# BGTD – 4. A termodinamika első főtétele zárt rendszerekre

4.3.1. $p_1 = 500\,[kPa]$ $\qquad p_2 = 400\,[kPa]$ $\qquad V = konst$

$T_1 = 150\,[°C]$ $\qquad T_2 = 65\,[°C]$

$M = 29\,\left[\frac{kg}{kmol}\right]$ $\qquad \kappa = 1{,}4\,[1]$

$$c_v = \frac{R}{\kappa - 1} = \frac{R}{M(\kappa-1)} = 716{,}7586\,\left[\frac{J}{kg\,K}\right]$$

$$u_2 - u_1 = q + w_f$$

$$w_f = -\int_{v_1}^{v_2} p(v)\,dv = 0 \quad /izochor/$$

$$du = c_v\,dT \xrightarrow{\int_1^2} u_2 - u_1 = c_v(T_2 - T_1)$$

$$q = c_v(T_2 - T_1) = -60{,}9245\,\left[\frac{kJ}{kg}\right]$$

4.3.2. $m = 4{,}5\,[kg]$

$p = 410\,[kPa]$ $\qquad T_1 = 160\,[°C]$

$T_2 = 200\,[°C]$

súrlódásmentesen mozgó dugattyú: $p = konst$

$T_{sat}(p) = 144{,}505\,[°C] < T_1, T_2 \Rightarrow$ túlhevített gőz állapot

$v_1 = 0{,}4717714\,\left[\frac{m^3}{kg}\right]$ $\qquad v_2 = 0{,}5210017\,\left[\frac{m^3}{kg}\right]$

$h_1 = 2774{,}43\,\left[\frac{kJ}{kg}\right]$ $\qquad h_2 = 2860{,}49\,\left[\frac{kJ}{kg}\right]$

$$W_f = -m\int_{v_1}^{v_2} p(v)\,dv \underset{p=konst}{=} -mp(v_2 - v_1) = -90{,}9640\,[kJ]$$

$$H_2 - H_1 = Q + W_t \Rightarrow Q = m(h_2 - h_1) = 387{,}27\,[kJ]$$

$$W_t = m\int_{p_1}^{p_2} v\,dp = 0 \quad /izobár/$$

4.3.3. $V_1 = 0{,}4\,[m^3]$ $V_2 = 0{,}1\,[m^3]$

$p = 100\,[kPa]$

$T = 80\,[°C] = \text{konst}$

levegő ezen a hőmérsékleten kb. 170 [bar]-ig ideális gáznak tekinthető ($z = \frac{pv}{RT} = 1 \div 1{,}05$)

$$\underbrace{U_2 - U_1}_{\underbrace{c_v m (T_2 - T_1)}_{=0}} = Q + W_f$$

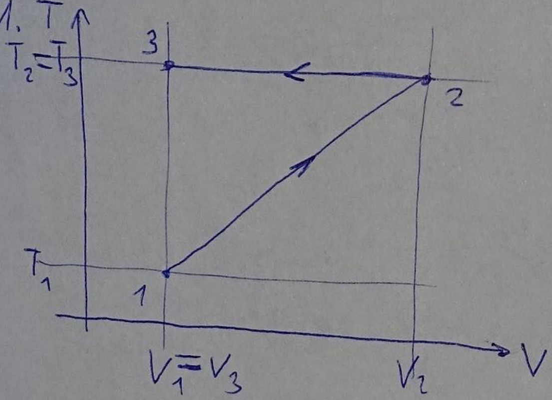
(ideális gázra)

$$W_f = -\int_{V_1}^{V_2} p(V)\,dV = -p_1 V_1 \int_{V_1}^{V_2} \frac{dV}{V} = -p_1 V_1 \ln\frac{V_2}{V_1} = 55{,}4518\,[kJ]$$

$$p_1 V_1 = pV \Rightarrow p(V) = p_1 V_1 V^{-1}$$

$$Q = -W_f = -55{,}4518\,[kJ]$$

4.4.1.




$V_1 = 15\,[dm^3]$

$T_1 = 15\,[°C]$

$p_1 = 150\,[kPa]$

$\frac{V_2}{V_1} = \frac{T_2}{T_1} = 4$

$\kappa = 1{,}3\,[1]$

$$pV = mRT$$

$$\frac{p_2 V_2}{p_1 V_1} = \frac{T_2}{T_1} \Rightarrow \frac{p_2}{p_1} = 1 \Rightarrow p_2 = p_1$$

1–2: izobár hőközlés

2 → 3: izoterm kompresszió: $\frac{p_3 V_3}{p_2 V_2} = \frac{T_3}{T_2} = 1$

$$p_3 = p_2 \frac{V_2}{V_3} = 600\,[kPa]$$

másképp $V_2 = 4V_1 = 60\ [dm^3]$

$$T_2 = T_3 = 4T_1 = 1152\ [K]$$

$$p_3 = \frac{mRT_3}{V_3} = p_1 \frac{V_1 T_3}{V_3 T_1} = 600\ [kPa]$$

$$mR = \frac{p_1 V_1}{T_1}$$

$$U_3 - U_1 = mc_v(T_3 - T_1) = \frac{p_1 V_1}{RT_1}\frac{R}{\kappa - 1}(T_3 - T_1) =$$

$$= \frac{p_1 V_1}{\kappa - 1}\left(\frac{T_3}{T_1} - 1\right) = 22{,}5\ [kJ]$$

$$H_3 - H_1 = mc_p(T_3 - T_1) = \underbrace{m\kappa c_v(T_3 - T_1)}_{=U_3 - U_1} = \kappa(U_3 - U_1) = 29{,}25\ [kJ]$$

$$S_3 - S_1 = \underbrace{m\left[c_v \ln\frac{T_3}{T_1} + R\ln\frac{V_3}{V_1}\right]}_{\text{azt válasszuk, mivel } \frac{V_3}{V_1} = 1,\ \text{így kevesebbet kell számolni, de ugyanazt az eredményt kell kapni}} = m\left[c_p \ln\frac{T_3}{T_1} - R\ln\frac{p_3}{p_1}\right]$$

