Name: Solution.

Problem #1 **(25 points)**

1) A bioreactor houses bacteria capable of converting glucose ($C_6H_{12}O_6$) to ethanol (C_2H_5OH) and carbon dioxide. Media comprised of 60% wt glucose (in H_2O) flows through the bioreactor at a rate of 3.0 L/min and the overall conversion of the reaction is 58%.

a. Draw a diagram of the process, labeling ALL of the species present.

b. Write the balanced chemical equation for this reaction.

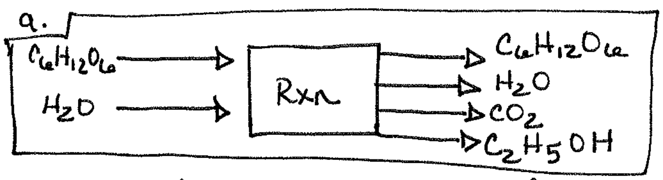
c. What is the selectivity of ethanol relative to carbon dioxide?

d. What is the extent of reaction?

e. What is the yield of ethanol produced (in kg mol ethanol per kg mol of glucose)?

assumptions: The density of the media is the same as H_2O (1 g/mL)

a.



b. $\boxed{1\,C_6H_{12}O_6 \xrightarrow{\text{Bacteria}} 2CO_2 + 2C_2H_5OH}$

c. selectivity $= \dfrac{n\ \text{Ethanol}}{n\ \text{Carbondioxide}}$

Assuming 1 mole of glucose reacts: 2 moles of CO_2 is produced
2 moles of C_2H_5OH is produced

$\therefore$ selectivity $= \dfrac{2}{2} = \boxed{1}$

d. ξ = extent of reaction $= (f)(\xi^{max})$

n glucose fed in $= 1\ \cancel{min} \times \dfrac{3.0\ \cancel{L}}{\cancel{min}} \times \dfrac{1000\ \cancel{mL}}{1\ \cancel{L}} \times \dfrac{1\ g}{\cancel{mL}} \times .60 = 1800\ g\ C_6H_{12}O_6$

$= 1800\ \cancel{g\ C_6H_{12}O_6} \times \dfrac{1\ mole}{180\ \cancel{g}} = 10\ n\ C_6H_{12}O_6$ fed in...

ξ^{max} = (100% completion) $= \dfrac{0-10}{-1} = 10$ moles of Glucose reacted.

$\xi^{actual} = (f)(\xi^{max}) = (.58)(10) = \boxed{5.8 \text{ moles = extent of Rxn}}$

e. Assuming 5.8 mol (or kg mol) react (But Remember 10 mol (or kg mol) fed in!)

10 mol (or kg mol) $C_6H_{12}O_6 \rightarrow$ (5.8 mol or kg mol)$\times$(2) of C_2H_5OH

$\therefore$ Yield based on definition $= \dfrac{(5.8)(2)}{10} \Rightarrow \dfrac{11.6 \text{ mol (or kg mol) } C_2H_5OH}{10 \text{ mol (or kg mol) } C_6H_{12}O_6}$

$\boxed{\text{Yield} = 1.16}$

Name: Solution

Problem #2 (25 points)

2) In order to treat a patient suffering from severe hypothermia (body temperature = 32°C), blood is heated outside of the body to normal body temperature by an extracorporeal heat exchanger. The density of blood is 1.025 g/ml, the normal blood flow rate is 5.0 L/min and the heat capacity (C_v) of blood is ~90% of water. What volumetric flow rate needs to be pumped through the heat exchanger if water enters at 50°C, exits at 40°C and it takes 5 minutes for the heat exchanger to completely warm the blood properly?

Assumptions: Basis = 5 min

$T_{1,Blood} = 32°C$

$T_{2,Blood} = 37°C$ = Normal Body temp.

$\rho_{Blood} = 1.025 g/mL$

$C_{v\,Blood} = (.90)\, C_{v\,H_2O}$

$\hat{V}_{in} = 5.0\ L/min$

$T_{1,H_2O} = 50°C$

$T_{2,H_2O} = 40°C$

$\rho_{H_2O} = 1.0 g/mL$

$C_{v\,H_2O} = 4.18\ J/g\cdot K$

$\hat{V}_{in} = ?$

(a.) $\Delta E = \Delta[PE + KE + \cancel{U}^{0}]_{system} = Q + W - m\cdot\Delta[\hat{PE} + \hat{KE} + \hat{H}]_{flow}$.

