11.1

a) $P = \frac{nRT}{V} = \frac{\frac{10^6}{18.02} \cdot 8{,}31 \cdot 633}{23.3} = 125 \cdot 10^5\ Pa$

$= 125\ bar$

b) $P = \frac{\bar{R}T}{\bar{v}-b} - \frac{a}{\bar{v}^2}$; a en b uit tabel A24

$= 103{,}76\ bar$

c) $p = \frac{\bar{R}T}{\bar{v}-b} - \frac{a}{\bar{v}(\bar{v}+b)\sqrt{T}}$; a en b uit tabel A-24

$= 101{,}34\ bar$

d) tabel A1 : $T_c = 647{,}3K$; $P_c = 220{,}9\ bar$

$T_R = T/T_c = \frac{633}{647{,}3} = 0{,}9779$; $V_R' = \frac{\bar{v}P_c}{\bar{R}T_c} = 1{,}724$

from Fig A-1 $\Rightarrow Z \approx 0.81 \Rightarrow P = \frac{ZRT}{v} = 101.40\ bar$

e) table A4 $\rightarrow$ 100 bar

11.13

$$\left(\frac{\partial p}{\partial V}\right)_T = \frac{-RT}{(V-b)^2}\exp\left(\frac{-a}{RTV}\right) + \frac{RT}{V-b}\exp\left(\frac{-a}{RTV}\right)\cdot\frac{a}{RTV^2}$$

$$= \frac{-RT}{(V-b)^2}\exp\left(\frac{-a}{RTV}\right) + \frac{a}{V^2(V-b)}\exp\left(\frac{-a}{RTV}\right)$$

$$\left(\frac{\partial^2 p}{\partial V^2}\right)_T = \frac{2RT}{(V-b)^3}\exp\left(\frac{-a}{RTV}\right) - \frac{a}{V^2(V-b)^2}\exp\left(\frac{-a}{RTV}\right) -$$

$$\frac{a(3V-2b)}{V^3(V-b)^2}\exp\left(\frac{-a}{RTV}\right) + \frac{a^2}{RTV^4(V-b)}\exp\left(\frac{-a}{RTV}\right)$$

uit $\left(\frac{\partial p}{\partial V}\right)_T = 0$ volgt: $0 = \frac{-RT_c}{V_c-b} + \frac{a}{V_c^2} \Rightarrow$

$$a = \frac{RT_c V_c^2}{V_c-b}$$

uit $\left(\frac{\partial^2 p}{\partial V^2}\right)_T = 0$ volgt: $0 = \frac{2RT_c}{(V_c-b)^2} - \frac{a}{V_c^2(V_c-b)}$

$$-\frac{a(3V_c-2b)}{V_c^3(V_c-b)} + \frac{a^2}{RT_cV_c^4}$$

invullen levert $b = V_c/2$ dus $a = 2RT_cV_c$

11.16

$$dp = \left(\frac{\partial p}{\partial V}\right)_T dV + \left(\frac{\partial p}{\partial T}\right)_V dT$$

De volgorde van differentieren mag niet uitmaken,

dus $\dfrac{\partial^2 p}{\partial V \partial T} = \dfrac{\partial^2 p}{\partial T \partial V}$

voor a) $\dfrac{\partial \frac{2(V-b)}{RT}}{\partial T} = \dfrac{-2(V-b)}{RT^2}$

$\dfrac{\partial (V-b)^2/RT^2}{\partial V} = \dfrac{2(V-b)}{RT^2}$ } ongelijk!

b) $\dfrac{\partial \frac{-RT}{(V-b)^2}}{\partial T} = -\dfrac{R}{(V-b)^2}$

$\dfrac{\partial \frac{R}{V-b}}{\partial V} = \dfrac{-R}{(V-b)^2}$ } OK!

