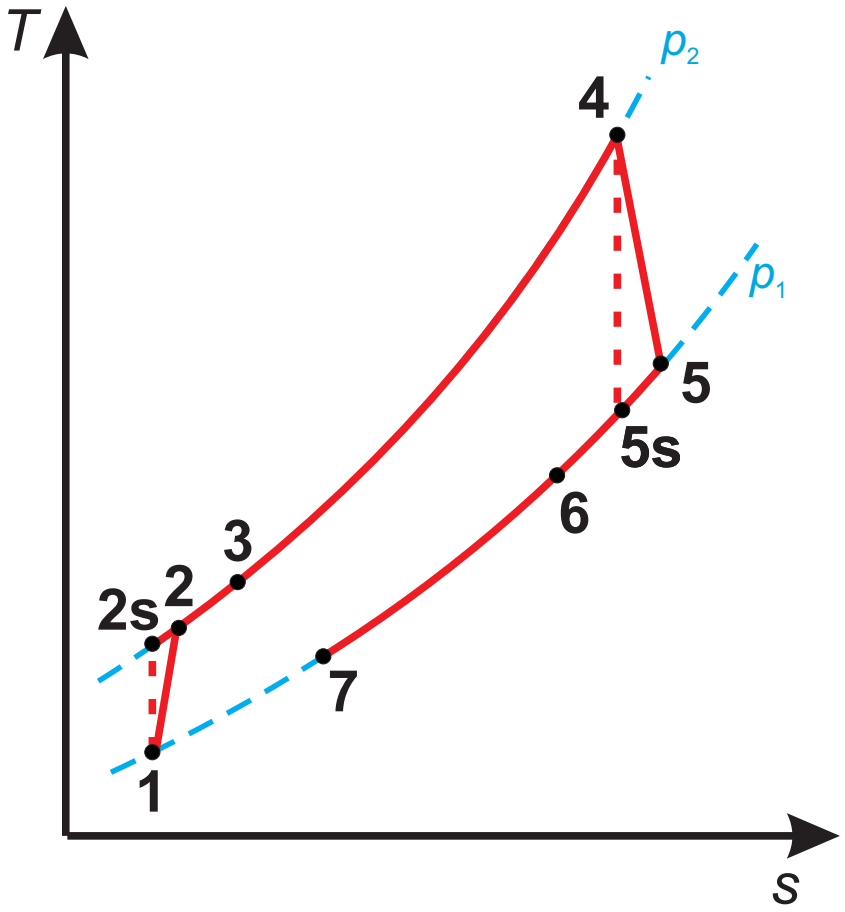
Musterlösung Aufgabe 1: «GuD-Heizkraftwerk»

I. TEILAUFGABE A) ⇒ 4 PUNKTE



II. TEILAUFGABE B) ⇒ 5 PUNKTE

$$\eta_{s,V} = \frac{w_{t,s}}{w_t} = \frac{c_p \cdot (T_{2,s} - T_1)}{c_p \cdot (T_2 - T_1)} = \frac{T_{2,s} - T_1}{T_2 - T_1}$$

$$\kappa = \frac{c_p}{c_v},\ R = c_p - c_v \quad \Rightarrow \kappa = \frac{c_p}{c_p - R} = \frac{1010}{1010 - 289} = 1,4$$

$$T_{2,s} = T_1 \cdot \left(\frac{p_2}{p_1}\right)^{\frac{\kappa - 1}{\kappa}} = 293,15K \cdot \left(\frac{5}{1}\right)^{\frac{1,4-1}{1,4}} = 464,3\ K$$

$$\eta_{s,V} = \frac{(464,3 - 293,15)K}{(230 - 20)K} = 0,815$$

$$P_V = \dot{m}_L \cdot w_t = \dot{m}_L \cdot c_p \cdot (T_2 - T_1) = 50\left(\frac{kg}{s}\right) \cdot 1010\left(\frac{J}{kg \cdot K}\right) \cdot (230 - 20)K = 10,605\ MW$$

