**Lösung 10.4**

$\dot{m}_C = 12\,\frac{\mathrm{t}}{\mathrm{h}}$ $\qquad\qquad \vartheta_{H_2O} = 327\,°\mathrm{C}$

$p_{H_2O} = p_{O_2} = 30\,\mathrm{bar}$ $\qquad\qquad M_C = 12\,\frac{\mathrm{kg}}{\mathrm{kmol}}$

$\vartheta_{CO} = \vartheta_{H_2} = 627\,°\mathrm{C}$ $\qquad\qquad \vartheta_{O_2} = \vartheta_C = \vartheta_u = 25\,°\mathrm{C}$

isobare, vollständige Reaktion

a) $\dot{n}_{H_2O,I}$ $\quad \dot{n}_{O_2,I}$ $\quad \dot{n}_{CO,II}$ $\quad \dot{n}_{H_2,II}$

$$C + \frac{1}{2}O_2 \longrightarrow CO \qquad \text{(A)}$$

$$C + H_2O \longrightarrow CO + H_2 \qquad \text{(B)}$$

$$\dot{n}_{C,I} = \frac{\dot{m}_C}{M_C} = 10^3\,\frac{\mathrm{kmol}}{\mathrm{h}}$$

$$\dot{n}_{O_2,I} = \frac{1}{2}\dot{n}_{C,A}$$

$$\dot{n}_{CO,II} = \dot{n}_{CO,A} + \dot{n}_{CO,B} = \dot{n}_{C,A} + \dot{n}_{C,B} = \dot{n}_{C,I}$$

$$\dot{n}_{H_2O,I} = \dot{n}_{C,B} = \dot{n}_{C,I} - \dot{n}_{C,A}$$

$$\dot{n}_{H_2,II} = \dot{n}_{C,B} = \dot{n}_{C,I} - \dot{n}_{C,A}$$

1. Hauptsatz:

$$\underbrace{\dot{Q}_{I,II}}_{=0} + \underbrace{\dot{W}_{t_{I,II}}}_{=0} = \dot{H}_{II} - \dot{H}_I \Rightarrow$$

$$0 = \dot{n}_{CO,II} \cdot h_{m_{CO}} + \dot{n}_{H_2,II} \cdot h_{m_{H_2}} - \dot{n}_{C,I} \cdot h_{m_C} - \dot{n}_{O_2,I} \cdot h_{m_{O_2}} - \dot{n}_{H_2O,I} \cdot h_{m_{H_2O}}$$

$$0 = \dot{n}_{C,I} \cdot h_{m_{CO}} + \left(\dot{n}_{C,I} - \dot{n}_{C,A}\right) \cdot h_{m_{H_2}} - \dot{n}_{C,I} \cdot h_{m_C} - \frac{1}{2} \cdot \dot{n}_{C,A} \cdot h_{m_{O_2}} - \left(\dot{n}_{C,I} - \dot{n}_{C,A}\right) \cdot h_{m_{H_2O}}$$

$$\Rightarrow \dot{n}_{C,A} = \frac{\dot{n}_{C,I} \cdot \left(h_{m_{CO}} + h_{m_{H_2}} - h_{m_C} - h_{m_{H_2O}}\right)}{h_{m_{H_2}} + \frac{1}{2} \cdot h_{m_{O_2}} - h_{m_{H_2O}}} = 630\,\frac{\mathrm{kmol}}{\mathrm{h}}$$

$$\Rightarrow \dot{n}_{H_2O,I} = \left(1000 - 630\right)\frac{\mathrm{kmol}}{\mathrm{h}} = 370\,\frac{\mathrm{kmol}}{\mathrm{h}}$$

$$\dot{n}_{O_2,I} = 1/2 \cdot 630\,\frac{\mathrm{kmol}}{\mathrm{h}} = 315\,\frac{\mathrm{kmol}}{\mathrm{h}}$$

