CornellEngineering
Civil and Environmental Engineering

CEE 4540

Sustainable municipal drinking water treatment

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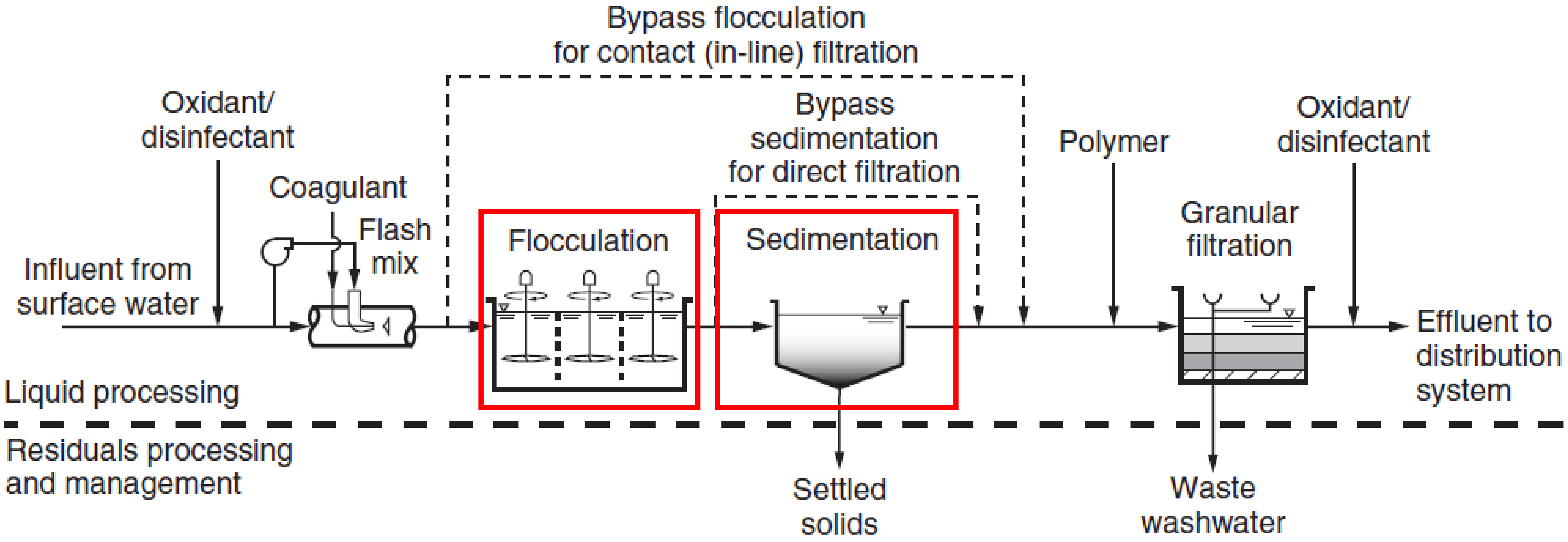
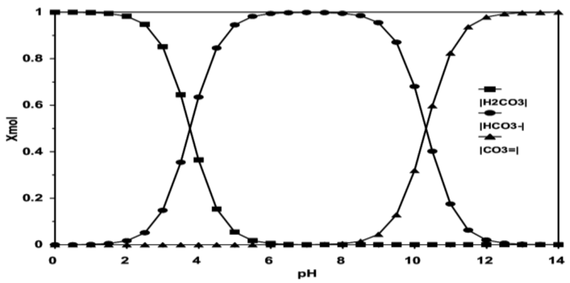
Quick Review: Intake; Screening; & Coagulation



Coagulation Type and Dosage Calculations



- Goal:
  - Form strong and settleable flocs
  - Remove enough % of Total Organic Carbon (TOC) for DBP control
- Consider the following WQ Parameters
  - Raw Water
    - Alkalinity (coagulants are usually acidic, could drive pH down and reduce H2CO3)
    - pH of finished water
    - TOC (how much TOC removal is required?)
  - Coagulated Water
    - Residual TOC level
    - Final pH may needs to be adjusted for downstream distribution system pipeline corrosion control
    - Jar testing and pilot testing are required

