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" (eg. 3+)

CHEMICAL TERMINOLOGY
IN WATER & WASTE-WATER

LIME, SLAKED LIME	Calcium hydroxide	$Ca(OH)_2$
QUICK LIME	calcium oxide	CaO
LIMEROCK, LIMESTONE	calcium carbonate	$CaCO_3$
SODA ASH	sodium carbonate	Na_2CO_3
POTASH	potassium carbonate	K_2CO_3
CAUSTIC SODA, LYE, SODA LYE	sodium hydroxide	$NaOH$
POTASH LYE	potassium hydroxide	KOH
ALUM, FILTER ALUM	aluminum sulfate	$Al_2(SO_4)_3 \cdot 14\,H_2O$
FERROUS SULFATE, COPPERAS	ferrous sulfate	$FeSO_4 \cdot 7H_2O$
MURIATIC ACID	hydrochloric acid	HCl

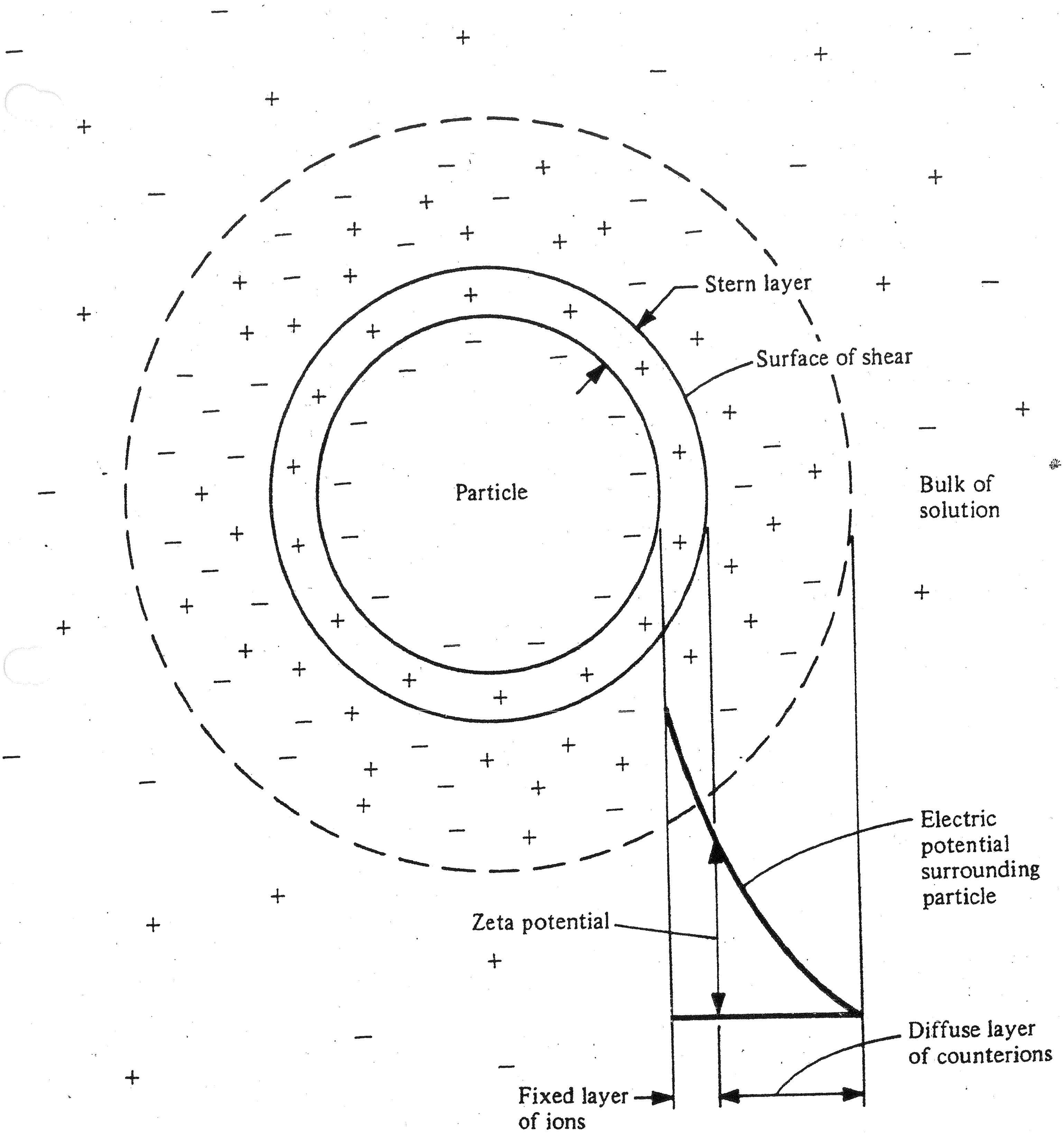


Figure 11.4 Derivation of the zeta potential in diffuse double-layer theory.

