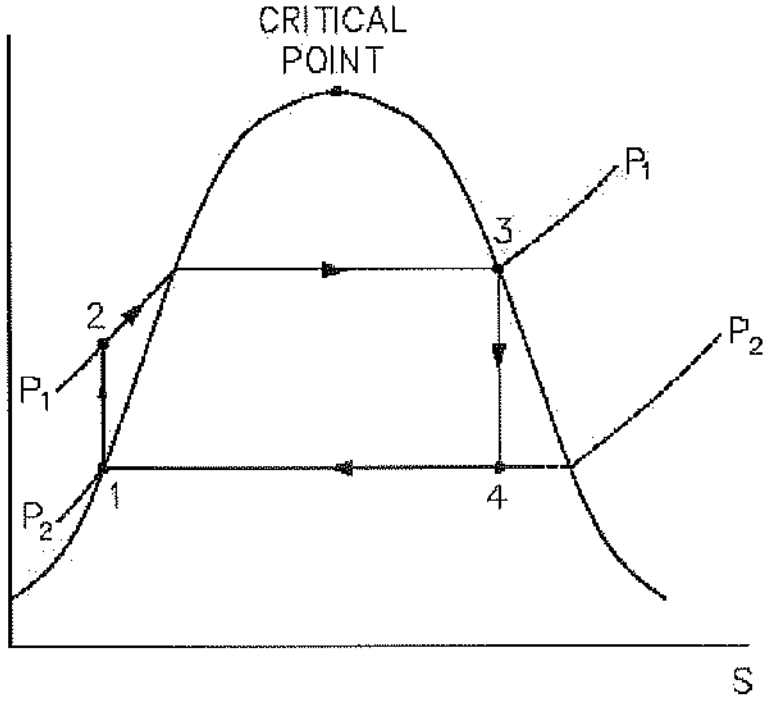
Termodynamik

Lösningar

EL



Av: Patrik "Putte" Andersson, kf-06

E.1.9) $V_1 = 4\,l$ $\quad P = 10^5\,Pa$

$T = 293\,°C$ $\quad \rho_L = 0.692\ g/cm^3$

$$V_2 = \frac{n R T}{P}$$

$$n = \frac{\rho V_1}{M}$$

$$M = 8 \cdot C + 18\,H = 114.232\ g/mol$$

$$\Rightarrow n = \frac{0.692 \cdot 4000}{114.232} = 24.23\ mol$$

$$\Rightarrow \underline{V_2 = 1.14\ m^3}$$

E.1.13) 20 mol% CO_2 80 mol% luft

$P = 10^5$ Pa $T = 360$ K

$\dot{V}_{in} = 1\ m^3/min$ luft = 20% O_2 = 80% N_2

a) $n_{TOT} = \frac{PV}{RT} = 33.41$ mol

$n_{CO_2} = 0.2 \cdot n_{TOT} = 6.682$ mol

$n_{luft} = 26.728$ mol

$n_{CO_2\,(slut)} = (1-0.98) \cdot n_{CO_2} = 0.13364$ mol

Inflöde

$m_{CO_2} = (C + 2O) \cdot n_{CO_2} = 294$ g

$m_{luft} = n_{luft} \cdot O_2 \cdot 0.2 + n_{luft} \cdot N_2 \cdot 0.8 = 770$ g

Totalt: $294 + 770 = 1064$ g/min

Utflöde

$m_{CO_2} = (C + O_2) \cdot n_{CO_2\,(slut)} = \underline{5.88}$ g

$m_{luft} = 770$ g

Totalt: $5.88 + 770 = \underline{775.88}$ g

b, $P = 10^5\ Pa$ $\quad T = 360\ K$

$PV = nRT \Rightarrow P\dot{V}^{ut} = n_{ut} RT$

$n_{ut} = n_{luft,ut} + n_{CO_2,ut} = 26.86164\ mol/min$

$\Rightarrow \dot{V}^{ut} = \underline{0.8}\ m^3/min$

EL 1.19) $\underline{V} = 2.42\ m^3$ $T = 90\,^\circ C$

a, Då det finns både gas och vätska måste systemet befinna sig i jämvikt.

$T = 90\,^\circ C \Rightarrow \underline{0.0702}$ MPa enligt tabell E 7

b, q = andel ånga i systemet

$M = M^L + q(M^V - M^L)$ där M är någon relevant storhet! :)

$\Rightarrow$ $V = V^L + q(V^V - V^L)$ (ekv 1.21)

