Dissolved Air Flotation

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Water Treatment

Flotation

- Flotation is described as a gravity separation process in which gas bubbles attach to solid particles to cause the apparent density of the bubble-solid agglomerates to be less than that of the water, thereby allowing the agglomerate to float to the surface.
- Flotation is employed mainly for the treatment of nutrient-rich reservoir waters that may have heavy algal blooms and for low-turbidity, low-alkalinity colored waters.

Types of Flotation

- Different methods of producing gas bubbles give rise to different types of flotation processes.
- These are *electrolytic flotation*, *dispersed air flotation*, and *dissolved air flotation*.
- The basis of electrolytic or electroflotation is the generation of bubbles of hydrogen and oxygen in a dilute aqueous solution by passing a dc current between two electrodes.
- The application of electrolytic flotation has been restricted mainly to sludge thickening and small wastewater treatment plants in the range 10 to 20 m3/h (50,000 to 100,000 gpd) and has limited application to drinking water treatment.

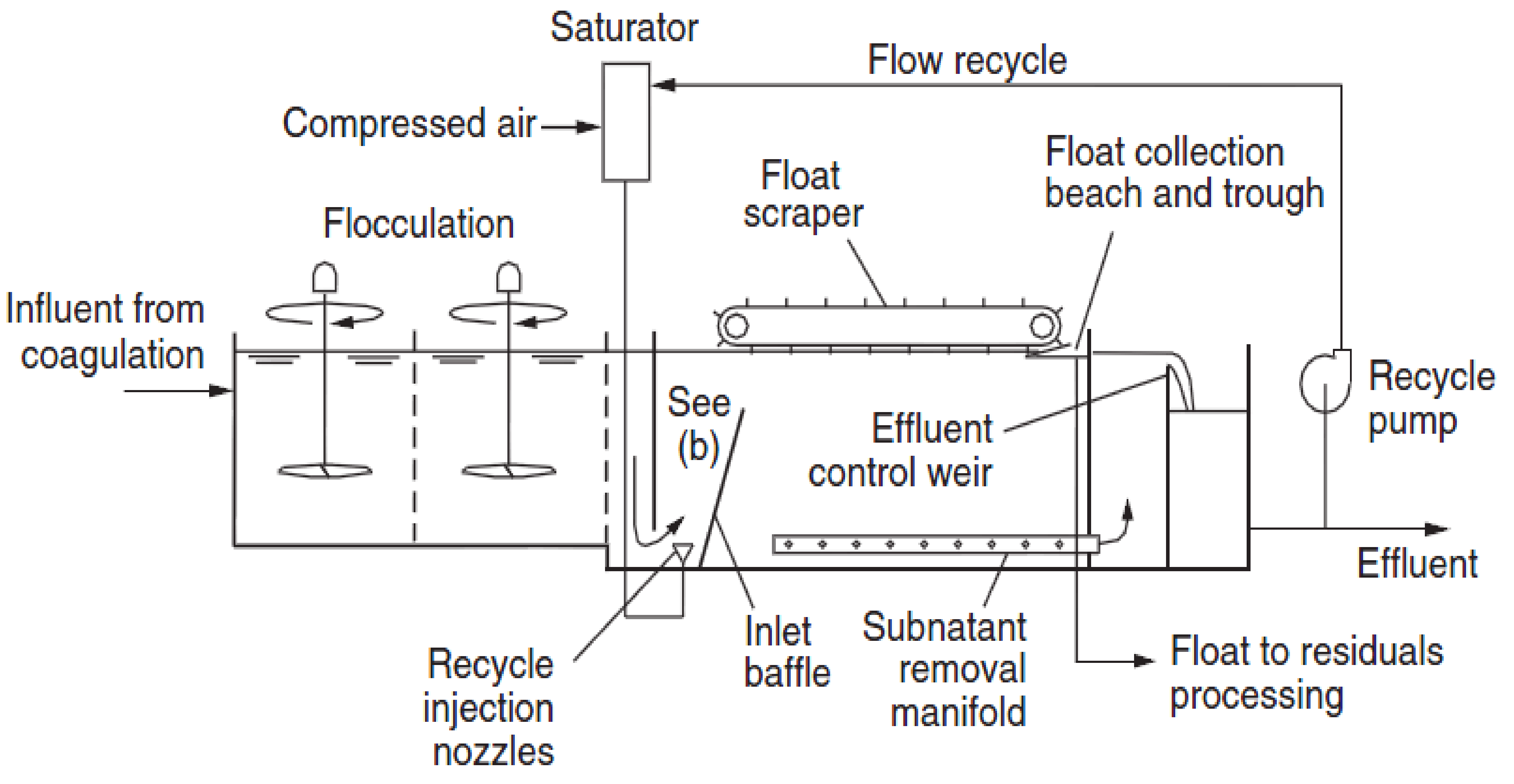
Types of Flotation

- **Dispersed air flotation** involves the formation of bubbles by diffusers, spargers, and other mechanical means. Large bubbles are formed (sizes of a mm) and can be effective in treating suspensions containing large particles such as mineral separation and industrial waste treatment.
- Dispersed air flotation is generally unsuitable for water treatment as the bubble size is large and because of high turbulence and use of undesirable frothing and surfactant chemicals.
- However, the French Ozoflot® system applies ozone-rich air as a pretreatment oxidation process for waters high in algae using diffusers to achieve dispersion.