$$= \frac{p_1 V_1}{RT_1}\frac{R}{\kappa - 1}\ln\frac{T_3}{T_1} = \frac{p_1 V_1}{T_1(\kappa - 1)}\ln\frac{T_3}{T_1} = 36{,}1014\ \left[\frac{J}{K}\right]$$

$$W_{13} = \underbrace{W_{12}}_{\text{izobár}} + \underbrace{W_{23}}_{\text{izoterm}} = -\int_{V_1}^{V_2} p(V)\,dV - \int_{V_2}^{V_3} p(V)\,dV =$$

$$= -p_1(V_2 - V_1) - \int_{V_2}^{V_3}\frac{p_2 V_2}{V}\,dV = -p_1(V_2 - V_1) - p_2 V_2 \ln\frac{V_3}{V_2} =$$

$$= 5{,}7266\ [kJ]$$

$$Q_{13} = (U_3 - U_1) - W_{13} = 16,7734 \text{ [kJ]}$$

másképp:

$$Q_{13} = \underbrace{Q_{12}}_{\text{izobár}} + \underbrace{Q_{23}}_{\text{izoterm}} = c_p m (T_2 - T_1) + T_2 \underbrace{(S_3 - S_2)}_{m\left[\underbrace{c_v \ln \underbrace{\frac{T_3}{T_2}}_{=1}}_{=0} + R \ln \frac{V_3}{V_2}\right]} =$$

$$= m\left[c_p (T_2 - T_1) + R T_2 \ln \frac{V_3}{V_2}\right] = \frac{p_1 V_1}{R T_1}\left[\frac{\varkappa R}{\varkappa - 1}(T_2 - T_1) + R T_2 \ln \frac{V_3}{V_2}\right] =$$

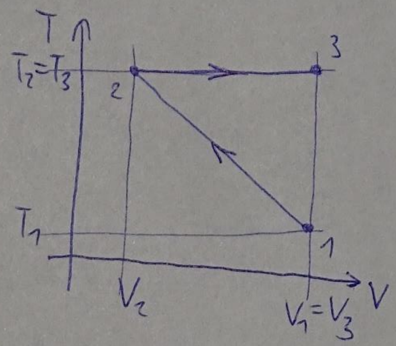
$$= \frac{p_1 V_1}{T_1}\left[\frac{\varkappa}{\varkappa - 1}(T_2 - T_1) + T_2 \ln \frac{V_3}{V_2}\right] = 16,7734 \text{ [kJ]}$$

4.4.2.

$V_1 = 25$ [dm$^3$] $\qquad \varkappa = 1,65$

$T_1 = 25$ [°C] $\qquad \frac{V_2}{V_1} = \frac{1}{3}$

$p_1 = 250$ [kPa] $\qquad \frac{T_2}{T_1} = \frac{4}{3}$




$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} \Rightarrow p_2 = p_1 \frac{V_1}{V_2} \frac{T_2}{T_1} = 1000 \text{ [kPa]}$$

$$V_2 = \frac{V_1}{3} = 8,3333 \text{ [dm}^3\text{]}$$

$$T_2 = \frac{4}{3} T_1 = 397,3333 \text{ [K]}$$

$$V_3 = V_1 = 25 \text{ [dm}^3\text{]}$$

$$T_3 = T_2 = 397,3333 \text{ [K]}$$

$$\frac{p_2 V_2}{T_2} = \frac{p_3 V_3}{T_3} \Rightarrow p_3 = p_2 \underbrace{\frac{V_2}{V_3}}_{=\frac{V_2}{V_1}} \underbrace{\frac{T_3}{T_2}}_{=1} = \frac{1}{3} p_2 = 333,3333 \text{ [kPa]}$$

$$U_3 - U_1 = m c_v (T_3 - T_1) = \frac{p_1 V_1}{R T_1} \frac{R}{\varkappa - 1} (T_3 - T_1) =$$

$$= \frac{p_1 V_1}{\varkappa - 1} \left( \frac{T_3}{T_1} - 1 \right) = 3{,}2051 \; [kJ]$$

$$H_3 - H_1 = \varkappa (U_3 - U_1) = 5{,}2884 \; [kJ]$$

$$S_3 - S_1 = m \left[ c_v \ln \frac{T_3}{T_1} + R \ln \frac{V_3}{V_1} \right] =$$

$$= \frac{p_1 V_1}{R T_1} \left[ \frac{R}{\varkappa - 1} \ln \frac{T_3}{T_1} + R \ln \frac{V_3}{V_1} \right] = \frac{p_1 V_1}{T_1} \left[ \frac{1}{\varkappa - 1} \ln \frac{T_3}{T_1} + \underbrace{\ln \frac{V_3}{V_1}}_{=0} \right] =$$

$$= 9{,}2825 \left[ \frac{J}{K} \right]$$

$$W_{13} = \underbrace{W_{12}}_{?} + \underbrace{W_{23}}_{\text{izoterm}} = - \int_{V_1}^{V_2} p(V)\, dV - \int_{V_2}^{V_3} p(V)\, dV = (*) =$$

