

COAGULATION PROCESS

- GOALS:**
- Destabilize Colloids
 - Agglomerate destabilized particles

- REMOVES:**
- Color
 - TURBIDITY
 - ODOR-PRODUCING COMPOUNDS
 - PATHOGENS

Process involves both CHEMICAL and PHYSICAL processes, linked.

CHEMICAL COAGULANTS:

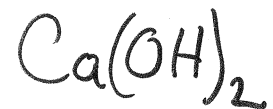
- COMMON:
- Alum (Al sulfate) $Al_2(SO_4)_3 \cdot 14.3H_2O$
 - Ferrous or Ferric Salts
 Fe^{2+} Fe^{3+}

"POLYVALENT CATIONS" (e.g. $3+$)

CHEMICAL TERMINOLOGY IN WATER & WASTE-WATER

LIME,
SLAKED LIME

Calcium
hydroxide



QUICK LIME

calcium oxide



LIMEROCK,
LIMESTONE

calcium
carbonate



SODA ASH

Sodium
Carbonate



POTASH

potassium
Carbonate



CAUSTIC SODA,
LYE,
SODA LYE

sodium
hydroxide



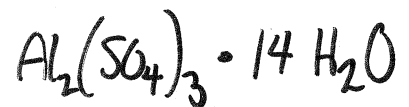
POTASH LYE

potassium
hydroxide



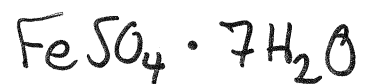
ALUM,
FILTER ALUM

aluminum
sulfate



FERROUS SULFATE,
COPPERAS

ferrous
sulfate



MURIATIC ACID

hydrochloric
acid



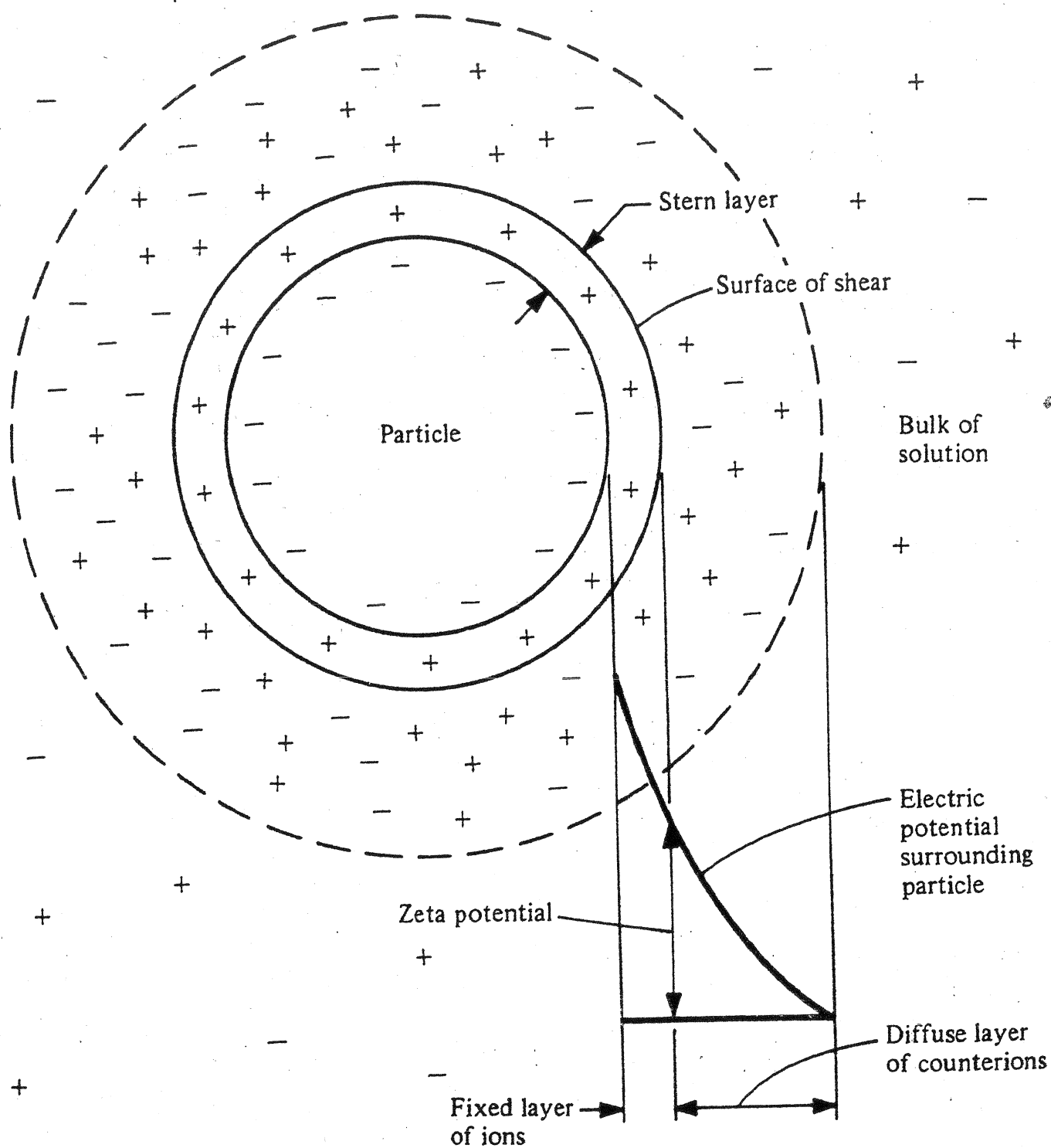
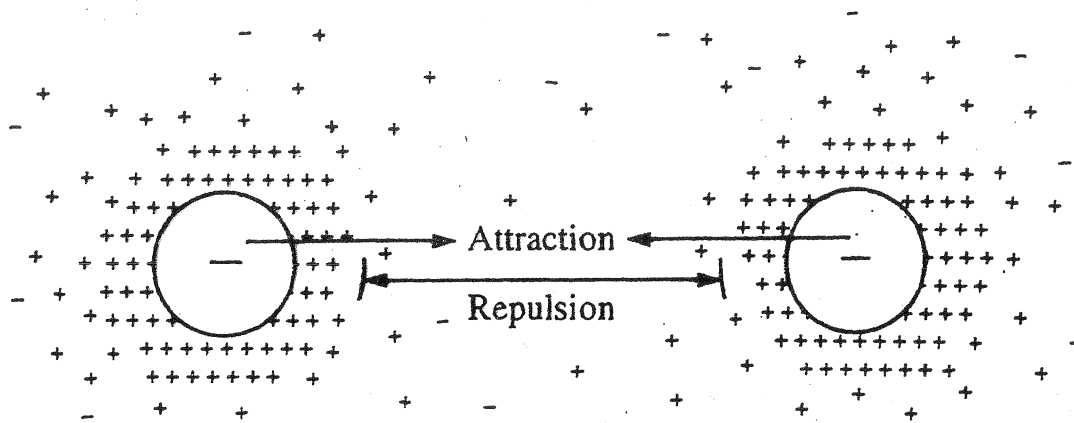
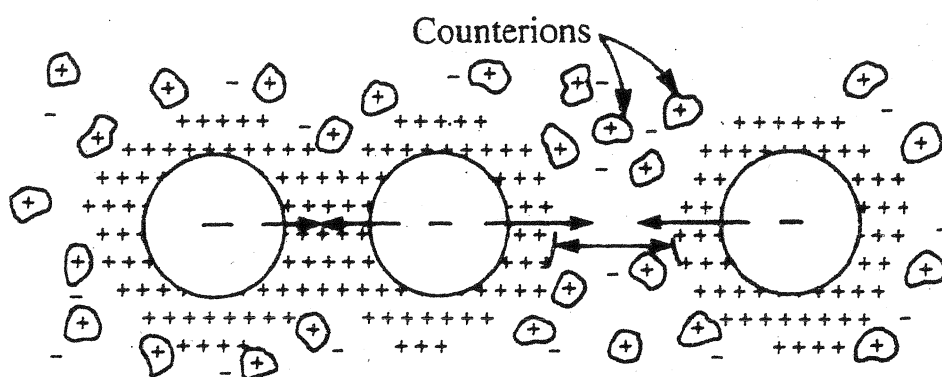


