Ops Cert: Chlorine Dosage, Breakpoint Chlorination, and Disinfection Math

Thursday, April 13, 2023
A.J. Barney

SOUTHWEST ENVIRONMENTAL FINANCE CENTER

This program is made possible under a cooperative agreement with US EPA.

www.efcnetwork.org

Email: ajbarney1@unm.edu

Operator Certification

- Certification programs are regulated by the states
  - Texas- TCEQ, New Mexico- NMED, Oklahoma- ODEQ
- Certification levels (1-4, D-A, etc.)
  - Complexity of the system
  - Population
  - Experience
- Available resources
  - California State University, Sacramento- Wastewater operation manuals
  - State distributed resources and need to know lists
- Certification exam- Study!!

Overview

- Important math terms
- Chlorine disinfection
  - Chlorine chemistry
  - Chlorine dosage
  - Chlorine loading
  - Breakpoint chlorination
- Ozone math
- UV math
  - Exposure

Important Math Terms

$$\frac{mg}{L} = milligrams\ per\ liter = 1\ ppm$$

$$MGD = million\ gallons\ per\ day = \frac{10^6 gal}{day}$$

$$1\% = 10{,}000\ mg/L$$

What is Chlorine Disinfection?

Chlorine disinfection is the destruction of all pathogenic microorganisms using chlorine gas, powder, or liquid bleach.

The goal of disinfection is to remove all disease causing pathogens before effluent is discharged into receiving waters

- Prevents the spread of disease by protecting public water supplies, irrigation, receiving waters for recreational uses and shellfish growing areas

Sterilization- is the destruction of all microorganisms, but is impractical

Chlorine Chemistry

Chlorine is applied to wastewater as free chlorine (Cl_2), hypochlorite (OCl^-), or chlorine dioxide (ClO_2).

$$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^-$$

$$2NaOCl + 2H_2O \rightarrow 2NaOH + HOCl + OCl^- + H^+$$

$$2ClO_2 + H_2O \rightarrow ClO_3^- + ClO_2^- + 2H^+$$

Chlorine Chemistry

Liquid bleach (sodium hypochlorite) can be generated onsite. Brine is created by combining water and salt and ran through an electric cell.

$$NaCl + H_2O + 2e \leftrightarrow NaOCl + H_2$$

Chlorine Chemistry

Chloramines are weaker disinfectants than hypochlorous acid, but are much longer lasting and form readily in the process of ammonia.

Monochloramines	$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$
Dichloramines	$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$
Trichloramines	$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$

Chlorine Requirements

- Chlorine Dosage- Amount of Chlorine added to water. Calculated by dividing the chlorine feed by the flow or volume
- Chlorine Demand- Amount of Chlorine required to act with all reactive substances in the flow
- Chlorine residual- Remaining Chlorine in the water after demand has been satisfiied

Chlorine Requirements

1) Chlorine Dosage = Chlorine Demand + Chlorine Residual

2) Residual = Dosage – Demand

Residual composed of free Chlorine and combined Chlorine

- Free Chlorine- unreacted Chlorine reacts with H2O to form hypochlorous and hydrochloric acid
- Combined Chlorine- In the presence of ammonia, hypochlorous acid forms chloramines

Dosage Practice Problems

$$Chlorine\ Dosage\ =\ Chlorine\ Demand\ +\ Chlorine\ Residual$$

Determine the chlorine demand of a treated wastewater effluent if the chlorine dosage used for disinfection is 8 mg/L and the measured chlorine residual is 1.3 mg/L.

Solution Strength

HTH = 3-12% available chlorine

Liquid bleach = 65-70% available Chlorine

$$Solution\ Strength(\%) = Solution\ Strength\ (decimal)\times 100\%$$

$$Solution\ Strength(decimal) = \frac{Solution\ Strength\ (\%)}{100\%}$$

Solution Strength

$$Solution\ Strength(decimal) = \frac{Solution\ Strength\ (\%)}{100\%}$$

Your wastewater treatment plant uses a 4% solution to disinfect treated wastewater. What is the strength of the solution expressed as a decimal?

Solution Strength

$$Solution\ Strength(decimal) = \frac{Solution\ Strength\ (\%)}{100\%}$$

Givens:

Solution Strength = 4%

Solution Strength

$$Solution\ Strength(decimal) = \frac{Solution\ Strength\ (\%)}{100\%}$$

Set up the equation:

$$Solution\ Strength(decimal) = \frac{4\%}{100\%}$$

Solution Strength

$$Solution\ Strength(decimal) = \frac{Solution\ Strength\ (\%)}{100\%}$$

Solve:

$$Solution\ Strength(decimal) = \frac{4\%}{100\%} = .04$$

Practice Problem

$$Solution\ Strength(decimal) = \frac{Solution\ Strength\ (\%)}{100\%}$$

Your wastewater treatment plant has decided to increase the strength of their chlorine solution to 8.5% to reduce the energy required for disinfection treatment. What is the strength of this solution expressed as a decimal?

