Aufgabe 16.1 – Lösung

a) **ges:** oberes Druckniveau p_2 (Wärmeabgabe an Umgebung)

$$T_3 = T_\mathrm{a} + \Delta T = 25\,^\circ\mathrm{C} + 10\,\mathrm{K} = 35\,^\circ\mathrm{C} \tag{1}$$

$$\Longrightarrow \boxed{p_2} = p_3 = p_s(T_3) = \boxed{8.87\,\mathrm{bar}} \text{ (aus Diagramm)} \tag{2}$$

b) **ges:** Kompressionsarbeit $w_{\mathrm{t},12}$

$$\text{1. Hauptsatz:} \quad w_{\mathrm{t},12} + \underbrace{q_{12}}_{=0} = \Delta h_{12} \quad \Longrightarrow w_{\mathrm{t},12} = h_2 - h_1 \tag{3}$$

$$h_1 = h''(T_1) = h''(0\,^\circ\mathrm{C}) = 398.6\,\frac{\mathrm{kJ}}{\mathrm{kg}} \text{ (aus Diagramm)} \tag{4}$$

$$\eta_{\mathrm{komp.}} = \frac{w_{\mathrm{t},12,\mathrm{rev}}}{w_{\mathrm{t},12}} = \frac{h_{2s} - h_1}{h_2 - h_1} \tag{5}$$

$$\Longrightarrow h_2 = h_1 + \frac{h_{2s} - h_1}{\eta_{\mathrm{komp.}}} \tag{6}$$

$$s_1 = s_{2s} = s''(T_1) = 1.7271\,\frac{\mathrm{kJ}}{\mathrm{kg\,K}} \tag{7}$$

$$\Longrightarrow h_{2s} = h(s_1, p_2) = 421.63\,\frac{\mathrm{kJ}}{\mathrm{kg}} \text{ (aus Diagramm)} \tag{8}$$

$$\Longrightarrow h_2 = 398.6\,\frac{\mathrm{kJ}}{\mathrm{kg}} + \frac{(421.63 - 398.6)\mathrm{kJ/kg}}{0,85} = 425.69\,\frac{\mathrm{kJ}}{\mathrm{kg}} \tag{9}$$

$$\Longrightarrow \boxed{w_{\mathrm{t},12}} = (425.69 - 398.6)\frac{\mathrm{kJ}}{\mathrm{kg}} = \boxed{27.09\,\frac{\mathrm{kJ}}{\mathrm{kg}}} \tag{10}$$

c) **ges:** Wärme Verdampfer q_0

$$q_0 = h_1 - h_4 \tag{11}$$

$$h_4 = h_3 = h'(p_3) = 249.01\,\frac{\mathrm{kJ}}{\mathrm{kg}} \text{ (aus Diagramm)} \tag{12}$$

$$\Longrightarrow \boxed{q_0} = (398.6 - 249.01)\frac{\mathrm{kJ}}{\mathrm{kg}} = \boxed{149.59\,\frac{\mathrm{kJ}}{\mathrm{kg}}} \tag{13}$$