Types of Flotation

- In dissolved air flotation, air bubbles are produced by the reduction in pressure of a water stream saturated with air.
- The three main types of dissolved air flotation are *vacuum flotation*, micro-flotation, and pressure flotation.

DAF Process Schematic



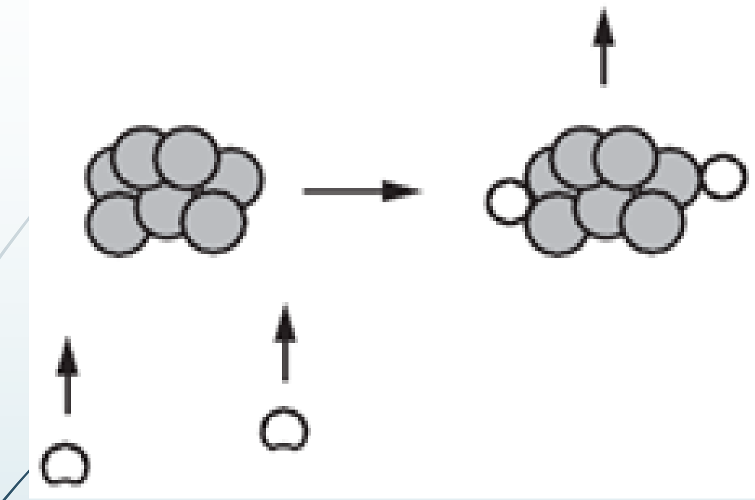
Advantages and Disadvantages

Advantages	Disadvantages
• High loading rate: Typically 10–20 m/h. New process variants have operated successfully up to 40–45 m/h. • Very thick float (sludge) product: Typically 2–3% total solids float can be achieved using hydraulic or mechanical skimming devices. Float can be dewatered without intermediate thickening. • Often, no polymer is required, as DAF does not require a large, dense floc. Coagulant dosages may also be reduced in some circumstances. • Shorter flocculation times, as compared to gravity separation, are possible, because a smaller floc particle size is required. • Rapid startup, typically $<30–60$ min to reach steady state, depending on size. • Excellent algae removal efficiencies. • Excellent *Giardia* and *Cryptosporidium* removal efficiencies (~2–2.5 log), depending on temperature. • Smaller footprint required as compared to conventional flocculation and gravity sedimentation	• Requires a cover or housing to protect the float layer from wind and precipitation. • Mechanically more complex than conventional gravity clarifiers. • More power intensive as compared to conventional flocculation and sedimentation (2.5–3 to 0.75–1 kWh/10^3 $m^3 \cdot d$). • Generally not well suited for clarification of high-turbidity silt-laden waters. • Because DAF is more mechanically intensive, may not be suitable for locations where equipment maintenance is likely to be neglected.

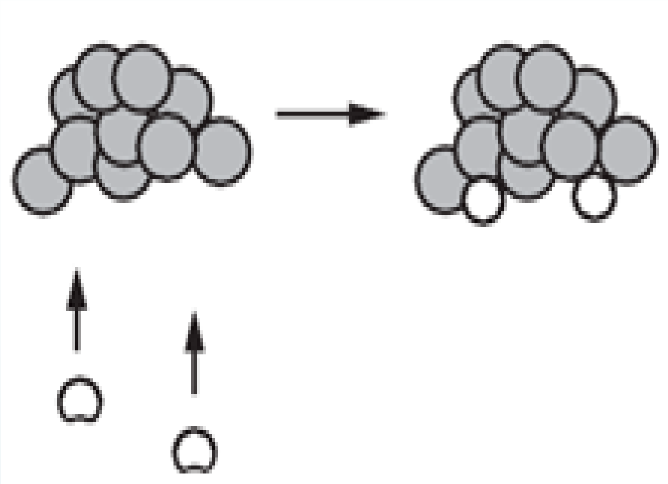
Factors that affect DAF performance

- Proper coagulation
  - Should produce destabilized flocs
- Floc characteristics
  - Small and low-density floc is preferred
- Bubble size and rise velocity
  - 10-100 μm floc bubble size
  - Laminar flow regime
- Air loading
  - Ensure dense bubble cloud
- Floc-bubble attachment
  - Important to know the mechanisms for floc-bubble attachment
- Solubility of gases
  - Ensure sufficient air delivery

