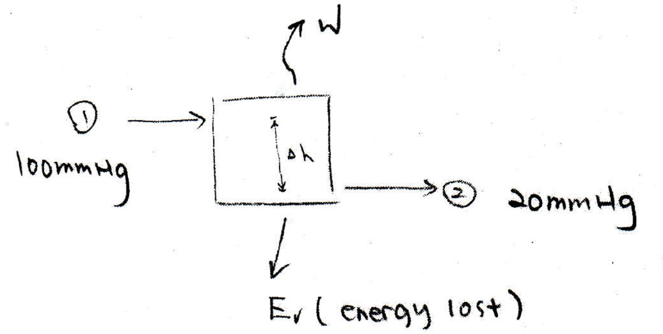
Problem #1 (25 points)

During hemodialysis, 20 J/min of energy is lost due to resistances in the tubing. Calculate the power done by the pump to move 300 mL/min blood from patient's artery (100 mmHg) to the machine and back to patient's vein (20 mmHg) if the inlet of the blood to the machine is 30 cm higher than the outlet? Assume ρ_{blood} is 1.056 g/mL.



Knowns

$\dot{V} = 300$ mL/min

$\rho_{blood} = 1.056$ g/mL

$\Delta h = h_1 - h_2 = 30$ cm.

$P_1 = 100$ mmHg

$P_2 = 20$ mm Hg

Basis: 1min

$m = \rho \cdot V = (1.056 \frac{g}{mL}) \cdot (300\ mL)$

$= 316.8\ g$

Assumptions

Steady-state

Open

No reaction

No accumulation.

Constant blood flow rate

$\Delta KE = 0$ (i.e. $v_1 = v_2$)

Mechanical Energy Balance Equation

$$W = \cancel{\Delta KE} + \Delta PE + \int_{P_1}^{P_2} V dP + E_v$$

$$= mg(h_2 - h_1) + V(P_2 - P_1) + E_v$$

Substitution

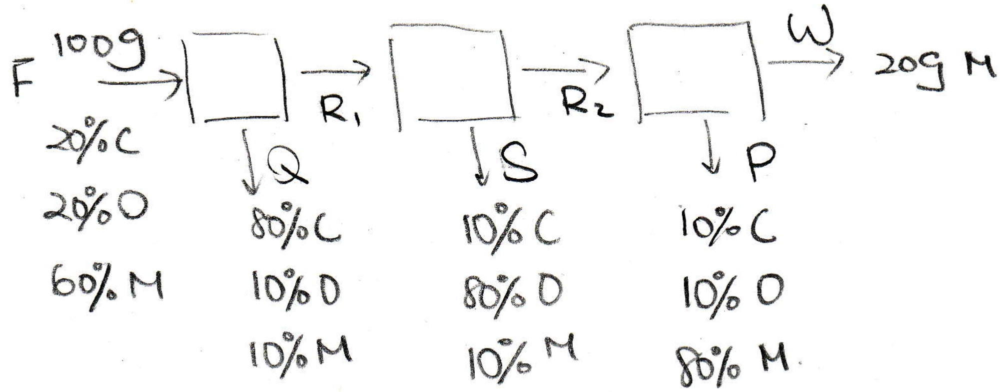
$$W = \left(316.8\ g \cdot \frac{10^{-3}\ kg}{g}\right)\left(9.8 \frac{m}{s^2}\right)(-0.3 m) + \left(300 mL \cdot \frac{10^{-6}\ m^3}{mL}\right)\left([20 - 100 mmHg] \cdot \frac{133.3 Pa}{mmHg}\right)$$

$$+ 20\ J. = 15.87\ J.$$

Therefore, $\dot{W} = 15.87 \frac{J}{min} \times \frac{min}{60 S} = \boxed{0.26\ Watt}$ #

Problem #2 (25 points)

A 100 g mixture of 20% chondrocytes (C), 20% osteoblasts (O), and 60% media (M) is separated via a multi-unit process. The product from the first stage comprised of 80% C, 10% O and 10% M exits the unit while the remainder is further separated into a product comprised of 10% C, 80% O and 10% M (that also leaves the unit). The remainder is fed to an evaporator, where 20 g of media is removed, and the resulting product consists of 10% C, 10% O, and 80% M. Calculate the composition of the feed right before entering the evaporator. Assume all concentrations are *wt. %*.



Knowns

W = 20g media

All fractions.

Assumptions

No reaction

No accumulation

Steady-state

open.

Basis: 100g mixture in F.

(20g C, 20g O, 60g M)

Overall Balance

Total: $F = Q + S + P + M$

C: $0.2F = 0.8Q + 0.1S + 0.1P$

O: $0.2F = 0.1Q + 0.8S + 0.1P$

Three Independent eqns.

three unknowns (Q, S, P)

$\Rightarrow \begin{cases} Q = 17.14 (g) \\ S = 17.14 (g) \\ P = 45.72 (g) \end{cases}$

Problem #2 (cont'd)