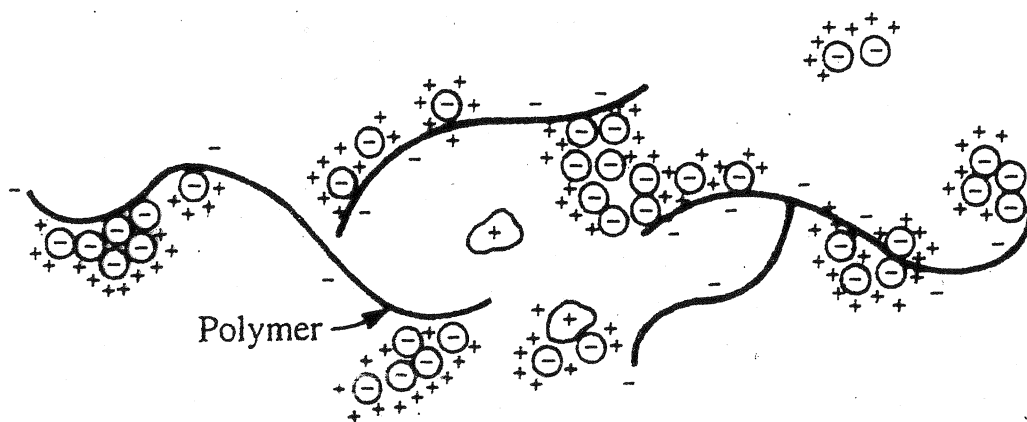
Figure 11.4 Derivation of the zeta potential in diffuse double-layer theory.