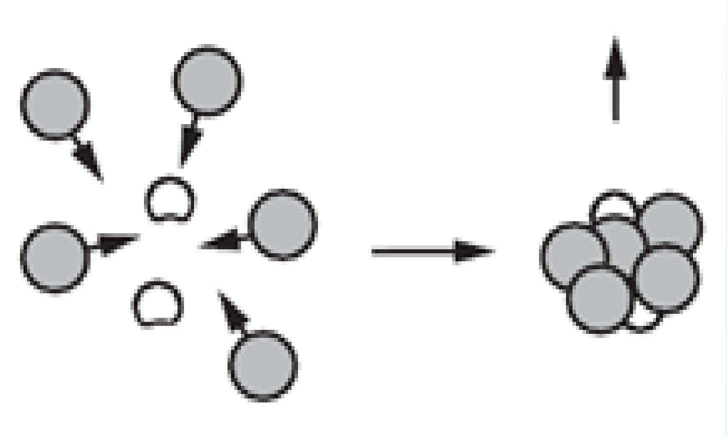
Possible mechanisms for floc–bubble attachment



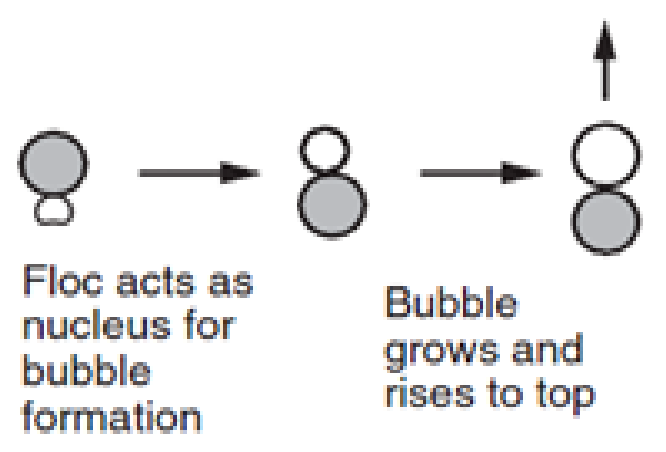
Bubbles adhere to preformed floc



Bubbles trapped in preformed floc

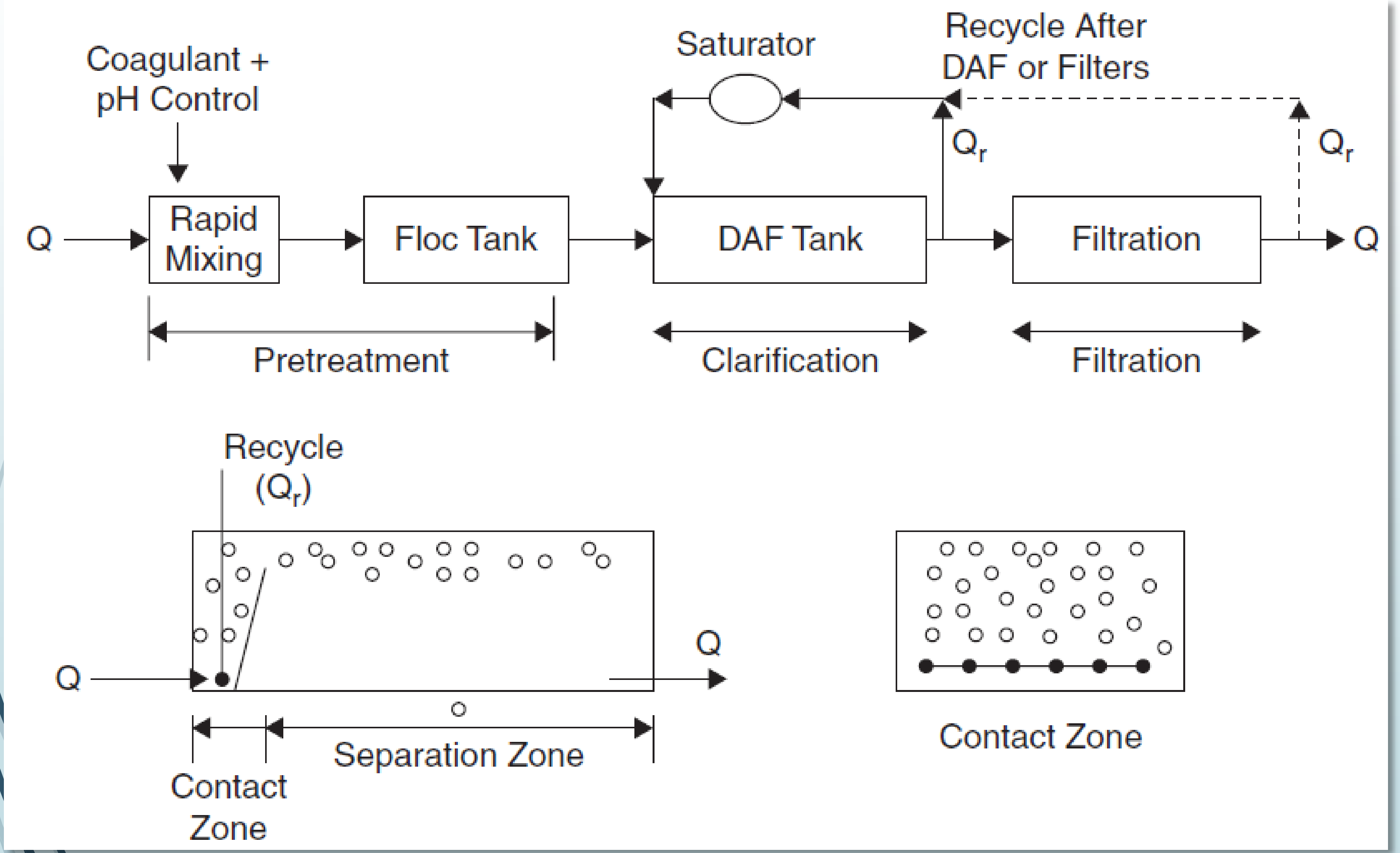


Bubbles trapped as floc forms



Floc acts as nucleus for bubble formation

DAF process



The recycle ratio or rate (*R*) is defined by

$$R = \frac{Q_r}{Q}$$

