Separation Processes, ChE 4M3, 2014

Assignment 2

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Objectives: Wrapping up the sedimentation section; dealing with more open-ended questions and moving on to other solid-fluid separation systems.

Question 1 [10]

A rectangular settling basin is used for clarifying a suspended solid stream at a feed rate of 150 m^3 per hour. The basin's size is 45 meters long by 10 meters wide.

There are sand particles with approximately the following sizes present: 24μm, 36μm, 42μm and 60μm and these particles have a density of 1200kg.m^{-3}.

1. Which particle sizes will be completely separated out?
2. Draw the trajectories of the 4 particles in a sketch.

Solution

Some basic solutions from Robin - *thank you!*

Q = 150 m^3.hour $^{-1}$
Basin length = 45 m
Basin width = 10 m
ϱ = 1200 kg.m^{-3}
Particle diameters: 24, 36, 42, 60 μm

Assume particles are settling in water:
ρ_f = 1000 kg.m^3
μ_f = 0.001 Pa.s

also assume:
- unhindered settling
- Stoke's Law applies for settling velocity
- the basin is 10 m tall so A_{cross} = 100 m^2

Using the equation for settling velocity with Stoke's Law applied: $v = \frac{(\varrho_p - \varrho_f)\, g\, D_p^2}{18\, \mu_F}$

Particle Size (μm)	Settling Velocity (mm.s^{-1})
24	0.0628
36	0.141
42	0.192
60	0.392

Also the horizontal fluid velocity is found to be:

$$v_{horiz} = \frac{Q}{A_{cross}} = \frac{150\ m^3/hour}{100\ m^2} = 0.000417\frac{m}{s} = 0.417\ mm/s$$

The time it would take for a particle to travel the length of the settling basin is found to be:

$$t = \frac{d}{v} = \frac{45\ m}{0.000417\ m/s} = 108{,}000\ seconds$$

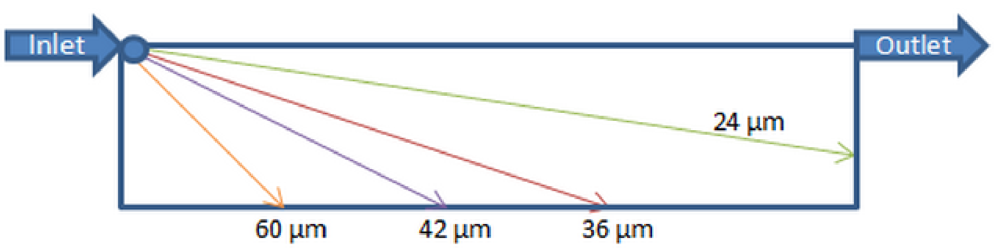
If the particle reaches the depth of the basin (assumed to be 10 m), by the time the particle travels the distance of the basin, the particle has completely separate out from the mixture. The distance travelled by the particle is calculated by:

$$d = v * t$$

Particle Size (μm)	Vertical Distance Travelled (m)	Completely separated out?
24	6.78 = 0.0628E-3 x 108000	No
36	15.3 > 10 m	Yes
42	20.7 > 10 m	Yes
60	42.4 > 10 m	Yes

Therefore, particles of size 36, 42 and 60 μm will completely settle out.

A sketch of the trajectories of the four particles in the settling basin:



You can prove to yourself that if you had chosen a depth of 20m, then the horizontal velocity would be half the amount of 0.417 mm/s, implying the time to travel across the basin is 216,000 seconds instead. But the same trajectories would still have been obtained, because the particle would have to fall double the depth.

Not shown here, but it should be checked, is whether the Reynolds number assumption applies.

Question 2 [3]

We are modifying an sedimentation unit. A flocculant test on laboratory samples appears to triple the settling time from 0.5mm.s^{-1} to almost 1.5mm.s^{-1} for a given waste stream. Assume hindered settling is occurring.

What does this imply about how we can improve the overall system's performance?

Solution

Parts of the solution are from Robin

Since $Q = Av$, and A is fixed for the given unit, then a 3-fold increase in settling rate, v means that the treatment rate Q can be tripled. The settling rate is increased (the question had called it a "time", but the units indicate that it is a "rate"; but with either interpretation, it is clear we are doing things 3 times faster).

