Effluent Treatment Processes for Energy Industry (10626584)

Lecture 7:

Screening, Equalization, and Mixing in Wastewater Treatment

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Objectives

By the end of this lecture, students will be able to define:

- Types of screens used in wastewater
- Equalization and its advantages and drawbacks
- Types of mixing processes used in wastewater treatment
- Types of mixers
- Energy dissipation in mixing
- Types of mixers used in flocculation in wastewater treatment
- Typical design parameters for mixing operations

WATER TREATMENT – FROM RESERVOIR TO HOME

We take the water coming from our taps for granted – but what happens to it before it gets there? Here's how chemistry helps!

RAW WATER

Water is drawn from lakes, rivers, or reservoirs, or can be drawn from groundwater using boreholes.

SCREENING

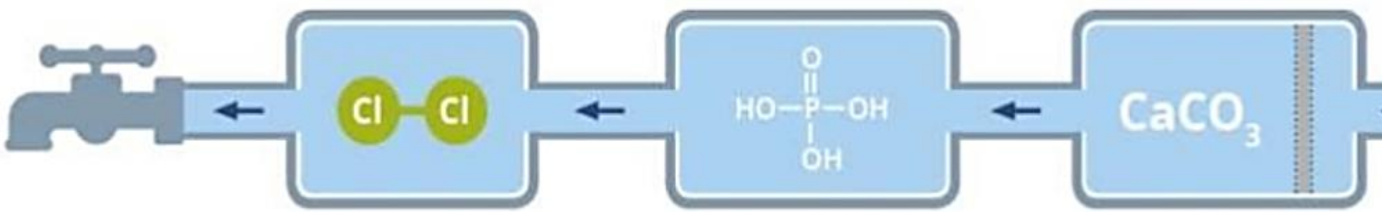
Screening helps to remove large matter from the water, such as leaves and rubbish, using a wire mesh. This prevents the debris from causing obstructions within the facility, making treatment easier.

COAGULANTS ADDED

Coagulants such as aluminium sulfate and ferric chloride are mixed into the water. These make particles of dirt and dissolved substances in the water clump together so that they can be removed.

SEDIMENTATION

Under slow mixing, the clumped particles increase in size, a process called flocculation. Most of them sink to the bottom and form a sludge, which can be removed from the water, treated and disposed of.



TO HOMES

Residual chlorine in the water safeguards against pathogens. Fluoride can be added after chlorination to help to prevent tooth decay.

CHLORINATION

Chlorine is added to water to kill bacteria and viruses, preventing water-borne diseases like cholera and typhoid. Ozone can be used instead of chlorine, and avoids disinfection byproducts.

ANTI-CORROSION AGENTS

Agents such as orthophosphates can be added to the water, particularly in areas with lead pipes. These agents form lead-phosphate complexes on the inside of the pipes, stopping lead getting into the water.

pH CORRECTION

Water that is too acidic can lead to water pipe corrosion. It can be passed through a filter containing crushed limestone (mainly calcium carbonate) to raise pH. Acids can be added if the pH is too high.

FILTRATION

Some particles remain in the water after sedimentation; these are removed by filtration through coal, sand, and gravel beds. They are cleaned by pumping air and water backwards through them.

Screening

- Screening is the first unit operation generally encountered in wastewater-treatment plant. The principle role of screening is to remove coarse materials that could:
  - Damage subsequent process equipment
  - Reduce overall treatment process reliability and effectiveness
  - Contaminate waterways