Recycle rates are usually in the range of 6 to 12 percent

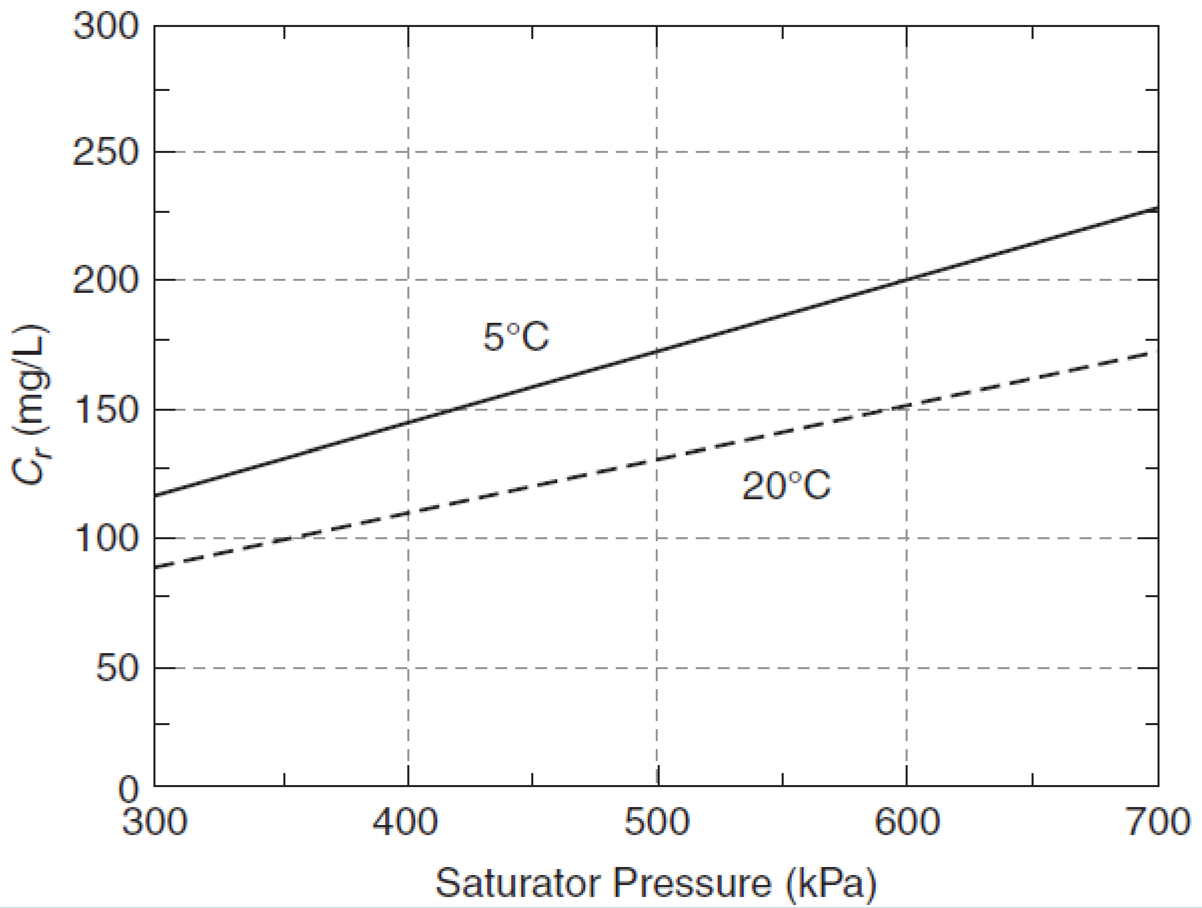
Air Bubbles

- Saturator gauge pressures are usually between 400 and 600 kPa.
- The recycle flow is injected through nozzles or special valves at the bottom entrance to the contact zone. Microbubbles are produced with sizes between 10 and 100 μm.
- Conventional DAF processes hydraulic load: 5 to 15 m/h.
- High-rate DAF processes hydraulic load:15 to 30 m/h

