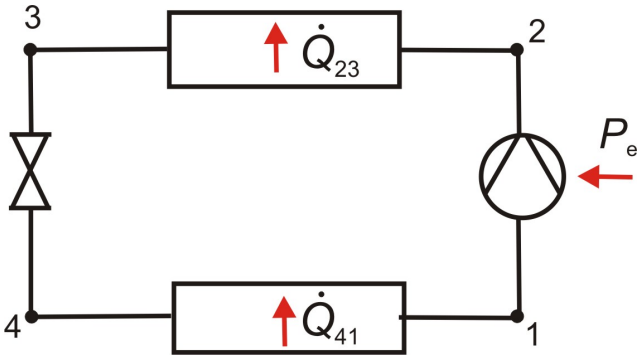
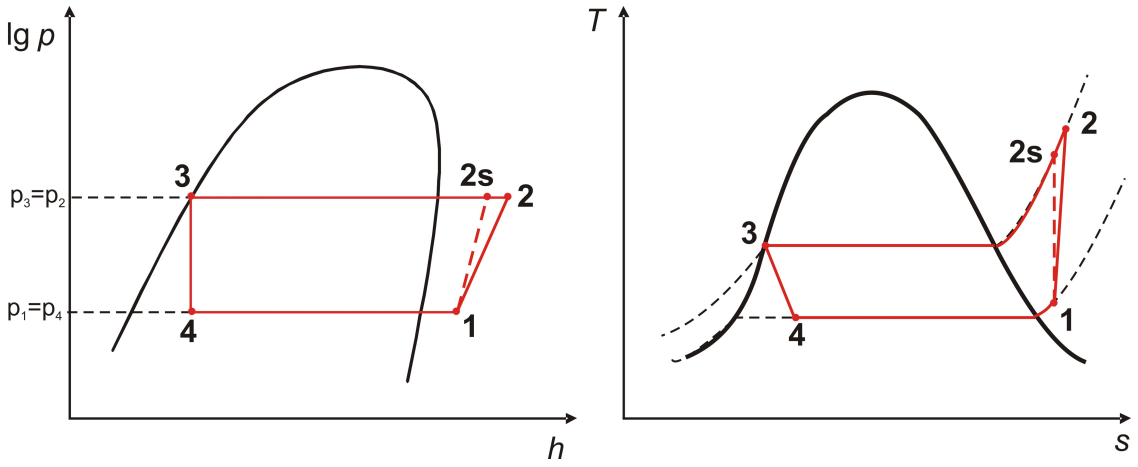
Musterlösung Aufgabe 1: «Kältemaschine»

I. TEILAUFGABE A) ⇒ 1 PUNKT



II. TEILAUFGABE B) ⇒ 4 PUNKTE



III. TEILAUFGABE C) ⇒ 1 PUNKTE

$p = p_s(-45°C) = 0,3912\ bar$

IV. TEILAUFGABE D) ⇒ 3 PUNKTE

$P_{el} = \dot{m}_{KM} \cdot \Delta h_{12}$

$h_2 = h_3 + \Delta h_{23}$

$h_3 = h_4 = 0,3 \cdot (h''(-45°C) - h'(-45°C)) + h'(-45°C)$

$= 0,3 \cdot (370,83 - 141,89)\ \frac{kJ}{kg} + 141,89\ \frac{kJ}{kg} = 141,89\ \frac{kJ}{kg} + 0,3 \cdot 228,94\ \frac{kJ}{kg} = 210,57\ \frac{kJ}{kg}$

$h_2 = 210,57\ \frac{kJ}{kg} + 212,93\ \frac{kJ}{kg} = 423,5\ \frac{kJ}{kg}$

$h_1 = 374{,}51\ \frac{kJ}{kg}$

$\Delta h_{12} = (423,5 - 374,51)\ \frac{kJ}{kg} = 48,99\ \frac{kJ}{kg}$

$P_{el} = 2,5\ \frac{kg}{s} \cdot 48,99\ \frac{kJ}{kg} = 122,48\ kW$

V. TEILAUFGABE E) $\Rightarrow$ 4 PUNKTE

$\varepsilon = \frac{q_0}{w_t}$ $\qquad w_t = \Delta h_{12} = 48,99\ \frac{kJ}{kg}$

