Rightarrow T \cdot V^{(n-1)} = ct.$$

$$P \left(\frac{mRgT}{P} \right)^n = ct.$$

$$\Rightarrow P^{(1-n)} \cdot T^n = ct$$

Berekening vd volumearbeid

$$W_{1\to2} = \int_1^2 P\,dV = \int_1^2 P_1 V_1^n \cdot V^{-n}\, dV$$

$$PV^n = P_1 V_1^n \Rightarrow P = \frac{P_1 V_1^n}{V^n}$$

$$= P_1 V_1^n \int_1^2 V^{-n} dV \underset{\text{als } n \neq 1}{=} \frac{P_1 V_1^n}{1-n} \left[V^{1-n} \right]_{V_1}^{V_2}$$

$$= \frac{P_1 V_1^n}{1-n} \left(V_2^{1-n} - V_1^{1-n} \right) = \frac{P_1 V_1^n}{n-1} \left(V_1^{1-n} - V_2^{1-n} \right)$$

$$= \frac{P_1 V_1}{n-1} \left(1 - \left(\frac{V_2}{V_1} \right)^{1-n} \right)$$

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

$$P_1 V_1 = Rg T_1$$

$$= \frac{Rg T_1}{n-1} \left(1 - \frac{T_2}{T_1} \right)$$

$$W_{1\to2} = \frac{Rg}{n-1} \left(T_1 - T_2 \right)$$

$$q_{1\to 2} = c_1\, dT \qquad W_{1\to 2} = \frac{R_g}{n-1}\left[T_1 - T_2\right]$$

$$c_1 = \frac{n c_v - c_p}{n-1}$$

$$R_g = c_p - c_v$$

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

$$\underbrace{W_{1\to 2} = \frac{R_g}{n-1}\left(T_1 - T_2\right) \qquad q_{1\to 2} = c_1\left(T_2 - T_1\right)}$$

$$\rightsquigarrow \quad \underbrace{W = \frac{R_g}{n-1}\,\frac{q}{-c_1} \qquad c_1 = \frac{n c_v - c_p}{n-1}}$$

$$\rightsquigarrow \quad \underbrace{W = \frac{R_g}{\cancel{(n-1)}} \cdot \frac{q\,\cancel{(n-1)}}{c_p - n c_v} \qquad R_g = c_p - c_v}$$

$$W = \frac{c_p - c_v}{c_p - n c_v}\, q \qquad k = \frac{c_p}{c_v}$$

$$W = \frac{k-1}{k-n}\, q$$

$$\Rightarrow \quad q = \frac{k-n}{k-1}\, W$$

$$W_{t,1\to 2} = -\int_1^2 v\,dp \qquad pv^n = ct.$$

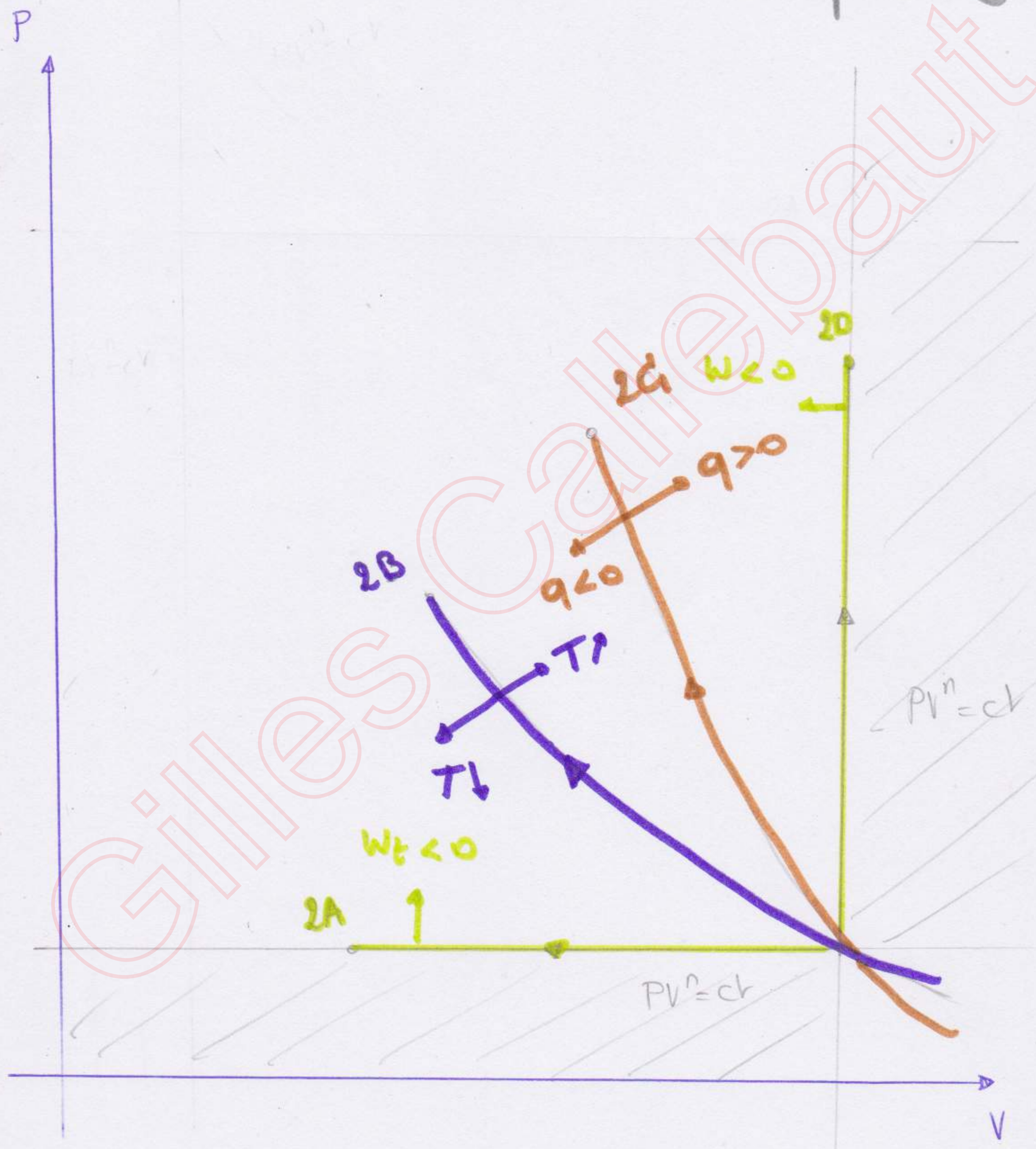
$$v^n dp + n p v^{n-1} dv = 0$$

$$= +n \int_1^2 p\,dv \qquad \rightarrow v\,dp = n p\,dv$$

$$= n\, W_{1\to 2}$$

$$\Rightarrow \quad W_{t,1\to 2} = n\, W_{1\to 2}$$

Compressie



(2A)

$T_{2A} < T_1$

$q_{1\to 2A} < 0$

$W_{1\to 2A} < 0$

<u>isobaar</u> $n = 0$

$W_{t,1\to 2A} = 0$

(2B) $T_{2B} = T$

<u>isotherm</u> $n = 1$

$q_{1\to 2B} = W_{1\to 2B}$
$= W_{t,1\to 2B}$ < 0

(2C)

<u>Isentroop</u> $n = k \rightarrow c_i = 0$

$q_{1\to 2C} = 0$

$W_{1\to 2C} < 0$ $T_{2C} > T_1$

$W_{t,1\to 2C} < 0$ $V_1 < V_{2C}$

(2D) $T_{2D} > T_1$

<u>Isochoor</u> $n = \infty$

$q_{1\to 2D} > 0$

$W_{1\to 2D} = 0$

$W_{t,1\to 2D} < 0$

Compressie

Expansie

(1)

helling: $pV^n = ct.$

$$V^n dp + n V^{n-1} p \, dV = 0$$

$$\frac{dp}{dV} = -\frac{np}{V}$$

vorm: hyperbool, buik naar beneden (2x afleiden)

↳ thuis

(2A)

$T_{2A} > T_1$

grootste ← $(q_{1 \to 2A}) > 0$

$w_{1 \to 2A} > 0$

$w_{t,1 \to 2A} = 0$

isobaar $n = 0$

(2B)

$T_{2B} = T_1$

$q_{1 \to 2B} = w_{1 \to 2B} = w_{t,1 \to 2B} > 0$

isotherm

$n = 1$

(2C)

$q_{1 \to 2C} = 0$

$w_{1 \to 2C} > 0$

$w_{t,1 \to 2C} > 0$

$U_{2C} < U_1$

$T_{2C} < T_1$

Isentroop $C_i = 0$

$n = k$

(2D)

$T_{2D} < T_1$

$q_{1 \to 2D} < 0$

$w_{1 \to 2D} = 0$

$w_{t,1 \to 2D} > 0$

Isochoor

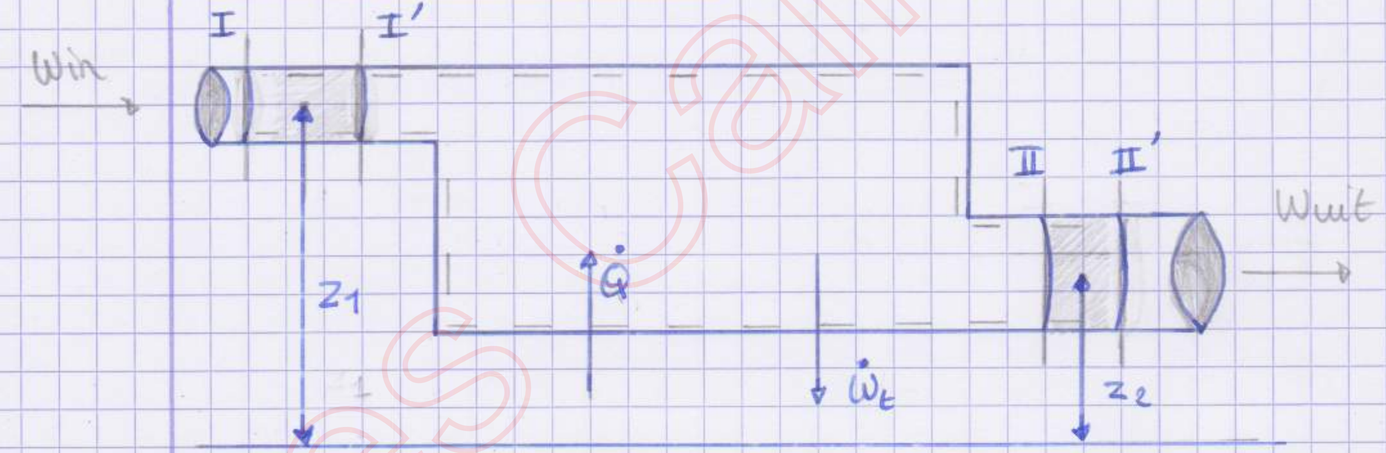
$n = \infty$

Expansie

H5 De eerste hoofdwet voor open systemen

Bij open systemen stroomt het fluidum door een energiewisselaar zodat ook de kinetische en potentiële energie ervan kunnen veranderen.

Energiewisselaar



Stel stroming stationair : $(\text{Energie})_{in} = (\text{Energie})_{uit}$

$$q_{1\to 2} + e_{II'} = w_{1\to 2} + e_{\text{II II'}}$$

$$\begin{cases} e_{II'} = \underbrace{u_1}_{\text{inw.}} + \underbrace{\frac{c_1^2}{2}}_{\text{kin.}} + \underbrace{g z_1}_{\text{pot.}} \quad \text{energie} \\ e_{\text{II II'}} = u_2 + \frac{c_2^2}{2} + g z_2 \\ w_{1\to 2} = w_{t,1\to 2} + w_{in} + w_{uit} \\ \qquad = w_{t,1\to 2} - p_1 v_1 + p_2 v_2 \end{cases}$$

$$\underbrace{(u_2 + p_2 v_2) - (u_1 + p_1 v_1)}_{= (h_2 - h_1)} + (c_2^2 - c_1^2)\frac{1}{2} + g(z_2 - z_1) = q - w_t$$

$$dh + d\left(\frac{c^2}{2}\right) + g\,dz = dq - dw_t$$

Toepassingen.

Warmtewisselaars

→ afkoelen of opwarmen

→ gn arbeid, kin. en pot. te verwaarlozen

$\Rightarrow \quad \Delta h = q_{1\to 2}$

$\Rightarrow \quad q_{1\to 2} = \Delta h = c_p(T_2 - T_1)$ Enkel ideaal gas

Isentrope arbeidswisseling

↳ zonder noemingswaardig warmteverlies

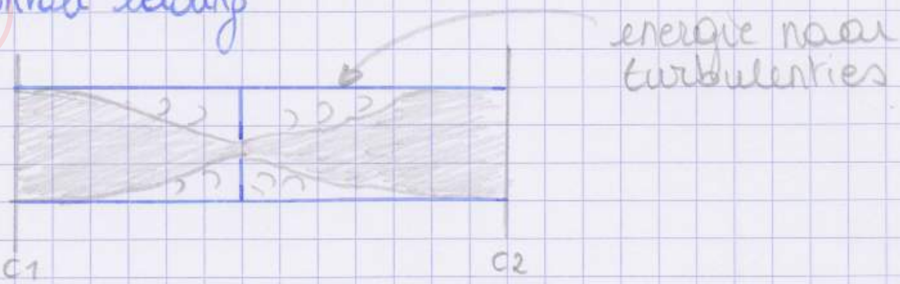
→ kin. en pot. te verwaarlozen

$\Rightarrow \quad \Delta h = -\underset{\substack{\uparrow \\ \text{compressie}}}{w_{t,1\to 2}}$ of $\Delta h = \underset{\substack{\uparrow \\ \text{expansie}}}{w_{t,1\to 2}}$

Smoorproces

→ gn arbeid, warmteoverdracht te verwaarlozen

→ horizontale leiding



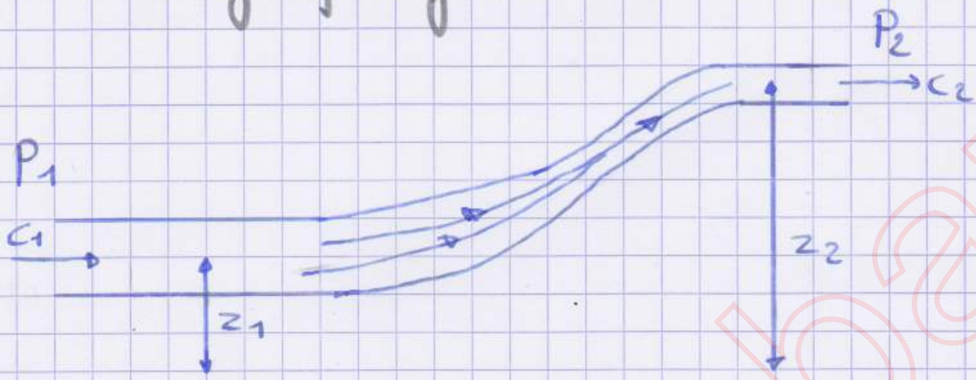
$dh + d\left(\frac{c^2}{2}\right) = 0$

→ kin. te verw. → $dh = 0$

→ ideaal gas: $\Delta h = c_p(T_2 - T_1)$

dus zonder temp. verandering

De vergelijking van Bernouilli



→ gn warmte of arbeid wisseling, gn temp. verandering

$$\Rightarrow \quad \Delta h + \frac{\Delta c^2}{2} + g\Delta z = 0 \qquad \Delta h = \Delta U + \Delta W$$

$$\Delta W + \frac{\Delta c^2}{2} + g\Delta z = 0 \qquad v = ct. \rightarrow v = \frac{1}{\rho} = ct.$$

$$W + \frac{c^2}{2} + gz = cte.$$

$$\Rightarrow \quad \frac{p}{\rho} + \frac{c^2}{2} + gz = cte.$$

$$\Rightarrow \quad \frac{p}{\rho g} + \frac{c^2}{2g} + z = cte.$$

De eerste hoofdwet voor gesloten systemen

→ gn kin., gn pot. energie

$$dh = dq - dw_t$$

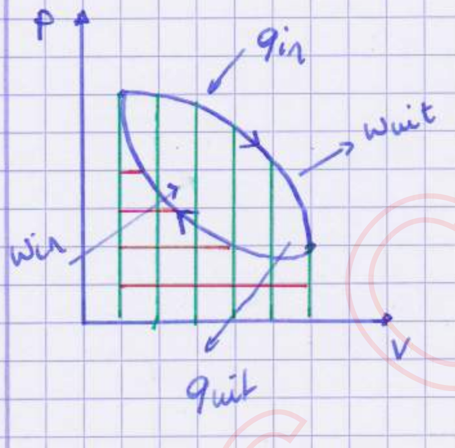
$$du + dw = dq - dw_t$$

$$du + dw_{1\to 2} = dq$$

H6 Soorten kringprocessen en hun rendementen

Arbeidsleverende of positieve kringprocessen (motoren)

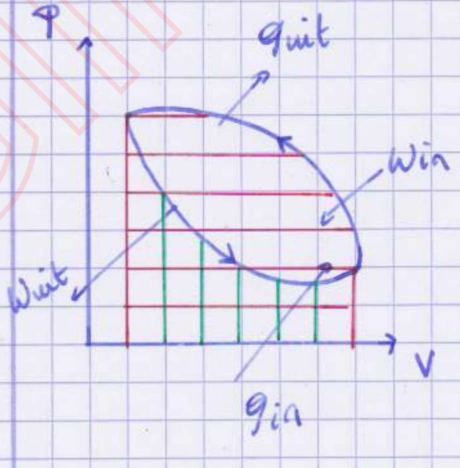
→ De expansielijn ligt hoger dan de compressielijn.