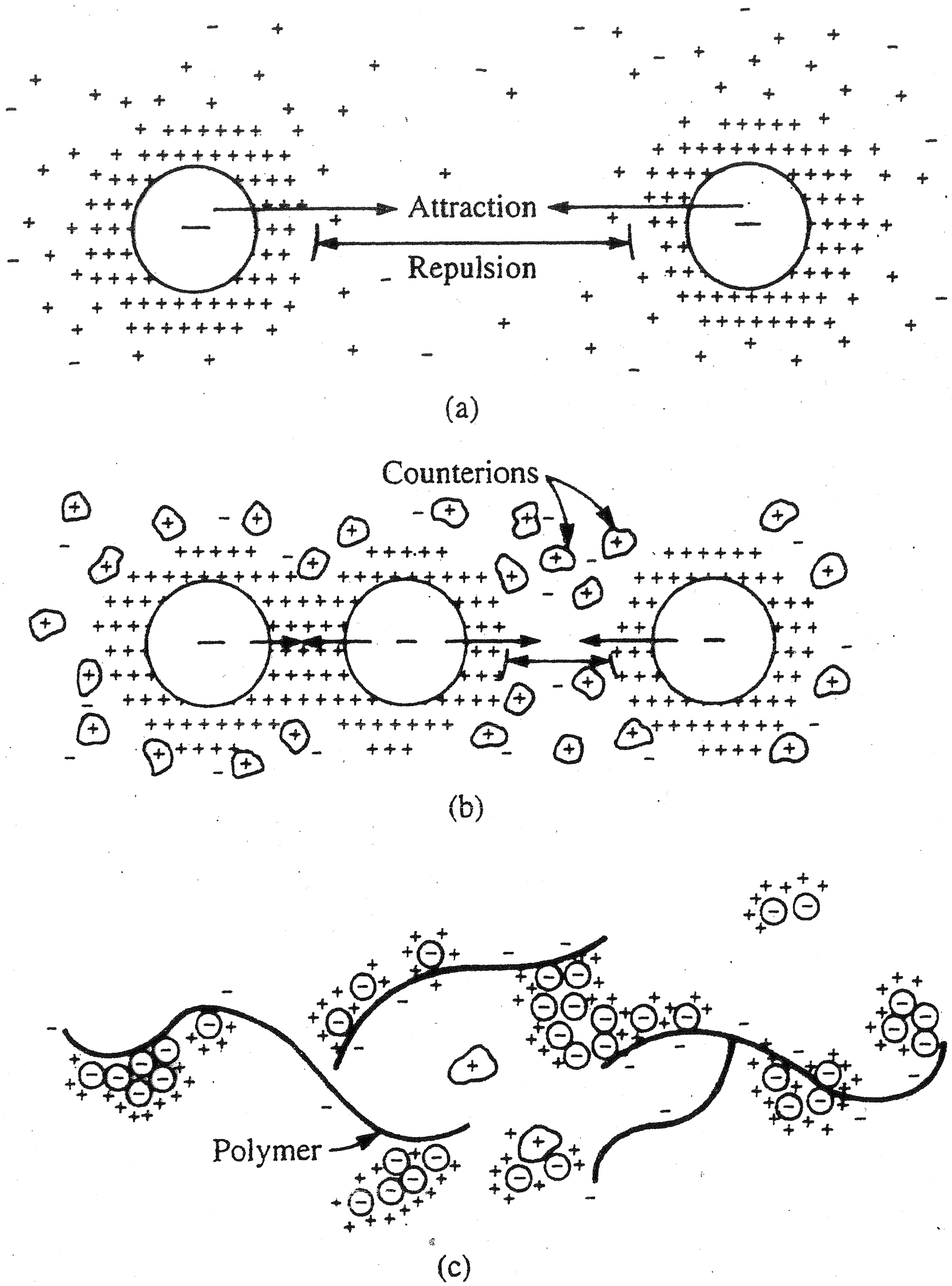


Figure 11.5 Schematic representations of coagulation and bridging of colloids. (a) A stable suspension of particles where forces of repulsion exceed the forces of attraction. (b) Destabilization and coagulation caused by counterions of a coagulant suppressing the double-layer charges. (c) Agglomeration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

COAGULANTS:

Typically Al or Fe salts

Coagulants work in <u>two</u> ways:

① $Al_2(SO_4)_3 \rightarrow 2Al^{3+} + SO_4^{2-}$

$$Al^{3+} + H_2O \rightarrow AlOH^{2+} + H^+$$

$$Al^{3+} + 2H_2O \rightarrow Al(OH)_2^+ + 2H^+$$

Al hydrolysis species

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

② $Al^{3+} + 3H_2O$

$\rightarrow Al(OH)_3 + 3H^+$

