جلسه ۱۲:

شناورسازی توسط هوای محلول

درس: مهندسی تصفیه آب و فاضلاب

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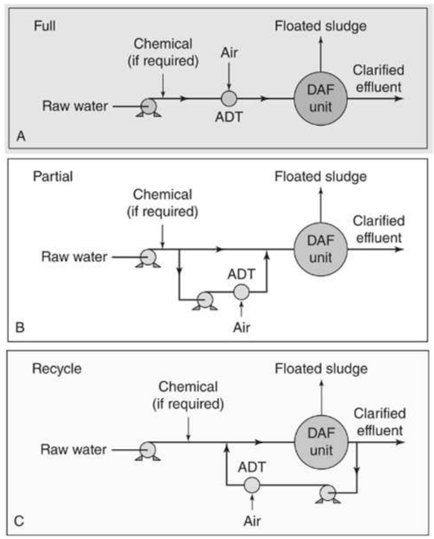
Dissolved air flotation (DAF)

- According to Henry's law, the solubility of gas (such as air) in an aqueous solution increases with increasing the pressure.
- In DAF a water stream is saturated at several times atmospheric pressure (25–90 psig or 172–620 kPa gauge) by a pressurizing system.
- The pressurized feed stream is held at this high pressure for about 0.5–3.0 min in a pressure vessel allowing for dissolution of air into the water…

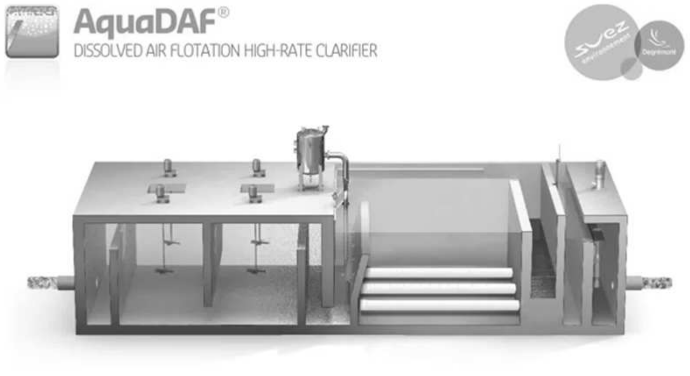
Dissolved air flotation (DAF)

- After pressurization the pressure is released to standard conditions, thus creating millions of microbubbles (<100 μm in diameter). The bubbles surround slow-settling particles and float them to the surface for removal.
- Initially the suspended solids rise freely forming a float/scum layer. As flotation continues, they accumulate and the layer thickens (compresses)
- In water treatment applications when compared to gravity sedimentation, DAF is a more efficient process for separating low density floc particles.

Operation Modes



Rectangular design



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Circular design

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Air to solids ratio

- The air/solids ratio becomes important when influent TSS is high (> 1000 mg/L), such as for treating stabilization pond effluent with high algal content.
- If TSS concentration is low, the quantity of air required for treatment is independent of the TSS present. For example, for raw surface water with an influent TSS of 20 mg/L, approximately 380 mL air/g TSS is required.
- The large air-to-solids ratio is required to ensure adequate collision between the floc particles and air bubbles to facilitate attachment before liquid/solids separation.

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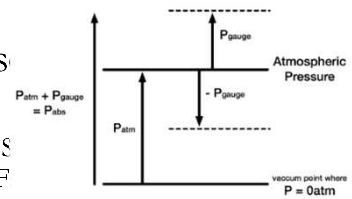
Air to s



- When TSS ... owing for full flow DAF

$$\frac{A}{S} = \frac{1.3\, s_a (f P - 1)}{S_a}$$

A/S = air-to-solids ratio, mL(air)/mg(solids)

s_a = air solubility, mL/L

f = fraction of air dissolved at pressure P, usually 0.5

$P = \text{pressure, atm} = \frac{p + 101.35}{101.35}$

where p = gage pressure, kPa

S_a = influent suspended solids, g/m³ (mg/L)

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Air to solids ratio

- For pressurized recycle flow

$$\frac{A}{S} = \frac{1.3\, s_a(f\,P - 1)R}{S_a Q}$$

R = pressurized recycle, m^3/d
Q = influent flowrate, m^3/d

- In both of the foregoing equations, the numerator represents the weight of air and the denominator the weight of the solids.
- The 1.3 factor is the weight of 1 mL of air (mg) and the term (−1) in the brackets accounts for the fact that the system is to be operated at atmospheric conditions.

