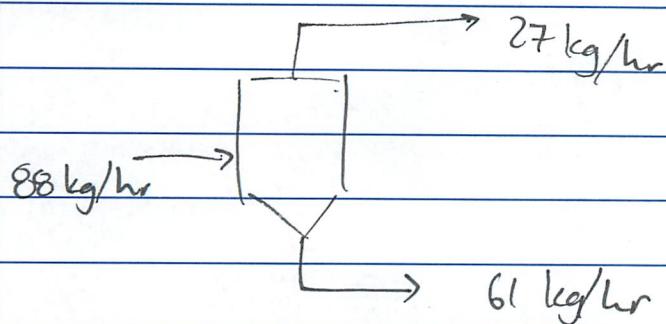


4M3 midterm 2013

8:02



1. Underflow mass flow =  $88 - 27 = 61 \text{ kg/hr}$  assuming steady state

$$\text{Mesh } 325^{450} \text{ in} = 88 \times 0.17 = 14.96 \text{ kg/hr}$$

$$\text{Mesh } 325^{450} \text{ overflow} = 27 \times 0.52 = 14.04 \text{ kg/hr}$$

$$\Rightarrow \text{mesh } 325^{450} \text{ underflow} = 14.96 - 14.04 = 0.92 \text{ kg/hr}$$

$$\Rightarrow \text{mesh } 325^{450} \text{ mass fraction} = \frac{0.92}{61.0} = \underline{\underline{1.5\%}}$$

4:08  
Mesh 325<sup>450</sup> is very fine material ( $32 \mu\text{m}$ ) so we expect it to leave from the overflow at a higher mass fraction 52%

2. Grade efficiency =  $\frac{(0.015)(61)}{(0.17)(88)} = \frac{0.92}{14.96} = 6.1\%$

3 Separation efficiency for 450 mesh vs rest  
 (1) = overflow and (2) = underflow

$$x_{i,1} = x_{450, \text{overflow}} = 14.04 \text{ kg/hr}$$

$$x_{j,1} = x_{\text{rest, overflow}} = 27 - 14.04 = 12.96 \text{ kg/hr}$$

$$x_{i,2} = 0.92 \text{ kg/hr}$$

$$x_{i,2} = 61 \text{ kg/hr}$$

$i$        $j$

use mass flows

$$S_{ij} = \frac{14.04}{12.96}$$

$$= \frac{0.92}{61.0}$$

$$S_{ij} = 7.18$$

$$= \frac{0.52}{(1-0.52)} \frac{1}{0.015 / (1-0.015)}$$

$$Q(2) \text{ (united) } a = sp$$

8:16

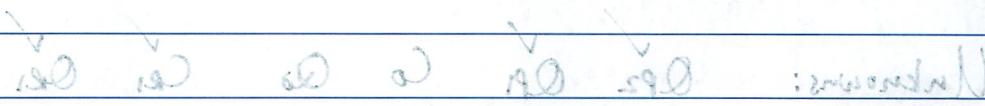
$$(united) Q = 19$$

$$when MWCO = sp$$

E

Flocculation: agglomerates particles together, allowing them to be filtered out (instead of fine particles passing through the filter)

~~End of~~ Filtration: removes flocs  $\Rightarrow$  allows effective membrane use  
 $MW_{floc} = sp$   $MW_{floc} = sp$  with less pore clogging  $\Rightarrow$  higher fluxes



MWCO 100,000 implies the membrane will reject particles of MW = 100000 with rejection coefficient of  $90\% = 1 - C_p$

(1) find N G

Only +10% of MW 100000 and higher will pass into the permeate

$$190 + 100 = 290 : \text{permeate quantity}$$

$$(190) \text{ at } \frac{16}{100} = \frac{190}{5} : \text{permeate quantity}$$

(3)

