Drinking Water Plant
Operator Certification Training
Instructor Guide

Display Slide 1 (cover of Mod 25 workbook)

Module 25:
Hypochlorite

Revised December 2013

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:

The Pennsylvania State Association of Township Supervisors (PSATS)
Gannett Fleming, Inc.
Dering Consulting Group
Penn State Harrisburg Environmental Training Center

Module 25 Instructor Guide Notes

TIME: 7 contact hours, plus 2 breaks and lunch = 9 hour day or 2 half-day sessions

METHODS:

- Lecture
- Full group discussion/Q&A
- Unit exercises

MATERIALS:

- PowerPoint slides for Module 25
- Flipchart stand or whiteboard (preferred) to perform math calculations
- Associated blank overhead sheets/markers or flipchart paper and markers or whiteboard/markers to perform math calculations
- Student Workbook – Module 25
- Basic Math Principles Job Aid
- Calculators

Notes to Instructors:

Please focus the instruction on the information highlighted in the instructor guide. You should get to the point in which you have practiced it so much you are not reading the instructor guide, but using it as notes for yourself.

Please see the course agenda for additional details, including what can be given for homework between sessions.

This module was substantially revised in 2013 to include:

- New math principles and process calculations unit 3
- Basic Math Job Aid (sample of each calculation)
- Expanded unit exercises and answer slides for all unit exercise questions
- Additional math practice problems in the Appendix and answer key
- 50 module review questions at the end of the Powerpoint presentation

Topical Outline

Unit 1 – Background and Properties

I. Basic Information

- A. History of Use
- B. Uses
- C. Hypochlorite Production
- D. AWWA Standard Product Specification

II. Properties

- A. Chemistry
- B. Concentration of Available Free Chlorine
- C. Stability
- D. Vapor Pressure

Unit 2 – Chemical Handling, Storage and Safety

I. Storage and Handling

- A. Product Deliveries and Storage
- B. Storage Vessels
- C. Product Dilution
- D. Storage Rooms

II. Safety

- A. Material Safety Data Sheets
- B. Safety Equipment
- C. Spill Handling
- D. OSHA Requirements

II. Unit 3 – Math Principles and Process Calculations

I. Math terms, principles and rules for solving equations

II. Unit Cancellation Steps

III. Calculations

- A. Calculation changing % concentrations of a chemical
- B. Dosage/Feed rate/Flow
- C. Chlorine Demand or Dose
- D. CT

Unit 4 – Chemical Feed

I. Feed Points and Purpose
   - A. Regulatory Requirements
   - B. Chlorination Mechanics and Terminology
   - C. Breakpoint Chlorination

II. Hypochlorite Feed Equipment, Operation and Maintenance
   - A. Sodium Hypochlorite
   - B. Hypochlorite Feed Equipment
   - C. Calcium Hypochlorite
   - D. On-Site Generated Sodium Hypochlorite
   - E. Hypochlorite Feed System Operation

III. Calcium Hypochlorite
   - A. Chemical Feed Equipment
   - B. Chemical Strength, Pumping and Dilution
   - C. Maintenance

IV. On-Site Generated Sodium Hypochlorite
   - A. Chemistry
   - B. System Components
   - C. Chemical Strength, Pumping and Dilution

V. Chemical Feed Control and Monitoring
   - A. Chlorine Residual Monitoring
   - B. Storage Monitoring
   - C. Chemical Feed Control

Appendix

MSDS for sodium hypochlorite

Additional Hypochlorite Practice Math Problems

Display Slide 2 (Unit 1 objectives)

Unit 1 – Background and Properties

Learning Objectives

- Outline the history of hypochlorite use.
- List the uses of hypochlorite.
- Explain how hypochlorite is produced.
- List and explain six properties of hypochlorite.

Turn to page 1-2 and we'll review the uses of hypochlorites.

Display Slide 3

History of Use

- During the early history of water chlorination, the only sources of chlorine were dry chlorine-containing compounds and sodium hypochlorite bleach solutions. Initially, the following problems occurred:
  - The poor stability and variable effective chlorine content resulted in operating difficulties.
  - Feeder equipment was crude, therefore, yielding erratic results.
- In 1909, liquid chlorine became commercially available and the use of hypochlorite for water chlorination gradually decreased in popularity.
- In 1928, the commercial availability of calcium hypochlorite resulted in renewed use.