V = totala volymiteten = $\frac{2.42}{2} = 1.21\ m^3/kg$

$V^V(90^\circ C) = 2.3591\ m^3/kg$

$V^L(90^\circ C) = 0.001036\ m^3/kg$

$\Rightarrow$ $q = 0.51 \Rightarrow \underline{51\%}$ ånga

c, $T = 100°C$ $\quad P_{(100°C)} = 0.1014\ MPa$

$V = 1.21\ m^3/kg$

$V^V_{(100°C)} = 1.6718\ m^3/kg$

$V^L_{(100°C)} = 0.001043\ m^3/kg$

$\Big\}\ q = 0.72$

$H = H^L + q(H^V - H^L) = H^L + q\,\Delta H_{vap}$

$U = U^L + q(U^V - U^L) = U^L + q\,\Delta U_{vap}$

90°C

$H^L = 377.04\ kJ/kg$

$\Delta H_{vap} = 2282\ kJ/kg$

$U^L = 376.97\ kJ/kg$

$\Delta U_{vap} = 2117\ kJ/kg$

$\Big\}\ H_{(90°C)} = 1541.1\ kJ/kg$, $U_{(90°C)} = 1456.6\ kJ/kg$

100°C

$H^L = 419.17\ kJ/kg$

$\Delta H_{vap} = 2256.4\ kJ/kg$

$U^L = 419.06\ kJ/kg$

$\Delta U_{vap} = 2086.96\ kJ/kg$

$\Big\}\ H_{(100°C)} = 2043.8\ kJ/kg$, $U_{(100°C)} = 1921.7\ kJ/kg$

$\Delta \underline{H} = m(H_{(100°C)} - H_{(90°C)}) = \underline{1005}\ kJ$

$\Delta U = m(U_{(100°C)} - U_{(90°)}) = \underline{930}\ kJ$

d, Mättad ånga $\Rightarrow q = 1$

$V = V^L + q(V^V - V^L) = V^V = 1.21 \ m^3/kg$

$V = 1.21 \Rightarrow T \approx 110°C \quad P \approx 0.1434 \ MPa$

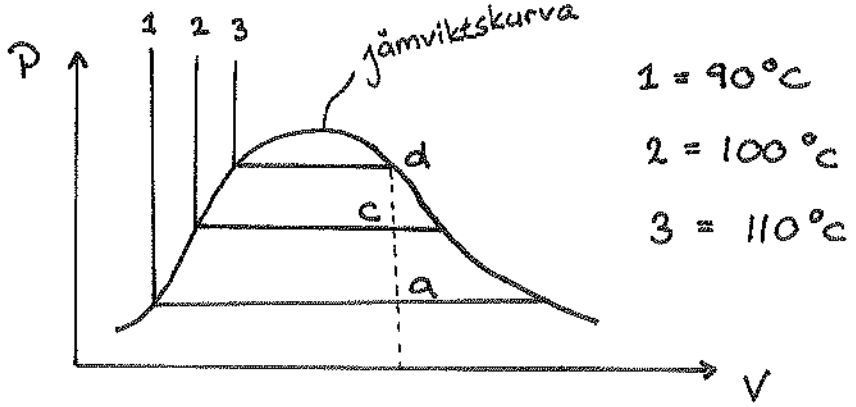
$U^{110} = U^V(110°C) = 2517.67 \ kJ/kg$

$H^{110} = H^V(110°C) = 2691.06 \ kJ/kg$

$\Delta \underline{H} = m(H^{110} - H^{90}) = \underline{2300} \ kJ$

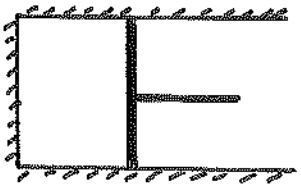
$\Delta \underline{U} = m(U^{110} - U^{90}) = \underline{2122} \ kJ$

e,



Innanför kurvan finns det både gas och vätska.
Till vänster om kurvan är det vätskefas.
Till höger om kurvan är det gasfas.

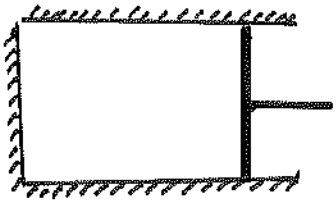
E. 2. 12



$P = 10\ bar$

$T = 600K$

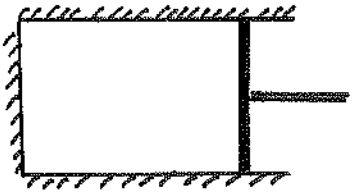
$\underline{V} = \frac{nRT}{P} = 9.977 \cdot 10^{-3}\ m^3$



$P = 1\ bar$

$T = ?$

$\underline{V} = 0.051683\ m^3$



$P = ?$

$T = 600K$

$\underline{V} = 0.051683\ m^3$

$C_p = 3.5R \Rightarrow C_v = 2.5R$

a) $\underline{W_{EC12}} = \Delta \underline{U} - \cancel{\underline{Q}}^{0} = nC_v(T_2 - T_1)$

$T_2 = \left(\frac{P_2}{P_1}\right)^{R/C_p} \cdot T_1 = 310.8\ K \qquad (2.54)$

$\underline{W_{EC12}} = -12.024\ kJ$

$\underline{Q_{23}} = \Delta \underline{U} - \cancel{\underline{W_{EC23}}}^{0} = nC_v(T_3 - T_2) = 12.024\ kJ$

$\underline{Q_{31}} = -W_{EC31} = -\int P dV = RT_3(\ln(\underline{V_1}) - \ln(\underline{V_3})) = 16.4\ kJ$

$\underline{Q_{tot}} = \underline{-4.4\ kJ} \qquad W_{ECtot} = \underline{4.4\ kJ}$

b, $\underline{U_1} = \underline{U_3} = 0$

$\underline{U_2} = C_v \cdot n \cdot \Delta T_{21} = -12{,}024\ kJ$

$\underline{H_1} = \underline{U_1} + \underline{P_1}V_1 = 9{,}977\ kJ$

$\underline{H_2} = \underline{U_2} + P_2\underline{V_2} = -6{,}856\ kJ$

$\underline{H_3} = \underline{U_3} + \underline{P_3}V_3 = 9{,}977\ kJ$

c, $\underline{W_{12}} = -\int PdV = 4.17\ kJ$

$\underline{W_{23}} = 0$

$\underline{W_{31}} = -4.17\ kJ$

$\underline{W_{S12}} = -\underline{W_{EC12}} - \underline{W_{12}} = 7{,}85\ kJ$

$\underline{W_{S23}} = 0$

$\underline{W_{S31}} = -\underline{W_{EC31}} - \underline{W_{31}} = -12.2\ kJ$

$W_{Stot} = -\underline{4.4}\ kJ$

E. 2.14) Energibalans:

$$0 = \left[H + \frac{u^2}{2} + gz\right]^{in} \cdot \dot{m} - \left[H + \frac{u^2}{2} + gz\right]^{ut} \cdot \dot{m} + \dot{Q} + \dot{\omega}_{EC} + \dot{\omega}_S$$

$\Delta H = 0$ för strypventil $\Rightarrow$

$\Delta H = C_p \Delta T = 0 \Rightarrow T_2 = T_1$

$$\left.\begin{aligned} u_1 &= V_1 \cdot \frac{\dot{m}^{in}}{A_1} \\ u_2 &= V_2 \cdot \frac{\dot{m}^{ut}}{A_2} \end{aligned}\right\} \quad \frac{u_1}{u_2} = \frac{V_1}{V_2} = \left[V = \frac{RT}{P}\right] = \frac{T_1 P_2}{T_2 P_1}$$

$A_1 = A_2 = A \qquad \dot{m}^{ut} = \dot{m}^{in} \qquad \Rightarrow$

$$u_2 = u_1 \frac{T_1 P_2}{T_2 P_1} = \frac{25 \cdot 2 \cdot 10^6}{0.3 \cdot 10^6} \approx \underline{166.67} \text{ m/s}$$

Utan försumning.

$$0 = \left[H + \frac{u^2}{2} + gz\right]^{in} \cdot \dot{m} - \left[H + \frac{u^2}{2} + gz\right]^{ut} \cdot \dot{m} + \dot{Q} + \dot{\omega}_{EC} + \dot{\omega}_S$$

$$\Delta H = \frac{u_1^2}{2} - \frac{u_2^2}{2} \qquad (1)$$

$$\Delta H = C_p \Delta T \Rightarrow T_2 = \frac{\Delta H}{C_p} + T_1 \qquad (2)$$

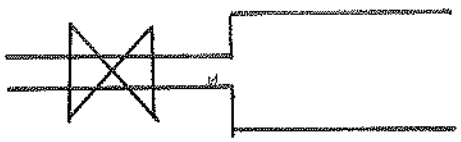
$$u_2 = u_1 \frac{T_1 P_2}{T_2 P_1} \qquad (3)$$