$\hookrightarrow$ $p(V)$ 1-2 között

$$p(V) = \frac{m R T}{V} = \underbrace{\frac{p_1 V_1}{T_1}}_{= mR} \frac{T}{V}$$

ehhez kell a $T(V)$ fgv 1-2 között, diagramon látszik, hogy $T(V)$ lineáris:

$$T(V) = aV + b$$

$$\boxed{\begin{aligned} T(V_1) &= T_1 = a V_1 + b \quad (1) \\ T(V_2) &= T_2 = a V_2 + b \quad (2) \end{aligned}}$$

$$(2) - (1): \quad T_2 - T_1 = a (V_2 - V_1) \Rightarrow a = \frac{T_2 - T_1}{V_2 - V_1} = -5{,}9599 \cdot 10^{+3} \left[ \frac{K}{m^3} \right]$$

$$(2) V_1 - (1) V_2: \quad T_2 V_1 - T_1 V_2 = b (V_1 - V_2) \Rightarrow b = \frac{T_2 V_1 - T_1 V_2}{V_1 - V_2} =$$

$$= 446{,}9997 \; [K]$$

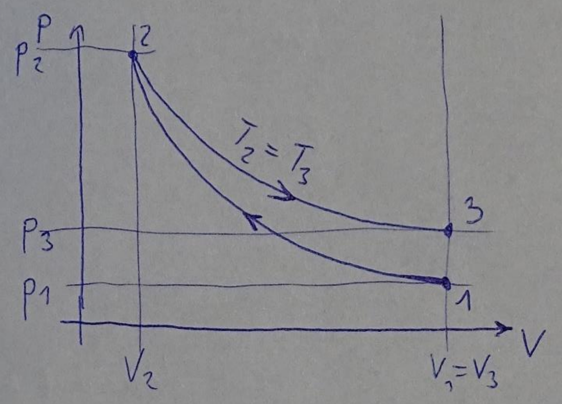
$$p(V) = p(T(V)) = \frac{p_1 V_1}{T_1}\frac{T}{V} = \frac{p_1 V_1}{T_1}\left(a + \frac{b}{V}\right)$$

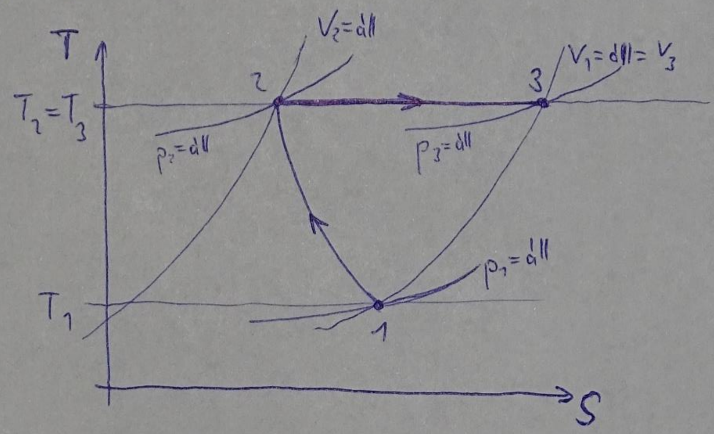
$$=(*)= -\int_{V_1}^{V_2} \frac{p_1 V_1}{T_1}\left(a + \frac{b}{V}\right) dV - \int_{V_2}^{V_3} \frac{p_2 V_2}{V} dV =$$

$$= \underbrace{-\frac{p_1 V_1}{T_1}\left[a(V_2 - V_1) + b \ln\frac{V_2}{V_1}\right]}_{= 8216{,}1807\ [J]} \underbrace{- p_2 V_2 \ln\frac{V_3}{V_2}}_{= -9155{,}1021\ [J]} =$$

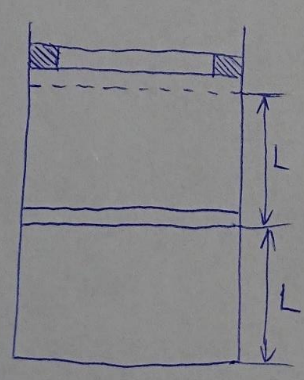
$$= -938{,}9214\ [J]$$

$$Q_{13} = (U_3 - U_1) - W_{13} = 4{,}144\ [kJ]$$




4.4.3.




$p_1 = 100\ [kPa]$ $\qquad p_3 = 2p_1$

$V_1 = 5\ [dm^3]$

$T_1 = 50\ [°C]$

$\kappa = 1{,}4\ [1]$

$1 \to 2$: amíg a dugattyú eléri a rögzítőgyűrűt, $p =$ konst

$2 \to 3$: a dugattyú felütközött a rögzítőgyűrűnek, nyomás növekszik, míg térfogata állandó, $V =$ konst

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} \Rightarrow T_2 = T_1 \underbrace{\frac{p_2}{p_1}}_{=1} \frac{V_2}{V_1} = T_1 \underbrace{\frac{V_2}{V_1}}_{=\frac{2L}{L}} = 2T_1 = 646\,[K]$$

$$\frac{p_2 V_2}{T_2} = \frac{p_3 V_3}{T_3} \Rightarrow T_3 = T_2 \underbrace{\frac{p_3}{p_2}}_{=\frac{p_3}{p_1}=2} \underbrace{\frac{V_3}{V_2}}_{=1} = 2T_2 = 1292\,[K]$$

$$U_3 - U_1 = c_v m (T_3 - T_1) = \underbrace{\frac{p_1 V_1}{R T_1}}_{=m} \underbrace{\frac{R}{\kappa - 1}}_{=c_v} (T_3 - T_1) =$$

$$= \frac{p_1 V_1}{\kappa - 1}\left(\frac{T_3}{T_1} - 1\right) = 3{,}75\,[kJ]$$

$$H_3 - H_1 = \kappa (U_3 - U_1) = 5{,}25\,[kJ]$$

$$S_3 - S_1 = m\left[c_v \ln\frac{T_3}{T_1} + R \ln\frac{V_3}{V_1}\right] =$$

$$= \frac{p_1 V_1}{R T_1}\left[\frac{R}{\kappa-1}\ln\frac{T_3}{T_1} + R\ln\frac{V_3}{V_1}\right] = \frac{p_1 V_1}{T_1}\left[\frac{1}{\kappa-1}\ln\frac{T_3}{T_1} + \ln\frac{V_3}{V_1}\right] =$$

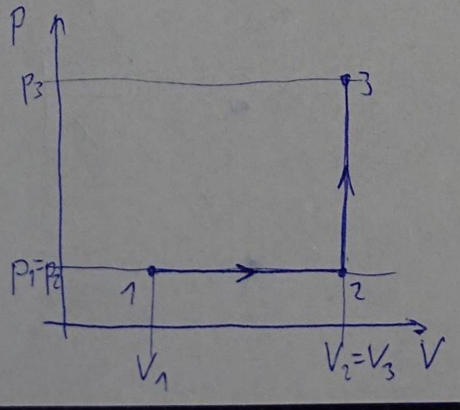
$$= 6{,}4379\,\left[\frac{J}{K}\right]$$