This indicates that the sedimentation unit is capable of handling higher inlet flow rates, which would allow for more materials to be separated, since $Q = Av$, where A is fixed for the given unit. So a 3-fold increase in means that the treatment rate, Q, can be tripled.

The question clearly was for an existing unit, but it we were designing a new unit, this result would imply that we can reduce the area ($Q = Av$), for a fixed treatment amount, Q.

Question 3 [5]

A thickener is operating at the designed feed rate of $180 \text{m}^3\text{hr}^{-1}$ but needs to be operated at $225 \text{m}^3\text{hr}^{-1}$ due to increased upstream production. It is the last step before discharging the overflow stream to municipal treatment. Since your company is under investigation from government authorities already, there can be absolutely no risk of discharging additional solids in the overflow.

Clearly explain at least 3 options you can realistically investigate to handle the increased flow; and be as creative as possible. Also, be clear on the expected magnitude of your effect: is it linear or some other function?

Solution

An increased flow rate implies an increase in the volumetric flow, Q.

1. **Add flocculants** - Flocculants will encourage the solids to coagulate, thus increasing the particle size and increasing the terminal settling velocity, v. This will allow the solids to settle quicker, despite the increased feed flow. The magnitude of this effect is expected to be linear with respect to the new terminal settling velocity, since $Q = Av$, and A is fixed.
2. **Enlarge thickener area**, A by expanding the existing unit (not too likely) or by purchasing an additional unit and splitting the feed, Q, across the additional unit. A second thickener of the same size indicates the total cross sectional area of the sedimentation unit has doubled, leading to a decreased horizontal velocity overall. A decreased horizontal velocity would allow the waste longer residence times to settle to the bottom of the thickener. This will also help prevent any dissolved solids from being discharged into the municipal treatment.
3. A costly option would be to lower the liquid's temperature and thereby **adjusting the viscosity**. This will be expensive from an operating cost point of view. Assuming Stokes' law applies, the terminal settling velocity, $v \propto \dfrac{1}{\mu_f}$, but this is not an efficient or economical option really.

Parts of the solution were from Robin

Question 4 [6]

Calculate the sphericity of a rectangular object whose sides are in the ratio $1:1:x$, where x is any value between 1 and 10. Plot the result as x vs sphericity (y-axis).

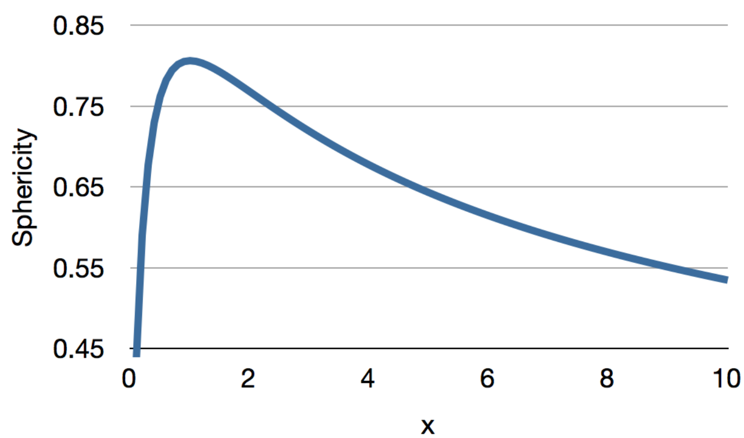
Solution

$$\text{Sphericity} = \psi = \frac{\text{surface area of sphere with same volume as particle}}{\text{surface area of particle}}$$

- Volume of particle = $V = x$
- General equation for volume of a sphere = $\frac{4}{3}\pi r^3$
- General equation for the surface area of a sphere = $4\pi r^2$
- A sphere with a volume of $V = x$ will have radius = $\sqrt[3]{\dfrac{3x}{4\pi}}$
- So surface area of sphere with this radius: $4\pi\left(\sqrt[3]{\dfrac{3x}{4\pi}}\right)^2$
- Surface area of particle = $1+1+x+x+x+x$

$$\psi = \frac{4\pi\left(\sqrt[3]{\frac{3x}{4\pi}}\right)^2}{2+4x}$$

A plot of sphericity with $0.1 \leq x \leq 10$ shows the sphericity increasing to a maximum when $x = 1$, then declining after that again, which makes intuitive sense. It was only required to plot $1.0 \leq x \leq 10$, but over the additional range it shows something informative.



