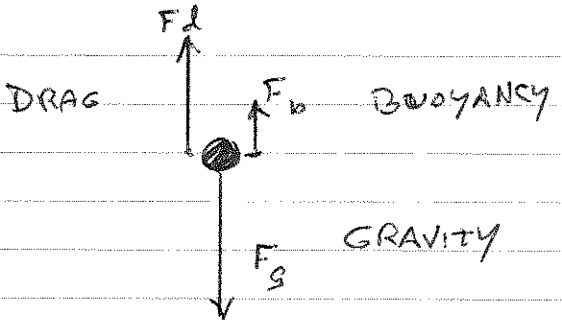
TOPIC: Sedimentation 1

DATE:

FILE UNDER: Supplemental Unit Ops Notes

①



Falling particle quickly achieves TERMINAL (STEADY) VELOCITY.

$$F_d + F_b = F_g$$

Can make various simplifications for small objects with very low Reynolds No.

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②

For: $Re < 0.5$ $\quad C_D \equiv$ drag coeff. $= \frac{24}{Re}$

$= vL/\nu$

$$\therefore \; vL < 0.5\nu = 5 \times 10^{-7} \; m^2 s^{-1}$$

or roughly

$$vL < 10^{-7} \; m^2 s^{-1}$$

E.g., for a 10 μm particle $L = 10^{-5}$ m

If $v \leq 10^{-2}$ m/s = 1 cm/s

then assumption is OK.

{ In fact 1 cm/s is a FAST settling rate in water, typical of, say, fine sand ($L \cong 10^{-4}$ m), so assumption seems OK for micron-range → mm-range sizes }

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③

STOKES LAW: Spherical particles in stationary fluid (non-mixing).

$$v_s = \frac{g(\rho_p - \rho_w)}{18\mu} d^2$$

HENCE: Doubling particle diameter increases v_s by 4X. ⇨

NOTE:

a) Buoyancy of particle ($\rho_p - \rho_w$) matters, linearly

b) For given ρ_p, $\boxed{v_s \propto d^2}$

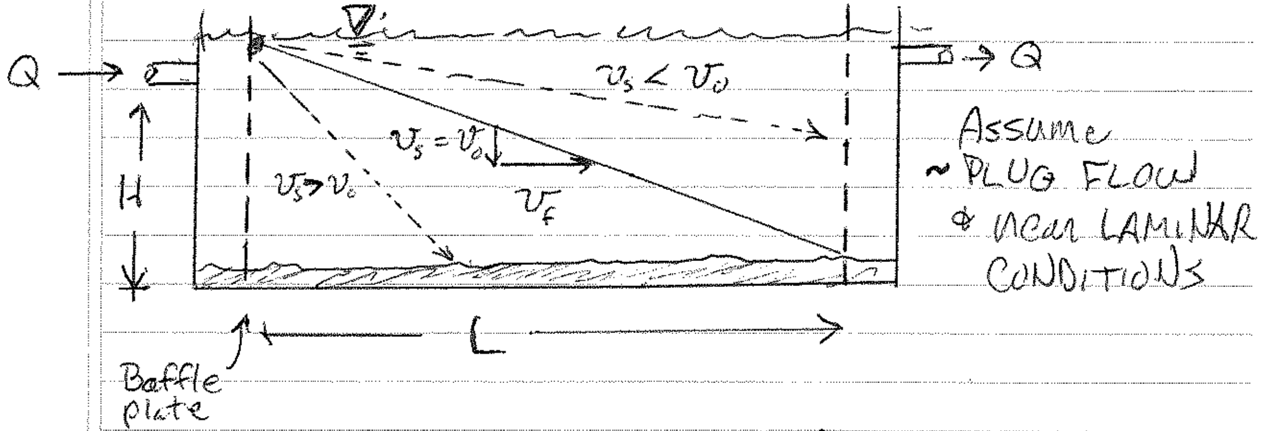
④ Stokes Law does not exactly work for real aquasols with irregular & varying shapes & composition.

BUT basic importance of ρ_p & $v_s \propto d^2$ is still true & helpful.