Iteration: $u_2 = 166.67 \overset{(1)}{\Rightarrow} \Delta H \overset{(2)}{\Rightarrow} T_2 \overset{(3)}{\Rightarrow} u_2 \overset{(1)}{\Rightarrow} \Delta H \ldots$

$\Rightarrow T_2 = \underline{17.5}\,^\circ C \qquad u_2 = \underline{160}$ m/s

E.2.26) $P = 10$ bar

$T = 200^\circ C$



a) Värmekapaciteten är försumbar

$$\frac{d}{dt}\left(mU + \frac{mu^2}{2} + mgz\right) = \sum_{in}\left[H + \frac{u^2}{2} + gz\right]\dot{m} - \sum_{ut}\left[H + \frac{u^2}{2} + gz\right]\dot{m} + \dot{Q} + \dot{W}_s + \dot{W}_{ec}$$

$$\Rightarrow \frac{d}{dt}(mU) = H^{in} \cdot \dot{m}^{in}$$

$$\Delta(mU) = \dot{m}_2 U_2 - \cancel{\dot{m}_1}^{\,0} U_1 = \dot{m}_2 U_2$$

$$U_2 \dot{m}_2 = H^{in} \cdot \dot{m}_{in} \Rightarrow \dot{m}_2 = \dot{m}^{in} \Rightarrow U_2 = H^{in}$$

$$H^{in} = H(10\text{ bar}, 200^\circ C) = 2828.3 \text{ kJ/kg}$$

$T_2 = T(10\text{ bar}, U_2)$ Måste interpolera!

$$T_2 = T_A + \frac{T_B - T_A}{U_B - U_A}(U_2 - U_A) \Rightarrow$$

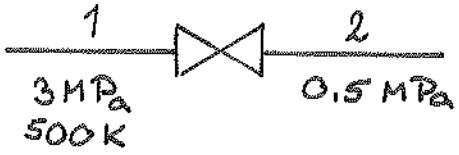
$$T_2 = 300 + \frac{350 - 300}{2875,7 - 2793.6}(2828,3 - 2793,6) = \underline{321}\,^\circ C$$

För att få ut m_2 interpolerar man över volymiteten

$$V_2 = 0.2580 + \frac{0.2825 - 0.2580}{2875,7 - 2793.6}(2828.3 - 2793.6) = 0,2684 \text{ m}^3/\text{kg}$$

$$m_2 = \frac{V}{V} = \underline{3,73} \text{ kg ånga}$$

E. 3.9)



Energibalans: $\frac{d}{dt}(mU) = \dot{m}\,\Delta H = 0$

$\Delta H = \Delta U + R\,\Delta T = 0 \quad \Rightarrow \quad T_1 = T_2$

$\Delta S = -R \ln\left(\frac{P_2}{P_1}\right)$ för en isoterm process $\Rightarrow$

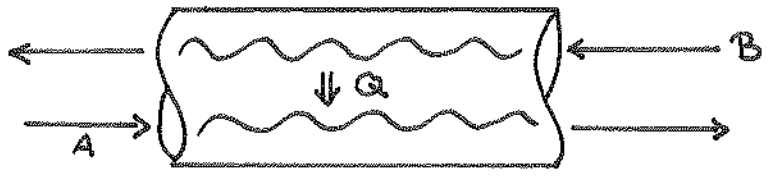
$\Delta S = 14.9 \ J/mol\,K$

Entropibalans:

$\frac{dS}{dt} = \Sigma s^{in} \cdot \dot{m} - \Sigma s^{ut} \cdot \dot{m} + \Sigma Q \cdot T^{-1} + \dot{S}_{gen}$

$\Rightarrow \dot{S}_{gen} = \dot{m}\,\Delta S = \underline{44.7} \ J/mol\,K$

E. 3.11



Steady-state $\Rightarrow$ $\dot{m}_{in} = \dot{m}_{ut} = \dot{m}$

a, Energibalans A:

$$\frac{d}{dt}(nU) = \dot{n}\Delta H + \dot{Q} = 0 \Rightarrow$$

$$\dot{n}\Delta H = \dot{Q}$$

Energibalans B:

$$\frac{d}{dt}(nU) = \dot{n}\Delta H - \dot{Q} = 0 \Rightarrow$$

$$\dot{n}\Delta H = -\dot{Q}$$

$$\Delta S_A = \int C_{P_A} T^{-1} dT \approx 5 \text{ J/mol K}$$

Energibalans vvx:

$$\frac{d}{dt}(nU) = \dot{n}_A \Delta H_A + \dot{n}_B \Delta H_B = 0$$

ideal gas: $\Delta H = \int C_p dT = C_p \Delta T \Rightarrow$

$$\Delta T_B = -\frac{\dot{n}_A C_{PA} \Delta T_A}{\dot{n}_B C_{PB}} = -63.5^\circ C \Rightarrow$$

$$T_{But} = \Delta T_B + T_{Bin} = 116.5^\circ C$$

$$\Delta S_B = \int C_{pB} \cdot T^{-1} dT = -4.39 \ J/molK$$

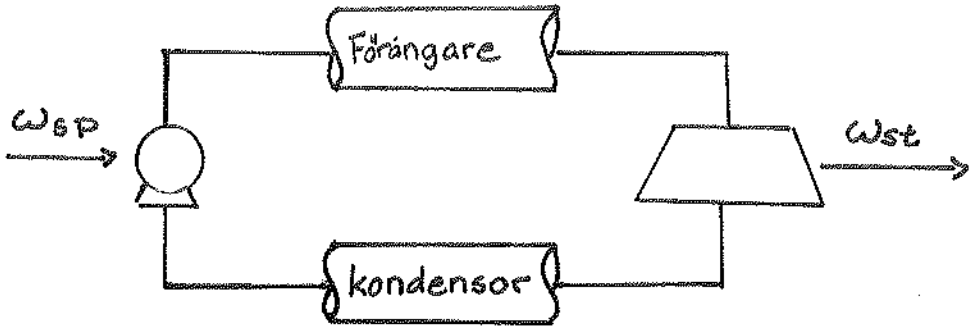
Entropibalans vvx:

$$\dot{S}_{gen} = \dot{n}_A \Delta S_A + \dot{n}_B \Delta S_B \Rightarrow$$

$$\dot{S}_{gen} = \underline{52.42} \ J/molK$$

b, Om strömmarna byter häll blir det precis samma sak

E. 4.13



$T_3 = 600°C$ $\quad\quad$ $\eta_t = 0.8$

$P_3 = 10\ MPa$ $\quad\quad$ $\eta_p = 0.75$

$P_4 = 0{,}01\ MPa$ $\quad\quad$ $\omega_{s,net} = -80\ MW$

$H_3 = H(10MPa, 600°C) = 3625.8\ kJ/kg$ "överhättad ånga"

