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CEE 370 Environmental Engineering Principles

Lecture #27

Water Treatment I: Introduction, Process Flow, Coagulation

Reading: Mihelcic & Zimmerman, Chapter 8

Reading: Davis & Cornwall, Chapt 4-1 to 4-3

Reading: Davis & Masten, Chapter 10-1 to 10-3

Definitions

- Pathogens
  - An agent that causes infection in a living host
  - Most are microorganisms, but most microorganisms are not pathogens
- Infection
  - A pathological condition due to the growth of microorganisms in a host
- Toxin
  - A poisonous substance from certain organisms
- Virulence
  - The capacity of a microorganism to cause disease

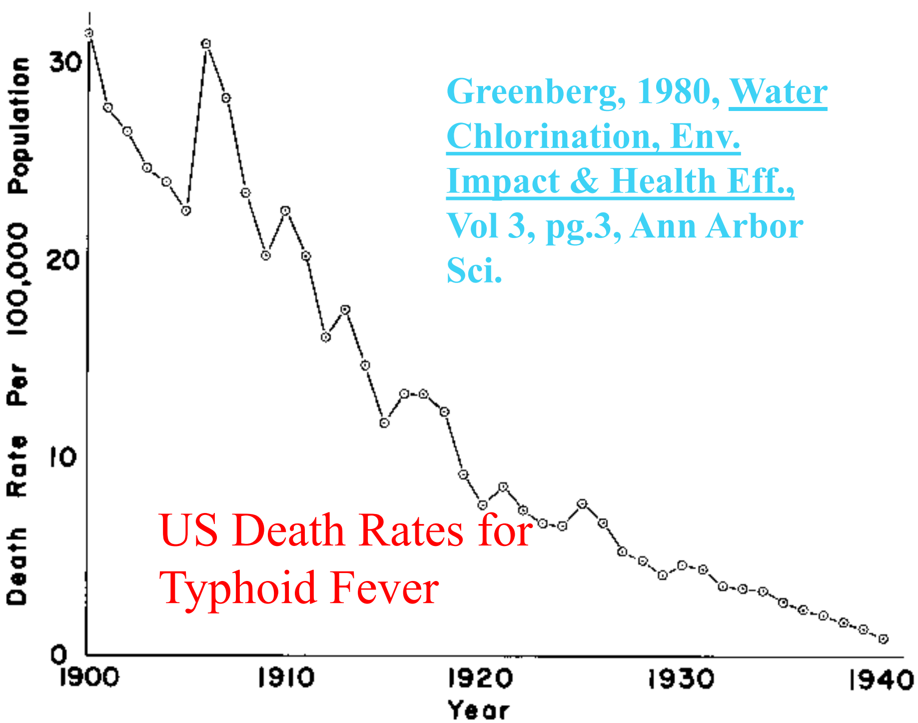
Types of pathogens

Many can be water borne

- Viral
  - Hepatitis, polio, yellow fever
- Rickettsial (between bacteria and viruses)
  - Typhus
- Bacterial
  - Antrax, Botulism, Cholera, Plague, Salmonellosis, Shigellosis, Typhoid
- Protozoan
  - Amebiasis, Malaria, Giardiasis, Cryptosporidiosis
- Helmenthic
  - Hookworm, Tapeworm, Schistosomiasis

Chlorination

- 1-2 punch of filtration &



US Death Rates for Typhoid Fever

Greenberg, 1980, Water Chlorination, Env. Impact & Health Eff., Vol 3, pg.3, Ann Arbor Sci.

Melosi, 2000, The Sanitary City, John Hopkins Press

Engineering & Disease

- Filtration & chlorination

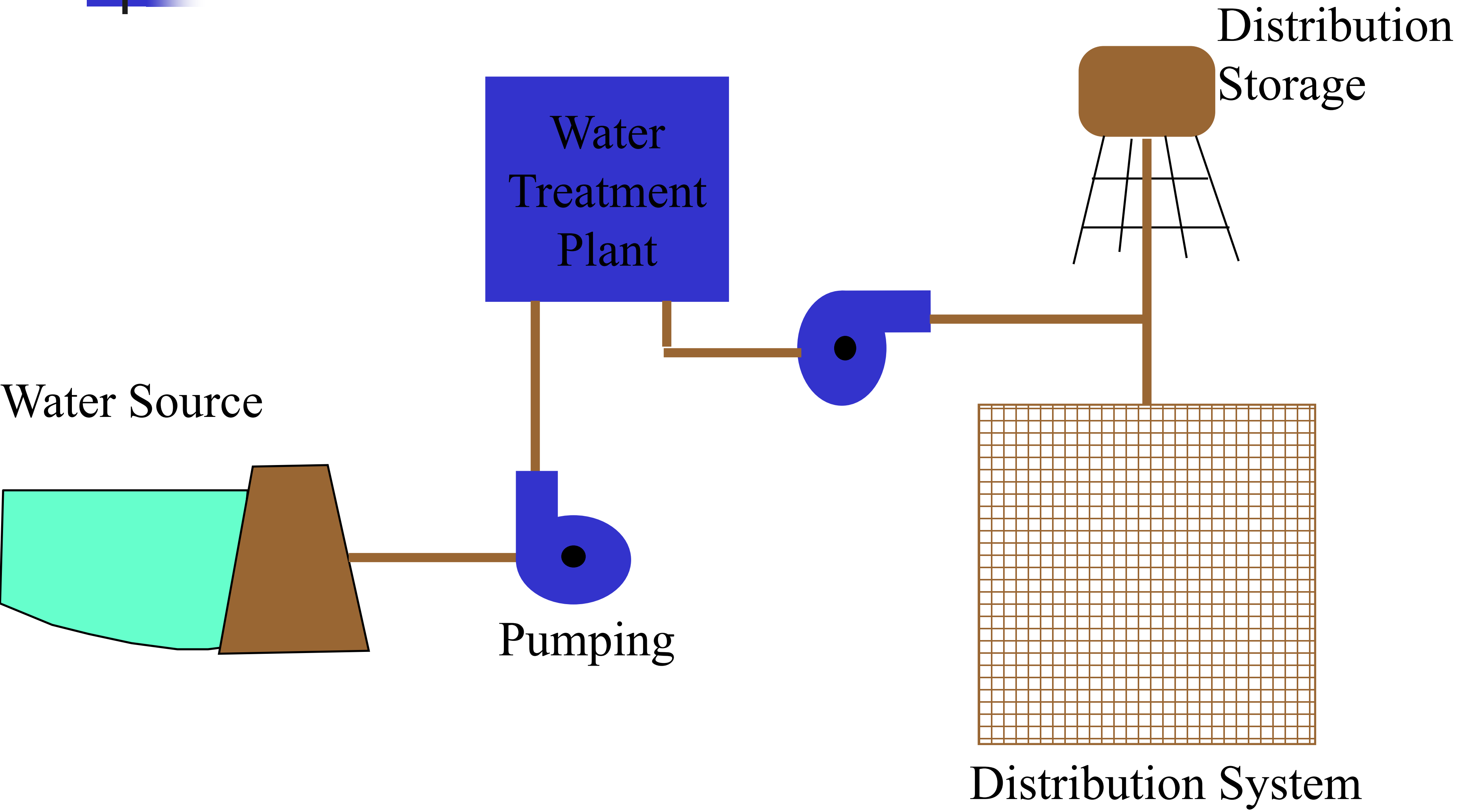
TABLE 7.6 DECLINE IN TYPHOID DEATH RATES AFTER USE OF HYPOCHLORITE

City	Before (1900–10)	After (1908–13)	Change
Baltimore	35.2	22.8	35%
Cleveland	35.5	10.0	72
Des Moines	22.7	13.4	41
Erie	38.7	13.5	65
Evanston	26.0	14.5	44
Jersey City	18.7	9.3	50
Kansas City	42.5	20.0	53
Omaha	22.5	11.8	47
Poughkeepsie	54.0	18.5	66