Assume System = open
= steady state
= No ΔKE
= No ΔPE
= No Work
= Adiabatic

$\therefore \cancel{\Delta E}^{0} = Q + \cancel{W}^{0} - m\cdot\Delta[\cancel{\hat{PE}}^{0} + \cancel{\hat{KE}}^{0} + \hat{H}]_{flow}$

$m\cdot\Delta\hat{H} = \cancel{Q}^{0} \Rightarrow m_{H_2O}\cdot\Delta\hat{H}_{H_2O} + m_{Blood}\cdot\Delta\hat{H}_{Blood} = 0$

$\underline{m_{H_2O}\cdot\Delta\hat{H}_{H_2O} = -m_{Blood}\cdot\Delta\hat{H}_{Blood}}$

(b.) $T_{1,Blood} = 32°C + (\sim 273) = 305\ K$

$T_{2,Blood} = 37°C + (\sim 273) = 310\ K$

m_{Blood} (in 5 mins) $= 5\ \cancel{min} \times \frac{5\ \cancel{L}}{1\ \cancel{min}} \times \frac{1000\ \cancel{mL}}{1\ \cancel{L}} \times \frac{1.025\ g}{1\ \cancel{mL}} = 25625\ g$ Blood

Q absorbed by blood $= m_{Blood}\int_{T_1}^{T_2} C_{v,Blood}\, dT = (m_{Blood})(C_{v,blood})(T_2 - T_1)$

$= (25625 g)(.90)(4.18 J/g\cdot K)(310 K - 305 K)$

$\cong \underline{482\ kJ}$

(c.) $T_{1,H_2O} = 50°C + (\sim 273 K) = 323 K$

$T_{2,H_2O} = 40°C + (\sim 273 K) = 313 K$

m_{H_2O} (in 5 mins) = ?

Q absorbed by blood = Q lost by $H_2O \cong 482006 J$ ∴

$-482006 J = m_{H_2O}\int_{T_1}^{T_2} C_{v,H_2O}\, dT = (m_{H_2O})(C_{v,H_2O})(T_2 - T_1)$

$-482006 J = (m_{H_2O})(4.18 J/g\cdot K)(313 - 323 K)$

$m_{H_2O} = \frac{-482006 J}{-41.8 J/g} \cong 11.5\ kg$

Name: Solution

Problem #2 (cont'd)

(d.) If 11.5 kg H_2O must flow in 5 mins, convert to volumetric flow rate ⇒

$$\frac{11.5 \text{ kg } H_2O}{5 \text{ min}} = \frac{2.3 \text{ kg } H_2O}{1 \text{ min}}$$

$$2.3 \cancel{\text{kg } H_2O} \times \frac{1000 \cancel{g}}{1 \cancel{kg}} \times \frac{1 \text{ mL}}{1.0 \cancel{g}} = \boxed{2300 \frac{\text{mL}}{\text{min}} \text{ volumetric flow rate of } H_2O}$$

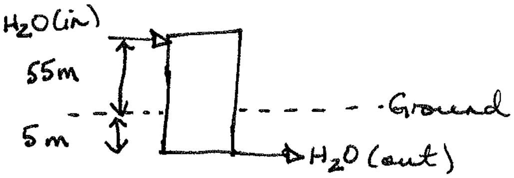
Name: Solution

Problem #3 (25 points)

3) A new heating device has been developed to extract energy from a flowing liquid. Water, initially at 50°C and 4 atm, enters the device at a rate of 150 L/hr from a height 55 m above the ground and exits 5 m below ground level. If the water exits at a final temperature of 38°C, what is the heat flow rate emanating from the device if it is to operate at steady-state?

$$\cancel{\Delta E}^{\,0} = \Delta[PE + \cancel{KE}^{\,0} + \cancel{U}^{\,0}]_{system} = Q + \cancel{W}^{\,0} - m\cdot\Delta[\hat{PE} + \cancel{\hat{KE}}^{\,0} + \hat{H}]_{flow}$$

Assumptions:
1. Flow rate out = flow rate in
2. PV in = PV out
3. Steady State
4. Basis = 1 hr.



$$0 = Q - m\cdot\Delta[\hat{PE} + \hat{H}]_{flow}$$

$$\underline{Q = m\cdot\Delta[\hat{PE} + \hat{H}]_{flow}}$$

(a.) Calculate $(m\cdot\Delta\hat{PE})$ $[1\,J = 1\,kg\cdot m^2/s^2]$

$m\cdot\Delta\hat{PE} = mg\,\Delta H$ (where ΔH = change in Height)

$\text{mass } H_2O = \frac{150\,\cancel{L}}{1\,\cancel{hr}} \times 1\,\cancel{hr} \times \frac{1000\,\cancel{mL}}{1\,\cancel{L}} \times \frac{1\,g}{1\,\cancel{mL}} = 150\,kg\ H_2O$