Jar Testing

- Establish testing matrix
  - pH range (e.g., pH 5 – pH 10)
  - Coagulant dose range (e.g., 1 ppm to 10 ppm)
  - Polymer dose range (e.g., 0.1 ppm to 1 ppm)
- Add same quantity of water to each jar (2L)
- Turn on mixer to appropriate speed
  - Single speed if just for adsorption (e.g., TOC, arsenic, etc.)
  - Adjust speed based on G-force desired at various stage
- Add coagulant and adjust pH to each jar according to testing plan

Jar Testing (continued)

- Stop the mixer
- Take water sample from different depth after certain time to measure turbidity
- Filter water sample from each jar with 0.45 micron filters
- Analyze for TOC and/or other desired water quality parameters
- Plot testing results
  - TOC vs. coagulant dose
  - TOC vs. pH
  - Turbidity vs. coagulant dose
- Determine optimal coagulation scheme

Coagulation Chemistry

– Both Ferric and Aluminum based coagulants are “acidic” and will consume the alkalinity in the water; thereby lowering pH in the treated water

$$FeCl_3 + 3H_2O \rightarrow Fe(OH)_{3\downarrow} + \underline{3H^+} + 3Cl^-$$

$$Fe_2(SO_4)_3 \cdot 9H_2O \rightarrow 2Fe(OH)_{3\downarrow} + \underline{6H^+} + 3SO_4^{2-} + 3H_2O \qquad (9\text{-}13)$$

$$Al_2(SO_4)_3 \cdot 14H_2O \rightarrow 2Al(OH)_{3\downarrow} + \underline{6H^+} + 3SO_4^{2-} + 8H_2O \qquad (9\text{-}11)$$

# of associated hydration water could change

Enhanced Coagulation

- Typical goal of coagulation is to achieve particle de-stabilization and sedimentation
- For public health protection from TTHM & HAAs, Enhanced Coagulation is required to remove certain % of TOC from the water. Coagulant dose will be higher that what's required for particle de-stabilization. Actual TOC removal % depending water alkalinity. Water with lower pH can remove more TOC, and water with lower alkalinity is easier to adjust pH lower either with acid or with coagulant itself ($FeCl_3$ and $Al_2 (SO_4)_3$ are acidic).

Table 3-3
Required Removal of Total Organic Carbon by Enhanced Coagulation and Enhanced Softening for Step 1 Compliance

Source Water TOC (*mg/L*)	Source Water Alkalinity (*mg/L* as $CaCO_3$) 0–60	>60–120	>120
>2.0–4.0	35.0%	25.0%	15.0%
>4.0–8.0	45.0%	35.0%	25.0%
>8.0	50.0%	40.0%	30.0%

Sludge Production

- Enhanced Coagulation could lead to additional sludge generated
- Solid calculations