(united) at HMP turned

but membrane turned off

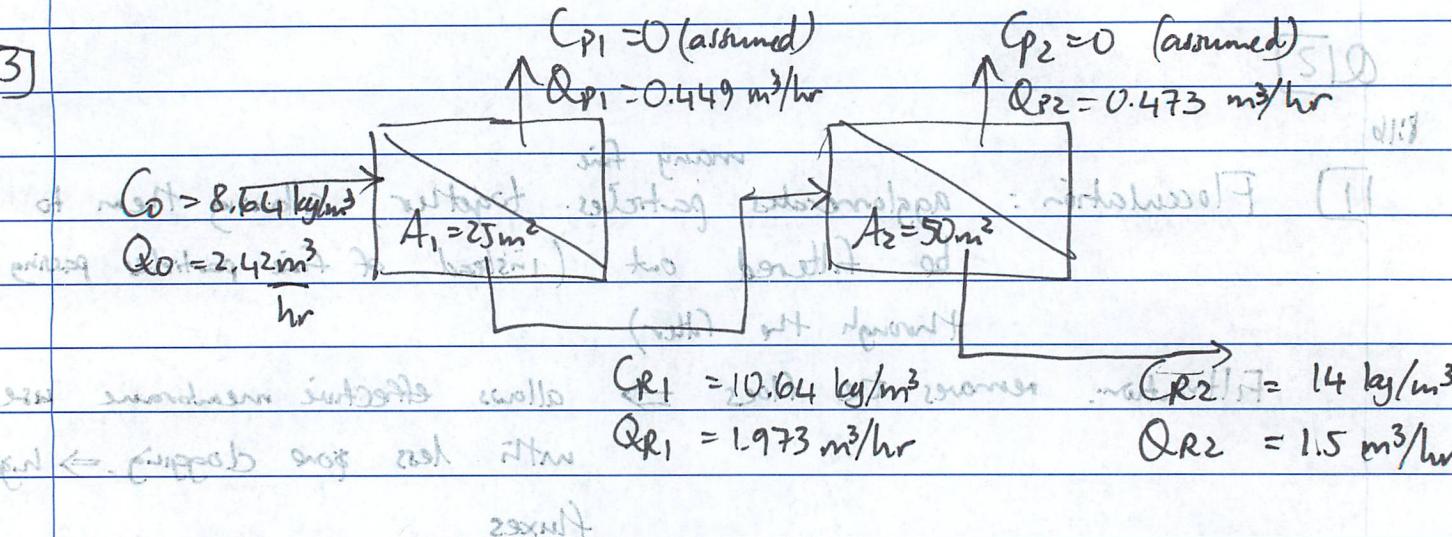
(5) find N

$$(1) sp - 290 = 190 : \text{permeate quantity}$$

$$(2) sp + sp = 190 : \text{permeate quantity}$$

$$(3) (sp) \text{ at } \frac{16}{100} = \frac{sp}{5} : \text{permeate quantity}$$

[3]



Unknowns:  $Q_{P2}$   $Q_{P1}$   $C_0$   $Q_0$   $C_{R1}$   $Q_{R1}$

Plan: to write all equations for each unit & 6 eqns & 6 unknowns

$Q - I = S.P$  to determine number of eqns  $= 6$

### Unit ①

Starting w/ the mass balance:  $Q_0 C_0 = M(C_{R1} Q_{R1}) + C_{P1} Q_{P1} \rightarrow 0$

$$\text{Volume balance: } Q_0 = Q_{R1} + Q_{P1} \quad (1)$$

$$\text{Flux } \frac{Q_{P1}}{A_1} = 0.03 \ln\left(\frac{19}{C_{R1}}\right) \quad (2)$$

Convert LMH to  $\text{m}^3/(\text{hr. m}^2)$

Too many unknowns here.

### Unit ②

$$\text{Mass balance: } Q_{R1} C_{R1} = Q_{R2} C_{R2} \quad (4)$$

$$\text{Volume balance: } Q_{R1} = Q_{R2} + Q_{P2} \quad (5)$$

$$\text{Flux } \frac{Q_{P2}}{A_2} = 0.03 \ln\left(\frac{19}{C_{R2}}\right) \quad (6)$$

From (6) :  $Q_{P2} = \frac{(0.03)}{1000} (50) \ln \left( \frac{19}{14} \right)$  inches

del not instantaneous  $\frac{1000}{1000}$  & write  $\frac{19}{14}$ : not 19

$$Q_{P2} = 0.473 \text{ LMH}$$

$$Q_{P2} = 0.473 \text{ m}^3/(\text{m}^2 \cdot \text{hr}) \quad \text{typical for UF}$$

