Separation Processes, 4M3

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Note:

- You may bring in any printed materials to the midterm; any textbooks, any papers, *etc*.
- You may use any calculator during the midterm.
- You may answer the questions in any order on all pages of the answer booklet.
- *Time saving tip*: please use bullet points to answer, where appropriate, and **never repeat the question** back in your answer.
- This exam requires that you apply the material you have learned here in 4M to new, unfamiliar situations, which is the level of thinking required from 4th and 5th year students.
- **Total marks**: 80 marks (3 bonus marks available), 15% of course grade.
- Total time: 2 hours (nominally), though you have "infinite" time to complete it. There are 4 pages on the exam, please ensure your copy is complete.
- Define, Explore, Plan, Do, Check and Generalize.

Question 1 [7 = 5 + 2 + (3 bonus)]

At a particular period of time an operator takes a sample of the feed stream entering a cyclone, and the overhead stream leaving the same cyclone. Around sampling time, the mass of solids entering the cyclone was 88 kg.hour^{-1}, and leaving in the overhead was 27 kg.hour^{-1}.

For the feed stream: mass fraction of material on a number 450 Tyler mesh screen is 17%.

For the overhead stream: mass fraction of material on a number 450 Tyler mesh screen is 52%.

1. Are these values realistic? Has the operator perhaps made a mistake calculating the particle size percentages? Explain your answer.

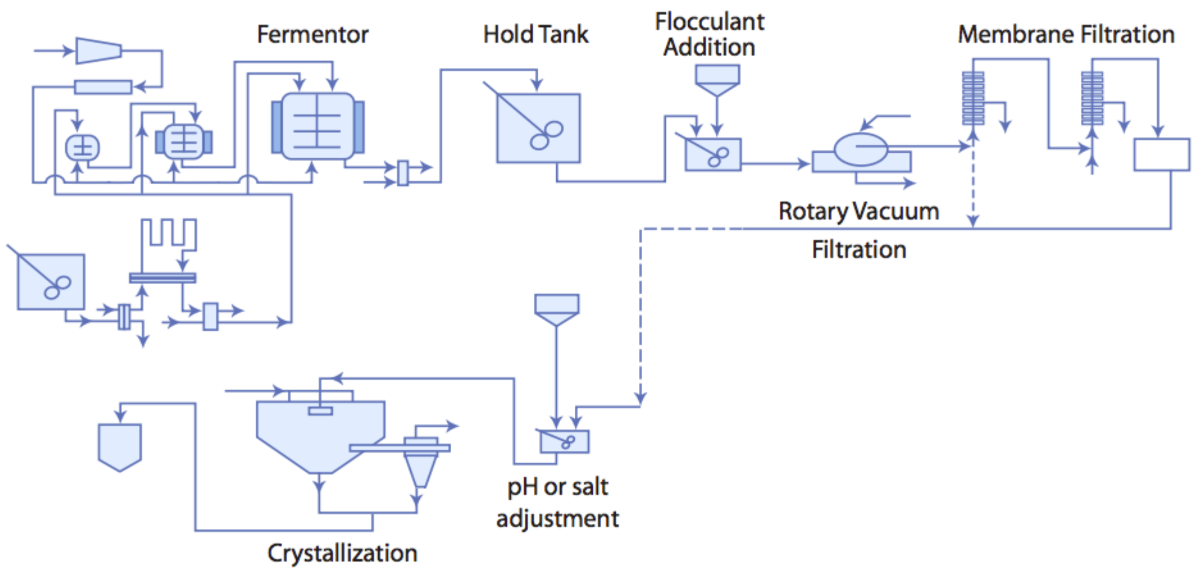
Assume the above values to be correct for the remainder of this question.

2. Calculate the grade efficiency for this particle size, if possible. If not, explain why.
3. *Bonus*: what is the separation factor for these particles relative to all the other solids?

Question 2 [23 = 3 + 2 + 17]

Ultrafiltration membranes have wide use. One particular area is the separation of biological solids from a broth after being cultivated in a fermentor. This flowsheet is from the MIT OpenCourseware website, "Separation Processes for Biochemical Products", shows the downstream steps for recovery of alkaline protease, a biological enzyme.

1. Why is the feed to the membrane flocculated and filtered?



2. In the article in *Bioprocess Engineering*, **7**, p 205-211, 1992, "Recovery of alkaline proteases by membrane filtration" the authors , Santos *et al.* state:

   "This work describes the recovery of an extracellular alkaline protease from fermentation broths of a *Bacillus* sp ATCC 21536, at pH=10.0 using ultrafiltration (MWCO 100,000) and microfiltration (0.1 μm) membranes in hollow fiber devices."

   Clearly explain what the authors mean by "MWCO 100,000"?

3. The enzyme feed from the vacuum filter is highly concentrated. It can be diluted to any specified concentration, C_0 using distilled water. The two membrane modules have area of $A_1 = 25\text{m}^2$ and $A_2 = 50\text{m}^2$, and are placed in series.