Air properties

Densities and solubilities of air at various temperatures, under 1 atm (14.7 psig) pressure in the absence of water vapor

Temperature		Volume solubility (s_a)		Weight solubility		Density	
°C	°F	mL/L	ft^3/1,000 gal	mg/L	lb/1,000 gal	g/L	lb/ft^3
0	32	28.8	3.86	37.2	0.311	1.293	0.0808
10	50	23.5	3.15	29.3	0.245	1.249	0.0779
20	68	20.1	2.70	24.3	0.203	1.206	0.0752
30	86	17.9	2.40	20.8	0.175	1.166	0.0727
40	104	16.4	2.20	18.5	0.155	1.130	0.0704
50	122	15.6	2.09	17.0	0.142	1.093	0.0682
60	140	15.0	2.01	15.9	0.133	1.061	0.0662
70	158	14.9	2.00	15.3	0.128	1.030	0.0643
80	176	15.0	2.01	15.0	0.125	1.000	0.0625
90	194	15.3	2.05	15.0	0.125	0.980	0.0612
100	212	15.9	2.13	15.0	0.125	0.949	0.0591

Solubility of air

- Alternatively, at 1 atm and in the range of 0-60 C, the following model can be used (C_{air} = air weight solubility in water, mg/L, and T = temp in C)

$$C_{air} = 38.00000 - 1.05905T + 2.19504 \times 10^{-2}T^2 - 0.28865 \times 10^{-3}T^3 + 1.67723 \times 10^{-6}T^4$$

Solubility of air

- Comparison of model and actual values (1 atm):

Temperature (°C)	Air solubility (mg/L)	Calculated solubility (mg/L)
0	37.2	38.0
5	32.7	33.2
10	29.3	29.3
15	26.9	26.2
20	24.3	23.7
25	21.7	21.4
30	20.8	19.8

Design

- In the design of a flotation chamber, the target suspended solids to be removed are selected and the chamber is designed so that all suspended solids that have a rise rate equal to or greater than V_T will be separated.
- The solids must have sufficient rise velocity to travel the effective depth (from the bottom to the water surface of the flotation chamber) within the detention time in order to be floated. That is, the rise rate V_T must be at least equal to the effective depth divided by the detention time.

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Design

$$V_T = D/t = Q/A_s = \text{HL}$$

where HL = hydraulic loading ($m^3/s/m^2$), V_T = vertical rise rate of suspended solids (m/s), D = effective depth of the flotation chamber (m), t = detention time (s), Q = influent flow rate (m^3/s), and A_s = surface area of the flotation chamber (m^2).

- In practical design, the rise rate (V_T) of suspended solids to be floated can be measured in the laboratory or in the field, and the influent feed rate (Q) is generally known. The minimum required surface area (A_s) of a flotation chamber can then be determined

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Design

- Reduction of the specific gravity for the aggregate particle causes separation from the carrying liquid in an upward direction. Attachment of the air bubble to the particle induces a vertical rise rate noted as V_T
- Meanwhile, in a rectangular tank, the particle to be removed will have a horizontal velocity V_H

$$V_H = Q/A_c$$

where V_H = horizontal velocity (m/s), Q = influent flow rate (m^3/s), and A_c = cross-sectional area of a flotation chamber (m^2).

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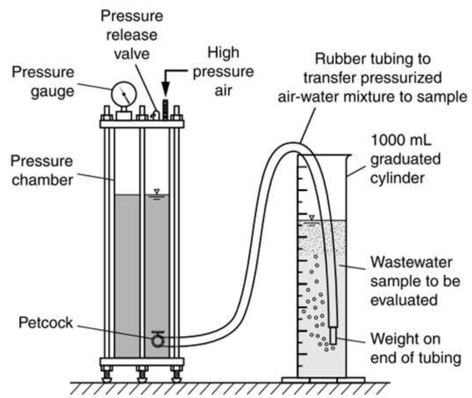
Bench scale flotation cell

Figure 8-40
Bench-scale flotation cell used to determine DAF performance. The cell is pressurized and the gas is dissolved by shaking the cell. Once the air is dissolved, the supersaturated liquid is released into the graduated cylinder.



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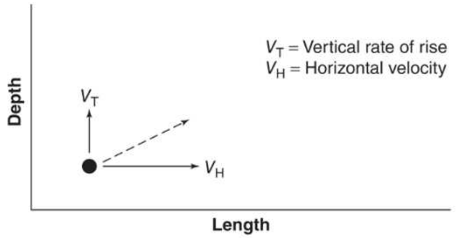
Theory



- Since reality is never perfect:

$$W = A_c/D = A_s/L$$

$$L = (A_s/W)F' = (V_H/V_T)F'D$$

where W = width of flotation chamber (m), L = effective length of flotation chamber (m), and F' = factor for short-circuiting and turbulence, assumed as 1.4.

