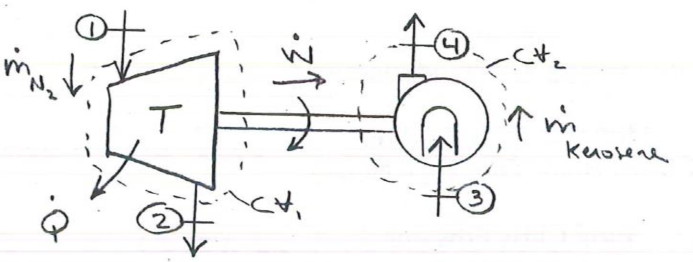
Aufgabe 1 (10 Punkte):

1. An exhaust turbine is used to drive a fuel pump.



$T_1 = 1000K$, $T_2 = 400K$

$\dot{m}_{N_2} = 10 g/s$, $\dot{Q} = 1kW$

$T_3 = T_4 = 20°C$, $P_3 = 100kPa$

$P_4 = 1000kPa$, $\underline{\underline{\dot{W} = ?}}$, $\underline{\underline{\dot{m}_{Kerosene} = ?}}$

$\underline{\underline{\dot{W}}}$ $[E]_{CV_1}$: $\underbrace{\frac{dE}{dt}}_{0} = \underbrace{\dot{m}_1}_{\dot{m}_{N_2}} h_1 - \underbrace{\dot{m}_2}_{\dot{m}_{N_2}} h_2 - \dot{Q} - \dot{W}$

Assume steady

$$\boxed{\dot{W} = \dot{m}(h_1 - h_2) - \dot{Q}}$$ Assume Ideal Gas for N_2

$\dot{W} = \dot{m}_{N_2} C_{P,AVG}(T_1 - T_2) - \dot{Q}$ Choose C_{P,N_2} at $T_{AVG} = 700K$

$\dot{W} = (10g/s)(1.098 \frac{kJ}{kg \cdot K})(1000-400)K - 1kW$ $\boxed{C_{P,AVG} = 1.098\ kJ/kg \cdot K}$

$$\boxed{\dot{W} = 5.59\ kW}$$

$\underline{\underline{\dot{m}_{Kerosene}}}$ $[E]_{CV_2}$: $0 = \dot{m}_{kerosene}(h_3 - h_4) + \dot{W}$

$$\boxed{\dot{m}_{kerosene} = \frac{\dot{W}}{h_4 - h_3}}$$

ICS: $\boxed{\Delta h = \Delta u + v \Delta P}$

$u = u(T)$ so $\Delta u = 0$ $(T_4 = T_3)$!

$\dot{m}_{kerosene} = \frac{\dot{W}}{v(P_4 - P_3)}$ $v = \frac{1}{\rho_{kerosene}} = \frac{1}{820 kg/m^3} = 0.00122 \frac{m^3}{kg}$

$\dot{m}_{kerosene} = \frac{5.588 kW}{(.00122 \frac{m^3}{kg})(1000kPa - 100kPa)} = \boxed{5.09\ kg/s}$

Alternative for Δh: $h_{ICS}(T,P) = h_f(T) + v_f(T)[P - P_{SAT}(T)]$

$h_4 = h_f(T_4) + v_f(T_4)[P_4 - P_{SAT}(T_4)]$

$h_3 = h_f(T_3) + v_f(T_3)[P_3 - P_{SAT}(T_3)]$

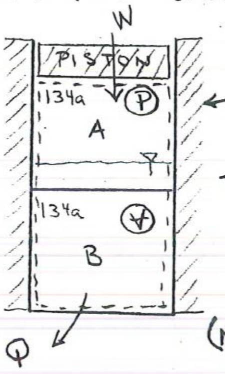
But $T_3 = T_4 = 20°C$

$\underbrace{h_4 - h_3 = v_f(20°C)(P_4 - P_3)}_{\Delta h = v \Delta P!}$

But $v_f = 1/\rho$ as above you get the same result.

Aufgabe 2 (30 Punkte):

2. A piston-cylinder contains a rigid, diathermal wall. The piston floats freely while heat is extracted from the bottom in two steps. Find: m_A, m_B, W_{12}, Q_{13}, T-v, T_3.