$S_3 = S(10MPa, 600°C) = 6.9045\ kJ/kg\,K$

$S_4' = S_3 = 6.9045\ kJ/kg\,K$

$S'^{L}(0{,}01\ MPa) = 0.6492\ kJ/kg\,K$

$S'^{V}(0{,}01\ MPa) = 8.1488\ kJ/kg\,K$

$S = S^L + q(S^V - S^L) \Rightarrow q = 0.834$ $\quad$ 83% ånga

$H = H^L + q(H^V - H^L)$

$H_4'^{L} = 191.81\ kJ/kg$

$H_4'^{V} = 2583.86\ kJ/kg$

$\Big\}\ H_4' = 2186.78\ kJ/kg$

$\eta_t = 0.8 = \dfrac{H_4 - H_3}{H_4' - H_3} \Rightarrow H_4 = 2474.58\ kJ/kg$

$H_5 = H(0.01 MPa) = 191.81 \ kJ/kg$ mättad vätska

$H_6 = H_5 + \Delta H_p = H_5 + \omega_{sp}$

$\omega'_{sp} = \int V dP \approx V \Delta P$ reversibel

$V(0.01 MPa) = 0.00101 \ m^3/kg \Rightarrow \omega'_{sp} = 10.0899 \ kJ/kg$

$\eta_p = 0.75 = \frac{\omega'_{sp}}{\omega_{sp}} \Rightarrow \omega_{sp} = 13.45 \ kJ/kg \Rightarrow$

$H_6 = 205.26 \ kJ/kg$

a) $\omega_{st} = H_4 - H_3 = \underline{-1151.2} \ kJ/kg$

b) $\omega_{sp} = \underline{13.45} \ kJ/kg$

c) $\dot{m} = \frac{\omega_{s\,net}}{\omega_{s,net}}$

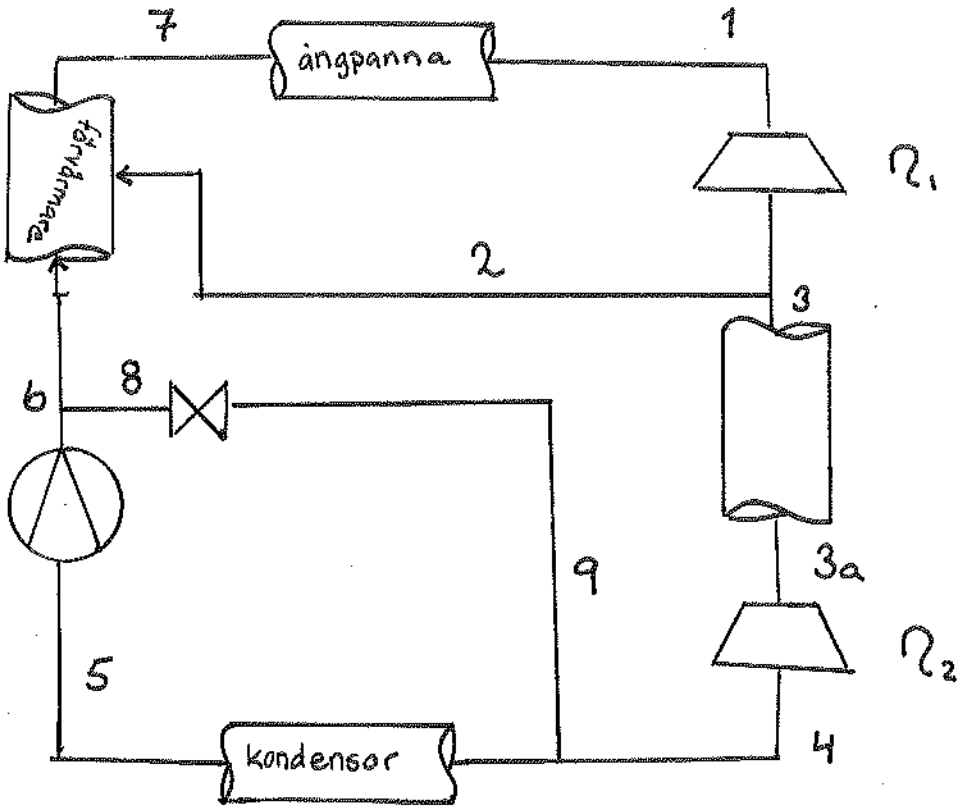
$\omega_{s,net} = \omega_{st} + \omega_{sp} = -1137.75 \ kJ/kg \Rightarrow$

$\dot{m} = \underline{70.3} \ kg/s$

d) $\underline{Q_H} = \dot{m}(H_3 - H_6) = \underline{240} \ kW$

e) $\eta_{term} = -\frac{\omega_{s.net}}{Q_H} = \underline{2.33}$

E.4.43



$\dot{m}_1 = \dot{m}_2 + \dot{m}_3 = \dot{m}_5 = \dot{m}_6 = \dot{m}_7$

$\dot{m}_3 = \dot{m}_4$

$H_1 = H(4\,MPa, 500°C) = 3446\ kJ/kg$

$S_1 = 7.0922\ J/molk$

$S_3' = S_1 = 7.0922\ J/molk$

$H_3' = 2979\ kJ/kg$

$\eta_1 = \frac{H_3 - H_1}{H_3' - H_1} = 0.85 \Rightarrow H_3 = 3049\ kJ/kg$

$H_2 = H_3 = 3049\ kJ/kg$

$H_{3a} = H(0{,}8\,MPa,\ 500°C) = 3481{,}3\ kJ/kg$

$S_{3a} = 7{,}869\ J/mol\,K$

$S_4' = S_{3a} = 7{,}869\ J/mol\,K$

$S_4' = q\,S^v + (1-q)\,S^l \Rightarrow q = \frac{7{,}869 - 0{,}6492}{8{,}1488 - 0{,}6492} = 0{,}963$

$H_4' = q\,H^v + (1-q)\,H^l = 2495\ kJ/kg$

$\eta_2 = \frac{H_4 - H_{3a}}{H_4' - H_{3a}} = 0{,}85 \Rightarrow H_4 = 2643\ kJ/kg$