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Demonstration DAF unit

Video clip inserted

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Design parameters

Factor	Unit	Solids concentration Low (<500 mg/L)	High (>1000 mg/L)
Hydraulic loading rate	m/h	8–20	10–20
Hydraulic detention time	min	5–30	5–30
Basin crossflow velocity	m/h	20–100	20–100
Contact zone detention time	s	30–240	30–240
Contact zone hydraulic loading rate[b]	m/h	35–90	35–90
Width-to-length ratio	unitless	1–2 to 1–4	1–2 to 1–4
Basin depth	m	1.5–3.0	1.5–3.0
Pressurization contact time	s	30–240	30–240
Pressurization tank operating pressure	kPa	400–600	450–600
Bubble size range	µm	10–100	10–100
Bubble size at 400 kPa	µm	50–60	50–60
Bubble size at 500 kPa	µm	40–50	40–50
Bubble size at 600 kPa	µm	30–40	30–40
Air loading[c]	g/m^3	8–12	n.a.

Example

EXAMPLE 8-5. Removal of Algae by Flotation.

Prepare an initial estimate of the size of a full-flow dissolved air flotation process to remove algae from reclaimed water drawn from a winter storage pond. Use the average design values given in Table 8-26 for low solids concentration and assume that the following conditions apply. Also, if the operating pressure is 400 kPa, estimate the number of bubbles that could potentially be formed per mL of water at the point of release.

1. Reclaimed water flowrate = 4000 m^3/d
2. Algal concentration in pond water = 75 mg/L
3. Concentration of alum to overcome alkalinity = 175 mg/L
4. Density of air at 20°C = 1.204 kg/m^3 (see Appendix B)

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Solution

1. Determine the required surface area. From Table 8-26 select a hydraulic loading rate of 14 m/h (14 $m^3/m^2 \cdot h$).

$$A = \frac{(4000\ m^3/d)}{(14\ m^3/m^2 \cdot h)(24\ h/d)} = 11.9\ m^2$$

2. Select tank dimensions. From Table 8-26 use width to length ratio of 1 to 3. Solve for tank length L and width W.

$$L = \sqrt{(11.9\ m^2) \times 3} = 6.97\ m, \text{ say } 6.0\ m$$

$$W = (1/3) \times 6.0 = 2.0\ m$$

3. Check detention time τ. From Table 8-26, assume a tank depth of 2.25 m.

$$\tau = \frac{V}{Q} = \frac{(2.0\ m \times 6.0\ m \times 2.25\ m)(1440\ min/d)}{(4000\ m^3/d)} = 18.0\ min, \text{ ok}$$

Solution

4. Check basin cross flow velocity v_{cf}.

$$v_{cf} = \frac{Q}{\text{Cross sectional area}} = \frac{(4000\ m^3/d)}{(2.0\ m \times 2.25\ m)(24\ h/d)} = 37.0\ m/h, \text{ ok}$$

5. Check contact zone hydraulic loading CZ_{hyd}. From Table 8-26, assume first 20 percent of the basin length serves as the contact zone.

$$CZ_{hyd} = \frac{Q}{A_{CZ}} = \frac{(4000\ m^3/d)}{[2.0\ m \times 6.0\ m \times (0.2)](24\ h/d)} = 69.4\ m/h, \text{ ok}$$

6. Compute the air flowrate Q_{air}. From Table 8-26, use an air volume of 10 g air/m^3 of water.

$$V_{air} = \frac{(10\ g/m^3)(4000\ m^3/d)}{(1.204\ kg/m^3)(10^3\ g/kg)(1440\ min/d)} = 0.023\ m^3/min$$

7. Compute the number of bubbles per mL of water at the point of release. From Step 6, the air per m^3 of liquid is equal to 10 g/m^3.

a. Determine the density of air at 20°C and 400 kPa.

$$\rho_{air,400\ kPa} = (400\ kPa/101.3\ kPa)(1.204\ kg/m^3\ air)$$
$$= 4.754\ kg/m^3 air$$

b. Determine the volume of air.

$$V_{air} = \frac{(0.010\ kg\ air/m^3\ water)}{(4.754\ kg/m^3\ air)} = 0.00210\ m^3\ air/m^3\ water$$

c. Determine the volume of an air bubble.

$$V_{bubble} = \frac{4 \times 3.14 \times [(55/2) \times 10^{-6}\ m]^3}{3} = 8.71 \times 10^{-14}\ m^3$$
$$= 8.71 \times 10^{-8}\ mL$$

d. Determine the number of air bubbles.

$$\text{Number of bubbles} = \frac{(0.00210\ mL\ air/mL\ water)}{(8.71 \times 10^{-8}\ mL/bubble)}$$
$$= 24{,}144\ bubbles/mL$$