Aufgabe 1

a) Energiebilanz stationärer Fliessprozess:

$$0 = \dot{m}\,(h_{ein} - h_{aus}) + \dot{Q}_R - \dot{Q}_{aus} - \cancel{\dot{W}_t}^{\,0}$$

$$\dot{Q}_{aus} = \dot{m}(h_{ein} - h_{aus}) + \dot{Q}_R$$

$h_f(100°C) = 419.04\ kJ/kg$

TAB A-2: $h_f(70°C) = 292.98\ kJ/kg$

$h_g(100°C) = 2676.0\ kJ/kg$

$h_{aus} = h_f + x_D(h_g - h_f) = 430.329\ kJ/kg$

$$\dot{Q}_{aus} = 62.182\,kW$$

b) $$\overline{T} = \frac{\int_e^a T\,ds}{s_a - s_e} = \frac{h_a - h_e}{s_a - s_e} = \frac{c^{if}(T_{aus} - T_{ein}) + \cancel{v(p_2 - p_1)}^{\,0}}{c^{if}\left(\ln\left(\frac{T_{aus}}{T_{ein}}\right)\right)}$$

$$= \frac{298.15K - 288.15K}{\ln\left(\frac{298.15K}{288.15K}\right)} = \underline{293.12\,K} = T_{KF}$$

c) Serz in Wand:

$\dot{Q}_{aus}$ ↑ 293.12 K

↑ 100°C

$\dot{Q}_{aus}$

Entropiebilanz st. Fliessprozess:

$$0 = \dot{m}\cancel{(s_e - s_2)}^{\,0} + \frac{-\dot{Q}_{aus}}{T_{KF}} + \frac{\dot{Q}_{aus}}{T_{Reaktor,1}} + \dot{S}_{erz}$$

$$\dot{S}_{erz} = \dot{Q}_{aus}\left(\frac{1}{T_{KF}} - \frac{1}{T_{Reaktor}}\right) =$$

$$= 53.91\ \frac{W}{K}$$

d) Energiebilanz halboffenes System:

$$\Delta E = m_2 \cdot u_2 - m_1 \cdot u_1 = \Delta m_{12} \cdot h_{12} + \cancel{Q_{R12}}^{0} - Q_{aus} - \cancel{W}^{0}$$

$$m_2 = m_{ges,1} + \Delta m_{12} \qquad m_1 = m_{ges,1}$$

TAB A2: $u_2 = u_f(70°C) = 292.95 \frac{kJ}{kg}$

~~u_{12}~~ $u_f(100°C) = 418.94 \frac{kJ}{kg}$ $\quad u_g(100°C) = 2506.5 \frac{kJ}{kg}$

$h_{12} = h_f(20°C) = 83.96 \frac{kJ}{kg}$ $\quad \hookrightarrow u_1 = u_f + x_D(u_g - u_f)$

$= 429.36 \frac{kJ}{kg}$

$$\Rightarrow \quad (m_1 + \Delta m_{12}) \cdot u_2 - m_1 \cdot u_1 = \Delta m_{12} \cdot h_2$$

$$\Delta m_{12} \cdot (u_2 - h_2) = m_1 u_1 - m_1 u_2$$

$$\Delta m_{12} = \frac{m_1 u_1 - m_1 u_2}{u_2 - h_2}$$

~~1306.9 kg~~ $= 3756.43 kg$

e) $\Delta S = m_2 s_2 - m_1 s_1$

$= (m_1 + \Delta m_{12}) \cdot s_2 - m_1 \cdot s_1$

$\Delta S_{12} = 1387.22 \frac{\cancel{kg}\ kJ}{K}$

TAB A2:

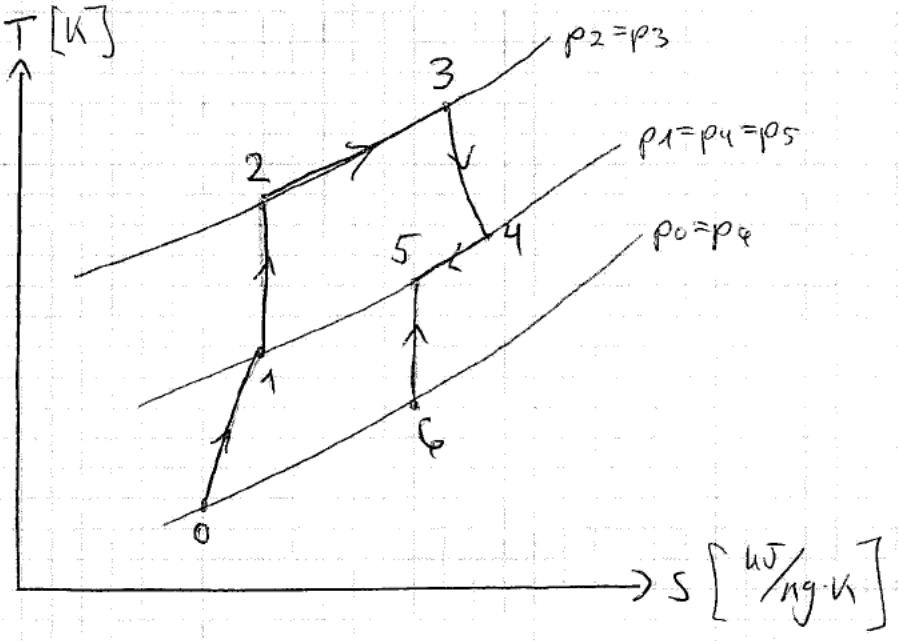
$s_2 = s_f(70°C) = 0.9549 \frac{kJ}{kg \cdot K}$

$s_1 = s_f(100°C) + x_D(s_g(100°C) - s_f(100°C))$

$1.3069 \frac{kJ}{kg \cdot K}$ $\qquad 7.3549 \frac{kJ}{kg \cdot K}$

$s_1 = 1.33714 \frac{kJ}{kg \cdot K}$

2a)



b) Geschwindigkeit:

Energiebilanz Schubdüse: stationärer Fliessprotess

$$0 = \dot{m}_{ges}\left(h_5 - h_6 + \frac{w_5^2 - w_6^2}{2}\right)$$

$$0 = c_p\left(T_5 - T_6\right) + \frac{w_5^2 - w_6^2}{2}$$

$$T_6 = T_5 + \frac{w_5^2 - w_6^2}{2c_p}$$

$\frac{\dot{m}_m}{\dot{m}_k} = 5.293$ $\quad \dot{m}_{ges} = \dot{m}_m + \dot{m}_k$

$\dot{m}_{ges} = 6.293\,\dot{m}_k$

$\hookrightarrow \dot{m}_k = 0.159\,\dot{m}_{ges}$

Energiebilanz Gesamtsystem:

$$0 = \dot{m}_{ges}\left(h_0 - h_6 + \frac{w_{luft}^2 - w_6^2}{2}\right) + q_B \cdot \dot{m}_k$$

$$0 = h_0 - h_6 + \frac{w_{luft}^2 - w_6^2}{2} + 0.159 \cdot q_B$$

$$= c_p\left(T_0 - T_6\right) + \frac{w_{luft}^2 - w_6^2}{2} + 0.159\,q_B$$

... 2 Gleichungen nach T_6 & w_6 auflösen

$$0 = c_p\left(T_0 - T_5 - \frac{w_5^2 - w_6^2}{2c_p}\right) + \frac{w_{luft}^2 - w_6^2}{2} + 0.159\,q_B$$

c)

$$\Delta e_{x,str} = \left(h_6 - h_0 - T_0 (s_6 - s_0) \overset{\nearrow}{\not{+}} \Delta u_e\right)$$

$$= c_p (T_6 - T_0) - T_0 \left(c_p \cdot \ln\left(\frac{T_6}{T_0}\right)\right) + \frac{w_6^2 - w_0^2}{2}$$

$$= 110.065 \frac{kJ}{kg}$$

d) Exergiebilanz stationärer Fliessprozess:

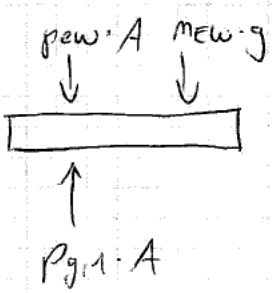
$$0 = \dot{m} \cdot -\Delta e_{x,str} + \left(1 - \frac{T_0}{T}\right) \cdot \dot{Q} \; \overset{\text{netto } 0}{\cancel{-\dot{W}_{t,in}}} \; - \dot{E}_{x,verl}$$