Advance Slide 3

Uses

Hypochlorite refers to the various salts of hypochlorous acid commonly used in water treatment for disinfection, oxidation, and taste and odor control. This term is commonly used interchangeably to refer to the liquid form, sodium hypochlorite, and the solid form, calcium hypochlorite.

Disinfection

- Chlorine compounds are added to water to destroy or inactivate disease-producing (pathogenic) organisms.
- Disinfection differs from sterilization, which is the destruction of all living organisms.

Oxidation

- Hypochlorites are commonly used to oxidize iron, manganese, organic matter, cyanide, and sulfide for subsequent removal.

Taste and Odor Control

- Removal (oxidization) of chemicals and organic matter helps to control tastes and odors in the treated water supply.

Q. Are any of you using chlorine to oxidize? If so, what are you attempting to remove?

Display Slide 4

Hypochlorite Production

Manufactured Products

- There are two types of hypochlorites that are manufactured: liquid sodium hypochlorite and granular calcium hypochlorite. These will be discussed in more detail later in this unit.

Advance Slide 4

On-Site Generation

- Hypochlorites can be generated on-site. This will be discussed in greater detail in Unit 4 of this module.

Q. Are any of you that already work at systems generating hypochlorites on site?

Advance Slide 4

AWWA Standard Product Specification

The American Water Works Association (AWWA) has established Standard ANSI / AWWA B300-99, covering the hypochlorite chemicals for use in the treatment of water supplies. The standard provides the minimum requirements for hypochlorites, including physical, chemical, packaging, shipping and testing requirements. Plant operators should verify that the chemicals used comply with this standard.

Turn to page 1-4 and we'll look at the chemical reactions that happen at pH levels.

Chemistry

Display Slide 5

- When chlorine is dissolved in water it forms hypochlorous acid.
- Hypochlorus acid (HOCl) dissociates into hydrogen (H^+) and hypochlorite (OCl^-) ions.
  - The reaction is almost instantaneous.
  - The reaction is dependent on temperature and pH.
  - The reaction is reversible:

$$HOCl \leftrightarrow H^+ + OCl^-$$

- Together, the hypochlorus acid and hypochlorite ions are considered the "Free Chlorine" available for disinfection. This free chlorine is the most effective disinfectant form of chlorine. We'll discuss this more in Unit 4.
- Hypochlorous acid (HOCl) is a more effective disinfectant than hypochlorite, so the reaction should be kept in favor of the left side of the equation. This is dependent on pH and temperature.

Display Slide 6 (Figure 25.1 on next page)

- Let's look at how the reaction is dependent on pH first.
  - At pH below 6, hypochlorous acid is weak and dissociates poorly.
  - Between pH 6 and 8.5, a sharp change from undissociated HOCl to almost complete dissociation occurs.
  - pH higher than 8.5 hypochlorite predominates, which is not as effective of a disinfectant.
- The normal pH of water supplies is within the range where both hypochlorous acid and hypochlorite ion exist as indicated in figure 25.1.
  - Solutions of hypochlorites contain excess alkali, which tends to increase pH.