(a)



(b)



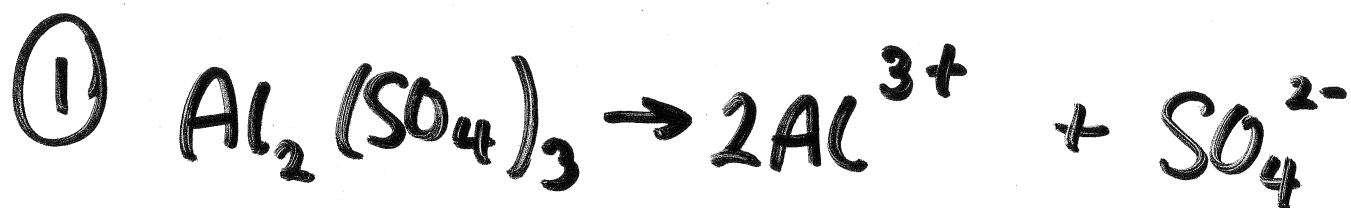
(c)

Figure 11.5 Schematic representations of coagulation and bridging of colloids. (a) A stable suspension of particles where forces of repulsion exceed the forces of attraction. (b) Destabilization and coagulation caused by counterions of a coagulant suppressing the double-layer charges. (c) Agglomeration of destabilized particles by attaching of coagulant ions and bridging of polymers.

COAGULANTS:

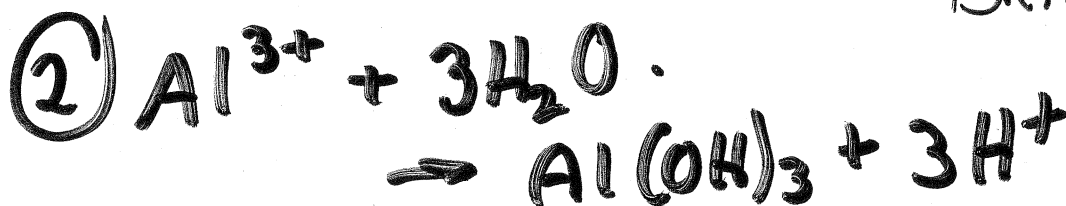
Typically Al or Fe salts

Coagulants work in two ways:



Al hydrolysis species

- Neutralize Charges on particles ("destabilize" them)
- "BRIDGE" between particles



AIDS IN
SOLIDS
REMOVAL

Alum & Iron SALTS

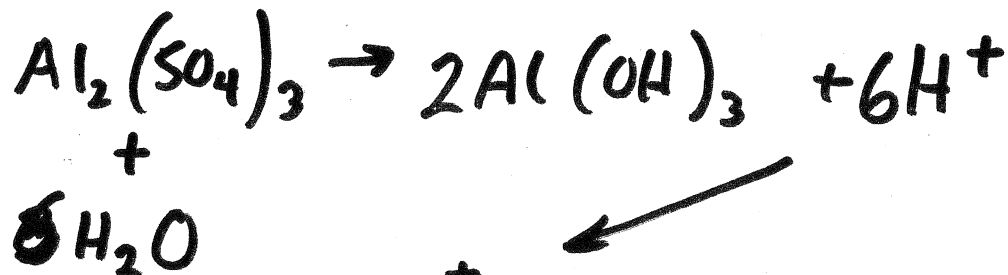
GIVE OFF H^+ DURING
HYDROLYSIS

(They are moderately strong
ACIDS, in effect)

→ ACIDS CONSUME ALKALINITY

∴ Coagulants w/ Al & Fe
consume alk

MUST REPLACE THAT ALK IN
MANY CASES TO AVOID
ACIDIC PRODUCT WATER



MECHANICAL MIXERS

- MECHANICAL (ROTOR)
- PNEUMATIC (AIR)
- HYDRAULIC (VENTURI)
- WEIR MIXERS (OVERFLOW)

We'll focus on ROTOR-TYPE, although all of them are pretty common

Using force balance & power balance can derive the following:

$$\mu G^2 = P/V$$

$$(\text{viscosity})(\text{velocity gradient})^2 = \text{Power input per unit Vol.}$$

OR

$$G = \left(\frac{P}{\mu V} \right)^{\frac{1}{2}}$$

$G \equiv$ r.m.s. velocity gradient in flow resulting from mixing w/ power input of P per unit volume V .

$G = \text{units: (Time)}^{-1} \Leftarrow$ MAIN DESIGN PARAM. FOR MIXERS

ROTOR-TYPE MIXER

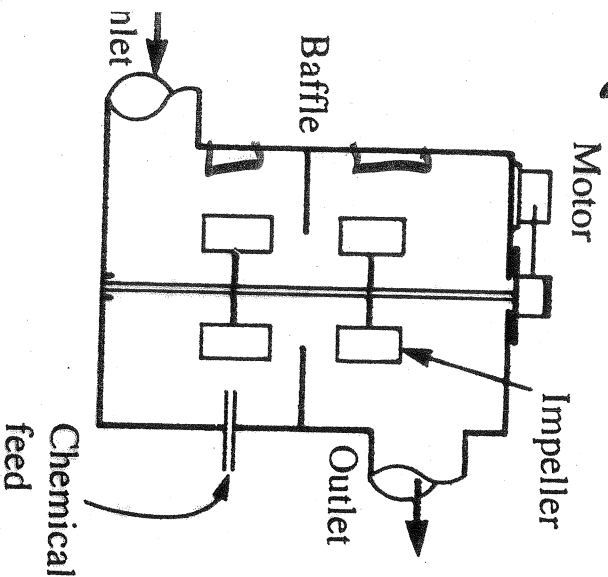


figure 10.12 Impeller-type mechanical rapid mixer for dispersion of chemicals into water.

