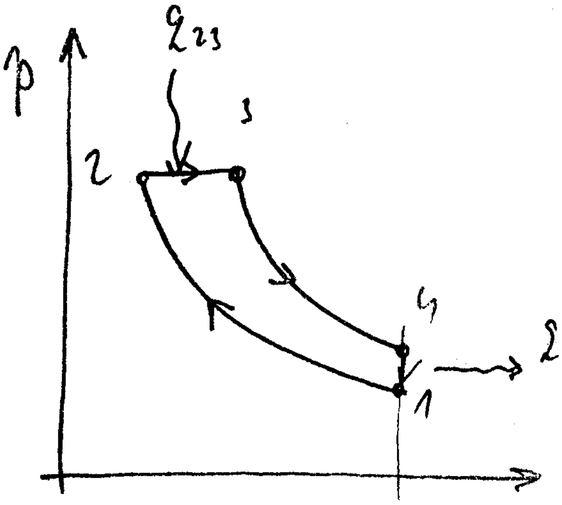
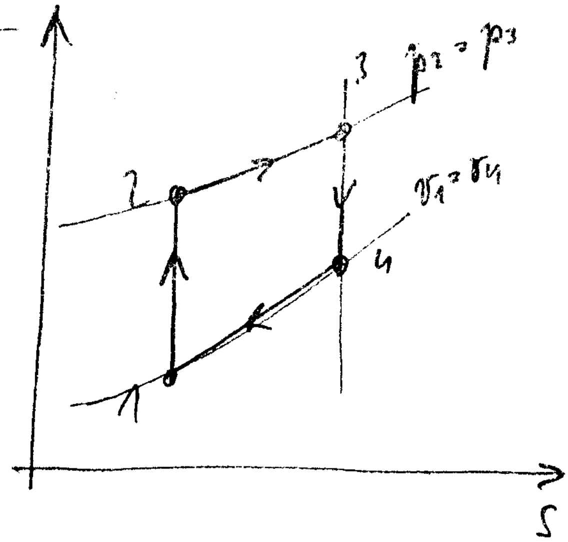
(STEIN)

29.) In einer Maschine wird die Luft als Kreisprozess-Medium verwendet. Die isentrope Kompression geht von 1–2, von 2–3 isobare Expansion ($p_2 = p_3$), danach isentrope Expansion von 3–4 und anschließend isochore Zustandsänderung 4–1 ($v_4 = v_1$); $t_3 - t_2 = 1100\,°C$ und bei 4–1 wird die Wärme abgeführt. Es ist $\frac{v_1}{v_2} = 13{,}5$ bei $p_1 = 1$ bar und $t_1 = 16\,°C$.

Es ist zu bestimmen:

a) p, T in den Eckpunkten
b) ausgetauschte Wärme
c) η_{th}
d) Skizze im p,v; T,s-Diagramm





$p_1 = 1$ bar; $T_1 = 289$ K

a)

② $$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}} = \left(\frac{v_1}{v_2}\right)^{\kappa-1} \longrightarrow T_2 = T_1 \cdot \left(\frac{v_1}{v_2}\right)^{\kappa-1} = 289 \cdot 13{,}5^{0{,}4} = \underline{\underline{828{,}14\ K}}$$

$$\left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}} = \left(\frac{v_1}{v_2}\right)^{\kappa-1} \rightarrow p_2 = p_1 \cdot \left(\frac{v_1}{v_2}\right)^{\kappa} = 1 \cdot 13{,}5^{1{,}4} = \underline{\underline{39{,}83\ bar}}$$

SS98 Aufg 2 TH1 S.1 von 4

Luft | $c_p = 1{,}004$; $c_v = 0{,}717$; $\varkappa = 1{,}4$

① $p_1 = 1{,}5\,bar$ / $t_1 = 17°C = 290K$

↓ isentrope Kompr. ($q_{12} = 0$; $v_2 < v_1$)

② $p_2 = 12$ bar

↓ isobare Wärmezufuhr $q_{23} = 1250\,kJ/kg$ ($t_3 > t_2$; $v_2 < v_3$)

③

↓ isentrope Exp. ($q_{34} = 0$; $v_3 < v_4$)

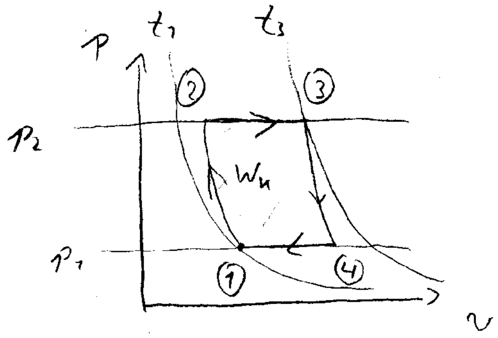
④ $p_4 = 1{,}5\,bar$

↓ isobare Wärmeabfuhr (q_{41} ist negativ; $t_4 > t_1$; $v_4 > v_1$)

① $p_1 = p_4$

$w_K = ?$; $\eta = ?$

p,v- und T,s- Diagr.



1.) p_1 einzeichnen

2.) t_1 einzeichnen → ①

3.) p_2 einzeichnen

4.) isentrope Komp. einzeichnen (steiler als isotherme + $v_2 < v_1$) → Schnittpunkt mit p_2 → ②

5) isobare Wärmezufuhr einz. ($t_3 > t_2$) + t_3 einzeichnen → ③

6.) isentr. Exp. einzeichnen (steiler als isotherme + $v_4 > v_3$)
→ Schnittpunkt mit p_1 → ④

7.) isobare Wärmeabfuhr einz. ($t_4 > t_1$) bis Punkt ① ⇒ fertig

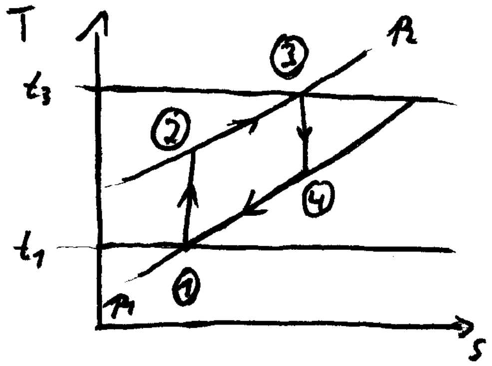
Werte, die noch zusätzl. aus dem Diagr. abgelesen werden

① → ② : $t_2 > t_1$; w_{e12} ist negativ (Kurve zeigt nach links); $p_2 > p_1$

② → ③ : w_{23} ist positiv (Kurve zeigt nach rechts); $p_2 = p_3$; $t_3 > t_2$

③ → ④ : $t_3 > t_4$; $p_4 < p_3$; w_{34} ist positiv

④ → ① : $t_1 < t_4$; $p_4 = p_1$; w_{41} ist negativ



1.) t_1 einzeichnen

2.) p_1 einzeichnen → ①

3.) p_2 einz. ($p_2 > p_1$)

4.) isentrop Komp. einz. (senkrecht nach oben, da $q_{12} = 0$ und $t_2 > t_1$) → ②

5.) isobare Wärmezufuhr einz. (entlang p_2 und $t_3 > t_2$, d.h. nach oben)

6.) t_3 einz. ($t_3 > t_2$) → Schnittpunkt mit p_2 → ③

7.) isentr. Expansion einz. (senkrecht nach unten, da $q_{23} = 0$ und $t_4 < t_3$) → Schnittpunkt mit $p_1 = p_4$ → ④

8.) isobare Wärmeabfuhr einz. (entlang p_1 und $t_1 < t_4$, d.h nach unten) bis Punkt ① ⇒ fertig

Werte, die aus dem T,s-Diagr. abgelesen werden

- $q_{12} = 0$ (isentrope)
- $q_{34} = 0$ (– " –)
- q_{23} ist positiv (Kurve läuft nach rechts)
- q_{41} ist negativ (Kurve läuft nach links)
- Kreisprozess ist rechtsdrehend, d.h. man erhält Nutzarbeit → w_K ist positiv

SS 98 TH1 Aufg 2 S.3

Berechnung

		T/K	p/bar	W_e kJ/kg	q kJ/kg
	1	290	1,5		
trope				-168,6	0
	2	525	12		
bare				357,3	1250
	3	1770	12		
trope				569	0
	4	977	1,5		
bare				-197,2	-689,8
	1				

1.) alle geg. Werte in Tabelle eintragen (t_1 ; p_1, p_2, p_3, p_4)

2.) T_2 bestimmen (isentrope)

$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\kappa-1}{\kappa}} \quad \Rightarrow \quad T_2 = \frac{290K}{\left(\frac{1,5}{12}\right)^{\frac{0,4}{1,4}}} = 525K$$

3.) T_3 bestimmen (isobare)

$$q_{23} = c_{pm} \cdot (T_3 - T_2) = 1.250 \quad \Rightarrow T_3 = \frac{1.250}{1,004} + T_2 = 1245 + 525$$

$$T_3 = 1770K$$

4.) T_4 bestimmen (isentrope)

$$\frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{\kappa-1}{\kappa}} \quad \Rightarrow \quad T_4 = \frac{1770}{\left(\frac{12}{1,5}\right)^{0,4/1,4}} = 977K$$

5.) w_{e12} bestimmen (isentrope)

$$w_{e12} = \frac{R}{\kappa-1} \cdot (T_1 - T_2) = \frac{0,287}{0,4} \cdot (290 - 525) = -168,6$$

SS 98 Aufg 2 TH 1 S. 4

6.) w_{e23} bestimmen (isobare)

$$w_{e23} = R \cdot (T_3 - T_2) = 0{,}287 \cdot (1770 - 525) = 357{,}3$$

7.) w_{e34} bestimmen (isentrope)

$$w_{e34} = \frac{R}{\varkappa - 1}(T_3 - T_4) = \frac{0{,}287}{0{,}4} \cdot (1770 - 977) = 569$$

8.) w_{e41} bestimmen (isobare)

$$w_{e41} = R \cdot (T_1 - T_4) = 0{,}287 \cdot (290 - 977) = -197{,}2$$

9.) q_{41} bestimmen (isobare)

$$q_{41} = c_{pm}(T_1 - T_4) = 1{,}004\,(290 - 977) = -689{,}8\ kJ/kg$$

10.) Wk berechnen

$$w_k = \sum w_e = \sum q = -168{,}6 + 357{,}3 + 569 - 197{,}2 = 1250 - 689{,}8$$

$$w_k \approx 560{,}2\ kJ/kg$$

$$\eta = \frac{w_k}{q_{zu}} = \frac{560{,}2}{1250} = 0{,}448$$

$$\eta = 0{,}448$$

Bemerkung: Für Klausur we's nicht berechnen, da man w_k und η mit q's schneller berechnen kann.
Die we's wurden nur zur demonstration berechnet, damit man Berechnung mit Diagramm vergleichen kann.

11.) Überprüfen der Berechnung mit Diagr. (und Plausibilität)

12.) –"– , ob alle ges. Werte berechnet wurden geg: Luft ($c_p = 1{,}004$; $c_v = 0{,}717$; $\varkappa = 1{,}4$)

1 $p_1 = 1{,}5$ bar / $t_1 = 17°C = 290K$

↓ isentrope Komp. ($q_{12} = 0$; $v_2 < v_1$)

2 $p_2 = 12$ bar

↓ isobare Wärmezufuhr $q_{23} = 1250 \, kJ/kg$ ($p_2 = p_3$)

($t_3 > t_2$; $v_2 < v_3$)

3

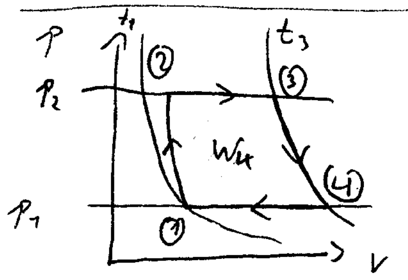
↓ isentrop Exp. ($q_{34} = 0$; $v_3 < v_4$)

4 $p_4 = 1{,}5$ bar

↓ isobare Wärme-abfuhr (q_{41} ist negativ; $t_4 > t_1$; $v_4 > v_1$)

1 $p_1 = p_4$

$w_k = ?$; $\eta = ?$ p,v- ; T,s- Diagr



1.) p_1 einzeichnen

2.) t_1 einz. → 1

3.) p_2 einz.

4.) isentr. Komp. einz. (steiler als isotherme u. $v_2 < v_1$) → Schnittpunkt ~~mit~~ mit p_2 → 2

5.) isobare Wärmezufuhr einz. ($t_3 > t_2$) und t_3 einz. → 3

6.) isentr. Exp. einz. (steiler als isotherme und $v_4 > v_3$) → Schnittpunkt mit p_1 → 4

7.) isobare Wärmeabfuhr einz. ($t_4 > t_1$) bis Punkt 1 ⇒ fertisch

22)

Gewichtsanteile

Stoff	μ_i	R_i $\left[\frac{J}{kgK}\right]$	$R_i \cdot \mu_i$ $\left[\frac{J}{kgK}\right]$	c_{pi} $\left[\frac{kJ}{kgK}\right]$	c_{pi} $\left[\frac{kJ}{kgK}\right]$	c_{pi} $\left[\frac{kJ}{kgK}\right]$	X X X	$\mu_i \cdot c_{pi}$ $\left[\frac{kJ}{kgK}\right]$
CO	0,564	296,8	167,4.				X	
H_2	0,057	4124,5	401,8.				X	
N_2	0,378	296,8	100,4				X	
							X	
		R_m	669,7				c_{pm}	$\left[\frac{kJ}{kgK}\right]$

$c_v = c_p - R =$ $\qquad W_{12} = \frac{\kappa \cdot R_m}{\kappa - 1}(T_2 - T_1)$

$\kappa = \frac{c_p}{c_v} =$ $\qquad = \frac{1,32 \cdot 669,7}{0,32}(300) = 828,8\ \frac{kJ}{kg}$