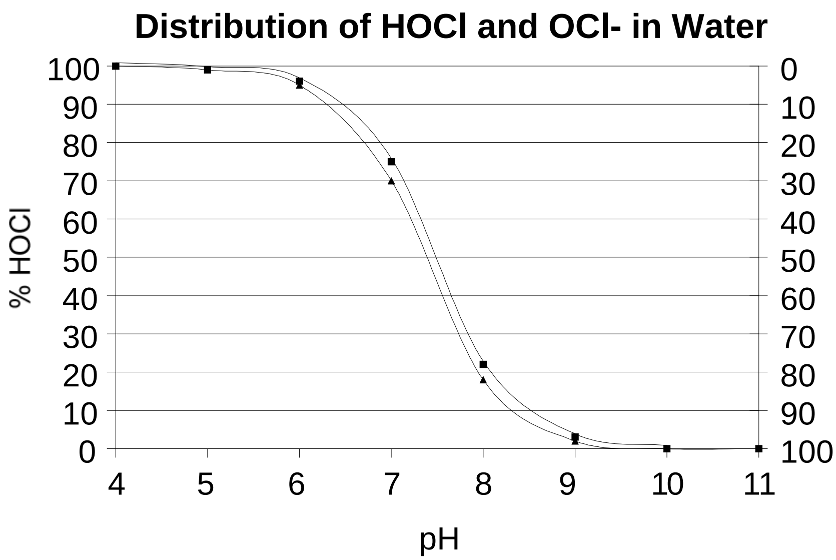


Figure 25.1 The Distribution of HOCl and OCl^- in Water

Display Slide 7 (Figure 25.2)

Q. What happens to the effectiveness of chlorine as the pH increases?
A. It decreases

Figure 25.3 shows how the effectiveness of chlorine **decreases** as the pH **increases**.

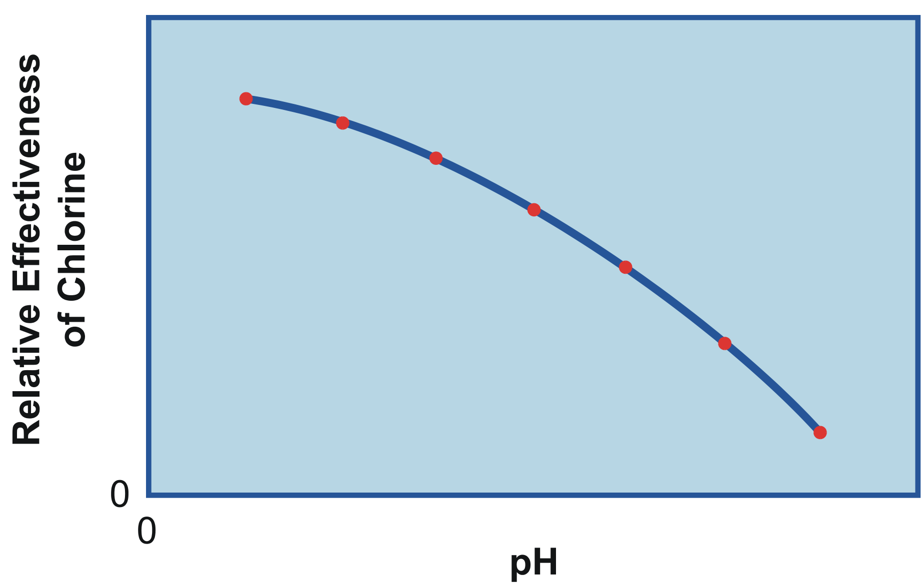


Figure 25.3 The Relationship Between pH and Disinfection When Using Chlorine.

Display Slide 8 (Figure 25.3)

The effectiveness of chlorine is also effected by temperature.

Figure 25.2 shows how the effectiveness of chlorine **increases** as temperature **increases**.

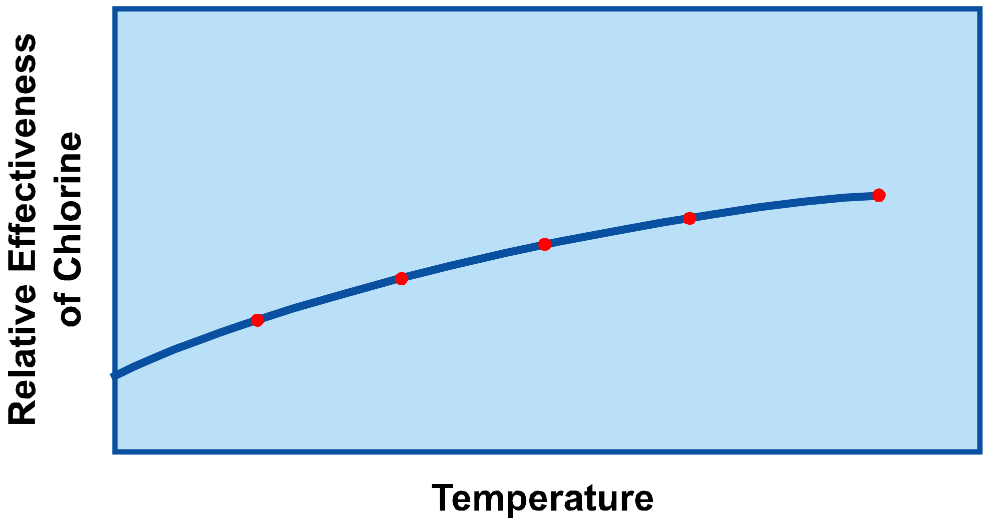


Figure 25.2 The Relationship Between Temperature and Disinfection When Using Chlorine.