$W_{in} < 0$

$W_{uit} < 0$

Arbeidsverbruikende of negatieve kringprocessen



$W_{net} < 0$

Rendement van een kringproces

De eerste hoofdwet:

Open systeem — gesloten systeem

$$dq = du + dw \qquad dq = dh + dw_t + d\left(\frac{c^2}{2}\right) + g\,dz$$

met $\oint du = \oint dh = \oint d(c^2/2) = \oint g\,dz = 0$

$$\Rightarrow \oint dq = \oint dw \qquad \oint dq = \oint dw_t$$

Thermisch rendement v.e. pos. kringproces

$$q_{in} - |q_{uit}| = w_{uit} - |w_{in}|$$

$$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{q_{in} - |q_{uit}|}{q_{in}} = 1 - \frac{|q_{uit}|}{q_{in}}$$

Koeleffect (of koudefactor) en warmte-productiegetal v. neg. kringproces

koelmachine — warmtepomp

$$\varepsilon = \frac{q_{in}}{|w_{net}|} = \frac{q_{in}}{|q_{uit}| - q_{in}} \qquad \varepsilon_w = \frac{|q_{uit}|}{|w_{net}|}$$

$$\varepsilon = \frac{1}{\frac{|q_{uit}|}{q_{in}} - 1}$$

$$|w_{net}| = |q_{uit}| - q_{in}$$

$$1 = \frac{|q_{uit}|}{w_{net}} - \frac{q_{in}}{w_{net}}$$

$$1 = \varepsilon_w - \varepsilon$$

H7 De tweede hoofdwet en Entropie

Principe van Kelvin

$$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{q_{in} - |q_{uit}|}{q_{in}}$$

⇒ $q_{uit} \neq 0$ ⇒ het is onmogelijk een kringproces uit te voeren die warmte uit één bron volledig omzet in arbeid.

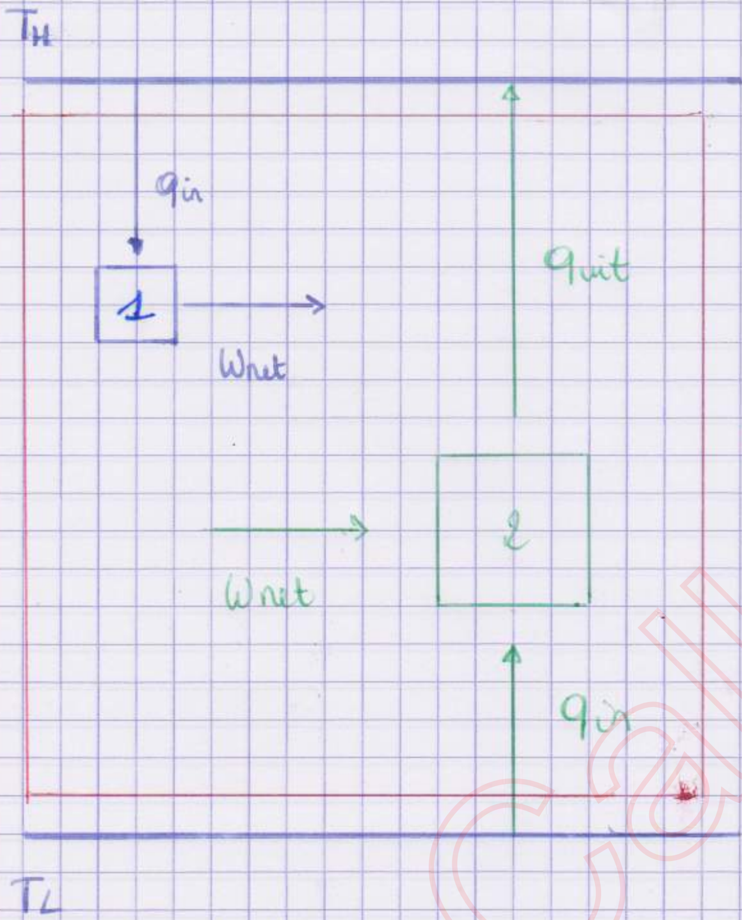
Principe van Clausius

$$\varepsilon = \frac{q_{in}}{W_{net}} = \frac{q_{in}}{|q_{uit}| - q_{in}}$$

$$\varepsilon_w = \frac{q_{uit}}{W_{net}}$$

Arbeid nodig . thermische energie lage temp → hogere

⇒ energieomzettingen zijn beperkt ook al is voldaan aan de wet van behoud van energie.



$\Rightarrow$ $W_{net} = 0$

$\Uparrow$

HW II !

① $\eta_{th} = 100\,\% \rightsquigarrow q_{in} = W_{net}$

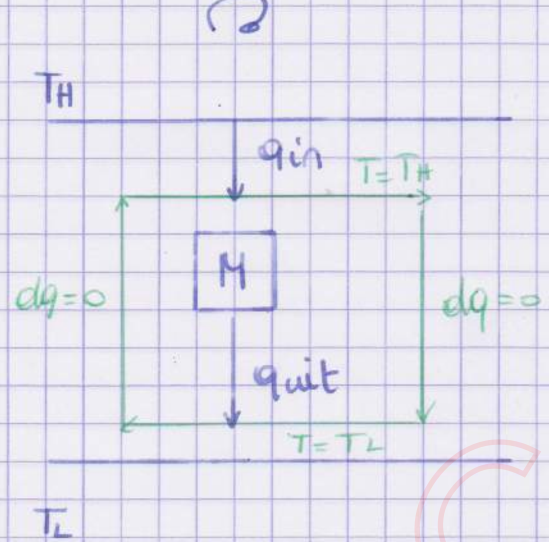
② $\varepsilon \neq \infty \Rightarrow |q_{uit}| = q_{in} + |W_{net}|$

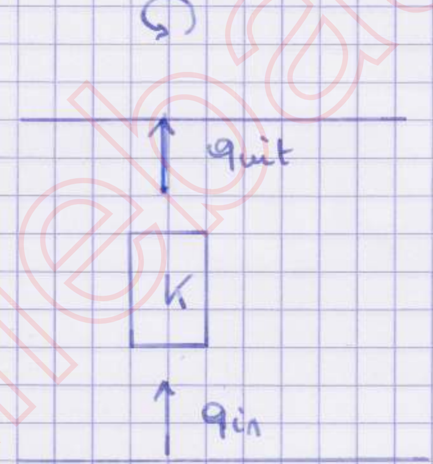
Koppelen ① & ② : $W_{net,1} = W_{net,2}$

$|q_{uit,2}| = |q_{in,2} + q_{in,1}|$

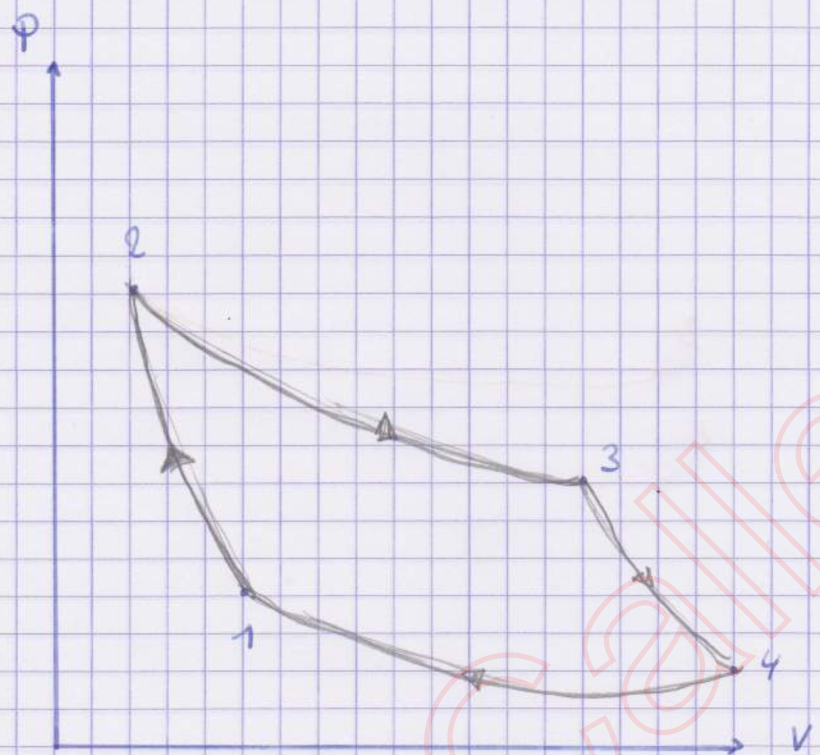
Het kringproces van Carnot

Een ideaal kringproces





Een omkeerbaar kringproces



↻ ↺

1 → 2 Isentrope compressie — exp.

→ $q_{1\to 2} = 0$ — $W_{2\to 1} > 0$

$W_{1\to 2} < 0$ — $q = 0$

2 → 3 Isotherme expansie — compr.

→ $q_{2\to 3} = W_{2\to 3} = P_2V_2 \ln\left(\frac{V_3}{V_2}\right)$ — $q_{3\to 2} = W_{3\to 2} < 0$

$= (R_gT_H)\ln\left(\frac{V_3}{V_2}\right)$

> 0

3 → 4 Isentrope expansie — compr.

→ $W_{3\to 4} > 0$ — $W_{4\to 3} < 0$

$q_{3\to 4} = 0$ — $q = 0$

4 → 1 Isotherme compressie — exp.

→ $q_{4\to 1} = W_{4\to 1} = P_4V_4 \ln\left(\frac{V_1}{V_4}\right)$ — $q_{1\to 4} = R_gT_L \ln\left(\frac{V_4}{V_1}\right)$

$= R_gT_L \ln\left(\frac{V_1}{V_4}\right)$

< 0

Rendement vh. Carnot-kringproces (ideaal gas)

Thermisch rendement

$$\eta_{th}^{c} = 1 - \frac{|q_{uit}|}{q_{in}}$$

$$|q_{uit}| = w_{4\to 1} = R_g T_L \ln\left(\frac{V_1}{V_4}\right)$$

$$q_{in} = w_{2\to 3} = R_g T_H \ln\left(\frac{V_3}{V_2}\right)$$

Isentropen → formule van Poisson

$$T_L V_1^{k-1} = T_H V_2^{k-1} \qquad T_L V_4^{k-1} = T_H V_3^{k-1}$$

$$\left(\frac{V_4}{V_1}\right)^{k-1} = \left(\frac{V_3}{V_2}\right)^{k-1}$$

$$\frac{|q_{uit}|}{q_{in}} = \frac{T_L}{T_H}$$

$$\Rightarrow \quad \eta_{th}^{c} = 1 - \frac{T_L}{T_H}$$

warmte toevoer → hoog mogelijke temp.

warmte afvoeren → laag " "

Het koeleffect of koudefactor

$$\varepsilon^c = \frac{q_{in}}{|q_{uit}| - q_{in}}$$

$$q_{in} = R_g T_L \ln\left(\frac{V_4}{V_1}\right)$$

$$|q_{uit}| = |w_{3\to 2}|$$

$$= R_g T_H \ln\left(\frac{V_2}{V_3}\right)$$

$$\varepsilon^c = \frac{T_L}{T_H - T_L}$$

Het warmteproductiegetal

$$\varepsilon^c_w = \frac{|q_{uit}|}{|q_{uit}| - q_{in}} = \frac{T_H}{T_H - T_L}$$

carnot, hoogst rendement

motor M eff. dan carnot-motor

$$\eta_{th} > \eta_{th}^{c} \qquad \text{bij } q_{in}$$

inverse carnot-motor (K koelmach.) gekoppeld aan M

$$|w_{net,K}| = |q_{uit,K}| - q_{in,K}$$

$$|q_{uit,K}| = q_{in,M}$$

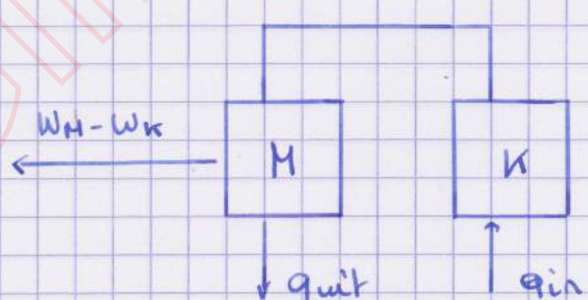
indien $\eta_{th}^{M} > \eta_{th}^{K}$

$\Rightarrow \quad w_{net,M} > w_{net,K}$

$\Rightarrow \quad w_{net} = w_{net,M} - w_{net,K}$

↳ met 1 warmtebron → arbeid

↳ HW II ! strijdig



Andere kringprocessen

Omkeerbaar

$$\eta_{th} = \eta_{th}^{c}$$ (kan bewezen ω)

$$1 - \frac{|q_{uit}|}{q_{in}} = 1 - \frac{T_L}{T_H}$$

$$\frac{|q_{uit}|}{T_L} = \frac{q_{in}}{T_H}$$

$$\Rightarrow \frac{q_{uit}}{T_L} + \frac{q_{in}}{T_H} = 0$$

$$\Rightarrow \oint \underbrace{\frac{dq}{T}}_{ds} = 0$$

Onomkeerbaar

$$\eta_{th} < \eta_{th}^{c}$$

$$\frac{|q_{uit}|}{T_L} > \frac{q_{in}}{T_H}$$

$$\Rightarrow \oint \frac{dq}{T} = \frac{q_{in}}{T_H} + \frac{q_{uit}}{T_L} < 0$$

De toestandsgrootheid _ Entropie

Def & basisform.

$$\begin{cases} ds = \dfrac{dq}{T} & (1) \\ dq = du + dw & (2) \\ dq = dh + dw_t & (3) \end{cases}$$