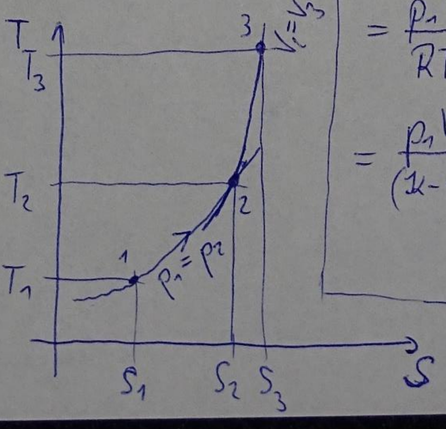
$$W_{13} = \underbrace{W_{12}}_{\text{izobár}} + \underbrace{W_{23}}_{\text{izochor}} = -\int_{V_1}^{V_2} p(V)\,dV - \underbrace{\int_{V_2}^{V_3} p(V)\,dV}_{=0} = -p_1 (V_2 - V_1) = -0{,}5\,[kJ]$$

$$Q_{13} = (U_3 - U_1) - W_{13} = 4{,}25\,[kJ] = c_p m (T_2 - T_1) + c_v m (T_3 - T_2) =$$

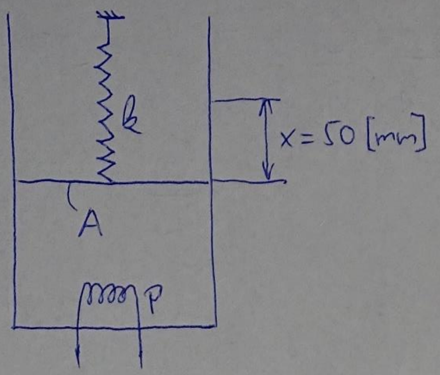
$$= \frac{p_1 V_1}{R T_1}\left[\frac{\kappa R}{\kappa-1}(T_2 - T_1) + \frac{R}{\kappa-1}(T_3 - T_2)\right]$$

$$= \frac{p_1 V_1}{(\kappa-1)T}\left[\kappa (T_2 - T_1) + (T_3 - T_2)\right]$$



4.4.4.




$p_1 = 110\ [kPa]$

$T_1 = 0\ [°C]$

$m = 10\ [g]$

$\varkappa = 1{,}3\ [1]$

$M_{CO_2} = 44\ \left[\frac{kg}{kmol}\right]$

$P = 5\ [W]$

$A = 5\ [cm^2]$

$k = 1\left[\frac{N}{cm}\right]$

$p_0 = 110\ [kPa]$

$p_2$ nyomás a külső nyomás és a rugóerőből származó nyomás összegével van egyensúlyban:

$$p_2 = p_0 + \frac{F_R}{A} = p_0 + \frac{k}{A}x = 120\ [kPa]$$

$$R_{CO_2} = \frac{R}{M_{CO_2}} = 188{,}9636\left[\frac{J}{kg\,K}\right] \qquad V_1 = \frac{m R_{CO_2} T_1}{p_1} = 4{,}6897 \cdot 10^{-3}\ [m^3]$$

$$V_2 = V_1 + xA = 4{,}7147 \cdot 10^{-3}\ [m^3]$$

$$T_2 = T_1 \frac{p_2 V_2}{p_1 V_1} = 299{,}4058\ [K]$$

$$U_2 - U_1 = m c_v (T_2 - T_1) = m \frac{R_{CO_2}}{\varkappa - 1}(T_2 - T_1) = 166{,}3245\ [J]$$

$$H_2 - H_1 = \varkappa (U_2 - U_1) = 216{,}2219\ [J]$$

$$S_2 - S_1 = m\left[c_p \ln\frac{T_2}{T_1} - R_{CO_2} \ln\frac{p_2}{p_1}\right] =$$

$$= m R_{CO_2}\left[\frac{\varkappa}{\varkappa - 1}\ln\frac{T_2}{T_1} - \ln\frac{p_2}{p_1}\right] = 0{,}5916\left[\frac{J}{K}\right]$$

$$W_f = -\int_{V_1}^{V_2} p(V)\,dV$$

$$p(x) = p_0 + \frac{b}{A}x \Rightarrow p(V) = p(x(V)) = \left(p_0 - \frac{bV_1}{A^2}\right) + \frac{b}{A^2}V$$

$$V(x) = V_1 + xA \Rightarrow x(V) = \frac{1}{A}(V - V_1)$$

$$W_f = -\int_{V_1}^{V_2} p(V)\,dV = \left(p_0 - \frac{bV_1}{A^2}\right)(V_1 - V_2) + \frac{b}{2A^2}\underbrace{(V_1^2 - V_2^2)}_{(V_1-V_2)(V_1+V_2)} =$$

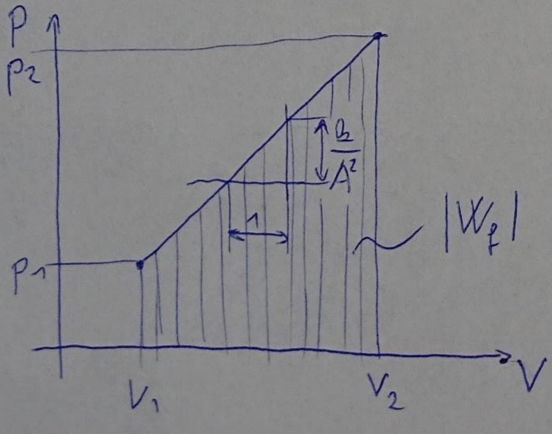
$$= \left[p_0 - \frac{bV_1}{A^2} + \frac{b}{2A^2}(V_1+V_2)\right](V_1 - V_2) =$$

