Water Treatment

CE 326 Principles of Environmental Engineering
Department of Civil, Construction and Environmental Engineering
Iowa State University
March 2, 2009
Tim Ellis, Ph.D., P.E.
Announcements

• Water Chemistry II Problem Set due today

• Schedule change: *Wednesday, March 4* lab will be part 1 of the water treatment plant design

• The Water Treatment Plant Field Trip has been moved to *Wednesday, March 11*
Water Treatment

- **Groundwater**
  - *hardness* (aesthetic consideration)
  - disinfection (required by SDWA)

- **Surface Water**
  - *turbidity* and *color* removal
  - filtration (required by SDWA)
  - disinfection (required by SDWA)
Coagulation = Charge reduction
Flocculation = Contact of particles
Charge Neutralization/Reversal

![Graph showing turbidity remaining vs alum dose]
Alkalinity in Coagulation

Needed to neutralize acid formed

\[ \text{Al}_2\left(\text{SO}_4\right)_3 \cdot 14\text{H}_2\text{O} + 6\text{HCO}_3^- \rightarrow 2\text{Al(OH)}_3 \cdot 3\text{H}_2\text{O} \]

\[ + 6\text{CO}_2 + 8\text{H}_2\text{O} + 3\text{SO}_4^{2-} \]

\[1 \text{ mole alum} \quad \text{MW = 594} \]

2 moles Al\(^{3+}\) in 1 mole alum

6 mole alk

Suppose we added \(8 \text{ mg} / \text{L}\) \(\text{Al}^{3+}\) how much alkalinity did we consume?

\[ \frac{8 \text{ mg}}{\text{L}} \times \frac{\text{mole Al}^{3+}}{275} \times \frac{5}{1000 \text{mg}} = 0.296 \times 10^{-3} \text{ mole Al}^{3+} \]

\[ 0.296 \times 10^{-3} \text{ mole Al}^{3+} \times 3 \text{ mole alk} = 0.889 \times 10^{-3} \text{ mole alk} \]
\[ 0.889 \times 10^{-3} \text{ mole alk} \times \frac{61.9 \text{ g}}{\text{ mole}} \times \frac{1000 \text{ mg}}{\text{s}} \times \frac{160/2}{61/1} = 44.9 \text{ mg/L as CaCO}_3 \]
Rapid Mix

G values:
700 - 1000 s⁻¹

3000 - 5000 s⁻¹

Rapid Mix Tank  In-line Blender  Static Mixer

http://www.postmixing.com/mixing%20forum/Macro/Fluid%20Motion/process_intensifier/images/hga%20model.jpg
http://www.pumppackage.co.uk/images/KOFLO_Page%206/Kofloflowani.gif
Paddle Mixer Details
Paddle Mixers in Left Chamber and Flocculators in Right Two Chambers
Mixing Calculations

- Find P for a rapid mix basin where 
  \( Q = 0.05 \text{ m}^3/\text{s} \); detention time = 60 s, 
  \( T = 20^\circ \text{C} \), \( G = 700 \text{ s}^{-1} \); \( \mu = 1.002 \times 10^{-3} \text{ Pa} \cdot \text{s} \)

\[
6 = \sqrt{\frac{P}{\mu G}}
\]

\[
V = \text{flow rate} \cdot \text{detention time} = \frac{0.05 \text{ m}^3}{\text{s}} \cdot 60 \text{ s}
\]

\[
= 3 \text{ m}^3
\]

\[
P = 6^2 \mu G = (700 \text{ s}^{-1})^2 \times (1.002 \times 10^{-3} \text{ Pa} \cdot \text{s}) 
3 \text{ m}^3 = \frac{1473 \text{ W}}{745.7}
\]

\[
hp = ? \quad 1 \text{ hp} = 745.7 \text{ W}
\]
How many hp would you need for a flocculation basin to provide a $G=100 \text{ s}^{-1}$ Gt value of 100,000 for a 10 mgd flow (1 mgd = 0.0438 m$^3$/s); $10 \text{ mgd} \times 0.0438 \text{ m}^3/\text{s} = 0.438 \text{ m}^3$, $\mu = 0.89 \times 10^{-3} \text{ Pa} \cdot \text{s}$; 1 hp = 745.7 Watts

$$V = \frac{Q \cdot t}{G} = \frac{100,000}{100} = 1000 \text{ s}$$

$$V = 0.438 \text{ m}^3 \times 1000 \text{ s} = 438 \text{ m}^3$$

$$P = G^2 \mu V = 100^2 (0.89 \times 10^{-3} \text{ Pa} \cdot \text{s}) 438 \text{ m}^3 = \frac{3898 \text{ W}}{745.7 \text{ W/ho}} = 5.22 \text{ hp}$$
Settling/Sedimentation

\[ p = \frac{100 \cdot v_s}{v_o} \]

\[ v_s = \text{settling velocity} \]

\[ v_o = \text{overflow rate} \]

will remove all particles with \( v_{cs} \geq v_o \)
$Q = 0.25 \text{ m}^3/\text{s}$  \hspace{1cm}  $A = 1270 \text{ m}^2$