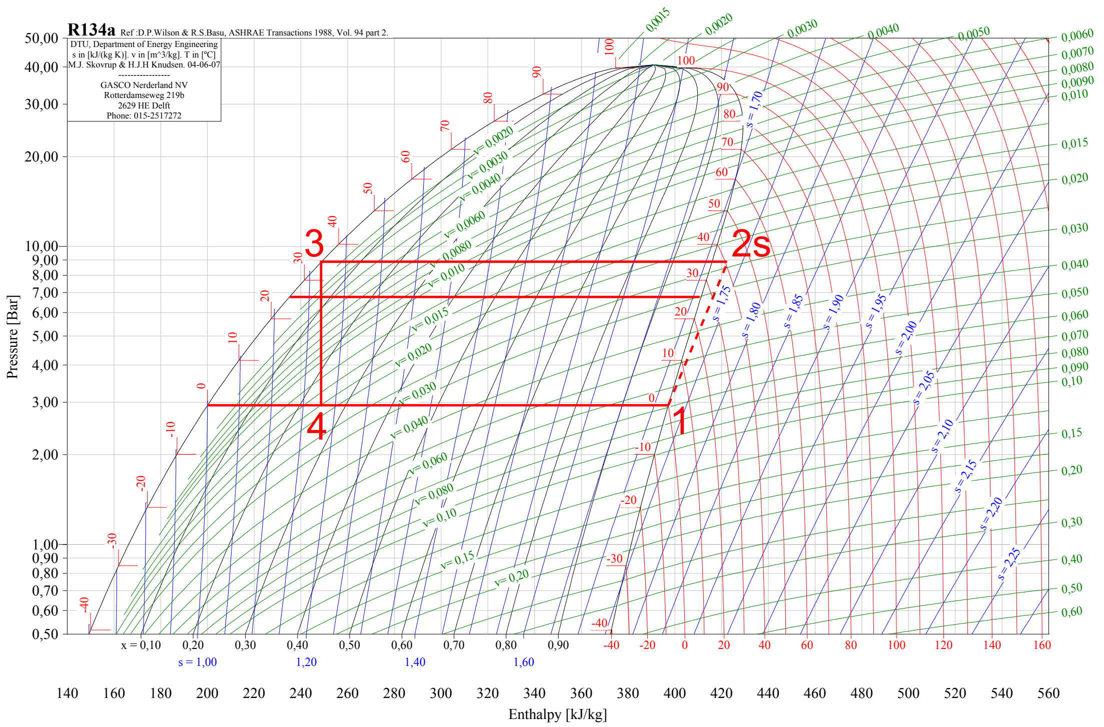
d) **ges:** Leistungszahl ϵ_{Km}

$$\boxed{\epsilon_{\mathrm{Km}}} = \frac{\dot{Q}_0}{P_\mathrm{el}} = \frac{q_0}{w_{\mathrm{t},12}} = \frac{149.59\,\mathrm{kJ/kg}}{27.09\,\mathrm{kJ/kg}} = \boxed{5.52} \tag{14}$$

e) **ges:** Antriebsleistung P_el

$$\epsilon_{\mathrm{Km}} = \frac{\dot{Q}_0}{P_\mathrm{el}} \tag{15}$$

$$\Longrightarrow \boxed{P_\mathrm{el}} = \frac{\dot{Q}_0}{\epsilon_{\mathrm{Km}}} = \frac{1.5\,\mathrm{kW}}{5.52} = \boxed{0.2717\,\mathrm{kW}} \tag{16}$$

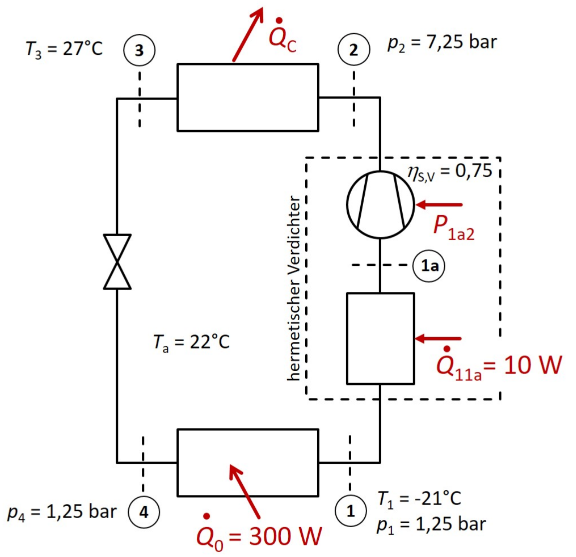


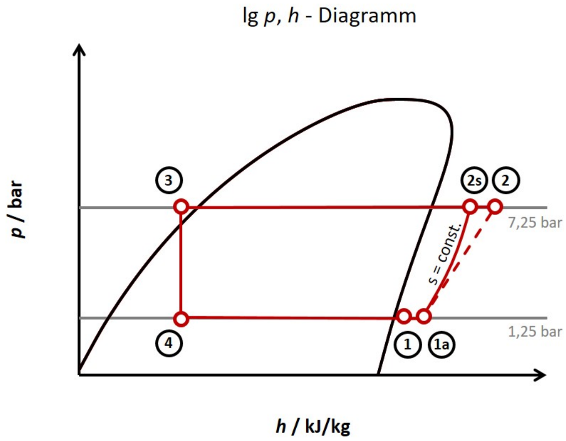
Aufgabe 16.2 – Lösung

T [°C]	ρ [kg/m^3]	h [kJ/kg]	s [kJ/(kg K)]
$p = 1.25\,\text{bar}$			
−21.381*	1362.5	171.85	0.8932
−21.381**	6.4102	385.70	1.7426
−21.000	6.3983	386.01	1.7438
−16.000	6.2482	390.06	1.7597
−15.000	6.2193	390.87	1.7629
−14.000	6.1908	391.68	1.7660
−13.000	6.1625	392.5	1.7691

T [°C]	ρ [kg/m^3]	h [kJ/kg]	s [kJ/(kg K)]
$p = 7.25\,\text{bar}$			
27.000	1199.2	237.40	1.1293
27.911*	1195.6	238.71	1.1337
27.911**	35.289	413.79	1.7152
41.000	32.703	427.21	1.7588
42.000	32.531	428.22	1.762
43.000	32.361	429.22	1.7652
44.000	32.193	430.23	1.7684
53.000	30.798	439.21	1.7963
54.000	30.654	440.21	1.7994
55.000	30.512	441.20	1.8024
56.000	30.372	442.20	1.8054