$$= \left[p_0 + \frac{b}{2A^2}(V_2 - V_1)\right](V_1 - V_2) = -2{,}875\ [J]$$

// $b = 1\left[\frac{N}{cm}\right] = 1\left[\frac{N}{10^{-2}m}\right] = \frac{1}{10^{-2}}\left[\frac{N}{m}\right] = 100\left[\frac{N}{m}\right]$ //

$$Q_{12} = (U_2 - U_1) - W_f = 169{,}1995\ [J]$$

$$\tau = \frac{Q_{12}}{P} = 33{,}8399\ [s]$$



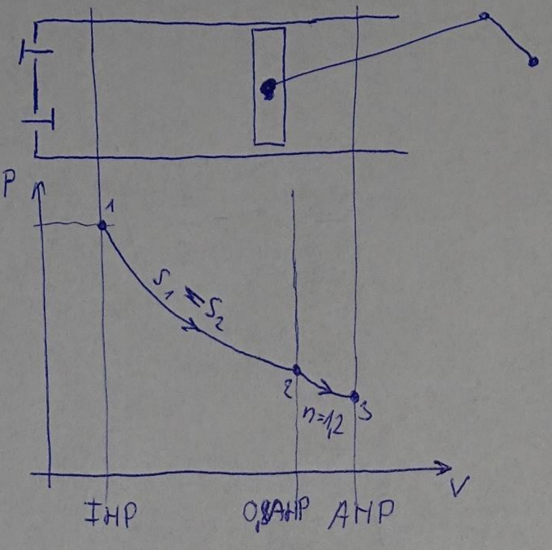

$$|W_f| = \frac{p_1+p_2}{2}(V_2 - V_1) = 2{,}875\ [J]$$

$\downarrow$

mint trapéz területe

előjel: $\ominus \rightarrow$ a gáz tágult, közben munkát végzett

4.4.5.




$V_{FHP} = 300\ [cm^3]$

$\varepsilon = \dfrac{V_{AHP}}{V_{FHP}} = 9{,}5\ [1]$

$V_{AHP} = \varepsilon V_{FHP} = 2850\ [cm^3]$

$T_{FHP} = 2200\ [K]$

$p_{FHP} = 9395\ [kPa]$

$\kappa = 1{,}4\ [1]$

$R = 287 \left[\dfrac{J}{kg\,K}\right]$

$n = 1{,}2\ [1]$

1 → 2: izentropikus expanzió

$$T_2 = T_{FHP}\left(\frac{V_{FHP}}{0{,}8V_{AHP}}\right)^{\kappa-1} = T_{FHP}\left(\frac{1}{0{,}8\varepsilon}\right)^{\kappa-1} = 977{,}4561\ [K]$$

2 → 3: n = 1,2 politropikus expanzió

$$T_3 = T_2\left(\frac{0{,}8V_{AHP}}{V_{AHP}}\right)^{n-1} = T_2 \cdot 0{,}8^{n-1} = 934{,}7926\ [K]$$

$$\frac{p_1 V_{FHP}}{T_{FHP}} = \frac{p_2 V_2}{T_2} \Rightarrow p_2 = p_1 \underbrace{\frac{V_{FHP}}{V_2}}_{} \frac{T_2}{T_{FHP}} = p_1 \frac{1}{0{,}8\varepsilon}\frac{T_2}{T_{FHP}} = \cancel{2782{,}3298}\ \cancel{[kPa]}$$

$$\frac{V_{FHP}}{0{,}8V_{AHP}} = \frac{1}{0{,}8\varepsilon} \qquad = 549{,}2345\ [kPa]$$

$$\frac{p_1 V_{FHP}}{T_{FHP}} = \frac{p_3 V_{AHP}}{T_3} \Rightarrow p_3 = p_1 \frac{V_{FHP}}{V_{AHP}}\frac{T_3}{T_{FHP}} = p_1 \frac{1}{\varepsilon}\frac{T_3}{T_{FHP}} = 420{,}2094\ [kPa]$$

$$Q_{13} = \underbrace{Q_{12}}_{=0} + Q_{23} = Q_{23} = c_n m \left(T_3 - T_2\right) = c_v \frac{n-\kappa}{n-1} \frac{p_1 V_{FHP}}{R T_{FHP}} \left(T_3 - T_2\right) =$$

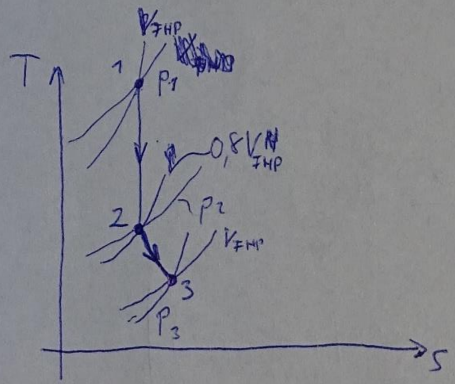
$$= \frac{R}{\kappa - 1} \frac{n-\kappa}{n-1} \frac{p_1 V_{FHP}}{R T_{FHP}} \left(T_3 - T_2\right) = 136,6444 \; [J]$$

$$U_3 - U_1 = c_v m \left(T_3 - T_{FHP}\right) = \frac{p_1 V_1}{\kappa - 1} \left(\frac{T_3}{T_{FHP}} - 1\right) = -4052,2580 \; [J]$$

$$W_f = \left(U_3 - U_1\right) - Q_{13} = -4188,9024 \; [J]$$

máslépp:

$$W_f = -\int_{V_{FHP}}^{0,8V_{AHP}} p(V)\,dV - \int_{0,8V_{AHP}}^{V_{AHP}} p(V)\,dV = \frac{p_1 V_{FHP}}{\kappa-1}\left[\left(\frac{1}{0,8\varepsilon}\right)^{\kappa-1} - 1\right] + \frac{p_2\, 0,8\varepsilon V_{FHP}}{n-1}\left[\underbrace{0,8}_{\left(\frac{0,8V_{AHP}}{V_{AHP}}\right)}{}^{n-1} - 1\right]$$




4.4.6.