Screening

Bar Screening

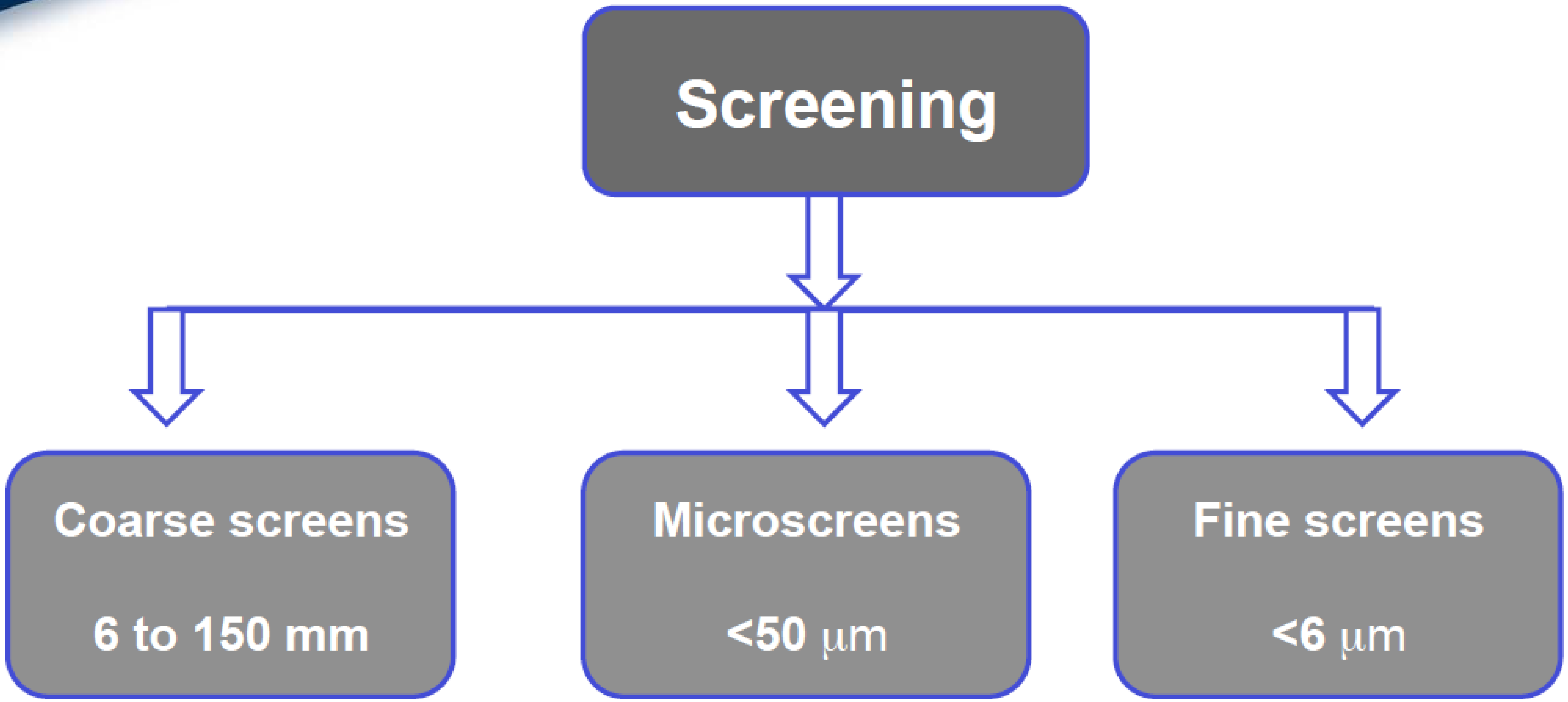
Mechanical Screening

Screening: Considerations

- The degree of screening removal required
- Health and safety of the operators as screenings contain pathogenic organisms and attract insects
- Odor potential
- Requirement for handling, transport and disposal
- Disposal options

- An integrated approach is required to achieve effective screening management.

Classifications of Screens



Flow Equalization

- In treating wastewater, the rate at which the waste arrives at the treatment process might vary dramatically during the day, so it is convenient to equalize the flow before feeding it to the various treatment steps.
- Flow equalization is the process of mitigating changes in flow rate through a portion of a system by providing storage to hold water when it is arriving too rapidly, and to supply additional water when it is arriving less rapidly than desired.
- In either case, the engineering issue is deciding how large an equalization basin is required to allow the treatment processes to operate with a steady average flow.

Flow Equalization: Advantages

- Biological treatment is enhanced, because shock loadings are eliminated or can be minimized, inhibiting substances can be diluted, and pH can be stabilized.

- The effluent quality and thickening performance of secondary sedimentation tanks following biological treatment is improved through improved consistency in solid loading.

- Effluent filtration surface area requirements are reduced.

- Chemical treatment, damping of mass loading improves chemical feed control and process reliability.

Flow Equalization: Disadvantages

- Relatively large land areas or sites are needed
- Equalization facilities may have to be covered for odor control near residential areas
- Additional operation and maintenance is required
- Capital cost is increased

Mixing in Wastewater Treatment

- The removal of suspended matter from water is one of the major goals of wastewater treatment. Process treatment usually involves:

  - Mixing
  - Coagulation
  - Flocculation
  - Settling
  - Filtration

Mixing

Mixing is an important unit operation in many phases of wastewater treatment; including:

- Mixing of one substance completely with another
- Blending of miscible liquids
- Flocculation of wastewater particles
- Continuous mixing of liquid suspensions
- Heat transfer

Classifications:

- Continuous rapid mixing (less than 30 sec)
- Continuous (i.e., ongoing)

Continuous Rapid Mixing

- Is used when one substance is to be mixed with another.

Applications:

- The blending of chemicals with wastewater (e.g., the addition of coagulants, such as alum or iron salts prior to flocculation)
- The blending of miscible liquids
- The addition of chemicals to sludge and bio-solids to improve their dewatering characteristics

Continuous Mixing

Is used when the contents of a reactor must be kept in suspension such as in:

- Equalization
- Flocculation
- Biological treatment processes
- Aerated lagoons
- Aerobic digesters.

Mixing

Mixing in a reactor causes two actions to occur:

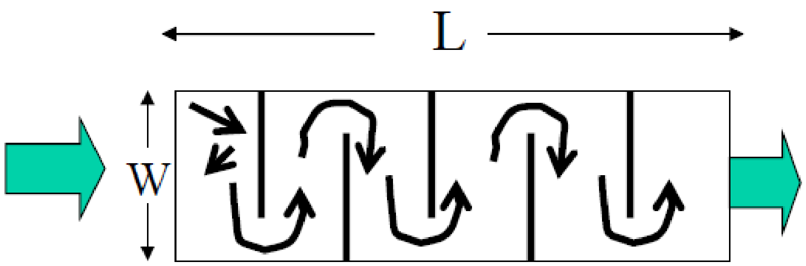
- Circulation
- Shearing of the fluid

- Mixing effectiveness can be measured based on the power input per unit volume of the liquid.
- Based on the reasoning that more input power creates greater turbulence, and greater turbulence leads to better mixing.