III. TEILAUFGABE C) ⇒ 4 PUNKTE

$$\eta_{s,T} = \frac{w_t}{w_{t,s}} = \frac{c_p \cdot (T_5 - T_4)}{c_p \cdot (T_{5,s} - T_4)} = \frac{T_5 - T_4}{T_{5,s} - T_4}$$

$$\Rightarrow (-T_4 + T_{5,s}) \cdot \eta_{s,T} = T_5 - T_4$$

$$p_4 = p_2 = 5\ bar$$

$$\left(\frac{T_{5,s}}{T_4}\right) = \left(\frac{p_5}{p_4}\right)^{\frac{\kappa-1}{\kappa}} \Rightarrow T_{5,s} = T_4 \cdot \left(\frac{p_5}{p_4}\right)^{\frac{\kappa-1}{\kappa}}$$

$$\left(-T_4 + T_4 \cdot \left(\frac{p_5}{p_4}\right)^{\frac{\kappa-1}{\kappa}}\right) \cdot \eta_{s,T} = T_5 - T_4$$

$$T_4 = \frac{T_5}{\left(-1 + \left(\frac{p_5}{p_4}\right)^{\frac{\kappa-1}{\kappa}}\right) \cdot \eta_{s,T} + 1} = \frac{(630 + 273,15)K}{\left(-1 + \left(\frac{1}{5}\right)^{\frac{1,4-1}{1,4}}\right) \cdot 0,8 + 1} = 1280,87\ K$$

$$P_T = \dot{m}_L \cdot w_{t,45} = \dot{m}_L \cdot c_p \cdot (T_5 - T_4)$$
$$= 50\left(\frac{kg}{s}\right) \cdot 1010\left(\frac{J}{kg \cdot K}\right) \cdot (903,15 - 1280,87)K = -19,07\ MW$$

IV. TEILAUFGABE D) ⇒ 5 PUNKTE

$$\dot{Q}_B = \dot{m}_L \cdot c_p \cdot (T_4 - T_3)$$

$$\Rightarrow T_3 = \frac{-\dot{Q}_B}{\dot{m}_L \cdot c_p} + T_4 = \frac{-37,5 \cdot 10^3 kW}{50\left(\frac{kg}{s}\right) \cdot 1,010\left(\frac{kJ}{kg \cdot K}\right)} + 1280,87K = 538,3K$$

$$\dot{Q}_{23} = \dot{m}_L \cdot c_p \cdot (T_3 - T_2) = -\dot{Q}_{56} = \dot{m}_L \cdot c_p \cdot (-T_6 + T_5)$$

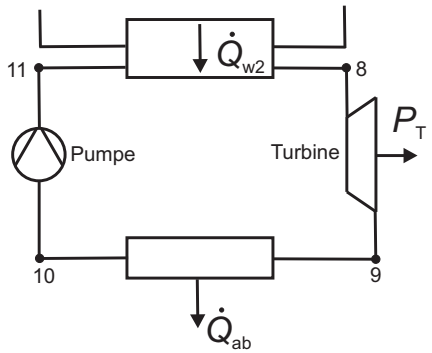
$$\Rightarrow T_3 - T_2 = T_5 - T_6 \quad \Rightarrow T_6 = T_5 - T_3 + T_2 = 868K$$

$$-\dot{Q}_{W2} = \dot{m}_L \cdot c_p \cdot (T_7 - T_6)$$

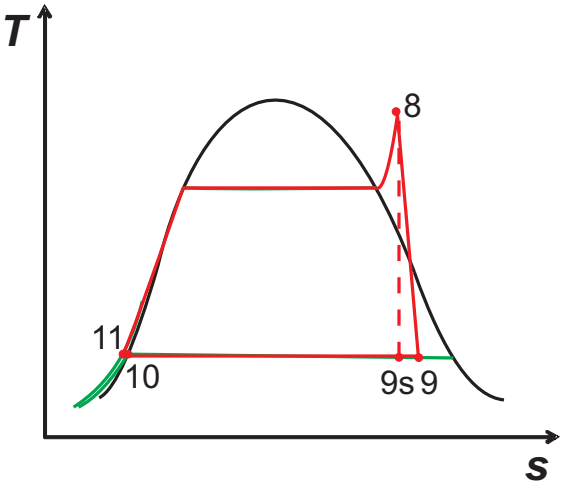
$$\Rightarrow T_7 = \frac{-\dot{Q}_{W2}}{\dot{m}_L \cdot c_p} + T_6 = \frac{-20 \cdot 10^3 kW}{50\left(\frac{kg}{s}\right) \cdot 1,010\left(\frac{kJ}{kg \cdot K}\right)} + 868K = 471,96K$$