<u>(1)&(2)</u>

$$ds = \frac{du}{T} + \frac{dw}{T}$$

$$= \frac{C_v\,dT}{T} + \frac{P\,dV}{T}$$

$$ds = \underbrace{\frac{C_v\,dT}{T}}_{} + \underbrace{\frac{R_g\,dV}{V}}_{}$$

toestr. grootheden

<u>(1)&(3)</u>

$$ds = \frac{dh}{T} + \frac{dw_t}{T}$$

$$= \frac{C_p\,dT}{T} - \frac{V\,dP}{T}$$

$$ds = C_p \frac{dT}{T} - R_g \frac{dP}{P}$$

$\cdot\, C_p \quad - \quad \cdot\, C_v$

$$\underbrace{(C_p - C_v)}_{R_g}\, ds = C_p R_g \frac{dV}{V} + C_v R_g \frac{dP}{P}$$

$$ds = C_p \frac{dV}{V} + C_v \frac{dP}{P}$$

Entropie berekenen

$$ds = \frac{dq}{T}$$

Als $T = ct.$

$$s_2 - s_1 = \frac{q_{1 \to 2}}{T}$$

open — systemen — gesloten

$S = m\,s$

[kJ/K]

$\dot{S} = \dot{m}\,s$

[kW/K]

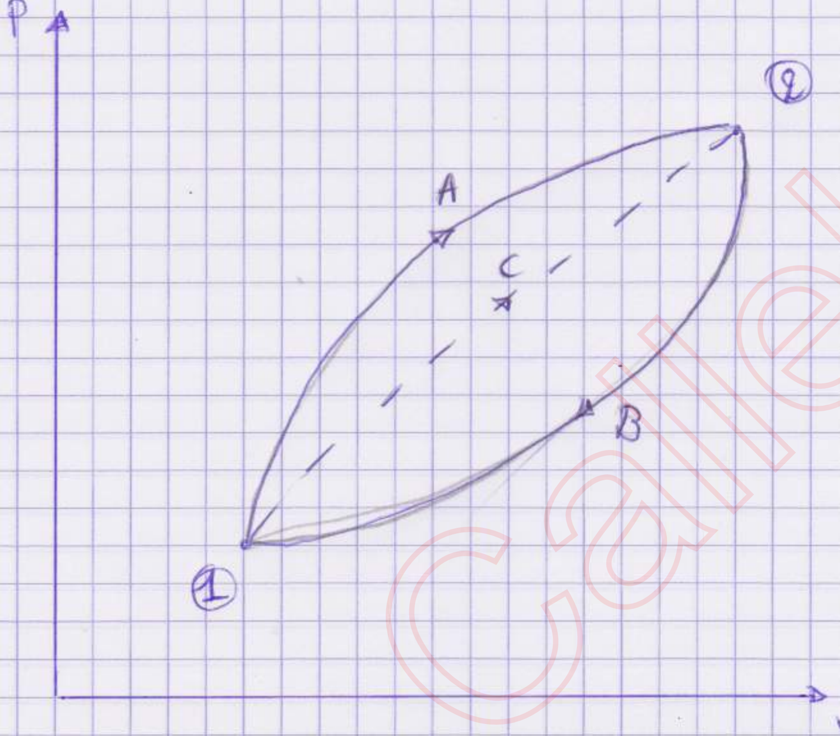
Als $T \neq ct.$

$$s_2 - s_1 = \int \frac{c\,dT}{T}$$

$$= c_i \ln\left(\frac{T_2}{T_1}\right)$$

[kJ/kgK]

Entropieverandering



Omkeerbaar

$$\oint \frac{dq}{T} = \underbrace{\int_1^2 \frac{dq}{T}}_{A} + \underbrace{\int_2^1 \frac{dq}{T}}_{B} = 0$$

$$\Rightarrow \int_B \frac{dq}{T} = s_2 - s_1 = (\Delta s_{rev})$$

Onomkeerbaar

$$\oint \frac{dq}{T} = \underbrace{\int_1^2 \frac{dq}{T}}_{C} + \underbrace{\int_2^1 \frac{dq}{T}}_{B} < 0$$

$$\Rightarrow \int_C \frac{dq}{T} < s_2 - s_1$$

$$\Rightarrow s_2 - s_1 = \int_C \frac{dq}{T} + \underbrace{\Delta s_{irr.}}_{>0}$$

Δs_{irr}:
- $< 0 \Rightarrow$ onmog.
- $= 0 \Rightarrow$ omkeerbaar
- $> 0 \Rightarrow$ onomkeerbaar

Adiabatische toestandsver.

↳ praktische, onomkeerbare en niet-evenwichtige toestandsverandering waarbij geen (gewilde) warmtewisseling optreedt.

$1 \rightarrow 2$ (adiab.)

$$\int_1^2 \frac{dq}{T} = 0 \qquad \text{of} \qquad s_2 > s_1$$

⇒ reële toest. zonder warmtewisseling → entropiestijging

ⓑ ⓐ

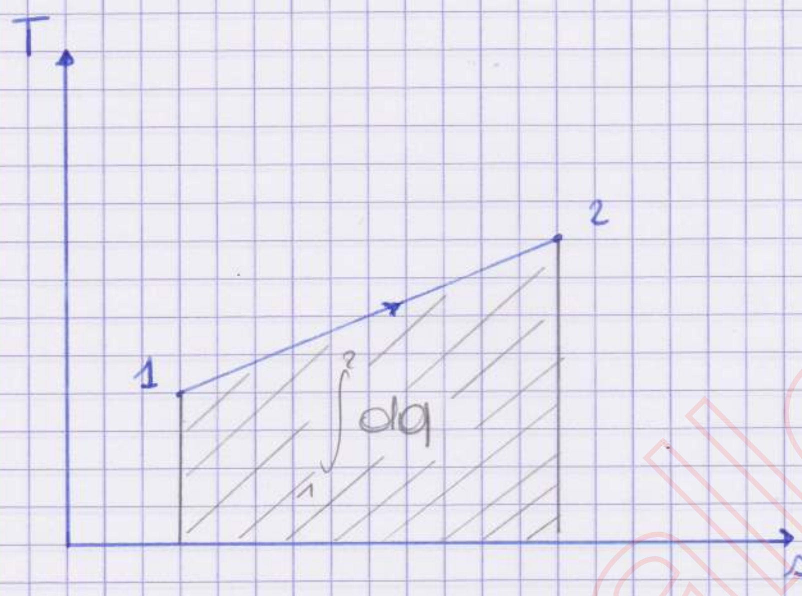
$$T_1 \xleftarrow{\quad q \quad} T_2 \qquad \text{met } T_1 > T_2$$

$$\Delta s = \underbrace{\Delta s\, rev}_{=0} + \underbrace{\Delta s\, irr}_{>0}$$

$$\Delta s\, irr = \underbrace{q_{a \to b}}_{! < 0} \underbrace{\left(\frac{1}{T_1} - \frac{1}{T_2} \right)}_{<0} > 0$$

$$\Delta s\, irr = \Delta s_a + \Delta s_b$$

Het (T, s) diagram



$$ds = \frac{dq}{T}$$

$$dq = T\,ds$$

$$= T(ds_{rev} + ds_{irr})$$

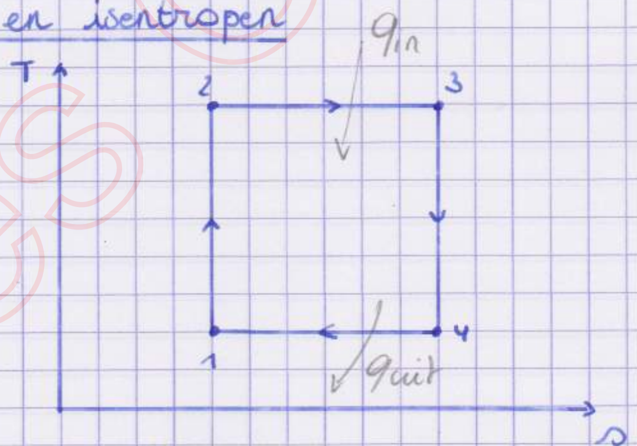
$\downarrow$ als $ds_{irr} = 0$

$$\int_1^2 dq = q_{1\to 2} = \int_1^2 T\,ds$$

Polytrope toest.

Isothermen en isentropen

Carnot



$$q_{in} = q_{2\to 3} = \int_2^3 T_H \cdot ds = T_H(s_3 - s_2)$$

$$q_{uit} = q_{4\to 1} = \int_4^1 T_L \cdot ds = T_L(s_1 - s_4)$$

$$\eta_{th}^{c} = 1 - \frac{|q_{uit}|}{q_{in}} = 1 - \frac{T_L(s_4 - s_1)}{T_H(s_3 - s_2)}$$

$$\eta_{th}^{c} = 1 - \frac{T_L}{T_H}$$

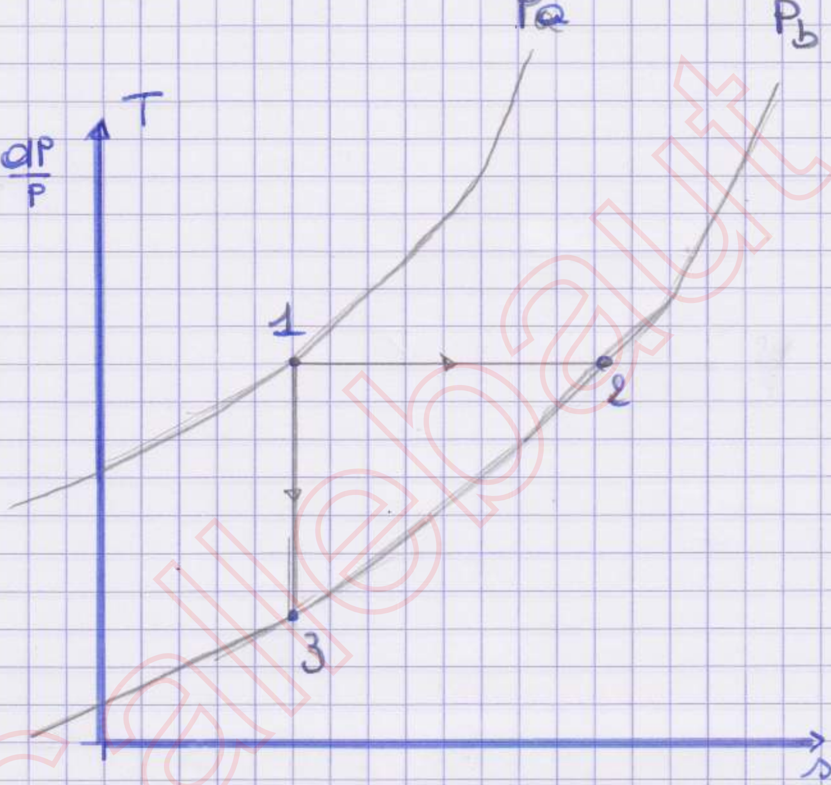
Isobaren

$$ds = C_p \frac{dT}{T} - R_g \frac{dP}{P}$$

{ isobaar

$$\Delta s = C_p \ln$$

$$T = T_1 \, e^{\left(\frac{\Delta s}{C_p}\right)}$$



ligging tov elkaar.

- $\underline{T = ct.}$

$$\underset{>0}{\Delta s} = -\underbrace{R_g \ln\left(\frac{P_b}{P_a}\right)}_{<0}$$

$$\frac{P_b}{P_a} < 1$$

- $\underline{s = ct.}$

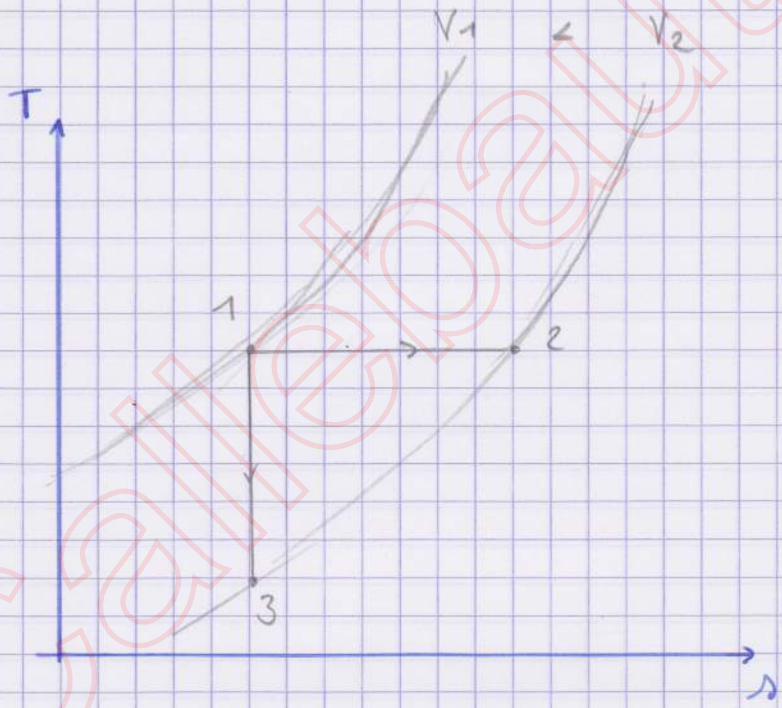
$$\underbrace{\Delta s}_{=0} = \underbrace{C_p \ln\left(\frac{T_3}{T_1}\right)}_{<0} - \underbrace{R_g \ln\left(\frac{P_b}{P_a}\right)}_{<0}$$

$$\frac{P_b}{P_a} < 1$$

Isochoren

$$ds = c_v \frac{dT}{T} + R_g \frac{dv}{v}$$

} isochoor



$$ds = c_v \frac{dT}{T}$$

$$\Rightarrow T = T_1 e^{(\Delta s / c_v)}$$

ligging:

- $T = ct.$

$$\Delta s = R_g \ln\left(\frac{v_2}{v_1}\right)$$

$>0 \longrightarrow\ >0$

$$\frac{v_2}{v_1} > 1$$

- $s = ct.$

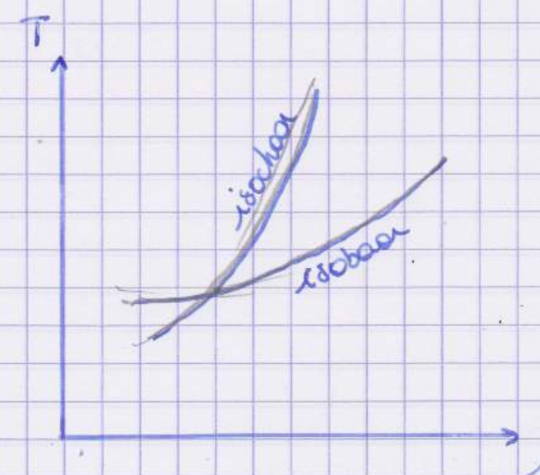
$$\underbrace{\Delta s}_{=0} = \underbrace{c_v \ln\left(\frac{T_3}{T_1}\right)}_{<0} + \underbrace{R_g \ln\left(\frac{v_3}{v_1}\right)}_{>0}$$

$$\frac{v_3}{v_1} > 1$$

Onderlinge ligging

isobaar: $ds = c_p \frac{dT}{T}$

↳ $dT = \frac{T}{c_p} ds$



isochoor: $ds = c_v \frac{dT}{T}$

↳ $dT = \frac{T}{c_v} ds$

mits $c_p = c_v + R_g \rightarrow c_p > c_v$

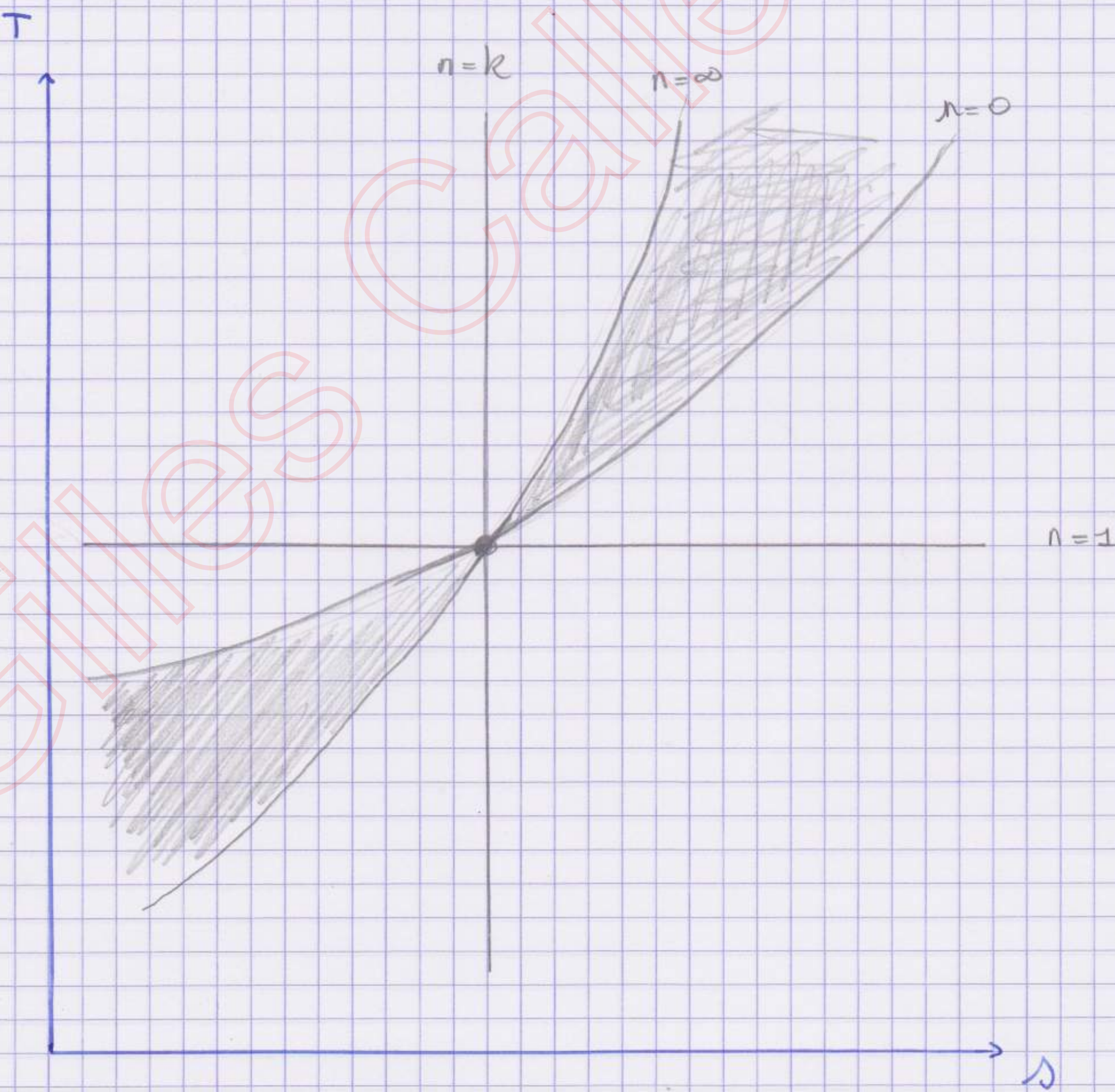
Willekeurige polytropen

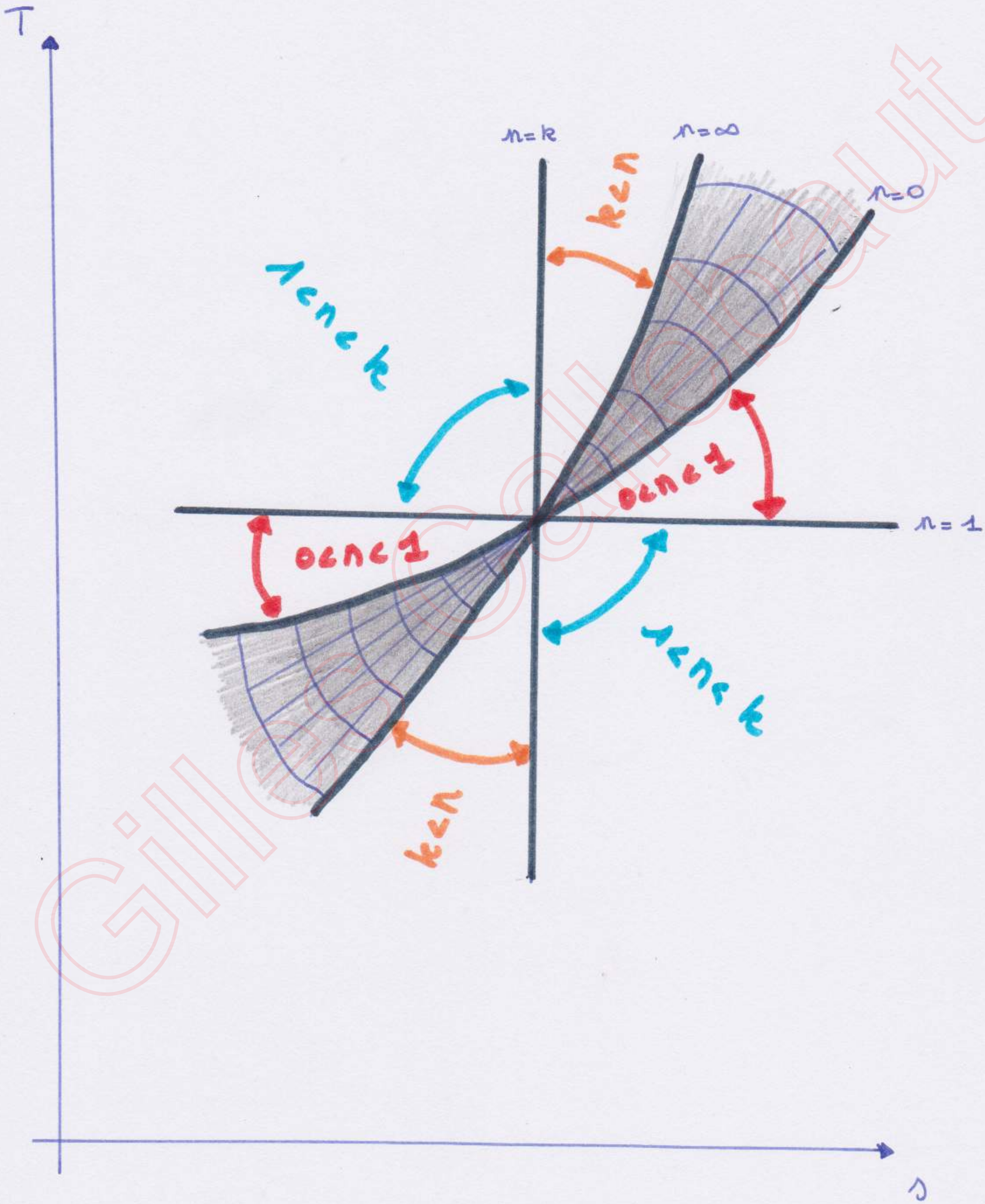
$$ds = c\,\frac{dT}{T}$$

$$\Delta s = c \ln\left(\frac{T_2}{T_1}\right) \qquad \text{met } n = \frac{c_p - c}{c_v - c}$$

$$\hookrightarrow c = \frac{c_v(n-k)}{(n-1)}$$

$$\Delta s = c_v \left[\frac{(n-k)}{(n-1)}\right] \ln\left(\frac{T_2}{T_1}\right)$$

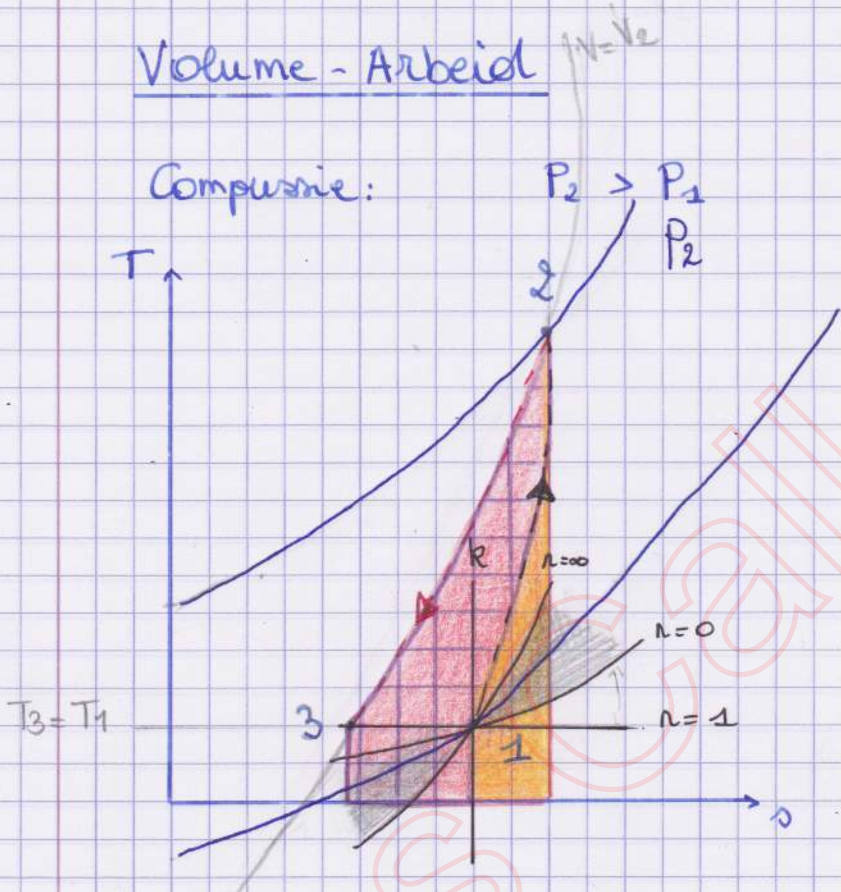



T
n=k
n=∞
n=0
n=1
k<n
1<n<k
0<n<1
k<n
1<n<k
0<n<1
s

Arbeid in (T, s) diagram

Volume - Arbeid

Compressie: $P_2 > P_1$



Hoe?

$k < n$

HWI: $q_{1\to2} = (U_2 - U_1) + W_{1\to2}$

$$\underset{<0}{W_{1\to2}} = \underset{>0}{q_{1\to2}} + \underset{<0}{(U_1 - U_2)}$$

Fictief proces $2 \to 3$:

↳ ? welk proces → isochoor → $W_{2\to3} = 0$

↳ ? (3) eindtoestand → $U_3 = U_1$ → $T_1 = T_3$

$q_{2\to3} = (U_3 - U_2) + W_{2\to3}$

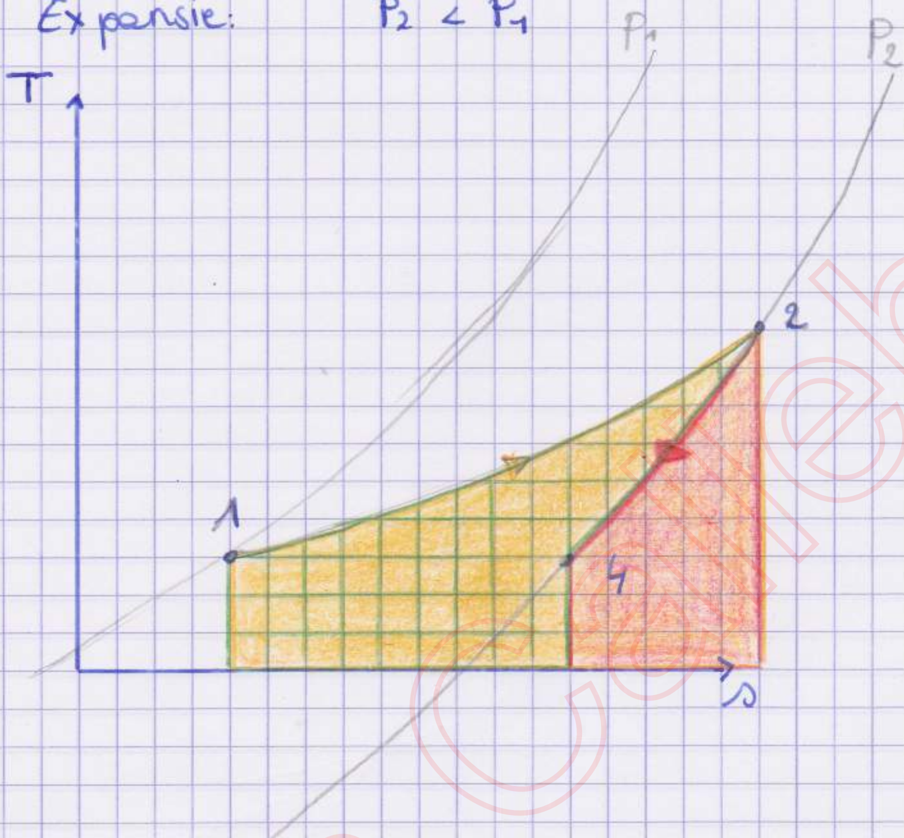
$q_{2\to3} = (U_1 - U_2)$

Technische arbeid

Expansie: $P_2 < P_1$

Hoe ?

$0 < n < 1$



HWI: $q_{1\to2} = (h_2 - h_1) + w_{t\,1\to2}$

$w_{t\,1\to2} = q_{1\to2} + (h_1 - h_2)$

Fictief proces $2\to4$:

↳ $w_{t\,2\to4} = 0$ als isobaar

↳ $h_4 = h_1 \leftrightarrow T_4 = T_1$ (ideaal gas)

$q_{2\to4} = (h_4 - h_2) + w_{t\,2\to4}$

$q_{2\to4} = (h_1 - h_2)$

Isentroop rendement

Expansie: $P_2 < P_1$

HW I: $\underbrace{q_{1\to2}}_{=0} = (h_2 - h_1) + w_{t,1\to2}$

(id.)

