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Prof Shankar

Lec. 27 21/11/2012

Advanced Reaction Engineering

Practice Problems: Energy Balance

Wed
21 Nov 12
1515–1615

$$N_2O_4 \rightarrow 2\,NO_2 \quad (1)$$

$$2\,NO_2 \rightarrow N_2O_4 \quad (2)$$

Instantaneous;

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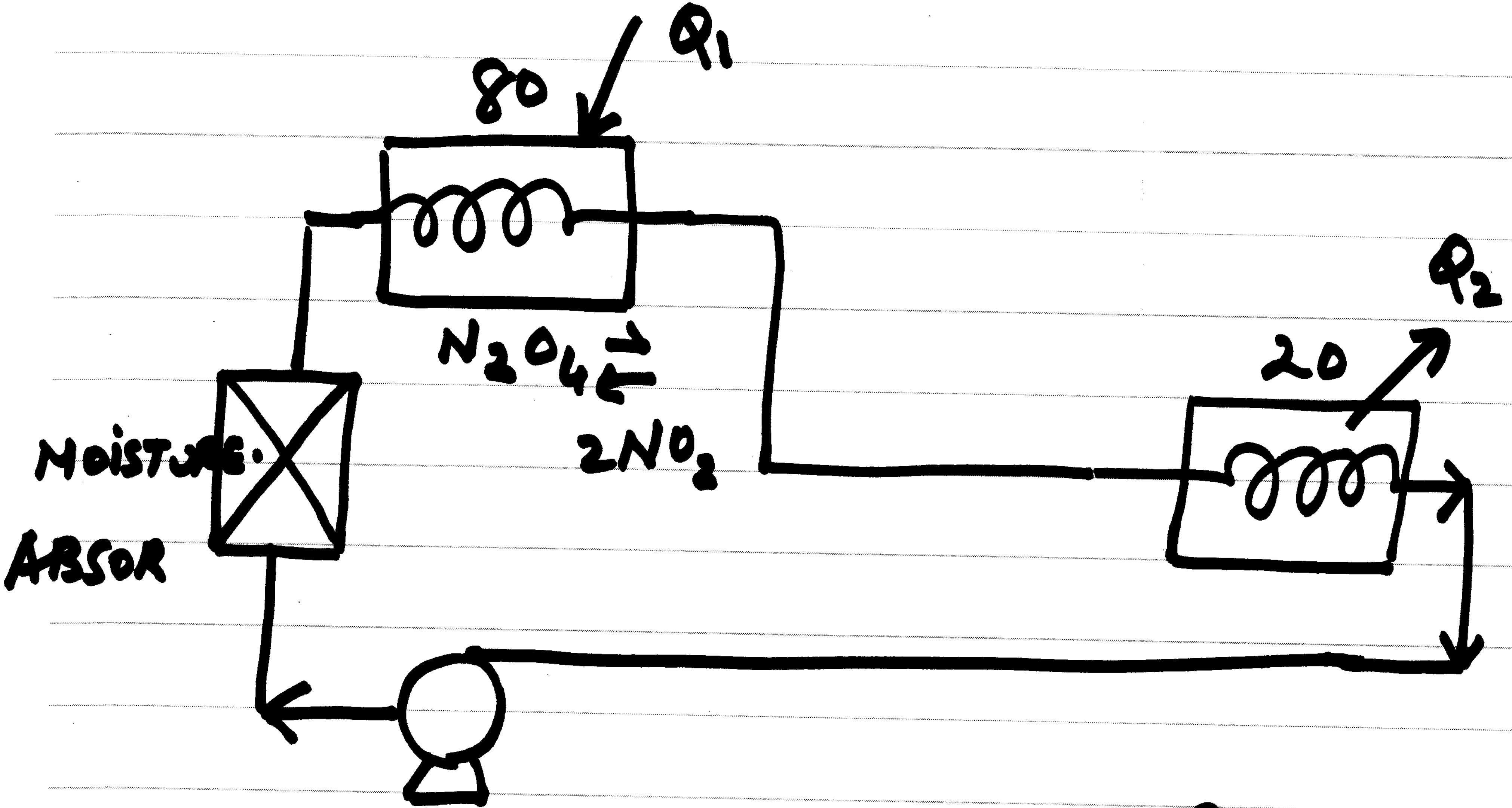
	kcal/mol	kcal/mol	
	ΔH_f	ΔG	Cp cal/mol °K
NO_2	7.96	12.26	12.5
N_2O_4	2.23	23.4	25