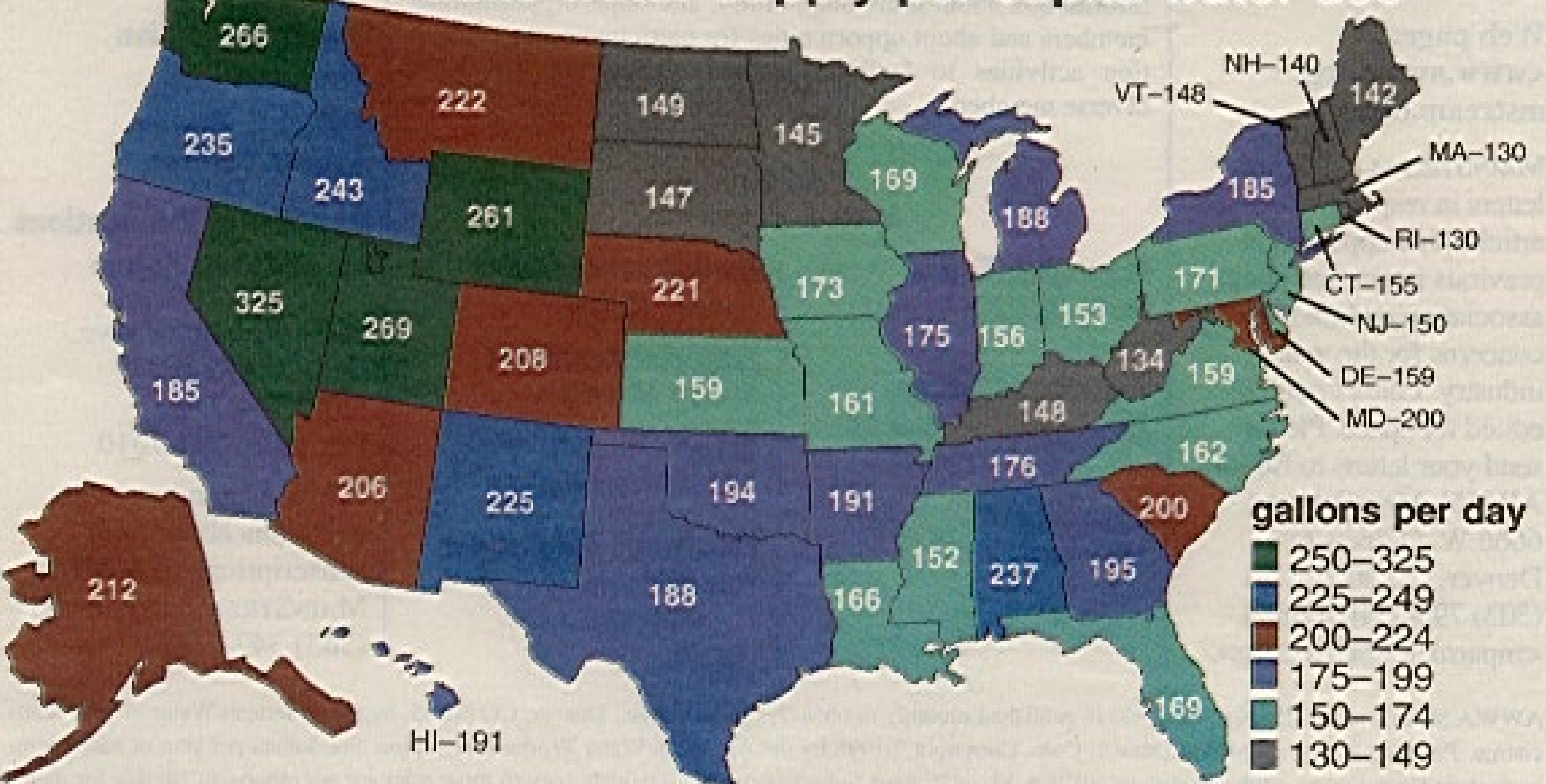
Source: John W. Alvord, "Recent Progress and Tendencies in Municipal Water Supply in the United States," *JAWWA* 4 (Sept. 1917): 284.

From: The Sanitary City

Water Supply and Distribution



Public water supply per capita water use*



*Includes domestic, commercial, industrial, thermoelectric power, losses, and public use.
Source: Estimated Use of Water in the United States in 1995 (USGS Circular 1200)

Purposes for Water Treatment

- Disinfection #1 concern
- Removal of Turbidity
- Removal of Color, and Tastes & Odors
- Removal of Iron & Manganese
- Hardness removal
- Protection from Toxic Organics and Inorganics

Raw Water Quality

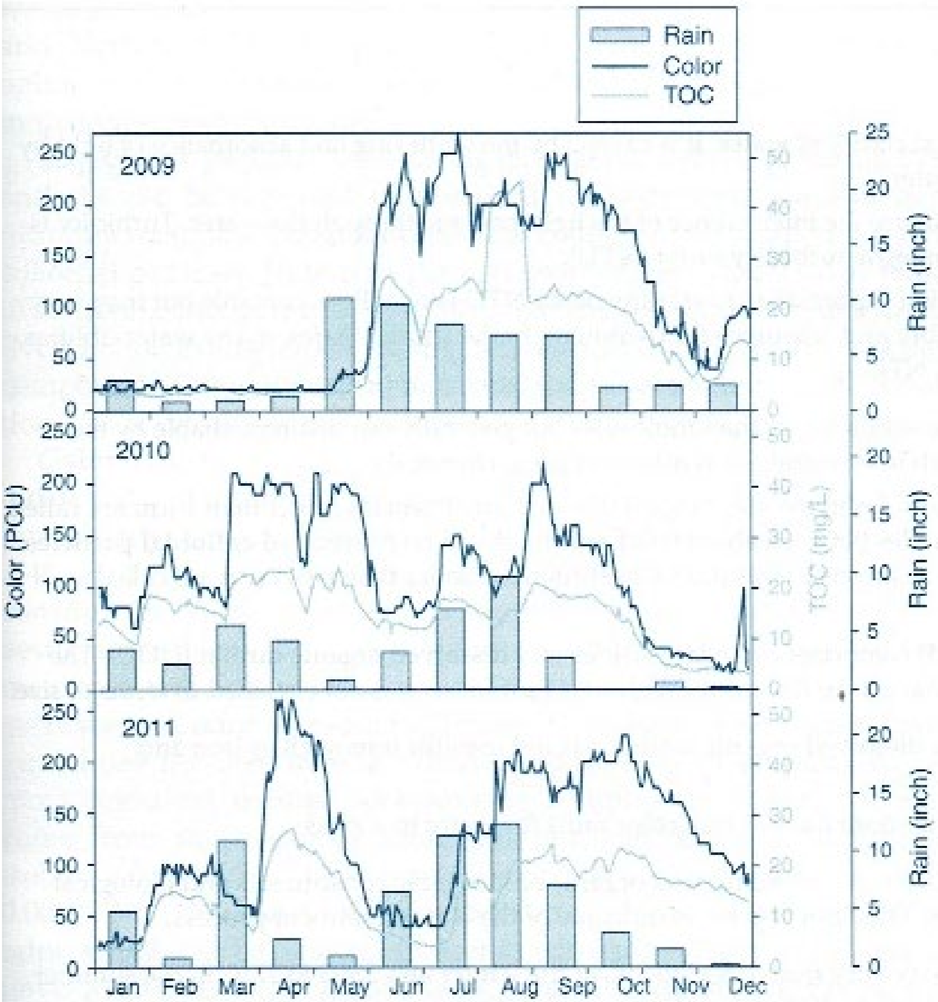


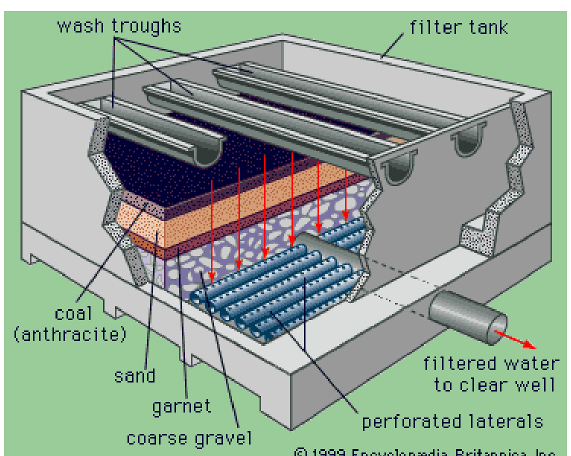
Figure / 8.1 Seasonal Differences in TOC and Color of Hillsborough River Raw Water That Serves the City of Tampa (FL) Water Treatment Plant (2009–2011) The water quality fluctuates largely over the course of the year, impacting the treatment process in many ways. The river's source water is primarily the Green Swamp located in Central Florida. During the wet season (June–September), TOC and color concentrations spike from the large amount of organic matter flushed out of the swamp and river tributaries by heavy rains.