$(h_1 - h_2) = w_{t,1\to2}$ met $(h_2 - h_1) = c_p(T_1 - T_2)$

HW II:

Omkeerbaar (ideaal)

$\underset{=0}{\Delta s} = \underset{=0}{\Delta s_{rev.}} + \Delta s_{irr.}$

isentroop $\to$ $= 0$

$\to s_1 = s_2$

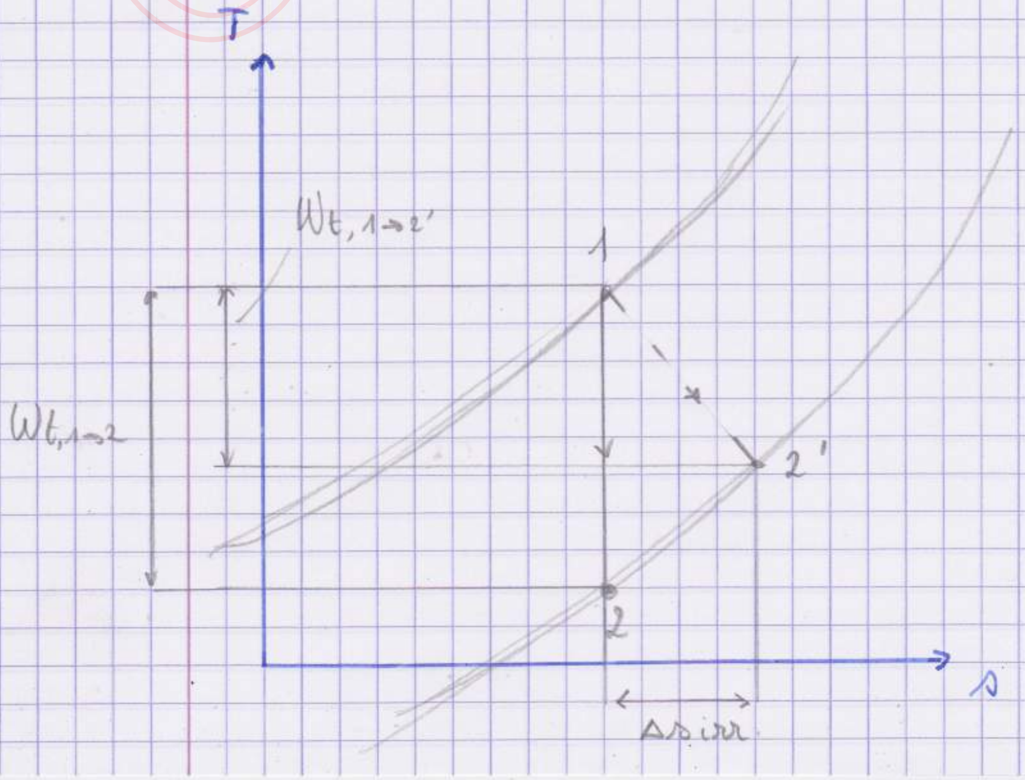
Onomkeerbaar (reëel) ← Adiabaat

$\underset{\neq 0}{\Delta s} = \underset{=0}{\Delta s_{rev}} + \underset{\neq 0}{\Delta s_{irr.}}$

$\to > 0$

$\downarrow$

$s_2' > s_1$ $\to \eta_{is} = \dfrac{w_{t,1\to2'}}{w_{t,1\to2}} < 1$



$$\eta_{is} = \frac{(T_1 - T_2')}{(T_1 - T_2)}$$

H8: Kringprocessen met ideale gassen

Ter vereenvoudiging is aangenomen dat het gebruikte fluïdum zich als een ideaal gas gedraagt en dat alle toestandsver. omkeerbaar en dus evenwichtig verlopen.

Compressieverhouding:

$$r_v = \rho = \frac{V_{max}}{V_{min}} = 1 + \frac{\Delta V}{V_{min}}$$

met $\Delta V = \frac{\pi D^2}{4} \cdot \underbrace{s}_{\text{slaglengte}}$

Referentie energie:

$$R_g T_1 \rightarrow \boxed{q_h^* = \frac{q_{in}}{R_g T_1}\ [-]}$$

Arbeid:

$$\frac{w_{net}}{R_g T_1} = \oint dw^* = \oint dq^* = \frac{q_{in} - |q_{uit}|}{R_g T_1}$$

$$\boxed{w_{th}^* = q_h^* - |q_e|^*}$$

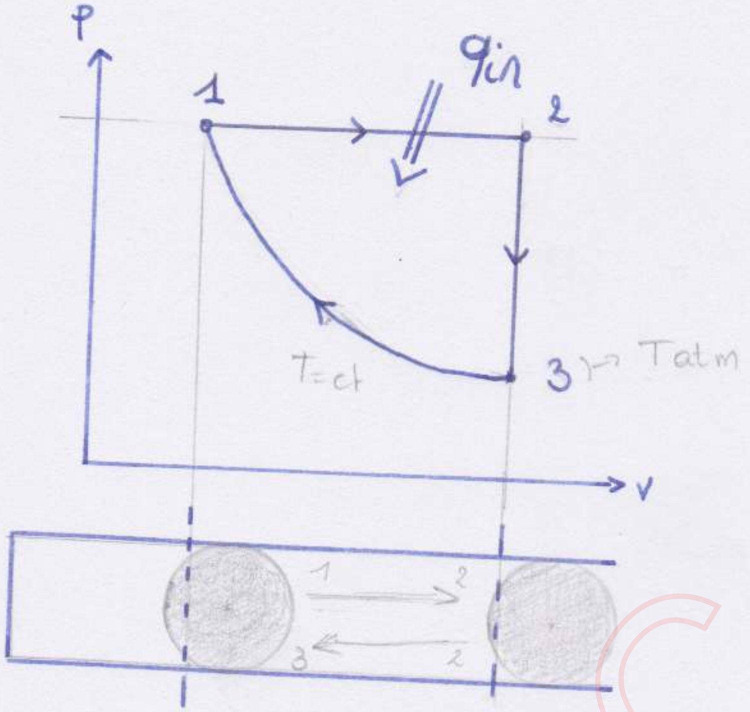
Rendement:

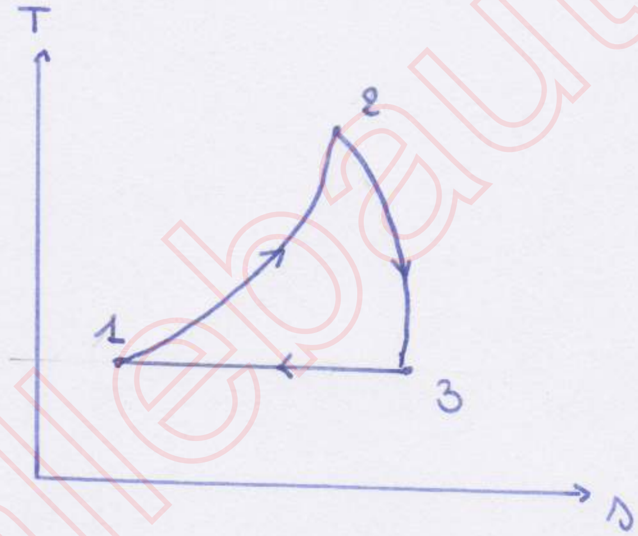
$$\boxed{\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{w_{th}^*}{q_h^*}}$$

Druk:

$$\bar{p} = \frac{w_{th}}{\Delta V} = \frac{w_{th}^*}{\Delta V / R_g T_1} \rightarrow \boxed{\frac{\bar{p}}{p_1} = \frac{w_{th}^*}{\frac{p_1}{R_g T_1} \cdot \Delta V}}$$

Vacuüm - motor





① → ②: $C = C_p$, $n = 0$

② → ③: $C = C_v$, $n = 0$

③ → ①: $C = \infty$, $n = 1$

①

$P_1 = P_{atm}$

$V_1 = V_1$

$T_1 = T_{atm}$

②

$P_2 = P_1$

$V_2 = r_v V_1$

$T_2 = r_v T_1$

③

$P_3 = \frac{P_{atm}}{r_v}$

$V_3 = V_2$

$T_3 = T_1$

① → ②

$$q = C_p(T_2 - T_1) = C_p T_1 (r_v - 1)$$

$$> 0 \Rightarrow q_{in}$$

② → ③

$$q = C_v(T_3 - T_2) = C_v T_1 (1 - r_v)$$

$$< 0$$

③ → ①

$$q = P_1 V_1 \ln\left(\frac{V_1}{V_3}\right)$$

$$< 0$$

$$\left.\begin{matrix} \\ \end{matrix}\right\} \Rightarrow q_{uit}$$

— — — — — — —

$$q_h^* = \frac{q_{in}}{R_g T_1} = \frac{C_p T_1 (r_v - 1)}{R_g T_1}$$

$$\frac{C_p}{R_g} = \frac{C_p}{C_p - C_v} = \frac{k}{k-1}$$

$$\boxed{q_h^* = \frac{k}{k-1}(r_v - 1)}$$

$$|q_l^*| = \frac{|q_{uit}|}{R_g T_1} \Rightarrow \boxed{\frac{1}{k-1}(r_v - 1) + \ln(r_v) = |q_l^*|}$$

$$W_{th}^* = q_h^* - |q_l^*| = \frac{k}{k-1}(r_v - 1) - \frac{1}{k-1}(r_v - 1) - \ln(r_v)$$

$$\boxed{W_{th}^* = (r_v - 1) - \ln(r_v)}$$

$$\boxed{\eta_{th} = \frac{W_{th}^*}{q_h^*}}$$

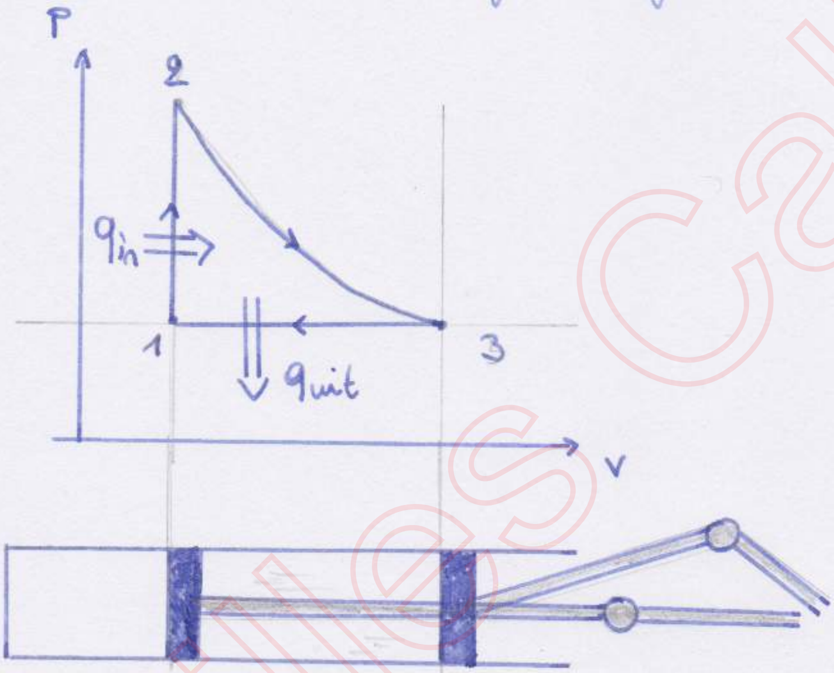
$$\frac{\bar{P}}{P_1} = \frac{W_{th}^*}{P_1/R_g T_1 \cdot \Delta V} = \frac{W_{th}^*}{P_1/R_g T_1 \cdot (r_v - 1) V_1} \Rightarrow \boxed{\frac{\bar{P}}{P_1} = \frac{W_{th}^*}{r_v - 1}}$$

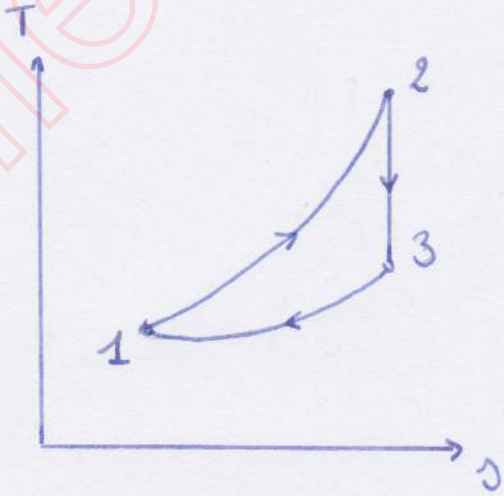
Lenoir kringproces

① → ② isochore verhitting

② → ③ adiabatische expansie

③ → ① isobare afkoeling





$$\textcircled{1} \xrightarrow[\substack{c = c_v}]{n=\infty} \textcircled{2} \xrightarrow[\substack{c=0\\ q=0}]{n=k} \textcircled{3}$$

$P_1 = P_{atm}$ $\qquad$ $P_2 = P_3\left(\frac{V_3}{V_2}\right)^k$ $\qquad$ $P_3 = P_1$

$V_1 =$ $\qquad$ $V_2 = V_1$ $\qquad$ $V_3 = r_v V_1$

$T_1 = T_{atm}$ $\qquad$ $T_2 = T_1 (r_v)^k$ $\qquad$ $T_3 = T_1 . r_v$

$$\textcircled{3} \xrightarrow[c = c_p]{n=0} \textcircled{1}$$

$$P_2 . V_2^k = P_3 . V_3^k \qquad \frac{T_3}{V_3} = \frac{T_1}{V_1}$$

$$T_2 = T_3 . \left(\frac{V_3}{V_2}\right)^{k-1}$$

$\textcircled{1} \rightarrow \textcircled{2}$

$$q_{in} = c_v(T_2 - T_1) \qquad q_h^* = \frac{q_{in}}{R_g T_1} \Rightarrow \boxed{q_h^* = \frac{1}{k-1}\left(r_v^k - 1\right)}$$

$\textcircled{2} \rightarrow \textcircled{3}$

$$q = 0$$

$\textcircled{3} \rightarrow \textcircled{1}$

$$|q_{out}| = c_p(T_3 - T_1) \qquad |q_e^*| = \frac{|q_{out}|}{R_g T_1} \Rightarrow \boxed{|q_e^*| = \frac{k}{k-1}(r_v - 1)}$$

$$\boxed{W_{th}^* = q_h^* - |q_e^*|}$$

$$\eta_{th} = 1 - \frac{|q_{out}|}{q_{in}} \rightarrow \boxed{\eta_{th} = 1 - \frac{k(r_v - 1)}{(r_v)^k - 1}}$$

$$\frac{\overline{P}}{P_1} = \frac{W_{th}^*}{\left(\frac{P_1 \Delta V}{R_g T_1}\right)} = \frac{W_{th}^*}{\underbrace{\frac{P_1 V_1}{R_g T_1}}_{=1}(r_v - 1)} \rightarrow \boxed{\frac{\overline{P}}{P_1} = \frac{W_{th}^*}{r_v - 1}}$$

