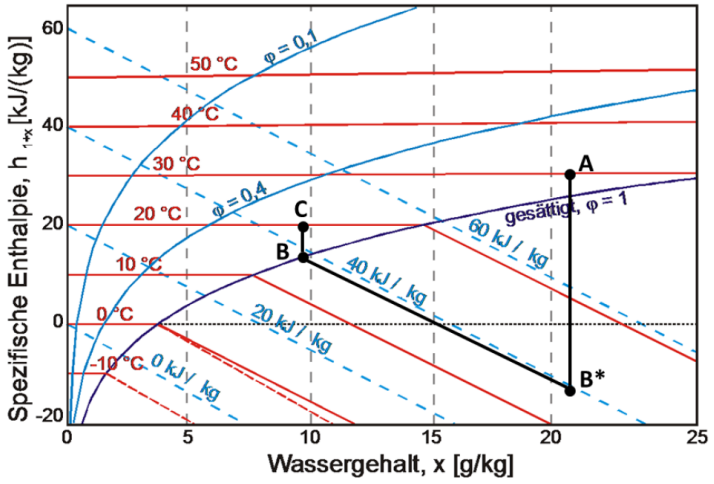
Aufgabe 19.1 – Lösung

geg: $\dot{V}_\mathrm{A} = 1000\,\mathrm{m^3/h}$, $T_\mathrm{A} = 30\,^\circ\mathrm{C}$, $\varphi_\mathrm{A} = 80\,\%$, $p_\mathrm{ges} = 1.013\,25\,\mathrm{bar}$, $T_\mathrm{B} = 14\,^\circ\mathrm{C}$, $\varphi_\mathrm{B} = 100\,\%$

Stoffdaten für R134a:

$T/^\circ\mathrm{C}$	p_s/bar	$h'/(\mathrm{kJ/kg})$	$h''/(\mathrm{kJ/kg})$	$\rho''/(\mathrm{kg/m^3})$	$s'/(\mathrm{kJ/(kg\,K)})$	$s''/(\mathrm{kJ/(kg\,K)})$
8	3.8761	210.84	403.20	18.94	1.0388	1.7230
9	4.0094	212.21	403.76	19.57	1.0437	1.7226
10	4.1461	213.58	404.32	20.23	1.0485	1.7221
11	4.2863	214.95	404.88	20.90	1.0533	1.7217
34	8.6263	247.54	416.72	42.18	1.1623	1.7131
35	8.8698	249.01	417.19	43.42	1.1670	1.7128
einphasig:			$h/(\mathrm{kJ/kg})$	$\rho/(\mathrm{kg/m^3})$		$s/(\mathrm{kJ/(kg\,K)})$
36	8.8698		418.29	43.12		1.7163
38	8.8698		420.47	42.55		1.7234
40	8.8698		422.62	42.00		1.7303
42	8.8698		424.76	41.48		1.7371

Zustand ① und ④
Zustand ②s zwischen den Zeilen
Zustand ③



a) **ges:** $\dot{m}_\mathrm{fL}$

$$v_{1+x,\mathrm{A}} = \frac{\dot{V}_\mathrm{ges,A}}{\dot{m}_\mathrm{L}} \tag{1}$$

$$\Longleftrightarrow\quad \dot{m}_\mathrm{L} = \frac{\dot{V}_\mathrm{ges,A}}{v_{1+x,\mathrm{A}}} \tag{2}$$

$$v_{1+x,\mathrm{A}} = \left(\frac{1}{M_\mathrm{L}} + \frac{x_\mathrm{A}}{M_\mathrm{W}}\right) \cdot \frac{R_\mathrm{m} \cdot T_\mathrm{A}}{p_\mathrm{ges}} \quad\Longrightarrow\quad x_\mathrm{A} = ? \tag{3}$$

$$x_\mathrm{A} = \frac{M_\mathrm{W}}{M_\mathrm{L}} \cdot \frac{p_\mathrm{wd}}{p_\mathrm{ges} - p_\mathrm{wd}} = 0.622 \cdot \frac{\varphi_\mathrm{A} \cdot p_{s,\mathrm{wd}}}{p_\mathrm{ges} - \varphi_\mathrm{A} \cdot p_{\mathrm{s,wd}}} \tag{4}$$

$$p_{\mathrm{s,wd}} \approx p_s(T) \implies p_{\mathrm{s,wd}}(T_\mathrm{A} = 30\,^\circ\mathrm{C}) \tag{5}$$