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

$$Al_2(SO_4)_3 + 6H_2O \rightarrow 2Al(OH)_3 + 6H^+$$

$$6H^+ + 6NaCO_3 \rightarrow 6Na^+ + 6HCO_3^-$$

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:

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

$$(\text{VISCOSITY})\left(\begin{matrix}\text{velocity}\\ \text{gradient}\end{matrix}\right)^2 = \begin{matrix}\text{Power input}\\ \text{per unit Vol.}\end{matrix}$$

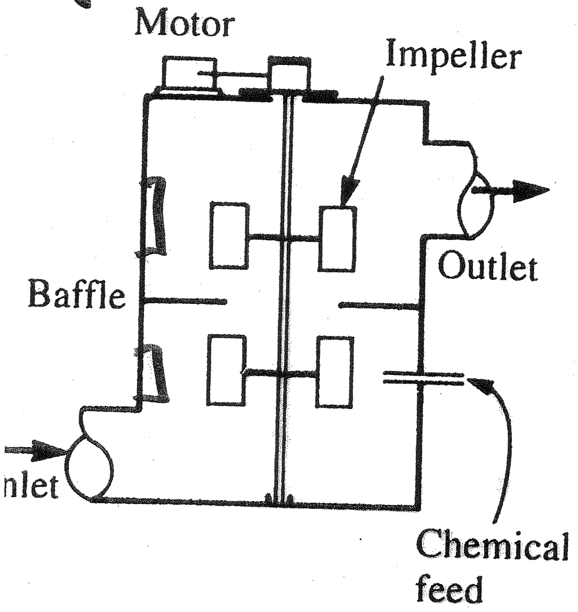
OR

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

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

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

ROTOR-TYPE MIXER



igure 10.12 Impeller-
ype mechanical rapid
nixer for dispersion of
hemicals into water.