1000 $= 2762,5$

Volumenanteile

$\Big|_{0°C}^{300°C} \qquad \Big|_{0°}^{1000°C}$

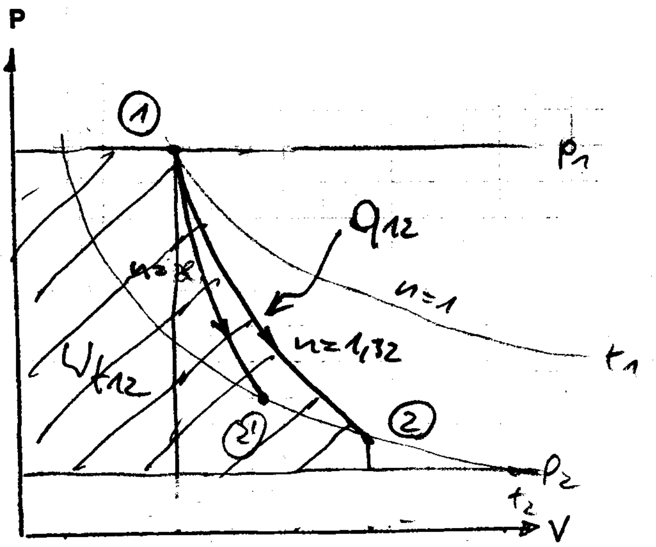
Stoff	r_i	M_i $\left[\frac{kg}{kmol}\right]$	$r_i \cdot M_i$ $\left[\frac{kg}{kmol}\right]$	$\mu_i = \frac{r_i \cdot M_i}{M_m}$	c_{pi} $\left[\frac{kJ}{kgK}\right]$	c_{pi} $\left[\frac{kJ}{kgK}\right]$	c_{pi} $\left[\frac{kJ}{kgK}\right]$	$\mu_i \cdot c_{pi}$ $\left[\frac{kJ}{kgK}\right]$
CO	0,25	28,0104	7,0...	0,564		1,13	1,053	0,593
H_2	0,6	2,0159	1,20...	0,097		14,78	14,45	1,407
N_2	0,15	28,0134	4,2..	0,338		1,116	1,048	0,354
		M_m	12,41...				2,4.. c_{pm}	2,356 $\left[\frac{kJ}{kgK}\right]$
							1,75 c_{vm}	1,683 $\left[\frac{kJ}{kgK}\right]$
							κ	1,4

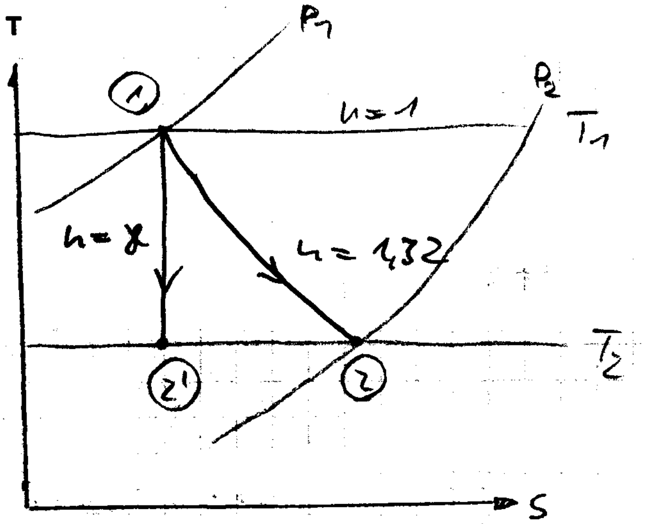
$$R = \frac{\Re}{M_m} = \frac{8315 \frac{J}{kmol \cdot K}}{\frac{kg}{kmol}} = \qquad \frac{J}{kg \cdot K}$$

$c_v = c_p - R =$

$\kappa = \frac{c_p}{c_v} \Rightarrow \quad c_v = \frac{c_p}{\kappa}$

c)





a) $w_{e12} = c_{vm}\Big|_{T_2}^{T_1} \cdot \frac{\varkappa-1}{n-1}(T_1-T_2)$; $w_{t12} = n \, w_{e12}$

$\Rightarrow w_{t12} = 1{,}32 \cdot 1{,}683 \cdot \frac{1{,}4-1}{1{,}32-1} \cdot 300 \cdot \frac{kJ}{kg} = \underline{\underline{833{,}2 \ \frac{kJ}{kg}}}$

1,75   1000   2887,5 ...

b) $\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\varkappa-1}{\varkappa}} \Rightarrow p_2 = p_1 \left(\frac{T_2}{T_1}\right)^{\frac{\varkappa}{\varkappa-1}}$

$= 25 \cdot \left(\frac{273}{573}\right)^{\frac{1{,}4}{0{,}4}} \text{ bar} = \underline{\underline{1{,}866 \text{ bar}}}$

23.)

Volumenanteile $\Big|_{25°}^{186°}$

stoff	r_i	M_i $\left[\frac{kg}{kmol}\right]$	$r_i \cdot M_i$ $\left[\frac{kg}{kmol}\right]$	$\mu_i = \frac{r_i \cdot M_i}{M_m}$	$c_{pi}\Big\|_0^{25}$ $\left[\frac{kJ}{kgK}\right]$	$c_{pi}\Big\|_0^{186}$ $\left[\frac{kJ}{kgK}\right]$	$c_{pi}\Big\|_{25}^{186}$ $\left[\frac{kJ}{kgK}\right]$	$\mu_i \cdot c_{pi}$ $\left[\frac{kJ}{kgK}\right]$
N_2	0,7	28,0134	19,6..	0,632	1,039	1,042	1,042	0,659
O_2	0,15	31,9988	4,7..	0,154	0,9169	0,933	0,935	0,145
CO_2	0,15	44,0098	6,0..	0,212	0,8296	0,905	0,917	0,195
		M_m	31,01..				c_{pm}	0,999 $\left[\frac{kJ}{kgK}\right]$
							c_{vm}	0,731 $\left[\frac{kJ}{kgK}\right]$
							κ	1,367

$$c_{pm} = \frac{c_{pm}\Big|_0^{186} \cdot 186 - c_{pm}\Big|_0^{25} \cdot 25}{186 - 25}$$

$$R = \frac{\Re}{M_m} = \frac{8315 \frac{J}{kmol \cdot K}}{31{,}01 \frac{kg}{kmol}} = 268{,}1 \ \frac{J}{kg \cdot K}$$

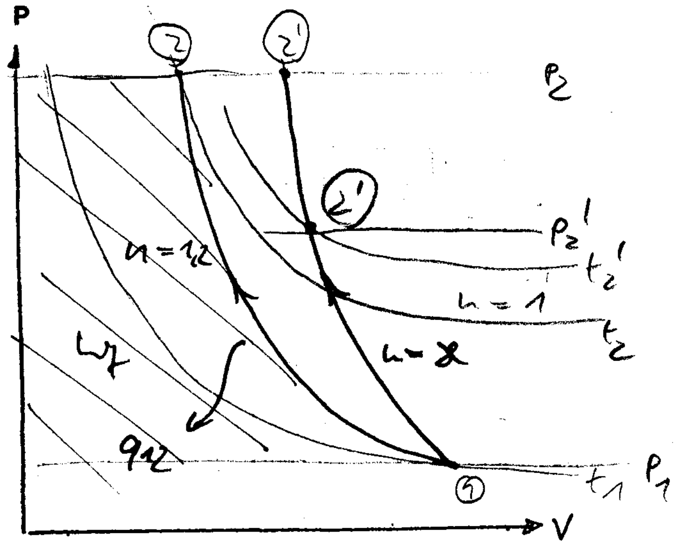
$$c_v = c_p - R = 0{,}731$$

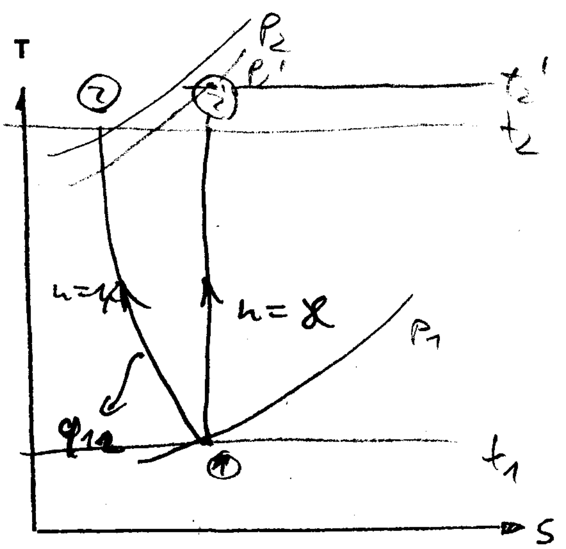
$$\kappa = \frac{c_p}{c_v} = 1{,}367$$

$$w_{t12} = n \cdot c_{vm} \cdot \frac{\kappa - 1}{n - 1}(T_1 - T_2)$$

$$= 1{,}2 \cdot 0{,}731 \cdot \frac{0{,}367}{0{,}2}(25 - 186) \frac{kJ}{kg}$$

$$= \underline{\underline{-259{,}2 \ \frac{kJ}{kg}}}$$





① 1,5 bar ; 25°C ≙ 298 K

↓ polytrop komprimiert: $n = 1,2$

② 20 bar ; $t_2 ≙ T_2$

a) $\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}} \Rightarrow T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}} = 298K \left(\frac{20}{1,5}\right)^{\frac{0,2}{1,2}} = \underline{\underline{459 K}}$
$= \underline{\underline{186 °C}}$

b) $P = \dot{m} \cdot w_{t12} \Rightarrow \dot{m} = \frac{P}{|w_{t12}|} = \quad = \frac{5000}{0,259 \cdot 10^{6}} \frac{kg}{s}$
$= 0,019.. \frac{kg}{s} = \underline{\underline{69,5 \frac{g}{s}}}$

c) $p_2' = p_1 \left(\frac{T_2'}{T_1}\right)^{\frac{\kappa}{\kappa-1}} = 1,5 bar \left(\frac{503}{298}\right)^{\frac{1,367}{0,367}} = \underline{\underline{10,54 bar}}$

21.)

Gewichtsanteile $\Big|_{15°}^{166°}$

Stoff	μ_i ($\frac{x_i \cdot M_i}{M_m}$)	R_i $\left[\frac{J}{kg K}\right]$	$R_i \cdot \mu_i$ $\left[\frac{J}{kg K}\right]$	$c_{pi}\big\|_0^{15}$ $\left[\frac{kJ}{kgK}\right]$	$c_{pi}\big\|_0^{166}$ $\left[\frac{kJ}{kgK}\right]$	$c_{pi}\big\|_{15}^{166}$ $\left[\frac{kJ}{kgK}\right]$	X X X	$\mu_i \cdot c_{pi}$ $\left[\frac{kJ}{kgK}\right]$
O_2				0,9162	0,931	0,932	x	0,205
N_2				1,039	1,041	1,041	x	0,746
H_2				14,23	14,40	14,42	x	0,942
							x	
		R_m					c_{pm}	1,891 $\left[\frac{kJ}{kgK}\right]$
								1,352
								1,399

$$c_{pm}\Big|_{15}^{166} = \frac{c_{pm}\big|_0^{15} \cdot 15 - c_{pm}\big|_0^{166} \cdot 166}{15 - 166}$$

$c_v = c_p - R = 1{,}352 \frac{kJ}{kgK}$

$\kappa = \frac{c_p}{c_v} = \underline{\underline{1{,}399}}$

Volumenanteile $\Big|_{110°}^{166°}$

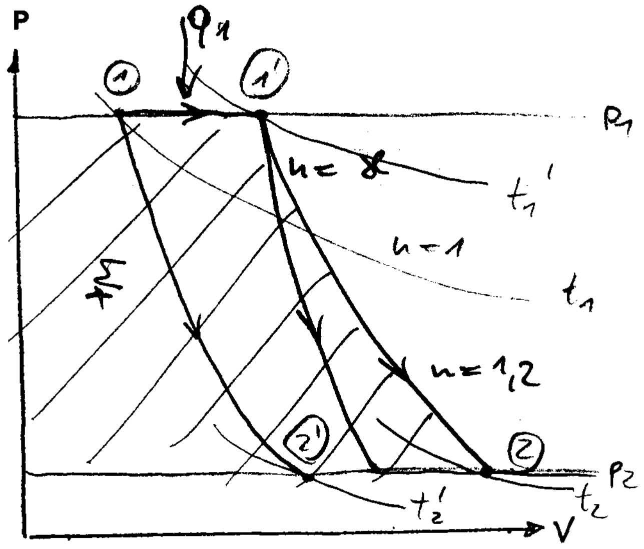
Stoff	r_i	M_i $\left[\frac{kg}{kmol}\right]$	$r_i \cdot M_i$ $\left[\frac{kg}{kmol}\right]$	$\mu_i = \frac{r_i \cdot M_i}{M_m}$	$c_{pi}\big\|_0^{166}$ $\left[\frac{kJ}{kgK}\right]$	$c_{pi}\big\|_0^{110}$ $\left[\frac{kJ}{kgK}\right]$	$c_{pi}\big\|_{110}^{166}$ $\left[\frac{kJ}{kgK}\right]$	$\mu_i \cdot c_{pi}$ $\left[\frac{kJ}{kgK}\right]$
O_2	0,105	31,9988	3,36	0,218	0,931	0,9232	0,946	0,206
N_2	0,395	28,0134	11,07	0,717	1,041	1,040	1,043	0,748
H_2	0,5	2,0159	1,01	0,065	14,40	14,37	14,46	0,944
		M_m	15,43				c_{pm}	1,898 $\left[\frac{kJ}{kgK}\right]$
							c_{vm}	1,359 $\left[\frac{kJ}{kgK}\right]$
							κ	1,396

$$c_{pm}\Big|_{15}^{110} = \frac{c_{pm}\big|_0^{166} \cdot 166 - c_p\big|_0^{110} \cdot 110}{166 - 110}$$

$$R = \frac{\Re}{M_m} = \frac{8315 \frac{J}{kmol \cdot K}}{15{,}43 \frac{kg}{kmol}} = 538{,}9 \frac{J}{kg \cdot K}$$

$c_v = c_p - R = 1{,}359 \frac{kJ}{kgK}$

$\kappa = \frac{c_p}{c_v} = 1{,}396$



p

$$\frac{T_1'}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}}$$

$$\Rightarrow T_1' = T_2 \left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}}$$

$$= 288\,K \left(\frac{25}{2}\right)^{\frac{0{,}2}{1{,}2}}$$

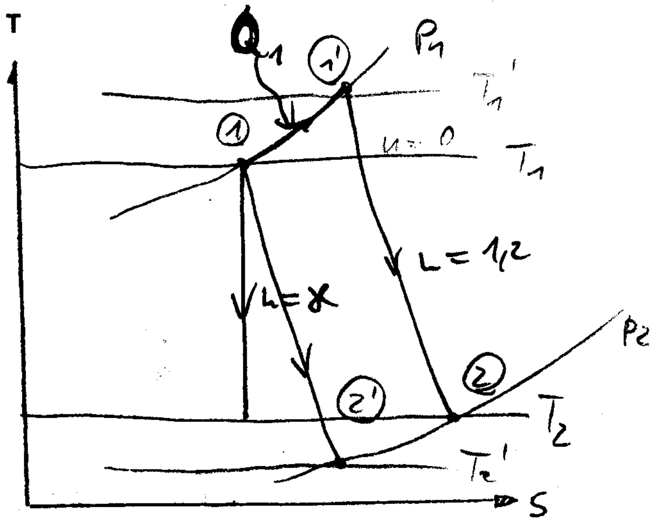
$$= 438\,K = \underline{\underline{166\,°C}}$$

V

$$P_t = n \cdot \dot{W}_e = n \cdot \dot{m} \cdot \frac{R}{n-1}\left(T_1' - T_2\right)$$

$$= 1{,}2 \cdot 5 \cdot \frac{0{,}5389}{0{,}2}\left(166 - 15\right)\,kW$$

$$= \underline{\underline{2441\,kW}}$$



T

s

isobar ① $5\,\frac{kg}{s}$; 25 bar ; 110 °C | ges: $\dot{Q}_1$; P_t

①' 166 °C ↓ polytrope Expansion: $n = 1{,}2$

② 2 bar ; 15 °C

$$\dot{Q}_1 = \dot{m} \cdot c_{pm}\Big|_{T_1}^{T_1'} \cdot \left(T_1' - T_1\right) = 5 \cdot 1{,}898 \cdot (166 - 110)\,kW$$

$$= \underline{\underline{531{,}44\,kW}}$$

$$P_t = \dot{W}_t = n \cdot \dot{W}_e = n \cdot \dot{m} \cdot c_{vm}\Big|_{T_1'}^{T_2} \cdot \frac{\varkappa - 1}{n-1}\left(T_1 - T_2\right)$$

$$= 1{,}2 \cdot 5 \cdot 1{,}352 \cdot \frac{0{,}399}{0{,}2}\left(166 - 15\right)\,kW$$

$$= \underline{\underline{2444\,kW}}$$

29.)