$H_5 = H(\text{mättad vätska},\ 0{,}01\,MPa) = 191{,}8\ kJ/kg$

$\Delta H = V\Delta P$ vid tryckhöjning av vätska

$V_L = 0{,}001010\ m^3/kg$

$H_6' - H_5 = V_L(4 - 0{,}01)\cdot 10^6 = 4\ kJ/kg$

$\eta_3 = \frac{H_6' - H_5}{H_6 - H_5} = 0{,}8 \Rightarrow H_6 = 196{,}8\ kJ/kg$

Jämviktstemperatur vid $0{,}8\,MPa = 170{,}4°C$

$T_7 = 170{,}4 - 5 = 165{,}4°C$

$H_7 = H^l(165{,}4°C) + V^l(165{,}4°C)\,\Delta P = 702{,}6\ kJ/kg$

$H_8 = H_9 = H^l(0{,}8\,MPa) = 721\ kJ/kg$

	T °C	P MPa	H kJ/kg
1	500	4	3446
2	296	0,8	3049
3'	263	0.8	2979
3	296	0.8	3049
3a	500	0.8	3481
4'	45,8	0,01	2495
4	45,8	0,01	2643
5	45,8	0,01	191,8
6	45,8	4	196,8
7	165,4	4	702,6
8	170,4	0,8	721
9		0,8	721

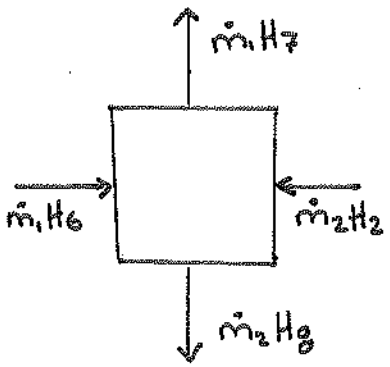
$W_{s,net} = \dot{m}_1(H_3 - H_1) + \dot{m}_3(H_4 - H_{3a}) + \dot{m}_1(H_6 - H_5) = 80\ MW$ (*)

$\dot{m}_3 = \dot{m}_1 - \dot{m}_2$

balans över förvärmare:

$\dot{m}_2 H_2 + \dot{m}_1 H_6 = \dot{m}_1 H_8 + \dot{m}_1 H_7$

$\dot{m}_1(H_6 - H_7) = \dot{m}_2(H_8 - H_2) \Rightarrow$



$\dot{m}_2 = 0.217\,\dot{m}_1 \Rightarrow$

$\dot{m}_3 = 0,783\,\dot{m}_1 \Rightarrow$

$\dot{m}_1 = \underline{76.3\ kg/s}$ (*)

b) $\eta_t = -\frac{\dot{W}_{s,net}}{\dot{Q}_H}$

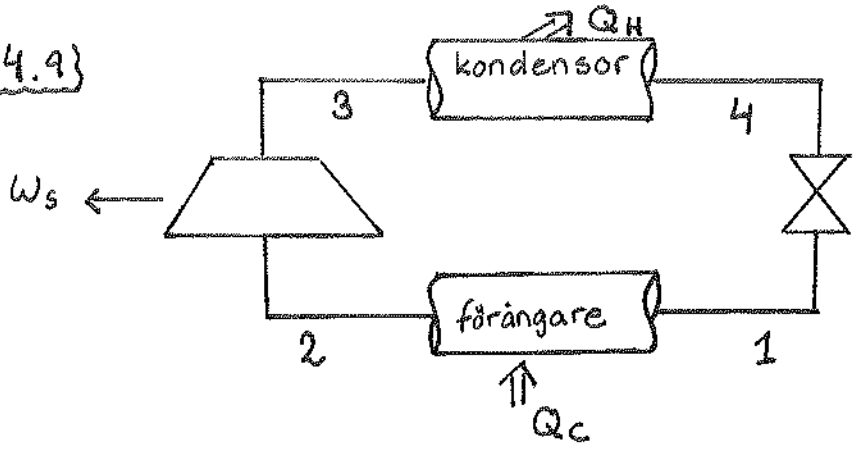
$\dot{W}_{s,net} = 80\ MW$

$\dot{Q}_H = \dot{m}_1 (H_1 - H_4) = 235 \cdot 10^3\ kJ/s \quad \Rightarrow$

$\eta_t = \underline{0,34}$

c) $\dot{W}_{sp} = \dot{m}_1 (H_6 - H_5) = \underline{381.5}\ kW$

E.4.9)



Mättad gas i (2)

Mättad vätska i (4)

$H_4 = 263.72 \text{ kJ/kg}$

$H_1 = H_4 = 263.72 \text{ kJ/kg}$

$H_2 = 392.56 \text{ kJ/kg}$

$S_2 = 1.73 \text{ kJ/kg K}$

$S_3' = S_2 = 1.73 \text{ kJ/kg K}$

$P_3 = P_4 = 1.16 \text{ MPa}$

Mollier diagram för $P = 1.16 \text{ MPa}$ och $S = 1.73 \Rightarrow$

$H_3' = 430 \text{ kJ/kg}$

$\eta = 0.8 = \frac{H_3' - H_2}{H_3 - H_2} \Rightarrow H_3 = 439.36 \text{ kJ/kg}$

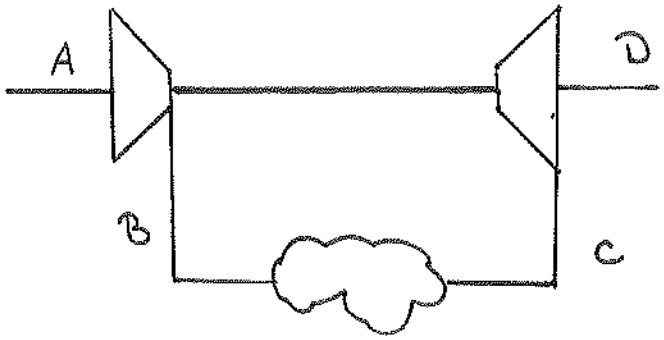
a) $Q_C = H_2 - H_1 = 128.8 \text{ kJ/kg}$

b) $Q_H = H_4 - H_3 = -175.6$

c) $\omega_s = H_3 - H_2 = 46.8 \text{ kJ/kg}$

$$COP = \frac{Q_C}{\omega_s} = \frac{\text{kylning}}{\text{tillfört arbete}} = 2.75$$

E.4.16)



C_p oberoende av T

$Q = C_p(T_C - T_B)$

$W_s = C_p\left((T_D - T_C) - (T_B - T_A)\right)$

$\eta_{te} = -\frac{W_{s,net}}{Q}$

a, $C_p = 0.79\,C_{pN_2} + 0.21\,C_{pO_2} = 29.15\ J/mol\,K$

$T_B' = \left(\frac{P_B}{P_A}\right)^{R/C_p} \cdot T_A = 497\,K$

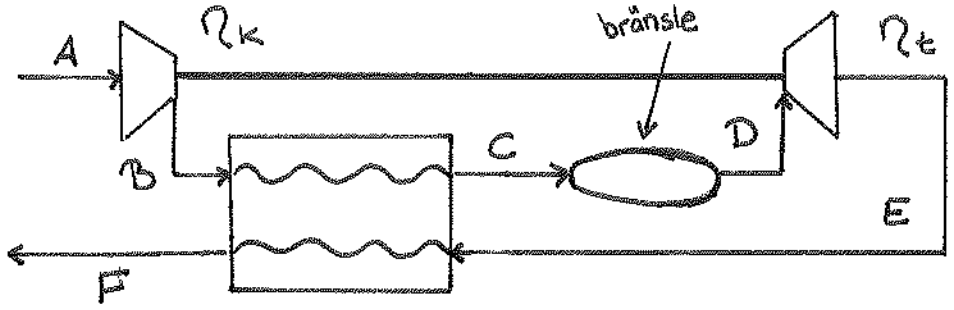
$\eta_C = \frac{T_B' - T_A}{T_B - T_A} = 0.85 \Rightarrow T_B = 532\,K$