$\rightarrow Q_2$  : maximum instant

From (5) :  $Q_{R1} = Q_{R2} + Q_{P2} = 1.5 \text{ m}^3 + 0.473$

of  $Q_{R1} = 9.8$  using  $\frac{\text{hr}}{\text{min}}$  : del

$$\therefore Q_{R1} = 1.973 \text{ m}^3/\text{hr}$$

also  $Q_1$

$$2000 = 0.01 \times 0.1 = f$$

$$\therefore Q_1 = A$$

From  $\frac{(1.973)(0.01)(0.1)}{A} = Q_1$  del not  $Q_2$   $Q_{R2}$   $\therefore Q_1 = V$

maximum minimum on  $\frac{(1.5)(\frac{\text{m}^3}{\text{hr}})(\frac{14}{\text{kg}})}{A}$  hr  
if half of the area bigger than  $A$

not from at initially  $Q_1 = 1.973 \text{ m}^3$  ✓

$$\frac{V_g}{S} + \frac{z}{g} = 10.64 \text{ kg/m}^3 \quad \text{wif } 14 \text{ kg/m}^3$$

: del not  $Q_1$

From (3)  $\frac{(0.01)(0.1)(0.449)}{S} = \frac{(31)}{1000} (25) \ln \left( \frac{19}{10.64} \right)$

$$Q_{P1} = 0.449 \text{ m}^3/\text{hr} \quad (449 \text{ LMH})$$

typical for UF

From (2)  $Q_o = Q_{R1} + Q_{P1} = 1.973 + 0.449 = 2.42 \text{ m}^3/\text{hr}$

$$(0.0005)^2 (20.0) (0.01)(0.1) = (Q_o)$$

From (1)  $Q_o = C_o (Q_o) = \frac{Q_{R1} (C_{R1})}{Q_o} = \frac{(1.973)(10.64)}{2.42}$

08:40  $C_o = 8.67 \text{ kg/m}^3$

your

$$\text{Question 3 (e) } \mu(\text{eff}) = 590 : (1) \text{ m/s}$$

Plan: obtain slurry & filter cake characteristics from lab  
solve for plate/frame calculations

$$\text{FN of height } (\text{eff})_{\text{lab}} \text{ EFP.0} = 590$$

Define unknowns:  $C_s$  &

$$\text{EFP.0} + \text{EFP.1} = 590 + 90 = 680 : (2) \text{ m/s}$$

Lab: constant pressure  $\Delta P = 30000 \text{ Pa}$

$$(\text{eff})_{\text{lab}} \text{ EFP.1} = 190 V = 0.5 \times 10^{-3} \text{ m}^3$$

$$t = 10 \times 60 = 600 \text{ s}$$

$$A = 0.05 \text{ m}^2$$

$$V = 10 ? \quad \text{cake volume} = \left( \frac{30 \text{ cm}}{1000} \right) \left( 0.05 \text{ m}^2 \right) = 0.0015 \text{ m}^3$$

At (constant pressure 2:1) assume no medium resistance  
(or we'd require more info to find it)

$$\text{Filter press } \text{EFP.1} \text{ at } t=0 \quad \frac{\partial V}{2} + \frac{K_p V^2}{2} \quad \text{assume small relative to next term}$$

$$\text{Lab: } (600) \left( \frac{180}{600} \right) + \frac{K_p (0.5 \times 10^{-3})^2}{2} : (3) \text{ m/s}$$

$$(4.8 \times 10^9) \text{ N/m}^2$$

FN of height

$$K_p = \mu C_s \alpha$$

$$\text{EFP.S} = \rho_{H_2O} g + \text{EFP.1} = \frac{A^2}{A^2} (-\Delta P)_{190} = 0 : (4) \text{ m/s}$$

$$(4.8 \times 10^9) (0.05)^2 (30000)$$

$$(1000) (\text{EFP.1}) = \frac{190 \mu C_s \alpha}{0.05} = 3.6 \times 10^{11} \frac{\text{N}}{\text{m}^2} \cdot \frac{\text{m}^4 \cdot \text{Pa}}{\text{m}^2} = \text{Pa.s.}$$

$$\text{EFP.F.D.S} = 0$$

Q1: 80

Same slurry in press and is as in lab filter

$\Rightarrow \mu, C_s$  and  $\alpha$  are the same

$L$  could be a function of  $\Delta P$  & assumed to be as such in the calculations