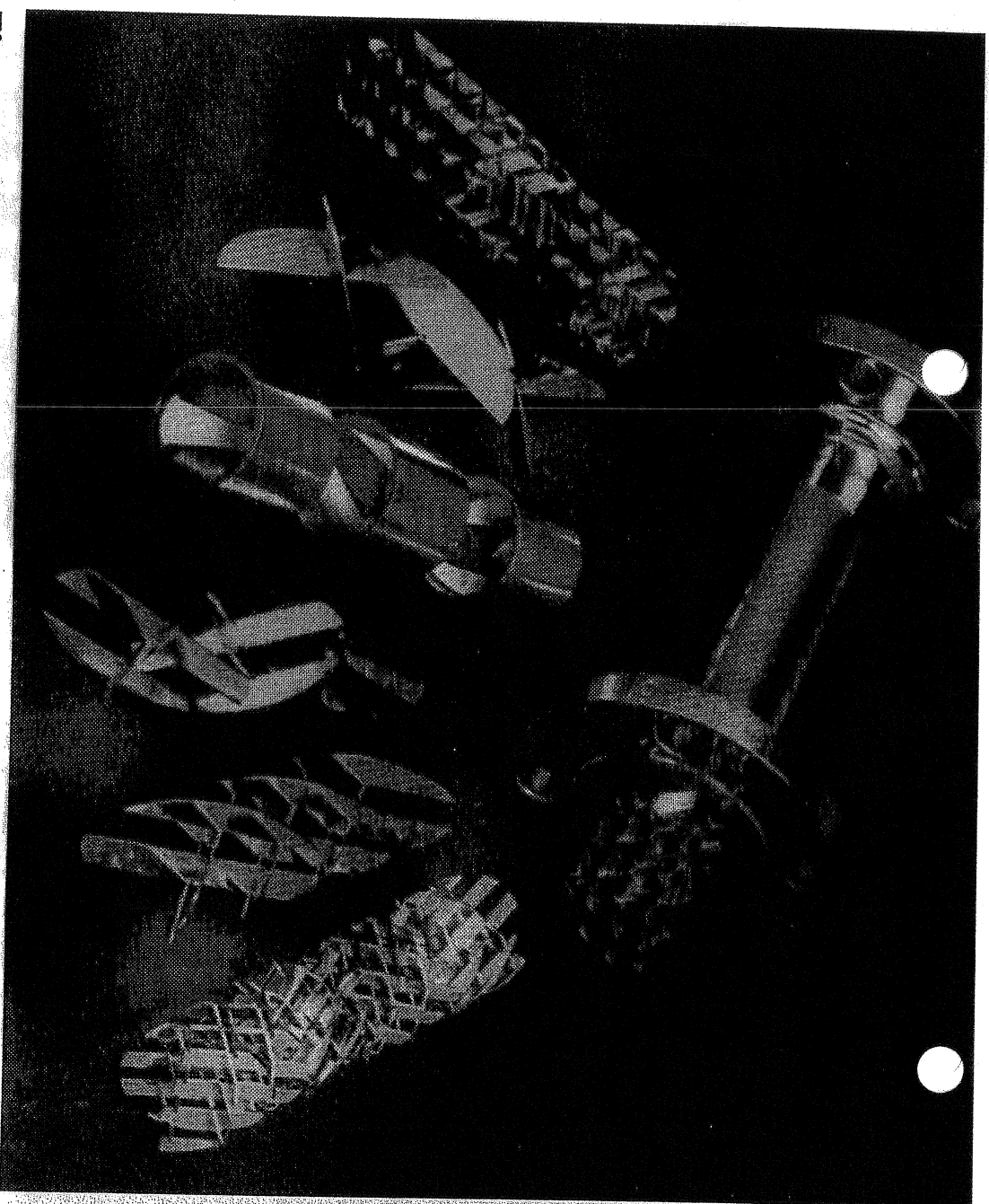
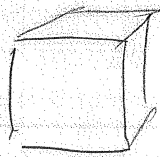


Figure 10.13 Static mixing elements that are inserted into a pipe for in-line blending of chemicals. (Courtesy of Koch Engineering Company, Inc.)