$q_0 = \Delta h_{41} \cdot (h_1 - h_4) = (374,51 - 210,57)\ \frac{kJ}{kg} = 163,94\ \frac{kJ}{kg}$

$\varepsilon = \frac{163,94}{48,99} = 3,346$

$\eta_{ex} = \frac{e_{q_0}}{w_t}$ $\qquad e_{q_0} = \left(1 - \frac{T_a}{T_m}\right) \cdot q_0$

$T_m = \frac{\Delta h_{41}}{\Delta s_{41}}$ $\qquad \Delta h_{41} = 163,94\ \frac{kJ}{kg}$

$\Delta s_{41} = s_1 - s_4$ $\qquad s_1 = 1,7880\ \frac{kJ}{kgK}$

$s_4 = s' + 0,3 \cdot (s'' - s') = [0,76852 + 0,3 \cdot (1,7720 - 0,76852)]\ \frac{kJ}{kgK} = 1,069564\ \frac{kJ}{kgK}$

$\Rightarrow \Delta s_{41} = 0,718436\ \frac{kJ}{kgK}$ $\qquad T_m = \frac{163,94}{0,718436}\ K = 228,19\ K$

$|e_{q_0}| = (1 - \frac{273,15}{228,19}) \cdot 163,94\ \frac{kJ}{kg} = 32,2\ \frac{kJ}{kg}$

$\eta_{ex} = \frac{32,3}{48,99} = 0,6593 = 65,93\ \%$

VI. TEILAUFGABE F) $\Rightarrow$ 2 PUNKTE

$e_v = T_a \cdot \frac{T_{m,M} - T_{m,KM}}{T_{m,M} \cdot T_{m,KM}} \cdot q_0$

$= 273,15\ K \cdot \frac{238,15 - 228,19}{238,15 \cdot 228,19} \cdot 163,94\ \frac{kJ}{kg} = 8,207\ \frac{kJ}{kg}$

$\dot{E}_v = 8,207\ \frac{kJ}{kg} \cdot 2,5\ \frac{kg}{s} = 20,52\ kW$

Musterlösung Aufgabe 2: ≪Wärmerückgewinnung - Passivhaus≫

I. TEILAUFGABE A) $\Rightarrow$ 3 PUNKTE

$$\dot{m}_L = \frac{\dot{V}}{v_{1+x}}$$

$$v_{1+x} = \frac{R_L \cdot T}{p} + x \cdot \frac{R_D \cdot T}{p} = \frac{R_m \cdot T}{p}\left(\frac{1}{M_L} + \frac{x}{M_D}\right)$$

$$x_1 = \frac{M_D}{M_L} \cdot \frac{p_D}{p_{ges} - p_D}$$

$$p_{DS} = exp\left(18,8314 - \frac{3964,8072}{20 + 232,8977}\right) = 23,427\ mbar$$

$$x_1 = 0,622 \cdot \frac{23,427 \cdot 0,5}{1000 - 23,427 \cdot 0,5} = 0,00737$$

$$v_{1+x} = 0,85161\ \frac{m^3}{kg}$$

$$\Rightarrow \dot{m}_L = \frac{60\frac{m^3}{h}}{0,85161\frac{m^3}{kg}} = 70,455\frac{kg}{h} = 0,01957\frac{kg}{s}$$