Display Slide 9

Instructor Note: Ask these questions as a full group.
Let's do a quick knowledge check. Try to answer these without looking at the workbook.

- As pH increases, what happens to the effectiveness of chlorine?
  - Answer: Decreases
- As temperature increases what happens to the effectiveness of chlorine?
  - Answer: Increases

Turn to page 1-6 and we'll identify a few properties for sodium hypochlorite and calcium hypochlorite.

Display Slide 10

Sodium Hypochlorite

- Sodium hypochlorite is a clear, light yellow-green liquid and is supplied in various strengths.
  - Common household laundry bleach is 5.25% available chlorine by weight.

- Commercial strength used for water disinfection is 12 – 15% available chlorine by weight.

- It is strongly alkaline and corrosive.
- Sodium hypochlorite has a strong chlorine odor.
- The chemical formula for sodium hypochlorite is NaOCl.
- *There are properties listed in your workbook that you can review later:* The properties of sodium hypochlorite are:
  - Boiling point: 110° C (230° F)
  - Specific Gravity: 1.19 (Specific Gravity of Water = 1.0)
  - pH: 9.0 to 12.0
    - Reaction in water:

$$NaOCl + H2O \rightarrow Na^{+} + OCL^{-} + H2O$$

Advance Slide 10

On-Site Generated Liquid Sodium Hypochlorite

A weak solution of liquid sodium hypochlorite can be generated on site.

- An electrical charge is applied to a salt brine solution to generate a weak sodium hypochlorite solution. This reaction produces hydrogen gas, which dissipates into the atmosphere.

$$NaCl + H2O \rightarrow NaOCl + H2$$

Instructor Note: The following is provided in the workbook for reference and does not need to be reviewed:

- Instructor Note: The following requirements must be met to generate hypochlorite on-site:
  - Power: 2.5 KWH/lb Cl
  - Salt: 3 lb/lb Cl
  - Water: 15 gal/lb Cl, softened to less than 17 mg/L total hardness
- The properties of on-site generated hypochlorite are:
  - 0.7 to 0.9% available chlorine
  - Solution pH: 9.1 to 9.3

Advance Slide 10

Calcium Hypochlorite - $Ca(OCl)_2$

- Calcium Hypochlorite has 65 to 70% available chlorine.
  - This means that every 100 pounds of $Ca(OCl)_2$ contains 65 – 70 pounds of available chlorine.
  - It is readily soluble in either warm or cold water.
  - Very strong (concentrated) solutions can be prepared. Usually a solution containing 1 to 3 % of available chlorine is prepared. 125 pounds per 1000 gallons of water makes a 1% solution.
- Calcium hypochlorite is a white free-flowing granular powder or solid cake.
  - Its common name is high test hypochlorite (HTH), which is commonly used for swimming pool chlorination.
  - It is stable and can be stored for long periods of time with only a small loss of strength.

Instructor Note: The following is provided in the workbook for reference and does not need to be reviewed

- It is readily soluble in either warm or cold water.
  - Very concentrated solutions can be prepared.
  - Solutions are strongly alkaline and corrosive.
- Calcium hypochlorite has a strong chlorine odor.
- The properties of calcium hypochlorite are as follows:
  - Specific Gravity: 2.35 at 20° C (S.G. of Water = 1.0)
  - pH: 11.5 (5% solution)
- Reaction in water:

$$Ca(OCl)_2 + 2\,H_2O \rightarrow 2\,HOCl + Ca(OH)_2$$

Turn to page 1-8 and we'll discuss stability and vapor pressure considerations.