Overflow rate $v_o = \frac{Q}{A} = \frac{0.25 \text{ m}^3/\text{s}}{1270 \text{ m}^2} = \frac{17 \text{ m}^3}{\text{m}^2 \cdot \text{d}} = 0.2 \text{ mm/s}$

- If settling velocity: $0.2 \text{ mm/s}$  \hspace{1cm}  $p = 100 \frac{v_s}{v_o} = 100 \%$ removed
- If settling velocity: $0.1 \text{ mm/s}$  \hspace{1cm}  $p = 100 \frac{0.1}{0.2} = 50 \%$ removal

Type II settling - flocculant
Stokes Equation

\[ v_s = \frac{g(\rho_s - \rho)}{18\mu} \]

- \( v_s \): Settling velocity, \( \text{m/s} \)
- \( g \): Acceleration due to gravity, \( 9.81 \text{ m/s}^2 \)
- \( \rho_s, \rho \): Density of particle, water, \( \text{kg/m}^3 \)
- \( d \): Diameter of sphere, \( \text{m} \)
- \( \mu \): Dynamic viscosity, \( \text{Pa}\cdot\text{s} \)
Example: Alum floc

what overflow rate do we need to achieve 100% removal of alum floc

\[ \dot{V}_o = \dot{V}_s \]

\[ \rho_s = 1200 \text{ kg/m}^3 \]
\[ d = 46 \mu = 46 \times 10^{-6} \text{ m} \]
\[ T = 20^\circ \text{C} \]
\[ \rho = 998.2 \times 10^3 \text{ kg/m}^3 \] Table A-1 in Appendix
\[ \mu = 1.002 \times 10^{-3} \text{ Pa.s} \]

\[ \dot{V}_s = \frac{9.81 \text{ m/s}^2 \left(1200 - 998.2\right)(46 \times 10^{-6})^2}{18 \left(1.002 \times 10^{-3} \text{ Pa.s}\right)} = 2.3 \times 10^{-4} \text{ m/s} \]

\[ \dot{V}_s \times \frac{1}{60} \times \frac{1}{60} \times \frac{1}{24} = \frac{20}{m^3} \]
Groundwater Treatment Plant
Treatment of Groundwater for **Hardness** Removal

**Aeration**
- Hard Water $\text{Ca}^{+2} + \text{Mg}^{+2}$
- Bore Hole Well
- add D. O. to remove $\text{CO}_2$ and $\text{H}_2\text{S}$
  - $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$

**Rapid Mix**
- add lime (for CH)
- raise pH to 10 - 11.5 to precip. hardness

**Slow Mix**
- add $\text{CO}_2$ to decrease pH

**Sedimentation**
- weir overflow rate: 268-322 $\text{m}^3/\text{m} \cdot \text{d}$
- surface overflow rate: 57-70 $\text{m}^3/\text{m}^2 \cdot \text{d}$
- 105-130 $\text{m}^3/\text{m}^2 \cdot \text{d}$ for upflow solids contact

**Filtration**
- E.S. = 0.35 - 0.55 mm
- U.C. = 1.3 - 1.7
- depth = 0.3 - 0.75
- loading rate = 120 - 240 $\text{m}^3/\text{m}^2 \cdot \text{d}$

**Clearwell**
- add $\text{Cl}_2$, polyphosphate and F-

**Cytation**
- Type                        $G(s^{-1})$    $G_{t_o}$
  Softening (10%)      130-200    200,000-250,000
  Softening (39%)       150-300    390,000-400,000

G values for Rapid Mix: 700-1000 $s^{-1}$
In-Line blender: 3000-5000 $s^{-1}$

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Surface Water Treatment Plant
Surface Water Treatment for Turbidity and Color Removal

Intake and Pump Station

Bacteria, Color, Turbidity

Stream

Intake and Pump Station

Bacteria, Color, Turbidity

Stream

Rapid Mix

Slow Mix

Sedimentation

weir overflow rate: surface O. R.:

143-179 m³/m²·d light floc 20 - 40 m³/m²·d

179-268 m³/m²·d heavy floc 50,000 - 80,000 m³/m²·d

G: 700-1000 s⁻¹

t: 30-60s

flocculation basin

sedimentation basin

alum or iron salts for coagulation

G values for Rapid Mix: 700-1000 s⁻¹
In-Line blender: 3000-5000 s⁻¹

Gt₀ values for Flocculation

<table>
<thead>
<tr>
<th>Type</th>
<th>G(s⁻¹)</th>
<th>Gt₀</th>
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<tbody>
<tr>
<td>Low turbidity</td>
<td>20-70</td>
<td>60,000-200,000</td>
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<tr>
<td>High turbidity</td>
<td>30-80</td>
<td>36,000-96,000</td>
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Filtration

E.S. = 0.35 - 0.55 mm
U.C. = 1.3 - 1.7
depth = 0.3 - 0.75
loading rate = 120 - 240 m³/m²·d

Clear-well

to distribution

add Cl₂, polyphosphate, and F⁻ lime for pH

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