Press:  $A = 1 m^2$

$\Delta P = 300000 Pa$

$t = 15 \times 60 = 900 s$

} at constant pressure  
(due to feedback control)

From std filtration equation (earlier)

$$\Rightarrow V = \sqrt{\frac{2t}{K_p}}$$

Unknown:

$K_p$  = for plate & frame  
not same as lab filter

goal is  
to find  
this "V"

$$\text{but } K_p = \frac{\mu C_s \alpha}{(A^2) \Delta P} = \frac{3.6 \times 10^{-6}}{(1)^2 (300000)}$$

$$K_p = 1.2 \times 10^{-6} \text{ s/m}^3$$

$$\text{so } V = \sqrt{\frac{(2)(900)}{1.2 \times 10^{-6}}} = 0.0387 \text{ m}^3$$

$$V = 38.7 \text{ L in 15 minutes.}$$

from plate & frame press

Question 3

[12]

Grading

Give equation  $t = bv + k_p V^2$

Recognise the lab step vs industrial step [2]

(explore)

Step reasonable

Assuming  $B = 0$  (no medium resistance) 3cm cake

Writing a plan down (any plan that's reasonable)

Use the same medium in the lab vs the press

$$\alpha = \alpha_0 (-AP)^f$$

OR  $f = 0$  assumption

(explore)  
Step

lab data  $\left\{ \begin{array}{l} k_p = \frac{\mu C_s \alpha}{A^2 (-AP)} \end{array} \right.$

Using lab values to get  $k_p = 4.8 \times 10^9 \frac{s}{m^6}$

Calculate  $(\mu C_s \alpha)$  or  $(C_s \alpha)$  from  $k_p$  equation

$$\mu C_s \alpha = 3.6 \times 10^{11} \frac{Pa.s}{m^2}$$

Recognise same slurry in lab + press

Use all t=900s in plate + frame press (ignore few seconds)

Recalculating  $K_p$  for plate + frame press =  $\frac{\mu C_s \alpha}{A^2 (-AP)} = 1.2 \times 10^6 \frac{m^6}{Pa.s}$

Volume of filtrate = 38.73 L = 0.0387 m<sup>3</sup>

Recognise a "batch" is one cycle of the plate and frame press (as discussed in class)

Any reasonable attempt scored 4/12

PTO

900

Question 4

(with intent) ↳

- (1) Material flow in is just being split into overhead and  
 $s_{ml} = A_{bottom}$   
 $\rightarrow$  ~~one~~ separation is occurring

$$200^2 = 0.2 \times 21 = 7$$

$$\frac{E_{ml}^2}{E_{ml} f_{80.0}} \times \text{Filters} (0.2)(s) = V = \frac{75}{\rho t}$$

- (2) If Faster settling  $\Rightarrow$  we can increase throughput on  
the same vessel for the separation factor/alt  
 $\Rightarrow$  we can have longer residence time  
and obtain higher separation factor

$$E_{ml}^2 \text{ days} = "0.2 \cdot s = \frac{720}{\rho t} = p$$

- (3) Notes :  $25.2 \text{ atm}^{(0.000001)} (1) (98.1)^{-1} A$

- (5) (c)

$$certain \text{ gOE} = \frac{E_{ml} f_{80.0}}{E_{ml} f_{100.0}} = fast \text{ due}$$

- (6) Pressure drop required through the cyclone, which is developed by a motor, blower, or some form of energy to accelerate the particles in ~~which~~ into ~~which~~  $E_{ml} f_{100.0} = 0.08 \times \text{start}$   $E_{ml} f_{80.0} \leftarrow$

- (7)  $\Sigma$  = equivalent surface area of a sedimentation vessel that would achieve the same settling cut size

$$E_{ml} f_{100.0} = E_{ml} f_{80.0} \times E_{ml} f_{100}$$

- (8) Tubular - barrel  $\Sigma$  < disc stack  $\Sigma$

$$2100.0 = (700) \times (0.0) = 0.0$$

because the diagonal plates drastically increase the area available for collecting the solids

2. answer

(9)  $\text{FeCl}_3$  (ferrix)

(10) A ~~130~~ Tyler mesh has openings of  $600 \mu\text{m}$ .  
i.e. 30 openings per linear inch.