Solubility of air

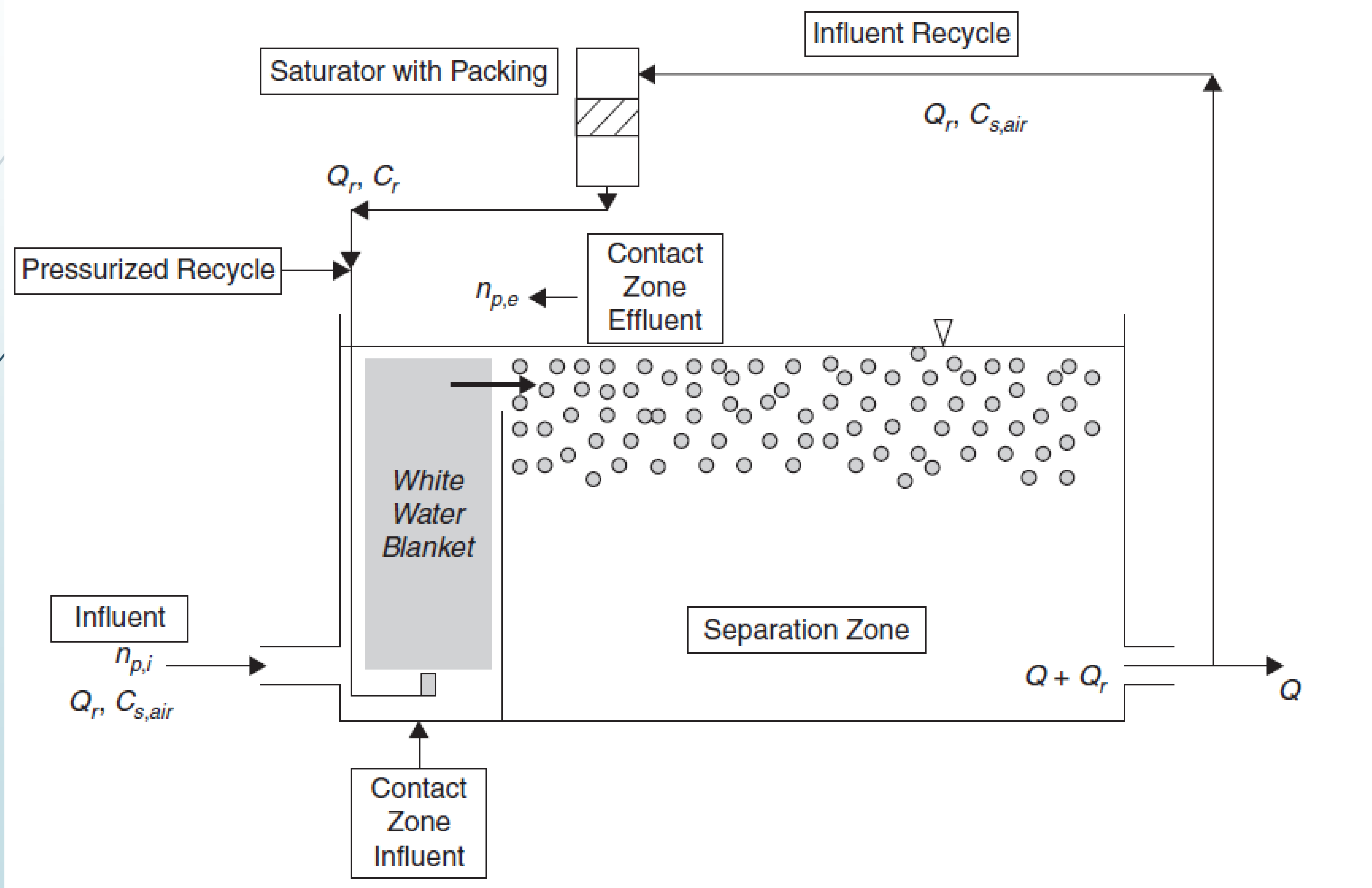
Solubility of Oxygen, Nitrogen, and Air in Water for Atmospheric Air (79.1 percent N_2 [accounts for small amounts of other gases] and 20.9 percent O_2)

Temperature (°C)	$C_{s,O}$ (mg/L)	$C_{s,N}$ (mg/L)	$C_{s,air}$ (mg/L)
5	12.3	19.5	31.8
10	10.9	17.7	28.6
15	9.8	16.1	25.9
20	8.9	14.8	23.7
25	8.1	13.6	21.7
30	7.4	12.6	20.0



Cr is the total dissolved air in the recycle flow from the saturator pressure (gauge pressure) plus atmospheric pressure

DAF tank components



Bubble Suspension in the Contact Zone

- ***The bubble suspension (White water blanket)*** in the contact zone achieves a steady state bubble concentration arising from the continuous input of pressurized recycle flow (*Qr*) mixing with the influent water (Q) from the flocculation tank.
- There are three measures of bubble concentrations: mass, volume, and number.