Homework: Calculate solid generation from coagulation using ferric chloride

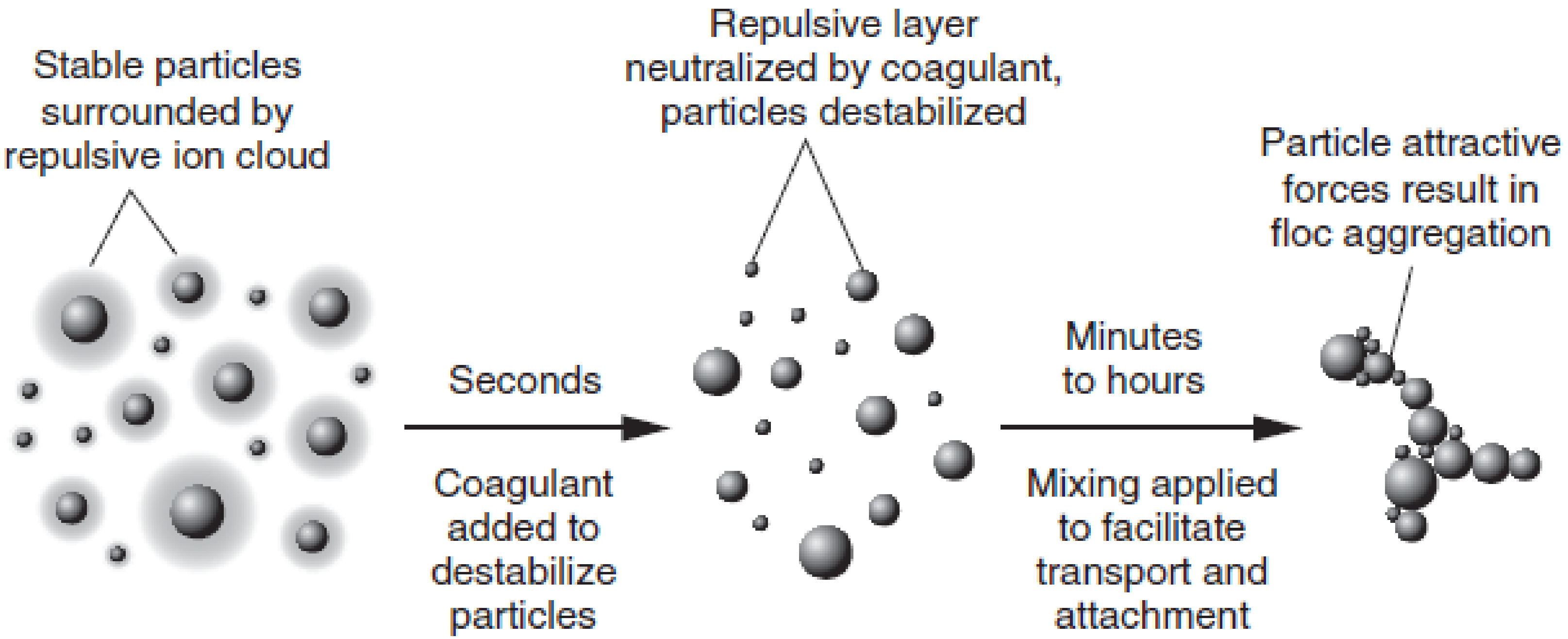
- Plant Capacity: 10 mgd
- Coagulant dose is 10 mg/L as $FeCl_3$
- Assume water content in the dewatered sludge is 75%

Q: How many lbs of dewatered solid will be generated daily?

Hint: Mwt. for Fe is 55.85 and Mwt. For Cl is 35.45. When FeCl3 is hydrolyzed ferric hydroxides solid $Fe(OH)_3$ is formed.

