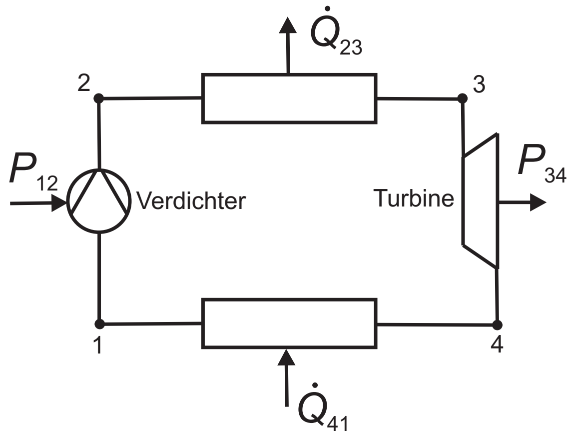
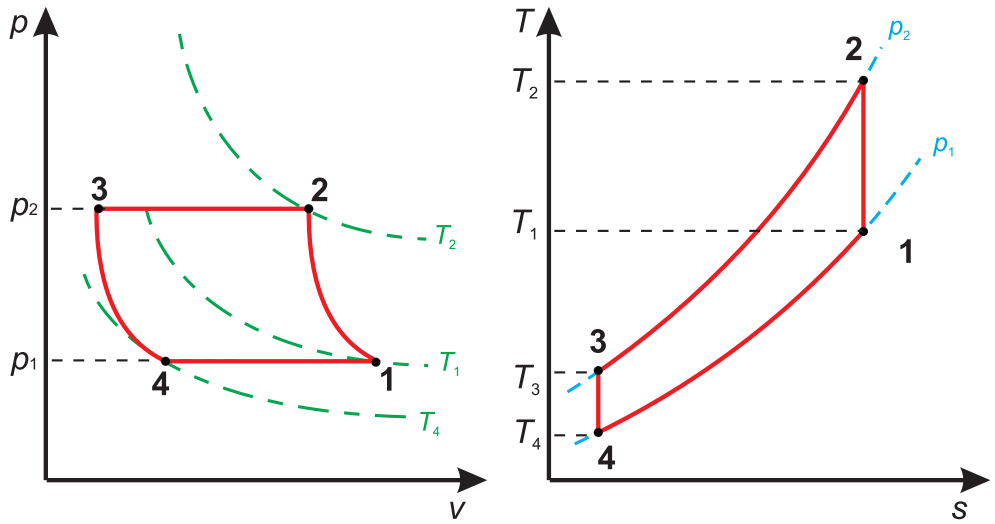
Musterlösung Aufgabe 1: ≪Ideales Gas≫

I. TEILAUFGABE A) $\Rightarrow$ 5 PUNKTE





II. TEILAUFGABE B) $\Rightarrow$ 2 PUNKTE

ideales Gas: $p_1 \cdot \dot{V} = \dot{m} \cdot R \cdot T_1 \Rightarrow \dot{m} = \dfrac{p_1 \cdot \dot{V}}{R \cdot T_1}$

4⟶1: isobare Wärmezufuhr: $p_1 = p_4 = 100\ kPa$

$$R = \frac{R_m}{M} = \frac{8.314472 \left(\frac{J}{mol \cdot K}\right)}{28.96 \cdot 10^{-3} \left(\frac{kg}{mol}\right)} = 287.1 \ \left(\frac{J}{kg \cdot K}\right)$$

$$\dot{m} = \frac{10^5\ Pa \cdot 10\ \left(\frac{m^3}{s}\right)}{287.1\ \left(\frac{J}{kg \cdot K}\right) \cdot 350\ K} = 9.95\ \left(\frac{kg}{s}\right)$$

III. TEILAUFGABE C) 3 PUNKTE

4⟶1: isochore Wärmezufuhr: $\dot{Q}_{zu} = \dot{Q}_i \cdot N = 0.8 \cdot 10^3 (W) \cdot 1000 = 8 \cdot 10^5\ (W)$

$$\dot{Q}_{zu} = \dot{Q}_{14} = \dot{m} \cdot c_p \cdot (T_1 - T_4) \quad \Rightarrow T_4 = T_1 - \frac{\dot{Q}_{zu}}{\dot{m} \cdot c_p}$$

$$R = c_p - c_v \quad \Rightarrow c_p = R + c_v = 287.1 \left(\frac{J}{kg \cdot K}\right) + 715 \left(\frac{J}{kg \cdot K}\right) = 1002.1 \ \left(\frac{J}{kg \cdot K}\right)$$

$$T_4 = 350(K) - \frac{8 \cdot 10^5 (W)}{9.95 \left(\frac{kg}{s}\right) \cdot 1002.1 \left(\frac{J}{kg \cdot K}\right)} = 269.78\ (K)$$