Gewichtsanteile $\Big|_{60^\circ}^{125^\circ}$

Stoff	μ_i ($\cancel{\frac{r_i \cdot M_i}{M_m}}$)	R_i $\left[\frac{J}{kgK}\right]$	$R_i \cdot \mu_i$ $\left[\frac{J}{kgK}\right]$	$c_{pi}\Big\|_0^{60}$ $\left[\frac{kJ}{kgK}\right]$	$c_{pi}\Big\|_0^{125}$ $\left[\frac{kJ}{kgK}\right]$	$c_{pi}\Big\|_{60}^{125}$ $\left[\frac{kJ}{kgK}\right]$	X X X	$\mu_i \cdot c_{pi}$ $\left[\frac{kJ}{kgK}\right]$
O_2	1/3	259,8	86,6	0,920	0,926	0,932	x	0,311
N_2	2/3	296,8	197,9	1,039	1,040	1,041	x	0,694
							x	
							x	
		R_m	284,5				c_{pm}	1,005 $\left[\frac{kJ}{kgK}\right]$
								0,720
								1,395

$$c_{pm}\Big|_{60}^{125} = \frac{c_{pm}\big|_0^{60} \cdot 60 - c_{pm}\big|_0^{125} \cdot 125}{60 - 125}$$

$c_v = c_p - R =$ 0,720

$\kappa = \frac{c_p}{c_v} =$ 1,395

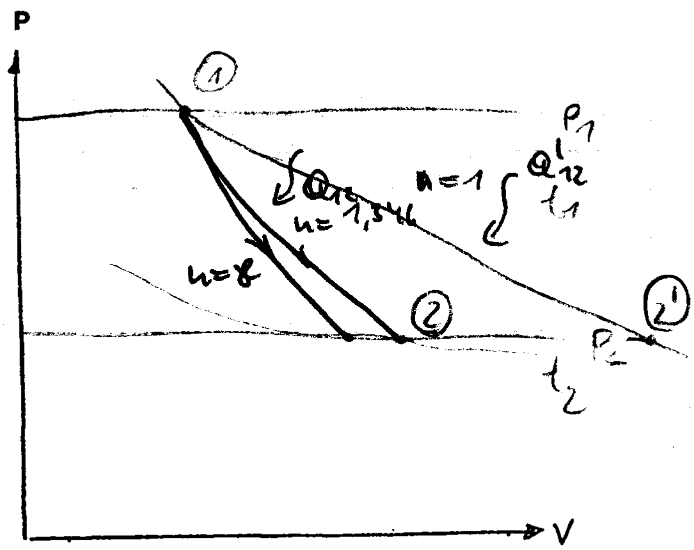
$$Q_{12} = m_2 \cdot c_{vm}\Big|_{60}^{125} \cdot \frac{\kappa - n}{n-1}(T_1 - T_2)$$
$$= 3{,}594 \cdot 0{,}72 \cdot \frac{1{,}395 - 1{,}346}{0{,}346}(125-60)\,K$$
$$= \underline{23{,}8\ kJ}$$

$R = \frac{\Re}{M_m} = \frac{8315 \frac{J}{kmol \cdot K}}{\frac{kg}{kmol}} =$ $\frac{J}{kg \cdot K}$

$c_v = c_p - R =$

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

$$\frac{p_1}{p_2} = \frac{V_2}{V_1} = 2$$
$$\Rightarrow V_2' = 2V_1$$
$$\Rightarrow \Delta V = V_1$$
$$\Rightarrow m_2' = \frac{p_2 \cdot V_1}{R_m \cdot T_2'} = \frac{56{,}6 \cdot 10^5 \cdot 0{,}96}{284{,}5 \cdot 398}\,kg = \underline{3{,}0\ kg}$$



$$\frac{T_1}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{n-1}{n}} \; ; \; p_2 = \frac{p_1}{2}$$

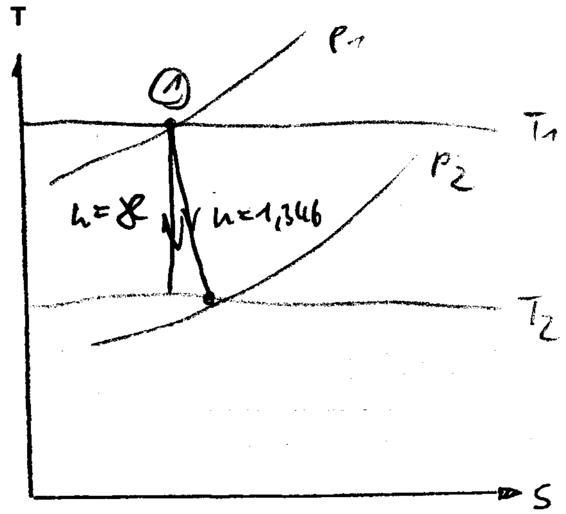
$$\Rightarrow \frac{T_1}{T_2} = 2^{\frac{n-1}{n}}$$

$$\Rightarrow \ln\left|\frac{T_1}{T_2}\right| = \ln|2| \cdot \frac{n-1}{n}$$

$$\Rightarrow n-1 = n \cdot \frac{\ln\left|\frac{T_1}{T_2}\right|}{\ln 2}$$

$$\Rightarrow n\left(1 - \frac{\ln\left|\frac{T_1}{T_2}\right|}{\ln 2}\right) = 1$$

$$n = \frac{\ln 2}{\ln 2 - \ln\left|\frac{T_1}{T_2}\right|} = \frac{\ln 2}{\ln 2 - \ln\left|\frac{398}{333}\right|} = \underline{\underline{1,346}}$$



① p_1 ; 125 °C ; 60 l ; 2 kg O_2 ; 4 kg N_2

↓ polytrop

② $\frac{p_1}{2}$; 60 °C ; ; $m_{O_2 2}$; Δm

$$p_1 \cdot V_1 = m_1 \cdot R_m \cdot T_1 \Rightarrow p_1 = \frac{m_1 \cdot R_m \cdot T_1}{V_1} = \frac{6 \cdot 284{,}5 \cdot 398}{0{,}06}\,\text{Pa}$$

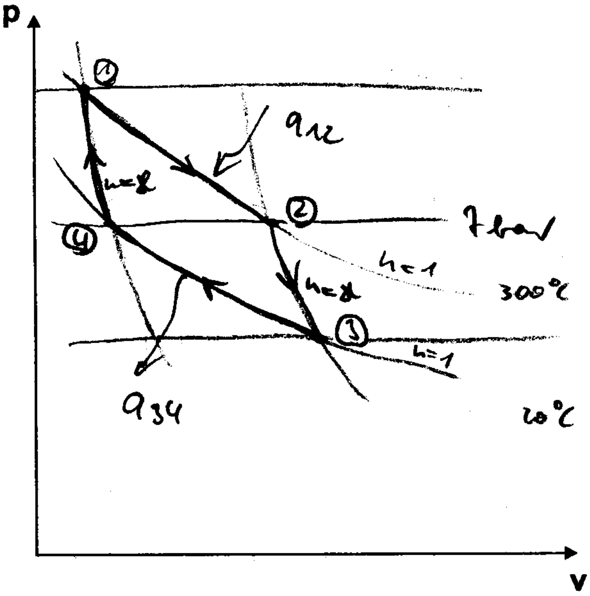
$$= 11{,}32 \cdot 10^6\,\text{Pa} = \underline{\underline{113{,}2\,\text{bar}}}$$

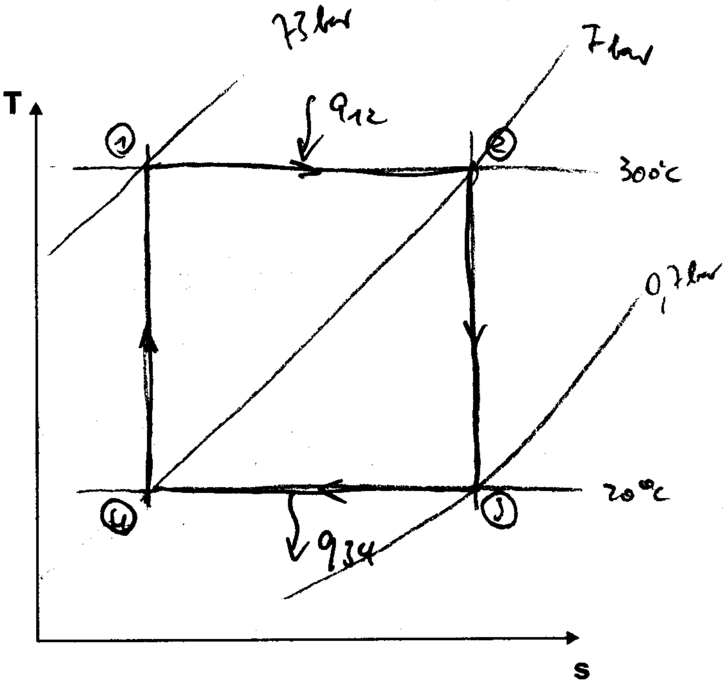
$$p_2 = \frac{p_1}{2} = \frac{113{,}2}{2}\,\text{bar} = \underline{\underline{56{,}6\,\text{bar}}}$$

$$m_2 = \frac{p_2 \cdot V_2}{R_m \cdot T_2} = \frac{56{,}6 \cdot 10^5 \cdot 0{,}06}{284{,}5 \cdot 333}\,\text{kg} = \underline{\underline{3{,}59\,\text{kg}}} \quad m_{O_2 2} = \frac{m_2}{3} = \underline{\underline{1{,}195\,\text{kg}}}$$

$$\Delta m = m_1 - m_2 = (6 - 3{,}59)\,\text{kg} = \underline{\underline{2{,}41\,\text{kg}}}$$

31 Carnot-Prozess





① 300°C ; $p_1 = 73{,}215$ bar

↓ isotherme Exp.

② 300°C ; 7 bar

↓ isentrope Exp.

③ 20°C ; $p_3 = 0{,}669$ bar

↓ isotherme Komp.

④ 20°C ; 7 bar

isentrope Komp.

$$w_{car} = |q_{12} + q_{34}|$$

$$q_{12} = R \cdot T_1 \ln \frac{p_1}{p_2}$$

$$= 287 \frac{J}{kg} \cdot 573 \ln \frac{73{,}215}{7}$$

$$= \underline{\underline{386{,}047 \frac{kJ}{kg}}}$$

$$q_{34} = R \cdot T_3 \ln \frac{p_3}{p_4}$$

$$= 287 \frac{J}{kg} \cdot 293 \ln \frac{0{,}669}{7}$$

$$= \underline{\underline{-197{,}436 \frac{kJ}{kg}}}$$

$$\Rightarrow w_{car} = (386{,}047 - 197{,}436) \frac{kJ}{kg} = \underline{\underline{188{,}611 \frac{kJ}{kg}}}$$

$$\frac{T_2}{T_3} = \left(\frac{p_2}{p_3}\right)^{\frac{\kappa-1}{\kappa}} \Rightarrow \frac{p_3}{p_2} = \left(\frac{T_3}{T_2}\right)^{\frac{\kappa}{\kappa-1}}$$

$$\Rightarrow p_3 = p_2 \left(\frac{T_3}{T_2}\right)^{\frac{\kappa}{\kappa-1}} = 7\,\text{bar} \left(\frac{293}{573}\right)^{\frac{1,4}{0,4}} = \underline{\underline{0{,}669\,\text{bar}}}$$

$$\frac{T_4}{T_1} = \left(\frac{p_4}{p_1}\right)^{\frac{\kappa-1}{\kappa}} \Rightarrow p_1 = p_4 \left(\frac{T_1}{T_4}\right)^{\frac{\kappa}{\kappa-1}} = 7\,\text{bar} \left(\frac{573}{293}\right)^{\frac{1,4}{0,4}}$$

$$= \underline{\underline{73{,}215\,\text{bar}}}$$

$$P = \dot{m} \cdot w_{car} \quad ; \quad \dot{m} = 80 \frac{2{,}5\ kg}{min} = 2{,}083 \ \frac{kg}{s}$$

$$P = 2{,}083 \cdot 188{,}611 \frac{kJ}{s} = \underline{\underline{392{,}9\ kW}}$$

$$\eta_{car} = \frac{w_{car}}{q_{12}} = \frac{188{,}611}{386{,}047} = \underline{\underline{0{,}489}}$$

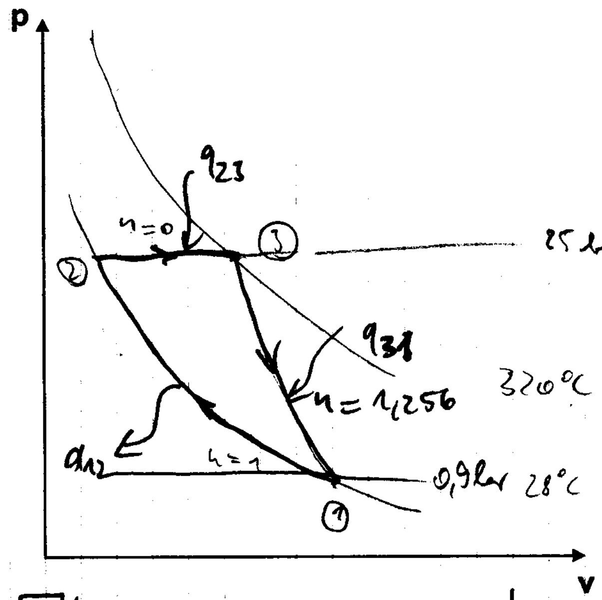
$$\eta'_{car} = 1 - \frac{T_{min}}{T_{max}} = 1 - \frac{253}{573} = \underline{\underline{0{,}558}}$$