$p_1 = 200$ [kPa] $\qquad p_2 = 400$ [kPa] $\qquad M_{CO_2} = 44 \left[\frac{kg}{kmol}\right]$

$T_1 = 20$ [°C] $\qquad T_2 = 140$ [°C] $\qquad c_v = 3615,6 \left[\frac{J}{kg\,K}\right]$

$V_1 = 0,5\,[m^3]$

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

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

$$n = \frac{1}{1 - \frac{\ln\frac{T_2}{T_1}}{\ln\frac{p_2}{p_1}}} = 1,98 \; [1]$$

$$R = \frac{\mathcal{R}}{M} = 188,9636 \left[\frac{J}{kgK}\right]$$

$$c_p = c_v + R = 3804,5636 \left[\frac{J}{kgK}\right] \qquad \kappa = \frac{c_p}{c_v} = 1,0523 \; [1]$$

$$m = \frac{p_1 V_1}{R T_1} = 1,8062 \; [kg]$$

$$Q = c_n m \left(T_2 - T_1\right) = c_v \frac{n-\kappa}{\kappa - 1} m \left(T_2 - T_1\right) = 741,8378 \; [kJ]$$

$$U_2 - U_1 = c_v m \left(T_2 - T_1\right) = 783,6596 \; [kJ]$$

$$W_f = (U_2 - U_1) - Q = 41,8218 \; [kJ]$$

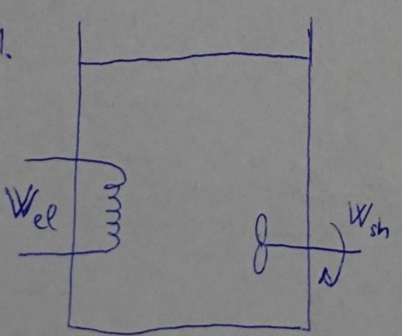
másképpen: $W_f = -\int_{V_1}^{V_2} p(V)\,dV = -\int_{V_1}^{V_2} \frac{p_1 V_1^n}{V^n}\,dV =$

$$= \frac{p_1 V_1^n}{n-1}\left(V_2^{1-n} - V_1^{1-n}\right) = \frac{p_1 V_1}{n-1}\left[\left(\frac{V_1}{V_2}\right)^{n-1} - 1\right] =$$

$$= \frac{m R T_1}{n-1}\left[\frac{T_2}{T_1} - T_1\right] = \frac{m R}{n-1}\left(T_2 - T_1\right)$$

$$S_2 - S_1 = m\left[c_p \ln\frac{T_2}{T_1} - R \ln\frac{p_2}{p_1}\right] = 2122,3427 \left[\frac{J}{K}\right]$$

4.5.1.




$V_1 = 5$ [l] $\qquad I = 8$ [A]

$p = 175$ [kPa] = konst $\qquad \tau = 45$ [min]

$W_{sh} = 400$ [kJ]

$V_1 \rightarrow$ telített folyadék $\rightsquigarrow$ víz

$p_{sat} = 175$ [kPa] $\rightarrow T_{sat} = 116,041$ [°C]

$v' = 0{,}0010 5679 \left[\frac{m^3}{kg}\right]$ $\qquad m = \frac{V}{v'} = 4{,}7313 \; [kg]$

$v'' = 1{,}00365 \left[\frac{m^3}{kg}\right]$

folyadék fele elgőzölög : $\quad x_2 = 0{,}5 \; [1]$

$$v_2 = (1-x_2)\,v' + x_2 v'' = 0{,}502353 \left[\frac{m^3}{kg}\right]$$

$$W_f = -m \int_{v_1}^{v_2} p\,dv \underset{p=\text{konst}}{=} -mp\,(v_2 - v') = -415{,}0620 \; [kJ]$$

$h' = 486{,}97 \left[\frac{kJ}{kg}\right]$ $\qquad u' = h' - pv' = 486{,}7851 \left[\frac{kJ}{kg}\right]$

$h'' = 2700{,}13 \left[\frac{kJ}{kg}\right]$ $\qquad u'' = h'' - pv'' = 2524{,}4913 \left[\frac{kJ}{kg}\right]$

$$u_2 = (1-x_2)\,u' + x_2 u'' = 1505{,}6382 \left[\frac{kJ}{kg}\right]$$

1. főtétel:

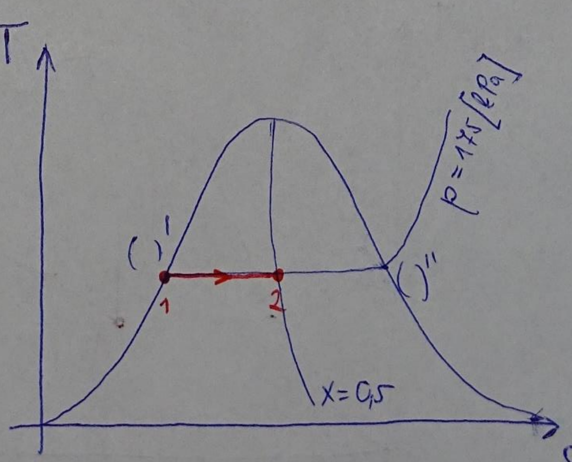
$$U_2 - U_1 = \underbrace{Q}_{W_{el}} + W_f + W_{sh} \Rightarrow$$

$$\Rightarrow Q = m\,(u_2 - u') - W_f - W_{sh} = 4835{,}5617 \; [kJ]$$

$$P_{el} = \frac{Q}{\tau} = 1{,}79 \; [kW]$$

$$P_{el} = UI \Rightarrow U = \frac{P_{el}}{I} = $$

$$= 223{,}8686 \; [V]$$



4.5.2. $p_1 = 1\ [bar]$ $\quad p_2 = 3\ [bar]$

$V = 100\ [dm^3]$ $\quad m = 0{,}1\ [kg]$

$Q = 50\ [kJ]$

$h_1' = 189\ \left[\frac{kJ}{kg}\right]$ $\quad h_1'' = 1300\ \left[\frac{kJ}{kg}\right]$

merevfalú tartály $\Rightarrow$ izochor folyamat: $v_1 = v_2 = v = \frac{V}{m} = 0{,}1\ \left[\frac{m^3}{kg}\right]$

első főtétel: $H_2 - H_1 = Q + \underbrace{W_t}_{\int_{p_1}^{p_2} V(p)\,dp \underset{V=\text{konst}}{=} V(p_2-p_1)} \Rightarrow$