   The next step in the flowsheet (after the membranes) was originally designed to expect an retentate flow of $1500\,\text{L.hour}^{-1}$ with an enzyme concentration of 14 gram of solids per litre.

   These membrane have been experimentally determined to deliver a solvent flux given by:

$$J_v = 31 \cdot \ln\left(\frac{19}{C}\right)$$

   where the bulk concentration C has units of g/L and flux is measured in LMH.

   Please show all calculations, assumptions and relevant details to determine (in any order):

   (a) the enzyme concentration from the *first* membrane module,

   (b) the retentate flow rate from the *first* membrane module,

   (c) the permeate flow rate from the *first* membrane module ,

   (d) the main value we are interested in, the feed concentration, C_0, that should be sent to the *first* membrane module,

   (e) the flow rate that should be used to feed the *first* membrane module,

   (f) the permeate flow rate from the *second* membrane module.

Question 3 [12]

A sample of slurry to be filtered is tested in a constant-pressure leaf filter operated at a pressure difference of 30 kPa. A volume of 0.5L of filtrate was collected over a 10 minute period, using an operational area of 0.05 m^2. The thickness of the cake deposited is 30 mm. This is all the information your lab technician gave you.

The same slurry is filtered in a small plate and frame press containing 1 square meter of area, and a 40 mm voidage exists for the cake to form inside the press. During the first few seconds, the rate of filtration is constant and the pressure rises rapidly to 300 kPa as the PI control loop tries to obtain a constant pressure. Thereafter, the filtration is continued at constant pressure and the cakes are formed completely in a further 15 minutes.

What is the total amount of filtrate leaving the press in each batch?

Question 4 [18 = 1 + 1 + 2 + 1 + 1 + 1 + 1 + 2 + 1 + 1 + 2 + 2 + 2]

Provide single word, or short sentence answers to the following (no explanation, no equations).

1. A distillation column is operating with a separation factor of 1.0. What does that imply about its operation? **[1]**
2. "Rotary drum", "Plate and frame", "Precoat": these are terms you will find associated with ______ (*type of unit operation*). **[1]**
3. For an existing solid/fluid sedimentation system; why would we aim to increase the rate of settling of the solid particles in the fluid? **[2]**
4. What is a lower bound on the pressure drop required to desalinate sea water from the ocean using reverse osmosis? **[1]**
5. Select all the options that are true for the statement: The Euler number for a cyclone: **[1]**
   (a) depends on the solid particle sizes entering in the feed.
   (b) is expensive and hard to measure experimentally
   (c) is approximately constant under different pressure drops and flowates through the cyclone
   (d) the higher the Euler number the higher the separation efficiency (for a given feed)
6. In a cyclone: what is the ESA? **[1]**
7. What is the interpretation of the Σ value for a disc stack centrifuge? **[1]**
8. Would the Σ for a tubular bowl centrifuge be larger or smaller than for a disc stack centrifuge when they have the same dimensions of inner and outer radius, rotational speed and height? No calculations required; simply explain your answer clearly. **[2]**
9. Name a chemical flocculant that is commonly used as an MSA for wastewater treatment. **[1]**
10. Describe the characteristics of a number 30 Tyler mesh screen. **[1]**

11. What is an estimate of the osmotic pressure of 5 grams of calcium chloride dissolved in a litre of water at room temperature? [molar mass of water is 18 g/mol and 111 g/mol for calcium chloride]. **[2]**
12. What is the osmotic pressure of 5 grams of protein in 1 L of water at room temperature if the protein has a molar mass of 42,500 g/mol. Contrast your answer to the previous question. **[2]**
13. You must choose between using a small sedimentation tank or a centrifuge in order to separate a given solid/fluid feed. Name two characteristics of the process that would immediately eliminate the sedimentation vessel from consideration. **[2]**

Question 5 [20 = 12 + 3 + 5]

Your problem is to separate a mixture of two types of solid particles. They have the same size of 10 μm. The particles are of different density, 1250 kg.m^{-3} and 1110 kg.m^{-3} respectively. The particles are not soluble in most liquids.

The plan is create a well-mixed slurry of the solids, in water, and feed it to a commercial-scale tubular bowl centrifuge with $\Sigma = (1.49 \times 10^{-3})\ (\omega^2)$, where Σ and ω are in SI units. The centrifuge has an operating range from zero to 10,000 revolutions per minute.

1. Clearly explain the logic and the calculations by which you find the highest volumetric feed rate possible to the centrifuge that will best separate the two solids.
2. You're not satisfied with the volumetric throughput you just calculated – it is too low. What can you *practically* do to double it without buying more equipment?
3. If you could purchase an alternative separator for this problem: name and explain two alternatives you could use. Also highlight one advantage it might have over the centrifuge.

The end.