(Courtesy of Dustin Boles, 2012; with permission).

- Hillsborough River: Tampa FL
  - An extreme case

How to Treat Drinking Water

- Historical
  - Use fine granular media to "sieve" out particles
    - Slow Sand Filtration
      - Too labor intensive, land intensive and slow



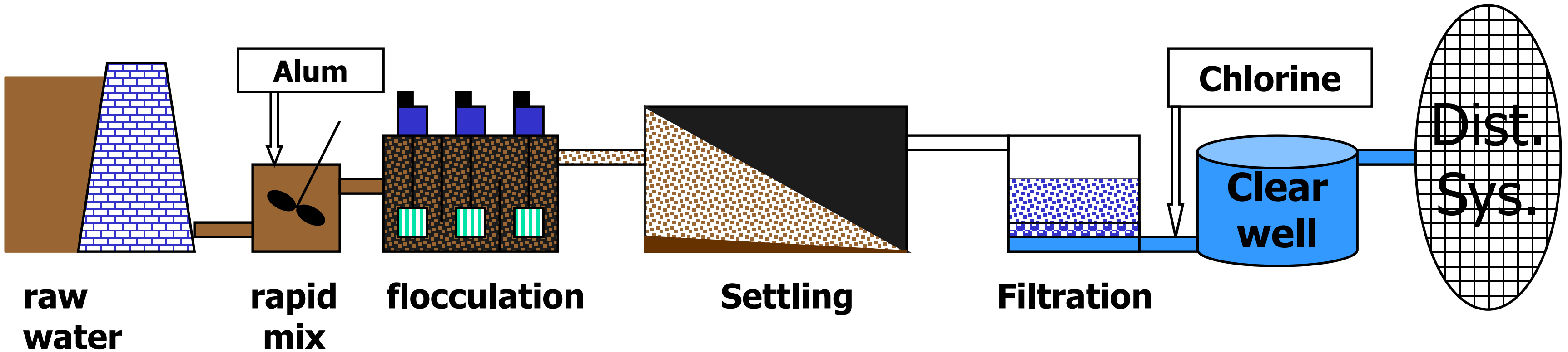
- Modern
  - Use coarser media with coagulant
    - Rapid Media Filtration
    - Better to precede it with settling

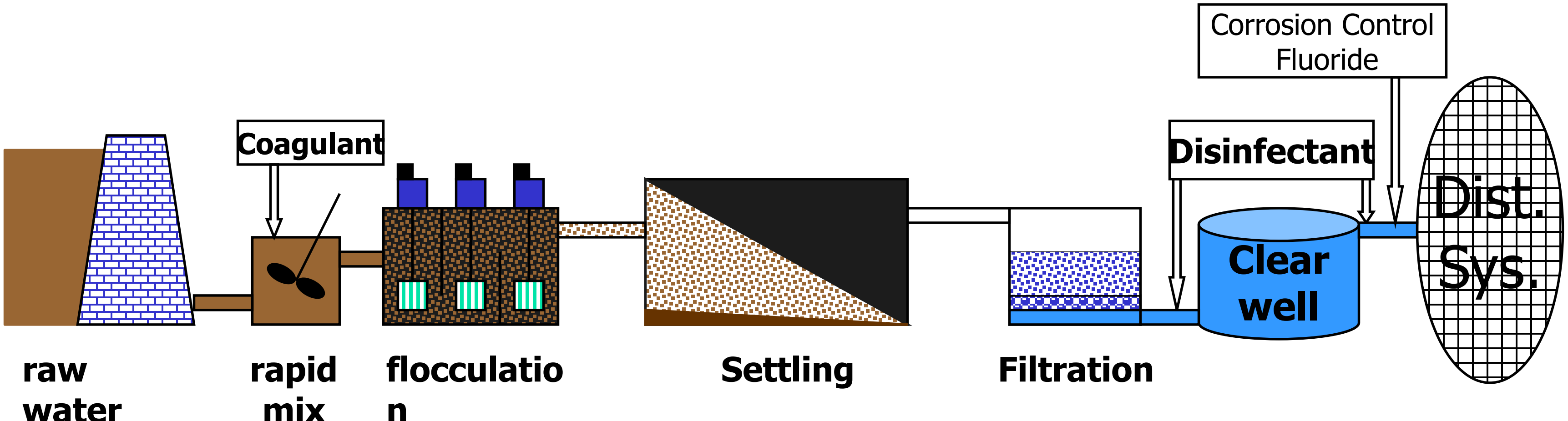
Drinking Water Treatment Processes

- Gas Transfer (stripping)
- Oxidation
- Coagulation & Flocculation
- Sedimentation or Flotation
- Softening
- Adsorption
- Disinfection

Conventional Water Treatment

- Coagulation, settling, filtration & disinfection

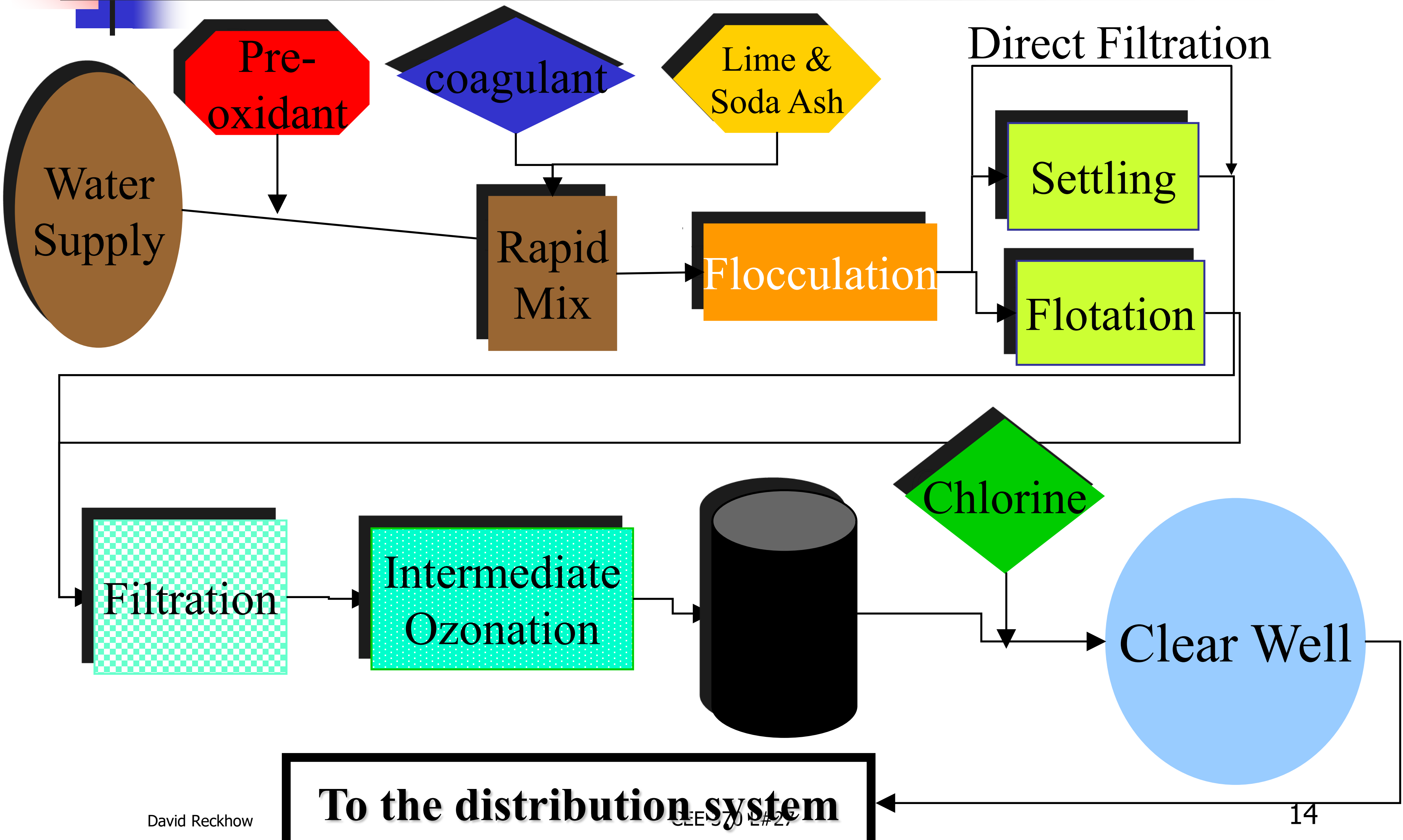




Some WTP video tours

- Beaufort Jasper WTP, SC (5:25)
  - Conventional treatment
    - https://www.youtube.com/watch?v=0bXIqS5NcRY
- Winnipeg, Manitoba (7:28)
  - DAF, ozone & UV
    - https://www.youtube.com/watch?v=20VvpASC2sU
- Severn Trent, England (3:20)
  - Screening, sludge blanket clarifiers, GAC, Ozone
    - https://www.youtube.com/watch?v=9z14l51ISwg