How to Achieve Rapid Mixing?

1. Horizontal baffled tank

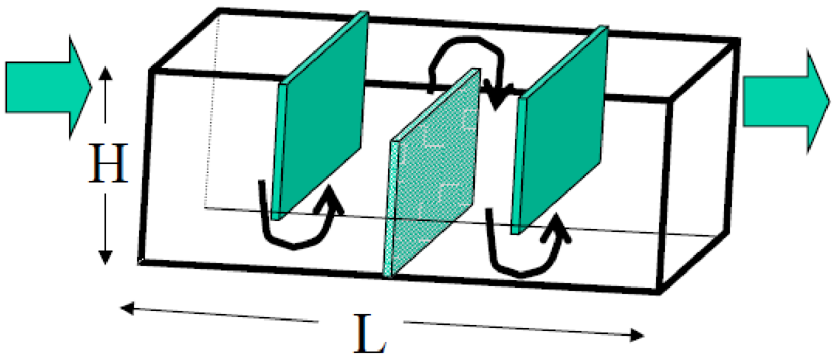
The water flows in a horizontal direction. The baffle walls help to create turbulence when the water hits the surface and thus facilitate mixing



Plan view (horizontal flow)

2. Vertical baffled tank

The water flows in a vertical direction. The baffle walls help to create turbulence when the water hits the surface and thus facilitate mixing

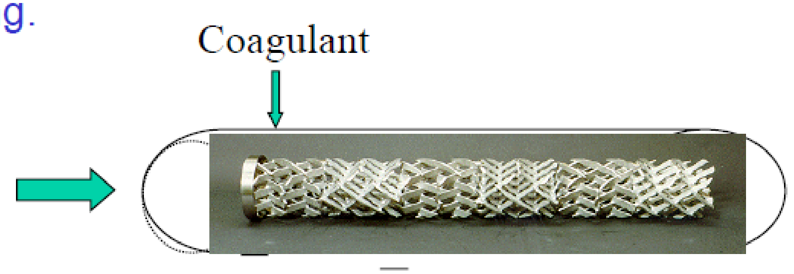


Isometric View (vertical flow)

How to Achieve Rapid Mixing?

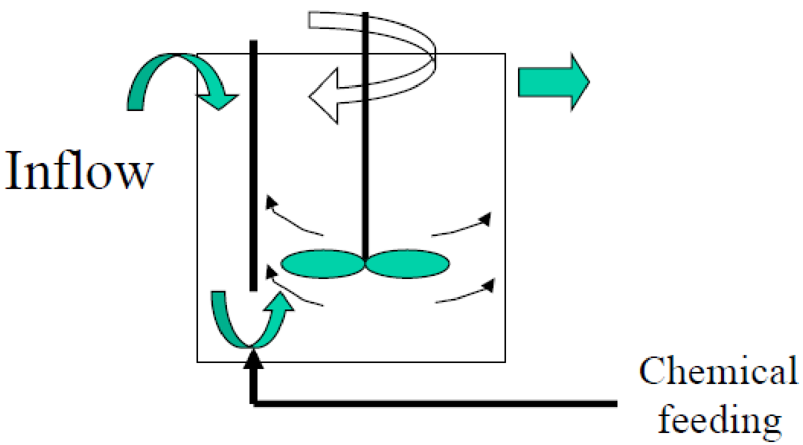
3. **Hydraulic Jump:** it creates turbulence and thus help better mixing.

4. In-line flash mixing

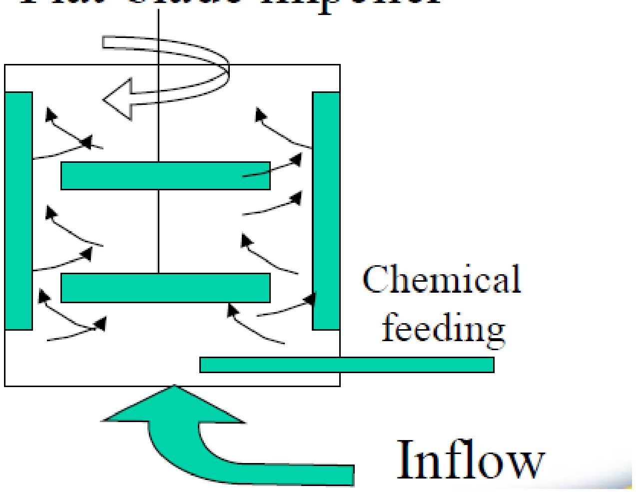


5. Mechanical mixing

Back mix impeller



Flat-blade impeller

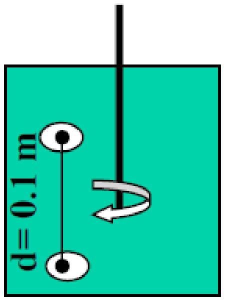


Mixing and Power

- The degree of mixing is measured by Velocity Gradient (G)
- The higher the G value, the intense the mixing and vice versa

