Question 1 Solution:

1) We have the relationship that A=Q/v for the cross-sectional area, volumetric flow rate and overflow rate, v_o. This relationship holds no matter the shape of the sedimentation vessel. Using available information:

$$Q = 500\text{m}^3.\text{hr}^{-1} \quad ; \quad A = L \times W = (15\text{m})(23\text{m}) = 345\text{m}^2$$

$$A = \frac{Q}{v_o} \quad \rightarrow \quad v_o = \frac{Q}{A} = \left(\frac{500\text{m}^3}{\text{hr}}\right)\left(\frac{1}{345\text{m}^2}\right) = 1.45\frac{\text{m}}{\text{hr}} = 4.03 \times 10^{-4}\frac{\text{m}}{\text{s}}$$

Assuming Stokes Law & fluid (water) is at ambient conditions; calculate terminal velocity of a particle with diameter D_p:

$$v_{TSV} = \frac{(\rho_p - \rho_f)gD_p^2}{18\mu_f} = \frac{(1200 - 1000)(9.81)(D_p)^2}{(18)(0.001)} = 109000D_p^2\ [\text{m.s}^{-1}]$$

D_p [micron]	V_{TSV} [m.s^{-1}]	Re
30	9.81×10^{-5}	2.94×10^{-3}
40	1.74×10^{-4}	6.98×10^{-3}
50	2.73×10^{-4}	1.36×10^{-2}
90	8.83×10^{-4}	7.95×10^{-2}

Any particle with a settling velocity (v_{TSV}) greater than or equal to the overflow rate (v_o) will settle out within the vessel. Thus, particles of size 90 micron will be completely separated out. Note that since for all particle sizes Re<1, Stokes' Law assumption is valid.

2) The other particle sizes (30, 40 and 50 micron) will only be partially removed, due to settling at a slower rate than the overflow rate. The smaller the particle, the less it will settle, and the more it will end up in the overflow.

3) To reach the bottom of the tank, a particle must have a terminal settling velocity (v_{TSV}) that is great enough to allow the particle to reach the bottom of the tank before its residence time in the vessel (t_o) expires. This can be explained by the following equation, where h is the height of the tank:

$$v_{TSV} = h \times t_o$$

The residence time can be described by the following equation, where V is the volume of the tank and Q is the volumetric flow rate of the fluid.

$$t_o = \frac{V}{Q}$$

Substituting this equation for residence time into the previous equation for terminal settling velocity gives the following:

$$v_{TSV} = h \times t_o = h \times \left(\frac{V}{Q}\right) = \frac{hQ}{V}$$

Finally, subbing the tank dimensions for volume results in the elimination of the height of the tank (ie. depth).

$$v_{TSV} = h \times t_o = \frac{hQ}{V} = \frac{hQ}{h \times l \times w} = \frac{Q}{l \times w} = \frac{Q}{A}$$

Therefore, it can be concluded that the depth of a sedimentation tank has no bearing on the problem.

Question 2 Solution:

Given: $v_o = 1\frac{mm}{s}$; $v_f = 3\frac{mm}{s}$; $Q_o = Q_f$

An increase in the settling velocity will reduce required settler area.

$$Q = Av \quad \rightarrow \quad A_o v_o = A_f v_f \quad \rightarrow \quad A_f = \frac{v_o}{v_f}A_o = \frac{1\cancel{mm.s^{-1}}}{3\cancel{mm.s^{-1}}}A_o$$

Capital cost estimate = ax^b , where x is tank diameter (b is 1.38).

$$A = \frac{\pi}{4}D^2 \quad \rightarrow \quad A_o = \frac{\pi}{4}x_o^2 \quad \rightarrow \quad x_o = \sqrt{\frac{4}{\pi}A_o} \quad \text{and} \quad x_f = \sqrt{\frac{4}{\pi}A_f} = \sqrt{\frac{4}{\pi}\frac{A_o}{3}}$$

$$\frac{\text{cost before}}{\text{cost after}} = \frac{ax_o^b}{ax_f^b} = \frac{\sqrt{\frac{4}{\pi}A_o}^{\,b}}{\sqrt{\frac{4}{\pi}\frac{A_o}{3}}^{\,b}} = \frac{\sqrt{\frac{4}{\pi}A_o}^{\,b}}{\sqrt{\frac{1}{3}}^{\,b}\sqrt{\frac{4}{\pi}A_o}^{\,b}} = \frac{1}{\sqrt{\frac{1}{3}}^{\,1.38}} = 2.134$$

Cost of the old system is approximately 2.13 times the cost of the new system (with flocculant).