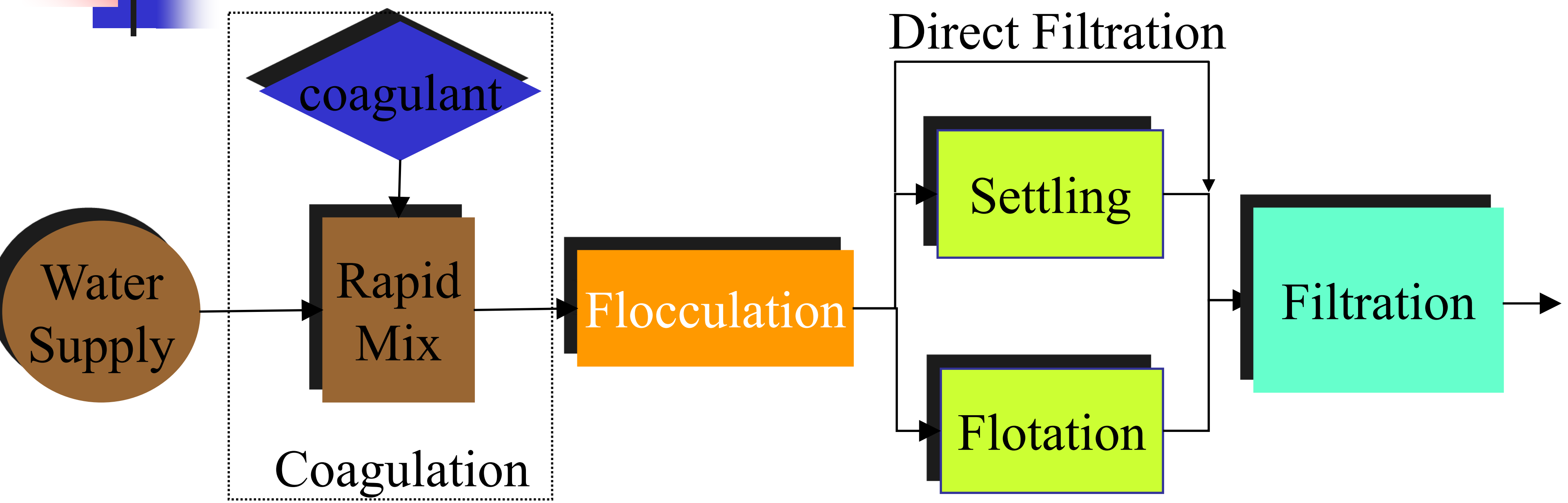
An advanced water treatment process

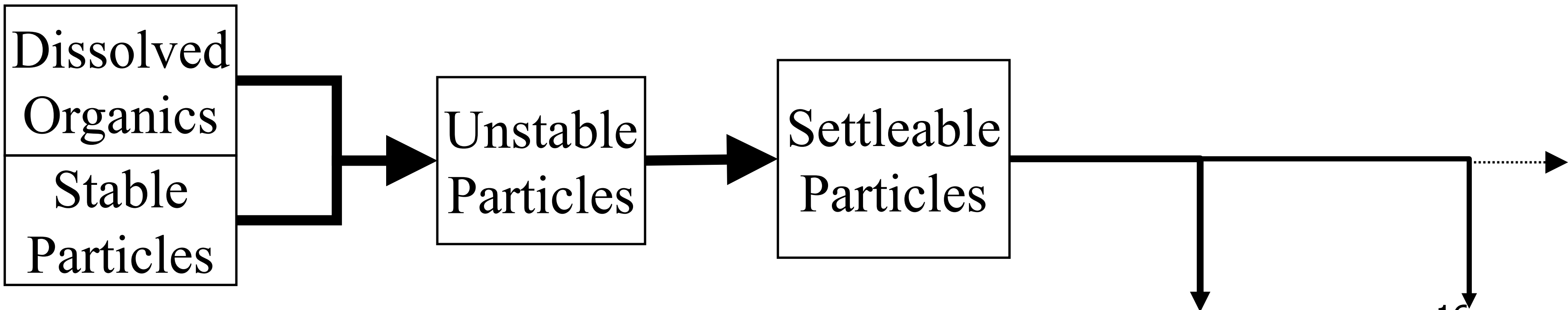


Coagulation: Purpose

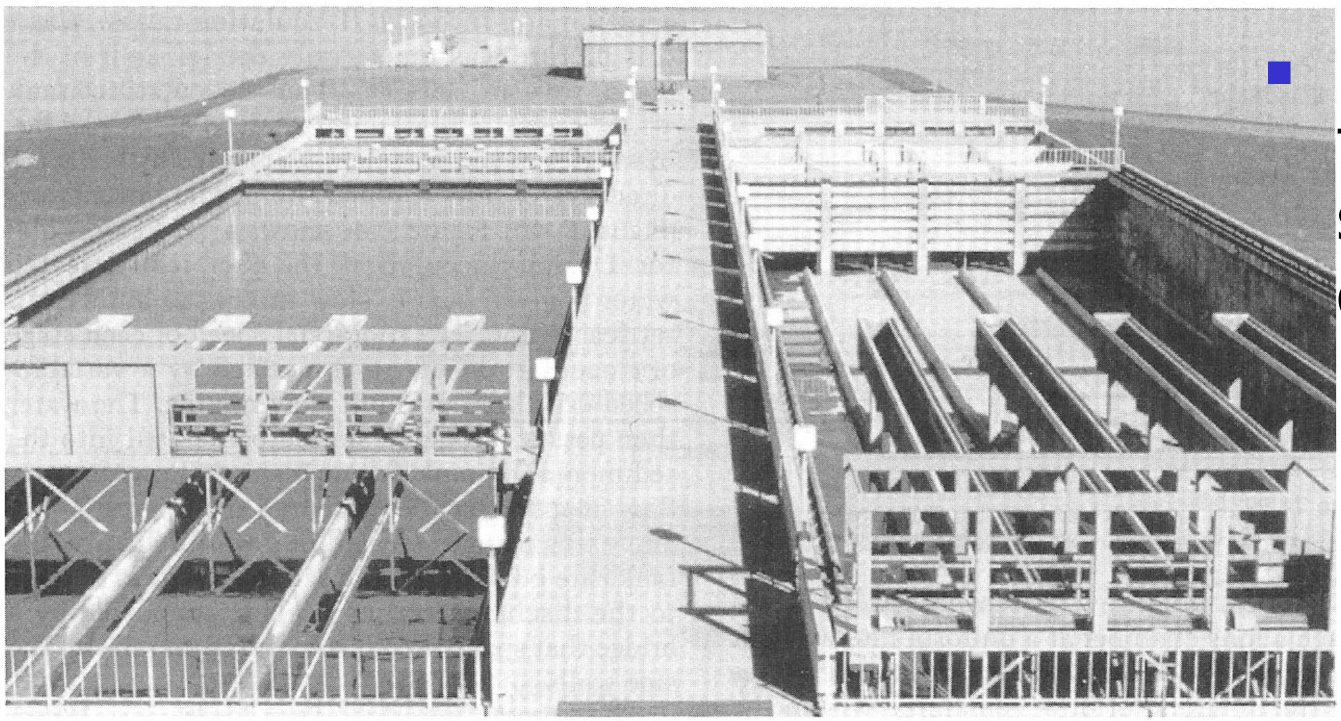
- Initiate the chemical reactions that render conventional treatment effective
- When combined with subsequent physical removal, it achieves:
  - Removal of turbidity
    - historically the reason for coagulation
    - Requires that particles be "destabilized"
  - Removal of natural organic matter
    - more recently of importance
  - Some removal of pathogens
    - *Giardia, Cryptosporidium*