Question 5 [10]

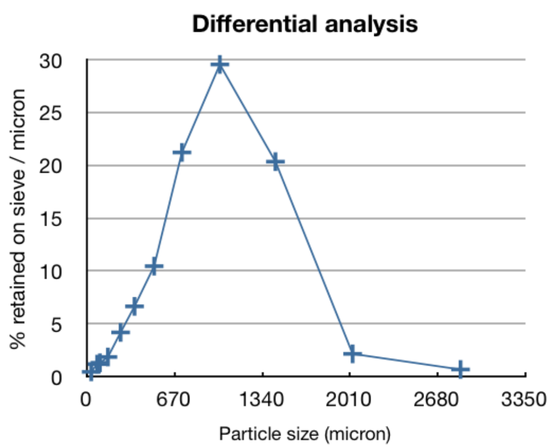
Plot the differential and cumulative analysis (only show the percent passing curve) for the following sieve test results:

Mesh number	Mass retained [g]
6	0.0
8	4.8
12	15.3
16	144.4
20	209.7
30	150.6
40	74.2
50	47.2
70	29.7
140	13.2
170	9.3
230	8.4
Pan	3.2

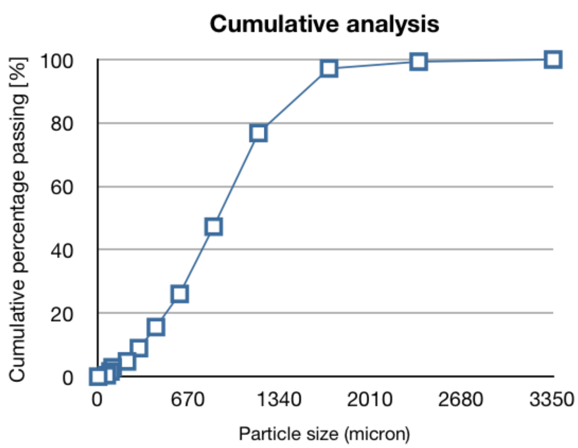
Solution

Mesh	Aperture	Avg aperture	Mass retained	% retained	Cuml % passing
[-]	[micron]	[micron]	[g]	[%]	[%]
6	3350		0	0.0	100
8	2360	2855	4.8	0.7	99.3
12	1700	2030	15.3	2.2	97.2
16	1180	1440	144.4	20.3	76.8
20	850	1015	209.7	29.5	47.3
30	600	725	150.6	21.2	26.1
40	425	512.5	74.2	10.5	15.6
50	300	362.5	47.2	6.6	9.0
70	212	256	29.7	4.2	4.8
140	106	159	13.2	1.9	2.9
170	90	98	9.3	1.3	1.6
230	63	76.5	8.4	1.2	0.5
Pan	~ 53	58	3.2	0.5	0.0

The plots of these data are shown below:



Plot using average screen sizes



Plot using actual screen sizes

Question 6 [4]

Provide 2 examples where centrifuges are used in industrial practice. Please cite your references for this question.

Explain whether a cyclone be a better option in any of these cases.

Solution

In industrial practice, centrifuges can be used to separate mixtures of macromolecules or to separate a macromolecule from solvents [1], such as separating bacteria cells from the culture broth and separating antibodies from the cell pellet. Centrifuges are also used in the food industry, such as the dairy industry to separate milk emulsions into skim milk and cream. [2]

A centrifuge would be a better option than a cyclone in both these conditions because a centrifuge can separate small particles, such as bacteria, and small density differences better. In addition, bacteria and biomolecules can be very delicate, so the force from the air flow can potentially denature the biomolecule in a cyclone. Also, it is easier to control temperature and pH in a centrifuge. In the milk example, a centrifuge would also be the better option, due to the small density difference between milk and cream [3]. A force greater than gravity can be created in a centrifuge to separate the emulsion, which cannot be done in a cyclone.

Solutions are from Robin - thanks.

END

[1] Ghosh, R. (2007). Principles of Bioseparations Engineering. Hamilton, Canada: World Scientific Papers

[2] Geankoplis, C. G. (2003). Transport Processes and Separation Process Principles. (4th ed.). New Jersey, USA: Prentice Hall

[3] Anton Parr. (2009). Density Measurement in Dairy Industry. Retrieved from http://www.mep.net.au/foodlab/FL_5/MEP_DMA35_dairy.pdf