Assume Adiabatic

$P_A = 200 kPa$, $x_{A1} = 0.8$, $V_{A1} = 1 m^3$

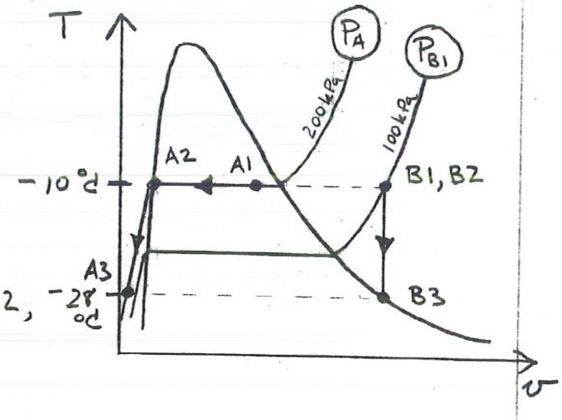
$x_{A2} = 0$ ← (Step 1→2)

$T_A = T_B$

$V_B = 1 m^3$, $T_A = T_B$, $P_{B1} = 100 kPa$

$x_{B3} = 1$ ← (Step 2→3)

(Neglect KE, PE)



Since $T_A = T_B$, the temperature in B cannot change until all of the vapor has disappeared in A.

Since T_B & v_B are fixed from 1→2, its state does not change.

Once A is outside the vapor dome, its temperature can change (at constant P), which allows the state in B to change.

$\underline{\underline{m_A}}$ $\quad v_{A1} = (1-x_{A1}) v_f + x_{A1} v_g = (0.2)\,.0007532\ m^3/kg + (0.8)\,.0993\ m^3/kg$

$v_{A1} = .07959\ m^3/kg$, $\quad m_{A1} = V_{A1}/v_{A1} = 1m^3/.07959\ m^3/kg = \boxed{12.56\ kg}$

$\underline{\underline{m_B}}$ $\quad \left.\begin{array}{l} T_{B1} = T_{A1} = -10°C \\ P_{B1} = 100kPa \end{array}\right\}$ Superheated $v_{B1} = .20686\ m^3/kg$ $\quad m_{B1} = \dfrac{V_B}{v_{B1}} = \dfrac{1 m^3}{.20686\ m^3/kg} = \boxed{4.834\ kg}$

$\underline{\underline{W_{12}}}$ $\quad$ Constant P! $\quad W_{12} = -P(V_2 - V_1) = -P m_A (v_{A2} - v_{A1})$

$v_{A2} = v_f(T_{A2}) = .0007532\ m^3/kg$, $\quad W_{12} = -(200kPa)(12.56kg) * (.0007532 - .07959)\ m^3/kg$

$\Rightarrow \boxed{W_{12} = 198.0\ kJ}$ ← Work done on the refrigerant!

(1%)

$\underline{\underline{T_3}}$ $\quad T_3 = T_{SAT}$ at same specific volume as B1. $\quad v_{B3} = .20686\ m^3/kg = v_g \approx .2052$

$\Rightarrow \boxed{T_3 = -28°C}$

$\underline{\underline{Q_{13}}}$ $\quad$ [E]: $\Delta U = W_{13} - Q_{13} \Rightarrow Q_{13} = -\Delta U_A - \Delta U_B + W_{12}$ $\quad \left\{ \begin{array}{l} \text{Assume} \\ W_{23} = 0 \\ \text{since it is incompressible!} \end{array} \right.$