Zustand 1
Zustand 1a - zwischen den Zeilen
Zustand 2s -zwischen den Zeilen
Zustand 3
Zustand 4 - zwischen den Zeilen





a) **ges:** Massenstrom $\dot{m}$

$4 \to 1$:

$$\dot{Q}_0 = \dot{m} \cdot \Delta h_{41} \tag{17}$$

$$\Longrightarrow \quad \dot{m} = \frac{\dot{Q}_0}{\Delta h_{41}} \tag{18}$$

$$h_4 = h_3 = h(p = 7.25\,\text{bar}, T = 27\,°\text{C}) = 237.4\,\frac{\text{kJ}}{\text{kg}}\ \text{(aus Tabelle)} \tag{19}$$

$$h_1 = h(p = 1.25\,\text{bar}, T = -21\,°\text{C}) = 386.01\,\frac{\text{kJ}}{\text{kg}}\ \text{(aus Tabelle)} \tag{20}$$

$$\Longrightarrow \quad \boxed{\dot{m}} = \frac{300 \cdot 10^{-3}\,\text{kW}}{(386.01 - 237.4)\text{kJ/kg}} = \boxed{2.019 \cdot 10^{-3}\,\frac{\text{kg}}{\text{s}}} \tag{21}$$

b) **ges:** Antriebsleistung P_{1a2}

$1 \to 1a$:

$$\dot{Q}_{11a} = \dot{m} \cdot (h_{1a} - h_1) \tag{22}$$

$$\Longrightarrow \quad h_{1a} = \frac{\dot{Q}_{11a}}{\dot{m}} + h_1 \tag{23}$$

$$h_{1a} = \frac{10 \cdot 10^{-3}\,\text{kW}}{2.019 \cdot 10^{-3}\,\text{kg/s}} + 386.01\,\frac{\text{kJ}}{\text{kg}} = 390.964\,\frac{\text{kJ}}{\text{kg}} \tag{24}$$

s_{1a} wird durch lineare Interpolation in der Stoffwerttabelle berechnet:

$$s_{1a} = \frac{(390.964 - 390.87)\text{kJ/kg}}{(391.68 - 390.87)\text{kJ/kg}} \cdot (1.766 - 1.7629)\frac{\text{kJ}}{\text{kg}} + 1.7629\,\frac{\text{kJ}}{\text{kg}} \tag{25}$$

$$= 1.7633\,\frac{\text{kJ}}{\text{kg K}} \tag{26}$$

$s_{2s} = s_{1\text{a}} \implies h_{2s}$ wird ebenfalls durch lineare Interpolation bestimmt:

$$h_{2s} = \frac{(1.7633 - 1.762)\text{kJ}/(\text{kg K})}{(1.7652 - 1.762)\text{kJ}/(\text{kg K})} \cdot (429.22 - 428.22)\frac{\text{kJ}}{\text{kg}} + 428.22\,\frac{\text{kJ}}{\text{kg}} \tag{27}$$

$$= 428.61\,\frac{\text{kJ}}{\text{kg}} \tag{28}$$

$$\eta_{S,V} = \frac{w_{\text{t,1a2,rev.ad}}}{w_{\text{t,1a2}}} \tag{29}$$

$$\implies w_{\text{t,1a2}} = \frac{w_{\text{t,1a2,rev.ad}}}{\eta_{S,V}} = \frac{h_{2s} - h_{1\text{a}}}{\eta_{S,V}} \tag{30}$$

$$\implies w_{\text{t,1a2}} = \frac{(428.61 - 390.964)\text{kJ/kg}}{0.75} = 50.2\,\frac{\text{kJ}}{\text{kg}} \tag{31}$$

$$\boxed{P_{1\text{a}2}} = \dot{m} \cdot w_{\text{t,1a2}} = 2.019 \cdot 10^{-3}\,\frac{\text{kg}}{\text{s}} \cdot 50.2\,\frac{\text{kJ}}{\text{kg}} = \boxed{0.1013\,\text{kW}} \tag{32}$$

c) **ges:** Exergieverluststrom in der Drossel $\Delta\dot{E}_{V,Drossel}$

$$\Delta\dot{E}_{V,\text{Drossel}} = \dot{m} \cdot T_{\text{a}} \cdot \Delta s_{34} \tag{33}$$

$$x_4 = \frac{h_4 - h'(p = 1.25\,\text{bar})}{h''(p = 1.25\,\text{bar}) - h'(p = 1.25\,\text{bar})} \tag{34}$$

$$= \frac{(237.4 - 171.85)\text{kJ/kg}}{(385.7 - 171.85)\text{kJ/kg}} = 0.3065 \tag{35}$$

$$s_4 = s'(p = 1.25\,\text{bar}) + x_4 \cdot \big(s''(p = 1.25\,\text{bar}) - s'(p = 1.25\,\text{bar})\big) \tag{36}$$

$$= 0.893\,19\,\frac{\text{kJ}}{\text{kg K}} + 0.3065 \cdot (1.7426 - 0.893\,19)\frac{\text{kJ}}{\text{kg K}} \tag{37}$$

$$= 1.1535\,\frac{\text{kJ}}{\text{kg K}} \tag{38}$$

$$s_3 = s(p = 7.25\,\text{bar}, T = 27\,^\circ\text{C}) = 1.1293\,\frac{\text{kJ}}{\text{kg K}}\ \text{(aus Tabelle)} \tag{39}$$

$$\implies \boxed{\dot{E}_{V,\text{Drossel}}} = 2.019 \cdot 10^{-3}\,\frac{\text{kg}}{\text{s}} \cdot 295.15\,\text{K} \cdot (1.1535 - 1.1293)\frac{\text{kJ}}{\text{kg K}} \tag{40}$$

$$= \boxed{14.42\,\text{W}} \tag{41}$$