- **G** is defined as the relative velocity of the two fluid particles at a given distance

$$G = \frac{du}{dy} = \frac{1.0}{0.1} = 10 \ s^{-1}$$



u=1 m/s

- In mixer design, the following equation is more useful:

$$G = \sqrt{\frac{P}{\mu V}}$$

G= average velocity gradient, s^{-1}; P = Power input, W
V = Tank volume, m^3; μ = Dynamic viscosity, (Pa.s)

Mixing and Power

Process		Detention time	G value, s^{-1}
Mixing	Typical rapid mixing operations in wastewater treatment	5-30 s	500-1500
	Rapid mixing for effective initial contact and dispersion of chemicals	<1 s	1500-6000
	Rapid mixing of chemicals in contact for filtration processes	<1 s	2500-7500
Flocculation	Typical flocculation processes used in wastewater treatment	30-60 min	50-100
	Flocculation in direct filtration processes	2-10 min	25-150
	Flocculation in contact filtration processes	2-5 min	25-200

Mixing and Power

Example:

Determine the theoretical power required to achieve a G value of 100/s in a tank with a volume of 2800 m^3. Assume the water temperature is 15 ^oC. What is the corresponding value when the water temperature is 5 ^oC?

Dynamic viscosity of water at 15 ^oC = 1.1373 cp.
Dynamic viscosity of water at 5 ^oC = 1.5215 cp.

Mixing and Power

- In the flocculator design, $G\tau$ (also known as Camp No.); a product of G and τ is commonly used as a design parameter

$$G\tau = \frac{V}{Q}\sqrt{\frac{P}{\mu V}} = \frac{1}{Q}\sqrt{\frac{PV}{\mu}}$$

- Typical $G\tau$ for flocculation is $2 \times 10^4 - 10^5$

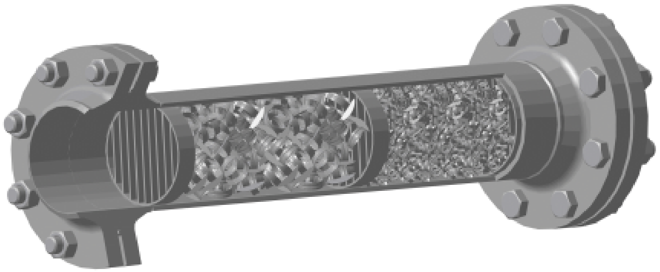
- Large G and small τ give small but dense floc
- Small G and large τ give big but light flocs

- We need big as well as dense flocs, which can be obtained by designing flocculator with different G values

Types of Mixers used for Rapid Mixing
1. Static Mixer

- is used most commonly for mixing of chemicals with wastewater
- sizes varying from 12 mm to 3 m x 3 m
- open channels or PFR
- mixing time is quite short, less than 1 s
- the degree of mixing is related to the headloss (i.e., pressure drop) through the mixer.

$$h \approx k\left(\frac{v^2}{2g}\right) \approx K_{SM} v^2$$



h = headloss dissipated as liquid passes through mixing device, m
k = empirical coefficient characteristic of the mixing
v = approach velocity, m/s
K_{SM} = overall coefficient for mixing device, s^2/m
g = acceleration due to gravity, 9.81 m/s^2

Types of Mixers used for Rapid Mixing
1. Static Mixer

- Typical value for K_{SM} vary from 1.0 to 4.0, with value of 2.5 being typical for the mixers used in wastewater treatment
- The power dissipated by static mixer can be calculated as follow:

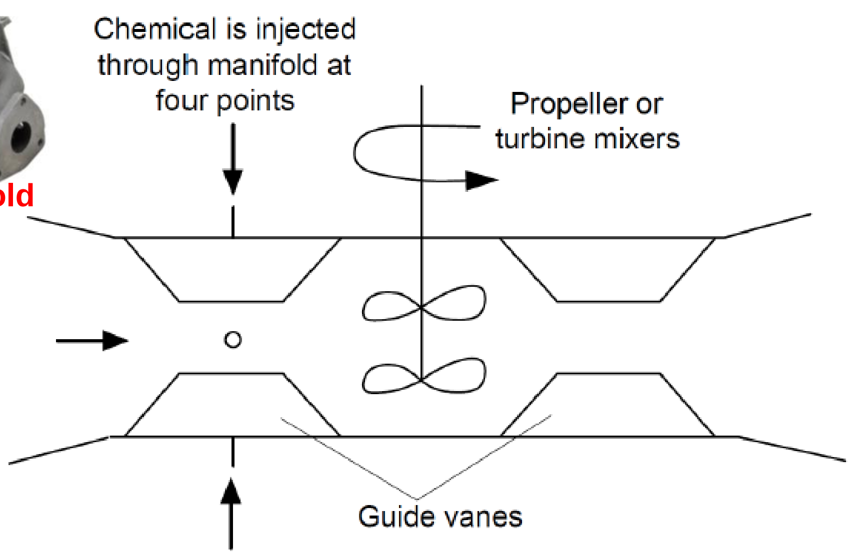
$$P = \gamma Q h$$

P = power dissipated, kW
γ = specific weight of water, kN/m^3
Q = flow rate, m^3/s