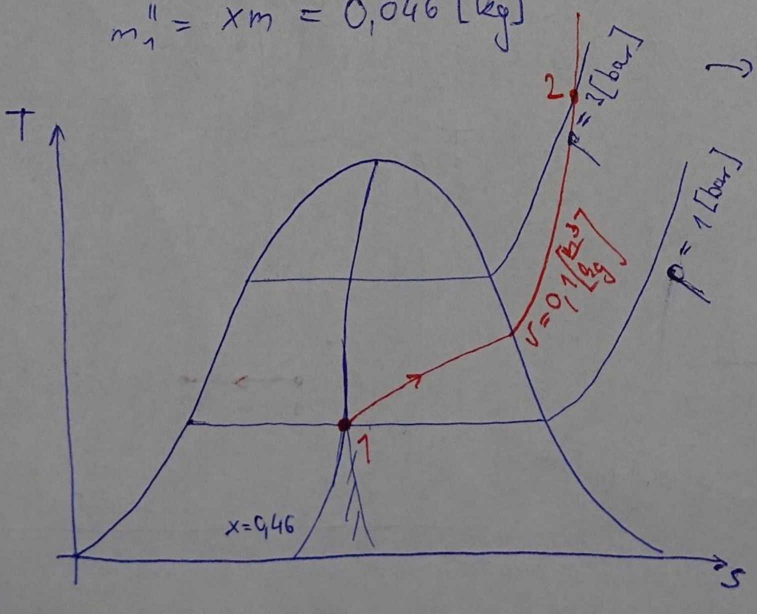
$$\Rightarrow H_1 = H_2 - Q - V(p_2-p_1) = 70\ [kJ] \Rightarrow h_1 = \frac{H_1}{m} = 700\ \left[\frac{kJ}{kg}\right]$$

$$\Rightarrow h_1 = (1-x_1)h_1' + x_1 h_1'' = h_1' + x_1(h_1'' - h_1') \Rightarrow$$

$$\Rightarrow x_1 = \frac{h_1 - h_1'}{h_1'' - h_1'} = 0{,}4599\ [1]$$

$m_1' = (1-x_1)m = 0{,}054\ [kg]$

$m_1'' = xm = 0{,}046\ [kg]$




→ 2-es pont a túlhevített gőz tartomány

(pl. T-s diagramról leolvasva)

4.5.3. $p_1 = 5$ [MPa] $\quad V = \text{konst}$

$T_1 = 300$ [°C]

$T_2 = 150$ [°C]

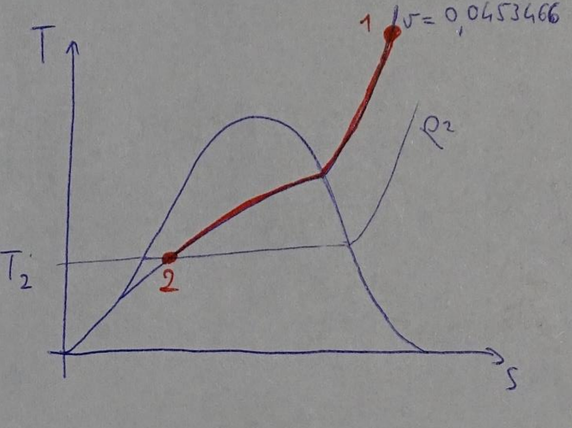
első főtétel:

$$U_2 - U_1 = Q + W_f \Longrightarrow q = u_2 - u_1 = h_2 - h_1 - v(p_2 - p_1)$$

$$\hookrightarrow = -\int_{V_1}^{V_2} p(V)\,dV = 0 \quad (V = \text{konst})$$

$$v(p = 5\,[\text{MPa}],\ T = 300\,[°\text{C}]) = 0{,}0453466 \left[\frac{m^3}{kg}\right]$$

$$h_1 = 2925{,}64 \left[\frac{kJ}{kg}\right] \rightsquigarrow u_1 = h_1 - p_1 v = 2698{,}907 \left[\frac{kJ}{kg}\right]$$




$$p_2 = p_{sat}(T_2) = 0{,}476101\ [\text{MPa}]$$

$$v'(p_2, T_2) = 0{,}0010905 \left[\frac{m^3}{kg}\right]$$

$$v''(p_2, T_2) = 0{,}392503 \left[\frac{m^3}{kg}\right]$$

$$h'(p_2, T_2) = 632{,}252 \left[\frac{kJ}{kg}\right]$$

$$h''(p_2, T_2) = 2745{,}92 \left[\frac{kJ}{kg}\right]$$

$$v = (1-x)v' + xv'' \Longrightarrow x = \frac{v - v'}{v'' - v'} = 0{,}1131\ [1]$$

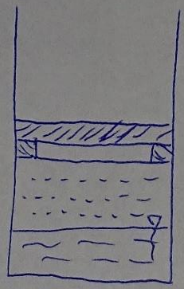
$$h_2 = (1-x)h' + xh'' = 871{,}3079 \left[\frac{kJ}{kg}\right]$$

$$u_2 = h_2 - p_2 v = 849{,}7183 \left[\frac{kJ}{kg}\right]$$

$$q = u_2 - u_1 = -1849{,}1887 \left[\frac{kJ}{kg}\right]$$

↳ el kell venni ezt a hőmennyiséget

4.5.4.