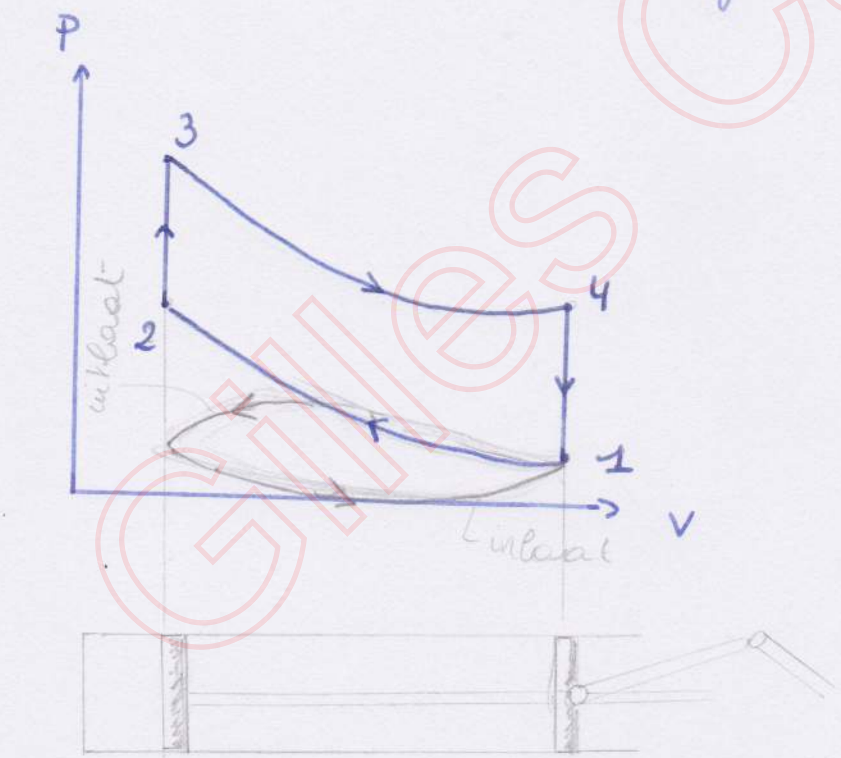
Otto-cyclus

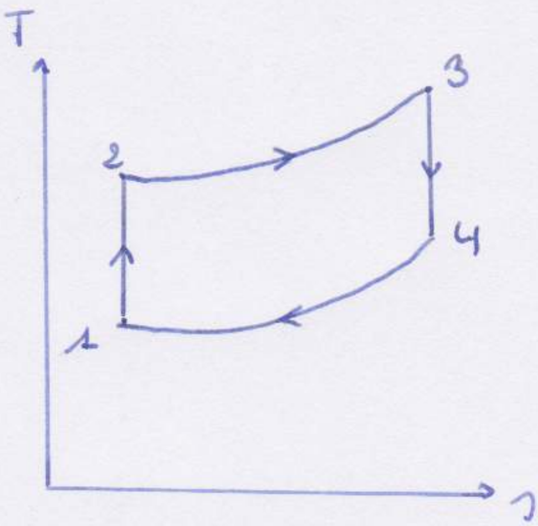
① → ② Isentrope compressie

② → ③ Isochore warmtetoevoer

③ → ④ Isentrope expansie

④ → ① Isochore warmteafvoer





2takt → per 2 slagen arbeid

4 takt → per 4 slagen arbeid

↳ extra energie → in- & uitlaten stoffen

1

$P_1 = P_{atm}$

$V_1 =$

$T_1 = T_{atm}$

$P_1 V_1^k = P_2 V_2^k$

$T_1 V_1^{k-1} = T_2 V_2^{k-1}$

$n = k$
$c = 0$
$q = 0$

2

$P_2 = P_1 (r_v)^k$

$V_2 = \frac{V_1}{r_v}$

$T_2 = T_1 (r_v)^{k-1}$

$n = \infty$
$c = c_v$
$q = c_v (T_3 - T_2)$

$T_3 = T_2 + \frac{q_h}{c_v}$

$\frac{T_3}{T_1} = (r_v)^{k-1} + (k-1) q_h^*$

$\frac{P_3 V_3}{T_3} = \frac{P_1 V_1}{T_1}$

$n = \infty$
$c = c_v$
$q = c_v (T_1 - T_4)$

3

$P_3 = P_1 \left(r_v \frac{T_3}{T_1}\right)$

$V_3 = V_2$

$T_3 = T_1 \left[(r_v)^{k-1} + (k-1) q_h^* \right]$

$n = k$
$c = 0$
$q = 0$

$\frac{T_4}{T_1} = \frac{T_4}{T_3} \cdot \frac{T_3}{T_1}$

$= (r_v)^{1-k} \left(\frac{T_3}{T_1}\right)$

$P_4 V_4^k = P_3 V_3^k$

4

$P_4 = P_3 \cdot r_v^{-k}$

$V_4 = V_1$

$T_4 = T_3 \cdot r_v^{1-k}$

$$\boxed{W_{th}^* = q_h^* - |q_e^*|}$$

$$\eta_{th}^* = 1 - \frac{|q_{uit}|}{q_{in}} = 1 - \frac{c_v(T_4 - T_1)}{c_v(T_3 - T_2)} = 1 - \frac{T_1}{T_2}\,\frac{(T_4/T_1 - 1)}{(T_3/T_2 - 1)}$$

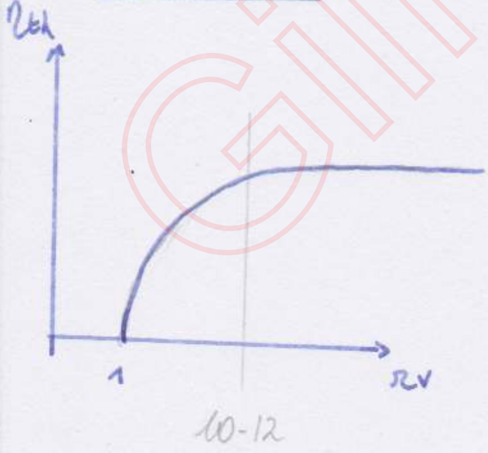
$$\boxed{\eta_{th}^* = 1 - (r_v)^{1-k}}$$

$$\left.\begin{array}{l} \dfrac{T_2}{T_1} = r_v^{\,k-1} \\[2ex] \dfrac{T_3}{T_4} = r_v^{\,k-1} \end{array}\right\} \rightarrow \frac{T_2}{T_1} = \frac{T_3}{T_4} \rightarrow \frac{T_4}{T_1} = \frac{T_3}{T_2}$$

$$\frac{\overline{P}}{P_1} = \frac{W_{th}}{P_1 \cdot \Delta V} = \frac{W_{th}^*}{\underbrace{\frac{P_1 v_1}{R_g T_1}}_{=1}\left(1 - \frac{v_2}{v_1}\right)}$$

$$\boxed{\frac{\overline{P}}{P_1} = \frac{W_{th}^*}{r_v - 1}\cdot r_v}$$

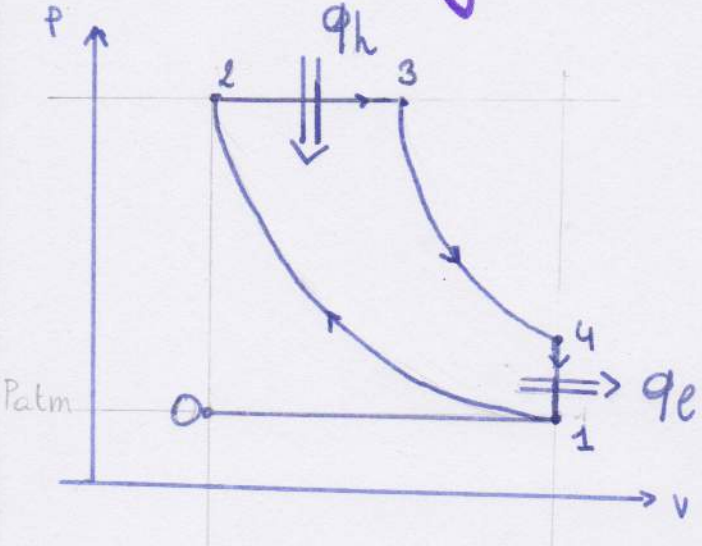
Opvallend:

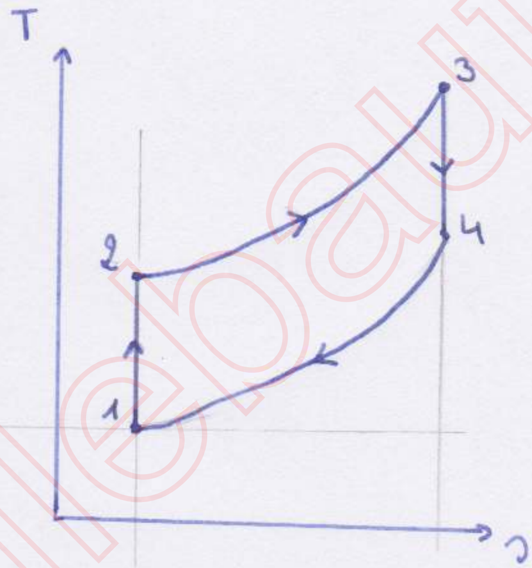


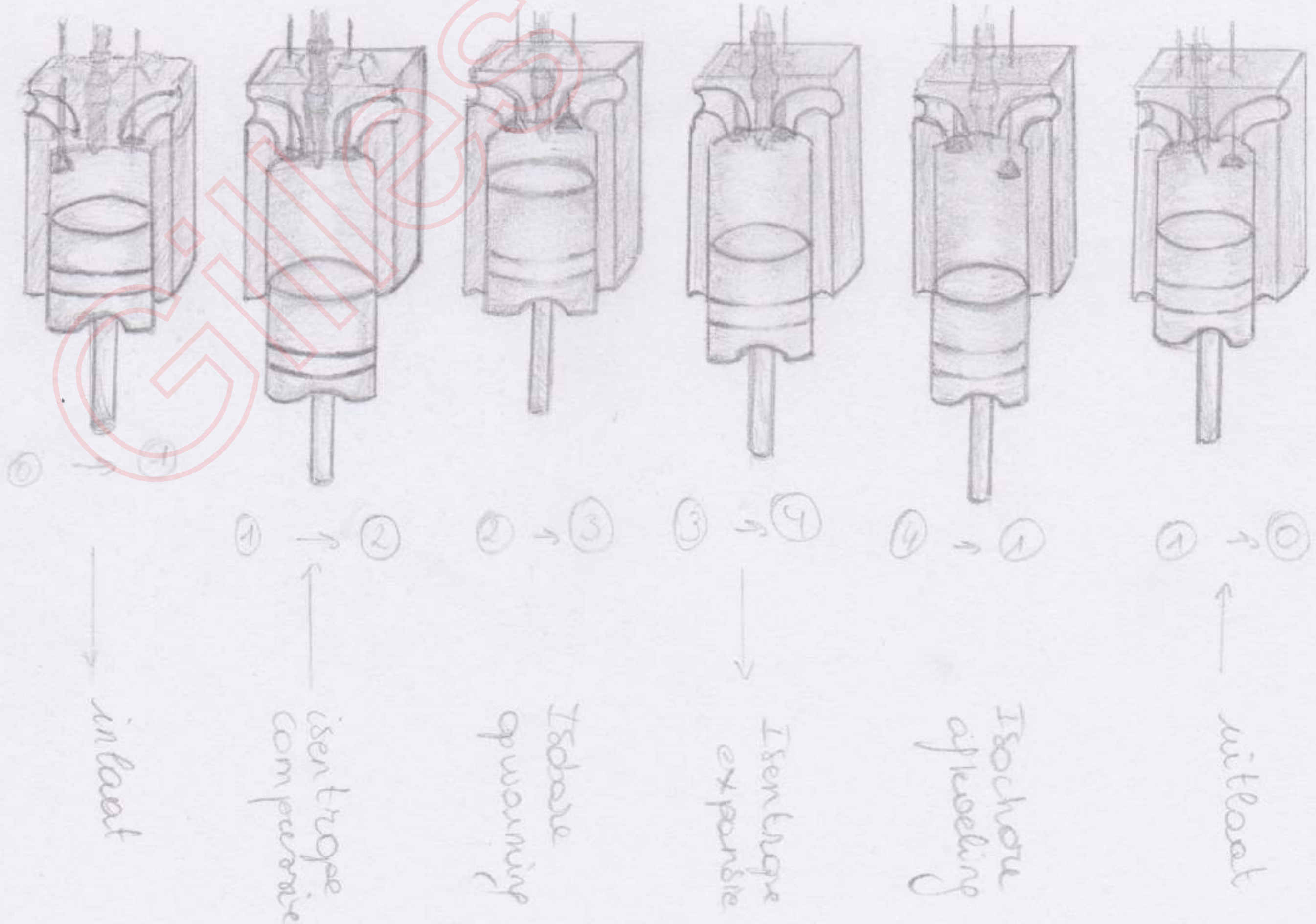
bij 10 à 12 → comp. verh.
het proces ifv. materiaal
→ naderen ideaal proces

- De brukssterkte vh materiaal zal de max. druk bepalen.
- T_4 (= uitlaatgastemp.) mag nt te hoog zijn, anders milieuschade. → bij wet vastgelegd
  Maar ook nt te laag, anders onvolledige verbranding.

Diesel kringproces







(1)

$P_1 = P_{atm}$

$V_1 =$

$T_1 = T_{atm}$

$n = k$
$c = 0$
$q = 0$

(2)

$P_2 = P_1 r_v^{k}$

$V_2 = \dfrac{V_1}{r_v}$

$T_2 = T_1 (r_v)^{k-1}$

$n = 0$
$c = c_p$
$q = c_p(T_3 - T_2)$
$= q_{in}$

(3)

$P_3 = P_2$

$V_3 = \left(1 + \dfrac{k-1}{k}(r_v)^{1-k} \cdot q_h^*\right) \cdot V_2$

$T_3 = \left((r_v)^{k-1} + \dfrac{k-1}{k} \cdot q_h^*\right) T_1$

$n = k$
$c = 0$
$q = 0$

(4)

$P_4 = P_1 \left(\dfrac{V_3}{V_2}\right)^k$

$V_4 = V_1$

$T_4 = T_1 \left(\dfrac{V_3}{V_2}\right)^k$

$n = \infty$
$c = c_v$
$q = c_v(T_1 - T_4)$
$= q_{uit}$

$$T_3 = T_2 + \frac{q_{in}}{c_p}$$

$$\frac{T_3}{T_1} = \frac{T_2}{T_1} + \frac{q_{in}}{c_p T_1} \cdot \frac{R_g}{R_g}$$
$$= (r_v)^{k-1} + \frac{k-1}{k} \cdot q_h^*$$

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

$$\frac{V_3}{V_2} = \frac{T_3}{T_2} = \frac{T_3}{T_1} \cdot \frac{T_1}{T_2}$$
$$= 1 + \frac{k-1}{k} \cdot (r_v)^{1-k} \cdot q_h^*$$

$$P_4 = P_3 \left(\frac{V_3}{V_4}\right)^k$$
$$= \left(P_1 r_v^k\right)\left(\frac{V_3}{V_4}\right)^k$$
$$= P_1 \left(\frac{V_1}{V_2}\right)^k \left(\frac{V_3}{V_4}\right)^k$$

$$|q_e^*| = \frac{|q_{uit}|}{R_g T_1}$$
$$= \frac{c_v}{R_g}\left(\frac{T_4}{T_1} - 1\right)$$

$$\boxed{w_{th}^* = q_h^* - |q_l|^*}$$

$$\eta_{th} = 1 - \frac{|q_{uit}|}{q_{in}} = 1 - \frac{c_v(T_4/T_1 - 1)}{c_p(T_3/T_2 - 1)} \cdot \frac{T_1}{T_2}$$

$$\boxed{\eta_{th} = 1 - \frac{1}{k}\left(\frac{(v_3/v_2)^k - 1}{(v_3/v_2) - 1}\right) \cdot \frac{1}{(r_v)^{k-1}}}$$

> 1, want $\frac{v_3}{v_2} > 1$

$\hookrightarrow$ $\underline{\underline{\eta_{th,diesel} < \eta_{th,otto}}}$

$$\frac{\bar{P}}{P_1} = \frac{w_{th}}{P_1 \cdot \Delta v} = \frac{w_{th}/(R_g \cdot T_1)}{P_1 (v_1 - v_2)/(R_g \cdot T_1)} = \frac{w_{th}^*}{\frac{P_1 v_1}{R_g \cdot T_1}\left(1 - \frac{1}{r_v}\right)}$$

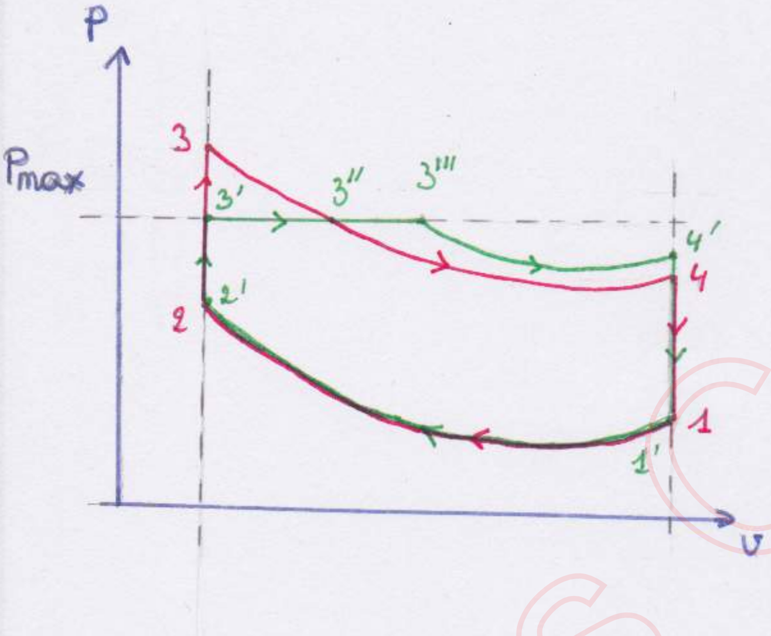
$$\boxed{\frac{\bar{P}}{P_1} = \frac{r_v \cdot w_{th}^*}{r_v - 1}}$$