$g = 9.8\,m/s^2$

$\Delta H = H_{final} - H_{initial} = (-5m) - (55m) = -60m.$

$\therefore\ \Delta PE(H_2O) = mg\,\Delta H$

$= (150\,kg)(9.8\,\frac{m}{s^2})(-60\,m)$

$= -88200\,kg\,\frac{m^2}{s^2}$

$\cong \underline{-88.2\,kJ} = m\cdot\Delta\hat{PE}$

(b.) Calculate $(m\cdot\Delta\hat{H})$

$T_1 = 50°C + (\sim 273\,K) = 323\,K$

$T_2 = 38°C + (\sim 273\,K) = 311\,K$

$m_{H_2O} = 150{,}000\,g$

$C_{v,H_2O} = 4.18\,J/g\cdot K$

$(m\cdot\Delta\hat{H})_{H_2O} = \left(\int_{T_1}^{T_2} C_{v,H_2O}\,dT\right) m_{H_2O}$

$(150{,}000\,g)(4.18\,J/g\cdot K)(311 - 323\,K) = m\cdot\Delta\hat{H}$

$-7524000\,J \cong m\cdot\Delta\hat{H}$

$\underline{-7524\,kJ} \cong m\cdot\Delta\hat{H}$

(c.) $Q = m\cdot\Delta\hat{PE} + m\cdot\Delta\hat{H} = -88.2\,kJ - 7524\,kJ \cong -7612\,kJ$

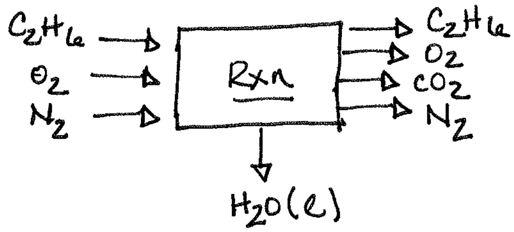
$\boxed{\text{The Heat flow rate} \cong -7612\ kJ/hr}$

Name: Solution

Problem #4 (cont'd)

a. $1\ C_2H_6 + \frac{7}{2} O_2 \longrightarrow 2\ CO_2 + 3\ H_2O$

Assumptions:
- 100 g mol Exiting Gas
- 99.97% ~ 100%
- Exiting % are in mol %.



b. Mole Composition Out stream:

$\eta\, C_2H_6 = 1.72$ g mol
$\eta\, O_2 = 12.4$ g mol
$\eta\, N_2 = 80.7$ g mol
$\eta\, CO_2 = 5.15$ g mol

c. Calculating the η air fed in:

N_2 not involved in Rxn $\therefore$ N_2 in $= N_2$ out
80.7 g mol out $= 80.7$ g mol in
Air $=$ 71 mole% N_2 $\therefore$ ~113.6 g mole Air in
29 mole% O_2 ~ 32.9 g mole O_2 in

d. Calculating the $\eta\ C_2H_6$ fed in:

5.15 g mol of CO_2 created $\therefore$ $5.15\ \cancel{\text{g mol } CO_2 \text{ created}} \times \dfrac{1 \text{ g mol } C_2H_6 \text{ Reacted}}{2\ \cancel{\text{g mol } CO_2 \text{ created}}} = 2.575$ g mol C_2H_6 reacted.

η fed in $= \eta$ reacted $+ \eta$ outstream (C_2H_6)
η fed in $= 2.575$ g mol $+ 1.72$ g mol $(C_2H_6) \cong$ 4.3 g mol C_2H_6 fed in

e. Calculating the conversion of C_2H_6:

$$f = \frac{\eta \text{ reacted}}{\eta \text{ fed in}} = \frac{2.575 \text{ g mol}}{4.3 \text{ g mol}} = .59 \qquad \therefore \boxed{f \cong 60\%}$$

f. $\%$ XS Air $= \dfrac{\text{moles of } O_2/\text{air in feed} - \text{moles of } O_2/\text{air theoretical}}{\text{moles of } O_2/\text{Air theoretical}}$

$$= \frac{32.9 \text{ g mol fed in} - (4.3\ \cancel{\text{g mol } C_2H_6} \times \frac{7}{2} \text{g mol } O_2 / 1\ \cancel{\text{g mol } C_2H_6})}{4.3\ \cancel{\text{g mol } C_2H_6} \times \frac{7}{2} \text{ g mol } O_2 / 1\ \cancel{\text{g mol } C_2H_6}}$$

$$= \frac{32.9 \text{ g mol } O_2 \text{ fed in} - 15.05 \text{ g } \cancel{\text{mol } O_2} \text{ needed}}{15.05 \text{ g } \cancel{\text{mol}}\ O_2 \text{ needed}} \cong \boxed{1.2\% \text{ XS Air}}$$