II. TEILAUFGABE B) $\Rightarrow$ 8 PUNKTE

Bilanz: $h_{1+x,1} + h_{1+x,2} - h_{1+x,ab} - h_{1+x,3} = 0$

$$h_{1+x,1} = c_{p,L} \cdot t_1 + x_1 \cdot (r_0 + c_{p,D} \cdot t_1)$$

$$= (1,007 \cdot 20)\ \frac{kJ}{kg} + 0,007372 \cdot (2500 + 1,86 \cdot 20)\ \frac{kJ}{kg} = 38,784\ \frac{kJ}{kg}$$

$$p_{D,s,ab} = \exp\left(18,8314 - \frac{3964,8072}{5 + 232,8977}\right) = 8,718\ mbar$$

$$x_{s,ab} = 0,622 \cdot \frac{p_{D,s,ab} \cdot 1}{p - p_{D,s,ab}} = 0,00547 \qquad \Rightarrow \dot{m}_{Kond}\ ?\ \text{Ja! da } x_{s,ab} < x_1$$

$$h_{1+x,ab} = c_{p,L} \cdot t_{ab} + x_{s,ab} \cdot (r_0 + c_{p,D} \cdot t_{s,ab}) + (x_1 - x_{s,ab}) \cdot c_{p,w} \cdot t_{ab}$$

$$= (1,007 \cdot 5)\ \frac{kJ}{kg} + 0,00547 \cdot (2500 + 1,86 \cdot 5)\ \frac{kJ}{kg} + (0,007372 - 0,00547) \cdot (4,19 \cdot 5)\frac{kJ}{kg} = 18,8\ \frac{kJ}{kg}$$

$$p_{D,s,2} = 3,999\ mbar \qquad p_{D,2} = p_{D,s,2} \cdot \phi \qquad x_2 = 0,000747$$

$$h_{1+x,2} = (1,007 \cdot (-5))\ \frac{kJ}{kg} + 0,000747 \cdot (2500 + 1,86 \cdot (-5))\ \frac{kJ}{kg} = -3,17\ \frac{kJ}{kg}$$

$$h_{1+x,3} = h_{1+x,1} + h1 + x,2 - h_{1+x,ab} = (38,784 - 3,17 - 18,8)\ \frac{kJ}{kg} = 16,814\ \frac{kJ}{kg}$$

$$t_3 = \frac{h_{1+x,3} - x_3 \cdot r_0}{c_{p,L} + x_3 \cdot c_{p,D}} = 14,822^{\circ}C$$

III. TEILAUFGABE C) ⇒ 5 PUNKTE

$x_4 = x_3 = x_2$

$\dot{m}_{L,4} \cdot x_4 + \dot{m}_w = \dot{m}_{L,5} \cdot x_5 \qquad \dot{m}_{L,5} = \dot{m}_{L,4}$

$\dot{m}_w = \dot{m}_L \cdot (x_5 - x_4) \qquad x_5 = x_1$

$\dot{m}_w = 0,01957 \ \frac{kg}{s}(0,00737 - 0,000747) = 0,0001296 \ \frac{kg}{s} = 0,4666 \ \frac{kg}{h}$ 0,5 P