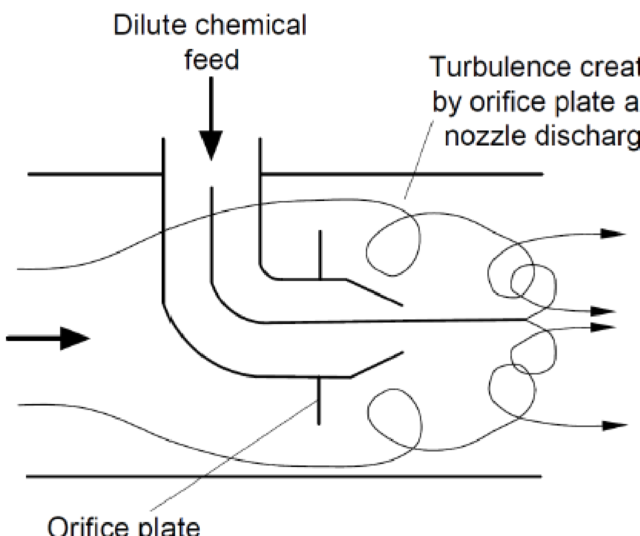
2. In-Line Mixer

- similar to static mixer but contains a rotating mixing element to enhance the mixing process
- the power required for mixing is supplied by an external source as in (a)
- or is supplied by the energy dissipation caused by the orifice plate and by the power input to the propeller mixer as in (b).

Manifold



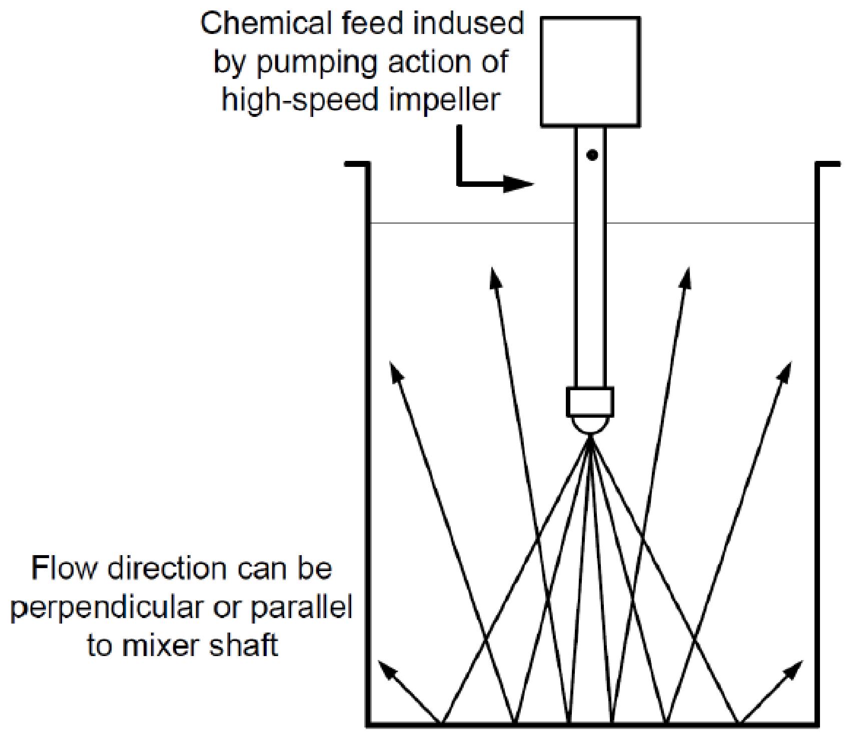
(a)



(b)

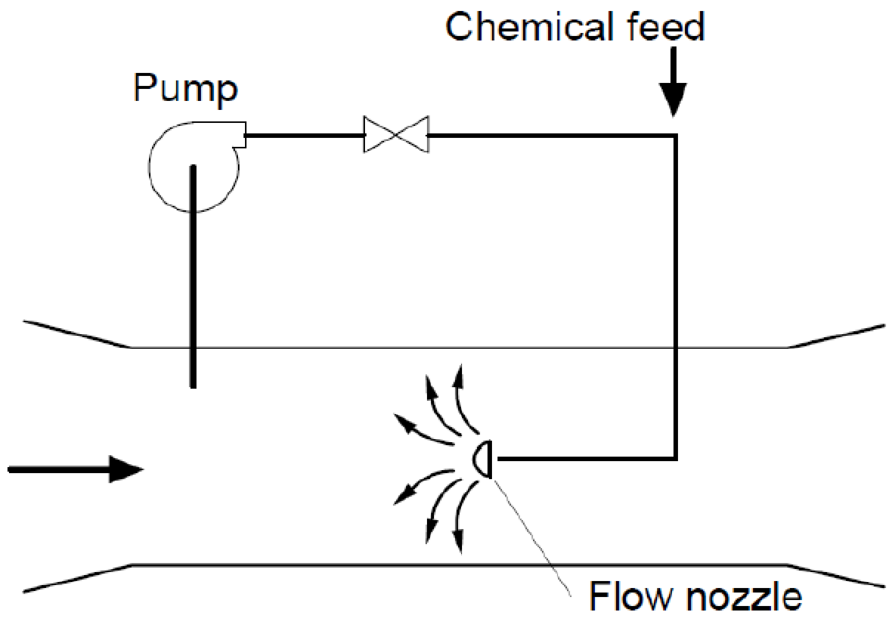
3. High-Speed Induction Mixer

- An efficient mixing device for a variety of chemicals
- High operation speed of the impeller (around 3450 rpm)