Balances at evaporator

Total: $R_2 = P + W$

C: $R_2^C = P^C = 0.1P$

O: $R_2^O = P^O = 0.1P$

M: $R_2^M = P^M + W = 0.8P + W$

$\Rightarrow$ $R_2 = 65.72\ (g)$

$R_2^C = 4.572\ (g)$

$R_2^O = 4.572\ (g)$

$R_2^M = 56.58\ (g)$

Composition in R_2

C: $\frac{4.572}{65.72} \times 100\% = 6.96\%$

O: 6.96%

M: $\frac{56.58}{65.72} \times 100\% = 86\%$

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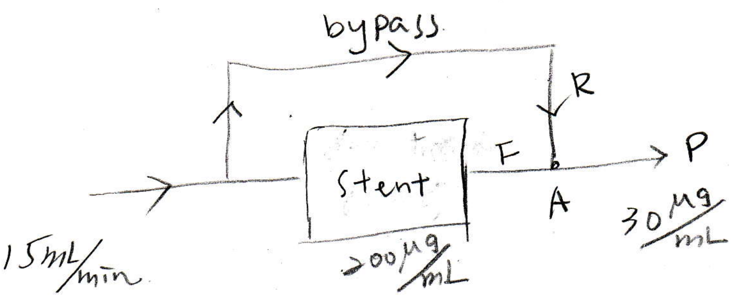
Problem #3 **(25 points)**

In order to treat an occluded ("blocked") artery, an arterial bypass is performed at the same time a drug-eluting stent is placed within the diseased artery in order to restore blood flow. If the average concentration of drug released locally from the stent is 200 μg/mL and the downstream concentration of the drug in the blood is 30 μg/mL, what fraction of the blood passes through the bypass versus the stented artery? Assume total blood flow remains constant at 15 mL/minute.



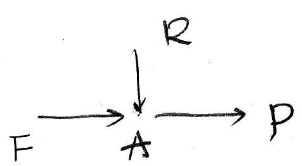
Assumptions

No reaction

No drugs in bypass

Basis: 1 min

Balance at mixer point (A)



Blood volume balance: $F + R = P$

Drug balance: $x_F \cdot F + x_R \cdot R = x_P \cdot P$

(x: concentration of drugs)

Substitution

$P = 15\ (mL)$, $x_F = 200\ \mu g/mL$, $x_R = 0$, $x_P = 30\ \mu g/mL$

$\Rightarrow \begin{cases} F = 2.25\ mL \\ R = 12.75\ mL \end{cases}$

Therefore, % of blood in bypass $= \frac{R}{P} \times 100\% = \boxed{85\%}$

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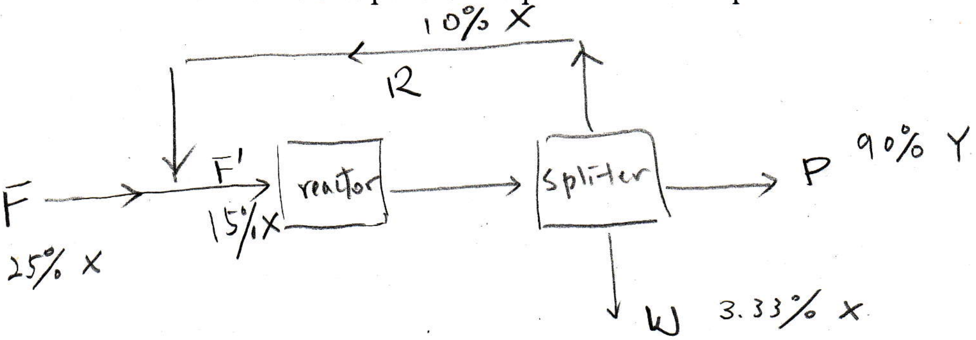
Problem #4 **(25 points)**

A 25% (wt) solution of component is continuously fed into a bioreactor system to produce product with an overall conversion of 90%. The output is split into a product stream (90% wt product) and a waste stream (3.33% unused component). The remaining unused component is recycled back into the bioreactor such that the gross feed is 15% component and the relative amount of the component constitutes 10% of the recycle stream. Under these conditions, what is the single pass conversion?

Assume the component and product are of equal MW.

Basis: 100g Feed (F)
(25g of X)



Assumptions

No accumulation

Equal M.W ($M_x = M_y$)

Open, S-S.

Knowns

- Overall conversion ($X \rightarrow Y$): 90%

Overall balance

Total: $F = P + W$

Components (X & Y): $F_x = P_x + W_x$

$\rightarrow 0.25F = 0.9P + 0.0333W$

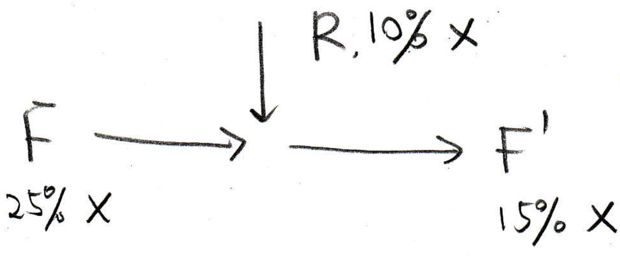
two eqns

two unknowns (P, W)

$\Rightarrow$ $P = 25(g) \Rightarrow P_Y = 0.9P = 22.5g$ of Y in P.

$W = 75(g)$

Balance at mixer point



Problem #4 (cont'd)

$$\left.\begin{array}{ll}\text{Total balance:} & F + R = F' \\ \text{X balance:} & F_x + R_x = F'_x\end{array}\right\} \quad \text{unknowns: } R,\ F'$$

$$\Rightarrow \left\{\begin{array}{l} R = 200\,(g) \\ F' = 300\,(g) \Longrightarrow F'_x = 0.15F' = 45\,g \text{ of } x \text{ in } F'\end{array}\right.$$

Therefore,

$$\text{Single conversion} = \frac{P_Y}{F'_x} \times 100\%$$

$$= \frac{22.5}{45} \times 100\%$$

$$= \boxed{50\%}$$

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