$Q_{13} = m_A(u_{A1} - u_{A3}) + m_B(u_{B1} - u_{B3}) + W_{12}$

$$u_{A1} = (1-x_{A1})\,u_f + x_{A1}\,u_g = (0.2)\,36.69\,\frac{kJ}{kg} + (0.8)\,221.43\,\frac{kJ}{kg} = 184.48$$

$$u_{A3} = u_f(T_{A3})\ (\text{ICS!}) \Rightarrow u_{A3} = u_f(-28°C) = 14.31\,\frac{kJ}{kg}$$

$$u_{B1} = 224.01\,\frac{kJ}{kg}\quad(\text{Superheated})$$

$$u_{B3} = u_g(T_3) = u_g(-28°C) = 211.29\,\frac{kJ}{kg}$$

$$Q_{13} = 12.56\,kg\,(184.48 - 14.31)\,\frac{kJ}{kg} \qquad \{\ 2137\ kJ$$

$$+\ 4.834\,kg\,(224.01 - 211.29)\,\frac{kJ}{kg} \qquad \{\ 61.5\ kJ$$

$$+\ 198.0\ kJ \qquad \{\ 198\ kJ$$

$$\boxed{Q_{13} = 2396.5\ kJ}$$

Note: If you wished to include the work from 2 → 3, it would amount to $W_{23} = m_A P_A\,(v_f(-10°C) - v_f(-28°C))$

$$= (12.56\,kg)(200\,kPa)(.0007532 - .0007233)\,\frac{m^3}{kg}$$

$$\boxed{W_{23} = 0.075\ kJ}$$ Not a significant contribution (.003%!)

Aufgabe 3 (10 Punkte):

3. Brayton & Pump

$\dot{W}_{pump}$

neglect ΔKE

$$[E]:\ 0 = \dot{W}_p + \dot{m}(h_1 + g z_1) - \dot{m}(h_2 + g z_2)$$

$$\dot{W}_p = \dot{m}\left[(h_2 - h_1) + g(z_2 - z_1)\right]$$

$$\text{ICS} \Rightarrow \Delta h = \underbrace{\cancel{\Delta u}}_{0\,(\text{Rev})} + v\underbrace{\cancel{\Delta P}}_{0\ \text{same pressure}} = 0$$

$$\Rightarrow \dot{W}_p = \dot{m}\,g(z_2 - z_1) = \left(10\,\frac{kg}{s}\right)(300\,m)\left(9.8\,\frac{m}{s^2}\right)$$

$$\boxed{\dot{W}_p = 29.4\ kW}$$

$$\text{Brayton} \Rightarrow \eta_{th} = 1 - \left(\frac{1}{r_P}\right)^{\frac{k-1}{k}},\quad k = 1.4,\quad r_p = 9 \Rightarrow \eta_{th} = 46.6\,\%$$

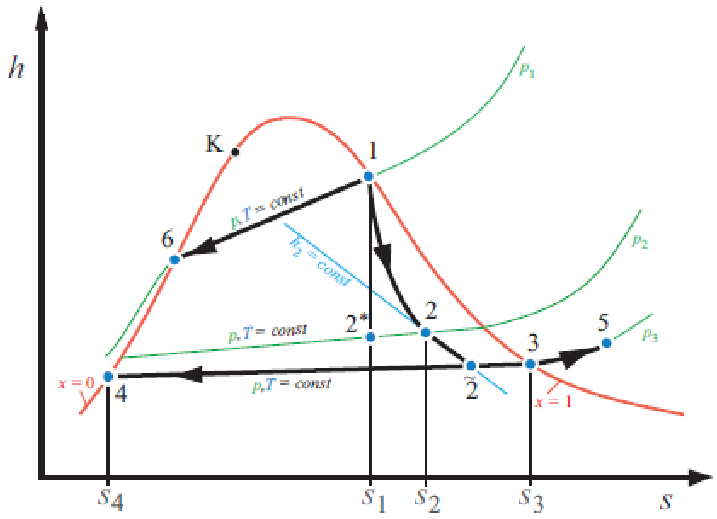
$$\eta_{th} = \frac{\dot{W}}{\dot{Q}} = \frac{\dot{W}_p}{\dot{Q}} \Rightarrow \dot{Q} = \frac{\dot{W}_p}{\eta_{th}} = \frac{29.4\,kW}{.466} = \boxed{63.1\ kW}$$

Aufgabe 4 (40 Punkte):

a) siehe Diagramm

b) Da der Wasserabscheider zwar mit Druckverlust aber adiabat arbeitet, bleibt die spezifische Enthalpie erhalten:

$\Rightarrow$ isenthalpe Zustandsänderung



c) Wasserabscheider:

Dampfgehalt: $x_{\tilde{2}} = \dfrac{h_{\tilde{2}} - h_4}{h_3 - h_4}$, $h_{\tilde{2}} = h_2$

aus Tab.:

$$h_4 = h(p_3, x_3) = h'(p_3)$$
$$h_3 = h(p_3, x_3) = h''(p_3)$$

Für die Turbine gilt:

$$\eta_{s,\mathrm{T}} = \frac{h_2 - h_1}{h_{2^*} - h_1} \quad \Rightarrow \quad h_2 \ \left(= h_1 + \eta_{s,\mathrm{T}}\,(h_{2^*} - h_1)\right)$$

aus Tab.: $h_{2^*} = h(p_2, s_{2^*})$, $s_{2^*} = s_1 = s(p_1, x_1) = s''(p_1)$, $h_1 = h(p_1, x_1) = h''(p_1)$

d) Massenbilanz Wasserabscheider: $\dfrac{\dot{m}_{\mathrm{III}}}{\dot{m}_{\mathrm{IV}}} = \dfrac{x_{\tilde{2}}}{1 - x_{\tilde{2}}}$

e) Energiebilanz Überhitzer (stationärer Fließprozess):

$$\left.\begin{array}{l} \dot{m}_{\mathrm{I}}\, h_1 + \dot{m}_{\mathrm{III}}\, h_3 = \dot{m}_5\, h_5 + \dot{m}_6\, h_6\,,\ \dot{m}_5 = \dot{m}_{\mathrm{III}}\,,\ \dot{m}_6 = \dot{m}_{\mathrm{I}} \\ \text{aus Tab.:}\ \ h_1, h_3 = \text{s.o.}\,,\ h_5 = h(p_3, \vartheta_5)\,,\ h_6 = h(p_1, x_6) = h'(p_1) \end{array}\right\} \Rightarrow \frac{\dot{m}_{\mathrm{I}}}{\dot{m}_{\mathrm{III}}} \left(= \frac{h_5 - h_3}{h_1 - h_6} > 0 \checkmark \right)$$

f) Massenbilanz Turbine:

$$\dot{m} = \dot{m}_{\mathrm{I}} + \dot{m}_{\mathrm{II}} = \dot{m}_{\mathrm{III}} \frac{h_5 - h_3}{h_1 - h_6} + \dot{m}_{\mathrm{II}} = \dot{m}_{\mathrm{II}} \left(x_{\tilde{2}} \frac{h_5 - h_3}{h_1 - h_6} + 1 \right) \quad \Rightarrow \quad \dot{m}_{\mathrm{II}} \left(= \frac{\dot{m}}{1 + x_{\tilde{2}} \frac{h_5 - h_3}{h_1 - h_6}} \right)$$

g) Energiebilanz Turbine:

$$\dot{Q}_{12} + P_{12} = \dot{H}_2 - \dot{H}_1 = \dot{m}_{\mathrm{II}}\,(h_2 - h_1)\,,\ Q_{12} = 0 \quad \Rightarrow \quad P_{\mathrm{T}} = \dot{m}_{\mathrm{II}}\,(h_2 - h_1)\ \ (< 0 \checkmark)$$

h) Entropiebilanz Wasserabscheider (stationärer Fließprozess):

$$\frac{\mathrm{d}S}{\mathrm{d}t} = 0 = \dot{S}_2 - \dot{S}_3 - \dot{S}_4 + \dot{S}_Q + \dot{S}_{\mathrm{irr}}\,,\ \dot{S}_Q = 0 \quad \Rightarrow \quad \dot{S}_{\mathrm{irr}} = \dot{m}_{\mathrm{III}}\, s_3 + \dot{m}_{\mathrm{IV}}\, s_4 - \dot{m}_{\mathrm{II}}\, s_2$$

aus Tab.: $s_3 = s(p_3, x_3) = s''(p_3)$, $s_4 = s(p_3, x_4) = s'(p_3)$, $s_2 = s(p_2, h_2)$