$T_D' = \left(\frac{P_B}{P_C}\right)^{R/C_p} \cdot T_C = 584\,K$

$\eta_t = \frac{T_D - T_C}{T_D' - T_C} = 0.85 \Rightarrow T_D = 642\,K$

$W_s = -2828\ J/mol$
$Q = 12855\ J/mol$
} $\eta_{te} = \underline{0.219}$

E. 4.17)



a) $C_p = 0.79 C_{pN_2} + 0.21 C_{pO_2} = 3.506\ R$

$$\eta_{term} = -\frac{\omega_{s,net}}{Q}$$

$$\omega_{s,net} = \omega_{sk} + \omega_{st}$$

$$\omega_{sk} = C_p (T_B - T_A)$$

$$\omega_{st} = C_p (T_E - T_D)$$

$$Q = C_p (T_D - T_C)$$

Adiabatisk kompressor:

$$\frac{T_B'}{T_A} = \left(\frac{P_B}{P_A}\right)^{R/C_p} \Rightarrow T_B' = 497\ K$$

$$\eta_k = 0.85 = \frac{\Delta H'}{\Delta H} = \frac{T_B' - T_A}{T_B - T_A} \Rightarrow T_B = 532\ K$$

adiabatisk turbin:

$$\frac{T_E'}{T_D} = \left(\frac{P_E}{P_D}\right)^{R/C_P} \Rightarrow T_E' = 584\ K$$

$$\eta_t = 0.85 = \frac{\Delta H'}{\Delta H} = \frac{T_E - T_D}{T_E' - T_D} \Rightarrow T_E = 642\ K$$

regenerator:

$$\Delta H_{in} = \Delta H_{ut} \Rightarrow H_B + H_E = H_C + H_F \Rightarrow$$

$$C_P (T_C - T_B) = C_P (T_E - T_F) \Rightarrow T_C = 611\ K$$

$$\omega_{s,net} = -2.8\ kJ/mol$$

$$Q = 10.55\ kJ/mol$$

$$\eta_{term} = \underline{0.27}$$

E. 7.6) $Z = 1 + \frac{aP}{RT}$

a) $\frac{H - H^{ig}}{RT} = -\int T\left(\frac{\partial Z}{\partial T}\right)_P \frac{dP}{P}$

$\left(\frac{\partial Z}{\partial T}\right)_P = \frac{-aP}{RT^2} \Rightarrow$

$\frac{H - H^{ig}}{RT} = \int \frac{a}{RT}\, dP = \frac{aP}{RT}$ V. S. V

b) $\Delta H = (H_2 - H_2^{ig}) + (H_2^{ig} - H_1^{ig}) - (H_1 - H_1^{ig})$

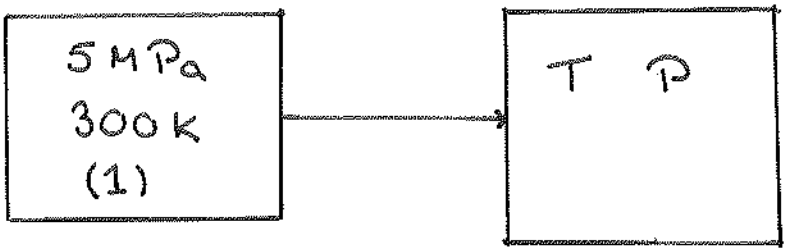
$H_2 - H_2^{ig} = \frac{RT \cdot aP_2}{RT} = aP_2 = -10\ kJ/mol$

$H_1 - H_1^{ig} = aP_1 = -100\ J/mol$

$\Delta H^{ig} = \int C_p\, dT = 15R(400 - 300) = 12471.7\ J/mol$

$\Delta H = \underline{2571.7}\ J/mol$

E. 7.12)

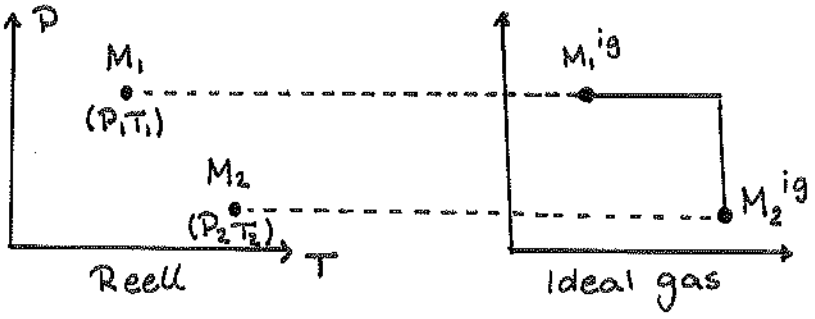


$$Z = \frac{PV}{RT} = 1 + \left(b - \frac{a}{T}\right)\frac{P}{RT}$$

a, $\frac{dU}{dt} = 0 \quad \dot{m}^{in} = \dot{m}^{ut} = 0 \quad \dot{Q} = 0 \quad \dot{\omega}_s = 0 \quad \dot{\omega}_{ec} = 0$

$\frac{dS}{dt} = \dot{S}_{gen}$ (ej reversibelt)

b,



$$\Delta M = M_2 - M_1 = (M_2 - M_2^{ig}) + (M_2^{ig} - M_1^{ig}) - (M_1 - M_1^{ig})$$

$M = U, H, S \ldots$ etc $\Rightarrow$

$$U_2 - U_1 = (U_2 - U_2^{ig}) + (U_2^{ig} - U_1^{ig}) - (U_1 - U_1^{ig}) \qquad (*)$$