Kp at 80C = 5.8

Kp at 20C = 0.45

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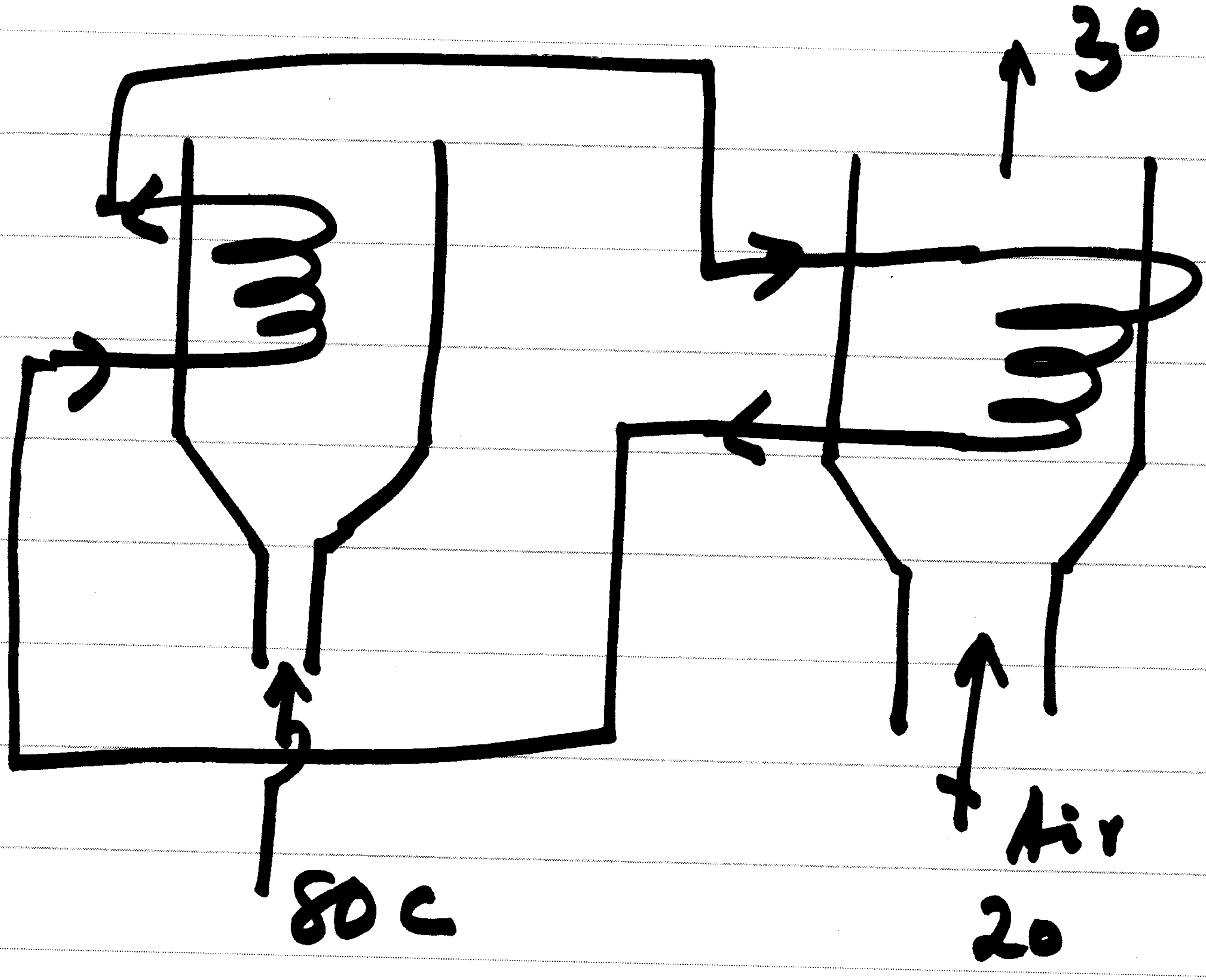
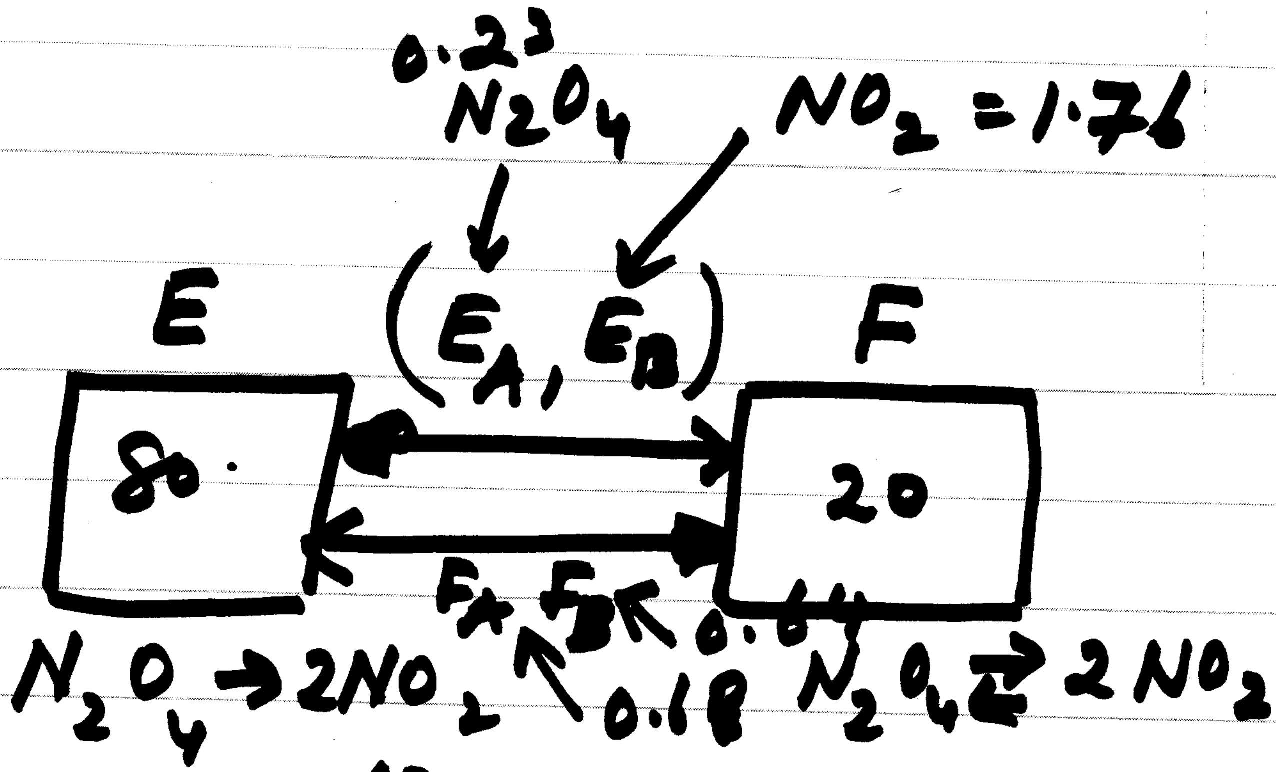