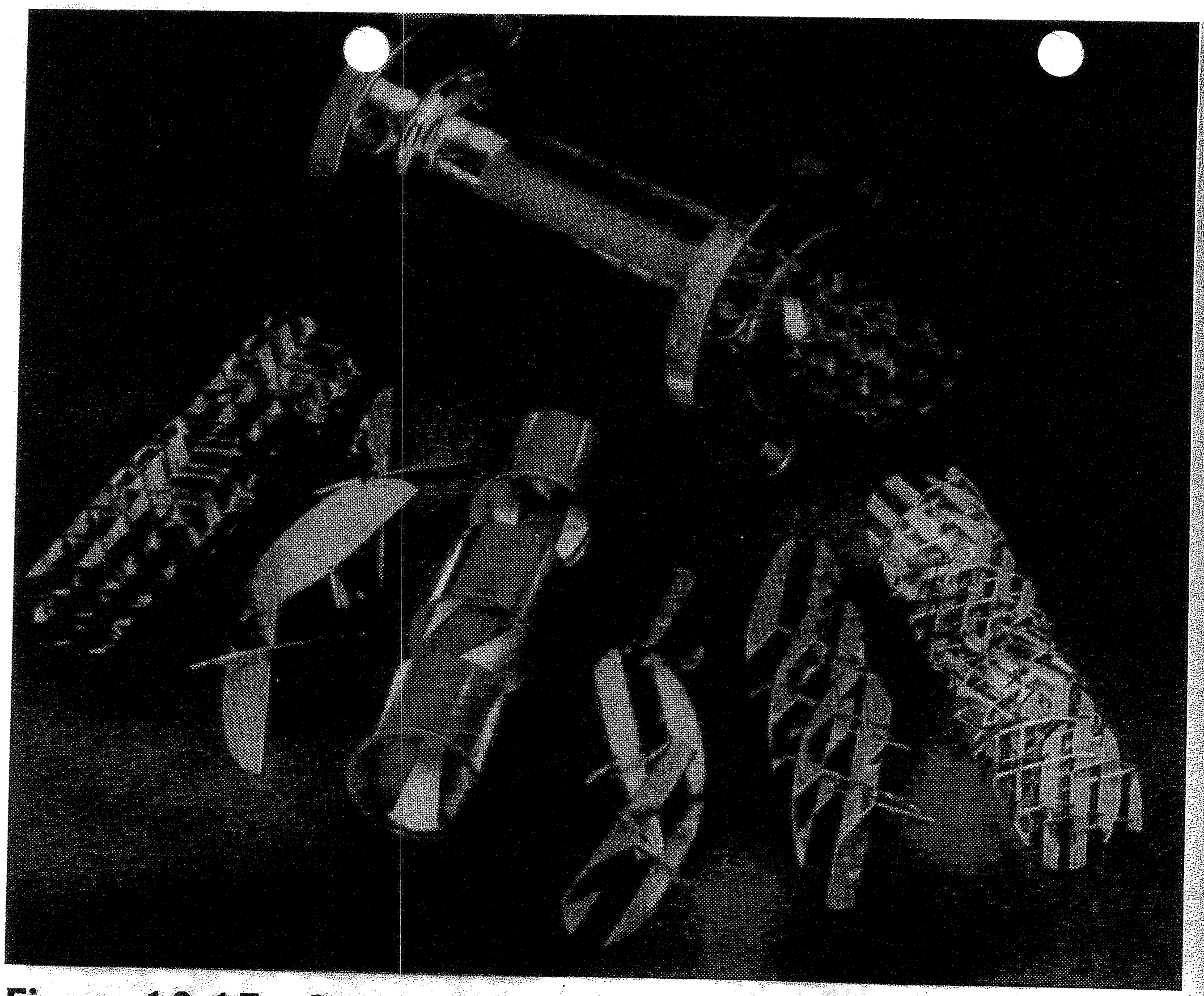
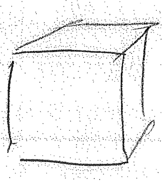


Figure 10.13 Static mixing elements that are inserted into a pipe for in-line blending of chemicals. (Courtesy of Koch Engineering Company, Inc.)

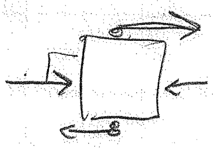
IN-LINE STATIC MIXERS



$$F = ma = m\frac{\partial v}{\partial t} = \frac{\partial (mv)}{\partial t} = \frac{\partial (\text{Momentum})}{\partial t}$$ ← NEWTONS 1st LAW