$$\dot{n}_{CO,II} = 1000\,\frac{\mathrm{kmol}}{\mathrm{h}}$$

$$\dot{n}_{H_2,II} = \left(1000 - 630\right)\frac{\mathrm{kmol}}{\mathrm{h}} = 370\,\frac{\mathrm{kmol}}{\mathrm{h}}$$

b) $\dot{E}_{V_{I,II}}$

$$\dot{E}_{V_{I,II}} = T_u \cdot \dot{S}_{irr_{I,II}}$$

$\dot{S}_{irr_{I,II}} = \dot{S}_{II} - \dot{S}_I$ , da adiabat

$$\dot{S}_{II} - \dot{S}_I = \dot{n}_{CO,II} \cdot \left( s_{m_{CO}} - R_m \cdot \ln \frac{p_{CO}}{p_0} \right) + \dot{n}_{H_2,II} \cdot \left( s_{m_{H_2}} - R_m \cdot \ln \frac{p_{H_2}}{p_0} \right) - \dot{n}_{C,I} \cdot s_{m_C}$$

$$- \dot{n}_{O_2,I} \cdot \left( s_{m_{O_2}} - R_m \cdot \ln \frac{p_{O_2}}{p_0} \right) - \dot{n}_{H_2O,I} \cdot \left( s_{m_{H_2O}} - R_m \cdot \ln \frac{p_{H_2O}}{p_0} \right)$$

$$p_{CO} = \frac{\dot{n}_{CO,II}}{\dot{n}_{CO,II} + \dot{n}_{H_2,II}} \cdot p_A = 21{,}9\,\text{bar}$$

$$p_{H_2} = p_A - p_{CO} = 8{,}1\,\text{bar}$$

$$p_{O_2} = p_{H_2O} = 30\,\text{bar}$$

mit $R_m = 8{,}3134 \cdot 10^{-3}\ \frac{\text{MJ}}{\text{kmol} \cdot \text{K}} \Rightarrow \dot{S}_{irr_{I,II}} = 129{,}8\ \frac{\text{MJ}}{\text{h} \cdot \text{K}}$

$$\Rightarrow \dot{E}_{V_{I,II}} = 298\ \text{K} \cdot 129{,}8\ \frac{\text{MJ}}{\text{h} \cdot \text{K}} = 36{,}68 \cdot 10^3\ \frac{\text{MJ}}{\text{h}} = 10{,}74\ \text{MW}$$

**Lösung 10.5**

Zustandsänderungen:

$1 \to 2$ adiabate, isobare Verbrennung von $H_2$ mit Luft mit $\lambda = 1$

$3 \to 4$ vollständige, isobare Verdampfung von siedendem Wasser

| | | |
|---|---|---|
| $M_L = 28{,}96\,\frac{\text{kmol}}{\text{kg}}$ | $M_{H_2} = 2\,\frac{\text{kmol}}{\text{kg}}$ | $M_{H_2O} = 18\,\frac{\text{kmol}}{\text{kg}}$ |
| $\dot{m}_L = 28{,}96\,\frac{\text{kg}}{\text{h}}$ | $\psi_{O_2} = 0{,}21$ | $\psi_{N_2} = 0{,}79$ |
| $p_{L,I} = 1\,\text{bar}$ | $T_{L,I} = 298\,\text{K}$ | $p_{H_2,I} = 1\,\text{bar}$ |
| $p_{Abg.II} = 1\,\text{bar}$ | $T_{Abg.II} = 1100\,\text{K}$ | $\Delta e_a = 0$ |
| $M_{N_2} = 28\,\frac{\text{kmol}}{\text{kg}}$ | $p_W = 120\,\text{bar}$ | $T_{H_2,I} = 298\,\text{K}$ |

a) $\dot{n}_{O_2,I}$ $\quad\dot{n}_{N_2,I}$ $\quad\dot{n}_{H_2,I}$ $\quad\dot{n}_{N_2,II}$ $\quad\dot{n}_{H_2O,II}$