③

voor b) weten we: $\left(\frac{\partial p}{\partial T}\right) = \frac{R}{V-b}$ dus $p = \frac{RT}{V-b} + f(V)$

Waarin $f(V)$ een of andere functie van V is

echter: $\left(\frac{\partial p}{\partial V}\right)_T = \frac{-RT}{(V-b)^2} + f'(V) \Rightarrow$ invullen levert $f'(V) = 0$

11.19

Uit $dH = -SdT + Vdp$ volgt direct

$$\left(\frac{\partial V}{\partial T}\right)_p = -\left(\frac{\partial S}{\partial p}\right)_T$$

dus $T = 4°C \Rightarrow \left(\frac{\partial S}{\partial p}\right)_T = 0$

$T < 4°C \Rightarrow \left(\frac{\partial S}{\partial p}\right)_T > 0$

$T > 4°C \Rightarrow \left(\frac{\partial S}{\partial p}\right)_T < 0$

11.20

Uit $dH = TdS + Vdp$ volgt direct

$V = \left(\frac{\partial H}{\partial p}\right)_S$; $V > 0$ dus als p toeneemt, neemt H ook toe

11.22

$$\psi = F = -RT \ln\frac{V}{V'} - cT'\left[1 - \frac{T}{T'} + \frac{T}{T'}\ln\frac{T}{T'}\right]$$

$$p = -\left(\frac{\partial F}{\partial V}\right)_T = \frac{RT}{V}$$

$$S = -\left(\frac{\partial F}{\partial T}\right)_V = R\ln\frac{V}{V'} + c\ln\frac{T}{T'}$$

$$U = F + TS = c\left[T - T'\right]$$

$$H = U + PV = c\left[T - T'\right] + RT$$

$$C_V = \left(\frac{\partial U}{\partial T}\right)_V = C$$

$$C_p = \left(\frac{\partial H}{\partial T}\right)_p = C + R$$

11.34

a) $T_t = 0.01^\circ C$; $P_t = 0.6113$ kPa

uit tabel A6: $h_{ig} = 2834.8$ kJ/kg

$v_g = 206.1$ m³/kg

$v_s = 1.0908$ m³/kg

uit tabel A2: $v_g = 206.136$ m³/kg

$v_e = 1.0002$ m³/kg

$h_{fg} = 2501.3$ kJ/kg

Clapeyron eq.: $\left(\frac{dp}{dT}\right)_{sat} = \frac{\Delta h}{T \Delta v}$

$$\frac{(dp/dT)_{subl}}{(dp/dT)_{vap}} = \frac{2834.8(206.1 - 1.0908)}{2501.3(206.136 - 1.0002)} = 1.134$$

b) $\left(\frac{\partial s}{\partial T}\right)_v = \frac{c_v}{T}$; $\left(\frac{\partial s}{\partial T}\right)_p = \frac{c_p}{T}$

$$\Rightarrow \frac{(\partial T/\partial s)_v}{(\partial T/\partial s)_p} = \frac{T/c_v}{T/c_p} = \frac{c_p}{c_v} = k > 1$$

7

11.34

c) uit $dH = TdS + Vdp$

volgt $\left(\frac{\partial h}{\partial s}\right)_p = T$

d) uit $dH = TdS + Vdp$ volgt

$$\left(\frac{\partial h}{\partial P}\right)_S = V \quad \text{dus} \quad \left(\frac{\partial p}{\partial h}\right)_S = \frac{1}{V}$$

8

11.35

$V_{①} = 0.2\ m^3$; $V_{②} = 0.4\ m^3$

① = toestand 1 ; ② = toestand 2

De temperatuur van ① en ② kan verschillend zijn.

allereerst: $C_V = \left(\frac{\partial U}{\partial T}\right)_V$

Hangt C_V van het volume af?