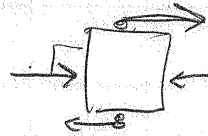
IN-LINE STATIC MIXERS



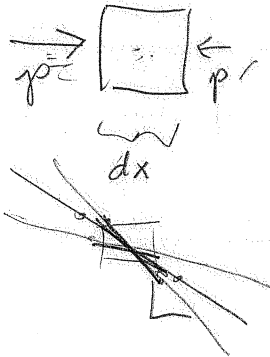
$$F = ma = m \frac{\partial v}{\partial t} = \frac{\partial(mv)}{\partial t} = \frac{\partial(\text{Momentum})}{\partial t} \leftarrow \text{NEWTON'S 1st LAW}$$

$$\frac{F}{A} = \text{STRESS} \rightarrow \text{NORMAL} = \tau$$

$$\text{TANGENTIAL} = p$$



① PRESSURE BALANCE: Induce accel. via pressure differential



$$\Delta p \sim \partial v / \partial t$$

$$\frac{\Delta p}{\Delta x} \rightarrow \frac{\partial p}{\partial x} = \frac{1}{L}$$

$$\frac{\partial F/A}{L} = \frac{\partial F}{\Delta V} = \left[\frac{\partial F}{\partial x} = \frac{1}{\partial x} \frac{\partial(mv)}{\partial t} \right]$$

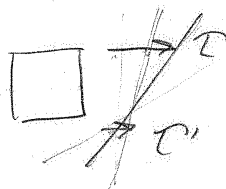
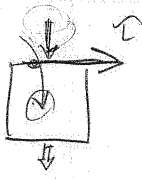
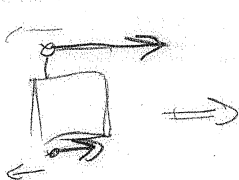
$$\partial F$$

$$\frac{\partial F}{\Delta V} = \frac{1}{\Delta V} \frac{\partial(mv)}{\partial t} \quad \frac{MK}{T^2 L^3}$$

$$\partial F = \frac{\partial(mv)}{\partial t}$$

$$\frac{MK}{L^3 T^2}$$

$$\partial F_p = - \frac{\partial(mv)}{\partial t}$$



$$\partial y \quad \frac{\partial(mv)}{\partial t} \sim \frac{\partial \tau}{\partial y}$$

$$\frac{\partial \tau}{\partial y} = \frac{\partial F_t/A}{L} = \frac{\partial F_t}{\Delta V} = \frac{1}{\Delta V} \frac{\partial(mv)}{\partial t} \Rightarrow \partial F_t = \frac{\partial(mv)}{\partial t}$$

$$\text{At SS} \quad \frac{\partial F_t}{\Delta V} = \frac{\partial F_t}{\Delta V} \Rightarrow \left[\frac{\partial p}{\partial x} = - \frac{\partial \tau}{\partial y} \right] = - \frac{\partial}{\partial y} \mu \frac{\partial v}{\partial t}$$

$$\text{NEWTON'S LAW OF VISC} \quad \tau = \mu \frac{\partial v}{\partial y}$$

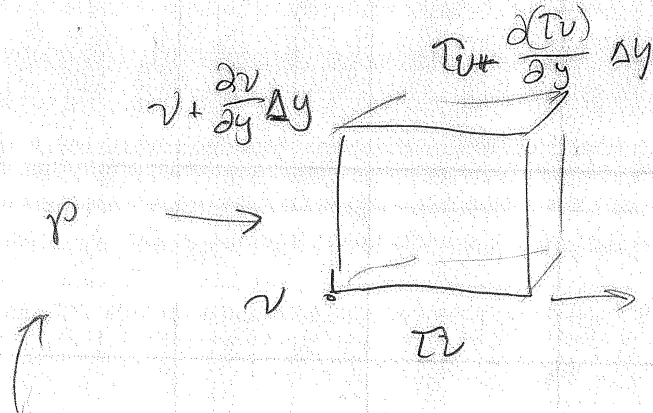


Diagram illustrating a fluid element (cube) in a shear flow. The cube has dimensions Δx , Δy , and Δz . The velocity on the left face is v , and on the right face it is $v + \frac{\partial v}{\partial y} \Delta y$. The pressure on the left face is p , and on the right face it is $p + \frac{\partial p}{\partial x} \Delta x$. The shear stress on the bottom face is τ , and on the top face it is $\tau + \frac{\partial \tau}{\partial y} \Delta y$.

$$\Delta P \cdot v$$

$$(p + \frac{\partial p}{\partial x} \Delta x) \left(v + \frac{\partial v}{\partial y} \frac{\Delta y}{2} \right) - \left(p + \frac{\partial p}{\partial x} \Delta x \right) \left(v + \frac{\partial v}{\partial y} \frac{\Delta y}{2} \right) \Delta y \Delta z$$

$$+ \tau \left(\frac{\partial \tau}{\partial y} \Delta y \right) \Delta x \Delta z - \left(\tau + \frac{\partial \tau}{\partial y} \Delta y \right) \Delta x \Delta z$$

$$-v \frac{\partial p}{\partial x} \Delta V - v \frac{\partial \tau}{\partial y} \Delta V - \tau \frac{\partial v}{\partial y} \Delta V = \Delta P_{\text{power}}$$

Div.
by
 ΔV

$$-v \left(\frac{\partial p}{\partial x} + \frac{\partial \tau}{\partial y} \right) - \tau \frac{\partial v}{\partial y} = \frac{\Delta P}{\Delta V}$$

At S.S.,

$$\frac{\text{Power Dissipated}}{\text{unit volume}} = -\tau \frac{\partial v}{\partial y}$$

$$\text{And } \tau = -\mu \frac{\partial v}{\partial y} \quad \mu \left(\frac{\partial v}{\partial y} \right)^2 = \frac{P}{V}$$

$$\frac{P}{V} = \mu G^2 \rightarrow G = \left(\frac{P}{\mu V} \right)^{1/2}$$

$$G \cdot t_d$$

GRADIENT Units $\frac{1}{T}$ DETENTION TIME Units T

Makes sense that the product $G \cdot t_d$ (dimensionless) is correlated with mixer/floculator performance

E.g.