Question 3 Solution:

1) The terminal falling velocity of particles of diameter 5 microns in water, of density ρ=1000kg/m^3 and of viscosity μ=0.001 Ns/m^2, is given by:

$$v_{TSV} = \frac{(\rho_p - \rho_f)gD_p^2}{18\mu_f} = \frac{(2800 - 1000)(9.81)(5\times10^{-6})^2}{(18)(0.001)} = 2.45\times10^{-5}m.s^{-1}$$

Capacity factor (Σ): $Q = v_{TSV}\Sigma \quad \rightarrow \quad \Sigma = \frac{Q}{v_{TSV}} = \frac{0.25}{2.45\times10^{-5}} = \boxed{1.02\times10^4\ m^2}$

2) For the suspension of coal particles in oil (using the same centrifuge):

$$v_{TSV} = \frac{Q}{\Sigma} = \frac{0.04}{1.02\times10^4} = 3.92\times10^{-6}m.s^{-1}$$

Calculate D_p associated with that terminal velocity:

$$D_p = \sqrt{\frac{18\mu_f v_{TSV}}{(\rho_p - \rho_f)g}} = \sqrt{\frac{(18)(0.01)(3.92\times10^{-6})}{(1300 - 850)(9.81)}} = 1.26\times10^{-5}m \rightarrow \boxed{D_p = 12.6\text{ microns}}$$

3) $Re = \frac{vD_p\rho_f}{\mu_f}$; $v_{cent} = \frac{D_p^2(\rho_p - \rho_f)r\omega^2}{18\mu_f}$

We do not have r or ω, but we can determine the maximum centrifugal acceleration ($a_e = r\omega^2$) where Stokes' Law still applies (Re=1):

$$v_{cent} = \frac{Re.\mu_f}{\rho_f D_p} = \frac{(1)(0.01)}{(850)(1.26\times10^{-5})} = 0.934\frac{m}{s}$$

$$\frac{v_{cent}}{v_{TSV}^{grav}} = \frac{a_e}{g} \quad \rightarrow \quad \frac{a_e}{g} = \frac{0.934}{3.92 \times 10^{-6}} = 238190Gs$$

238190Gs represents the maximum g-force that the centrifuge can operate at for Stokes' Law to still apply.

Question 4 Solution:

I would attempt the following, and investigate capital and operating costs while proceeding:

• Purchase an additional thickener: we could build an additional thickener and operate it in parallel. It could be smaller than the first, saving on capital costs. The diameter of the new vessel is quadratically related: $\mathrm{Q} \propto \mathrm{d}^2$.

• Investigate the use of upstream flocculation, or mix flocculant at the current entry point of the thickener (requires retro-fit). The function would be linear: Q = Av, and since A is fixed, any increase in v results in a direct ability to increase Q.

• Consider increasing the liquid's temperature and thereby adjusting the viscosity. This might be expensive from an operating cost point of view. Assuming Stokes' law applies, $\mathrm{v} \propto \frac{1}{\mu_f}$, so a linear decrease in fluid viscosity results in a linear increase in settling velocity, and by extension to the volumetric flow rate.

Question 5 Solution:

Separation units:

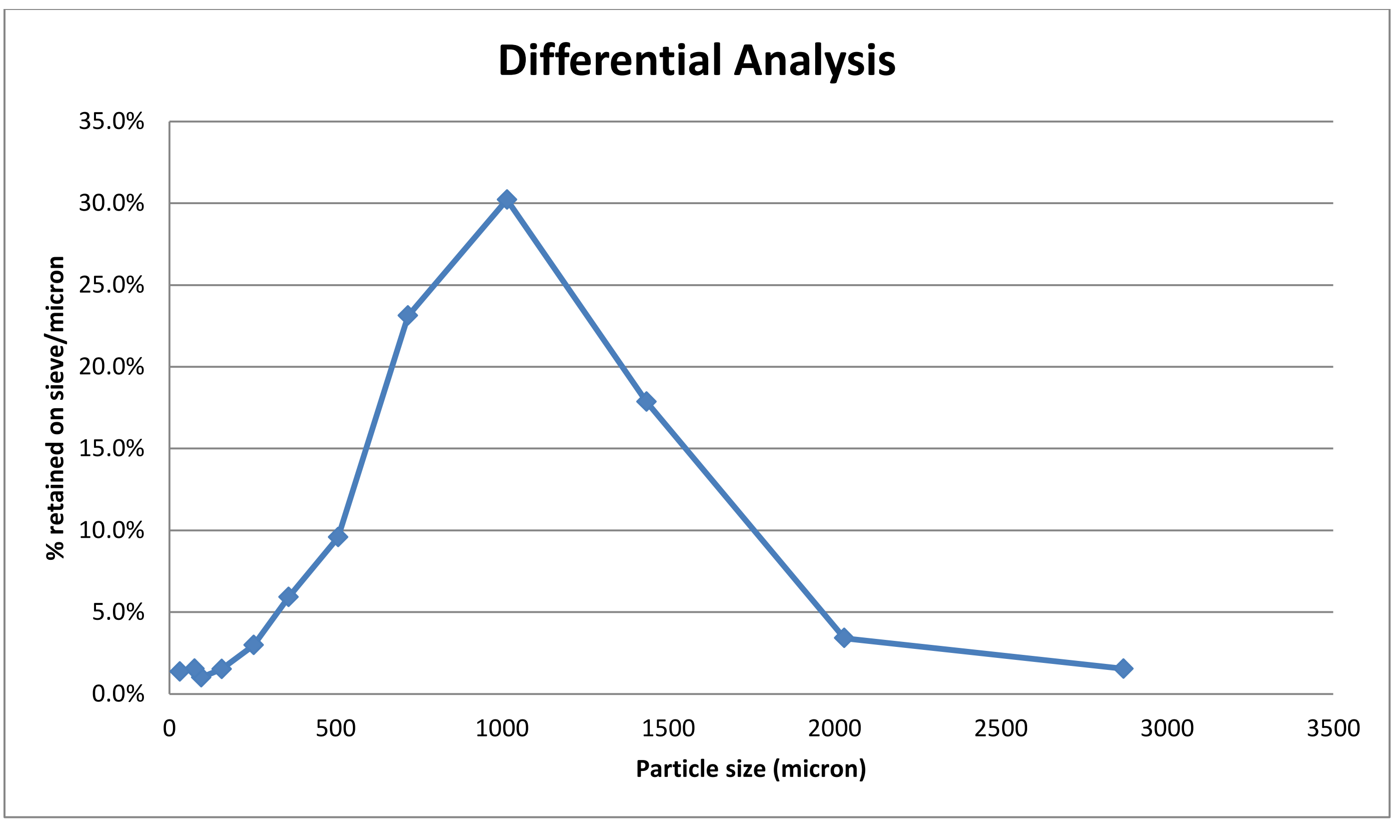
• Sieve separation: separates solid garbage from the liquid waste by employing adequately small mesh sizes. The required liquid waste (sludge) passes through the sieve and onto the next step.