$$F = U - TS \Rightarrow \left(\frac{\partial F}{\partial V}\right)_T = \left(\frac{\partial U}{\partial V}\right)_T - T\left(\frac{\partial S}{\partial V}\right)_T$$

$$-p = \left(\frac{\partial U}{\partial V}\right)_T - T\left(\frac{\partial p}{\partial T}\right)_V$$

$$\Rightarrow \frac{\partial C_V}{\partial V} = \frac{\partial}{\partial V}\left(\left(\frac{\partial U}{\partial T}\right)_V\right)_T = \frac{\partial}{\partial T}\left(\left(\frac{\partial U}{\partial V}\right)_T\right)_V$$

$$= T\left(\frac{\partial^2 p}{\partial T^2}\right)_V$$

voor ideaal gas en vdW gas $\Rightarrow \left(\frac{\partial C_V}{\partial V}\right)_T = 0$

voor het proces van ① naar ② geldt dat $\Delta U = 0$

11.35

Aangezien C_v niet van het volume afhangt

$$\Delta U = \int_{①}^{②} C_v \, dT + \int_{①}^{②} \left[T\left(\frac{\partial p}{\partial T}\right)_V - p \right] dV$$

gebruikmakend van 11.47 en 11.51

Voor argon geldt: $C_v \approx \frac{3}{2} R$

Invullen voor een ideaal gas levert:

$$\Delta U = 0 = \frac{3}{2} R \left[T_2 - T_1 \right] \Rightarrow T_1 = T_2 = 300K$$

Voor een vdW gas:

$$\frac{3}{2} R \left[T_2 - T_1 \right] = a \left[\frac{1}{V_2} - \frac{1}{V_1} \right]$$

(immers voor een vdW gas $T\left(\frac{\partial p}{\partial T}\right)_V - p = \frac{a}{V^2}$)

Gebruik makend van
Eq. 11.4a en tabel A-1 levert $T_2 = 272,6 K$

11.36

$$C_p - C_v = \left(\frac{\partial H}{\partial T}\right)_p - \left(\frac{\partial U}{\partial T}\right)_V \quad (H = U + PV)$$

$$= \left(\frac{\partial U}{\partial T}\right)_p + P\left(\frac{\partial V}{\partial T}\right)_p - \left(\frac{\partial U}{\partial T}\right)_V$$

U als functie van T en V

$$dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV$$

V als functie van T en P

$$dV = \left(\frac{\partial V}{\partial T}\right)_p dT + \left(\frac{\partial V}{\partial p}\right)_T dp$$

invullen

$$dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_p dT + \left(\frac{\partial U}{\partial V}\right)_T \left(\frac{\partial V}{\partial P}\right)_T dp$$

P constant houden ($dp = 0$)

$$\left(\frac{\partial U}{\partial T}\right)_p = \left(\frac{\partial U}{\partial T}\right)_V + \left(\frac{\partial U}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_p$$

11.36 vervolg

Invullen: $C_p - C_v = p\left(\frac{\partial v}{\partial T}\right)_p + \left(\frac{\partial u}{\partial v}\right)_T \left(\frac{\partial v}{\partial T}\right)_p$

$$\left(\frac{\partial u}{\partial v}\right)_T = T\left(\frac{\partial p}{\partial T}\right)_v - p \quad (11.47)$$

Invullen

$$C_p - C_v = T\left(\frac{\partial p}{\partial T}\right)_v \left(\frac{\partial v}{\partial T}\right)_p$$

Invullen $p = \frac{RT}{v-b}$ levert $C_p = C_v + R$

11.37

a) uit $dG = -SdT + Vdp$ volgt $\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$

voor dit systeem: $\left(\frac{\partial V}{\partial T}\right)_P = \frac{R}{P} + \frac{A}{RT^2}$

$$S(P_2, T) - S(P_1, T) = \int_{P_1}^{P_2} \left(\frac{\partial S}{\partial P}\right)_T dp$$

$$= \int_{P_1}^{P_2} -\left(\frac{\partial V}{\partial t}\right)_P dp = -R \ln \frac{P_2}{P_1} - \frac{A}{RT^2}\left[P_2 - P_1\right]$$

$$h(P_2, T) - h(P_1, T) = \int_{P_1}^{P_2} \left(\frac{\partial h}{\partial P}\right)_T dp$$