Bubble Suspension in the Contact Zone

- ***Mass Concentration.*** Mass concentration of air bubbles (C_b) in the contact zone is given by:

Saturator efficiency
Unpacked: 60 - 70 %
Packed: 90 – 95 %

Air deficit in the incoming water

$$C_b = \frac{[e(C_r - C_{s,\mathrm{air}})R - k_a]}{1+R}$$

Recycle ratio

- ***Volume Concentration.*** The air bubble volume concentration in the contact zone (Φ*b*) is calculated from:

$$\Phi_b = \frac{C_b}{\rho_b}$$

Moist air density

Bubble Suspension in the Contact Zone

- ***Number Concentration***. The air bubble size (d_b) must be known or assumed to calculate the bubble number concentrations (n_b).
- The bubble sizes formed depend mainly on the saturator pressure and the injection device (nozzle type or needle and gate valves)
- at saturator gauge pressures of 400 to 600 kPa, the bubble sizes are between 10 and 100 µm with most bubbles about 40 to 80 µm with mean size of 60 µm

The number concentration = $n_b = \dfrac{\Phi_b}{\left(\dfrac{\pi (d_b)^3}{6}\right)}$

Example: Bubble Concentrations

Consider a DAF plant operating at 10 % recycle with a saturator pressure of 500 kPa and 90 % efficiency. The flocculated water enters the contact zone of the flotation tank with a floc particle concentration (n_p,*i*) of 20,000 particles/mL and a floc volume concentration (Φ_p) of 20 ppm. Compute the air mass concentration (c_b), bubble volume concentration (Φ_b), and number concentration (n_b) in the contact zone of the DAF tank, and compare the concentrations of bubbles to floc particles. For these calculations use a water temperature of 20° C; at this temperature ρ_b is 1.19 kg/m^3. Assume the flocculated water is saturated with air so k_a is 0.

Solution

1. *Mass of air in DAF tank*.

- C_r= 130 mg/L (from graph slide 8)
- $C_{s,air}$ = 23.7 mg/L (from table slide 8)

$$C_b = \frac{[e(C_r - C_{s,\text{air}})R - k]}{1+R} = \frac{[0.90(130-23.7)0.10]}{1+0..10} = 8.7 \text{ mg/L}$$

2. *Bubble volume concentration*.

$$\Phi_b = \frac{C_b}{\rho_{\text{air}}} = \frac{8.7 \text{ mg/L}}{1.19 \text{ kg/m}^3} = 7.31\left(\frac{\text{mg}}{\text{kg}}\right)\left(\frac{\text{m}^3}{\text{L}}\right) = 7.31\left(\frac{\text{mg}}{\text{kg}} \times \frac{\text{kg}}{10^6\text{mg}}\right)\left(\frac{\text{m}^3}{\text{L}} \times \frac{10^3\text{L}}{\text{m}^3}\right)$$

$$\Phi_b = \frac{7310 \text{ m}^3 \text{ of air}}{10^6 \text{ m}^3 \text{ of water}} = 7310 \text{ parts per million (pppm)}$$

Solution

3. <u>*Bubble number concentration*</u>. *nb* is calculated using a mean bubble diameter of 60 μm

$$n_b = \frac{6\Phi_b}{\pi d_b^3} = \left[\frac{6(7310\times10^{-6})}{\pi(60\times10^{-6})^3}\right] = 6.47\times10^{10}\left(\frac{\text{bubbles}}{\text{m}^3}\right)\times\left(\frac{\text{m}^3}{10^3\ \text{L}}\right)$$