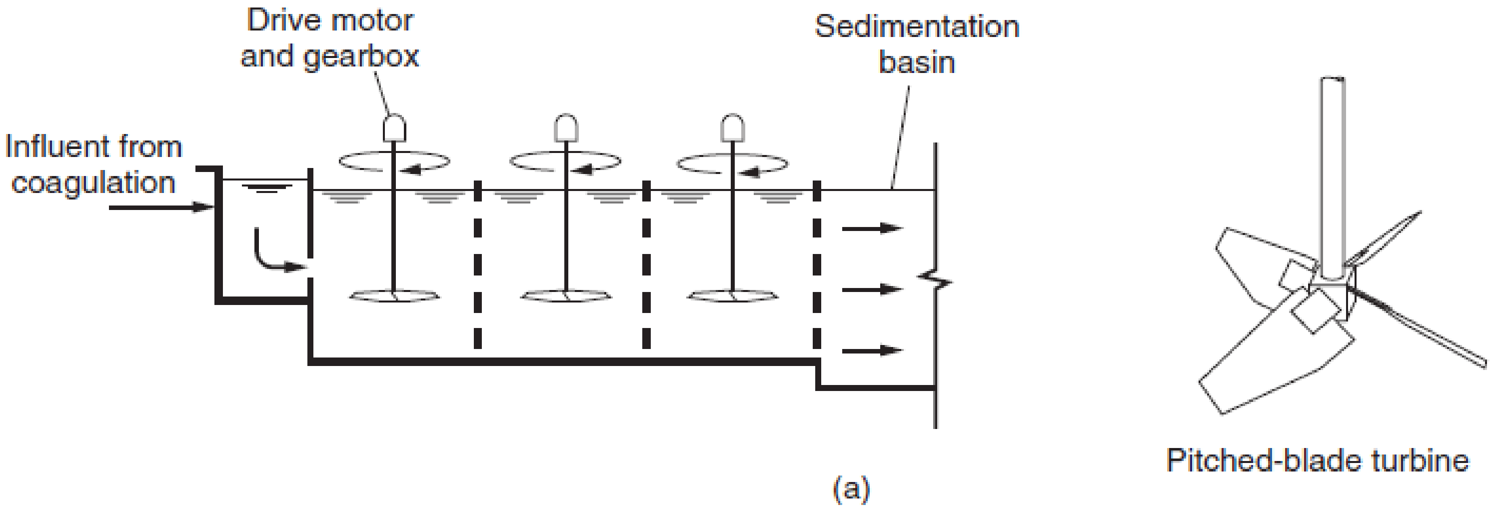
Steps of Flocculation

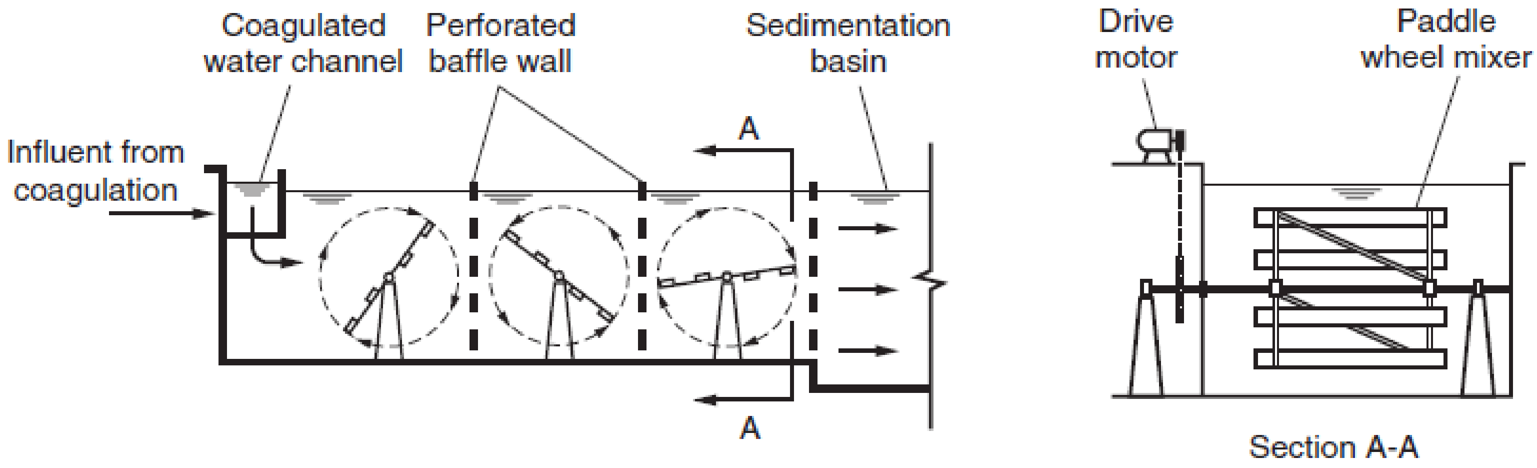
- Perkinetic/Microscale Flocculation (Browning Motion)
  - Aggregation of micro particles (in seconds)
- Orthokinetic/Macroscale Flocculation assisted with mixing energy