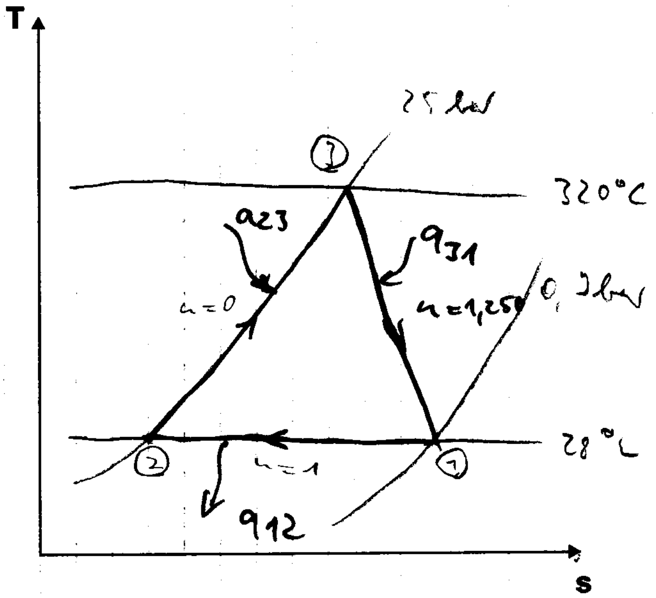
$$\Delta \eta_{car} = 0{,}558 - 0{,}489 = 0{,}0695$$

$$\Rightarrow \quad \frac{0{,}0695}{0{,}489} = \frac{\Delta \eta \%}{100\,\%} \Rightarrow \Delta \eta \% = \frac{100\,\% \cdot 0{,}0695}{0{,}489}$$

$$= \underline{\underline{14{,}2\ \%}}$$

(32)





(1) 28°C; 0,9 bar

↓ isotherm

(2) 28°C; 25 bar

↓ isobar

(3) 320°C; 25 bar

polytrope Z.-Äg.

$$n = \frac{1}{1 - \dfrac{\ln \frac{T_3}{T_1}}{\ln \frac{p_2}{p_1}}}$$

$$n = \frac{1}{1 - \dfrac{\ln \frac{593}{301}}{\ln \frac{25}{0,9}}} = 1,256 < \kappa$$

$$q_{12} = R T_1 \ln \frac{p_1}{p_2} = 0,2872 \frac{kJ}{kg} \cdot 301 \ln \frac{0,9}{25} = \underline{\underline{-287,37 \frac{kJ}{kg}}}$$

$$q_{23} = c_{pm} \cdot (T_3 - T_2) = 1,005 \frac{kJ}{kg} (593 - 301) = \underline{\underline{293,46 \frac{kJ}{kg}}}$$

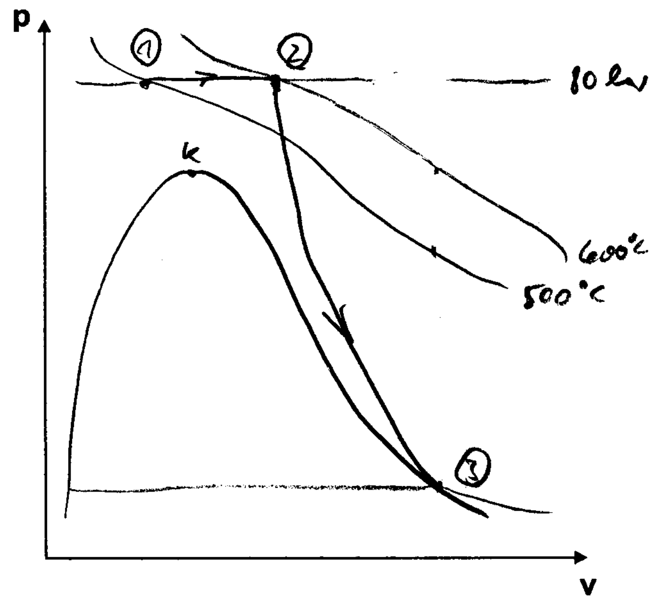
$$q_{31} = \frac{c_{pm}}{\kappa} \cdot \frac{\kappa - n}{n-1} (T_3 - T_1) = \frac{1,005 \ kJ}{1,4 \ kg} \cdot \frac{1,4 - 1,256}{0,256} (593 - 301)$$

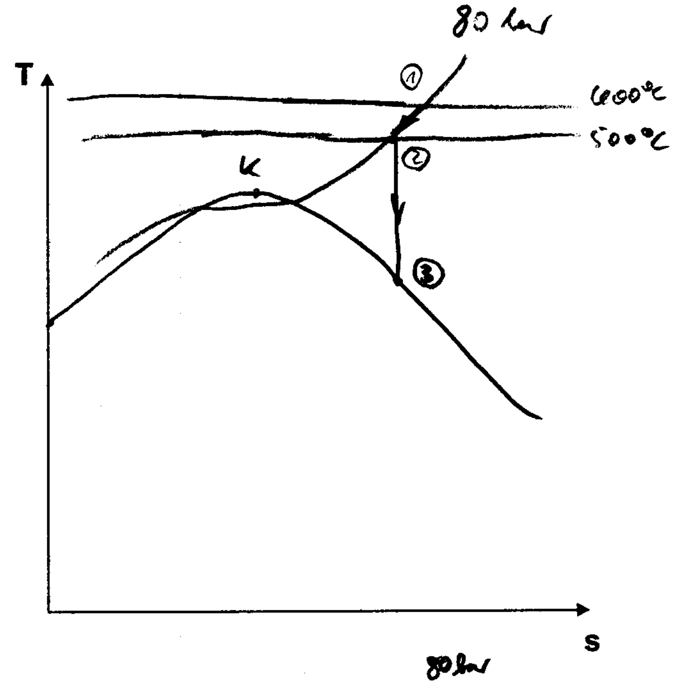
$$= \underline{\underline{117,908 \frac{kJ}{kg}}}$$

$$\eta = \frac{\sum q}{q_{zu}} = \frac{117,908 + 293,46 - 287,37}{117,908 + 293,46} = \underline{\underline{0,301}}$$

$$\eta_{car} = 1 - \frac{T_{min}}{T_{max}} = 1 - \frac{301}{593} = 0{,}492$$

SS 97 14:





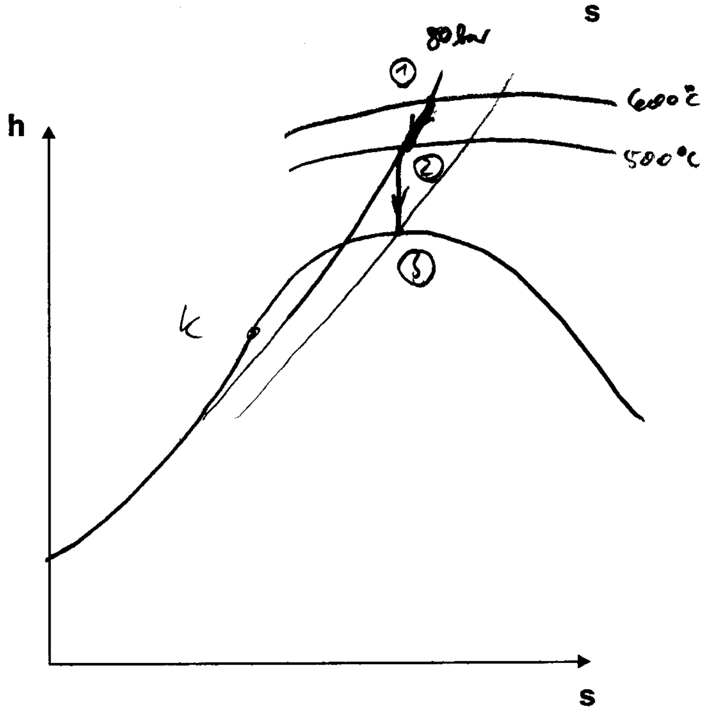
① überh. Dampf 80 bar; 600°C; h_1

↓ Δh_{12} : Kond. 90°C; h_K → 500°C

② üb. Dampf 80 bar; 500°C; h_2

↓ isentrope Exp. 800 kW

③ gesättigter Dampf; p_3; t_3; h_3



$$\left.\begin{aligned} h_1 &= 3639{,}5 \ \frac{kJ}{kg} \\ h_2 &= 3398{,}8 \ \frac{kJ}{kg} \end{aligned}\right\} \text{Tab.}$$

$$\Rightarrow \Delta h_{12} = (3639{,}5 - 3398{,}8) \frac{kJ}{kg} = \underline{\underline{240{,}7 \ \frac{kJ}{kg}}}$$

$$h_K = 376{,}77 \ \frac{kJ}{kg} \quad \text{(Tab.)}$$

$$\dot{m} h_D \overset{!}{=} \dot{m}_K (h_2 - h_K)$$

$$\Rightarrow \frac{\dot{m}_K}{\dot{m}_D} = \frac{\Delta h_{12}}{h_2 - h_K} = \frac{240{,}7}{3398{,}8 - 376{,}77} = \underline{\underline{0{,}0796}}$$

$$h_3 = 2760 \frac{kJ}{kg} \quad (\text{Diagr.})$$

$$P = \dot{m} \cdot \Delta h_{23} \Rightarrow \dot{m} = \frac{P}{\Delta h_{23}} \quad ; \quad \Delta h_{23} = h_2 - h_3$$

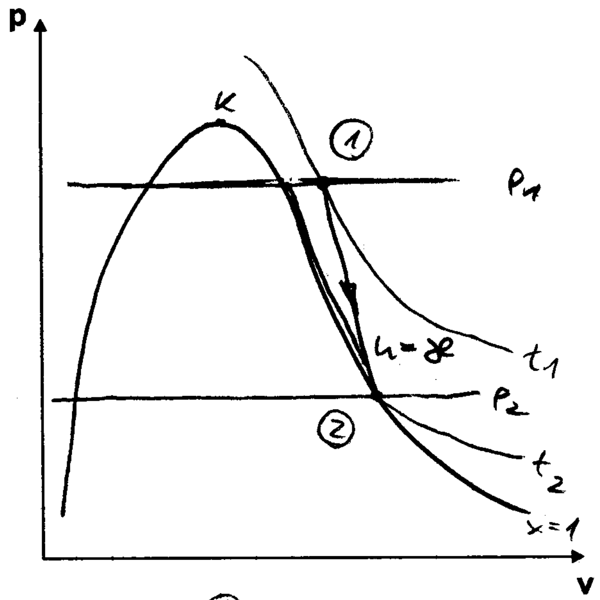
$$\Rightarrow \dot{m} = \frac{P}{h_2 - h_3} = \frac{800\, \cancel{kJ} \cdot kg}{(3398{,}8 - 2760)\cancel{kJ} \cdot s} = \underline{\underline{1{,}252 \frac{kg}{s} = 4508{,}4 \frac{kg}{h}}}$$

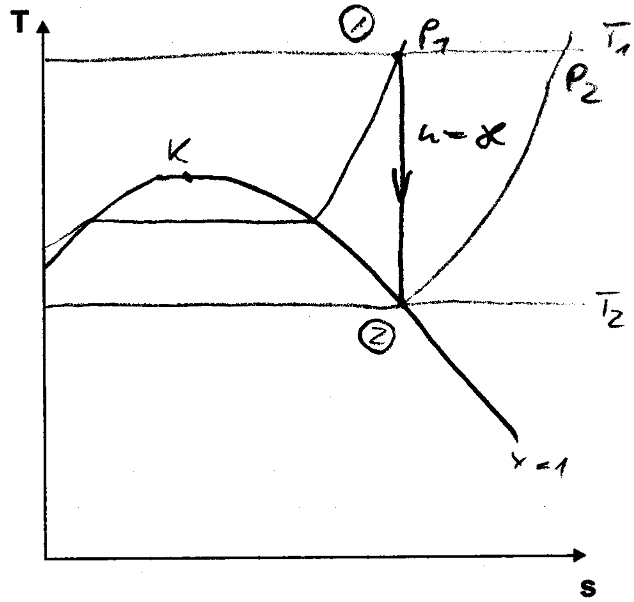
$$\dot{m} = \dot{m}_D + \dot{m}_K \quad ; \quad \dot{m}_D = \frac{\dot{m}_K}{0{,}0796}$$

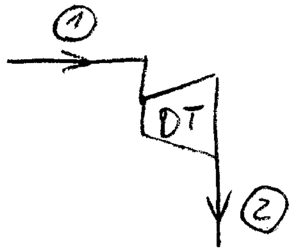
$$\Rightarrow \dot{m} = \dot{m}_K \left(1 + \frac{1}{0{,}0796}\right) = \dot{m}_K \frac{1{,}0796}{0{,}0796}$$

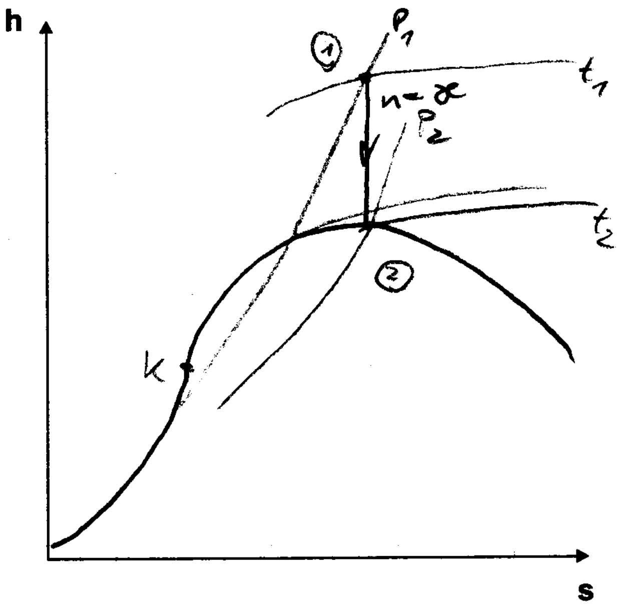
$$\Rightarrow \dot{m}_K = \dot{m} \frac{0{,}0796}{1{,}0796} = \underline{\underline{0{,}0924 \frac{kg}{s} = 332{,}6 \frac{kg}{h}}}$$

WS 97/98 / 4:









① $50\,\frac{m}{s}$; 60 bar; 500 °C; $\dot m_1$; d_1

↓ 2500 kW; isentrop entspannt

② $x = 1$

$$P_T = \dot m_1 \cdot w_{t12}\ ;\quad w_{t12} = \Delta h = h_1 - h_2$$

$$\Rightarrow \dot m_1 = \frac{P_T}{h_1 - h_2}\ ;\quad h_1(60\,\text{bar}; 500\,°C) = \underline{\underline{3423\,\frac{kJ}{kg}}}\ \text{(Tab.)}$$