4. Pressurized Water Jets

- The velocity of the jet containing the chemical to be mixed must be sufficient to achieve mixing in all parts of the pipe line
- The power for mixing is provided by an external source (i.e., the solution feed pump)



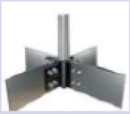
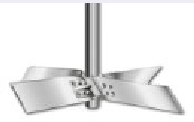
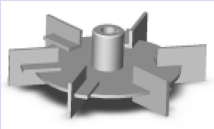
5. Turbine and Propeller Mixer

- commonly used in wastewater treatment process
- usually constructed with a vertical shaft driven by a speed reducer and electric motor
- two type of impellers:
  - radial flow impeller
  - axial flow impeller

Applications:

- mixing and blending of chemicals
- keeping materials in suspensions
- aeration

Typical Power and Flow Numbers for Common Impellers

Type of impeller	Photograph	Power number, N_P	Flow number, N_Q	Application
Flat-bladed turbine (FBT)		3.6	0.9	Blending, maintaining suspension, flocculation
Pitched-blade turbine (45° PBT)		1.26	0.75	Blending, maintaining suspension, flocculation
Pitched-blade turbine with camber (hydrofoil, 3 blades)		0.2-0.3	0.45-0.55	Blending, maintaining suspension, flocculation
Cast foil with proplets		0.23	0.59	Blending viscous liquid
Rushton turbine (6 blades)		4.5-5.5	0.72	Gas-liquid dispersion, solids suspension, flocculation
Propeller		0.32-0.36	0.4	Blending viscous liquid

Power for Mixing and Pumping Capacity

Power for mixing:

$$P = N_P \rho n^3 D^5$$

- Typically, applies if the Reynolds number is in the turbulent range (greater than 10, 000).
- For intermediate values of Reynolds number, manufacturers' catalog should be consulted.
- The Reynolds number is given by: $N_R = \dfrac{D^2 n \rho}{\mu}$

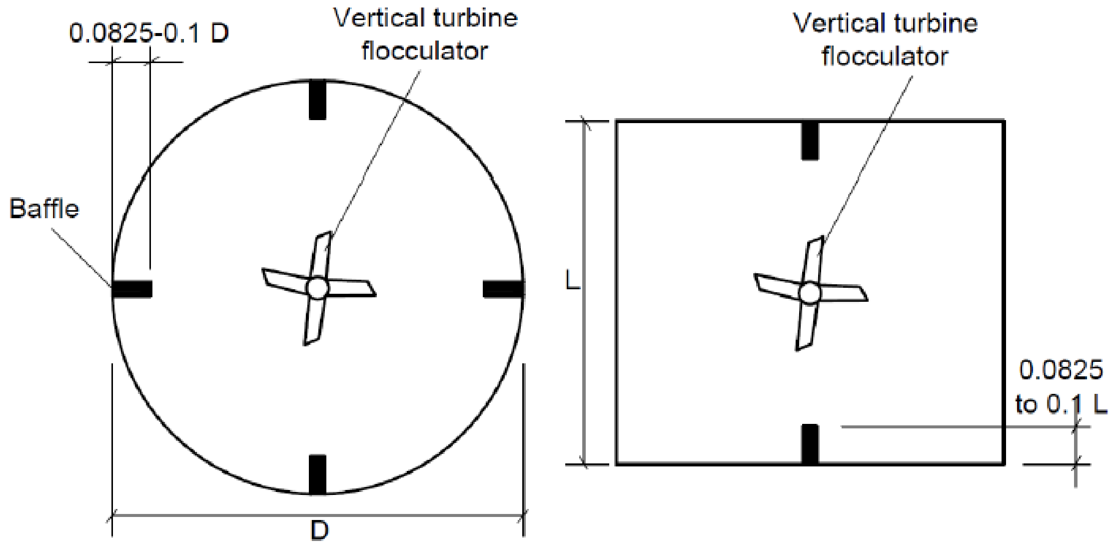
Pumping capacity:

$$Q_i = N_Q n D^3$$

P: power input, W (kg.m^2/s^3)
N_P: power number for impeller, unitless
ρ: density, kg/m^3
n: revolutions per second, r/s
D: diameter of impeller, m
Q_i: pump discharge, m^3/s
N_Q: flow number for impeller, unitless