$$= \exp\left\{\left(14.233 - \frac{5200.1\,\mathrm{K}}{(273.15+30)\mathrm{K} - 4.114\,\mathrm{K}}\right)\right\} \cdot 1\,\mathrm{bar} \tag{6}$$

$$= 0.042\,57\,\mathrm{bar} \tag{7}$$

$$\implies x_A = 0.622 \cdot \frac{0.8 \cdot 0.042\,57\,\mathrm{bar}}{1.013\,25\,\mathrm{bar} - 0.8 \cdot 0.042\,57\,\mathrm{bar}} = 0.021\,64 \tag{8}$$

$$\implies v_{1+x,\mathrm{A}} = \left(\frac{1}{28.96\,\mathrm{kg/kmol}} + \frac{0.021\,64}{18.02\,\mathrm{kg/kmol}}\right) \cdot \frac{8.3145\,\mathrm{kJ/(kmol\,K)} \cdot 303.15\,\mathrm{K}}{1.013\,25 \cdot 10^5\,\mathrm{Pa}}$$

$$= 0.8888\,\tfrac{\mathrm{m}^3}{\mathrm{kg}} \tag{9}$$

$$\implies \dot{m}_\mathrm{L} = \frac{1000\,\mathrm{m}^3/\mathrm{h}}{0.8888\,\mathrm{m}^3/\mathrm{kg}} = 1125.0567\,\tfrac{\mathrm{kg}}{\mathrm{h}} = 0.3125\,\tfrac{\mathrm{kg}}{\mathrm{s}} \tag{10}$$

$$\boxed{\dot{m}_\mathrm{fL}} = \dot{m}_\mathrm{L} + \dot{m}_\mathrm{wd} = \dot{m}_\mathrm{L} + x \cdot \dot{m}_\mathrm{L} = (1+x) \cdot \dot{m}_\mathrm{L} = \boxed{0.32\,\tfrac{\mathrm{kg}}{\mathrm{s}}} \tag{11}$$

ges: $\dot{Q}_\mathrm{ab}$

$$\dot{Q}_\mathrm{ab} = \dot{Q}_{\mathrm{AB}^*} \tag{12}$$

$$\dot{Q}_{\mathrm{AB}^*} = \dot{m}_\mathrm{L} \cdot (h_{1+x,\mathrm{B}^*} - h_{1+x,\mathrm{A}}) \tag{13}$$

$$x_\mathrm{B} = x_s(T = 14\,^\circ\mathrm{C}) = 0.622 \cdot \frac{p_{s,\mathrm{wd}}(T = 14\,^\circ\mathrm{C})}{p_\mathrm{ges} - p_{s,\mathrm{wd}}(T = 14\,^\circ\mathrm{C})} \tag{14}$$

$$p_{s,\mathrm{wd}}(T = 14\,^\circ\mathrm{C}) = \exp\left\{\left(14.233 - \frac{5200.1\,\mathrm{K}}{287.15\,\mathrm{K} - 4.144\,\mathrm{K}}\right)\right\} \cdot 1\,\mathrm{bar} = 0.0159\,\mathrm{bar} \tag{15}$$

$$x_\mathrm{B} = 0.622 \cdot \frac{0.0159\,\mathrm{bar}}{1.013\,25\,\mathrm{bar} - 0.0159\,\mathrm{bar}} = 0.009\,919 \tag{16}$$

$$h_{1+x,\mathrm{A}} = c_{p,\mathrm{L}} \cdot t_\mathrm{A} + x_\mathrm{A}(\Delta h_{v,\circ} + c_{p,\mathrm{D}} \cdot -t_\mathrm{A}) \tag{17}$$

$$= 1.007\,\tfrac{\mathrm{kJ}}{\mathrm{kg\,K}} \cdot 30\,\mathrm{K} + 0.021\,64 \cdot \left(2500\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} + 1.86\,\tfrac{\mathrm{kJ}}{\mathrm{kg\,K}} \cdot 30\,\mathrm{K}\right) \tag{18}$$

$$= 85.52\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} \tag{19}$$

$$h_{1+x,\mathrm{B}^*} = c_{p,\mathrm{L}} \cdot t_\mathrm{B} + x_\mathrm{B}(\Delta h_{v,\circ} + c_{p,\mathrm{D}} \cdot t_\mathrm{B}) + (x_{\mathrm{B}^*} - x_\mathrm{B}) c_{p,\mathrm{W}} \cdot t_\mathrm{B} \tag{20}$$

$$= \underbrace{1.007 \cdot 14}_{\text{Luft}}\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} + \underbrace{(0.009\,919 \cdot (2500 + 1.86 \cdot 14))}_{\text{Wasser gasförmig}}\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} \tag{21}$$