$\left(\frac{\partial h}{\partial P}\right)_T$?? $\Rightarrow$ $G = H - TS$

$$\left(\frac{\partial G}{\partial P}\right)_T = \left(\frac{\partial H}{\partial P}\right)_T - T\left(\frac{\partial S}{\partial P}\right)_T$$

$$V = \left(\frac{\partial H}{\partial P}\right)_T + T\left(\frac{\partial V}{\partial T}\right)_P$$

$$\Rightarrow \left(\frac{\partial H}{\partial P}\right)_T = V - T\left(\frac{\partial V}{\partial T}\right)_P$$

11.37 vervolg

$$h(P_2,T) = h(P_1,T) + \int_{P_1}^{P_2} \left[V - T\left(\frac{\partial V}{\partial T}\right)_P \right] dp$$

$$= h(P_1,T) + \int_{P_1}^{P_2} \left[B - \frac{2A}{RT} \right] dp$$

$$= h(P_1,T) + \left(B - \frac{2A}{RT} \right)\left(P_2 - P_1 \right)$$

$$u(P_2,T) - u(P_1,T) = h(P_2,T) - h(P_1,T)$$

$$- P_2 V_2(P_2,T) + P_1 V(P_1,T)$$

(immers, $H = U + PV$)

Invullen levert $u(P_2,T) - u(P_1,T) = -\frac{A}{RT}(P_2 - P_1)$

11.42

$$\frac{\Delta V}{V} = -0.001$$

$$K = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T \Rightarrow \left(\frac{\partial V}{\partial p}\right)_T = -KV$$

Aanname:

$$\Delta V = \int_{P_1}^{P_2}\left(\frac{\partial V}{\partial p}\right)_T dp = \int_{P_1}^{P_2}(-K\cdot V)\,dp$$

$$\approx -K\cdot V\cdot \Delta p$$

$$\Rightarrow \frac{\Delta V}{V} \approx -K\cdot \Delta p$$

Indien $\frac{\Delta V}{V} = -0.001$, dan $\Delta p = 1209$ bar

Opmerking: de parameters ρ en β zijn niet nodig om de som te maken

11.42

alternatieve oplossing:

$$\left(\frac{\partial V}{\partial p}\right)_T = -\kappa \cdot V \Rightarrow \left(\frac{\partial \ln V}{\partial p}\right)_T = -\kappa$$

$$\Rightarrow \ln\frac{V_2}{V_1} = -\kappa\Delta p \Rightarrow V_2 = V_1 \exp(-\kappa \cdot \Delta p)$$

$$\Rightarrow \Delta V = V_2 - V_1 = V_1\left[\exp(-\kappa\Delta p) - 1\right]$$

$$\frac{\Delta V}{V_1} = -0.001 \Rightarrow \exp(-\kappa\Delta p) = 0.999$$

$$\Rightarrow \Delta p = 1209 \text{ bar}$$

de oplossingen zijn identiek omdat voor kleine x: $\exp(x) \approx 1 + x$

11.43

$$\kappa = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T \quad ; \quad \beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_p$$

ideaal gas: $pV = nRT$

$$\left(\frac{\partial V}{\partial T}\right)_p = \frac{nR}{p} \quad ; \left(\frac{\partial V}{\partial p}\right)_T = \frac{-nRT}{p^2} = -\frac{pV}{p^2} = -\frac{V}{p}$$

$$\Downarrow$$

$$\kappa = \frac{1}{p}$$

$$\beta = \frac{1}{V}\frac{pV}{T \cdot p} = \frac{1}{T}$$

gas waarvoor $p = \frac{RT}{V-b} \Rightarrow V = b + \frac{RT}{p}$

$$\left(\frac{\partial V}{\partial T}\right)_p = \frac{R}{p} \Rightarrow \beta = \frac{1}{V}\frac{R}{p} = \frac{1}{V}\frac{R(V-b)}{RT}$$

