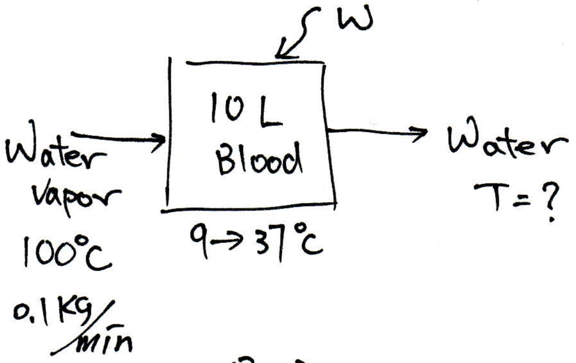
Name: Solution.

Problem #1 **(25 points)**

100˚C water vapor is used to heat 10 L bloods contained in a bioreactor from 9˚C to 37˚C. A stirrer adds work to the system at a rate of 0.1 kW. Assume the process takes 5 minutes to achieve, ρ_{blood} is 1.025 g/ml, and the specific heat of blood is equal to that of liquid water. Calculate the final temperature of outlet stream if vapor enters the reactor at a rate of 0.1 kg/min?



Knowns

- $\dot{W} = 0.1 KW = 0.1 KJ/s$
- $\rho_{blood} = 1.025\ g/ml$
- $C_{p,blood} = C_{p,H_2O} = 4.18\ J/g.K$

Basis: 5 mins

($m_{vapor} = 500g$, $W = 30000J$)

Assumptions

- *Constant flow rate
- *unsteady-state & open system
- No reaction
- No accumulation of water
- *$\Delta KE = \Delta PE = 0$ for both blood and water
- *insulated ($Q=0$)
- Constant heat capacities.
- *$\Delta(pV)_{blood} = 0$

Energy Balance Equation

$$\Delta E_{sys} = \Delta(U + \cancel{KE} + \cancel{PE})_{sys}$$

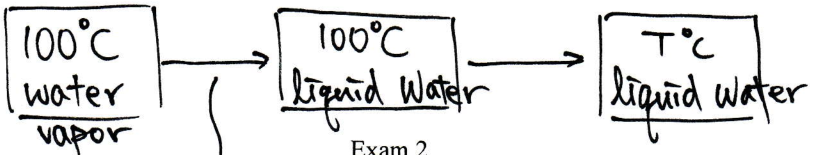
$$= \cancel{Q} + W - \Delta(H + \cancel{PE} + \cancel{KE})_{flow}$$

$$\Rightarrow \Delta U_{sys} = W - \Delta H_{flow}$$

$$\Rightarrow [\Delta H - \Delta(\cancel{pV})]_{blood} = W - \Delta H_{water}$$

$$\Rightarrow \Delta H_{blood} = W - \Delta H_{water}$$

To calculate ΔH_{water}:



Not enough heat to warm up the blood!

Name: Solution

Problem #1 (cont'd)

$$\Rightarrow \Delta H_{blood} = W - \Delta H_{water}$$

$$\Rightarrow \left(m_{blood} \cdot C_{p,blood} \cdot \Delta T\right) = W - \left(m_{water} \cdot \Delta \hat{H}_{cond.} + m_{water} \cdot C_{p,H_2O} \cdot \Delta T\right)$$

$$\Rightarrow (10\times10^{3})\cdot(1.025)\cdot 4.18\cdot(37-9) = 30000 - \left[500\cdot(-2260) + 500\cdot 4.18\cdot(T-100)\right]$$

$$\Rightarrow \boxed{T = 81^{\circ}C \quad \text{or} \quad 354K}$$

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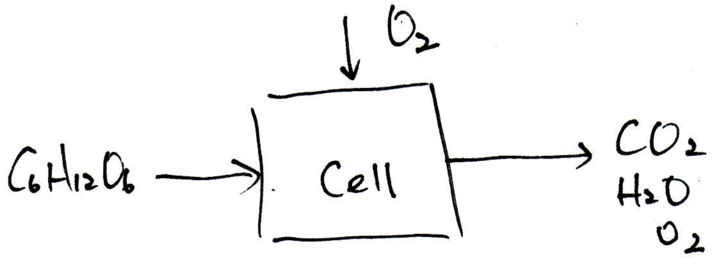
Name: Solution

Problem #2 (25 points)

In cellular metabolism, sugars react with oxygen and convert into carbon dioxide and water to generate energy. Assume glucoses at cellular level at a rate of 180 g/day and 190L of oxygen per day at 1 atm and 37°C are available for combustion. Calculate

(a) % excess oxygen

(b) the mass rate of each compound released after metabolism



Assumptions
- O_2 is ideal gas
- No accumulation

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Basis: 1 day

$$n_{O_2} = \frac{p \cdot V}{RT} = \frac{(1\,\text{atm})\cdot(190\,\text{L})}{\left(0.082\,\frac{\text{L}\cdot\text{atm}}{\text{gmol}\cdot\text{K}}\right)\cdot(37+273\,\text{K})} = 7.47\ (\text{gmol})$$

$$n_{C_6H_{12}O_6} = \frac{180\,\text{g}}{180\,\text{g/gmol}} = 1\ (\text{gmol.}) \sim \text{limiting reactant.}$$

$$\text{(a) \% excess oxygen} = \frac{7.47-(1\times 6)}{(1\times 6)} \times 100\% = \boxed{24.5\%}$$

(b) Material balance ⇒ $\boxed{\text{in}} - \boxed{\text{consumption}} = \boxed{\text{out}}$

O_2: $7.47 - 6 = 1.47\ (\text{gmol})$

$\boxed{\text{Generation}} = \boxed{\text{out}}$

CO_2: $1\times 6 = 6\ (\text{gmol})$

H_2O: $1\times 6 = 6\ (\text{gmol})$

Name: Solution.