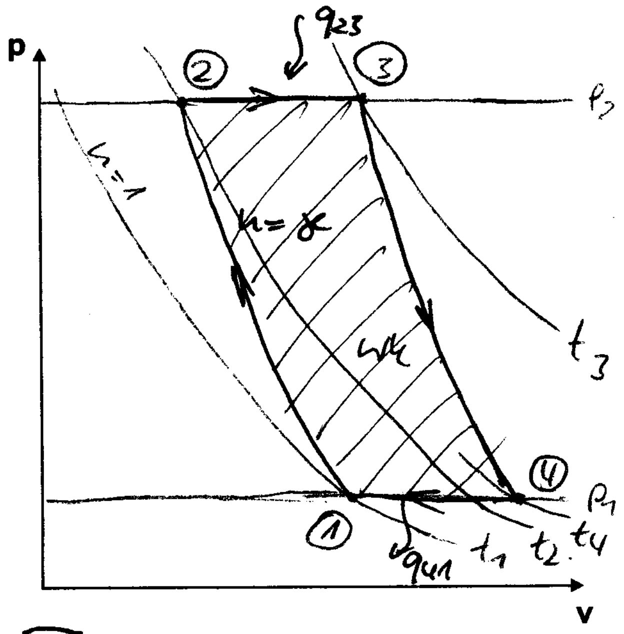
$$h_2(p_2;\ t_2;\ x=1) = \underline{\underline{2740\,\frac{kJ}{kg}}}\ \text{(Diagr.)}$$

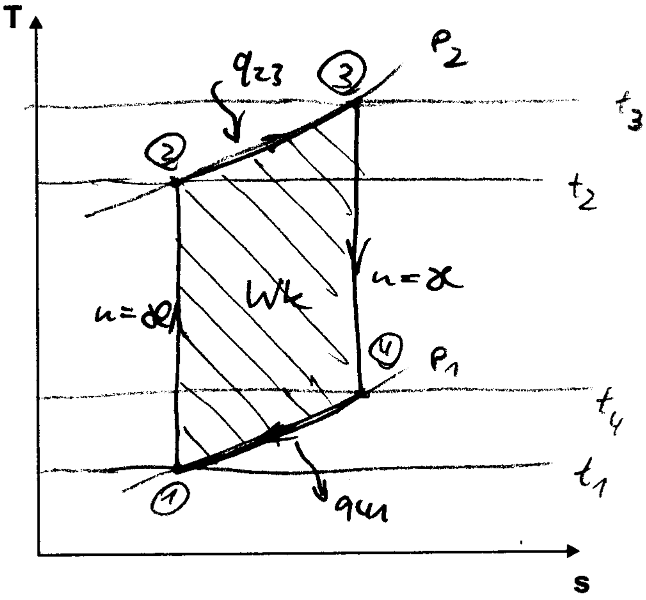
$$\Rightarrow \dot m_1 = \frac{2500}{3423 - 2740}\,\frac{kJ}{s} = \underline{\underline{3{,}660\,\frac{kg}{s}}}$$

$$\dot V = A_1 \cdot \bar c_1\ ,\ A_1 = \frac{\pi}{4} d_1^2 \Rightarrow d_1 = \sqrt{\frac{4\dot V}{\pi \bar c_1}}\ ;\quad \dot V = \dot m_1 \cdot v$$

$$\Rightarrow d_1 = \sqrt{\frac{4 \cdot \dot m_1 \cdot v}{\pi \cdot \bar c_1}} = \sqrt{\frac{4 \cdot 3{,}66 \cdot 0{,}05667}{\pi \cdot 50}}\ \cdot m = 0{,}0727\,m \underline{\underline{= 72{,}7\,mm}}$$

WS 98/99 / 1:





① 1,5 bar 20 °C

↓ isentrope Kompression

② 12 bar t_2

↓ isobare Wärmezufuhr $q_{23} = 1200 \frac{kJ}{kg}$

③ 12 bar t_3

↓ isentrope Expansion

④ 1,5 bar t_4

isobare Wärmeabfuhr q_{41}

$$\frac{q_{23}}{w_{e23}} = \frac{\varkappa - n}{\varkappa - 1} \; ; \; n = 0 \quad \Rightarrow \quad \frac{q_{23}}{\varkappa} = \frac{w_{e23}}{\varkappa - 1}$$

$$w_{e23} = \frac{\varkappa \cdot q_{23}}{\varkappa} - \frac{q_{23}}{\varkappa} = q_{23}\left(1 - \frac{1}{\varkappa}\right)$$

$$= 1200 \frac{kJ}{kg}\left(1 - \frac{1}{1{,}401}\right) = \underline{\underline{343{,}469 \frac{kJ}{kg}}}$$

$$w_{e12} = \frac{R \cdot T_1}{\varkappa - 1}\left(1 - \left(\frac{p_2}{p_1}\right)^{\frac{\varkappa-1}{\varkappa}}\right) = \frac{0{,}2872 \cdot 293}{0{,}401}\left(1 - \left(\frac{12}{1{,}5}\right)^{\frac{0{,}401}{1{,}401}}\right)$$

$$\underline{\underline{= -170{,}685 \frac{kJ}{kg}}}$$

$$w_k = |v_{e12}| + v_{e23} = (170,685 + 343,469)\,\frac{kJ}{kg}$$

$$= \underline{\underline{514,154\ \frac{kJ}{kg}}}$$

$$\eta_{th} = \frac{w_k}{q_{zu}} = \frac{w_k}{q_{23}} = \frac{514,154}{1200} = 0,428 = \underline{\underline{42,8\%}}$$

Aufgabe: SS 99 / 1:

Volumenanteile

Stoff	r_i	M_i $\left[\frac{kg}{kmol}\right]$	$r_i \cdot M_i$ $\left[\frac{kg}{kmol}\right]$	$\mu_i = \frac{r_i \cdot M_i}{M_m}$	$c_{pi}\Big\vert_0^{250}$ $\left[\frac{kJ}{kg \cdot K}\right]$	$c_{pi}\Big\vert_0^{20}$ $\left[\frac{kJ}{kg \cdot K}\right]$	$c_{pi}\Big\vert_{20}^{250}$ $\left[\frac{kJ}{kg \cdot K}\right]$	$\mu_i \cdot c_{pi}\Big\vert_{20}^{250}$ $\left[\frac{kJ}{kg \cdot K}\right]$
CO	0,2	28,0104	5,602	0,230	1,044	1,040	1,044	0,240
H_2	0,2	2,0159	0,403	0,017	14,43	14,23	14,45	0,246
N_2	0,2	28,0134	5,603	0,230	1,045	1,039	1,046	0,241
O_2	0,4	31,9988	12,800	0,524	0,932	0,917	0,933	0,489

$M_m = \boxed{24{,}407} \left[\frac{kg}{kmol}\right]$

$\sum\left(\mu_i \cdot c_{pi}\big\vert\right) = c_{pm} = \boxed{1{,}215} \left[\frac{kJ}{kg \cdot K}\right]$

$c_{vm} = \boxed{0{,}875} \left[\frac{kJ}{kg \cdot K}\right]$

$\kappa = \boxed{1{,}390}$

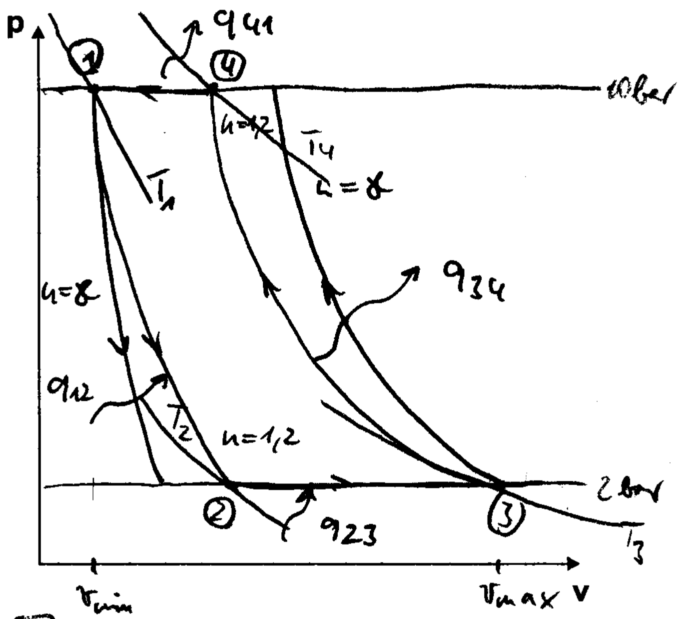
$$c_{pi}\Big\vert_{t_1}^{t_2} = \frac{\left(c_{pi}\Big\vert_0^{t_2} \cdot t_2 - c_{pi}\Big\vert_0^{t_1} \cdot t_1\right)}{t_2 - t_1} = \frac{c_{pi}\Big\vert_0^{250} \cdot 250\,°C - c_{pi}\Big\vert_0^{20} \cdot 20\,°C}{(250 - 20)\,°C}$$

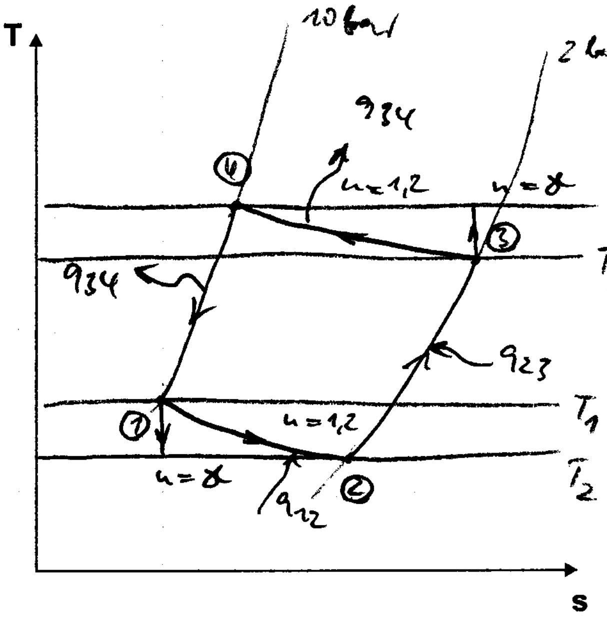
$$R = \frac{\Re}{M_m} = \frac{8315 \frac{J}{kmol \cdot K}}{24{,}407 \frac{kg}{kmol}} = 340{,}68 \frac{J}{kg \cdot K}$$

$$c_v = c_p - R_m = 0{,}875 \frac{J}{kg \cdot K}$$

$$\kappa = \frac{c_p}{c_v} = 1{,}390$$

WS 99/2000/1:





① 10 bar; $T_1 = 368{,}798\,K$; $v_{min} = \frac{v_{max}}{8}$

↓ polytrope Exp. $n = 1{,}2$

② 2 bar; $T_2 = 282{,}561\,K$; $v_2 = 0{,}478\, v_{max}$

↓ isobare Wärmezufuhr

③ 2 bar; $T_3 = 591{,}132\,K$; $v_{max} = 8\, v_{min}$

↓ polytrope Komp. $n = 1{,}2$

④ 10 bar; $500°C = 773\,K$ $v_4 = 0{,}262\, v_{max}$

↓ isobare Wärmeabfuhr

$$\frac{p_2}{p_1} = \left(\frac{v_{min}}{v_2}\right)^n = \left(\frac{v_{max}}{8 v_2}\right)^n \Rightarrow \frac{v_{max}}{8 v_2} = \left(\frac{p_2}{p_1}\right)^{\frac{1}{n}} \Rightarrow \frac{8 v_2}{v_{max}} = \left(\frac{p_1}{p_2}\right)^{\frac{1}{n}}$$

$$\Rightarrow v_2 = \frac{v_{max}}{8}\left(\frac{p_1}{p_2}\right)^{\frac{1}{n}} = \frac{v_{max}}{8}\left(\frac{10}{2}\right)^{\frac{1}{1,2}} = \underline{\underline{0{,}478\, v_{max}}}$$

$$\frac{T_3}{T_4} = \left(\frac{p_3}{p_4}\right)^{\frac{n-1}{n}} \Rightarrow T_3 = T_4\left(\frac{p_3}{p_4}\right)^{\frac{n-1}{n}} = 773\,K\left(\frac{2}{10}\right)^{\frac{0,2}{1,2}} = \underline{\underline{591{,}132\,K}}$$

$$\frac{v_2}{v_{max}} = \frac{T_2}{T_3} \Rightarrow T_2 = T_3 \frac{v_2}{v_{max}} = \frac{0{,}478\cancel{v_{max}}}{\cancel{v_{max}}} \cdot 591{,}132\,K = \underline{\underline{282{,}561\,K}}$$

$$\frac{p_4}{p_3} = \left(\frac{v_{max}}{v_4}\right)^n \Rightarrow \left(\frac{p_3}{p_4}\right)^{\frac{1}{n}} = \frac{v_4}{v_{max}} \Rightarrow v_4 = v_{max}\left(\frac{p_3}{p_4}\right)^{\frac{1}{n}}$$

$$v_4 = v_{max}\left(\frac{2}{10}\right)^{\frac{1}{1,2}} = \underline{\underline{0{,}262\, v_{max}}}$$

$$\frac{v_4}{v_{min}} = \frac{T_4}{T_1} \Rightarrow T_1 = T_4 \frac{v_{min}}{v_4} = 773K \cdot \frac{\cancel{v_{max}}}{8 \cdot 0{,}262\,\cancel{v_{max}}} = \underline{\underline{368{,}798\,K}}$$

$$w_t = n \cdot w_e$$

$$\Rightarrow w_{t34} = \frac{n \cdot R}{n-1}(T_3 - T_4) = \frac{1{,}2 \cdot 0{,}2872\,kJ}{0{,}2\,kg}(591{,}132 - 773)$$

$$\underline{\underline{= -313{,}395\,\frac{kJ}{kg}}} \quad (\Rightarrow \text{Energiezufuhr})$$

$$w_{t12} = \frac{n \cdot R}{n-1}(T_1 - T_2) = \frac{1{,}2 \cdot 0{,}2872\,kJ}{0{,}2\,kg}(368{,}798 - 282{,}561)$$

$$\underline{\underline{= 148{,}604\,\frac{kJ}{kg}}} \quad (\Rightarrow \text{Energieabgabe})$$

$$w_{tg} = w_{t34} + w_{t12} = (-313{,}395 + 148{,}604)\frac{kJ}{kg} = \underline{\underline{-164{,}791\,\frac{kJ}{kg}}}$$