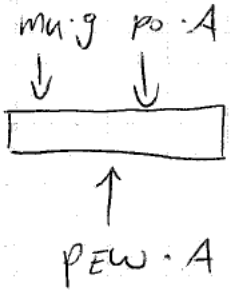
$$e_{x,verl} = -\Delta e_{x,str} + \left(1 - \frac{T_0}{T_B}\right) \cdot q_B$$

$$= -100 \frac{kJ}{kg} + \left(1 - \frac{243K}{1289K}\right) \cdot 1195 \, kJ/kg$$

$$e_{x,verl} = 869.72 \, kJ/kg$$

3a)





$$p_{g,1} = p_{EW} + \frac{m_{EW} \cdot g}{A}$$

$$= \underline{\underline{1.4\ bar}}$$

$$p_{EW} = p_0 + \frac{m_K \cdot g}{A} = 1.4\ bar$$

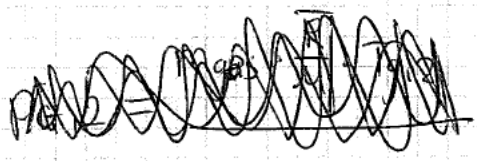
$A = \left(\frac{D}{2}\right)^2 \pi$

$$m_{gas} = \frac{p_{g,1} \cdot V_{g,1}}{\frac{R}{M} \cdot T_{g,1}} = \underline{\underline{3.4224\ g}}$$

b) $T_{g,2} = T_{EW,1} = 0\,°C$ → das Eis-Wasser-Gemisch ändert durch den Wärmestrom seine Temperatur nicht, da es bereits im fest-flüssigen Gebiet ist

→ isotherm

⇒ im GGW haben Gas & Eis die gleiche Temperatur



$p_{g2} = p_{g1} = 1.4\ bar$

Druck bleibt gleich, weil sich am Kräftegleichgewicht nichts ändert, nur weil Wärme übertragen wurde (s. Aufgabe 2))

c) Energiebilanz Geschlossenes System (GzS):

$$\Delta E = Q_{12} - W_{v12}$$

$$m_{gas} \cdot c_v \cdot (T_{2,g} - T_{1,g}) = Q_{12} - \int_{V_1}^{V_2} p \, dV$$

$$V_2 = \frac{m_{gas} \cdot \frac{R}{M} \cdot T_{2,g}}{p_{2,g}} = 0.00111\,m^3$$

$$Q_{12} = m_{gas} \cdot c_v (T_{g,2} - T_{g,1}) + p_{2,g} (V_2 - V_1)$$

$$= -1.0832\,kJ + 1114.4\,J$$

$$= 31.21\,J \quad ? \text{ (sollte < 0 sein)}$$

d) $|Q_{12}| = 1500\,J$

Energiebilanz gesch. System (Eiswasser):

$$\Delta E = m_{EW} (u_2 - u_1) = Q_{12}$$

$$u_1 = u_{flüssig}(0°C) + x_{Eis} (u_{fest}(0°C) - u_{flüssig}(0°C))$$

$-0.045\,kJ/kg$ $\qquad$ $-333.458\,kJ/kg$

$$= -200.0928$$

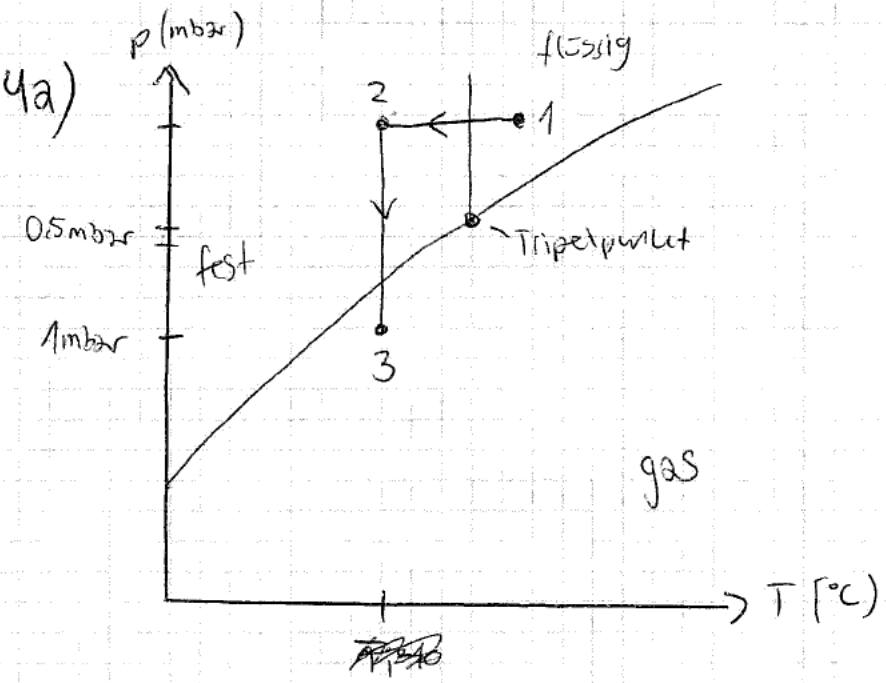
$$u_2 = u_{fl}(0°C) + x_{Eis,2} (u_{fest} - u_{flüssig})$$