(11) 5 g  $\text{CaCl}_2$  in 9 L water

left over

$$C = \frac{5 \text{ g}}{111 \text{ g}} \text{ mol} = \frac{0.045 \text{ mol}}{0.001 \text{ m}^3} \times \frac{3}{1 \text{ mol of } \text{Ca}^{2+}} \rightarrow \begin{matrix} \text{2nd of Cl-} \\ \text{1 mol of Ca}^{2+} \end{matrix}$$

$$\overline{P} = \frac{(3)(0.045)(8.2057 \times 10^{-5})(298)}{0.001} = 0.001$$

$$\overline{P} = 3.3 \text{ atm}$$

$$\text{Ansatz ORS} = 49$$

$$\text{Ansatz ORS} = 49$$

(12) 5g of protein

$$C = \frac{5 \text{ mol}}{42500 \text{ g}} = 0.117 \text{ mol/m}^3$$

$$(0.117)(0.001 \text{ m}^3 - 9) = \text{vstV}$$

$$\overline{P} = \frac{(0.117)(8.2057 \times 10^{-5})(298)}{(0.001 - 9)} = 0.003 \text{ atm}$$

barely noticeable.

$$2 \text{ atm } \rightarrow \text{barely noticeable.} = 0.003 \text{ atm}$$

(13) • ~~aspects~~ operation  $\rightarrow$  ~~0.003 atm~~ =  $\text{vstV}$

• ~~high throughput~~

• ~~small particle size separation not possible in sedimentation~~  
~~and we cannot flocculate~~

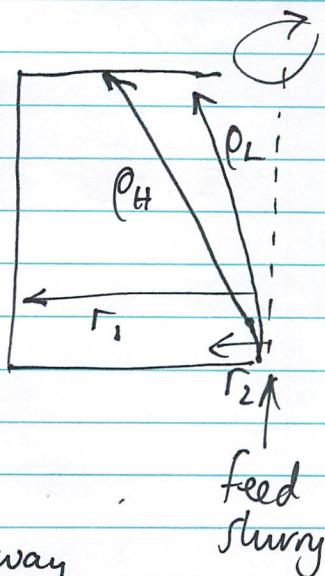
## Question 5

Define: Find a fluorate  $\Omega$  in the centrifuge

" $\Omega$ " must be able to separate the two solids from each other

Explore: It's a centrifuge, so we will like need  
 $\Omega = \sum v_{TSV}^{\text{grav}}$

Trajectories taken by the "heavier" (more dense)  $\rho_H$  particle vs the lighter (less dense)  $\rho_L$  particle



Plan The " $\Omega$ " in the  
 $\Omega = \sum v_{TSV}^{\text{grav}}$  is the  $\Omega$

that just gets the particle midway between  $r_1$  and  $r_2$  for a given solid particle that has  $v_{TSV}^{\text{grav}}$

Which  $\Sigma$ ? Then The one that gives highest throughput  $\Rightarrow$  fastest  $\omega = 10000 \text{ rpm}$   
 $= \frac{10000}{9.55} \text{ rad/s}$

Which  $v_{TSV}^{\text{grav}}$ : for the heavy particle  $\rightarrow$  so we retain it and allow the lighter particle to leave in the overflow.