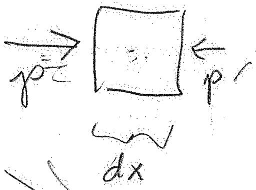
$\frac{F}{A}$ = STRESS → NORMAL = τ

→ TANGENTIAL = p

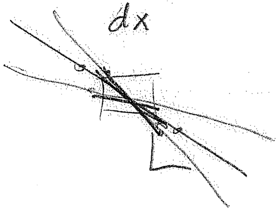


① PRESSURE BALANCE: Induce accel. via pressure differential

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



$$\frac{\Delta p}{\Delta x} \to \frac{\partial p}{\partial x} = \frac{1}{\ }$$



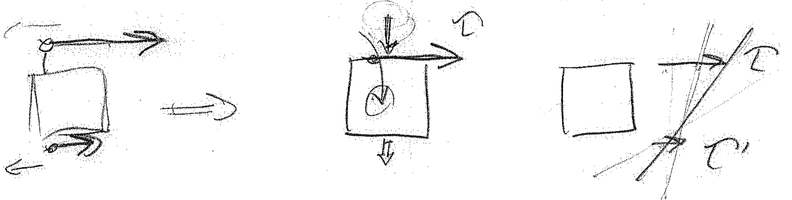
$$\frac{dF/A}{L} = \frac{\partial F}{\Delta V} = \boxed{\frac{\partial F}{\partial \cancel{V}} = \frac{1}{\partial \cancel{V}}\frac{\partial (mv)}{\partial t}}$$

∂F

$$\frac{\partial F}{\Delta V} = \frac{1}{\Delta U}\frac{\partial mv}{\partial t} \qquad \frac{M\cancel{L}}{T^2 L^{\cancel{3}2}} \qquad \frac{M\cancel{L}}{L^{3}T^2}$$

$$\partial F = \frac{\partial mv}{\partial t} \qquad \frac{M}{T^2L^2}$$

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

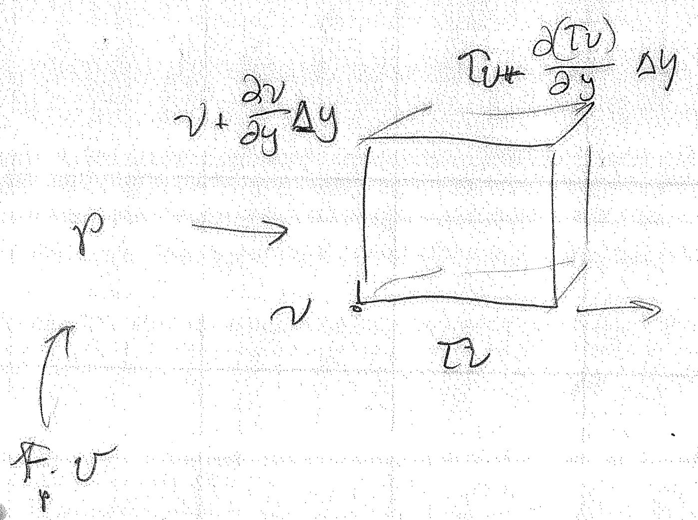


$\} \partial y \qquad \frac{\partial (mv)}{\partial t} \sim \frac{\partial \tau}{\partial y}$

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

@ At SS $\frac{\partial F_p}{\Delta V} = \frac{\partial F_\tau}{\Delta V} \Rightarrow \boxed{\frac{\partial p}{\partial x} = -\frac{\partial \tau}{\partial y}} = -\frac{\partial}{\partial y}\mu\frac{\partial v}{\partial}$

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



ΔP

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

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

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

Div
∂y
ΔV

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

At S.S.,

$$\frac{\text{Power Dissipated}}{\text{Unit Volume}} = -\tau\frac{\partial v}{\partial y}$$

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

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

$$G \cdot t_d$$

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

DETENTION TIME
Units T

Makes sense that the product $G \cdot t_d$ (dimensionless) correlates with mixer/flocculator performance

E.g.
For rapid mixing of Alum coagulat

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

optimal vel. Gradiant

optimal t_d

mg/L DOSE of ALUM

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

$$G = 900\ s^{-1}$$
$$t_d = 30\ s$$

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:

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

↖ where $V = Qt_d$, t

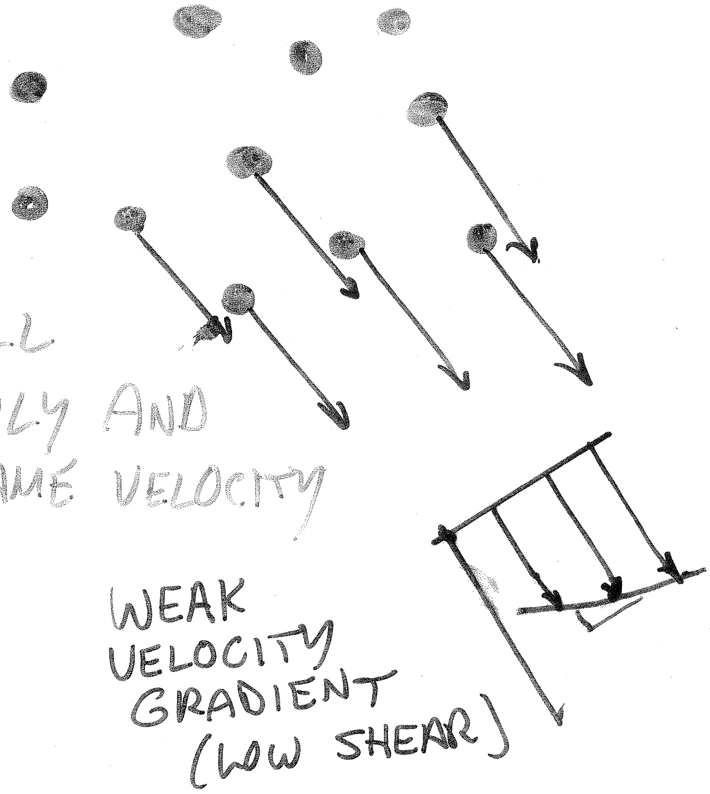
③ Use general design guidelines to get dimensions of mixer, then use those to size the DIAMETER ($\underline{D}$) of the impeller.

④ Obtain $\phi \equiv$ power number $= \dfrac{P}{\rho N^3 D^5}$ from table such as 13.4 in text.

⑤ Solve Rotation Rate $= N = \left[P / \rho \phi D^5 \right]^{1/3}$ (speed of rotor motor)