Types of Flocculators

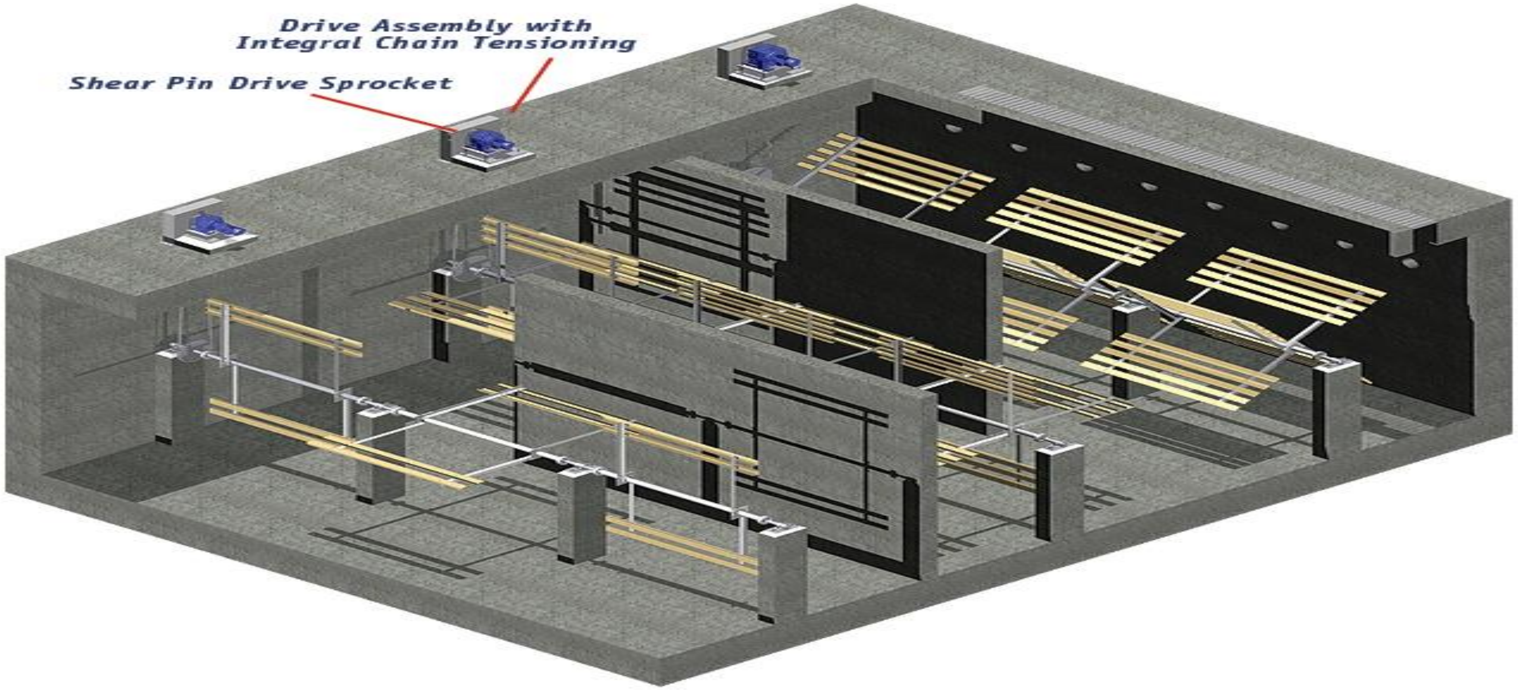
– Mechanical





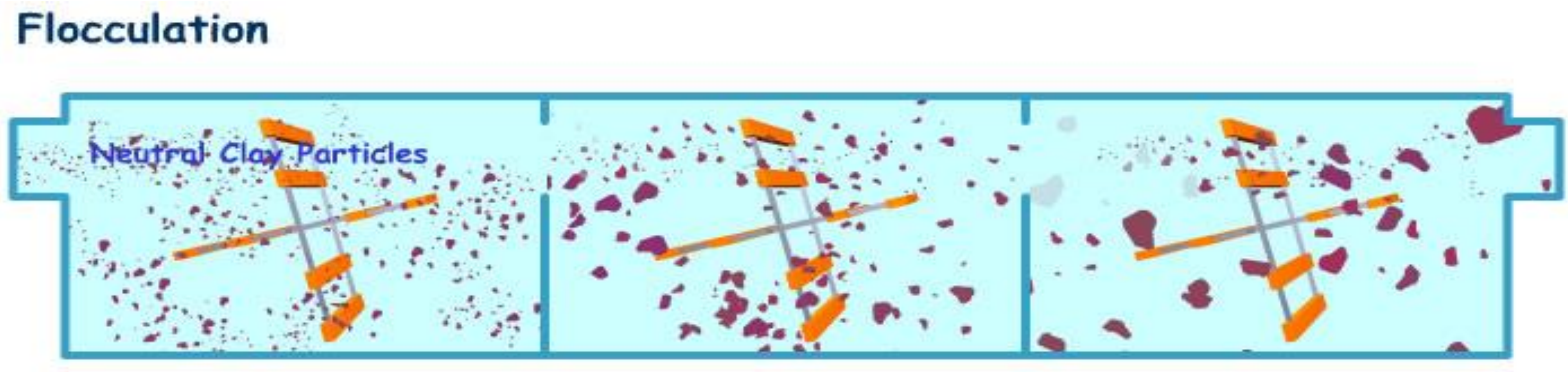
Mechanical Mixing to Facilitate Flocculation