$$+ \underbrace{((0.021\,64 - 0.009\,919) \cdot 4.18 \cdot 14)}_{\text{Wasser flüssig}}\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} \tag{22}$$

$$= 39.89\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} \tag{23}$$

$$\implies \boxed{\dot{Q}_{\mathrm{AB}^*}} = 0.3125\,\tfrac{\mathrm{kg}}{\mathrm{s}} \cdot (39.89 - 85.52)\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} = \boxed{-14.28\,\mathrm{kW}} \tag{24}$$

b) **ges:** φ_C mit $T_\mathrm{c} = 20\,^\circ\mathrm{C}$

$$\varphi_\mathrm{C} = \frac{p_\mathrm{wd,C}}{p_{s,\mathrm{wd}}(t_\mathrm{C} = 20\,^\circ\mathrm{C})} \tag{25}$$

$$p_\mathrm{s,wd}(T_\mathrm{C} = 20\,^\circ\mathrm{C}) = \exp\left\{\left(14.233 - \frac{5200.1\,\mathrm{K}}{293.15\,\mathrm{K} - 4.114\,\mathrm{K}}\right)\right\} \cdot 1\,\mathrm{bar} \tag{26}$$

$$= 0.023\,33\,\mathrm{bar} \tag{27}$$

$$x_\mathrm{C} = x_\mathrm{B} = 0.622 \cdot \frac{p_\mathrm{wd,C}}{p_\mathrm{ges} - p_\mathrm{wd,C}} \tag{28}$$

$$\Longrightarrow p_\mathrm{wd,C} = \frac{x_\mathrm{C} \cdot p_\mathrm{ges}}{(0.622 + x_\mathrm{C})} = \frac{0.009\,919 \cdot 1.013\,25\,\mathrm{bar}}{(0.622 + 0.009\,919)} = 0.0159\,\mathrm{bar} \tag{29}$$

$$\Longrightarrow \boxed{\varphi_\mathrm{C}} = \frac{0.0159}{0.023\,33} = \boxed{0.6814} \tag{30}$$

ges: $\dot{Q}_\mathrm{BC}$

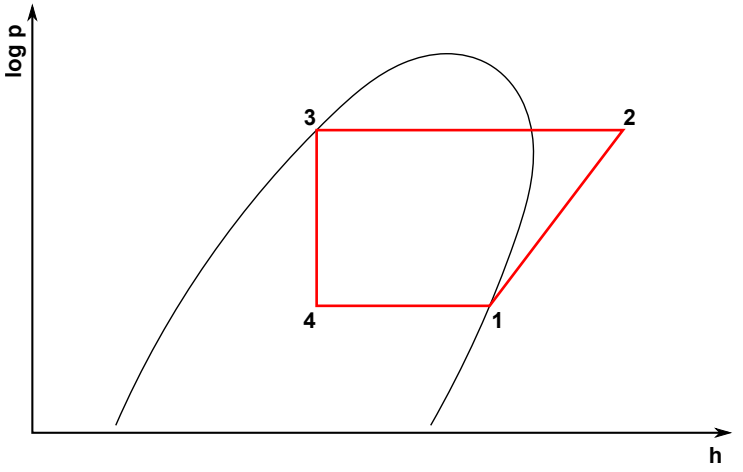
$$\dot{Q}_\mathrm{BC} = \dot{m}_\mathrm{L} \cdot (h_{1+x,\mathrm{C}} - h_{1+x,\mathrm{B}}) \tag{31}$$

$$h_{1+x,\mathrm{B}} = (1.007 \cdot 14)\tfrac{\mathrm{kJ}}{\mathrm{kg}} + 0.009\,919 \cdot (2500 + 1.86 \cdot 14)\tfrac{\mathrm{kJ}}{\mathrm{kg}} = 39.154\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} \tag{32}$$

$$h_{1+x,\mathrm{C}} = (1.007 \cdot 20)\tfrac{\mathrm{kJ}}{\mathrm{kg}} + 0.009\,919 \cdot (2500 + 1.86 \cdot 20)\tfrac{\mathrm{kJ}}{\mathrm{kg}} = 45.306\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} \tag{33}$$

$$\Longrightarrow \boxed{\dot{Q}_\mathrm{BC}} = 0.3125\,\tfrac{\mathrm{kg}}{\mathrm{s}} \cdot (45.306 - 39.154)\tfrac{\mathrm{kJ}}{\mathrm{kg}} = \boxed{1.926\,\mathrm{kW}} \tag{34}$$