Overview of conventional treatment

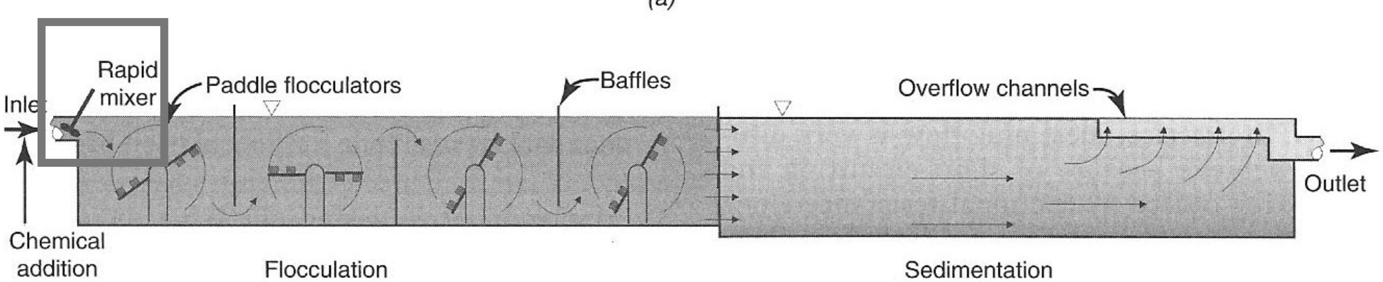




Conventional Treatment



(a)



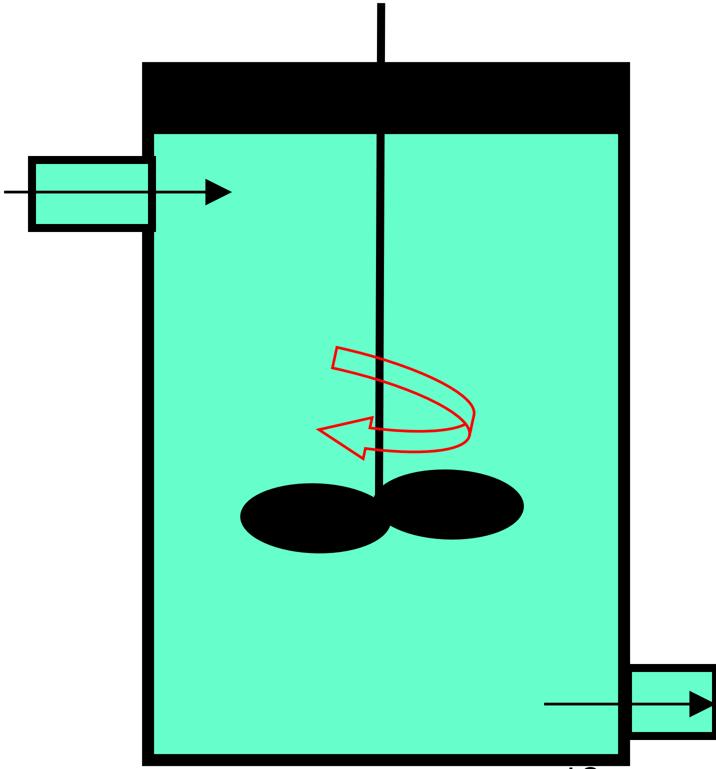
(b)

- rapid mix, flocculation, sedimentation in one long tank with baffles

H&H, Fig 7-4, pg. 212

Coagulant Addition: Rapid Mix

- Purpose
  - to provide rapid and complete mixing of chemicals at the head of a plant
  - Two types: tank mixer or in-line
- Tank Mixer
  - Tank
    - 3 to 10 ft diameter
    - flow through, top to bottom
    - 10 to 60 second detention time
  - vertical shaft turbine impeller
    - $G=600\text{-}1000\ s^{-1}$



Rapid mix Tank

- Impeller
  - Iron deposits

Reading, MA

Rapid Mix Design

- Detention Time
  - 10-60 seconds is most common
- Mixing Energy
  - differences in fluid velocity: velocity gradient
    - change in velocity as you move up or down vertically in a reactor
    - since velocity is [L/T] and vertical distance is [L], the G value is in units of reciprocal time [T^{-1}]
  - Camp: related it to power input (P), tank volume (V) and viscosity (μ)

$$G \equiv \frac{dv}{dy}$$

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

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

Typical values for mixing

Type	Gradient (G) in sec^{-1}	Detention Time	Gt values
Mechanical Mixing	600-1,000	10-120s	$5x10^4 – 5x10^5$
In-line mixing	3,000-5,000	1 s	$1x10^3 – 1x10^5$
Horizontal-shaft paddle flocculator	20-50	10-30 min	$1x10^4 – 1x10^5$
Vertical-shaft turbine flocculator	10-50	10-30 min	$1x10^4 – 1x10^5$

From: M&Z table 8.12

In-line static mixers

- Many manufacturers

Coagulant chemistry

Ferric Sulfate (also ferric chloride)

$$Fe_2(SO_4)_3 + 6\,OH^- \rightarrow 2Fe(OH)_3 \Downarrow + 3\,SO_4^{2-}$$

Alum (the most common coagulant)

$$\underbrace{Al_2(SO_4)_3 \bullet 18H_2O}_{\text{GFW= 666}} \rightarrow 2\,\underbrace{Al}_{\text{AW= 27}}(OH)_3 \Downarrow + 3SO_4^{-2} + 6H^+ + 12H_2O$$

GFW= 666 AW= 27

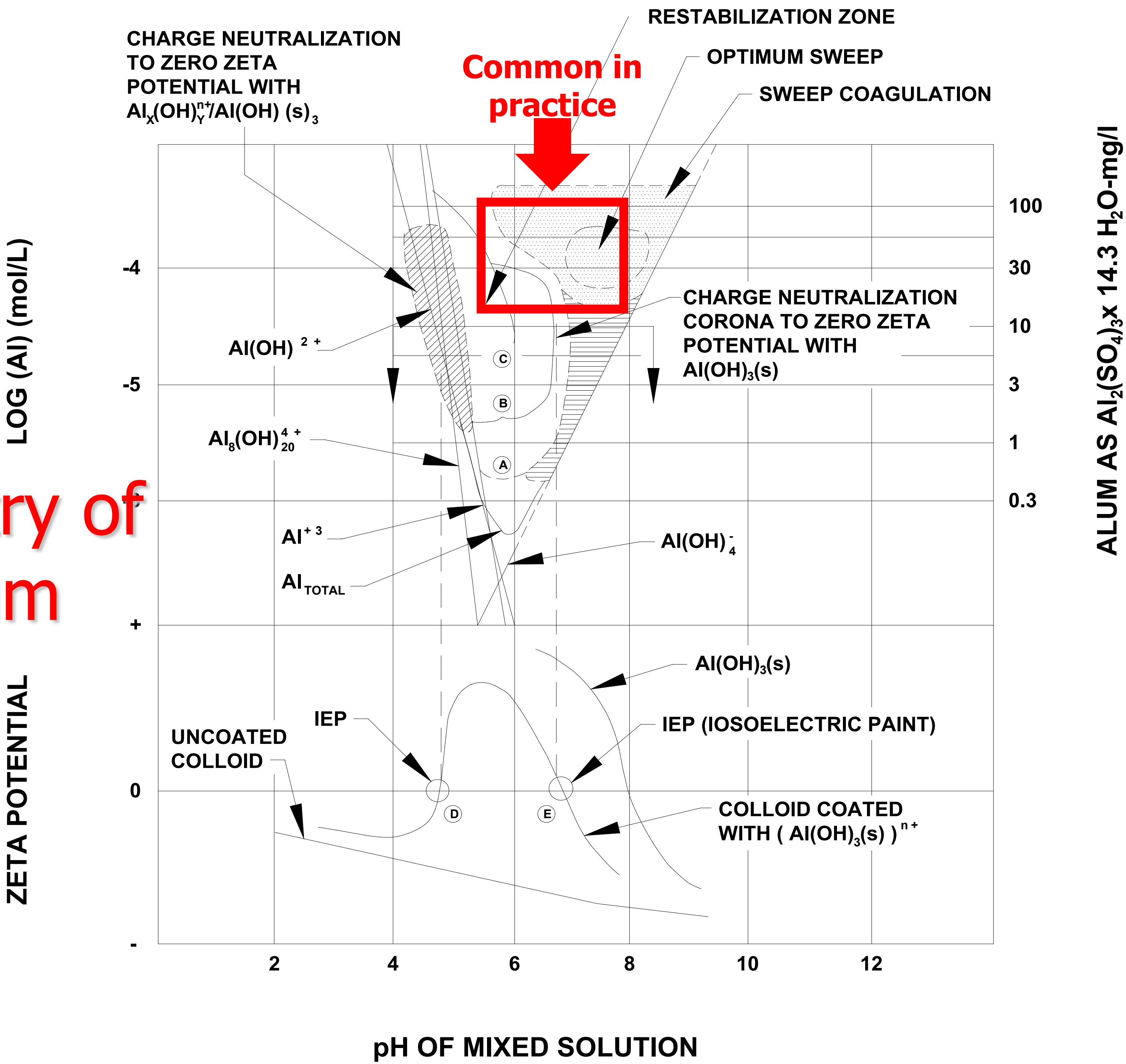
Alum is ~8.4% Al by wt.