$$2H_2 + O_2 + \frac{\psi_{N_2}}{\psi_{O_2}} N_2 \longrightarrow 2H_2O + \frac{\psi_{N_2}}{\psi_{O_2}} N_2$$

$$\dot{n}_{L,I} = \frac{\dot{m}_L}{M_L} = 1\,\frac{\text{kmol}}{\text{h}} \qquad \dot{n}_{O_2,I} = \psi_{O_2} \cdot \dot{n}_{L,I} = 0{,}21\,\frac{\text{kmol}}{\text{h}}$$

$$\dot{n}_{N_2,I} = \psi_{N_2} \cdot \dot{n}_{L,I} = 0{,}79\,\frac{\text{kmol}}{\text{h}} \qquad \dot{n}_{H_2,I} = 2 \cdot \dot{n}_{O_2,I} = 0{,}42\,\frac{\text{kmol}}{\text{h}}$$

$$\dot{n}_{H_2O,II} = \dot{n}_{H_2,I} = 0{,}42\,\frac{\text{kmol}}{\text{h}} \qquad \dot{n}_{N_2,II} = \dot{n}_{N_2,I} = 0{,}79\,\frac{\text{kmol}}{\text{h}}$$

b) $\dot{m}_d$

1. Hauptsatz Gesamtsystem:

$$\dot{Q}_{I,II} + \dot{W}_{t_{I,II}} = \dot{H}_{aus} - \dot{H}_{ein} = \dot{H}_2 - \dot{H}_1 + \dot{H}_4 - \dot{H}_3$$

$$\Rightarrow \dot{H}_2 - \dot{H}_1 = -\dot{H}_4 + \dot{H}_3 = -\dot{m}_d \cdot (h_4 - h_3) = -\dot{m}_d \cdot \Delta h_v(p_W)$$

$$\Rightarrow -\dot{m}_d \cdot \Delta h_v(p_W) = \dot{n}_{H_2O,II} \cdot h_{m_{H_2O}}(T_2) + \dot{n}_{N_2,II} \cdot h_{m_{N_2}}(T_2) - \dot{n}_{O_2,I} \cdot h_{m_{O_2}}(T_1) - \dot{n}_{N_2,I} \cdot h_{m_{N_2}}(T_1) - \dot{n}_{H_2,I} \cdot h_{m_{H_2}}(T_1)$$

mit den Beträgen aus der Tabelle molarer Enthalpien

$$\Rightarrow -\dot{m}_d \cdot 1{,}194\,\frac{\text{MJ}}{\text{kg}} = \left(-0{,}42 \cdot 198{,}8 + 0{,}79 \cdot 33{,}43 - 0{,}21 \cdot 8{,}68 - 0{,}79 \cdot 8{,}67 - 0{,}42 \cdot 8{,}45\right)\frac{\text{MJ}}{\text{h}}$$

$$\Rightarrow -\dot{m}_d = \frac{69{,}3074}{1{,}1974}\,\frac{\text{kg}}{\text{h}} = 57{,}88\,\frac{\text{kg}}{\text{h}}$$

c) $\dot{S}_{irr}$ $\dot{E}_v$

2. Hauptsatz

$$\dot{S}_{irr} = \dot{S}_{aus} - \dot{S}_{ein} = \sum \dot{S}_{Gase} + \sum \dot{S}_d$$

$\sum \dot{S}_d = \dot{m}_d \cdot \left(s^{//} - s^{/}\right)$ bei $p = 120\,\text{bar}$

$$\Rightarrow \sum \dot{S}_d = 57{,}88\,\tfrac{\text{kg}}{\text{h}} \cdot \left(5{,}5002 - 3{,}4972\right)\tfrac{\text{kJ}}{\text{kg}\cdot\text{K}} = 115{,}93\,\tfrac{\text{kJ}}{\text{h}\cdot\text{K}}$$

$$\sum \dot{S}_{Ga\ e} \underset{s}{=} \dot{n}_{H_2O,II} \cdot s_{m_{H_2O},II} + \dot{n}_{N_2,II} \cdot s_{m_{N_2,II}} - \dot{n}_{O_2,I} \cdot s_{m_{O_2,I}} - \dot{n}_{N_2,I} \cdot s_{m_{N_2,I}} - \dot{n}_{H_2,I} \cdot s_{m_{H_2,I}}$$