$$= \frac{1}{T}\frac{V-b}{V}$$

$$\left(\frac{\partial V}{\partial P}\right)_T = -\frac{RT}{p^2} \Rightarrow \kappa = \frac{RT}{Vp^2} = \frac{1}{p}\frac{V-b}{V}$$

opmerking: als $b = 0$ krijgen we het resultaat voor een ideaal gas

11.43 vervolg

vdW: $p = \frac{RT}{v-b} - \frac{a}{v^2}$

$\left(\frac{\partial v}{\partial T}\right)_p$?? $\Rightarrow$ gebruik min 1 regel (example 11.2)

$$\left(\frac{\partial v}{\partial T}\right)_p \left(\frac{\partial T}{\partial p}\right)_v \left(\frac{\partial p}{\partial v}\right)_T = -1$$

$$\Rightarrow \left(\frac{\partial v}{\partial T}\right)_p = -\left(\frac{\partial p}{\partial T}\right)_v \Big/ \left(\frac{\partial p}{\partial v}\right)_T$$

$$= \frac{-R/(v-b)}{-RT/(v-b)^2 + 2a/v^3} \quad \text{(invullen)}$$

$$\Rightarrow \beta = \frac{-R(v-b)v^2}{2a(v-b)^3 - RTv^3}$$

Idem $\left(\frac{\partial v}{\partial p}\right)_T = \frac{-\left(\frac{\partial v}{\partial T}\right)_p}{\left(\frac{\partial p}{\partial T}\right)_v}$

$$\Rightarrow \kappa = \frac{-v^2(v-b)^2}{2a(v-b)^2 - RTv^3}$$

11.46

Schrijf V als functie van T en P

$$dV = \left(\frac{\partial V}{\partial T}\right)_P dT + \left(\frac{\partial V}{\partial P}\right)_T dP$$

$$= (V\beta)\, dT + (-V\kappa)\, dP$$

Maxwell (volgorde differentieren maakt niet uit)

$$\left(\frac{\partial (V\beta)}{\partial P}\right)_T = \left(\frac{\partial(-V\kappa)}{\partial T}\right)_P$$

$$\Rightarrow \beta\left(\frac{\partial V}{\partial P}\right)_T + V\left(\frac{\partial \beta}{\partial P}\right)_T = -V\left(\frac{\partial \kappa}{\partial T}\right)_P - \kappa\left(\frac{\partial V}{\partial T}\right)_P$$

$$\frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P\left(\frac{\partial V}{\partial P}\right)_T + V\left(\frac{\partial \beta}{\partial P}\right)_T = -V\left(\frac{\partial \kappa}{\partial T}\right)_P + \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P\left(\frac{\partial V}{\partial P}\right)_T$$

$$\Rightarrow \left(\frac{\partial \beta}{\partial P}\right)_T = -\left(\frac{\partial \kappa}{\partial T}\right)_P$$

11.48

$\left(\frac{\partial T}{\partial p}\right)_S$?? $\Rightarrow$ min 1 regel

$$\left(\frac{\partial T}{\partial p}\right)_S \left(\frac{\partial S}{\partial T}\right)_p \left(\frac{\partial p}{\partial S}\right)_T = -1$$

uit $dG = -SdT + Vdp$ volgt $\left(\frac{\partial S}{\partial p}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_p$

en $\left(\frac{\partial S}{\partial T}\right)_p = \frac{C_p}{T}$

dus $\left(\frac{\partial T}{\partial p}\right)_S = \frac{T}{C_p}\left(\frac{\partial V}{\partial T}\right)_p = \frac{TV\beta}{C_p}$

aanname : $\beta, C_p, \bar{V}$ zijn constant en ΔT is klein

$$\Rightarrow \Delta T = \Delta p \cdot \frac{TV\beta}{C_p}$$

invullen levert $\Delta T = 2.55\ K$

11.50

a) $$\left(\frac{\partial C_V}{\partial V}\right)_T = \frac{\partial}{\partial V}\left[\left(\frac{\partial U}{\partial T}\right)_V\right]_T = \frac{\partial}{\partial T}\left[\left(\frac{\partial U}{\partial V}\right)_T\right]_V$$