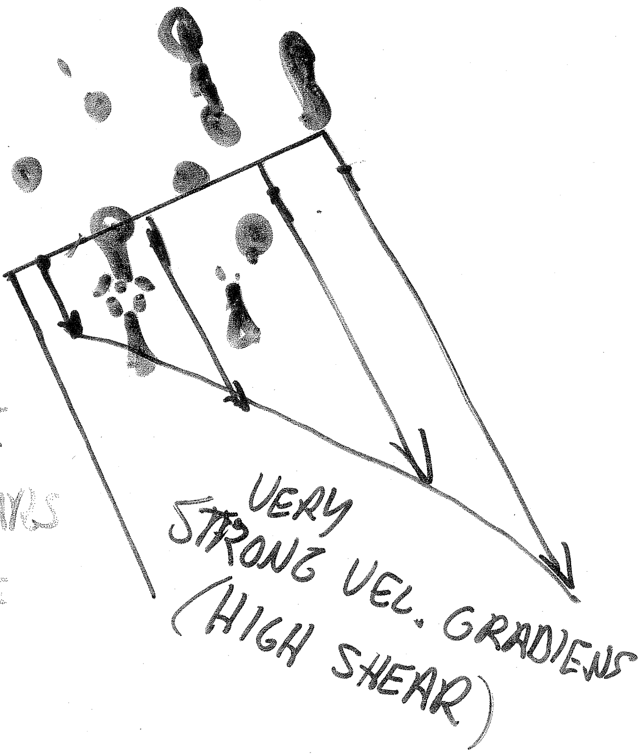
FLOCCULATION

TOO SLOW



PARTICLES ALL MOVING SLOWLY AND AT ABOUT SAME VELOCITY

TOO FAST



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

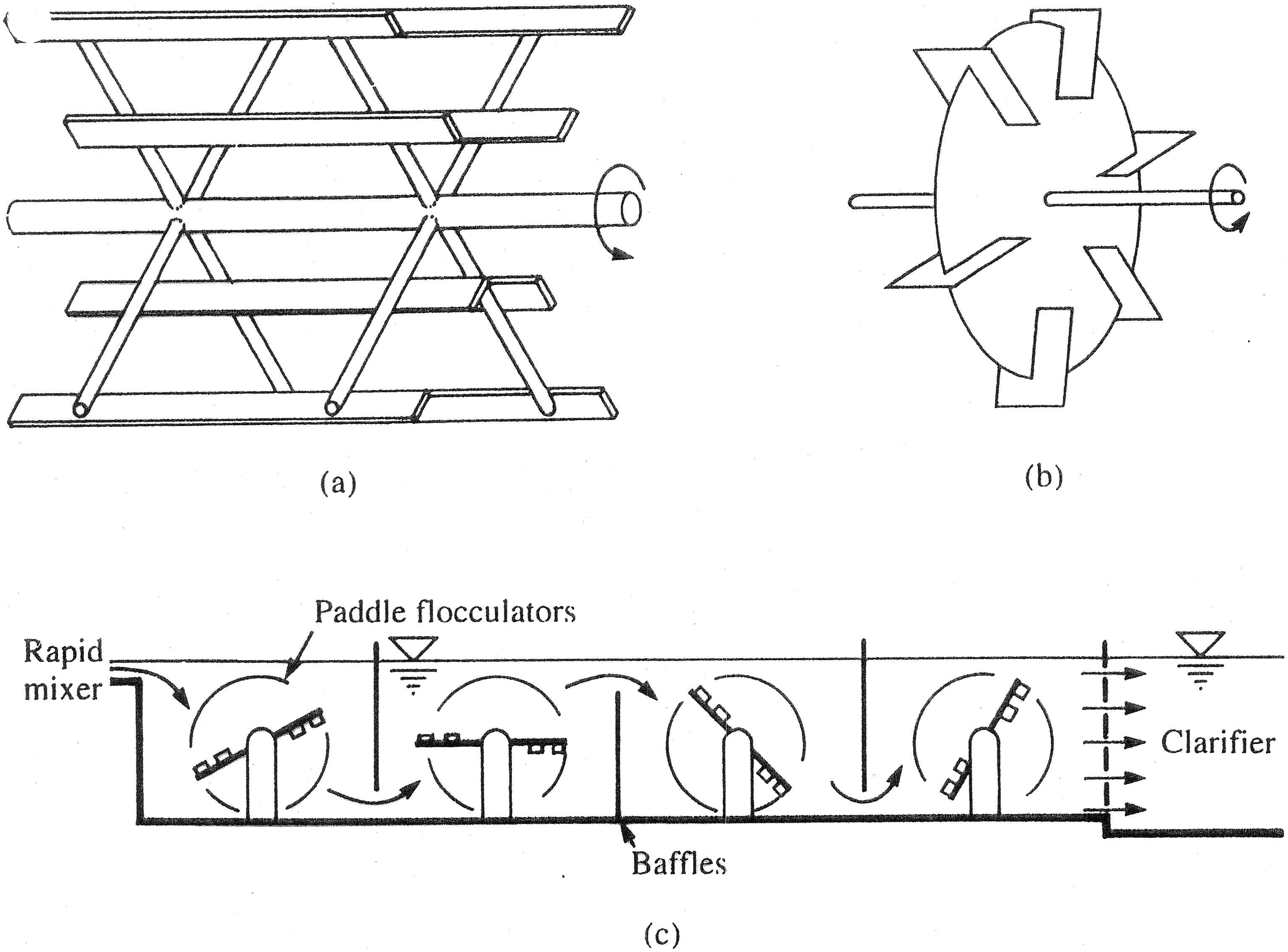


Figure 10.14 The common mixing devices for flocculation in water treatment are: (a) The paddle flocculator. (b) The flat-blade turbine. (c) A typical flocculation tank arrangement is horizontal shaft paddles in a series of compartments separated by baffles to direct water flow through the paddle flocculators.