- Agitators shall be used to assist flocculation at different stages without breaking larger flocs
- Tapered mixing speed. Driven by variable speed drives with the peripheral speed of paddles ranging from 0.5 to 3.0 feet per second; faster at the front & slower in the back



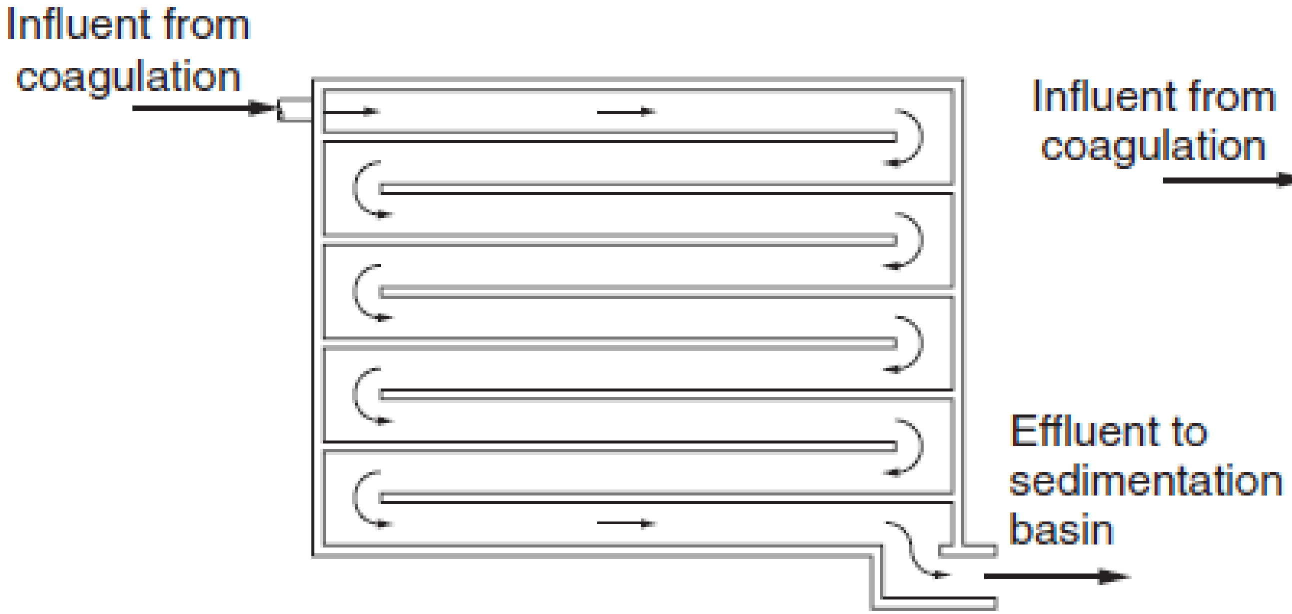
Flocculation Basin

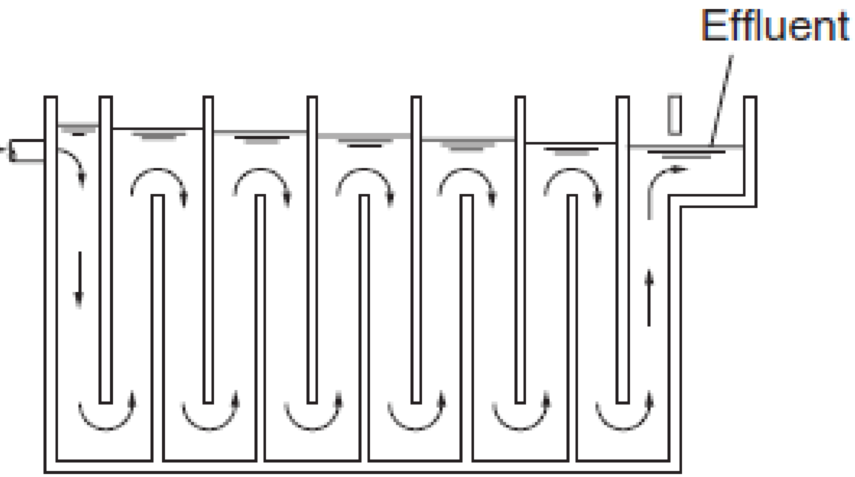
- The flocs are getting larger and larger as it passes from stage to stage.
- The mixing intensity is generally reduced as flow passes through the compartments
- Overall detention time is around 30 min with a flow-through velocity of 0.5 – 1.5 ft/min