Chlorine Dosage

$$Chlorine\ Dosage\ \left(\frac{mg}{L}\right) = \frac{Chlorine\ Feed\ (\frac{lbs}{day})}{Flow\ (MGD) \times 8.34\,\frac{lbs}{gallon}}$$

$$Chlorine\ Dosage\ \left(\frac{mg}{L}\right) = \frac{Chlorine\ Feed\ \left(\frac{lbs}{day}\right) \times Cl\ solution\ strenth}{Flow\ (MGD) \times 8.34\,\frac{lbs}{gallon}}$$

Chlorine Dosage Practice Problem

$$Chlorine\ Dosage\ \left(\frac{mg}{L}\right) = \frac{Chlorine\ Feed\ \left(\frac{lbs}{day}\right) \times Cl\ solution\ strenth}{Flow\ (MGD) \times 8.34\,\frac{lbs}{gallon}}$$

A chlorinator is set to feed 417 lbs/day of 12% chlorine bleach to treat a flow of 2 MGD. What will be the resulting chlorine dosage in mg/L?

Chlorine Dosage Practice Problem

A chlorinator is set to feed 417 lbs/day of 12% chlorine bleach to treat a flow of 2 MGD. What will be the resulting chlorine dosage in mg/L?

Givens:

Chlorine Feed = 417 lbs/day

Cl Solution Strength = 12%

Flow = 2 MGD

Chlorine Dosage Practice Problem

$$Chlorine\ Dosage\ \left(\frac{mg}{L}\right) = \frac{Chlorine\ Feed\ \left(\frac{lbs}{day}\right) \times Cl\ solution\ strenth}{Flow\ (MGD) \times 8.34\,\frac{lbs}{gallon}}$$

$$Solution\ Strength(decimal) = \frac{Solution\ Strength\ (\%)}{100\%}$$

Set up the equation:

$$Chlorine\ Dosage\ \left(\frac{mg}{L}\right) = \frac{417\ \frac{lbs}{day} \times .12}{2\,\frac{million\ gallons}{day} \times 8.34\,\frac{lbs}{gallon}}$$

Chlorine Dosage Practice Problem

$$Chlorine\ Dosage\ \left(\frac{mg}{L}\right) = \frac{Chlorine\ Feed\ \left(\frac{lbs}{day}\right) \times Cl\ solution\ strenth}{Flow\ (MGD) \times 8.34\,\frac{lbs}{gallon}}$$

Solve:

$$Chlorine\ Dosage\ \left(\frac{mg}{L}\right) = \frac{417\ \frac{\cancel{lbs}}{\cancel{day}} \times .12}{2\,\frac{million\ \cancel{gallons}}{\cancel{day}} \times 8.34\,\frac{\cancel{lbs}}{\cancel{gallon}}} = 3ppm = 3\,\frac{mg}{L}$$

Chlorine Dosage Practice Problem

A change in operations requires the minimum chlorine dosage to be increased to 3.5 mg/L. Plant management has decided to increase the feed rate from 417 lbs/day to 500 lbs/day. Will this increase allow the plant to meet the minimum dosing requirement?

Previous givens: Strength = 12% Flow = 2 MGD

$$Chlorine\ Dosage\ \left(\frac{mg}{L}\right) = \frac{Chlorine\ Feed\ \left(\frac{lbs}{day}\right) \times Cl\ solution\ strenth}{Flow\ (MGD) \times 8.34\,\frac{lbs}{gallon}}$$

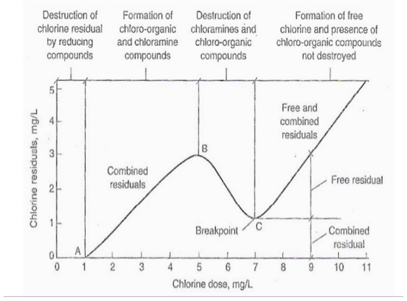
$$Solution\ Strength(decimal) = \frac{Solution\ Strength\ (\%)}{100\%}$$

Chlorine Loading/ Feed Rate

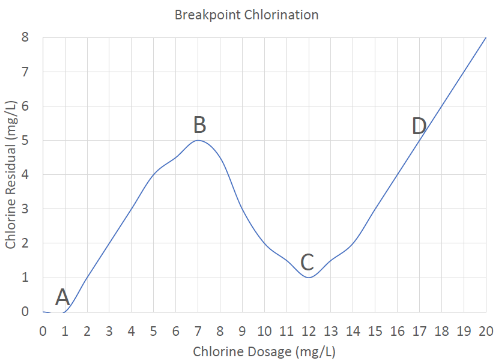
$$Chlorine\ Feed\left(\frac{lbs}{day}\right) = Chlorine\ Dosage\left(\frac{mg}{L}\right)\times Flow\ (MGD)\times 8.34\frac{lbs}{gallon}$$

$$Chlorine\ Feed\left(\frac{lbs}{day}\right) = Chlorine\ Dosage\left(\frac{mg}{L}\right)\times Flow\ (MGD)\times 8.34\frac{lbs}{gallon}\times Cl\ solution\ strength$$

Breakpoint Chlorination



Breakpoint Chlorination Practice Problems



At what point is the combined residual the highest?

What is the approximate Free chlorine residual at point D?