$$= \frac{\partial}{\partial T}\left[T\left(\frac{\partial p}{\partial T}\right)_V - p\right]_p = T\left(\frac{\partial^2 p}{\partial T^2}\right)_V$$

vdWaals EOS: $\left(\frac{\partial p}{\partial T}\right)_V = \frac{R}{V-b}$; $\frac{\partial^2 p}{\partial T^2} = 0 \Rightarrow \left(\frac{\partial C_V}{\partial V}\right)_T = 0$

b) start met eq. 11.60

zie Exercise 11.2 voor $\left(\frac{\partial V}{\partial T}\right)_p$

Invullen

$$C_p - C_V = -T\left[\frac{R/(V-b)}{2a/V^2 - RT/(V-b)^2}\right]^2\left[\frac{2a}{V^3} - \frac{RT}{(V-b)^2}\right]$$

$$= \frac{R}{1 - 2a(V-b)^2/RTV^3}$$

c) $$S(T_2,V_2) - S(T_1,V_1) = \int_{T_1}^{T_2}\frac{C_V}{T}dT + \int_{V_1}^{V_2}\frac{R}{V-b}dV = \int_{T_1}^{T_2}\frac{C_V}{T}dT + R\ln\left(\frac{V_2-b}{V_1-b}\right)$$

$$U(T_2,V_2) - U(T_1,V_1) = \int_{T_1}^{T_2} C_V\,dT + \int_{V_1}^{V_2}\left[T\left[\frac{R}{V-b}\right] - \left(\frac{RT}{V-b} - \frac{a}{V^2}\right)\right]dV$$

11.50 vervolg

$$\ldots = \int_{T_1}^{T_2} C_v dT - a\left[\frac{1}{V_2} - \frac{1}{V_1}\right]$$

d) $$\Delta S = \int_{T_1}^{T_2} \frac{a+bT}{T} dT + R \ln \frac{V_2 - b}{V_1 - b} = a \ln \frac{T_2}{T_1} + b(T_2 - T_1) + R \ln \frac{V_2 - b}{V_1 - b}$$

$$\Delta U = \int_{T_1}^{T_2} (a+bT) dT - a\left[\frac{1}{V_2} - \frac{1}{V_1}\right] = a(T_2 - T_1) + b(T_2^2 - T_1^2) - a\left[\frac{1}{V_2} - \frac{1}{V_1}\right]$$

11.69

Energiebalans: $\frac{\dot{W}_{cv}}{\dot{m}} = \cancel{\frac{\dot{Q}_{cv}}{\dot{m}}} + h_1 - h_2$

$$\Rightarrow \frac{\dot{W}_{cv}}{\dot{m}} = h_1 - h_2$$

voor een ideaal gas:

$$\frac{\dot{W}_{cv}}{\dot{m}} = \frac{1}{M}\left[c_{p0}(T_1 - T_2)\right] = 163.7\ \frac{kJ}{kg}$$

molmassa

niet ideaal gas: $T_{R1} = \frac{300}{191} = 1.57$ $T_{R2} = \frac{225}{191} = 1.18$

tabel A-1

$P_{R1} = \frac{100}{46.4} = 2.16$ $P_{R2} = \frac{20}{46.4} = 0.43$

Uit figuur A-4 (zie tabellen blackboard)

$$\left(\frac{\bar{h}^* - \bar{h}}{\bar{R}T_c}\right)_1 = 1 \qquad \left(\frac{\bar{h}^* - \bar{h}}{\bar{R}T_c}\right)_2 = 0.34$$

$$h_1 - h_2 = \frac{1}{M}\left[c_{p0}(T_1 - T_2) - \bar{R}T_c\left[\left(\frac{\bar{h}^* - \bar{h}}{\bar{R}T_c}\right)_1 - \left(\frac{\bar{h}^* - \bar{h}}{\bar{R}T_c}\right)_2\right]\right]$$