IV. TEILAUFGABE D) ⇒ 4 PUNKTE

2⟶3: isochore Abkühlung: $p_2 = p_3$

3⟶4: reversibel adiabate Entspannung:

$$p_3^{(1-\kappa)} \cdot T_3^{\kappa} = p_4^{(1-\kappa)} \cdot T_4^{\kappa} \quad \Rightarrow \left(\frac{p_3}{p_4}\right)^{1-\kappa} = \left(\frac{T_4}{T_3}\right)^{\kappa} \quad \Rightarrow p_3 = p_4 \cdot \left(\frac{T_4}{T_3}\right)^{\frac{\kappa}{1-\kappa}}$$

$$\kappa = \frac{c_p}{c_v} = \frac{287.1 \left(\frac{J}{kg \cdot K}\right)}{715 \left(\frac{J}{kg \cdot K}\right)} = 1.4$$

$$p_3 = 10^5 (Pa) \cdot \left(\frac{269.78(K)}{310(K)}\right)^{\frac{1.4}{1-1.4}} = 162424.78\ (Pa) = 1.62\ (bar)$$

V. TEILAUFGABE E) ⇒ 3 PUNKT

$$P = P_{12} - |P_{34}| = \dot{m} \cdot c_p \cdot (T_2 - T_1) - |\dot{m} \cdot c_p \cdot (T_4 - T_3)|$$

1⟶2: reversibel adiabate Verdichtung: $p_1^{(1-\kappa)} \cdot T_1^{\kappa} = p_2^{(1-\kappa)} \cdot T_2^{\kappa} \Rightarrow T_2 = T_1 \cdot \left(\frac{p_1}{p_2}\right)^{\frac{1-\kappa}{\kappa}}$

$$T_2 = 350(K) \cdot \left(\frac{10^5 (Pa)}{1.62 \cdot 10^5 (Pa)}\right)^{\frac{1-1.4}{1.4}} = 402.18\ (K)$$

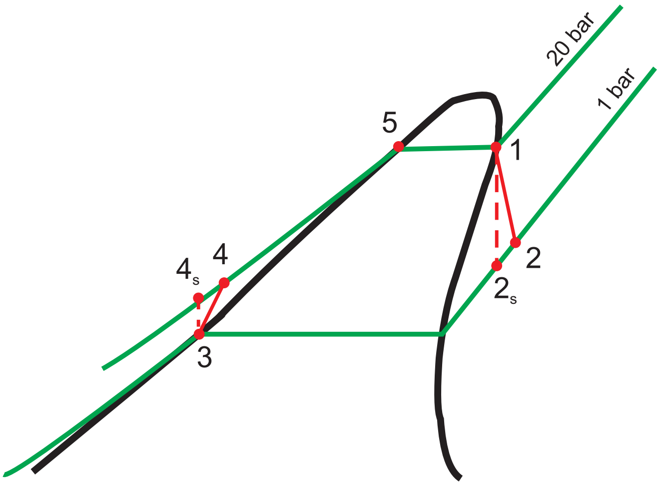
$$P_{12} = 9.95 \left(\frac{kg}{s}\right) \cdot 1002.1 \left(\frac{J}{kg \cdot K}\right) \cdot (402.18(K) - 350(K)) = 0.52\ (MW)$$

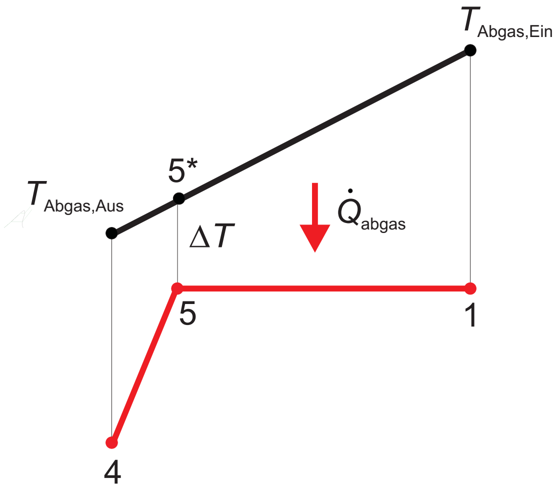
$$P_{34} = 9.95 \left(\frac{kg}{s}\right) \cdot 1002.1 \left(\frac{J}{kg \cdot K}\right) \cdot (269.78(K) - 310(K)) = -0.4\ (MW)$$

$$P = 0.52(MW) - |0.4(MW)| = 0.12\ (MW)$$

Musterlösung Aufgabe 2: «Kreisprozess»