For rapid mixing of Alum coagulant

$$G \cdot t_{d, \text{opt}} C^{1.46} = 5.9 \times 10^6$$

optimal vel. Gradient optimal t_d $\uparrow$ mg/L DOSE OF ALUM

Ex: At $C = 40 \text{ mg/L}$ $G \cdot t_d \approx 27,000$

$$G = 900 \text{ s}^{-1}$$

$$t_d = 30 \text{ s}$$

BASIC DESIGN STEPS FOR A ROTOR-TYPE RAPID MIXER

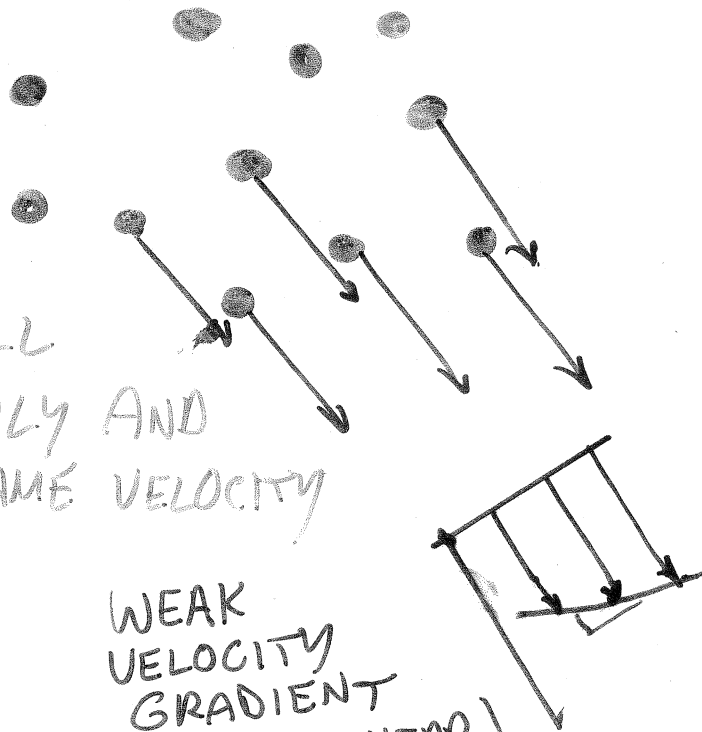
1. Find $G \cdot t_d$ and decide on a reasonable pair of G & t_d values
Ex: $G = 800 s^{-1}$ $t_d = 30 s$
2. Find the POWER input needed to produce G value:
 $G = \left(\frac{P}{\mu V} \right)^{\frac{1}{2}}$ solve for P
where $V = Q t_d$
3. Use general design guidelines to get dimensions of mixer, then use those to size the DIAMETER (D) of the impeller.
4. Obtain $\phi \equiv$ power number $= \frac{P}{\rho N^3 D^5}$
from table such as 13.4 in text.
5. Solve Rotation Rate $= N = \left[\frac{P}{\rho \phi D^5} \right]^{\frac{1}{3}}$
(speed of rotor motor)