Neutralized by natural alkalinity (bicarbonate)

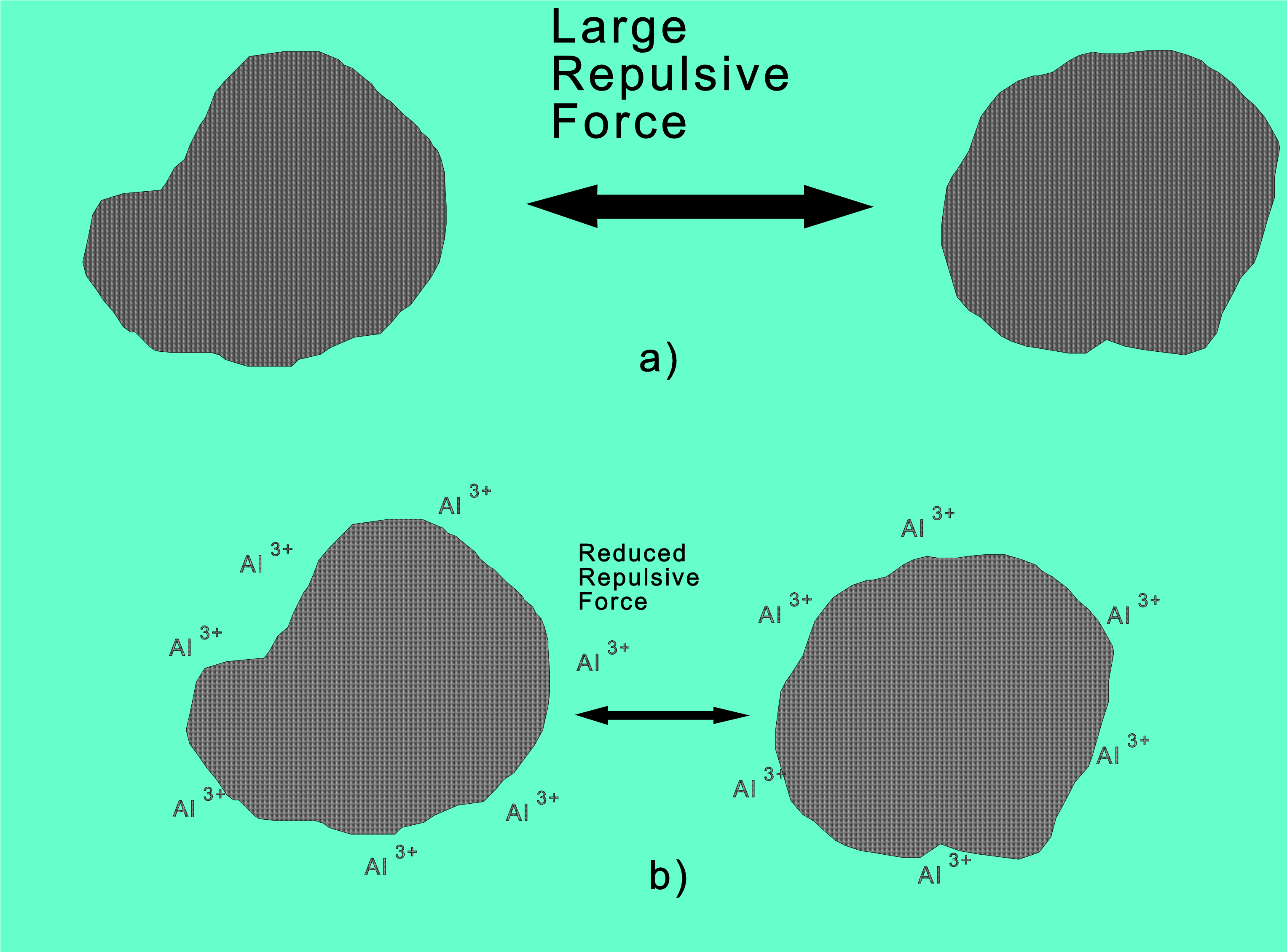
<u>Mechanisms</u>

- Charge Neutralization
- Sweep Floc (enmeshment)
- Adsorption / complexation ← for Dissolved substances