$$\rho_H = 1280 \text{ kg/m}^3$$

$$\rho_L = 1110 \text{ kg/m}^3$$

$$V_{TSV} = \frac{(\rho - 1000)(9.81)(10 \times 10^{-6})^2}{18 \mu}$$

$$V_{TSV} = (\rho - 1000)(5.54 \times 10^{-8})$$

$$V_{TSV, H} = 1.36 \times 10^{-5} \text{ m/s}$$

$$V_{TSV, L} = 6.0 \times 10^{-6} \text{ m/s}$$

$$\text{Then } \Sigma = \left(1.49 \times 10^{-3}\right) \left(\frac{10000}{9.55}\right)^2 = 1633.7 \text{ m}^2$$

$$\text{so } Q_{cut} = (1633.7) (V_{TSV, H}) = (1633.7)(1.36 \times 10^{-5}) \\ = 0.0222 \text{ m}^3/\text{s}$$
$$Q_{cut}^H = 22.2 \text{ L/s}$$

Quick check:

$$Q_{cut, H} = 22.2 \text{ L/s} \quad \text{and } Q_{cut, L} = 9.79 \text{ L/s}$$

Residence time  $\propto \frac{1}{Q_{cut}}$  for a fixed centrifuge volume  
proportional to

Key: residence time  $\propto \frac{1}{0.0222} = 45 \text{ seconds} \leftarrow$  time to reach the cut point

High residence time  $\propto \frac{1}{0.0979} = 102 \text{ seconds} \leftarrow$  requires longer time to reach cut point, so it will be "washed" out if we operate at 22.2 L/s

2. Improved throughput?  $\Rightarrow Q$  increased

$$Q = \sum V_{BSV}^{grav}$$

(1)  $\Sigma$  is fixed and at maximum already.

(2)  $V_{BSV}$ ?

$$V_{BSV} = \frac{(\rho_p - \rho_f) g D_p^2}{18 \mu_f}$$

(a) Cannot alter  $D_p$  (if you did you would alter both  $D_p$  or if you could alter only one  $D_p \Rightarrow$  ~~you can see~~ impossible)

(b)  $g$  is fixed

(c) adjust  $(\rho_p - \rho_f)$  difference to be double

(d) halve  $\mu_f$

(e) some combination of (d) and (c) to get double

3. Alternative separator?

(a) cyclone: cheap, no moving parts, no water/slurry  
can stack them in a series circuit to  
get better separation

(b) Electrifier (discussed in an earlier class)

(c) if magnetic / electrostatic properties differ you could  
exploit that

(d) No: sedimentation vessel unlikely:  $\Sigma \approx 600 \text{ m}^2$  is a really  
large device, unlikely to get careful liquid flows to  
separate  $10 \mu\text{m}$  particles at such small density differences.

(e) No: disc bowl centrifuge: entraps both particles right near the  
feed entry point. Unlikely to work well.

### Question 5

12 + 3 + 5

Explore: use the centrifuge equations  $\sum V_{TBV}^{\text{grav}} = Q_{\text{out}}$

Explore: understand what  $Q_{\text{out}}$  is doing i.e. time taken for particle to be isolated at a given flow and  $\Sigma$  factor.

Plan, or any reasonable plan started? Not just a bunch of calculations.

Calculate $V_{TBV, H}$	$(\text{heavy})$	$(\text{light})$
and/or $1.36 \times 10^{-5} \text{ m/s}$		$V_{TBV, L}$ $5.995 \times 10^{-6} \text{ m/s}$

Recognise that max throughput is  $\omega = (2\pi) 20 \text{ rpm}$   
 $= 1047 \text{ rad/s}$

Use  $\omega$  in SI units of rad/s and not rpm

Calculate a reasonable  $\Sigma$  value (we know what  $\Sigma$ 's interpretation is)

Assume  $Re < 1$

Calculate highest  $\Sigma = (1.49 \times 10^{-3})(1047)^2 = 1634 \text{ m}^2$   
 $2.27 \text{ rad/s}$

②  $Q_{\text{out}, H} = 0.00222 \text{ m}^3/\text{s} = 222 \text{ L/s}$

Check Re assumption  $Re = \frac{D_p \cancel{\rho_f}}{\mu_f} = \frac{(10 \times 10^{-6})(\cancel{136})}{1.36 \times 10^{-5}}$   
 $0.001$

$= 1.36 \times 10^{-4}$  OK ✓