FLOCCULATION

Too SLOW

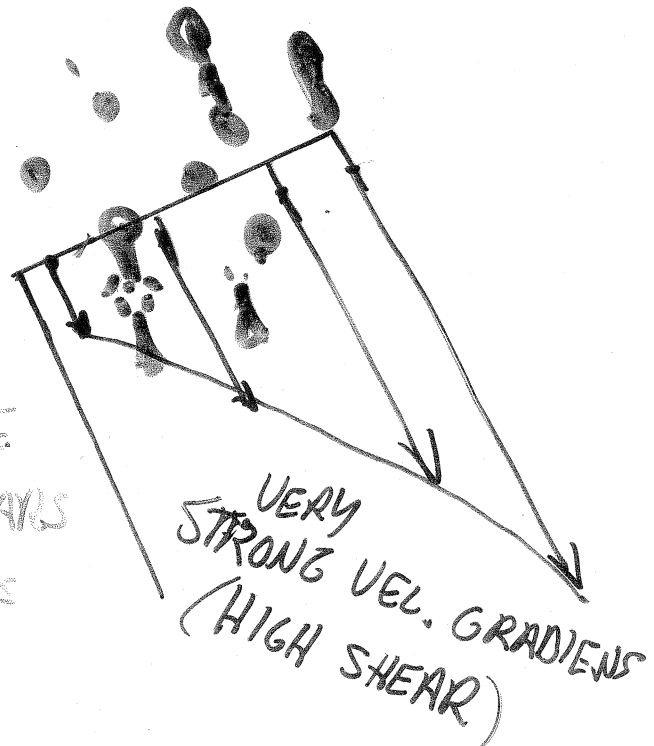
PARTICLES ALL
MOVING SLOWLY AND
AT ABOUT SAME VELOCITY

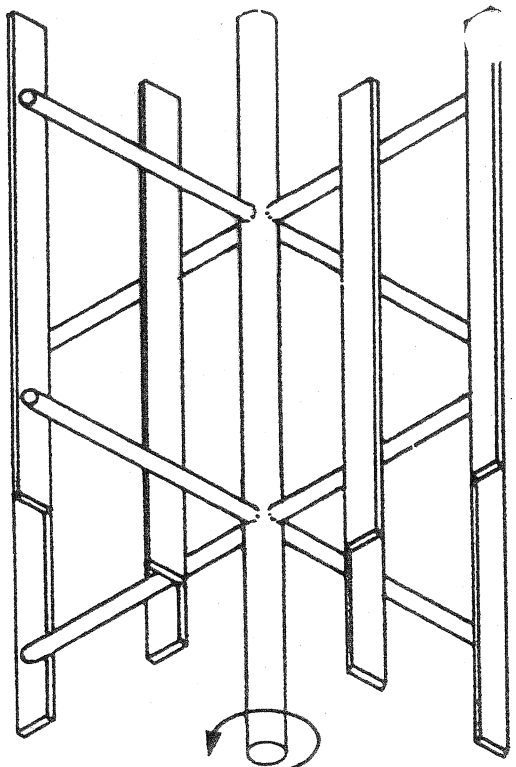
WEAK
VELOCITY
GRADIENT
(LOW SHEAR)



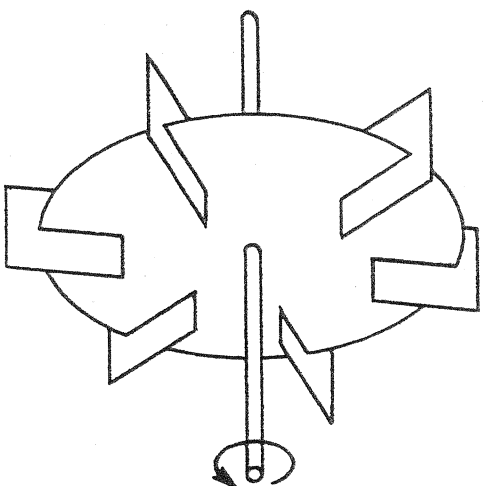
Too FAST

PARTICLES CONTACT
EACH OTHER
RAPIDLY, BUT THE
FLUID SHEAR TEARS
APART ANY FLOCS
THAT FORM.

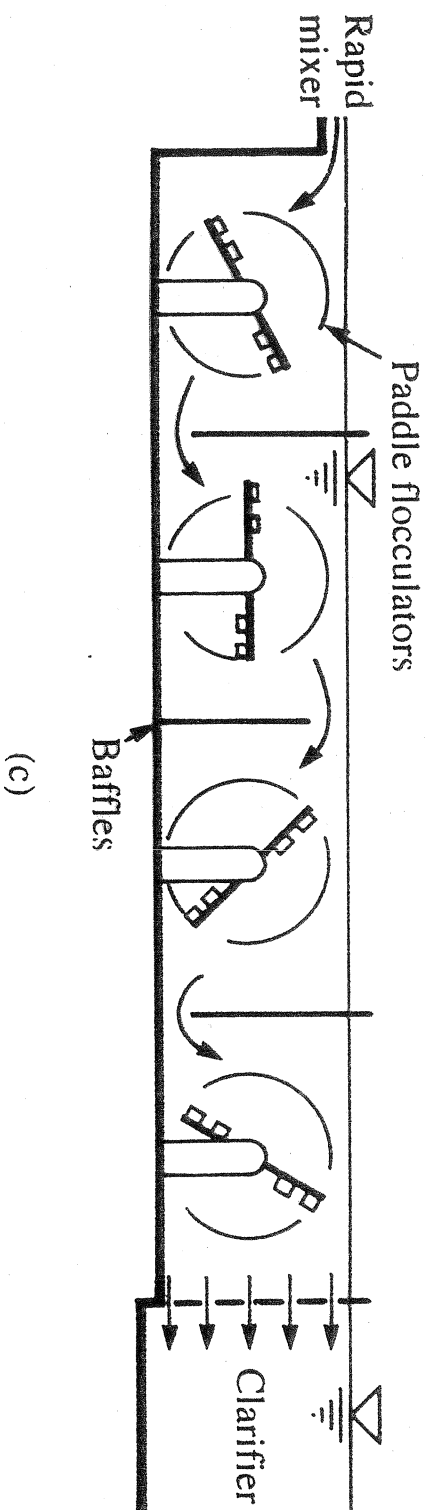




(a)



(b)



(c)