Problem #2 (cont'd)

Mass rate:

$$\boxed{\begin{array}{l} O_2: \; 1.47 \, gmol/day \cdot 32 \, g/gmol = 47.04 \, g/day \\ CO_2: \; 6 \, gmol/day \cdot 44 \, g/gmol = 264 \, g/day \\ H_2O: \; 6 \, gmol/day \cdot 18 \, g/gmol = 108 \, g/day \end{array}}$$

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Name: Solution

Problem #3 (25 points)

Calculate the heat of reaction at the standard reference state.

$$Na_2CO_3\ (s) + 2Na_2S\ (s) + 4SO_2\ (g) \rightarrow 3Na_2S_2O_3\ (s) + CO_2\ (g)$$

$$\Delta H_{rxn} = \sum_{products} \nu_i \Delta \hat{H}^{o}_{f,i} - \sum_{reactants} \nu_i \Delta \hat{H}^{o}_{f,i}$$

$$= \left\{ 3\times(-1117.13) + 1\times(-393.51) \right\} -$$

$$\left\{ 1\times(-1130.94) + 2\times(-373.21) + 4\times(-296.90) \right\}$$

$$= (-3744.9) - (-3064.96)$$

$$= \boxed{-679.94\ (KJ)}$$

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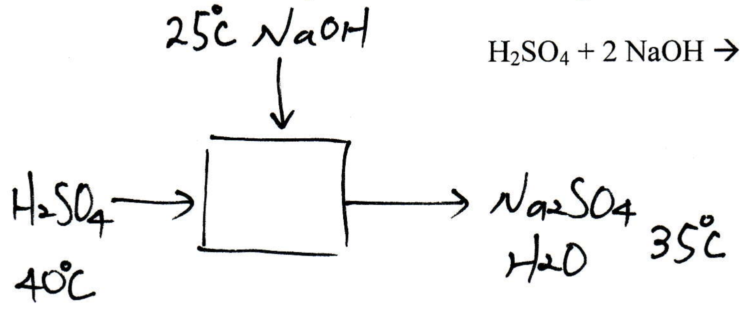
Problem #4 **(25 points)**

A H_2SO_4 solution at 40°C is to be neutralized with a NaOH solution at 25°C in a continuous reactor. At what rate in (kJ)/(kg H_2SO_4 solution) must heat be removed or added from the reactor if the product solution emerges at 35°C? Assume 100% completion of the reaction.

$$H_2SO_4 + 2\,NaOH \rightarrow Na_2SO_4 + 2\,H_2O\,(l)$$



$MW._{H_2SO_4} = 98\ kg/kgmol.$

Assumptions

- No accumulation
- 100% completion
- Steady-state & open
- $\Delta KE = \Delta PE = 0$
- $W = 0$
- Constant heat capacit

Basis : 1 kg H_2SO_4 solution

$$n_{H_2SO_4} = \frac{1}{98} = 0.01\,(kgmol.)$$

$$\Delta \cancel{E} = Q + \cancel{W} - \Delta(H + \cancel{KE} + \cancel{PE})$$

$$\Rightarrow \quad Q = \Delta H_{rxn}$$

$$= \sum_{P.} n_i \Delta \hat{H}_{f,i} - \sum_{R.} n_i \Delta \hat{H}_{f,i}$$

$$* \quad \Delta \hat{H}_{f,i} = \Delta \hat{H}^{o}_{f,i}\,(25°C) + \int_{25°C}^{T°C} C_p \cdot dT$$

$$= \Delta \hat{H}^{o}_{f,i} + C_p \cdot (T - 25)$$

Name: Solution

Problem #4 (cont'd)

Therefore,

For H_2SO_4, 40°C , $\Delta\hat{H}_{f,H_2SO_4} = (-909.3) + (-0.293)\cdot(40-25)$

$= -913.695\ KJ/gmol$

For NaOH, 25°C . $\Delta\hat{H}_{f,NaOH} = \Delta\hat{H}_f^\circ = -426.7\ KJ/gmol$

For Na_2SO_4, 35°C . $\Delta\hat{H}_{f,Na_2SO_4} = (-1389.5) + (-0.201)\cdot(35-25)$

$= -1391.51\ KJ/gmol.$

For H_2O, 35°C . $\Delta\hat{H}_{f,H_2O} = (-285.84) + (4.18\times18\times10^{-3})\cdot(35-25)$

$= -285.09\ KJ/gmol.$

$$\therefore\ Q = \left[(.0102\times10^3)\cdot(-1391.51) + (.0204\times10^3)\cdot(-285.09)\right] - \left[(.0102\times10^3)\cdot(-913.695) + (.0204\times10^3)\cdot(-426.7)\right]$$

$= -1984.87\ (KJ)$

$\Rightarrow$ $\boxed{\text{Remove 1984.87KJ from the reactor per kg } H_2SO_4}$

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