Enklare med ideala gaser

$dU^{ig} = C_v^{ig} dT = (C_p^{ig} - R) dT$ $\quad U^{ig}$ oberoende av P

Detta löser mittermen, men avvikelsen reell-ideal är kvar

$$H = U + PV$$

$$\frac{H - H^{ig}}{RT} = \frac{U - U^{ig}}{RT} + \frac{PV - RT}{RT} = \frac{U - U^{ig}}{RT} + Z - 1$$

$$\frac{H - H^{ig}}{RT} = -\int_0^P T\left(\frac{\partial Z}{\partial T}\right)_P \frac{dP}{P} \qquad (7.31)$$

$$Z = \frac{PV}{RT} = 1 + \frac{bP}{RT} - \frac{aP}{RT^2}$$

$$\left(\frac{\partial Z}{\partial T}\right)_P = -\frac{bP}{RT^2} + \frac{2aP}{RT^3} \quad \Rightarrow$$

$$\frac{H - H^{ig}}{RT} = -\int_0^P \left(\frac{2a}{RT^3} - \frac{bP}{RT^2}\right) dP = \frac{P}{RT}\left(b - \frac{2a}{T}\right)$$

$$U - U^{ig} = H - H^{ig} - ZRT + RT = Pb - \frac{2aP}{T} - RT - Pb + \frac{aP}{T} + RT$$

$$\Rightarrow U - U^{ig} = -\frac{aP}{T}$$

idealt: $U_1^{ig} \rightarrow U_2^{ig}$

$$\Delta U^{ig} = \int (C_p - R)\, dT \quad \Rightarrow$$

$$U_2 - U_1 = -a\frac{P_2}{T_2} + \int (C_p - R)\, dT + \frac{aP_1}{T_1} = 0 \qquad (*)$$

$$\Delta U = -a\frac{P_2}{T_2} + 33.526\,(T_2 - T_1) + 0.042\,(T_2^2 - T_1^2) + \frac{aP_1}{T_1} = 0$$

T_2 & P_2 är obekanta $\Rightarrow$ behövs 2 ekvationer

$$V_2 = 2V_1 \qquad \left[V = \frac{RT}{P} + \left(b - \frac{a}{T}\right) \right]$$

$$\frac{RT_2}{P_2} + \left(b - \frac{a}{T_2}\right) = 2\left(\frac{RT_1}{P_1} + \left(b - \frac{a}{T_1}\right) \right)$$

$$P_2 = \left(33.526\,(T_2 - T_1) + 0.042\,(T_2^2 - T_1^2) + \frac{aP_1}{T_1} \right) \frac{T_2}{a} \qquad (**)$$

$$P_2 = \frac{RT_2}{2\left(\frac{RT_1}{P_1} + b - \frac{a}{T_1}\right) - \left(b - \frac{a}{T_2}\right)} \qquad (***)$$

$P_2\,(**) = P_2\,(***) \Rightarrow$ $\quad T_2 = \underline{295}$ K

$\qquad\qquad\qquad\qquad\quad P_2 = \underline{2.77}$ MPa

E. 7.14)

b) $$\frac{H - H^{ig}}{RT} = Z - 1 - \ln\left[\frac{Z + (1+\sqrt{2})B}{Z + (1-\sqrt{2})B}\right]\frac{A}{B\sqrt{8}}\left[1 + \frac{K\sqrt{T_r}}{\sqrt{\alpha}}\right]$$

$K = 0{,}37464 + 1{,}54226\,\omega - 0{,}26993\,\omega^2 = 0.639$

$P_c = 3{,}648 \cdot 10^6\ Pa$

$T_c = 408.1$

$T_r = 1{,}0981$

$b = 0{,}07779607 \cdot R T_c \cdot P_c^{-1} = 7.235 \cdot 10^{-5}$

$\alpha = (1 + K(1 - \sqrt{T_r}))^2 = 0.9397$

$a_c = 0{,}45723553 \cdot R^2 T_c^2 \cdot P_c^{-1} = 1{,}4429$

$a = a_c \alpha = 1.356$

$$A = \frac{aP}{R^2T^2} \qquad B = \frac{bP}{RT}$$

P(atm)	A	B	Z	beräknad ΔH^{ig}	litteratur ΔH^{ig}	Fel %
10	0,099	0,0197	0,9185	-968	-895	8.19
20	0.1979	0,0394	0,8318	-2060	-1906	8,06
35	0,3464	0,0689	0,6884	-4059	-3762	7,91
70	0.6927	0,1377	0,4230	-10270	-10310	-0.44

E.8.9) $f = \varphi P$

$$\ln(\varphi) = \frac{BP}{RT} = \frac{P_r}{T_r}(B^\circ + \omega B')$$

$T_c = 469.7\ K$

$P_c = 3.369\ MPa$

$\omega = 0.249$

$$T_r = \frac{T}{T_c} = 0.788$$

$$B^\circ = 0.083 - \frac{0.422}{T_r^{1.6}} = -0.5348$$

$$B' = 0.139 - \frac{0.172}{T_r^{4.2}} = -0.3289 \Rightarrow$$

$\varphi = 0.8499 \Rightarrow$

$f = \underline{0.6}\ MPa$

E.9.1) 47,23 % etylbromid ⇒ 52.77 % n-heptan

$P_b = x_1 P_1^{sat} + x_2 P_2^{sat}$

$P_1^{sat} = 0.7569$ bar etylbromid

$P_2^{sat} = 0.0773$ bar n-heptan ⇒

$P_b = 0,398$ bar

$K_i = \frac{y_i}{x_i} = \frac{P_i^{sat}}{P}$ ⇒ $y_i P = x_i P_i^{sat}$ ⇒

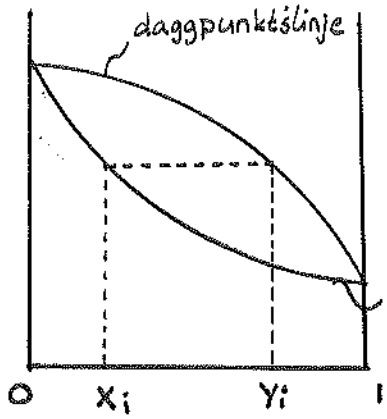
$y_1 = \underline{0.898}$ etylbromid

$y_2 = \underline{0.102}$ n-heptan ⇒

89.8 % etylbromid 10.2 % n-heptan

$\frac{P_b}{P_{bexp}} = \underline{0.877}$ ⇒ 87,7 % av experimentella

E.9.4) 50 % n-pentan (p) 50 % n-butan (b)



x_i = molfraktion vätskefas

y_i = molfraktion gasfas

$z = x_i + y_i$

$$K_i = \frac{y_i}{x_i} \qquad T_{r,i} = \frac{T}{T_{c,i}}$$

Raults lag: $y_i P = x_i P^{sat}$

ideal blandning $\Rightarrow P = z_b P_b^* + z_p P_p^* \Rightarrow$

$$K_i = \frac{P^{sat}}{P}$$

$$K_i = \frac{P_{c,i} \cdot 10^{7/3 (1+\omega)(1-T_r^{-1})}}{P} \qquad (9.50)$$

	P_c (MPa)	T_c (K)	ω	z_i
b	3.797	425.2	0.193	0.5
p	3.369	469.7	0.249	0.5

$$K_b(T) = \frac{3.797 \cdot 10^{7/3\,(1+0.193)\left(1-\frac{425.2}{T}\right)}}{1.4}$$

$$K_p(T) = \frac{3.369 \cdot 10^{7/3\,(1+0.249)\left(1-\frac{469.7}{T}\right)}}{1.4}$$