Mixer Design Criteria

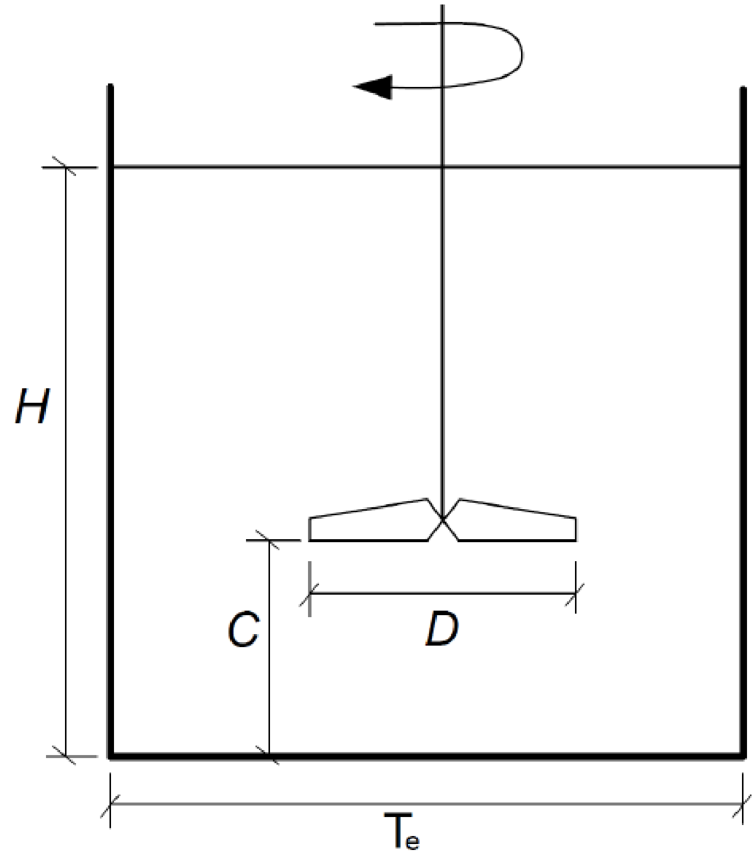
- Mixers are selected on the basis of lab or pilot-plant tests
- Geometrical similarity should be preserved
- Power input/unit volume should be kept the same
- Vortexing or mass swirling of the liquid should be eliminated.
  - Mounting the impeller off-center or at an angle with the vertical, or having them enter the side of the basin at an angle
  - In circular and rectangular tanks, install four or more vertical baffles extending approximately one-tenth the diameter out from the wall. These baffles effectively break up the mass rotary motion and promote vertical mixing.



Key Design Criteria for Vertical-Turbine Flocculator

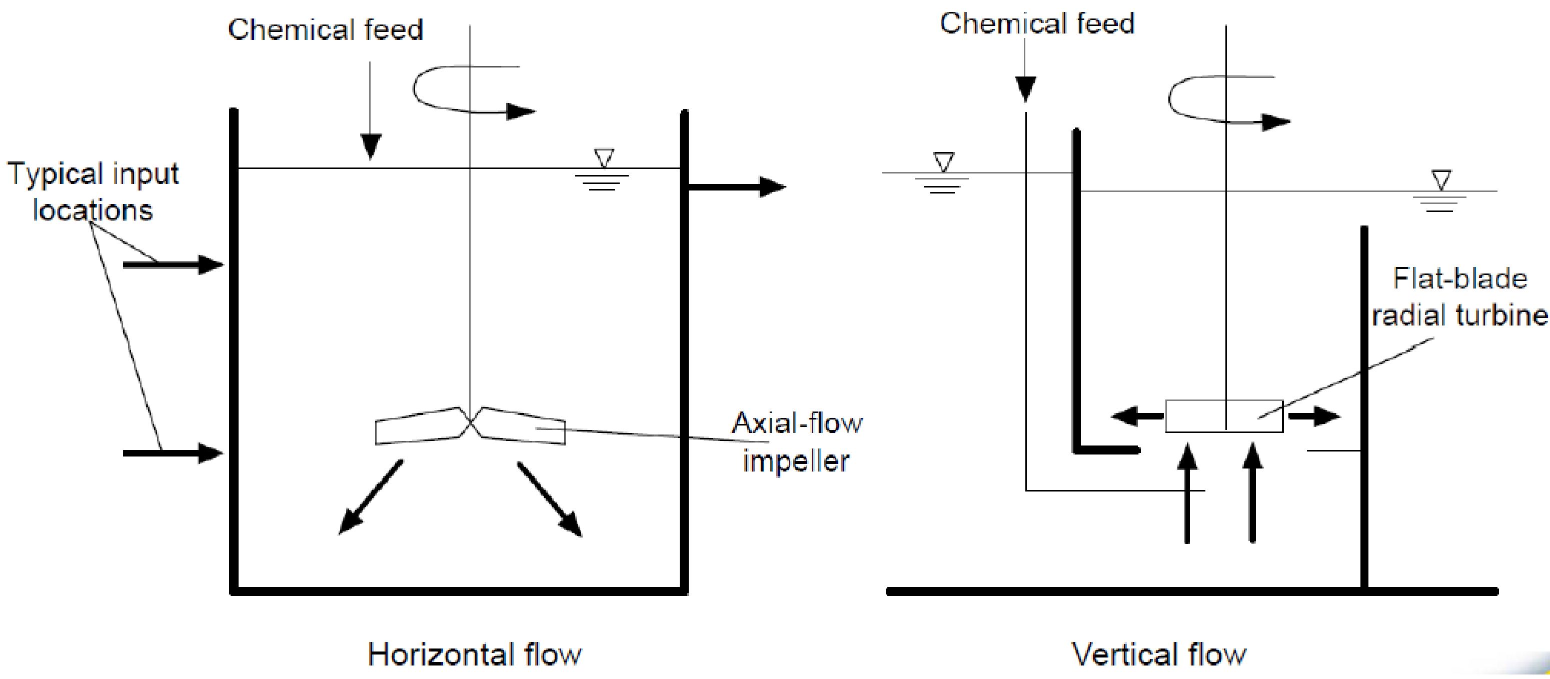
Parameter	Range
Impeller	Hydrofoil or 45° pitched-blade turbine (PBD), hydrofoil preferred
D/T_e	0.3-0.6, 0.4-0.5 preferred
H/T_e	0.9-0.11
C/H	0.5-0.33
N	10-30 rev/min
Tip speed	2-3 m/s