Bestimmung der Partialdrücke zur Berechnung der $S_m$ :

$p_{O_2,I} = 0{,}21\,\text{bar}$ $p_{N_2,I} = 0{,}79\,\text{bar}$ $\text{p}_{H_2,I} = 1\,\text{bar}$

$$\dot{n}_{Abg.II} = \dot{n}_{H_2O,II} + \dot{n}_{N_2,II} = 1{,}21\,\tfrac{\text{kmol}}{\text{h}}$$

$$p_{H_2O,II} = \frac{\dot{n}_{H_2O,II}}{\dot{n}_{Abg.II}} \cdot p_{II} = \frac{0{,}42}{1{,}21} \cdot 1\,\text{bar} = 0{,}347\,\text{bar}$$

$$p_{N_2,II} = \frac{\dot{n}_{N_2,II}}{\dot{n}_{Abg.II}} \cdot p_{II} = \frac{0{,}79}{0{,}21} \cdot 1\,\text{bar} = 0{,}653\,\text{bar}$$

$$s_{m_{H_2O,II}} = s_{m_{H_2O}}(T_{II}, p_0) - R_m \cdot \ln \frac{p_{H_2O,II}}{p_0}$$

$$s_{m_{H_2O,II}} = \left(236{,}8 - 8{,}314 \cdot \ln 0{,}347\right)\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}} = 245{,}6\,\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}}$$

$$s_{m_{N_2,II}} = \left(231{,}3 - 8{,}314 \cdot \ln 0{,}653\right)\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}} = 234{,}86\,\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}}$$

$$s_{m_{N_2,I}} = \left(191{,}6 - 8{,}314 \cdot \ln 0{,}79\right)\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}} = 193{,}57\,\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}}$$

$$s_{m_{O_2,I}} = \left(205{,}15 - 8{,}314 \cdot \ln 0{,}21\right)\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}} = 218{,}13\,\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}}$$

$$s_{m_{N_2,II}} = \left(130{,}63 - 8{,}314 \cdot \ln 1\right)\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}} = 130{,}63\,\tfrac{\text{kJ}}{\text{kmol}\cdot\text{K}}$$

$$\sum \dot{S}_{Gase} = \left(0{,}42 \cdot 245{,}6 + 0{,}79 \cdot 234{,}86 - 0{,}21 \cdot 218{,}13 - 0{,}79 \cdot 193{,}57 - 0{,}42 \cdot 130{,}63\right)\tfrac{\text{kJ}}{\text{h}\cdot\text{K}}$$
$$= 35{,}01\,\tfrac{\text{kJ}}{\text{h}\cdot\text{K}}$$

$$\Rightarrow \dot{S}_{irr} = \sum \dot{S}_{Gase} + \sum \dot{S}_d = 150{,}94\,\tfrac{\text{kJ}}{\text{h}\cdot\text{K}}$$

$$\Rightarrow \dot{E}_v = T_u \cdot \dot{S}_{irr} = 298\,\text{K} \cdot 150{,}94\,\tfrac{\text{kJ}}{\text{h}\cdot\text{K}} = 44{,}98 \cdot 10^3\,\tfrac{\text{kJ}}{\text{h}} = 12{,}5\,\text{kW}$$

d) $\vartheta_{H_2O}$

$p_{H_2O} = 0{,}347\,\text{bar} \Rightarrow$ aus h,s-Diagramm: $\vartheta_{H_2O} \geq 72{,}3\,°\text{C}$