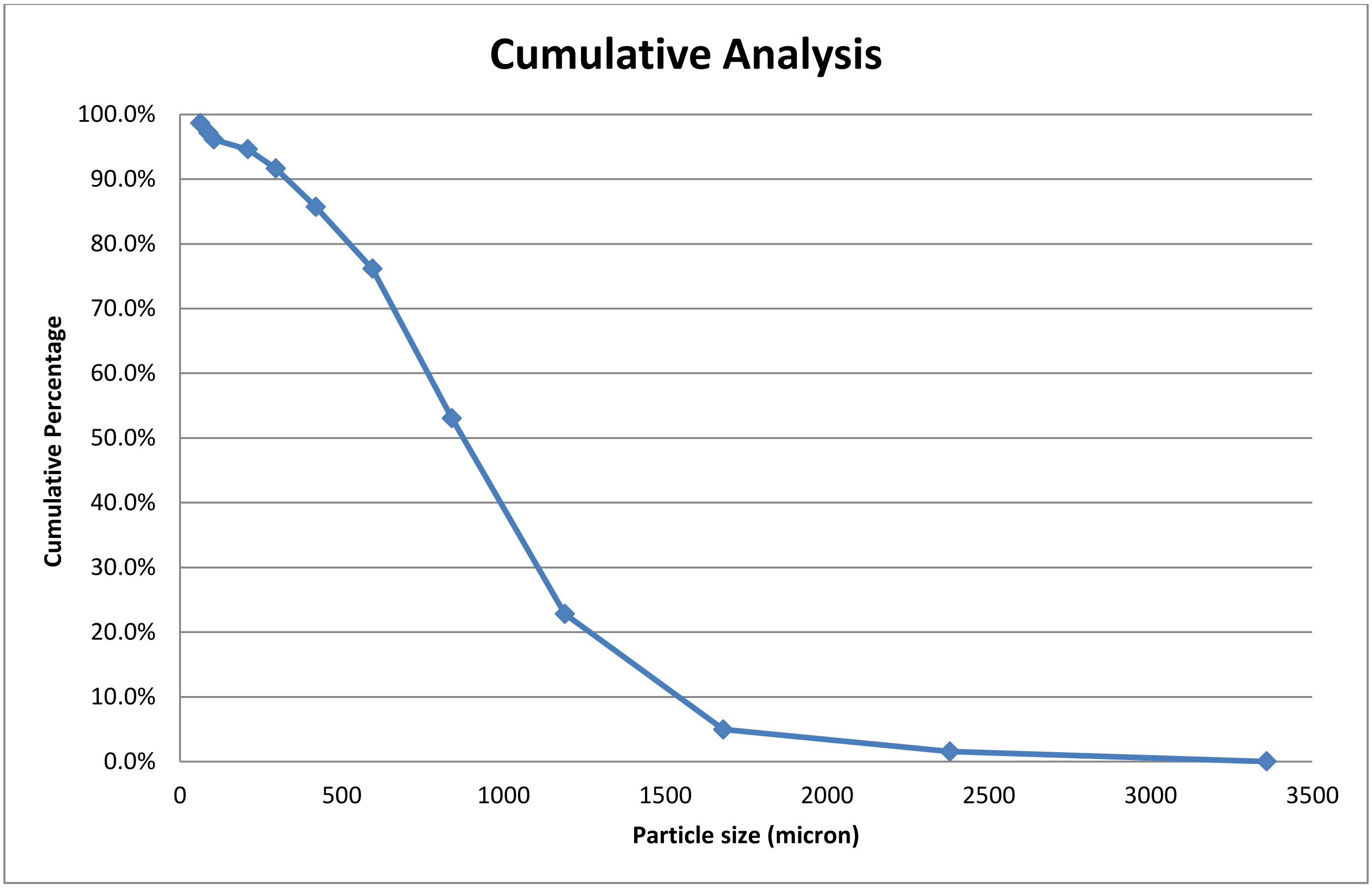
• Sludge dewatering: a polymer (MSA) is added to the pumped sludge stream, causing the waste to agglomerate and settle quickly to the bottom of the container/holding tank.

• Drying: drying beds employ evaporation to remove remaining moisture from the dewatered sludge, using heat as the ESA.

Question 6 Solution:

Mesh number	Aperture	Avg Aperture	Mass retained	% retained	Cum % passing	Cum % retained
[-]	[microns]	[microns]	[g]	[%]	[%]	[%]
6	3360		0	0	100.0%	0.0%
8	2380	2870	12.8	1.5%	98.5%	1.5%
12	1680	2030	28.3	3.4%	95.1%	4.9%
16	1190	1435	148.6	17.9%	77.2%	22.8%
20	841	1015.5	251.3	30.2%	47.0%	53.0%
30	595	718	192.3	23.1%	23.9%	76.1%
40	420	507.5	79.6	9.6%	14.3%	85.7%
50	297	358.5	49.2	5.9%	8.4%	91.6%
70	210	253.5	24.7	3.0%	5.4%	94.6%
140	105	157.5	12.6	1.5%	3.9%	96.1%
170	88	96.5	8.4	1.0%	2.9%	97.1%
230	63	75.5	12.8	1.5%	1.3%	98.7%
Pan	0	31.5	11.2	1.3%	0.0%	100.0%





Note: aperture related to mesh number sourced from Kuo and Acharya:
http://onlinelibrary.wiley.com/doi/10.1002/9781118107683.app05/pdf