Stel : $q_h^* = 30$; $k = 1,4$

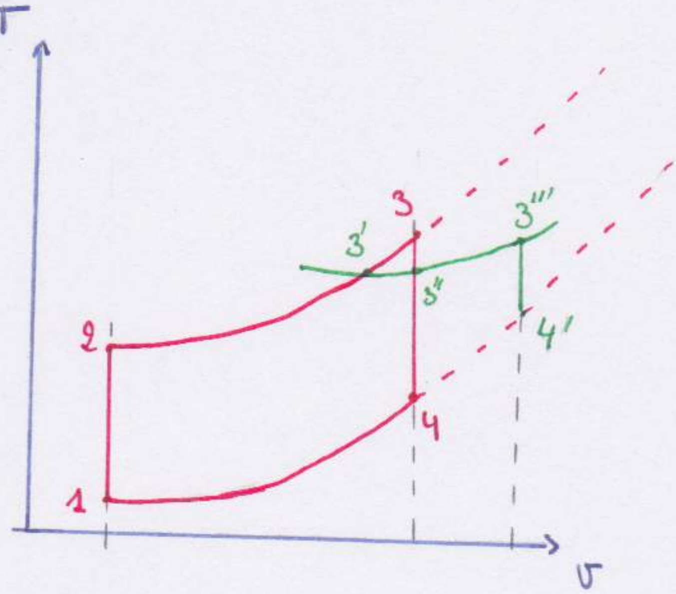
	Lenoir	Otto	Diesel
r_v	6,25	10	16
w_{th}^*	11,6	18	16,1
η_{th}	39%	60%	54%
$\overline{p}/p_1$	2,22	20	17,2

Duaal kringproces

Otto - Duaal



Ppiek ↘



q = ct.
↳ opp onder grafiek = ct.
↳ 3'''

4' → verlengde $q_{1\to4}$ &
$T_{3''\to4'}$ = ct.

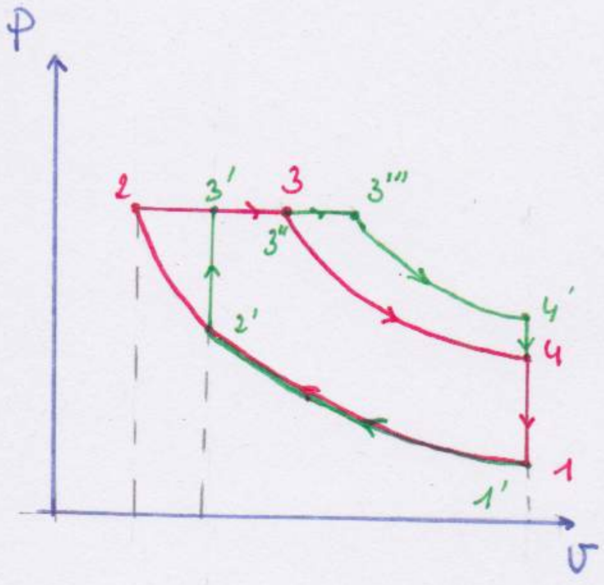
$\boxed{q_h^*,\ \text{otto} = q_h^*,\ \text{duaal}}$

$\boxed{\eta_{th,\ \text{otto}} > \eta_{th,\ \text{duaal}}}$

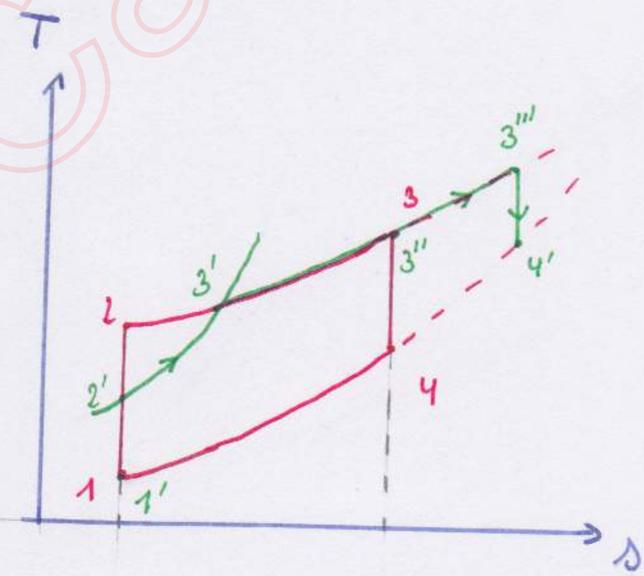
$\boxed{|q_{uit,\ \text{otto}}| < |q_{uit,\ \text{duaal}}|}$

$c_v(T_4 - T_1) < c_v(T_4' - T_1) \rightarrow \boxed{T_4 < T_4'}$

Diesel - Duaal



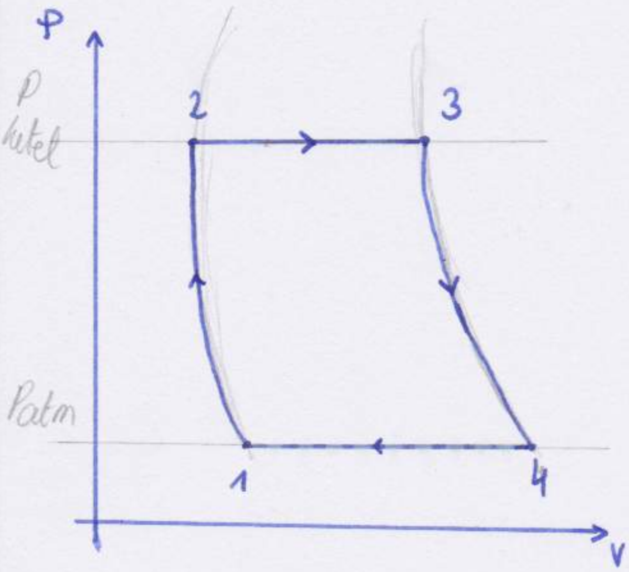
$r_v \searrow$

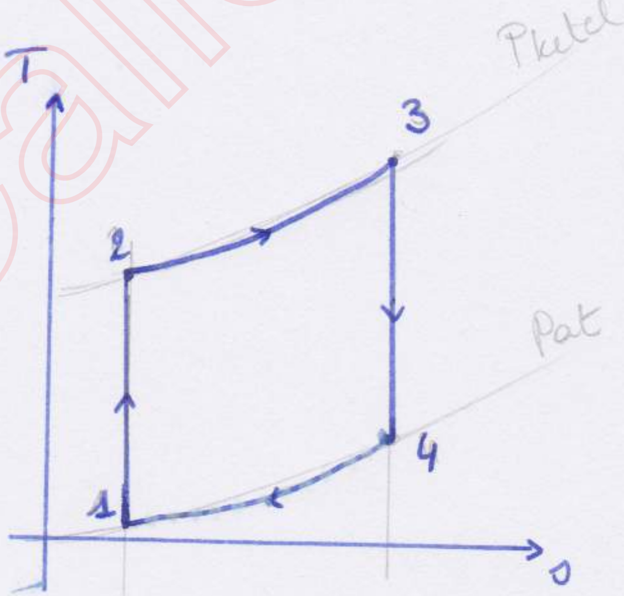


$q_{h,diesel}^{*} = q_{h,duaal}^{*}$

$\eta_{th,diesel} > \eta_{th,duaal}$

Heteluchtmotor van Joule





$$\varepsilon = \frac{P_{ketel}}{P_{atm}} = \frac{P_2}{P_1}$$

①

$P_1 = P_{atm}$

$V_1 =$

$T_1 = T_{atm}$

$n = k$
$c = 0$
$q = 0$

②

$P_2 = \varepsilon P_1$

$V_2 = V_1 \, \varepsilon^{-1/k}$

* $T_2 = T_1 \, \varepsilon^{(k-1)/k}$

$n = 0$
$c = c_p$
$q = c_p(T_3 - T_1)$

③

$P_3 = P_2$

$V_3 = V_2 \dfrac{T_3}{T_2}$

* $T_3 = T_2 + \dfrac{q_{in}}{c_p}$

* $T_3 < T_{max}$
materiaal limiet

$n = k$
$c = 0$
$q = 0$

④

$P_4 = P_1$

$V_4 = V_3 \, \varepsilon^{1/k}$

$T_4 = T_3 \, \varepsilon^{(1-k)/k}$

$n = 0$
$c = c_p$
$q = c_p(T_1 - T_4)$
$= q_{uit}$

$$W_{net} = q_{in} - |q_{uit}|$$

$$\boxed{W_{net} = c_p \left[T_3 + T_1 - T_2 - T_4 \right]}$$

$$\eta_{th} = 1 - \frac{|q_{uit}|}{q_{in}} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

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

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

$$= 1 - \frac{T_1}{T_2}$$

$$\boxed{\eta_{th} = 1 - \varepsilon^{(1-k)/k}}$$

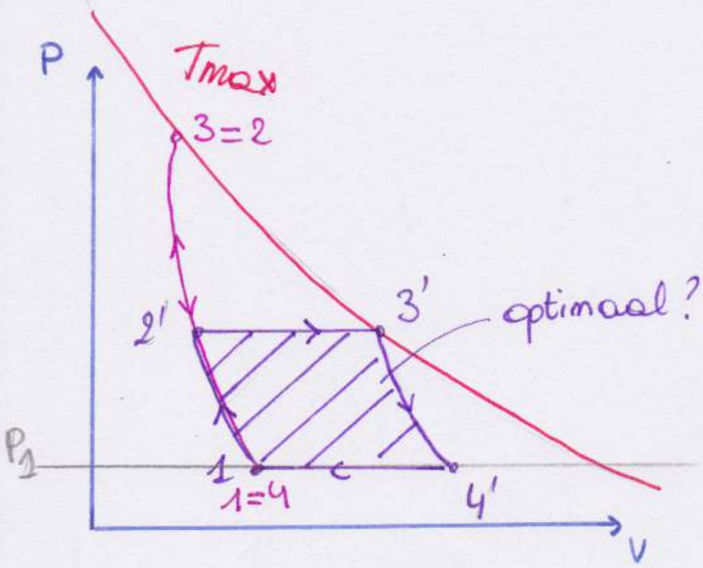
vermits $(1-k)/k < 0$

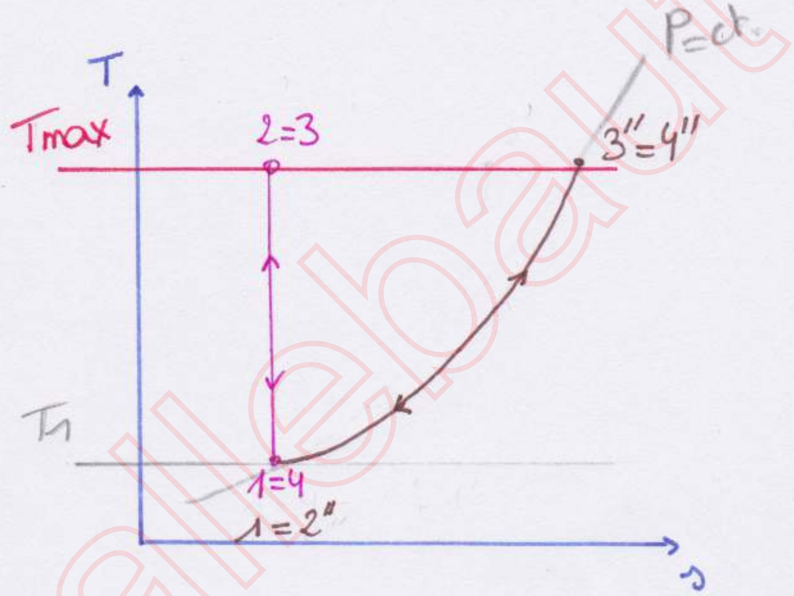
↳ $\eta_{th} \nearrow$ als $\varepsilon \nearrow$

maar

*

Gasturbine → ε_{opt}





$P_2 \rightarrow \max \Leftarrow$

$\hookrightarrow T_2 = T_3 = T_{max}$ $\quad \varepsilon_{max}$

$\hookrightarrow q_{in} = 0$

$w_{net} = 0$

vermits $3 \rightarrow 4$ isentroop

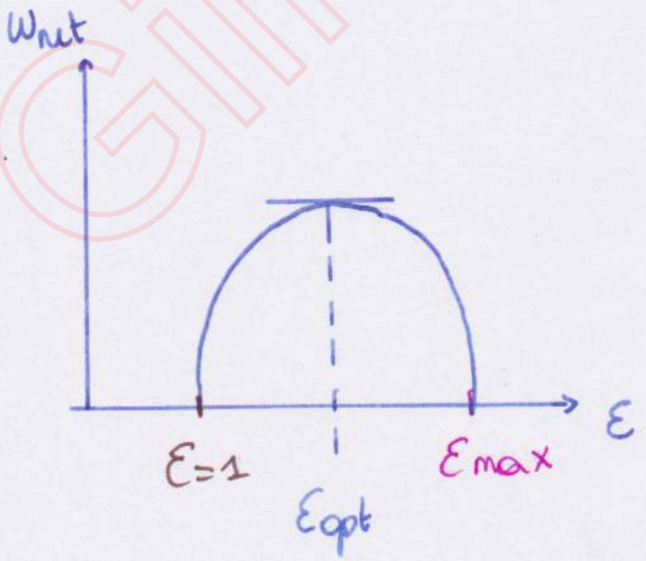
$\hookrightarrow 4 = 1$

$\varepsilon = 1 \rightarrow P_2'' = P_1''$

$\rightarrow P_3'' = P_4''$

$\hookrightarrow$ gn compr./exp.