b



$E_A + \frac{1}{2} E_B = 1$

(A) (B)

$K_{p\,(80)} = \frac{p_B^2}{p_A}$ | $K_{p\,(20)} = \frac{p_B^2}{p_A}$

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ENV E:

$$K_p = \frac{p_B^2}{p_A} = \frac{P_t^2 \cdot y_B^2}{P_t\, y_A} = \frac{P_t\, y_B^2}{y_A}$$

$$E_A + \frac{E_B}{2} = 1 \quad \cdots (1)$$

$$y_A = \frac{E_A}{E_A + E_B}$$

$$y_B = \frac{E_B}{E_A + E_B}$$

$$K_p = \frac{P_t\, E_B^2}{(E_B + E_A)\, E_A}$$

$$K_p = \frac{P_t\, (2 - 2E_A)^2}{(2 - 2E_A + E_A)\, E_A}$$

$$K_p = \frac{P_t\,(2 - 2E_A)^2}{(2 - 2E_A + E_A)\,E_A}.$$

$$\frac{P_t\,(2 - 2E_A)^2}{(2 - E_A)\,E_A} = 5.8 \quad \text{at } 80c$$

$$K_p = \frac{4P_t\,(1 - E_A)^2}{(2 - E_A)\,E_A} = 5.8 \quad \text{at } 80c$$

$P_t = 1 atm$

$$11.6E_A - 5.8E_A^2 = 4(1 - 2E_A + E_A^2)$$

$$9.8E_A^2 - 19.6E_A + 4 = 0$$

$$E_A = \frac{19.6 \pm \sqrt{(19.6)^2 - 4(9.8)4}}{2(9.8)}$$

$E_A = 0.23$ ✓ $\frac{mol}{s}$ $E_B = 2 - 2E_A$

$1.76 \times$

$= 2 - 2(0.23)$

$= 1.76\ mol/s$

ENV f.

$$K_p = 0.45 = \frac{p_B^2}{p_A}$$

$$0.45 = \frac{P_t\, y_B^2}{y_A} = K_p = \frac{4P_t(1-F_A)^2}{(2-2F_A+F_A)F_A}$$

$$0.9F_A - 0.45F_A^2 = 4(1-2F_A+F_A^2)$$

$$4.45F_A^2 - 8.9F_A + 4 = 0.$$ ✓

ENV f.

$F_B = 2 - 2F_A.$

$4.45\, f_A^2 - 8.9 f_A + 4 = 0$

$$F_A = \frac{8.9 \pm \sqrt{(8.9)^2 - 4(4.45)\,4}}{2(4.45)}$$

$$= \frac{8.9 \pm 2.83}{2(4.45)} \Rightarrow \begin{matrix} 0.68 \text{ m/s} \\ 1.317 \text{ m/s} \times \end{matrix}$$

$F_B = 2 - 2(0.68) = 0.64 \text{ m/s}.$

Energy Balance

$H_T(80) = H_A \epsilon_A + H_B \epsilon_B$

$H_A(80) = H_A(25) + C_{pA}(T - T_R)$

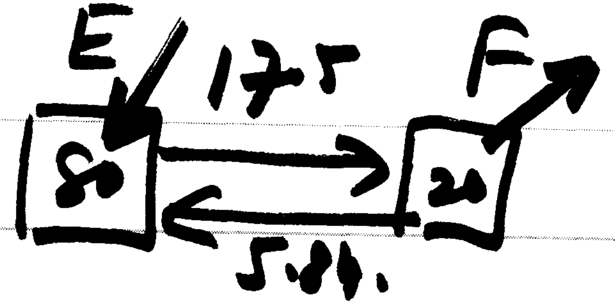
$22.3 + 25(80 - 25)/1000$

$H_A(80) = 22.3 + 25(55)$

22.3 kcal/mol.

$H_B(80) = H_B(25) + C_p(T - T_R)$

7.9 kcal/mol.



$H_T(80)$

$= E_A H_A + E_B H_B$

$(0.23)(22.3) + 1.54(7.96)\ \frac{kcal}{s}$

$5.5 + 12 = 17.5\ kcal/s$

Energy Released at F = $17.5 - 5.84$

$= 11.64\ kcal/s$

Nitrogen Availability = 1 mol/s = 28 g/s

Sp Energy Delivered: $11.64/0.028\ kg = 350\ \frac{kcal}{kg\ N}$

$H_T(20) = F_A H_A + F_B H_B$

$H_A(20) = 2.23 + \sout{Cp_A (T - T_{12})}$

$H_B(20) = 7.96 + \sout{Cp_A (\ldots)}$

$H_T(20) = F_A H_A + F_B H_B$

$(0.68)(2.23) + 0.64(7.96)$ kcal/s.

$0.74 + 5.1 = 5.84$ kcal/s

Energy Delivered

$$= \frac{11.64}{0.028} = 390 \frac{\text{kcal}}{\text{kg N}}.$$

Work output:

$$G_T(80) - G_T(20)$$

$$G_T(80) = E_A G_A + E_B G_B$$

$$G_T(20) = F_A G_A + F_B G_B.$$

Work output = 17 kcal/s

N circulation = 1 mol/s = 28 g/s

Sp output = 17 kcal/0.028 = 510 kcal/kg N