$m = 5\,[kg]$ $\qquad m_1' = 2\,[kg]$

$p_1 = 125\,[kPa]$ $\qquad m_1'' = m - m_1' = 3\,[kg]$

$p_2 = 300\,[kPa]$

$V_2 = 1{,}2\,V_1$

$p_1 - p_2$ között: izochor hőközlés, ezután $V_1 - V_2$ között izobár hőközlés

$$x_1 = \frac{m_1''}{m} = 0{,}6\,[1]$$

$$T_{sat}(p_1) = 105{,}966\,[°C] \rightarrow v_1' = 0{,}00104823\,\left[\frac{m^3}{kg}\right]$$

$$v_1'' = 1{,}37494\,\left[\frac{m^3}{kg}\right]$$

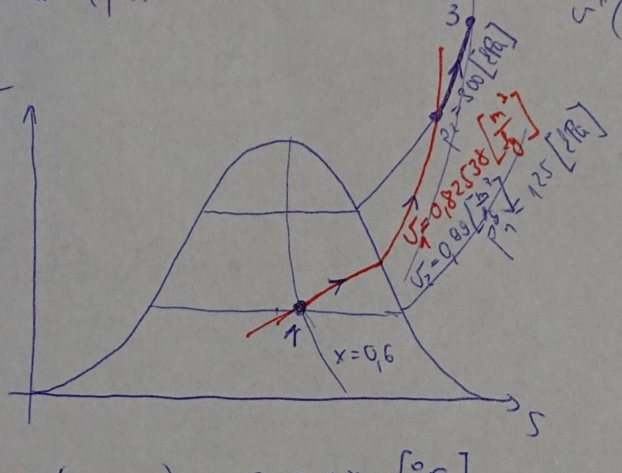
$$v_1 = (1-x)v_1' + x v_1'' = 0{,}82538\,\left[\frac{m^3}{kg}\right] = \text{konst}$$

$$T_{sat}(p_2) = 133{,}525\,[°C] \rightarrow v'(p_2, T_{sat}(p_2)) = 0{,}00107318\,\left[\frac{m^3}{kg}\right]$$

$$v''(p_2, T_{sat}(p_2)) = 0{,}605785\,\left[\frac{m^3}{kg}\right]$$

$$\downarrow$$

$v'' < v_1 \Rightarrow$ ki kell lépni a kétfázisú mezőből




$$T_2(p_2, v_1) = 268{,}275\,[°C]$$

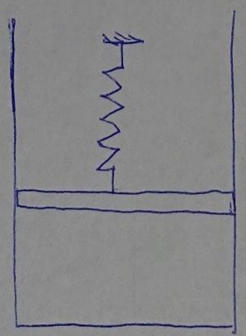
$$V_2 = 1{,}2\,V_1 \underset{m = \text{konst}}{\Longrightarrow} v_2 = 1{,}2\,v_1 = 0{,}990456\,\left[\frac{m^3}{kg}\right]$$

$$T_3(p_2, v_2) = 373{,}6135\,[°C]$$

$$h(p_2, T_3) = 3220{,}66\,\left[\frac{kJ}{kg}\right]$$

$$W_f = \underbrace{W_{12}}_{=0\ /\text{izochor}/} + W_{23} = -\int_{V_A}^{V_B} p(V)\,dV = -pm(v_2 - v_1) = -247{,}614\ [kJ]$$

4.5.5.

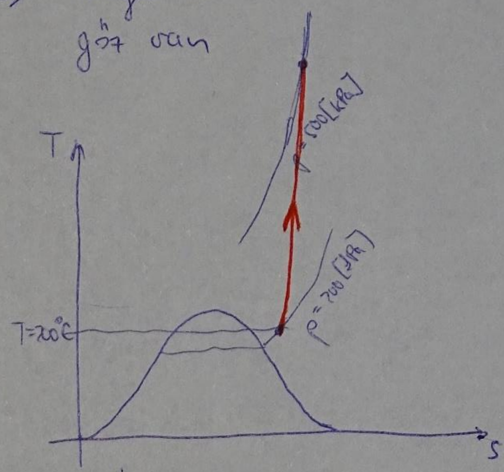


$V_1 = 0{,}5\ [m^3]$ $\quad V_2 = 0{,}6\ [m^3]$

$p_1 = 200\ [kPa]$ $\quad p_2 = 500\ [kPa]$

$T_1 = 200\ [°C]$

$T_{sat}(p_1) = 120{,}212\ [°C] < T_1 \Rightarrow$ hengerben túlhevített gőz van




↓ pontos lefutás meghatározása ebből nehézkes

$v_1(T_1, p_1) = 1{,}08052\ \left[\frac{m^3}{kg}\right]$

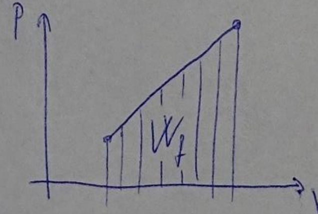
$m = \frac{V_1}{v_1} = 0{,}4627\ [kg]$

$v_2 = \frac{V_2}{m} = 1{,}2967\ \left[\frac{m^3}{kg}\right]$

$T_2(p_2, v_2) = 1131{,}8\ [°C]$

$p(x) = p_1 + \frac{k}{A}x \rightsquigarrow p(V) = p_1 + cV$

↳ tetszőleges konstans




$|W_f| = \frac{p_1 + p_2}{2}(V_2 - V_1) = 35\ [kJ]$

előjel: ⊖ → gáz tágult, ezáltal munkát végzett

$h_1(p_1, T_1) = 2870{,}78\ \left[\frac{kJ}{kg}\right]$ $\qquad u_1 = h_1 - p_1 v_1 = 2654{,}678\ \left[\frac{kJ}{kg}\right]$

$h_2(p_2, T_2) = 4973{,}67\ \left[\frac{kJ}{kg}\right]$ $\qquad u_2 = h_2 - p_2 v_2 = 4325{,}32\ \left[\frac{kJ}{kg}\right]$

$Q = m(u_2 - u_1) - W_f = 808{,}0061\ [kJ]$