Tillvägagångssätt:

1, Beräkna K_b och K_p vid valfri temperatur T

2, Beräkna $\sum y_i \cdot x_i^{-1}$

3, Om rätt: $\sum y_i \cdot x_i^{-1} = 1$ annars gissa nytt T

$\Rightarrow$ $K_b = 1.72$ $K_p = 0.704$ $T = 397\ K$

Daggpunkt: $397\ K \Rightarrow 138\ K$

x_i (daggpunkt):

$$x_i = \frac{y_i}{K_i} \Rightarrow x_b = \underline{0.29} \quad x_p = \underline{0.71}$$

E.11.6) aceton (1) + metanol (2) $T = 50^\circ C$

Excessfunktion = avvikelse från ideal lösning

$V^E = V - V^{ig} = V - \sum x_i V_i$

$G^E = G - G^{ig} = RT \sum x_i \ln(\gamma_i)$

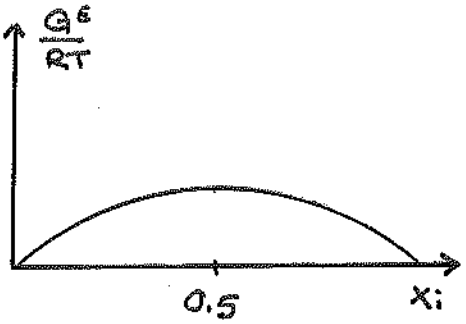
$\gamma_i \to 1 \Rightarrow G^E \to 0$

Margules ekvation

$\frac{G^E}{RT} = A x_1 x_2 \qquad A = 0.605$

$\ln(\gamma_1) = A x_2^2$

$\ln(\gamma_2) = A x_1^2$



a) $y_i P = x_i \gamma_i P_i^{sat}$ (11-2)

$\sum y_i = 1 \Rightarrow P = \gamma_1 x_1 P_1^{sat} + \gamma_2 x_2 P_2^{sat}$

$\log(P^{sat}) = A - \frac{B}{T+C}$ (Antoine's ekvation) (mm Hg)

Värden på konstanterna finns i E/L $\Rightarrow$

$P_1^{sat} = 81902\ Pa$

$P_2^{sat} = 55540\ Pa$

$\ln(\gamma_1) = A x_2^2 = 0.15125 \Rightarrow \gamma_1 = 1.1632 = \gamma_2$

$P_{bubbel} = x_1 \gamma_1 P_1^{sat} + x_2 \gamma_2 P_2^{sat} = \underline{80}\ kPa$

E. 11.11)

	T_c	P_c	ω
etanol (1)	516.4	6.384	0.637
1-propanol (2)	536.7	5.17	0.628

a) $\frac{G^E}{RT} = x_1 \ln(\gamma_1) + x_2 \ln(\gamma_2)$

$\gamma_i = \frac{y_i P}{x_i P_i^{sat}}$

Antoine

$\log_{10} P^{sat} = A - \frac{B}{T+C}$

$\log_{10} P_1^{sat} = 8.1122 - \frac{1592.864}{55 + 226.184} \Rightarrow P_1^{sat} = 280.126 \text{ mmHg}$

$\log_{10} P_2^{sat} = 8.37895 - \frac{1788.02}{55 + 227.438} \Rightarrow P_2^{sat} = 111.759 \text{ mmHg}$

$P_1^{sat} = 280.126 \text{ mmHg} = 37347.13 \text{ Pa}$

$P_2^{sat} = 111.759 \text{ mmHg} = 14900.1 \text{ Pa} \Rightarrow$

$\gamma_1 = 1.1363$

$\gamma_2 = 2.5144$

$$\frac{G^E}{RT} = x_1 \ln(\gamma_1) + x_2 \ln(\gamma_2) = 0.3513$$

$$\frac{G^E}{RT} = A x_1 x_2 = 0.3513 \Rightarrow A = 1.737$$

$\underline{x_1 = 0.1} \Rightarrow$

$$\gamma_1 = \exp(A x_2^2) = 4.08$$
$$\gamma_2 = \exp(A x_1^2) = 1.0175$$

$$y_1 P = \gamma_1 x_1 P_1^{sat} = 15237.63$$
$$y_2 P = \gamma_2 x_2 P_2^{sat} = 13645.09$$

$$P_{bubbel} = y_1 P + y_2 P = \underline{28.88} \text{ kPa}$$

E.14.6) $C_2H_4 + H_2O \rightleftharpoons C_2H_5OH$ ((1) + (2) ⇌ (3))

a)

	$\Delta_f G_{298}$	$\Delta_f H_{298}$
1	68.43	52.51
2	-228.614	-241.835
3	-167.73	-234.95

$$\Delta G^{\circ}_{298} = \sum \nu_i \Delta_f G^{\circ}_{298} = -7.546 \text{ kJ/mol}$$

$$\Delta H^{\circ}_{298} = \sum \nu_i \Delta_f H^{\circ}_{298} = -45.625 \text{ kJ/mol}$$

Van't Hoff

$$\ln\left(\frac{K_a}{K_{a,R}}\right) = -\frac{\Delta H^{\circ}_R}{R}\left(\frac{1}{T} - \frac{1}{T_R}\right) \Rightarrow$$

$$K_{a,R} = \exp\left(\frac{-\Delta G^{\circ}}{RT}\right) = 20.993$$

$$\ln\left(\frac{K_a}{K_{aR}}\right) = -4.62 \Rightarrow K_a = \underline{0.207}$$

b, $\dot{n}_i^{ut} = \dot{n}_i^{in} - \nu_i \dot{\xi}$

	in	ut
1	1	$1-\xi$
2	3	$3-\xi$
3	0	ξ
		$n_{tot} = 4-\xi$

$$\left.\begin{aligned} y_1 &= \frac{1-\xi}{4-\xi} \\ y_2 &= \frac{3-\xi}{4-\xi} \\ y_3 &= \frac{\xi}{4-\xi} \end{aligned}\right\} \quad K_a = \frac{y_3}{y_1 y_2} = \frac{\xi(4-\xi)}{(1-\xi)(3-\xi)} = 0.207$$

$$1.206\,\xi^2 - 4.824\,\xi + 0.618 = 0 \Rightarrow \xi = \underline{0.132}$$