Dechlorination

- Sulfur dioxide (SO_2) is used to dechlorinate treated wastewater
- SO_2 has a similar molecular weight to Cl_2 and can be used at almost a 1 to 1 ratio for dichlorination
- A safety factor of 3 mg/L is often initially used for a sulfonator setting when sulfur dosing is used for dechlorination

Sulfur Loading/ Feed Rate Practice

$$Sulfur\ Feed\ Rate\left(\frac{lbs}{day}\right) = (Chlorine\ Residual + Safety\ Factor)\left(\frac{mg}{L}\right)\times Flow\ (MGD)\times 8.34\frac{lbs}{gallon}$$

A wastewater treatment plant with a 2 MGD flow has an average chlorine residual of 4.5 mg/L after disinfection treatment. What is the sulfur feed rate required to properly dechlorinate the wastewater, if a safety factor of 3 mg/L is desired?

Sulfur Sample Problem

A wastewater treatment plant with a 2 MGD flow has an average chlorine residual of 4.5 mg/L after disinfection treatment. What is the sulfur feed rate to properly dechlorinate the wastewater, if a safety factor of 3 mg/L is desired?

Givens:

Chlorine Dosage = 4.5 mg/L

Safety Facto r= 3 mg/L

Flow = 2 MGD

Sulfur Sample Problem

$$Sulfur\ Feed\ Rate\left(\frac{lbs}{day}\right) = (Chlorine\ Residual + Safety\ Factor)\left(\frac{mg}{L}\right)\times Flow\ (MGD)\times 8.34\frac{lbs}{gallon}$$

Set up:

$$Sulfur\ Feed\ Rate\left(\frac{lbs}{day}\right) = (4.5+3)\left(\frac{mg}{L}\right)\times 2\ (MGD)\times 8.34\frac{lbs}{gal}$$

$$= (7.5)\left(\frac{mg}{L}\right)\times 2\ \frac{MG}{day}\times 8.34\frac{lbs}{gal}$$

Sulfur Sample Problem

Solve:

$$Sulfur\ Feed\ Rate\left(\frac{lbs}{day}\right) = (7.5)\left(\frac{mg}{L}\right)\times 2\ \frac{M\ \cancel{gal}}{day}\times 8.34\frac{lbs}{\cancel{gal}}$$

$$Sulfur\ Feed\ Rate\left(\frac{lbs}{day}\right) = (7.5)\ \cancel{(ppm)}\times 2\ \frac{\cancel{M\ gal}}{day}\times 8.34\frac{lbs}{\cancel{gal}}$$

$$= 125\ \frac{lbs}{day}$$

Sulfur Practice Problem

$$Sulfur\ Feed\ Rate\left(\frac{lbs}{day}\right) = (Chlorine\ Residual + Safety\ Factor)\left(\frac{mg}{L}\right)\times Flow\ (MGD)\times 8.34\frac{lbs}{gallon}$$

Another wastewater treatment plant with a 3 MGD flow and an average chlorine residual of 2 mg/L has been operating with a safety factor of 1 mg/L. What is the required sulfur feed rate need for the desired dechlorination?

Ozone (O_3) Disinfection

Ozone is a powerful oxidizing agent and destroys virus more effectively than chlorine.

Typical ozone math examples:

- Calculating the ozone demand
- Dosage

$$Ozone\ Dose\left(\frac{mg}{L}\right) = \frac{gas\ flowrate\left(\frac{L}{min}\right)}{liquid\ flowrate\left(\frac{L}{min}\right)}\times\left(Conc.of\,O_3\ in\ feed\ gas\left(\frac{mg}{L}\right) - Conc.of\,O_3\ in\ off-gas\left(\frac{mg}{L}\right)\right)$$

Ultraviolet (UV) Disinfection

UV lamps produce UV radiation with a wavelength = 254 nm

$$UV\ Dosage\left(\frac{mJ}{cm^2}\right) = UV\ Intensity\left(\frac{mW}{cm^2}\right)\times Retention\ Time\ (s)$$

$$UV\ Channel\ Volume\ perBank(ft^3) = Width\ (ft)\times Water\ Depth\ (ft)\times Lamp\ Arc\ Length\ (ft)$$

$$Retention\ Time\ \text{per Bank (s)} = \frac{\text{Channel Volume }(ft^3)}{Flow\ Rate\ (\frac{ft^3}{s})}$$

Final Poll Problems

A wastewater treatment plant with a flow of 15 MGD has determined that their disinfection process has a chlorine demand of 4.3 mg/L. Their NPDES permit requires that they maintain a chlorine residual of 1.5 mg/L. What must the minimum solution strength of their chlorine solution (as a percentage) be if the maximum feed rate of their equipment is 475?

What is the most likely form of chlorine that the WWTP will use?

CONTACT INFORMATION

SOUTHWEST
ENVIRONMENTAL
FINANCE CENTER

A.J. Barney: ajbarney1@unm.edu
James Markham: jmarkham@unm.edu

Department of Civil Engineering MSC01 1070
1 University of New Mexico
Albuquerque, NM 87131
505-277-0644
swefc@unm.edu
http://swefc.unm.edu