Chemistry of Aluminum

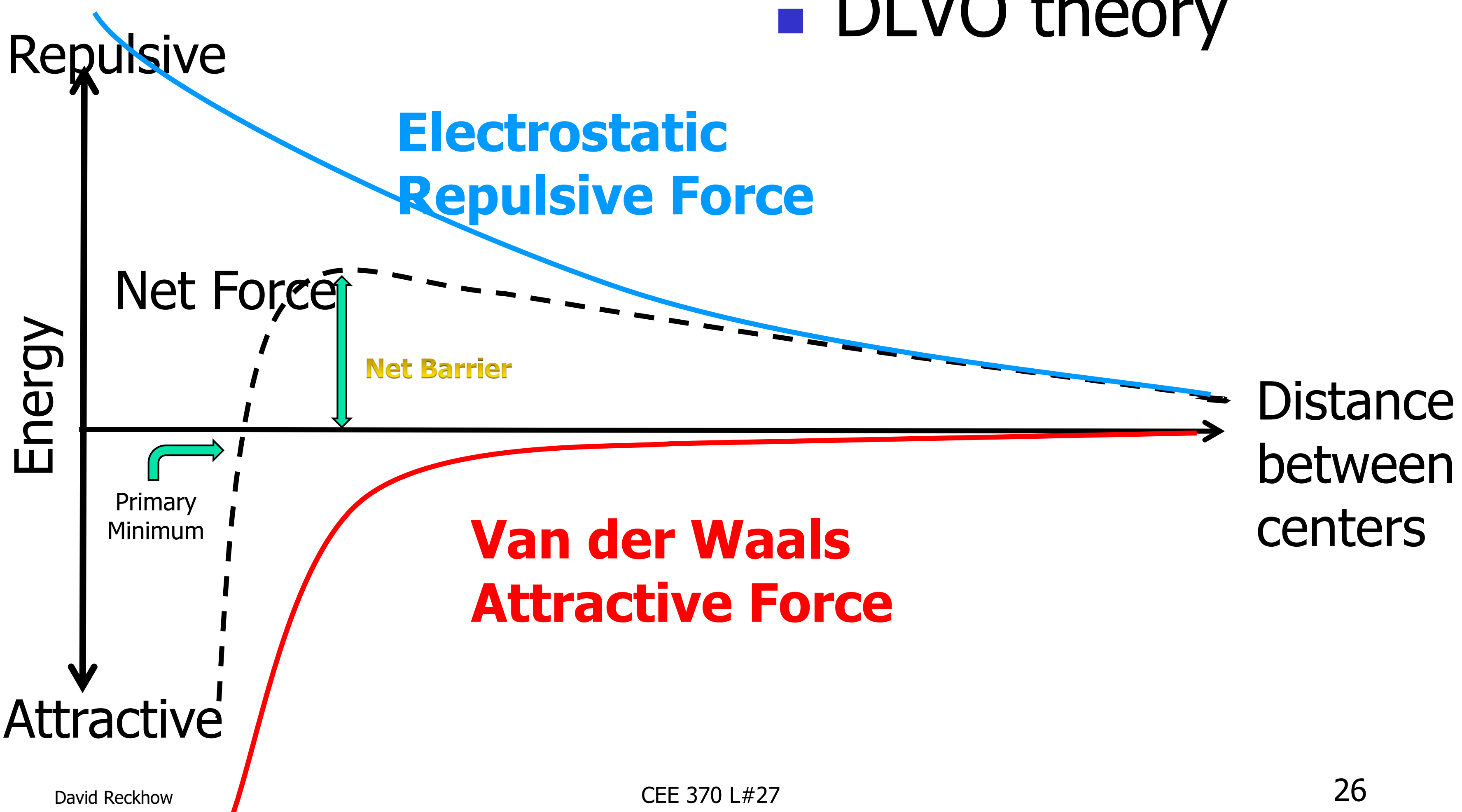


Charge neutralization



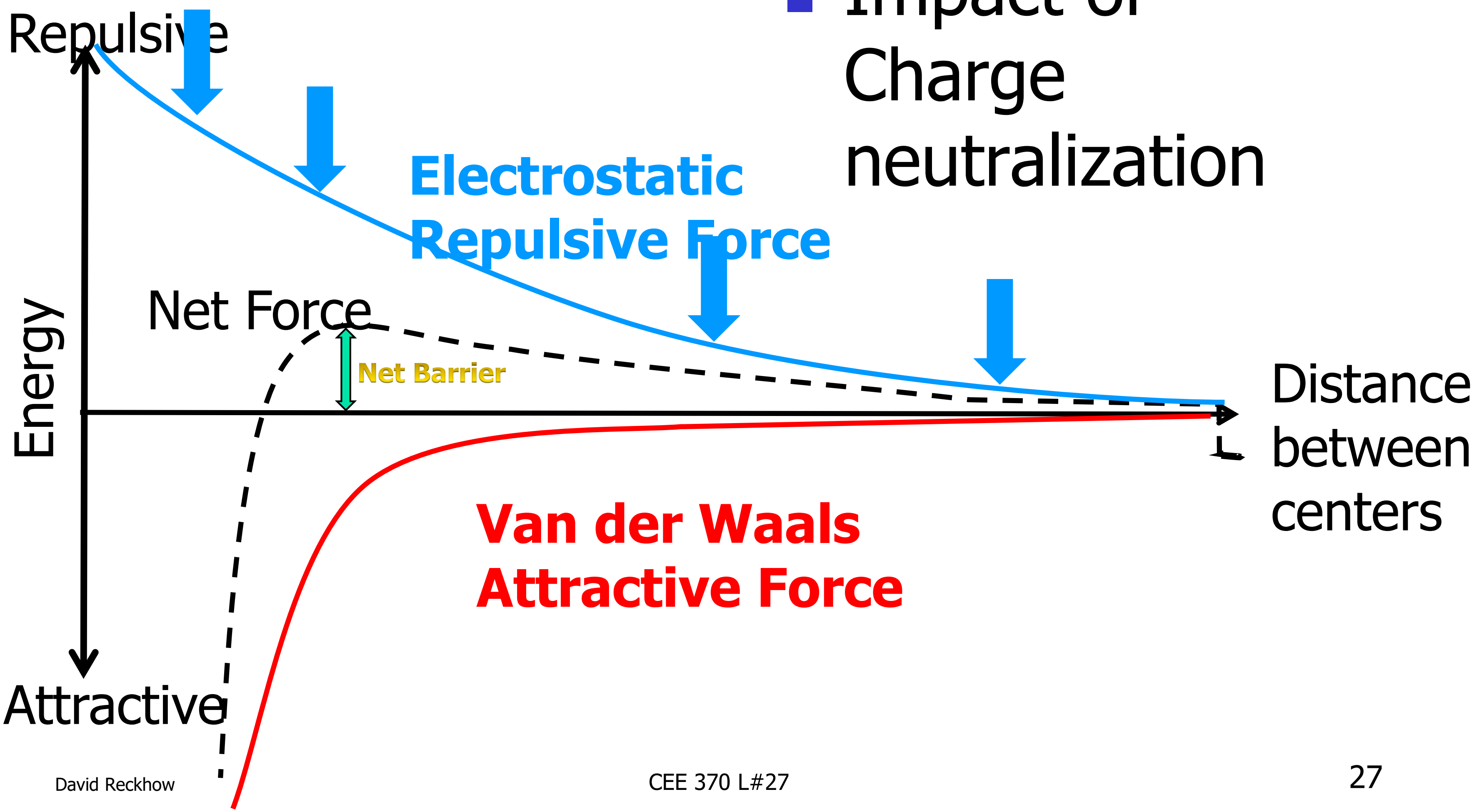
Colloid Stability

- DLVO theory



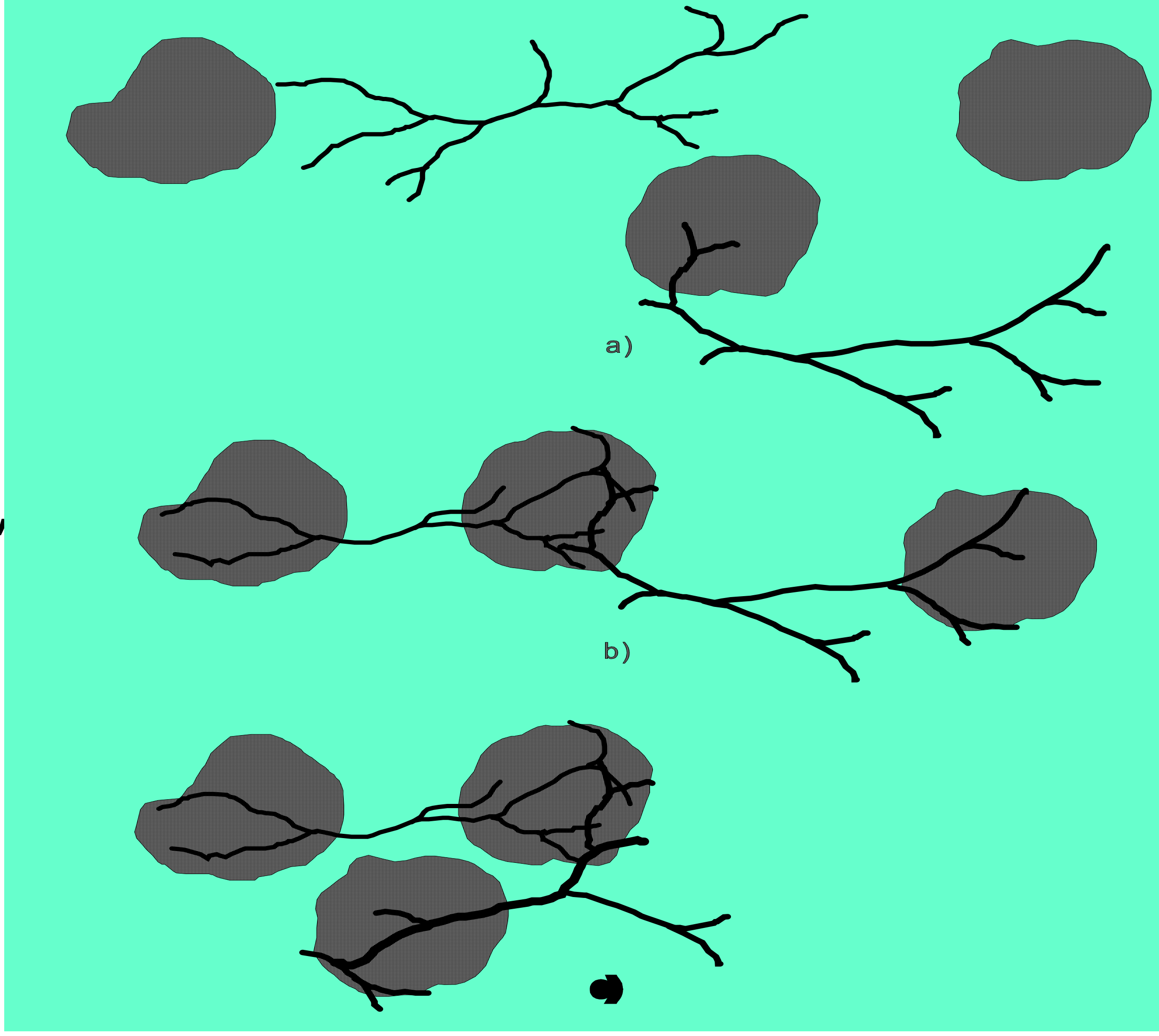
Colloid Stability

- Impact of Charge neutralization



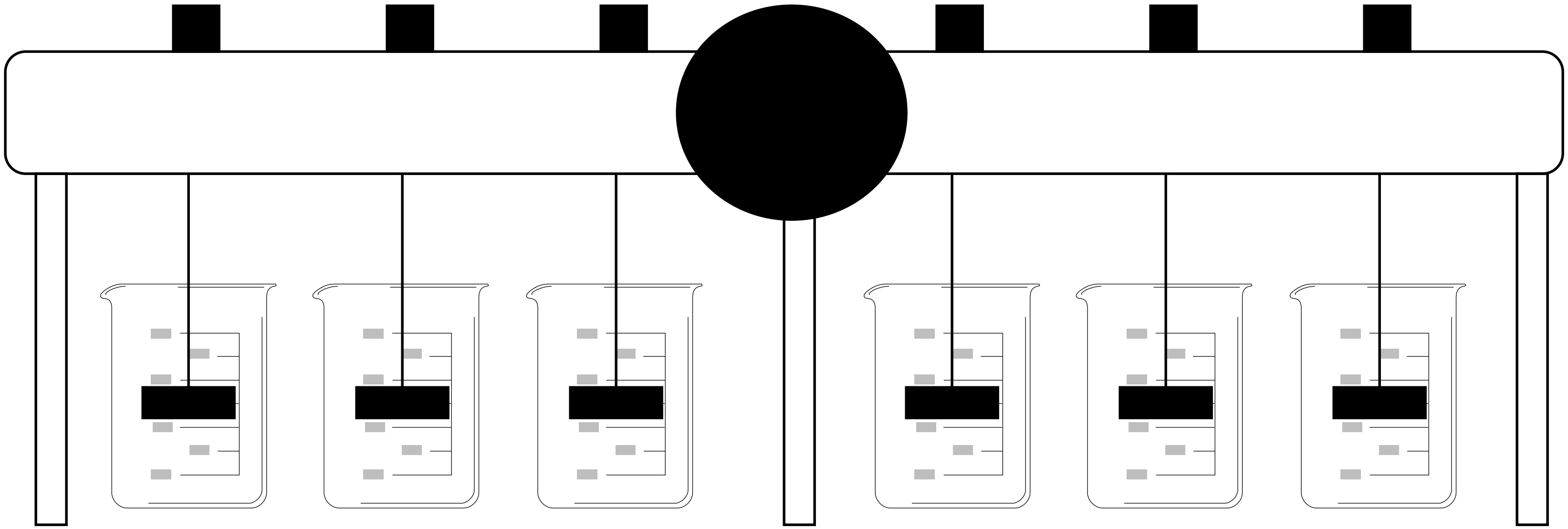
Destabilization with Polymers

- Natural polymers
  - Alginates
- Synthetic polymers
  - Cationic, anionic, non-ionic
- No need to reach "primary minimum" distance
- Also used to strengthen floc



Coagulation: Empirical Tests

- Jar Testing
  - Laboratory experiments with varying coagulant doses at varying pHs



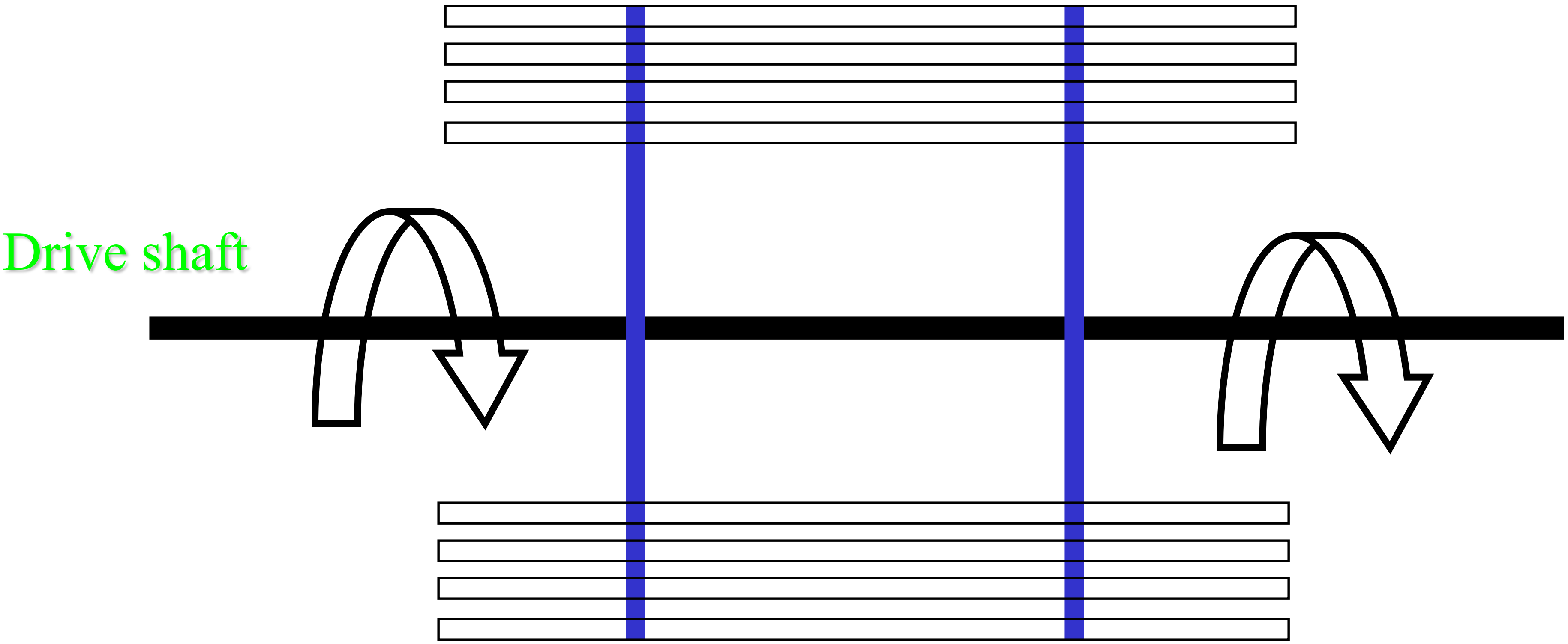
Flocculation: Purpose

- Provides slow mixing to allow "destabilized" particles and precipitates to grow in size
- Larger size helps with subsequent physical removal
  - Gravity settling
  - Flotation
  - Filtration

Flocculation: Purpose

- Promote agglomeration of particles into larger floc
- Units often designed on the basis of mixing intensity as described by the velocity gradient, G
  - some mixing is needed to keep particles in contact with other particles
  - too much mixing can cause floc break-up

Flocculators



Usually 4 arms with 3-4 slats per arm

Flocculation

- Horizontal Shaft

Flocculation

- 4 Wooden paddles

Flocculation

- 2 parallel shafts

Vertical Shaft Flocculator

- Motor and gear box

Flocculation: Design

- Flow through velocity: 0.5 to 1.5 ft/min
- variable speed paddle flocculators
  - peripheral velocities of 0.5-2.0 ft/sec
  - horizontal shaft: slower, best for conventional
  - vertical shaft: faster, best for direct filtration
- typical dimensions
  - 12 ft deep
  - length/width = 4

- To next lecture