$$\Rightarrow \frac{Q_{12}}{m_{EW}} + u_1 = u_{fl} + x_2 (u_f - u_{fl})$$

$$\frac{\frac{Q_{12}}{m_{EW}} + u_1 - u_{fl}}{u_f - u_{fl}} = x_2 = 0.555$$

[redacted]

4a)



b) Kühlmittel: $T_i - 6K$

$p_i = 1\,mbar$

$T_i = -10°C$

	p	T	x	s
1		$-16°C$		
2		$-16°C$	1	
3	8bar			
4	8bar		0	

Energiebilanz Verdampfer (stationärer Fliessprozess):

$$0 = \dot{m}_{R134a}\,(h_2 - h_3) - \dot{W}_K$$

(negatives VZ (wird zugeführt))

$$\frac{\dot{W}_K}{h_2 - h_3} = \dot{m}_{R134a}$$

TAB A-10:

$h_2 = h_g(-16°C) = 237.74$

$s_2 = s_g(-16°C) = 0.9298\ kJ/kg\cdot K$

$= s_3$ (weil reversibel)

$h_3 = h(8bar,\ s = 0.9298\ kJ/kg\cdot K)$ ⇒ TAB A-12

$h(s = 0.9066\ kJ/kg\cdot K) = 264.15\ kJ/kg$

$h_3(s = 0.9298\ kJ/kg\cdot K) = ? = \frac{273.66\ kJ/kg - 264.15\ kJ/kg}{0.9394\ kJ/kg\cdot K - 0.9066\ kJ/kg\cdot K} \cdot (0.9298\ kJ/kg\cdot K - 0.9066\ kJ/kg\cdot K) + 264.15\ kJ/kg$

$h(s = 0.9394\ kJ/kg\cdot K) = 273.66\ kJ/kg$

$271.3134\ kJ/kg = h_3$

$$\dot{m}_{R1342} = \frac{-28\cdot 10^{-3}\ kW}{h_2 - h_3} = 0.000834\ kg/s$$

$$= 3.0024\ kg/h$$

c) Drossel isenthalp : $h_1 = h_4$

$h_4 = h_f(8bar) = 93.42\ kJ/kg$

TAB A-11 ↗ TAB A-10

$$x_1 = \frac{h_1 - h_f(-16°C)}{h_g(16°C) - h_f(16°C)} = 0.3076$$

$h_f(-16°C) = 29.3\ kJ/kg$

$h_g(16°C) - h_f(16°C) = 237.74\ kJ/kg$

d) $\varepsilon_K = \frac{|\dot{Q}_{zu}|}{|\dot{Q}_{ab}| - |\dot{Q}_{zu}|} = \frac{|\dot{Q}_K|}{|\dot{Q}_{ab}| - |\dot{Q}_K|} = \frac{|\dot{Q}_{12}|}{|\dot{Q}_{34}| - |\dot{Q}_{12}|}$

Energiebilanz st. Fliessprozess 12 :

$0 = \dot{m}(h_1 - h_2) + \dot{Q}_{12}$

$\dot{Q}_{12} = \dot{m}(h_2 - h_1)$

$h_2 = 237.74\ kJ/kg$, $h_1 = 93.42\ kJ/kg$

$\dot{Q}_{34}$:

$\dot{Q}_{34} = \dot{m}(h_4 - h_3)$

$h_4 = h_1$

$\varepsilon_K = 5.465$

[redacted]

e) konstanter Wärmestrom abgeführt

$\Rightarrow$ T_i würde sinken