I. TEILAUFGABE A) $\Rightarrow$ 5 PUNKTE





II. TEILAUFGABE B) $\Rightarrow$ 5 PUNKTE

$$\dot{Q}_{41} = \dot{m}_{Iso} \cdot \Delta h_{41} = \dot{m}_{Iso} \cdot (h_1 - h_4) \;\Rightarrow\; \dot{m}_{Iso} = \frac{\dot{Q}_{41}}{h_1 - h_4}$$

$$h_1 = h''(bei\ 20\ bar) = 531.26\ (\tfrac{kJ}{kg})$$

$$\eta_{s,V} = \frac{w_{t,34s}}{w_{t,34}} = \frac{h_{4s} - h_3}{h_4 - h3} \;\Rightarrow\; h_4 = h_3 + \frac{h_{4s} - h_3}{\eta_{s,V}}$$

$$h_3 = h'(bei\ 1\ bar) = -0.87(\tfrac{kJ}{kg})$$

$$s_{4s} = s_3 = s'(bei\ 1\ bar) = -0.0029(\tfrac{kJ}{kg \cdot K})$$

$$h_{4s} = h(20\ bar,\ s_{4s},\ homogenes\ Fluid) \;\Rightarrow\; \text{Interpolation:}$$

$$h_{4s} = -16.13 + \frac{(6.52 - (-16.13))}{(0.0113 - (-0.0647))} \cdot (-0.0029 - (-0.0647)) = 2.288\ \left(\frac{kJ}{kg}\right)$$

$$h_4 = -0.87 + (\frac{2.288 - (-0.87)}{0.85}) = 2.845\ \left(\frac{kJ}{kg}\right)$$

$$\dot{m}_{Iso} = \frac{8.25 \cdot 10^3\ (kW)}{(531.26 - 2.845)\left(\frac{kJ}{kg}\right)} = 15.6\ (\tfrac{kg}{s})$$

$$\dot{Q}_{5*,Ein} = \dot{Q}_{15}$$

$$\dot{Q}_{5*,Ein} = \dot{m}_{Abgas} \cdot c_{p,Abgas} \cdot (T_{Abgas,Ein} - T_{5*})$$

$$\dot{Q}_{15} = \dot{m}_{Iso} \cdot (h_1 - h_5) \;\Rightarrow\; \dot{m}_{Abgas} \cdot c_{p,Abgas} \cdot (T_{Abgas,Ein} - T_{5*}) = \dot{m}_{Iso} \cdot (h_1 - h_5)$$

$$\Rightarrow \dot{m}_{Abgas} = \frac{\dot{m}_{Iso} \cdot (h_1 - h_5)}{c_{p,Abgas} \cdot (T_{Abgas,Ein} - T_{5*})}$$

$$T_{5*} = T_5 + \Delta T = 154.07^oC + 10K = 164.07\ ^\circ C$$

$$h_5 = h'(bei\ 20\ bar) = 343.52\ \left(\frac{kJ}{kg}\right)$$

$$\dot{m}_{Abgas} = \frac{15.6(\frac{kg}{s}) \cdot (531.26(\frac{kJ}{kg}) - 343.52\left(\frac{kJ}{kg}\right))}{1.013\left(\frac{kJ}{kg \cdot K}\right) \cdot (230^oC - 164.07^oC)} = 43.85\ (\frac{kg}{s})$$

III. TEILAUFGABE C) $\Rightarrow$ 2 PUNKTE

$$\dot{Q}_{Abgas} = \dot{m}_{Abgas} \cdot c_{p,Abgas} \cdot (T_{Abgas,Ein} - T_{Abgas,Aus})$$

$$\Rightarrow T_{Abgas,Aus} = T_{Abgas,Ein} - \frac{\dot{Q}_{Abgas}}{\dot{m}_{Abgas} \cdot c_{p,Abgas}} = 503,15K - \frac{8.25 \cdot 10^3\ (kW)}{43.85(\frac{kg}{s}) \cdot 1.013\left(\frac{kJ}{kg \cdot K}\right)} = 44.27\ ^\circ C$$