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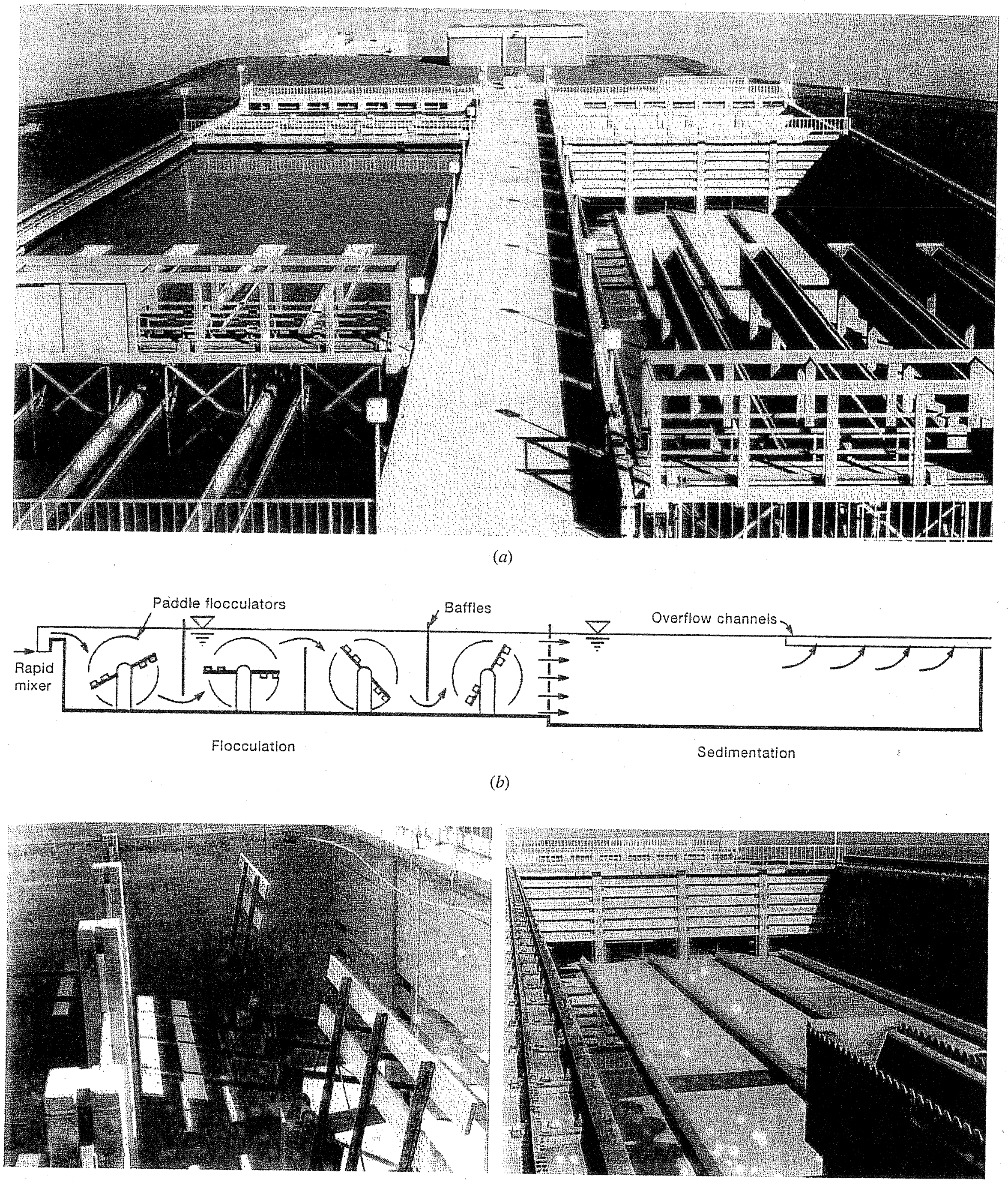

Figure 7-6 In-line rapid mixing, flocculation, and sedimentation in water treatment.