$$= 65\times10^6\left(\frac{\text{bubbles}}{\text{L}}\right)$$

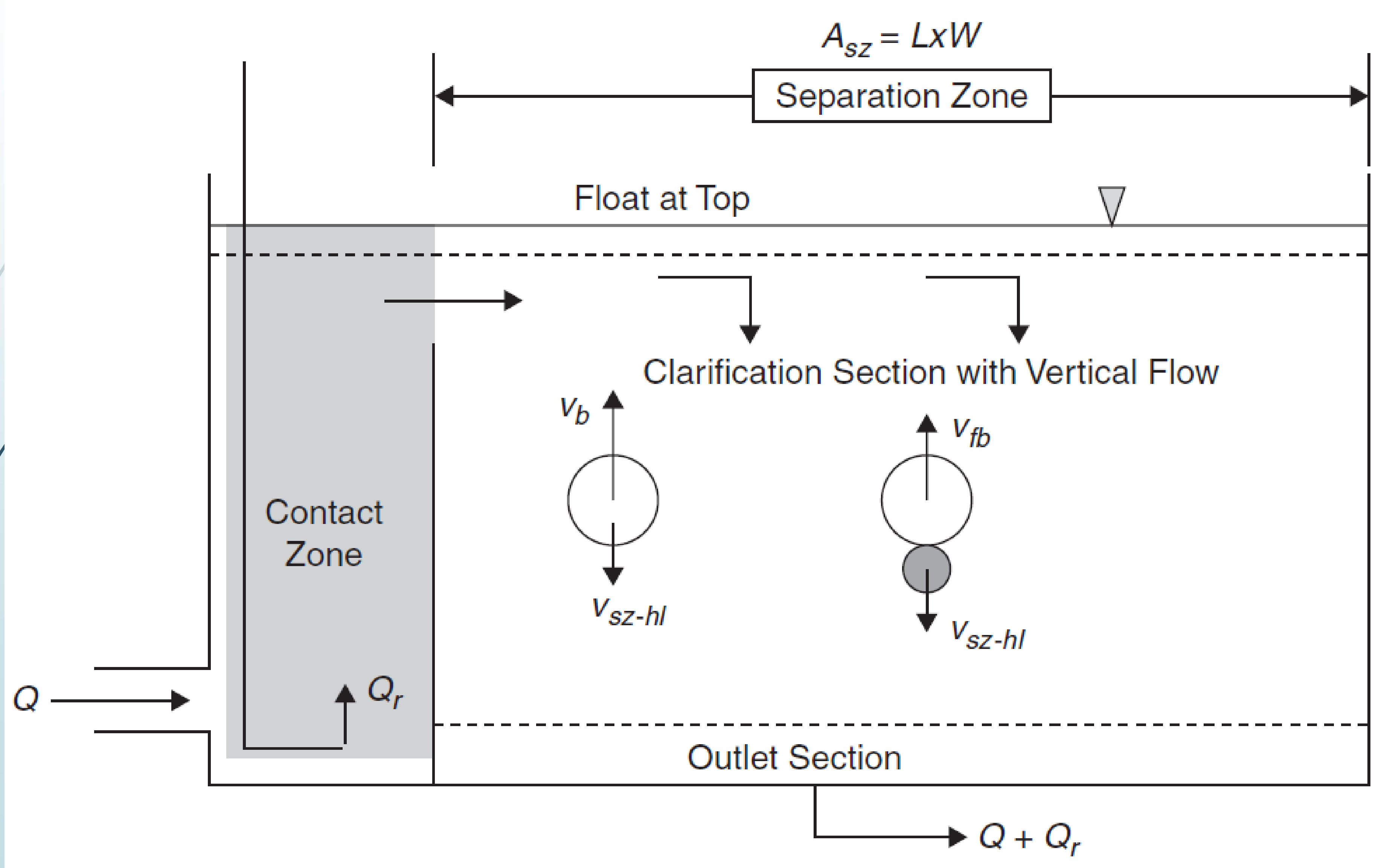
4. <u>*Ratios of concentrations*</u>.

$$\frac{n_b}{n_{p,i}} = \frac{65\times10^6}{20\ 000}\left(\frac{\text{bubbles}}{\text{L}}\right)\left(\frac{\text{mL}}{\text{particles}}\right)\times\frac{\text{L}}{10^3\ \text{mL}} = 3.3$$

or about 4 bubbles per floc particle

$$\frac{\Phi_b}{\Phi_p} = \frac{7310\ \text{ppm}}{20\ \text{ppm}} = 365\ \text{bubble volume per floc particle volume}$$

Ideal DAF Tank



Conventional and High-Rate DAF Systems

- classified by the nominal hydraulic loading rate

$$v_{nom-hl} = \frac{Q}{A}$$

← throughput plant flow (Q)

← the contact and separation zones (A)

- Hydraulic loading rate of separation zone ($V_{sz\text{-}hl}$)