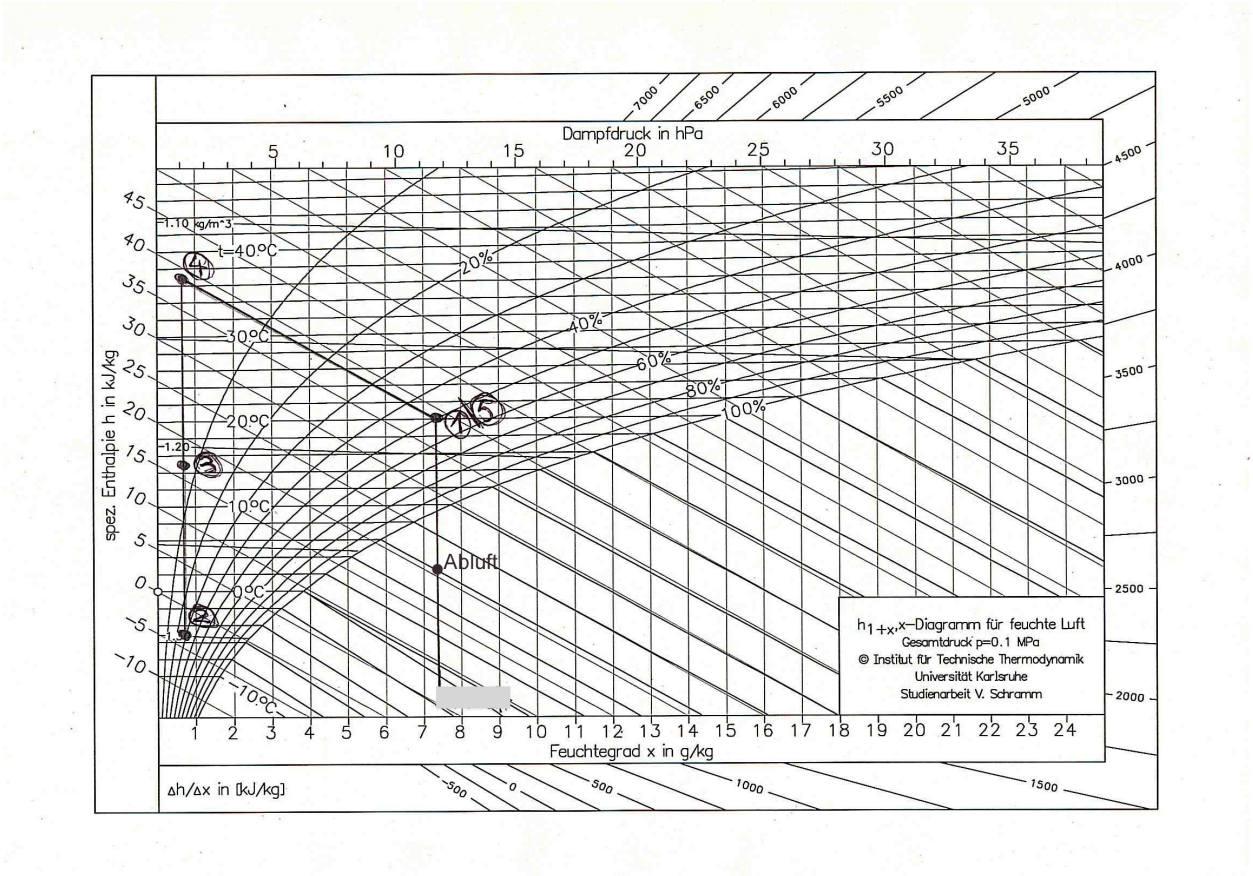
$h_{1+x,4} + h_w \cdot \Delta x = h_{1+x,5} \qquad h_{1+x,5} = h_{1+x,1}$

$h_w = c_{p,H2O,fl} \cdot t_w = 4,19 \cdot 10 = 41,9 \ \frac{kJ}{kg}$

$\Rightarrow h_{1+x,4} = h_{1+x,5} - \Delta x \cdot h_w = 38,784 \ \frac{kJ}{kg} - (0,00737 - 0,000747 = \cdot 41,9 \frac{kJ}{kg} = 38,506 \frac{kJ}{kg}$

$t_4 = \frac{h_{1+x,4} - x_4 \cdot r_0}{c_{p,L} + x_4 \cdot c_{p,D}} = \frac{38,506 \ \frac{kJ}{kg} - 0,000747 \cdot 2500 \ \frac{kJ}{kg}}{1,007 \ \frac{kJ}{kgK} + 0,000747 \cdot 1,86 \ \frac{kJ}{kgK}} = 36,33°C$