Musterlösung Aufgabe 2: «Dampfkraftprozess»

I. TEILAUFGABE A) ⇒ 2 PUNKTE



II. TEILAUFGABE B) ⇒ 2 PUNKTE



III. TEILAUFGABE C) ⇒ 2 PUNKTE

$$\dot{Q}_{W2} = \dot{m}_D \cdot (h_8 - h_{11})$$

$$h_8 = h(360°C, 50\ bar) = 3095,6 \left(\frac{kJ}{kg}\right)$$

$$h_{11} = h_{10}\ (P_{10,11} = \dot{m}_D \cdot (h_{11} - h_{10}) = 0)\ = h'(5bar) = 640,09 \left(\frac{kJ}{kg}\right)$$

$$\dot{m}_D = \frac{\dot{Q}_{W2}}{h_8 - h_{11}} = \frac{20 \cdot 10^3 kW}{(3095,6 - 640,09)\left(\frac{kJ}{kg}\right)} = 8,145\ \frac{kg}{s}$$

IV. TEILAUFGABE D) $\Rightarrow$ 4 PUNKTE

$$P_T = \dot{m}_D \cdot (h_9 - h_8)$$

$$s_8 = s_{9s} = s(360°C, 50bar) = 6,4935 \left(\frac{kJ}{kg \cdot K}\right)$$

$$x_{9s} = \frac{s_{9s} - s'}{s'' - s'} = \frac{6,4935 - 1,8604}{6,8209 - 1,8604} = 0,934$$

$$h_{9s} = h' + x_{9s} \cdot (h'' - h') = 640,09 + 0,934 \cdot (2748,1 - 640,09) = 2608,97 \left(\frac{kJ}{kg}\right)$$

$$\eta_{s,T} = \frac{w_t}{w_{t,s}} = \frac{h_9 - h_8}{h_{9s} - h_8}$$

$$\Rightarrow h_9 = \eta_{s,T} \cdot (h_{9s} - h_8) + h_8 = 0,85 \cdot (2608,97 - 3095,6) + 3095,6 = 2681,96 \left(\frac{kJ}{kg}\right)$$

$$P_T = 8,145 \left(\frac{kg}{s}\right) \cdot (2681,96 - 3095,6) \left(\frac{kJ}{kg}\right) = -3,37MW$$

V. TEILAUFGABE E) $\Rightarrow$ 3 PUNKTE

$$x_9 = \frac{h_9 - h'}{h'' - h'} = \frac{2681,96 - 640,09}{2748,1 - 640,09} = 0,9686$$

$$v_9 = v' + x_9 \cdot (v'' - v') = \frac{1}{915,29} + 0,9686 \cdot \left(\frac{1}{2,668} - \frac{1}{915,29}\right) = 0,3631 \left(\frac{m^3}{kg}\right)$$

$$\Rightarrow \rho_9 = \frac{1}{0,3631} = 2,7542 \left(\frac{kg}{m^3}\right)$$

VI. TEILAUFGABE F) $\Rightarrow$ 5 PUNKTE

$$\eta_{th} = \frac{Nutzen}{Aufwand} = \frac{|\, P_T + \dot{Q}_{ab} \,|}{\dot{Q}_{zu}} = \frac{|\, P_T + 0,9 \cdot \dot{m}_D \cdot (h_{10} - h_9) \,|}{\dot{Q}_{W2}}$$

$$\eta_{th} = \frac{|-3,37MW + 0,9 \cdot 8,145 \frac{kg}{s} \cdot (640,09 - 2681,96) \frac{kJ}{kg}|}{20MW} = 0,917$$

$$\eta_{ex} = \frac{|\, P_T + \dot{E}_{\dot{Q}ab} \,|}{\dot{E}_{\dot{Q}W2}} = \frac{|\, P_T + \left(1 - \frac{T_a}{T_{m,9,10}}\right) \cdot \dot{Q}_{9,10} \,|}{\left(1 - \frac{T_a}{T_{m,11,8}}\right) \cdot \dot{Q}_{W2}}$$