Types of Flocculators

– Hydraulic Flocculators



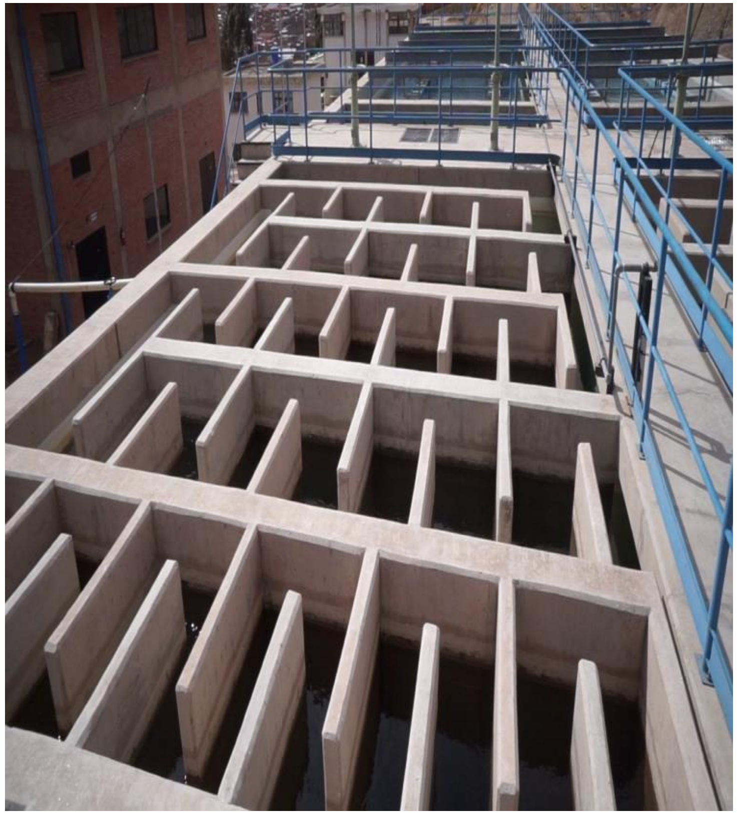


Types of Flocculators

Horizontal Shaft Flocculation

Vertical Turbine Flocculation

Hydraulic Flocculation



Selection of Proper Flocculation Approach

– Include justification in your design

Table 9-10
Comparison of basic approaches to flocculation

Process Issue	Horizontal Shaft with Paddles	Vertical-Shaft Turbines	Hydraulic Flocculation
Type of floc produced	Large and fluffy	Small to medium, dense	Very large and fluffy
Head loss	None	None	0.05–0.15 m
Operational flexibility	Good, limited to low $\bar{G}$	Excellent	Moderate to poor
Capital cost	Moderate to high	Moderate	Low to moderate
Construction difficulty	Moderate	Easy to moderate	Easy to difficult
Maintenance effort	Moderate	Low to moderate	Low to moderate
Compartmentalization	Moderate compartmentalization	Excellent compartmentalization	Excellent compartmentalization, some designs nearly plug flow

Typical design criteria for mechanical flocculators

Table 9-11

Typical design criteria for horizontal-shaft paddles and vertical-shaft turbines

Design Parameter	Unit	Horizontal Shaft with Paddles	Vertical-Shaft Turbines
Velocity gradient, $\overline{G}$	s^{-1}	5–40	10–80
Tip speed, maximum	m/s	<0.5	1–3
Rotational speed	rev/min	0.5–3	5–20
Compartment [a] dimensions (plan)			
Width	m	3–25	3–8
Length	m	3–8	3–8
Number of stages	No.	2–6	2–4
Variable-speed drives	—	Common	Common

[a]The compartment is the region influenced by an individual flocculator. Horizontal-shaft flocculators often have multiple paddle wheel assemblies on a single flocculator shaft. Vertical turbine flocculators may or may not have baffle walls between the compartments in a single stage.

Types of Flocculators

Horizontal Shaft Flocculation

Vertical Turbine Flocculation

Hydraulic Flocculation