IV. TEILAUFGABE D) ⇒ 4 PUNKTE



Musterlösung Aufgabe 3: ≪Reaktion - Flüssigtreibstoff≫

I. TEILAUFGABE A) ⇒ 5 PUNKTE

$2N_2H_4 + N_2O_4 \rightarrow 4H_2O + 3N_2$

$\dot{Q} = 0 = \Delta^R h = \Delta^R h^{\Theta} + \sum_{E,P} \nu_i c_{p_i}(T_i - T_{Theta}) = \sum \nu_i \Delta^B h_{\Theta,i} + \sum_P c_{p_i} \cdot \nu_i \cdot (T_{ad,V} - T_{\Theta})$

$T_{ad,V} = T_{\Theta} - \frac{\sum_i \nu_i \Delta^B h_{\Theta,i}}{\sum_P \nu_i c_{p_i}} = 298\ K - \frac{-1076,411 \frac{kJ}{molFU}}{0,2548 \frac{kJ}{molFU \cdot K}} = 4522,5\ K$

$\Delta^R h_{\Theta} = \sum \nu_i \Delta^B h_{\Theta,i} = -2 \cdot 50,2 - 1 \cdot 9,611 + 4 \cdot (-241,6) + 3 \cdot 0 = -1076,411 \frac{kJ}{molFU}$

$\sum_P \nu_i c_{p_i} = (4 \cdot 38,95 + 3 \cdot 33,0) \frac{J}{molK} = 254,8 \frac{J}{molK}$

II. TEILAUFGABE B) ⇒ 5 PUNKTE

$2N_2H_4 + N_2O_4 \rightarrow 0,95 \cdot 4H_2O + 0,05 \cdot (8H + 4O) + 3N_2 = 3,8H_2O + 0,4H + 0,2O + 3N_2$

$\Delta^R h_{Theta} = (-2 \cdot 50,2 - 1 \cdot 9,11 + 3,8 \cdot (-241,6) + 3 \cdot 0 + 0,4 \cdot 218 + 0,2 \cdot 249) \frac{kJ}{molFU}$

$= -891,091 \frac{kJ}{mol}$

$\sum_P \nu_i c_{p_i} = (3,8 \cdot 38,95 + 3 \cdot 33 + 0,4 \cdot 20,78 + 0,2 \cdot 20,78) \frac{J}{molFU \cdot K}$

$= -259,478 \frac{J}{molFU \cdot K}$

$T_{ad,V} = \left(298 - \frac{-891,091}{0,259478}\right)\ K = 3732,2\ K$

III. TEILAUFGABE C) ⇒ 5 PUNKTE

$2N_2H_4 + N_2O_4 + 2H_2O_{(l)} \rightarrow 6H_2O_{(g)} + 3N_2$

$\Delta^R h_{\Theta} = (-2 \cdot 50,2 - 1 \cdot 9,11 - 2 \cdot (-285,6) + 6 \cdot (241,6) + 3 \cdot 0)\ \frac{kJ}{molFU}$

$= -988,411\ \frac{kJ}{molFU}$

$\Delta^B h_{\Theta,W,(l)} = \Delta^B h_{\Theta,W,g} - \Delta h_{V,W} = (-241,6 - 44)\ \frac{kJ}{mol} = -285,6\ \frac{kJ}{mol}$

$\sum_p \nu_i c_{p_i} = (6 \cdot 38,95 + 3 \cdot 33)\ \frac{J}{molFU \cdot K} = 332,7\ \frac{J}{molFU \cdot K}$

$T_{ad,V} = (298 - \frac{-988,411}{0,3327}\ K = 3268,9\ K$

$p = n \cdot R \cdot \frac{T}{V}$ alle Gase = ideale Gase

$\frac{p_{(c)}}{p_{(a)}} = \frac{n_{(c)} \cdot T_{(c)}}{n_{(a)} \cdot T_{(a)}} = \left(\frac{7 \cdot 4522,5}{9 \cdot 3268,9}\right)^{-1} = 1,076^{-1} = 0,9293$

Der Druck fällt um höchstens 7,06% , da in a) die maximale Temperatur (4522 K) nicht erreicht wird.