$$T_{m9,10} = 151,83°C + 273,15K = 424,98K = const.$$

$$s_{11} = s(h = 640.09 \frac{kJ}{kg}) = 1,8488 \left(\frac{kJ}{kg \cdot K}\right)$$

$$T_{m11,8} = \frac{\Delta h_{11,8}}{\Delta s_{11,8}} = \frac{h_8 - h_{11}}{s_8 - s_{11}} = \frac{3095,6 - 640,09}{6,4935 - 1,8488} = 528,67K$$

$$\eta_{ex} = \frac{|-3,37MW + \left(1 - \frac{293,15K}{424,98K}\right) \cdot 0,9 \cdot 8,145 \frac{kg}{s} \cdot (2681,96 - 640,09) \frac{kJ}{kg}|}{\left(1 - \frac{293,15K}{528,67K}\right) \cdot 20MW} = 0,899$$

Musterlösung Aufgabe 3: «Versuchsanlage CO2»

I. TEILAUFGABE A)

$$V_{Anlage} = \frac{m \cdot R \cdot T}{p} = \frac{0,000115kg \cdot 289\frac{J}{kg \cdot K} \cdot 298,15K}{101300Pa} = 9,78185 \cdot 10^{-5}m^3 = 97,82\ ml$$

$$V_{Kompressor(X=0)} = 64\ ml$$

$$V_{Zelle} = V_{Anlage} - V_{Kompressor(X=0)} = 33,82\ ml = 3,38185 \cdot 10^{-5}\ m^3$$

II. TEILAUFGABE B)

$$p_{Vorratsbehalter} = p(25°C) = 64,342\ bar$$

III. TEILAUFGABE C)

$$V_{Kompressor(X=70)} = -0,4\ ml \cdot 70 + 64\ ml = 36\ ml = 0,000036\ m^3$$

$$p = 90\ bar$$

$$T = 298,15\ K$$

$$\rho = 799,65\frac{kg}{m^3}$$

$$m = \rho \cdot V_{Kompressor(X=70)} = 0,0287874\ kg = 28,7874\ g$$

IV. TEILAUFGABE D)

$$V_{Kompressor(X=120)} = 16\ ml$$

$$m_{Zelle} = \frac{2}{3} \cdot m = 0,0191916\ kg$$

$$\rho_{gas} = \rho''(25°C) = 242,73\frac{kg}{m^3}$$

$$\rho_{fl} = \rho'(25°C) = 710,5\frac{kg}{m^3}$$

$$\frac{V_{fl}}{V_{Zelle}} = 1 - w \qquad w\text{: Volumenanteil Dampf}$$

$$w = \frac{\rho - \rho_{fl}}{\rho_{gas} - \rho_{fl}} = \frac{567.4882 - 710.5}{242.73 - 710.5} = 0.3057$$

$$\rho = \frac{m_{Zelle}}{V_{Zelle}} = \frac{0.0191916}{3,38185 \cdot 10^{-5}} = 567.4882\frac{kg}{m^3}$$

$$\frac{V_{fl}}{V_{Zelle}} = 1 - w = o.6943 = 69,43\%$$

V. TEILAUFGABE E)

T interpolieren bei $\rho' = \rho = 567.4882 \frac{kg}{m^3}$

$$T = 30°C + \frac{567.49 - 593.31}{593.31 - 565.29} \cdot (30 - 30.5)$$

$$T = 30,46°C$$

VI. TEILAUFGABE F)

u_e interpolieren

$$u_e = 292.4 + \frac{567.49 - 593.31}{593.31 - 565.29} \cdot (292.4 - 297.9)$$

$$u_e = 297,47 \frac{kJ}{kg}$$

$$x = \frac{\frac{1}{\rho_{ges}} - \frac{1}{\rho_{fl}}}{\frac{1}{\rho_{gas}} - \frac{1}{\rho_{fl}}} = 0,13$$

$$u_{gas} = u''(25°C) = 367,92 \frac{kJ}{kg}\ (d.))$$

$$u_{fl} = u'(25°C) = 265,73 \frac{kJ}{kg}\ (d.))$$

$$u_d = u_{fl} + x \cdot (u_{gas} - u_{fl}) = 279,01 \frac{kJ}{kg}$$

$$Q_{d \to e} = (u_e - u_d) \cdot m_{Zelle} = 0,3543\ kJ$$