$\underline{\underline{\hat{=}\ \text{Arbeitsaufnahme}}}$

$$w_k = \frac{W_k}{m} \Rightarrow m = \frac{W_k}{w_k} = \frac{-15000\,kJ}{-164{,}791} = \underline{\underline{91{,}024\,kg}}$$

$$q_{12} = c_{vm} \cdot \frac{\kappa - n}{n-1}(T_1 - T_2) = 1{,}009\,\frac{kJ}{kg} \cdot \frac{1{,}4 - 1{,}2}{0{,}2}(368{,}798 - 282{,}561)$$

$$\underline{\underline{= 87{,}013\,\frac{kJ}{kg}}}$$

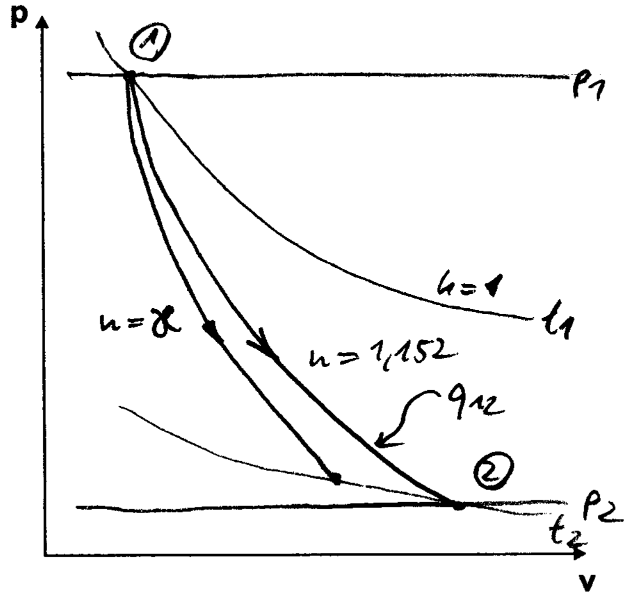
$$q_{23} = \kappa \cdot c_{vm}(T_3 - T_2) = 1{,}4 \cdot 1{,}009\,\frac{kJ}{kg}(591{,}132 - 282{,}561)$$

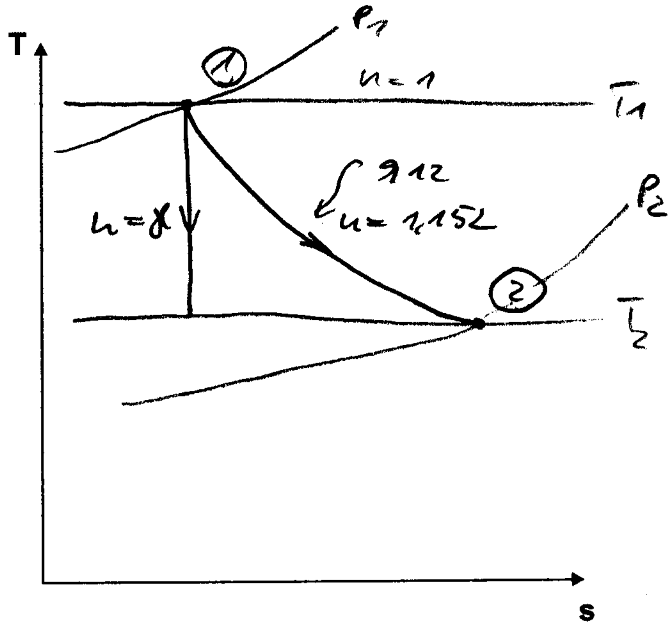
$$\underline{\underline{= 435{,}887\,\frac{kJ}{kg}}}$$

$$\eta_{th} = \frac{|w_k|}{q_{zu}} = \frac{|w_k|}{q_{12} + q_{23}} = \frac{164{,}791}{87{,}013 + 435{,}887} = 0{,}3151$$

$$\underline{\underline{= 31{,}51\,\%}}$$

WS 99/2000 / 2 :





① $15\,m^3$; $10\,bar$; $100\,°C$; m_1

↓ polytrope Expansion

② V_2 ; $1\,bar$; t_2 ; m_2

a) $u_1 - u_2 = p_2 (v_2 - v_1)$

$u_1 - u_2 = c_{vm} (T_1 - T_2)$

$$\Rightarrow c_{vm} (T_1 - T_2) = p_2 (v_2 - v_1)$$

$$\Rightarrow c_{vm} T_1 - c_{vm} T_2 = p_2 v_2 - p_2 v_1 \quad ; \quad v_i = \frac{R T_i}{p_i}$$

$$\Rightarrow c_{vm} T_1 - c_{vm} T_2 = \cancel{p_2} \frac{R T_2}{\cancel{p_2}} - p_2 \frac{R T_1}{p_1}$$

$$\Rightarrow c_{vm} T_1 + \frac{p_2}{p_1} R T_1 = c_{vm} T_2 + R T_2$$

$$\Rightarrow T_2 = T_1 \frac{c_{vm} + \frac{p_2}{p_1} R}{c_{vm} + R} = 373\,K \cdot \frac{10{,}0758 + \frac{1}{10} 4{,}1245}{10{,}0758 + 4{,}1245}$$

$$\underline{\underline{= 275{,}495\,K = 2{,}495\,°C}}$$

$$n = \frac{\ln \frac{p_1}{p_2}}{\ln \frac{p_1}{p_2} - \ln \frac{T_1}{T_2}} = \frac{\ln 10}{\ln 10 - \ln \frac{373}{275{,}495}} \underline{\underline{= 1{,}152}}$$

b)

$$\rho_2 = \frac{p_2}{RT_2} = \frac{10^5\,kg}{4124{,}5 \cdot 275{,}495\,m^3} = \underline{\underline{0{,}088\,\frac{kg}{m^3}}}$$

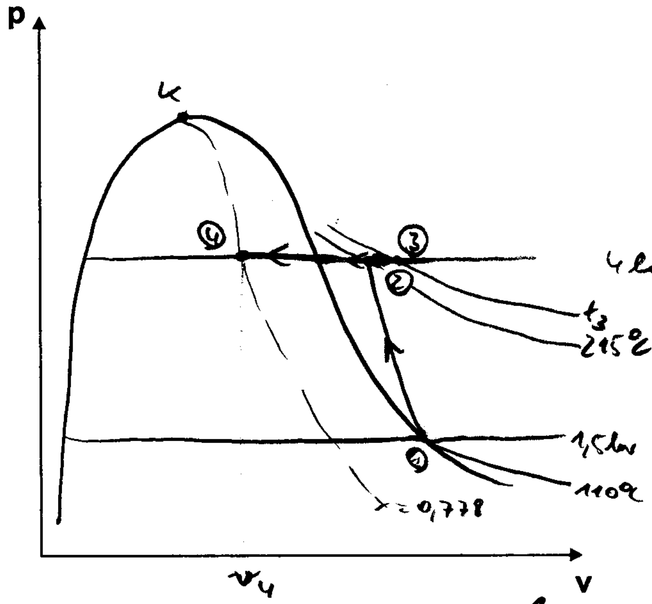
$$\rho_1 = \frac{p_1}{RT_1} = \frac{10^6\,kg}{4124{,}5 \cdot 373\,m^3} = \underline{\underline{0{,}65\,\frac{kg}{m^3}}}$$

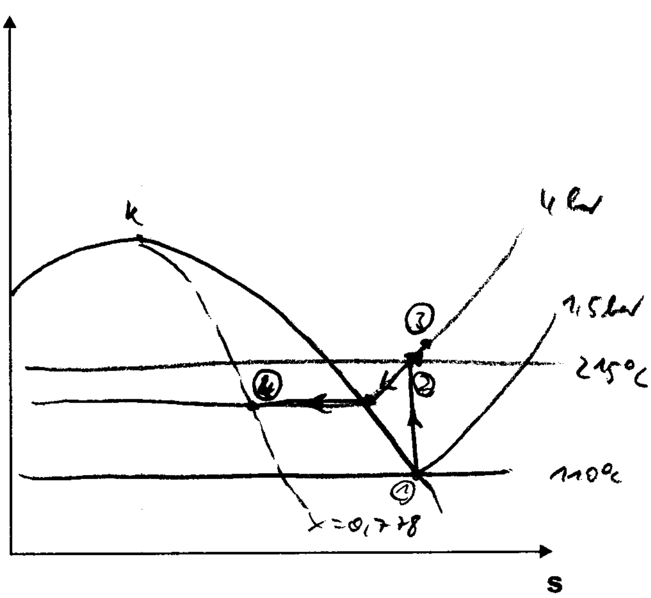
$$\rho_1 = \frac{m}{V_1} \Rightarrow m = V_1 \rho_1 = 15 \cdot 0{,}65\,kg = \underline{\underline{9{,}75\,kg}}$$

$$m_{2B} = V_1 \cdot \rho_2 = 15 \cdot 0{,}088 = \underline{\underline{1{,}32\,kg}}$$

$$m_{2A} = m - m_{2B} = (9{,}75 - 1{,}32)\,kg = \underline{\underline{8{,}43\,kg}}$$

WS 99/2000 / 3:





① Sattdampf; 1,5 bar; 2,8 $\frac{kg}{s}$; h_1

↓ isentrope Kompr.

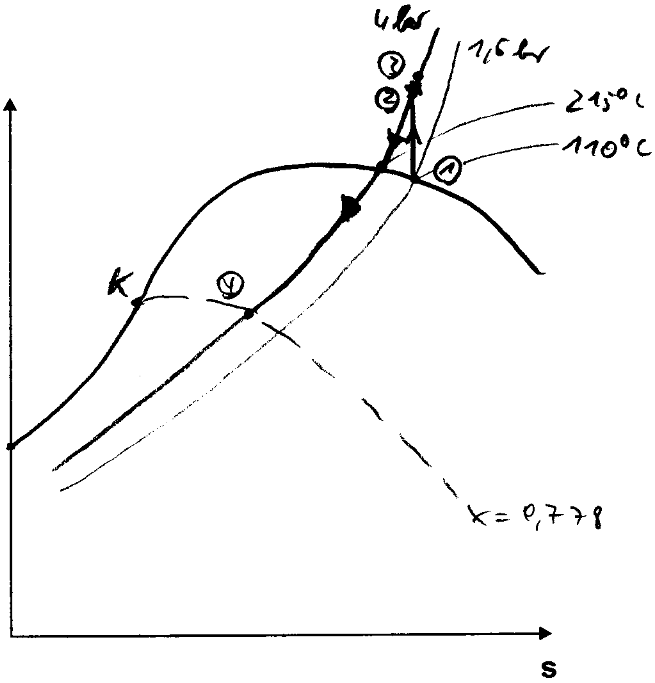
② überh. Dampf; 4 bar; t_2; h_2

↓ isobare Energiezufuhr $\Delta h = 25 \frac{kJ}{kg}$

③ überh. D. 4 bar; t_3; h_3

↓ ← Siedewasser 1,1 $\frac{kg}{s}$

④ p_4; t_4; h_4; v_4



$$\left.\begin{array}{l} h_1 \approx 2700 \frac{kJ}{kg};\ t_1 \approx 110°C \\ h_2 = 2890 \frac{kJ}{kg};\ t_2 \approx 215°C \end{array}\right\} \text{Diagramm}$$

$$h_3 = h_2 + \Delta h = (2890 + 25)\frac{kJ}{kg} = \underline{\underline{2915 \frac{kJ}{kg}}}$$

$$\dot m\, h_4 = \dot m_S h_S + \dot m_D h_3; \quad \dot m = \dot m_S + \dot m_D$$

$$h_S = h'(4\,bar) = \underline{\underline{604{,}67 \frac{kJ}{kg}}} \text{ (Tab.)}$$

$$\Rightarrow h_4 = \frac{\dot m_S h_S + \dot m_D h_D}{\dot m_S + \dot m_D}$$

$$= \frac{1{,}1 \cdot 604{,}67\,kJ + 2{,}8 \cdot 2915\,kJ}{(1{,}1 + 2{,}8)\,kg} = \underline{\underline{2263{,}37 \frac{kJ}{kg}}}$$

$$h_4 = h_4' + x_4 \, (h_4'' - h_4')$$

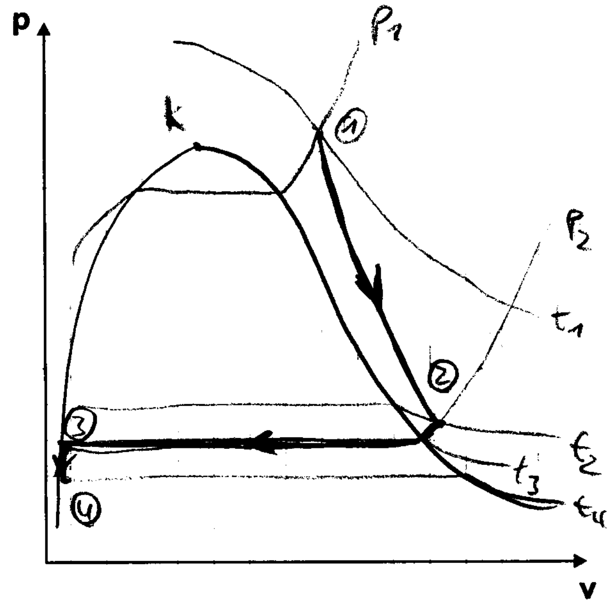
$$\Rightarrow x_4 = \frac{h_4 - h_4'}{h_4'' - h_4'} = \frac{2263{,}37 - 604{,}67}{2737{,}6 - 604{,}67} = \underline{\underline{0{,}778}}$$

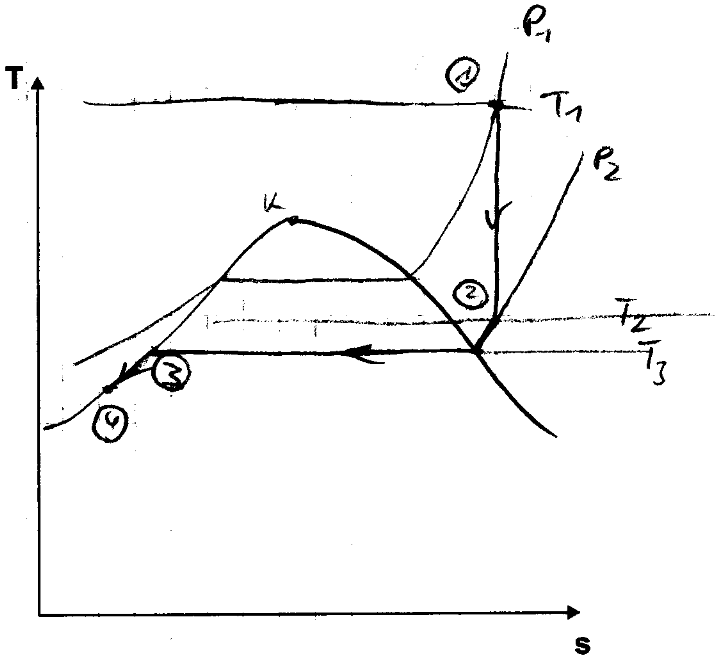
$$v_4 = v_4' + x_4 \, (v_4'' - v_4')$$

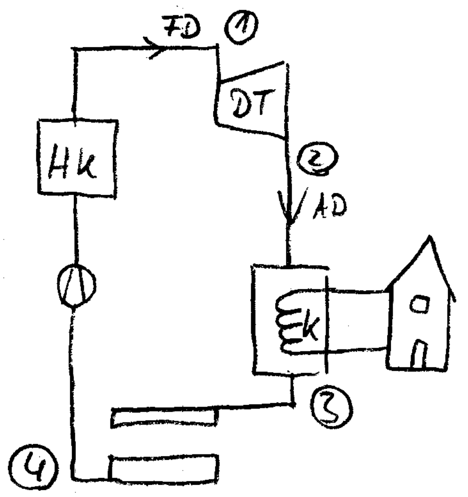
$$= (0{,}0010839 + 0{,}778\,(0{,}4622 - 0{,}0010839)\ \frac{m^3}{kg}$$

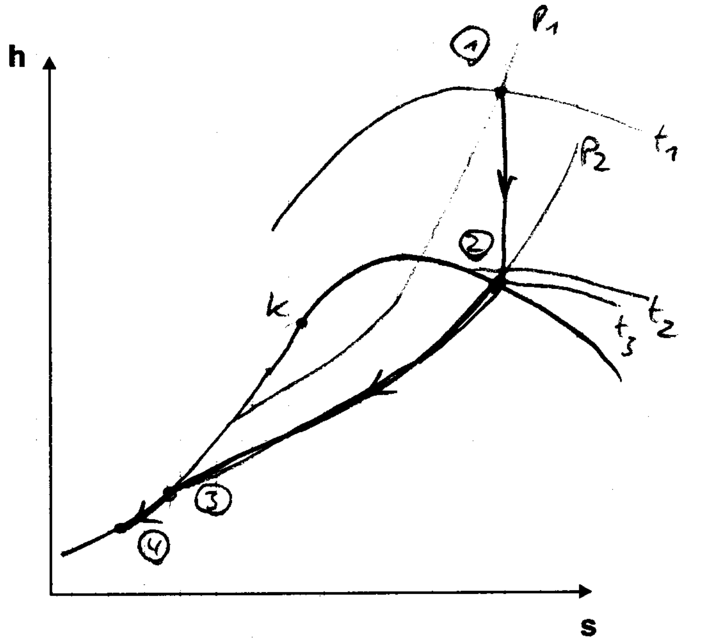
$$\underline{\underline{= 0{,}3598\ \frac{m^3}{kg}}}$$

WS 99/2000 / 4:









① ü. D.; 45 bar; 500°C

↓ isentrope Expansion: 50 kW

② 3 bar; t_2

↓ isobare Kondensation: q_{23}; P_{23}

③ Heißwasser; 3 bar; t_3

↓ Nachverdampfung

④ ; 1 bar; 100°C

$h_1 = 3440 \frac{kJ}{kg}$ (Diagr.)