11.69 analog

invullen in $\frac{\dot{W}_{cv}}{\dot{m}} = h_1 - h_2$

levert $\frac{\dot{W}_{cv}}{\dot{m}} = 900.3 \ kJ/kg$

11.70

$$\frac{\dot{Q}_{cv}}{\dot{m}} = \frac{\dot{W}_{cv}}{\dot{m}} + (h_2 - h_1)$$

data uit tabel A-1 ($M = 28.01$ g/mol, $T_c = 126$ K
$P_c = 33.9$ bar)

$$T_{R1} = \frac{300}{126} = 2.38 \quad T_{R2} = \frac{500}{126} = 3.97$$

$$P_{R1} = \frac{15}{33.9} = 0.44 \quad P_{R2} = \frac{50}{33.9} = 2.36$$

uit figure A4

$$\left(\frac{\bar{h}^* - \bar{h}}{\bar{R}\,T_c}\right)_1 = 0.12 \quad \left(\frac{\bar{h}^* - \bar{h}}{\bar{R}\,T_c}\right)_2 = 0.09$$

Tabel A-23 $\bar{h}_1^* = 8723$ kJ/kmol $\bar{h}_2^* = 14{,}581$ $\frac{kJ}{kmol}$

$$h_2 - h_1 = \frac{1}{M}\left[\bar{h}_2^* - \bar{h}_1^* - \bar{R}T_c\left[\left(\frac{\bar{h}^* - \bar{h}}{\bar{R}T_c}\right)_2 - \left(\frac{\bar{h}^* - \bar{h}}{\bar{R}T_c}\right)_1\right]\right]$$

$$= \frac{1}{28.01}\left[(14{,}581 - 8723) - (8.314)(126)\left[0.09 - 0.12\right]\right]$$

$$= 210.3 \text{ kJ/kg}$$

dus $\frac{\dot{Q}_{cv}}{\dot{m}} = -240 \frac{kJ}{kg} + 210.00 \frac{kJ}{kg} = -29.7 \frac{kJ}{kg}$

25

11.76

$$\frac{W}{n} = \int_1^2 p\,dV \quad ; \; p = \text{constant dus}$$

$$\frac{W}{n} = p\left[\bar{V}_2 - \bar{V}_1\right]$$

$$Z = \frac{p\bar{V}}{RT} \qquad = \bar{R}\left[T_2 Z_2 - T_1 Z_1\right]$$

tabel A-1: $T_c = 126\,K$ $\quad P_c = 33.9$ bar

dus $P_{R1} = \frac{80}{33.9} = 2.36 \quad T_{R1} = \frac{220}{126} = 1.75$

$$T_{R2} = 2.38$$

Uit figuur A2: $Z_1 = 0.91$ en $Z_2 = 0.99$

dus $\frac{W}{n} = 8.314\left[(300)(0.99) - (220)(0.91)\right] =$

$$805 \text{ kJ/kmol}$$

Energie balans:

$$\frac{Q}{n} = (u_2 - u_1) + \frac{W}{n} = (\bar{u}_2 - \bar{u}_1) + p(\bar{V}_2 - \bar{V}_1)$$

$$= \bar{h}_2 - \bar{h}_1$$

11.76 vervolg

$$\frac{Q}{n} = \bar{h}^*(T_2) - \bar{h}^*(T_1) - \bar{R}T_c\left[\left(\frac{\bar{h}^* - \bar{h}}{\bar{R}T_c}\right)_2 - \left(\frac{\bar{h}^* - \bar{h}}{\bar{R}T_c}\right)_1\right]$$

Invullen met data uit tabel A-23 en Fig A-4

$$\frac{Q}{n} = 9423 - 6391 - (8.314)(126)[0.43 - 0.06]$$

$$= 2702 \frac{kJ}{kmol}$$