IV. TEILAUFGABE D) $\Rightarrow$ 6 PUNKTE

$$\eta_{th} = \frac{Nutzen}{Aufwand} = \frac{|P_{12}| - P_{34}}{\dot{Q}_{Abgas}}$$

$$P_{12} = \dot{m}_{Iso} \cdot (h_2 - h_1)$$

$$\eta_{s,T} = \frac{w_{t,12}}{w_{t,12s}} = \frac{h_2 - h_1}{h_2 s - h1} \quad \Rightarrow \quad h_2 = h_1 + \eta_{s,T} \cdot (h_{2s} - h_1)$$

$$s_{2s} = s_1 = s''(bei\ 20\ bar) = 1.3727\ (\frac{kJ}{kg \cdot K})\ \ ;\ \ h_{2s} = h(1\ bar,\ s_{2s},\ homogenes\ Fluid) = 417.44\ (\frac{kJ}{kg})$$

$$h_2 = 531.26(\frac{kJ}{kg}) + 0.95 \cdot (417.44 - 531.26)(\frac{kJ}{kg}) = 423.131(\frac{kJ}{kg})$$

$$P_{12} = 15.6(\frac{kg}{s}) \cdot (423.131 - 531.26) = -1686.8\ (kW)$$

$$P_{34} = \dot{m}_{Iso} \cdot (h_4 - h_3) = 15.6(\frac{kg}{s}) \cdot (2.845 - (-0.87))\left(\frac{kJ}{kg}\right) = 57.954\ (kW)$$

$$\eta_{th} = \frac{|-1686.8| - 57.954}{8.25 \cdot 10^3} = 0.1974 = 19.74\%$$

$$\eta_{ex} = \frac{\dot{E}_{Nutzen}}{\dot{E}_{Aufwand}} = \frac{|P_{Nutz}|}{\dot{E}_Q}$$

$$\dot{E}_Q = \dot{Q}_{zu} \cdot (1 - \frac{T_u}{T_m})$$

$$T_m = \frac{\Delta h_{41}}{\Delta s_{41}} \qquad s_4 = -0.0647 + \frac{(2.845 - (-16.13))}{(6.52 - (-16.13))} \cdot (0.0113 - (-0.0647)) = -0.001\ (\frac{kJ}{kg \cdot K})$$

$$T_m = \frac{531.26 - 2.845}{1.3727 - (-0.001)} = 384.67\ (K)$$

$$\eta_{ex} = \frac{|-1686.8| - 57.954}{8.25 \cdot 10^3 (kW) \cdot (1 - \frac{298.15(K)}{384.67(K)})} = 0.878 = 87.8\%$$

Musterlösung Aufgabe 3

I. TEILAUFGABE A) $\Rightarrow$ 6 PUNKTE

Massenströme umrechnen:

$\dot{m}_D = 200(\frac{t}{h}) = 55.556(\frac{kg}{s})$ und $\dot{m}_W = 8500(\frac{t}{h}) = 2361.111(\frac{kg}{s})$

Enthalpie h_1 berechnen:

$$x_1 = \frac{h_1 - h'}{h'' - h'}$$

$$\Rightarrow h_1 = (2560.7(\frac{kJ}{kg}) - 137.75(\frac{kJ}{kg})) \cdot 0.923 + 137.75(\frac{kJ}{kg}) = 2374.133(\frac{kJ}{kg})$$

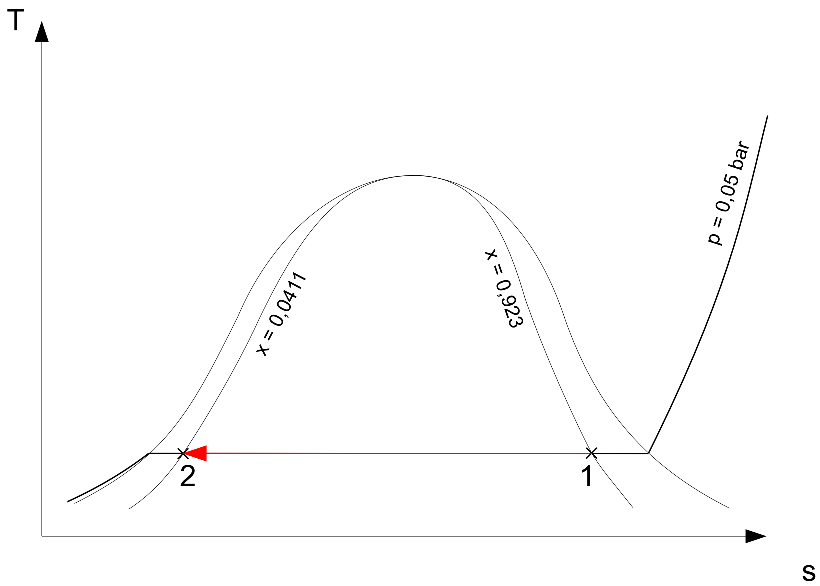
Enthalpie am Austritt des Kondensators:

$$\dot{Q}_{W1W2} = -\dot{Q}_{12} \Leftrightarrow \dot{m}_W \cdot c_{p,W} \cdot \Delta T = -\dot{m}_D(h_2 - h_1)$$

$$\Rightarrow h_2 = \frac{\dot{m}_W \cdot c_{p,W} \cdot \Delta T}{-\dot{m}_D} + h_1 = 237.233(\frac{kJ}{kg})$$

Dampfgehalt x_2:

$$x_2 = \frac{h_2 - h'}{h'' - h'} = \frac{237.233(\frac{kJ}{kg}) - 137.75(\frac{kJ}{kg})}{2560.7(\frac{kJ}{kg}) - 137.75(\frac{kJ}{kg})} = 0.0411$$



II. TEILAUFGABE B) $\Rightarrow$ 4 PUNKTE

Die Fläche unter der Kurve stellt die reversible spezifische Wärme q_{rev} dar, denn $q_{12,rev} = \int_1^2 T\mathrm{d}s$.

III. TEILAUFGABE C) $\Rightarrow$ 5 PUNKTE

Entropien s_1 und s_2 berechnen:

$$x_1 = \frac{s_1 - s'}{s'' - s'} \Leftrightarrow$$

$$s_1 = x_1 \cdot (s'' - s') + s' = 0.923 \cdot \left(8.394(\tfrac{kJ}{kgK}) - 0.476(\tfrac{kJ}{kgK})\right) + 0.476(\tfrac{kJ}{kgK} = 7.784(\tfrac{kJ}{kgK})$$

$$s_2 = x_2 \cdot (s'' - s') + s' = 0.0411 \cdot \left(8.394(\tfrac{kJ}{kgK}) - 0.476(\tfrac{kJ}{kgK})\right) + 0.476(\tfrac{kJ}{kgK}) = 0.801(\tfrac{kJ}{kgK})$$

Exergieströme $\dot{E}_{12}$, $\dot{E}_{W1W2}$, $\dot{E}_{W2U}$:

$$\dot{E}_{12} = \dot{m}_D \cdot [(h_2 - h_1) - T_U \cdot (s_2 - s_1)]$$

$$\dot{E}_{12} = 55.556(\tfrac{kg}{s}) \cdot \left[(237.233(\tfrac{kJ}{kg}) - 2374.133(\tfrac{kJ}{kg})) - 286.65(K) \cdot (0.801(\tfrac{kJ}{kgK}) - 7.784(\tfrac{kJ}{kgK}))\right]$$

$$= -7509.011(kW)$$

$$\dot{E}_{W1W2} = \dot{m}_W \cdot \left(c_{p,W} \cdot \Delta T - T_U \cdot c_{p,W} \cdot \ln\left(\frac{T_U + \Delta T}{T_U}\right)\right)$$

$$\dot{E}_{W1W2} = 2361.111(\tfrac{kg}{s}) \cdot \left(4.19(\tfrac{kJ}{kgK}) \cdot 12(K) - 286.65(K) \cdot 4.19(\tfrac{kJ}{kgK}) \cdot \ln\left(\frac{286.65(K) + 12(K)}{286.65(K)}\right)\right)$$

$$= 2417.668(kW)$$

$$\dot{E}_{W2U} = \dot{m}_W \cdot c_{p,W} \cdot \left(-\Delta T - T_U \cdot \ln\left(\frac{T_U}{T_U + \Delta T}\right)\right)$$

$$\dot{E}_{W2U} = 2361.111(\tfrac{kg}{s}) \cdot 4.19(\tfrac{kJ}{kgK}) \cdot \left(-12(K) - 286.65(K) \cdot \ln\left(\frac{286.65(K)}{286.65(K) + 12(K)}\right)\right)$$

$$= -2417.668(kW)$$

gesamter Exergieverluststrom $\dot{E}_{V,ges}$:

$$\dot{E}_{V,ges} = |\dot{E}_{12} + \dot{E}_{W1W2} + \dot{E}_{W2U}|$$

$$= |-7509.011(kW) + 2417.668(kW) + -2417.668(kW)| = 7509.011(kW)$$