$$T_e = \sqrt{\frac{4A_{plan}}{\pi}}$$

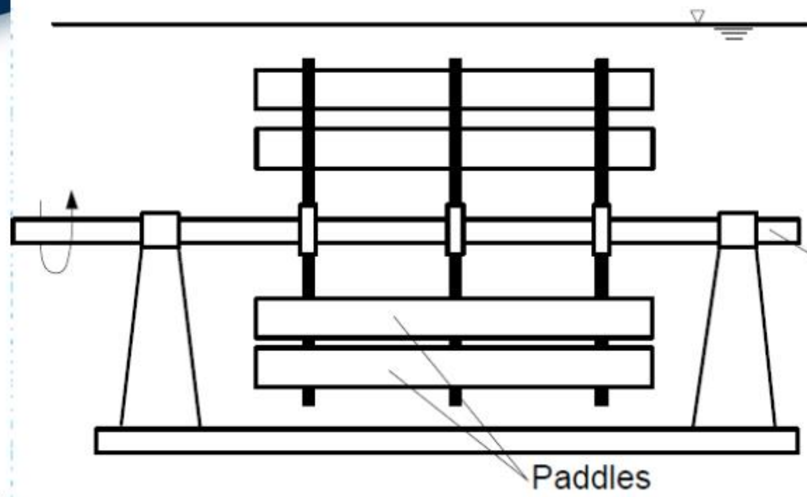


Important Design Considerations

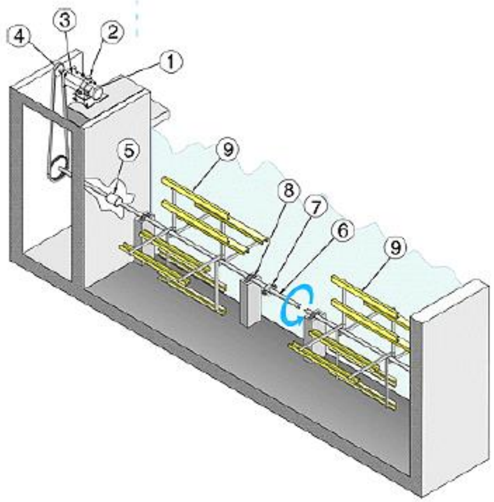
- The velocity gradient G
- The ratio of the impeller diameter to the equivalent tank diameter
- The rotational speed, depends on the flow through the mixer

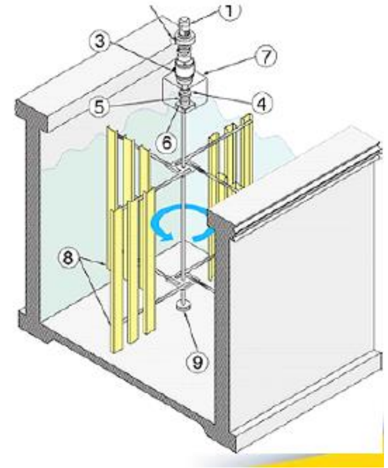


Paddle Mixers



Paddle mixers are driven by variable-speed drives. A disadvantage of paddle flocculators is that the supports and bearings for the paddles are submerged





Paddle Mixers

- Are used as flocculation devices when coagulants, such as aluminum or ferric sulfate, and coagulant aids, such as polyelectrolytes and lime, are added to wastewater or solids (sludge).
- Flocculation is promoted by gentle mixing (< 1 rpm) brought about by slow-moving paddles, which rotate the liquids and promote mixing.
- Agitation should be controlled carefully so that the floc particles will be of suitable size and will settle readily.
- Variable speeds are often used to regulate the paddle speed

➢ Power in a mechanical paddle system can be related to the drag force on the paddle as follows:

$$F_D = \frac{C_D A \rho v_p^2}{2}$$

$$P = F_D v_p = \frac{C_D A \rho v_p^3}{2}$$

F_D: drag force, N
C_D: drag coefficient of paddle moving perpendicular to fluid flow
A: cross-sectional area of paddles, m^2
ρ: mass density of fluid, kg/m^3
v_p: relative velocity of paddles with respect to the fluid, m/s (usually assumed to be 0.6 to 0.75 times the paddle-tip speed)
P: power requirement, W

Design Criteria for Paddle Wheel Flocculator

Parameter	Unit	Value
Diameter of wheel	m	3-4
Paddle board section	mm	100 × 150
Paddle board length	m	2-3.5
$A_{paddle\ boards}$/tank section area	%	< 20
C_D	L/W = 1 L/W = 5 L/W = 20 L/W >> 20	1.16 1.2 1.5 1.9
Paddle tip speed	m/s m/s	Strong floc, 4 Weak floc, 2
Spacing between paddle wheels on same shaft	m	1
Clearance from basin walls	m	0.7
Minimum basin depth	m	1 m greater than diameter of paddle wheel
Minimum clearance between stages	m	1

Practical Problems (Tutorial 03)