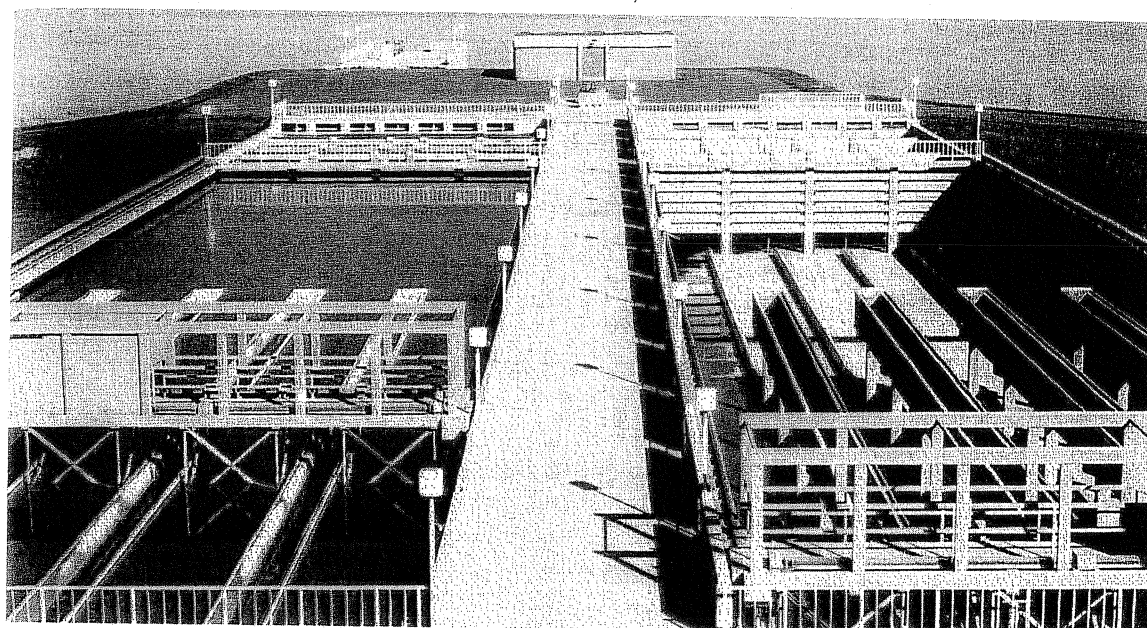
Figure 10.14 The common mixing devices for flocculation in water treatment are: (a) The paddle flocculator. (b) The flat-blade turbine. (c) A typical flocculation tank arrangement is horizontal shaft paddles in a series of compartments separated by baffles to direct water flow through the paddle flocculators.

nix, flocculation 7-6, at the top mixers for ss. When it was in horizontal tanks separated by paddle flocculation tanks are discharge the tank

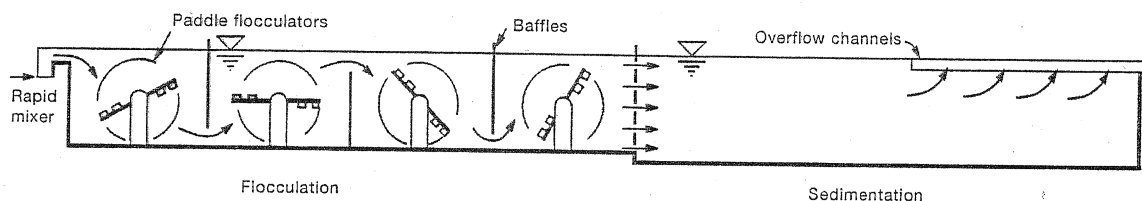
Public B)¹ recemicals cal mix-30 sec. culation

rcuiting

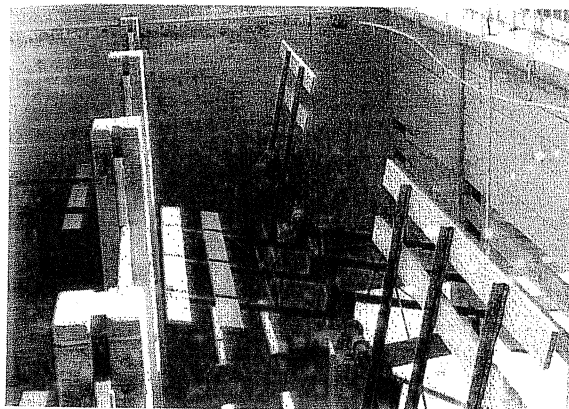
ess than i) with a 30 min. ves with .5 to 3.0 imenta-ble. The s to set-ter than



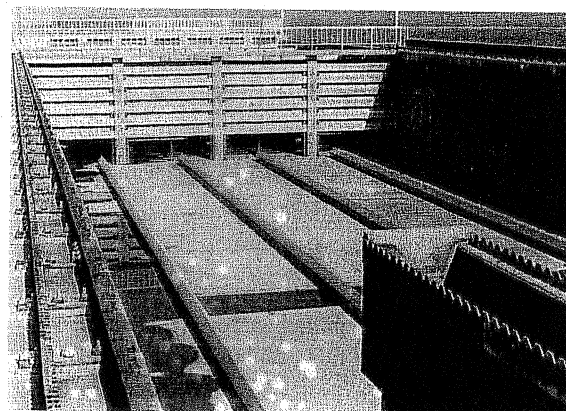
(a)



(b)



(c)



(d)

Figure 7-6 In-line rapid mixing, flocculation, and sedimentation in water treatment.