TYPE I (DISCRETE) SETTLING

Discrete ≡ No particle-particle interactions

Suitable for some simple, non-flocculation suspensions



Assume ~ PLUG FLOW & near LAMINAR CONDITIONS

"Worst case" for particle removal: Enter at very TOP (has farthest to reach bottom.) Distance down = H depth of tank

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⑤ CRITICAL SETTLING VELOCITY v_o:

Must have $v_s = v_o$ such that it travels H in t_d

(Length H in detention time t_d)

$$t_d = \frac{V}{Q} \leftarrow \text{tank volume}$$

$$\therefore \quad v_o = H/t_d = \underset{\uparrow\, = 1/A_{SURF} \Leftarrow}{\frac{H}{V}} Q = \frac{Q}{A_s}$$

$$\boxed{v_o = \frac{Q}{A_s}} = \text{SURFACE LOADING RATE}$$

= Total Flow / Tank Surface Area

⇨ As long as $\frac{Q}{A_s} \leq v_o$ ALL PARTICLE WITH $v_s \leq v_o$ WILL BE REMOVED

⑥ If Stokes law used as approx. v_s:

$$v_s \cong \frac{(10\ \mathrm{m\,s^{-2}})(1800\ \mathrm{kg/m^3})}{18(10^{-3}\ \mathrm{kg\,s^{-1}\,m^{-1}})} d^2$$

$$v_s \approx (10^{-6}\ \mathrm{m^{-1}s^{-1}})\, d^2 (\mathrm{m^2})$$

Assume $\rho_p = 2800 \frac{kg}{m}$ ~ TYPICAL OF Silica OR Al-Si Minerals

E.g.
$d = 1$ mm
$d^2 = 10^{-6}$ m $\Rightarrow v_s \simeq 1$ m/s

$d = 0.1$ mm $\Rightarrow v_s \simeq 1$ cm/s
$d = 100\ \mu m \Rightarrow v_s \simeq 0.1$ mm/s

$\downarrow \frac{1}{d^2}$

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⑦ Suppose we want to remove all particles $d \gtrsim 100\ \mu m$

$v_0 = \frac{Q}{A_s}$ $Q = 1\ m^3/s \approx 20$ MGD (Given)

$$A_s = \frac{1\ m^3 s^{-1}}{10^{-4}\ m\, s^{-1}} = 10{,}000\ m^2$$

or tank(s) ~ surface = 100m × 100m
(two football fields)

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⑧ What if we can flocculate to get same % removal @ $d = 10^{-3}$ m = 1 mm

$$A_s = \frac{1\ m^3 s^{-1}}{10^{-2}\ m\, s^{-1}} = 100\ m^2$$ or just 10 m × 10 m
(100x less tank area)

Hence PARTICLE SIZE MATTERS

Also, this all assumes $\rho_p \simeq$ MINERAL SOLID

NOT TRUE of organics, cells, or Fe/Al flocs
(ρ_p much smaller; close to ρ_w)

So ∴ DENSITY ALSO MATTERS

⑨ But two factors

a) "Slower" part's ($v_s < v_o$) can still settle if enter tank @ $h < H$

Fract. removal $r = \frac{h}{H} = \frac{v_s}{v_o}$

E.g. <u>50%</u> of particles $v_s = 0.5\, v_o$ will be removed

20% with $v_s = 0.2\, v_o$, and so on

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10 $$R_{\text{overall}} = 1 - p_o + \sum_i r_i$$

↑ fraction w/ $v_s \leq v_o$

E.g. $R = 1 - 0.30 + (0.5 \cdot 0.30) + (0.2)(0.3)$

$$= \underbrace{1 - 0.3}_{70\%\text{ removal}} + 0.15 + 0.06 = 0.91$$

— Vs —

91% Removal overall

Get this "extra" removal only w/ horizontal flow, <u>not</u> w/ <u>upflow</u>

But in EITHER CASE, R is fcn ONLY of Q/A_s; <u>INDEPENDENT</u> OF DEPTH