c) **geg:** $\Delta T_\mathrm{min} = 5\,\mathrm{K}$, $T_\mathrm{u} = 30\,^\circ\mathrm{C}$
ges: $T_\mathrm{Waermeaufnahme}$, $T_\mathrm{Waermeabgabe}$



$$\boxed{T_\mathrm{Waermeaufnahme}} = T_4 = T_1 = T_B - \Delta T_\mathrm{min} = 14\,^\circ\mathrm{C} - 5\,\mathrm{K} = \boxed{9\,^\circ\mathrm{C}} \tag{35}$$

$$\boxed{T_\mathrm{Waermeabgabe}} = T_3 = T_\mathrm{u} + \Delta T_\mathrm{min} = 30\,^\circ\mathrm{C} + 5\,\mathrm{K} = \boxed{35\,^\circ\mathrm{C}} \tag{36}$$

d) **ges:** $p_{\min}$, $p_{\max}$

$$\boxed{p_{\max}} = p_2 = p_3 = p_s(T = 35\,^\circ\mathrm{C}) = \boxed{8.8698\,\mathrm{bar}} \tag{37}$$

$$\boxed{p_{\min}} = p_1 = p_4 = p_s(T = 9\,^\circ\mathrm{C}) = \boxed{4.0094\,\mathrm{bar}} \tag{38}$$

e) **ges:** $\dot{m}_1$; $\dot{V}_1$

$$\dot{Q}_{\mathrm{AB}*} = -\dot{Q}_{\mathrm{zu}} = -\dot{m}_1 \cdot (h_1 - h_4) \tag{39}$$

$$\Longleftrightarrow \quad \dot{m}_1 = -\frac{\dot{Q}_{\mathrm{AB}*}}{h_1 - h_4} \tag{40}$$

$$h_1 = h''(T = 9\,^\circ\mathrm{C}) = 403.76\,\tfrac{\mathrm{kJ}}{\mathrm{kg}}\ \text{(Tabelle)} \tag{41}$$

$$h_4 = h_3 = h'(T = 35\,^\circ\mathrm{C}) = 249.01\,\tfrac{\mathrm{kJ}}{\mathrm{kg}}\ \text{(Tabelle)} \tag{42}$$

$$\Longrightarrow \quad \boxed{\dot{m}_1} = -\frac{-14.28\,\mathrm{kW}}{(403.76 - 249.01)\mathrm{kJ/kg}} = \boxed{0.0923\,\tfrac{\mathrm{kg}}{\mathrm{s}}} \tag{43}$$

$$\boxed{\dot{V}_1} = \frac{\dot{m}_1}{\rho_1} = \frac{\dot{m}_1}{\rho''(T = 9\,^\circ\mathrm{C})} = \frac{0.0923\,\mathrm{kg/s}}{19.57\,\mathrm{kg/m^3}} = \boxed{0.004\,72\,\tfrac{\mathrm{m}^3}{\mathrm{s}}} \tag{44}$$

f) **ges:** $P_{\text{Antr.}} = P_{12}$ mit $\eta_{s,V} = 0.9$

$$\eta_{s,V} = \frac{h_{2s} - h_1}{h_2 - h_1} \tag{45}$$

$$\Longrightarrow \quad P_{12} = \dot{m}_1 \cdot \left(\frac{h_{2s} - h_1}{\eta_{s,V}}\right) \tag{46}$$

$$s_{2s} = s_1 = s''(T = 9\,^\circ\mathrm{C}) = 1.7226\,\tfrac{\mathrm{kJ}}{\mathrm{kg\,K}} \tag{47}$$

$$h_{2s} = h(p_{\max}, s_{2s}) = 418.29\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} + (420.47 - 418.29)\tfrac{\mathrm{kJ}}{\mathrm{kg}} \cdot \frac{(1.7226 - 1.7163)\mathrm{kJ/(kg\,K)}}{(1.7234 - 1.7163)\mathrm{kJ/(kg\,K)}} = 420.22\,\tfrac{\mathrm{kJ}}{\mathrm{kg}} \tag{48}$$

$$\boxed{P_{12}} = 0.0923\,\tfrac{\mathrm{kg}}{\mathrm{s}} \cdot \frac{(420.22 - 403.76)\mathrm{kJ/kg}}{0.9} = \boxed{1.688\,\mathrm{kW}} \tag{49}$$

g) **ges:** ε_K

$$\boxed{\varepsilon_{\mathrm{K}}} = \frac{\dot{Q}_{\mathrm{zu}}}{P_{12}} = \frac{14.28\,\mathrm{kW}}{1.688\,\mathrm{kW}} = \boxed{8.46} \tag{50}$$