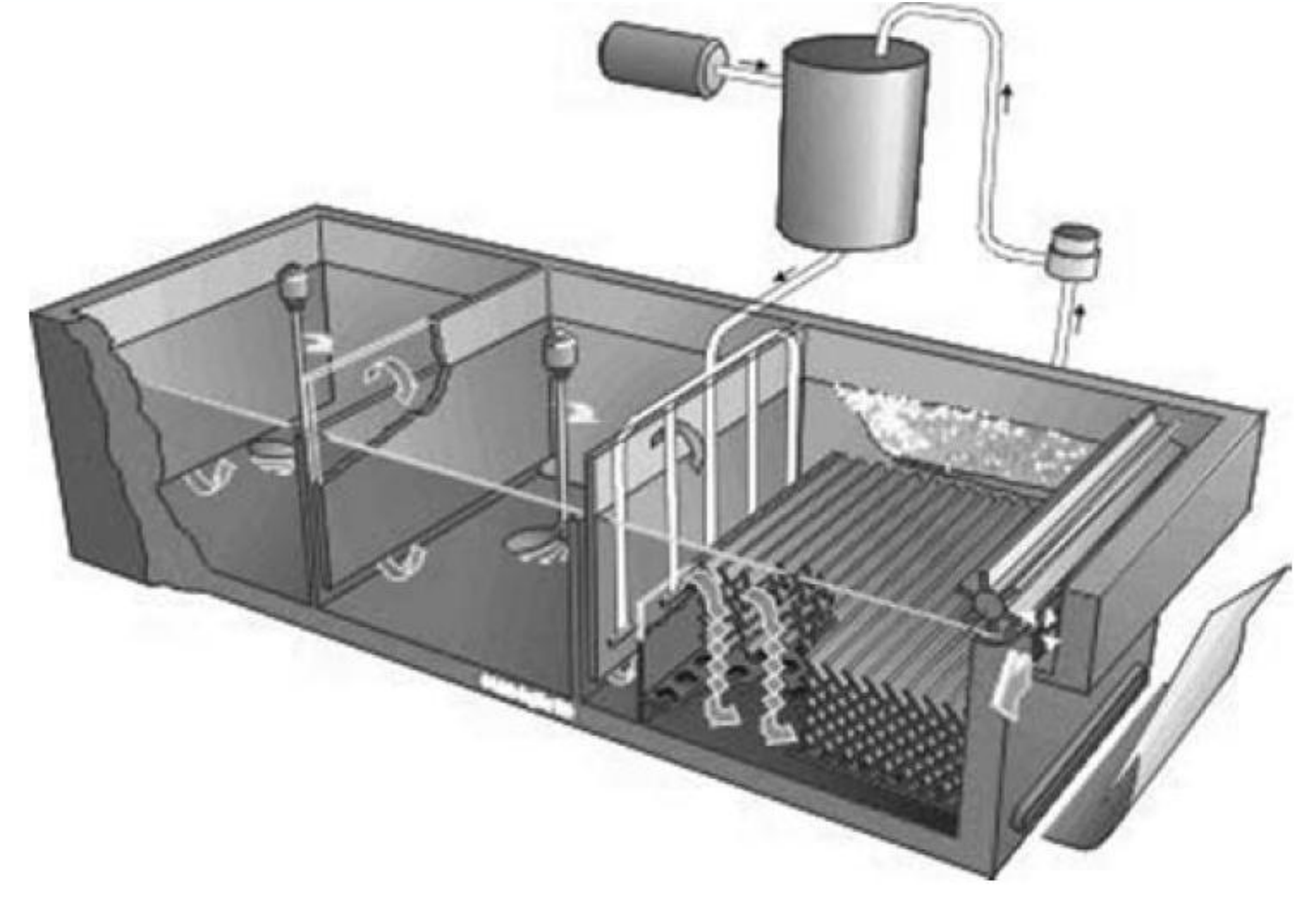
$$v_b \geq v_{sz-hl} = \frac{Q+Q_r}{A_{sz}}$$

$$v_{fb} \geq v_{sz-hl} = \frac{Q+Q_r}{A_{sz}}$$

free bubbles and floc bubble aggregates are removed if their rise velocity is greater than the vertical water velocity or hydraulic loading

Conventional and High-Rate DAF

	Conventional	High-rate
Detention time (min)	10 – 20	10 – 15
Mixing intensity (G) sec-1	50 - 100	
Contact zone loading rate (m/h)	100–200	120–300
Contact zone detention time (min)	1–2.5	1.0–2.0
Hydraulic loading	5 - 15	10 - 30
Separation zone loading rate (m/h)	6–18	20–40
Basin depth (m)	2.0–3.5	2.5–4.5
Recycle rate %	6–12	
Saturator gauge pressure (kPa)	400–600	
Saturator efficiency (%)	80–95 packed	



Example: Separation Zone

Consider a DAF process with a nominal hydraulic loading of 15 m/h. The recycle rate is 10 percent.

- Calculate the separation zone hydraulic loading assuming the separation zone footprint area is 90 percent of the gross footprint area, and compare it to bubble and floc bubble aggregate rise velocities.
- Determine the separation zone area for a design flow of 37,850 m^3/d (10 mgd).

Solution

- *Separation zone hydraulic loading*

$$v_{sz-hl} = v_{nom-hl}\left(\frac{1.1}{0.9}\right) = 15\left(\frac{1.1}{0.9}\right) = 18.3 \text{ m/h}$$

Good performance is expected because bubbles and floc-bubble aggregates with rise velocities of 20 m/h will be removed.

- *Separation zone area.*

$$v_{sz-hl} = \frac{Q+Q_r}{A_{sz}}$$

$$A_{sz} = \frac{Q+Q_r}{v_{sz-hl}} = \frac{(37850+3785)}{18.3}\,\frac{\text{m}^3/\text{d}}{\text{m}^3/\text{m}^2\,\text{h}}\left(\frac{\text{d}}{24\text{h}}\right) = 94.8 \text{ m}^2$$

If we choose a *L* /*W* ratio of 1.3, then the separation zone *L* is 11 m and *W* is 8.5 m.

Thank you!

All the best!