$h_2 = 2745 \frac{kJ}{kg}$ " "

$t_2 = 140°C$ " "

$$P_{12} = \dot m_D \Delta h = \dot m_D \cdot (h_1 - h_2)$$

$$\Rightarrow \dot m_D = \frac{P_{12}}{h_1 - h_2} = \frac{50}{3440-2745} \frac{kg}{s} = 71{,}94 \cdot 10^{-3} \frac{kg}{s}$$

$t_3 = 133{,}54\,°C$ (Tab)

$h_3 = h'(3\,bar) = 561{,}43 \frac{kJ}{kg}$ (Tab)

$$\Rightarrow P_{23} = \dot m_D (h_2 - h_3) = 71{,}94 \cdot 10^{-3} \cdot (2745 - 561{,}43)\,kW = 157{,}086\,kW$$

$$\dot m_D \cdot h_3' = \dot m_{W4} h_4' + \dot m_{D4} h_4''$$

$$\dot m_D = \dot m_{W4} + \dot m_{D4} \Rightarrow \dot m_{W4} = \dot m_D - \dot m_{D4}$$

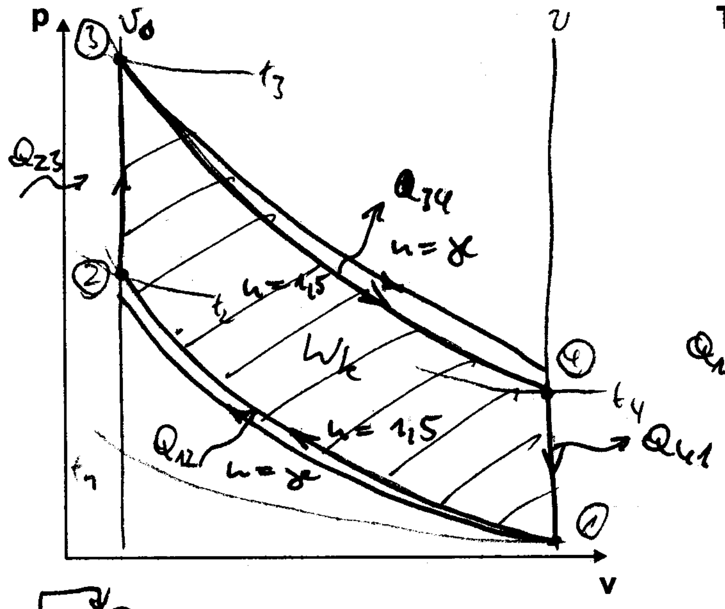
$$\Rightarrow \dot m_D h_3' = \dot m_D h_4' + \dot m_{D4} (h_4'' - h_4')$$

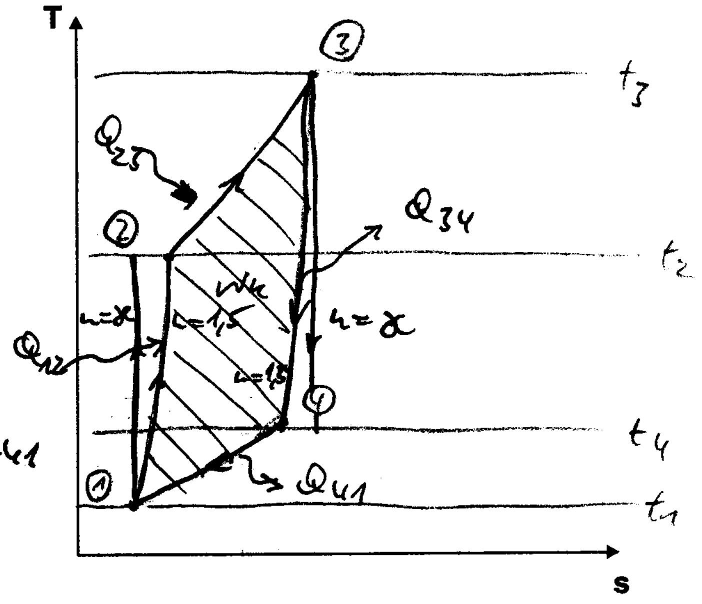
$$\Rightarrow \dot m_D (h_3' - h_4') = \dot m_{D4} (h_4'' - h_4')$$

$$\Rightarrow \dot m_{D4} = \dot m_D \frac{h_3' - h_4'}{h_4'' - h_4'} = 71{,}94 \cdot 10^{-3} \frac{kg}{s} \cdot \frac{561{,}43 - 417{,}51}{2675{,}4 - 417{,}51}$$

$$= 4{,}586 \cdot 10^{-3} \frac{kg}{s} = \underline{\underline{16{,}51 \frac{kg}{h}}}$$

SS 2000 / 1 :





① 1,5 bar ; 25°C ; $V_1 = 5\,m^3 = v \cdot m$

↓ polytrope: $n = 1{,}5$

② p_2 ; t_2 ; $V_2 = v_0 \cdot m = \frac{v}{10} m = \frac{V_1}{10}$

↓ isochor

③ p_3 ; $t_3 = t_2 + 500K$; $V_3 = V_2 = \frac{V_1}{10}$

↓ polytrop: $n = 1{,}5$

④ p_4 ; t_4 ; $V_4 = V_1$

isochor

$$\frac{p_2}{p_1} = \left(\frac{V_1}{V_2}\right)^n \Rightarrow p_2 = p_1 \left(\frac{V_1}{V_2}\right)^n = 1{,}5\,(10)^{1{,}5}\ \text{bar} = \underline{\underline{47{,}434\ \text{bar}}}$$

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{n-1} \Rightarrow T_2 = T_1 \left(\frac{V_1}{V_2}\right)^{n-1} = 298K\,(10)^{0{,}5} = \underline{\underline{942{,}4K}}$$

$$\Rightarrow t_2 = \underline{\underline{669{,}4\,°C}}$$

$$t_3 = t_2 + 500K = \underline{\underline{1169{,}4\,°C}} \Rightarrow \underline{\underline{T_3 = 1442{,}4K}}$$

$$\frac{p_2}{T_2} = \frac{p_3}{T_3} \Rightarrow p_3 = p_2 \frac{T_3}{T_2} = 47{,}434\ \text{bar} \cdot \frac{1442{,}4}{942{,}4} = \underline{\underline{72{,}602\ \text{bar}}}$$

$$\frac{p_4}{p_3} = \left(\frac{V_3}{V_4}\right)^n \Rightarrow p_4 = p_3 \left(\frac{V_3}{V_4}\right)^n = 72{,}602\,\text{bar}\left(\frac{1}{10}\right)^{1{,}5} = \underline{\underline{2{,}296\,\text{bar}}}$$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{n-1} \Rightarrow T_4 = T_3 \left(\frac{V_3}{V_4}\right)^{n-1} = 1442{,}4\,K\left(\frac{1}{10}\right)^{0{,}5} = \underline{\underline{456{,}1\,K}}$$

$$\Rightarrow \underline{\underline{t_4 = 183\,°C}}$$

$$c_{pm}\Big|_{300}^{700} = \frac{c_{pm}\Big|_0^{300} \cdot 300 - c_{pm}\Big|_0^{700} \cdot 700}{300 - 700}$$

$$= \frac{1{,}048 \cdot 300 - 1{,}085 \cdot 700}{300 - 700} \frac{kJ}{kgK}$$

$$= \underline{\underline{1{,}113 \frac{kJ}{kgK}}} \qquad \kappa = \frac{c_{pm}}{c_{vm}} = \frac{1{,}113}{0{,}816} = \underline{\underline{1{,}364}}$$

$$c_{vm} = c_{pm} - R = (1{,}113 - 0{,}2968) \frac{kJ}{kgK} = \underline{\underline{0{,}816 \frac{kJ}{kgK}}}$$

$$p_1 \cdot V_1 = m R T_1 \Rightarrow m = \frac{p_1 \cdot V_1}{R T_1} = \frac{150000 \cdot 5}{296{,}8 \cdot 298} kg = \underline{\underline{8{,}48\,kg}}$$

$$Q_{12} = m \cdot c_{vm} \cdot \frac{\kappa - n}{n-1}(T_1 - T_2) = 8{,}48 \cdot 0{,}816\,kJ \frac{1{,}364 - 1{,}5}{0{,}5}(298 - 942{,}4)$$

$$= \underline{\underline{1212{,}82\,kJ}}$$

$$Q_{34} = 8{,}48 \cdot 0{,}816\,kJ \frac{1{,}364 - 1{,}5}{0{,}5}(1442{,}4 - 456{,}1)$$

$$= \underline{\underline{-1856{,}3\,kJ}}$$

$$Q_{23} = m \cdot c_{vm} \cdot (T_3 - T_2) = 8{,}48 \cdot 0{,}816\,kJ \cdot (500)$$

$$= \underline{\underline{3459{,}72\,kJ}}$$

$$Q_{41} = 8{,}48 \cdot 0{,}816\,kJ \cdot (298 - 456{,}1)$$

$$= \underline{\underline{-1094{,}00\,kJ}}$$

$$W_e = \Sigma Q = \underline{\underline{1722{,}24\,kJ}}$$

$$\eta = \frac{W_e}{Q_{zu}} = \frac{W_e}{Q_{12} + Q_{23}} = \frac{1722{,}24}{1212{,}82 + 3459{,}72} = 0{,}36859$$

$$= \underline{\underline{36{,}859\,\%}}$$

Aufgabe: SS 2000/2:

Gewichtsanteile

Stoff	μ_i	R_i $\left[\frac{J}{kg \cdot K}\right]$	$R_i \cdot \mu_i$ $\left[\frac{J}{kg \cdot K}\right]$	$c_{pi}\Big\|_0^{80}$ $\left[\frac{kJ}{kg \cdot K}\right]$	$c_{pi}\Big\|_0^{220}$ $\left[\frac{kJ}{kg \cdot K}\right]$	$c_{pi}\Big\|_{80}^{220}$ $\left[\frac{kJ}{kg \cdot K}\right]$	$\mu_i \cdot c_{pi}\Big\|_{80}^{220}$ $\left[\frac{kJ}{kg \cdot K}\right]$
O_2	0,2	259,8	51,96	0,921	0,938	0,948	0,1896
CO	0,4	296,8	118,72	1,041	1,048	1,052	0,4208
N_2	0,4	296,8	118,72	1,039	1,043	1,045	0,418

$R_m =$ 289,4 $\left[\frac{J}{kg \cdot K}\right]$ $\qquad C_{pm} =$ 1,0284 $\left[\frac{kJ}{kg \cdot K}\right]$

$$c_{pi}\Big|_{t_1}^{t_2} = \frac{\left(c_{pi}\Big|_0^{t_2} \cdot t_2 - c_{pi}\Big|_0^{t_1} \cdot t_1\right)}{t_2 - t_1}$$

$c_v = c_p - R_m = 0{,}739 \ \frac{J}{kg \cdot K}$ $\qquad \kappa = \frac{c_p}{c_v} = 1{,}392$

$m = (2+4+4)\,kg = 10\,kg$

(1) 20 bar; 220°C; v_1; $\dot{m}$

↓ Drosselung = isotherm (ideales Gas)

(2) 8 bar; 220°C; v_2

↓ polytrope Entspannung; $n = 1{,}25$

(3) 1,5 bar; t_3; v_3

= 80°C

20 °C

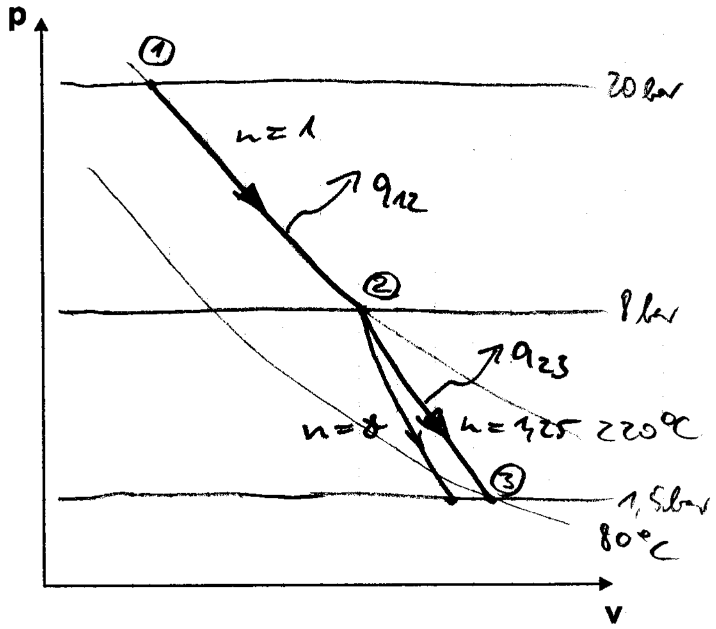
$$\frac{T_2}{T_3} = \left(\frac{p_2}{p_3}\right)^{\frac{n-1}{n}} \Rightarrow T_3 = T_2\left(\frac{p_3}{p_2}\right)^{\frac{n-1}{n}} = 493\,K \cdot \left(\frac{1{,}5}{8}\right)^{\frac{0{,}25}{1{,}25}} = 352{,}734\,K$$