$\hookrightarrow w_{net} = 0$



$$\left.\frac{dW_{net}}{dT_2}\right|_{T_2,opt} = 0$$

$$W_{net} = c_p\left(\underset{ct.}{T_1} - T_2 + \underset{ct.}{T_3} - \frac{T_1 T_3}{T_2}\right)$$

$$\frac{dW_{net}}{dT_2} = -1 + \frac{T_1 T_3}{T_{2,opt}^2} = 0$$

$$T_{2,opt} = \sqrt{T_1 T_3}$$

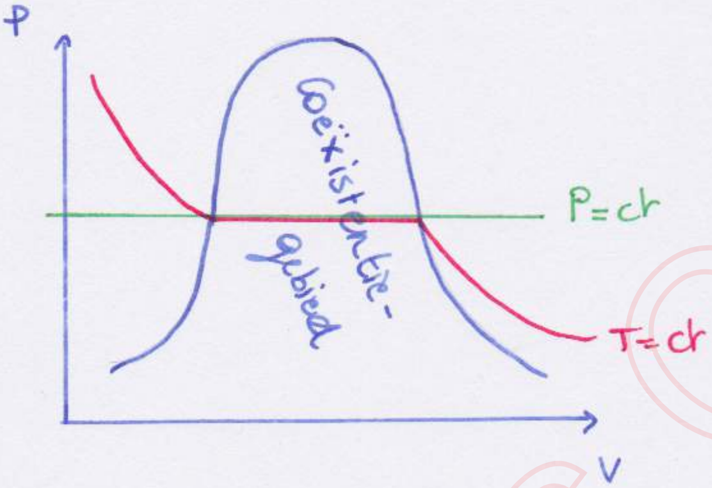
$$\frac{T_2}{T_1} = \varepsilon^{(k-1)/k} \hookrightarrow \varepsilon_{opt} = \left(\frac{T_3}{T_1}\right)^{k/2(k-1)}$$

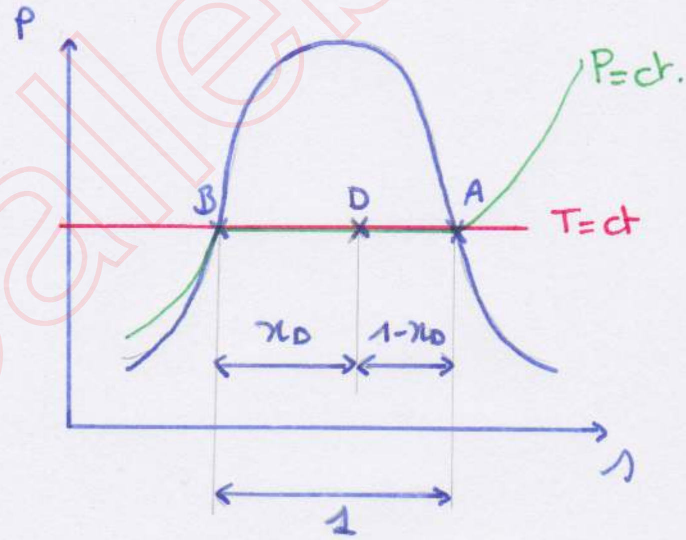
$$\eta_{th,opt} = 1 - (\varepsilon_{opt})^{1-k/k}$$

$$\eta_{th,opt} = 1 - \sqrt{\frac{T_1}{T_3}}$$

H9 : Kringprocessen met reële fluïda

Diagrammen





Dampgehalte

$m_{tot} = m_d + m_{vl}$

$x = \frac{m_d}{m_{tot}}$

$1 - x = \frac{m_{vl}}{m_{tot}}$

$V_{tot} = V_d + V_{vl}$

$m_{tot} \underset{v_D}{\underset{\shortparallel}{v_{tot}}} = m_d v_d + m_{vl} v_{vl}$

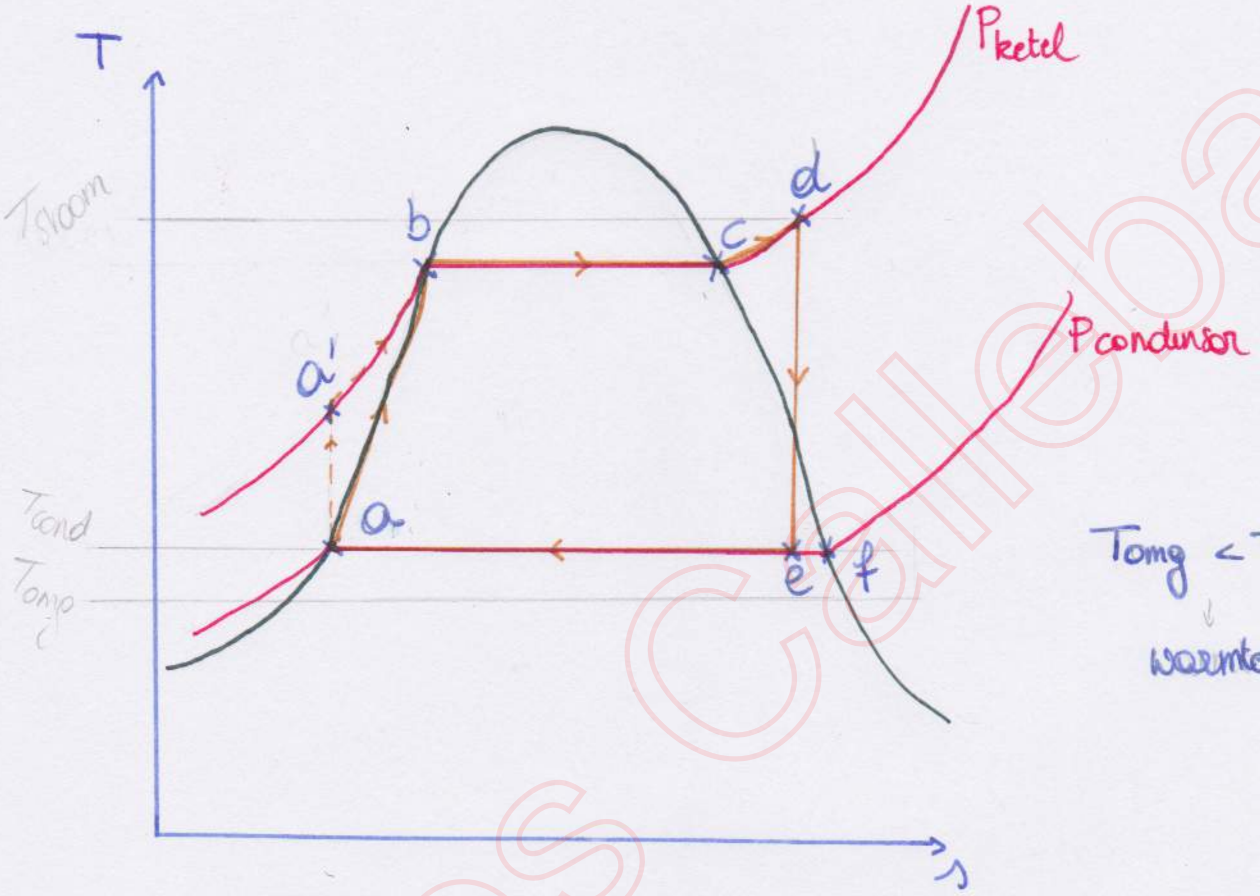
$v_D = \frac{m_d}{m_{tot}} v_d + \frac{m_{vl}}{m_{tot}} v_{vl}$

$\underline{v_D = x_D v_A + (1 - x_D) v_B}$

$h_D = x_D h_A + (1 - x_D) h_B$

$s_D = x_D s_A + (1 - x_D) s_B$

Het kringproces van Rankine → stoomturbine



$T_{omg} < T_{cond}$
↓
warmte afgeven

① Pomp $a \to a'$: isentroop → $q = 0$
→ $w_t = h_a - h_{a'} < 0$

↳ verwaarlozen → $w_t = 0$

② Stoomketel $a' \to d$: isobaar → $w_t = 0$
$\ddot{a}$
→ $q = h_d - h_a > 0 \quad = q_{in}$

③ Stoomturbine $d \to e$: isentroop → $q = 0$
→ $w_t = h_d - h_e > 0$

④ Condensor $e \to a$: isobaar → $w_t = 0$
→ $q = h_a - h_e < 0 \quad = q_{uit}$

$h_a = h_{vl}\,(P_{cond})$

$h_d = h\,(P_{ketel}, T_{stoom})$

$h_c = x_c\, h_f + (1 - x_c)\, h_a$

$h_f = h_d\,(P_{cond})$

$x_c \rightarrow s_e = s_d = s\,(P_{ketel}, T_{stoom})$

$$s_e = x_e \cdot \underbrace{s_f}_{s_d(P_{cond})} + (1 - x_e) \cdot \underbrace{s_a}_{s_a(P_{cond})}$$

langs $P = P_{ketel}$

↳ $dh = c_p\, dT \rightarrow \underbrace{h_d}_{h_d(P_{ketel})} - h_c = c_p\,(\underbrace{T_d}_{T_{stoom}} - \underbrace{T_c}_{T_{kook}(P_{ketel})})$

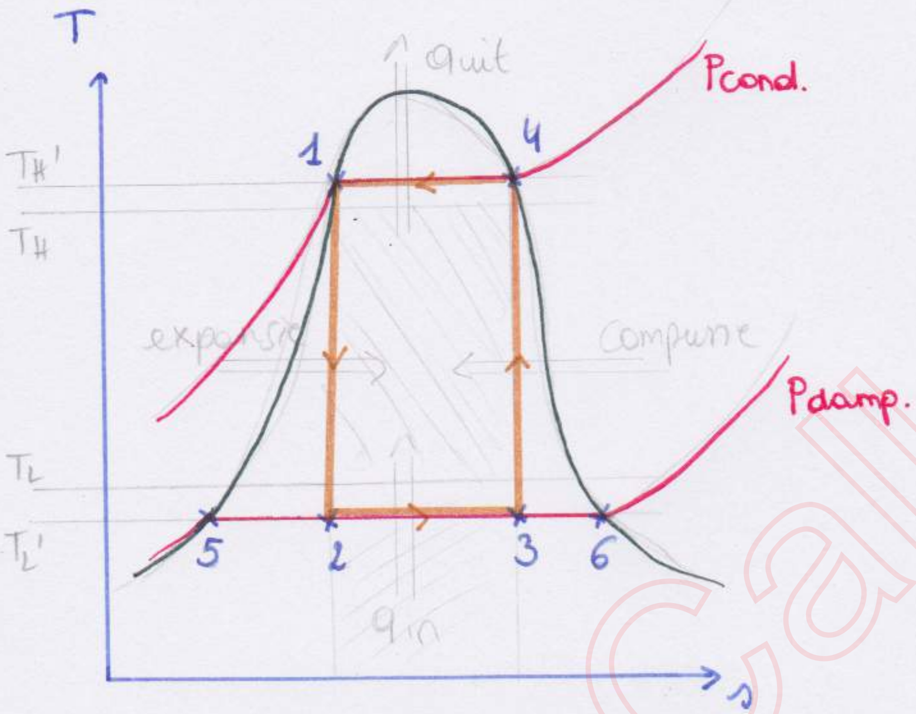
↳ $ds = c_p \dfrac{dT}{T} \rightarrow \underbrace{s_d}_{s_d(P_{ketel})} - s_c = c_p \ln\left(\dfrac{T_d}{T_c}\right)$

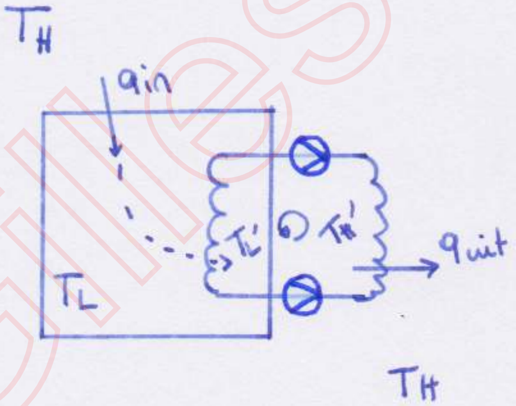
$\eta_{th} = \dfrac{w_{t,turbine}}{q_{in}}$ $(\approx 45\%)$

$\underline{P} = \dot{m} \cdot w_t \rightarrow \dot{m} \rightarrow \dot{Q}_{toevoer} = \dot{m}\, q_{in}$

$\dot{Q}_{afvoer} = \dot{m}\, q_{uit}$

Het kringproces voor koelmachines





Carnot	koelproces
→ 2x isotherm	→ 2 isobaren
	in coëxistentiegebied isotherm = isobaar
→ 2 isentropen	→ 2 isentropen

$T_L' < T_L$ → spontaan q_{in} naar T_L'

$T_H' > T_H$ → spontaan q_{uit} naar T_H

① isentroop expanderen

$$1 \rightarrow 2 : \quad w_t = h_1 - h_2 > 0$$

② isobaar verdampen

$$2 \rightarrow 3 : \quad q_{in} = h_3 - h_2 > 0$$

③ isentroop compr.

$$3 \rightarrow 4 : \quad w_t = h_3 - h_4 < 0$$

④ isobaar condenseren

$$4 \rightarrow 1 : \quad q_{uit} = h_1 - h_4 < 0$$

$$h_1 = h_{vl}(P_{cond})$$

$$h_4 = h_d(P_{cond})$$

$$h_2 \rightarrow \quad h_2 = x_2 \underbrace{h_6}_{h_d(P_{verd.})} + (1 - x_2) \underbrace{h_5}_{h_{vl}(P_{verd.})}$$

$$\left.\begin{aligned} s_2 &= s_1 = s_{vl}(P_{cond.}) \\ s_2 &= x_2 \underbrace{s_6}_{s_d(P_{verd})} + (1 - x_2) \underbrace{s_5}_{s_{vl}(P_{verd.})} \end{aligned}\right\} \rightarrow x_2$$

$h_3 \rightarrow$ idem

$$\varepsilon = \frac{q_{in}}{|w_{net}|} \qquad \varepsilon_w = \frac{|q_{uit}|}{|w_{net}|}$$

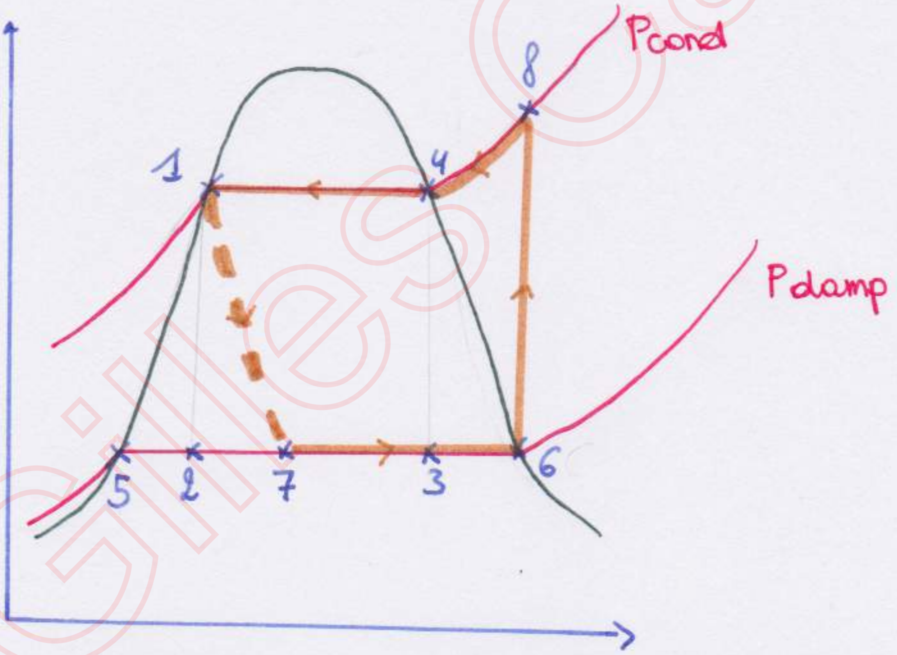
Expansieventiel $\propto$ droge compressie

↓ smoorproces
- ↳ $w_t = 0$
- ↳ $h_1 = h_7$
- ↳ $\overline{n}t$ omkeerbaar

$q_{in} \searrow$
$\propto$
$|w_{net}| \nearrow$ → $\varepsilon \searrow$

↓ vloeistofafscheider
- ↳ $q_{in} \nearrow$ (extra)
- ↳ $w_t = h_8 - h_6 \nearrow$

↳ $\varepsilon \searrow$



langs $P = P_{cond}$

↳ $h_8 = h_4 + c_p (T_8 - T_4)$

↳ $s_8 = s_4 + c_p \ln\left(\frac{T_8}{T_4}\right) \rightarrow T_8$

s_6

$$\left.\begin{array}{l} q_{in} = h_6 - h_7 \\ |w_{net}| = h_8 - h_6 \\ |q_{uit}| = h_8 - h_1 \end{array}\right\} \rightarrow \varepsilon = \frac{q_{in}}{|w_{net}|}$$

$\dot{Q}_{in} = \dot{m}\, q_{in}$

↓

$\dot{m}$

↓

$P = \dot{m}\, |w_{net}|$