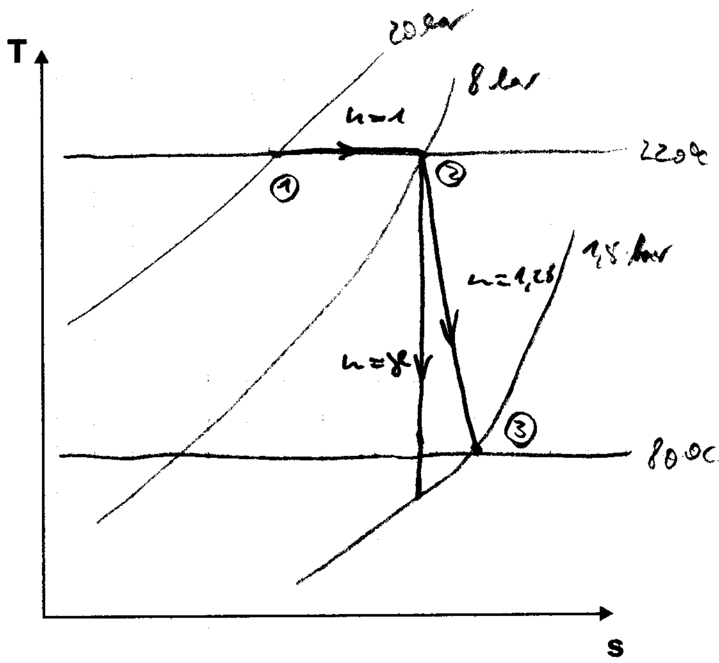
$$= 79{,}734\,°C$$

$$w_{t23} = \frac{R}{n-1}(T_2 - T_3) \cdot n \quad \frac{0{,}2894}{0{,}25}(493 - 352{,}734)\frac{kJ}{kg} \cdot 1{,}25 = 202{,}965\,\frac{kJ}{kg}$$

$$P = \dot{m} \cdot w_{t23} \Rightarrow \dot{m} = \frac{P}{w_{t23}} = \frac{15\,kJ\,kg}{202{,}96\,kJ\,s} = 0{,}0739\,\frac{kg}{s} = 266{,}06\,\frac{kg}{h}$$

SS 2000/2 :



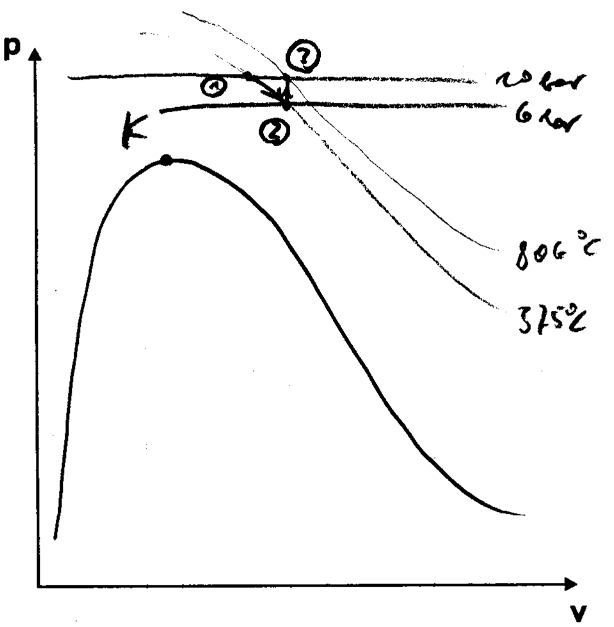


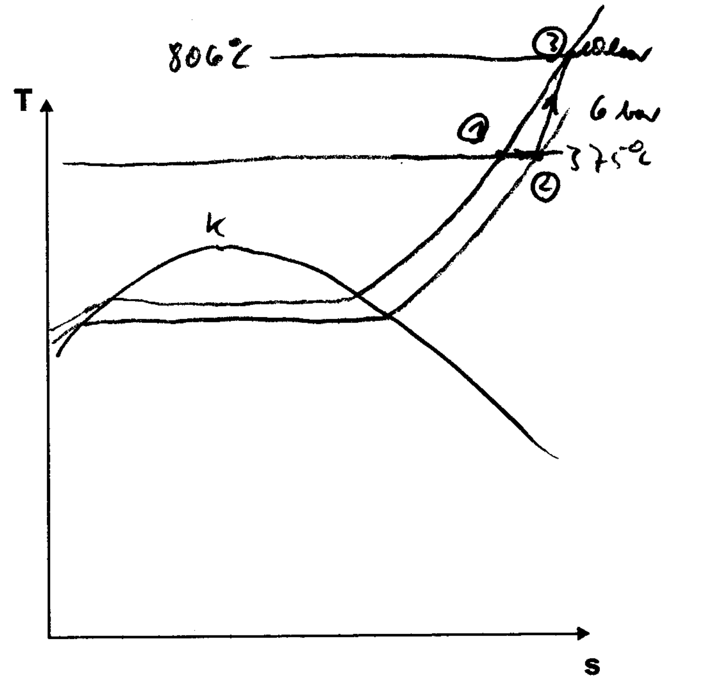
$$q_{23} = \frac{w_{t23}}{n} \cdot \frac{\kappa - n}{\kappa - 1} = \frac{202{,}965\ kJ}{1{,}25\ kg} \cdot \frac{1{,}392 - 1{,}25}{0{,}392}$$

$$= \underline{\underline{58{,}818\ \frac{kJ}{kg}}}$$

$$\dot{Q} = \dot{m} \cdot q_{23} = 0{,}0739\ \frac{\cancel{kg}}{s} \cdot 58{,}818\ \frac{kJ}{\cancel{kg}} = \underline{\underline{4{,}347\ kW}}$$

SS 2000 / 3:





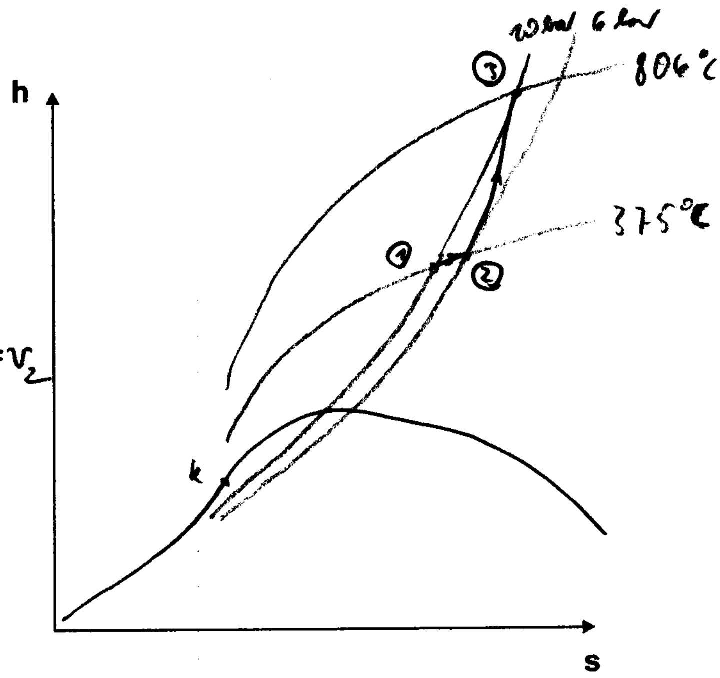
(1) üb. Dampf; 10 bar; 375°C; h_1; v_1

↓

(2) " 6 bar; 375°C; h_2; v_2

↓

(3) 10 bar; t_3; h_3; $v_3 = v_2$



$h_1 = 3215 \frac{kJ}{kg}$; $v_1 \approx 0{,}3 \frac{m^3}{kg}$

$h_2 = 3220 \frac{kJ}{kg}$; $v_2 \approx 0{,}5 \frac{m^3}{kg}$

$$v_1 = \frac{R T_1}{p_1} = \frac{461{,}5 \cdot 648\ m^3}{10^6\ kg} = \underline{\underline{0{,}299 \frac{m^3}{kg}}}$$

$$v_2 = \frac{R T_2}{p_2} = \frac{461{,}5 \cdot 648\ m^3}{6 \cdot 10^5\ kg} = \underline{\underline{0{,}498 \frac{m^3}{kg}}}$$

$$m_1 = \frac{V}{v_1} = \frac{5\ kg}{0{,}299} = \underline{\underline{16{,}722\ kg}} \; ; \; m_2 = \frac{V}{v_2} = \frac{5\ kg}{0{,}498} = \underline{\underline{10{,}04\ kg}}$$

$$\Delta m = m_1 - m_2 = 16{,}722\ kg - 10{,}04\ kg = \underline{\underline{6{,}682\ kg}}$$

$$\rho_2 = \frac{1}{v_2} = \underline{\underline{2{,}008 \frac{kg}{m^3}}}$$

$$p \cdot V = m R T$$

$$\Rightarrow T_3 = \frac{p \cdot V}{m R} = \frac{p \cdot v}{R} = \frac{10^6 \cdot 0{,}498\,k}{461{,}5} = \underline{\underline{1079{,}1\,k}}$$

$$\underline{\underline{= 806{,}1\,°C}}$$

$$\Rightarrow h_3 = \underline{\underline{4155}}\ \frac{kJ}{kg} \quad (\text{Diagramm})$$

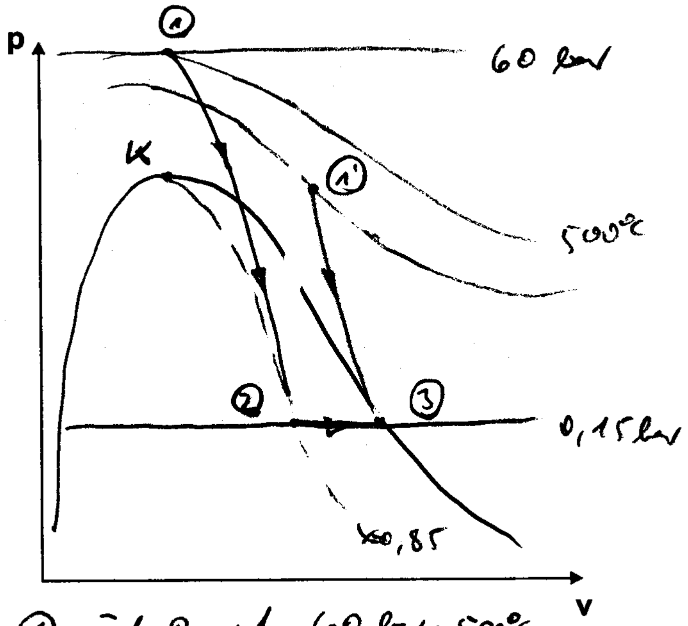
$$q_{23} = (h_3 - p_3 v_2) - (h_2 - p_2 v_2) = (4155 - 10^3 \cdot 0{,}498)\frac{kJ}{kg}$$

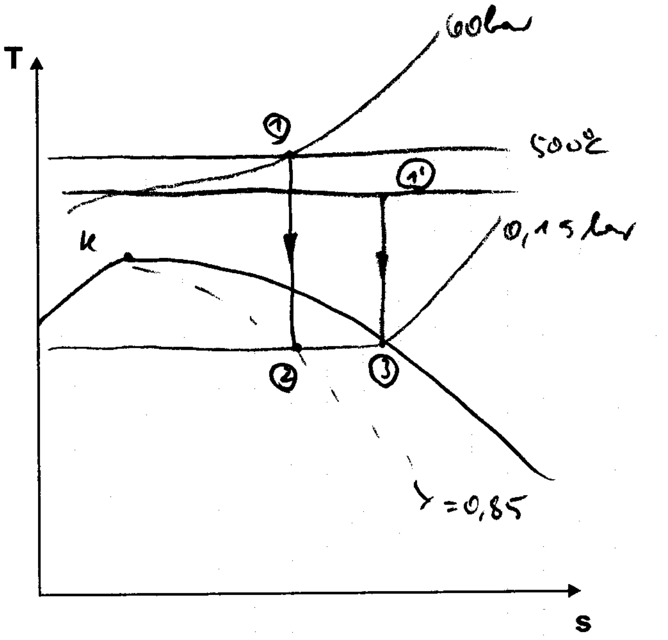
$$- (3220 - 6 \cdot 10^2 \cdot 0{,}498)\frac{kJ}{kg}$$

$$\underline{\underline{= 735{,}8\ \frac{kJ}{kg}}}$$

$$Q_{23} = q_{23} \cdot m_2 = = 735{,}8\ \frac{kJ}{kg} \cdot 10{,}04 = \underline{\underline{7{,}387\,MJ}}$$

SS 2000 / 4:





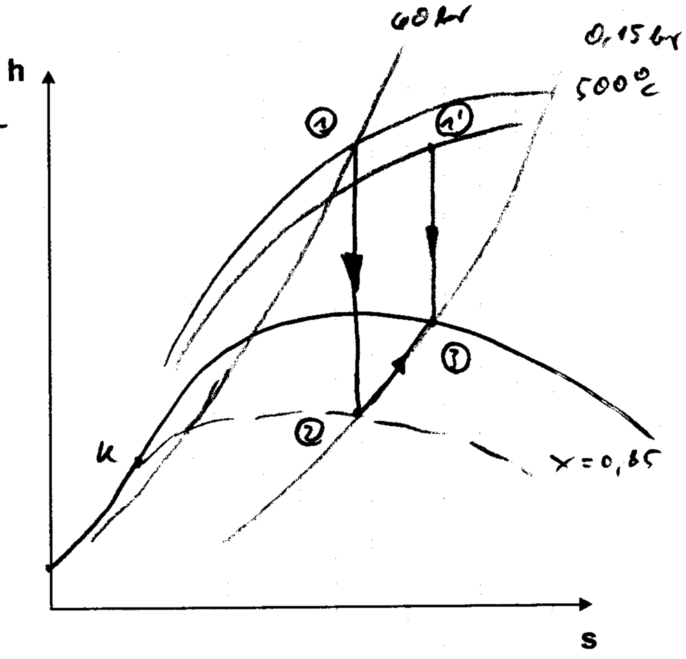
① üb. Dampf 60 bar; 500°C

↓ isentrop

② Nassdampf p_2 ; t_2 ; $x = 0{,}85$

↓ isobar

③ Sattdampf p_2 ; t_3 ;



$p_2 \approx 0{,}15$ bar ; $t_2 \approx 60°C$

$h_1 = 3422{,}2 \frac{kJ}{kg}$

$h_2 = 2250 \frac{kJ}{kg}$

$h_3 = h_3'' = 2605 \frac{kJ}{kg}$

$h_{1'} = h_1 = 3422{,}2$

$\Delta h = h_3 - h_2 = (2605 - 2250) \frac{kJ}{kg} = \underline{\underline{355 \frac{kJ}{kg}}}$