Stability

Display Slide 11 (Stability)

Liquid Sodium Hypochlorite

- The stability of hypochlorite solutions is greatly affected by concentration, heat, light, storage time, and the presence of heavy metals. Let's look briefly at some of these.
  - The higher the concentration, the faster the rate of deterioration.
  - The most stable solutions are of low concentration. On-site generated solution at 1% is more stable than bulk purchased solution at 12%.
  - The higher the temperature, the faster the rate of deterioration.

Table 25.1 The Effects of Temperature of Various Concentrations

Percent Available Chlorine	Half-life (days)		
	140 ºF	77 ºF	59 ºF
10.0	3.5	220	800
5.0	13.0	790	5000
2.5	28.0	1800	--
0.5	100.0	6000	--

- To maintain a somewhat constant solution concentration, quantities should be used within 30 days and stored at 60 to 70 ºF.
- Solutions exposed to light deteriorate faster than those kept in darkness. The half-life of 10 to 15 percent solution will be reduced about 3 or 4 times when exposed to light.
- The presence of iron, copper, nickel, or cobalt catalyzes the rate of deterioration; therefore, piping systems should be plastic or other non-metallic material to prevent active corrosion of iron, copper or brass materials.
- In summary: The most stable hypochlorite solutions are those with low hypochlorite concentration, a pH of 11 and low iron, copper, or nickel content, stored in the dark at low temperature.

Display Slide 12

Calcium Hypochlorite

- Dry material is relatively stable under normal atmospheric conditions and will lose 3 to 5 percent available chlorine per year.
    - Reduce deterioration by maintaining a 30 to 60 day stock supply of dry material and mixing fresh solution daily.
- Decomposition is exothermic, meaning it gives off heat. Decomposition proceeds rapidly if heated to 350º F.
    - Many fires of spontaneous origin have been caused by improperly stored calcium hypochlorite.
- Never store calcium hypochlorite where it may be subject to heat or allowed to contact organic material.
    - Calcium hypochlorite releases chlorine fumes when exposed to heat. It may build up pressure in sealed storage containers if containers are exposed to sunlight or other heat sources.
- It should be stored in cool, dry places, isolated from other chemicals since moisture contributes to its deterioration and spontaneous reactions may occur with organic materials and other oxidizable materials.

Q. Has anyone ever had any negative experiences with calcium hypochlorite?

Advance Slide 12

Vapor Pressure

- All hypochlorite solutions, whether purchased liquid sodium hypochlorite or plant prepared solutions of calcium hypochlorite, will release oxygen gas as the solution decomposes.
- Provisions must be included in the chemical feed system to vent this gas to prevent air binding of the feed lines.
- Care must be taken to prevent trapping the solution between two closed valves since the build up of pressure may rupture the piping system.

Display Slide 12 (Review Unit 1 key points on page 1-10)

Instructor Note: Each unit has a slide to direct participants to turn to the Key Points page. Review each key point before proceeding to the Unit exercise.

Key points for Unit 1 – Background and Properties

- Chlorine compounds are added to water to destroy or inactivate pathogenic organisms.
- The disinfection effectiveness of liquid chlorine will increase with temperature and decrease with pH.
- Hypochlorites can be used to oxidize dissolved metals and to help control taste and odor problems.
- Hypochlorites are provided as liquid sodium hypochlorite or granular calcium hypochlorite.
- Sodium hypochlorite is a clear light yellow-green liquid with a chlorine odor.
- Sodium hypochlorite used for water disinfection is 12 – 15% available chlorine by weight. (12.5% solution strength is common).
- Concentration, heat, light, storage time, and the presence of dissolved heavy metals can affect the stability of hypochlorite solutions.
- Calcium hypochlorite is a white free-flowing granular powder or a solid cake.
- Calcium hypochlorite is readily soluble in either warm or cold water. However, if it is kept dry and cool, it can be stored for long periods of time.
- Calcium hypochlorite will lose 3 to 5 percent of available chlorine per year. A 30 to 60 day stock supply is often recommended to keep chlorine losses within acceptable limits.
- Calcium Hypochlorite has 65 to 70% available chlorine.

As a review of Unit 1, let's complete the questions on pages 1-10 and 1-11 and we'll review the answers on the following slides.

Display Slides 14-18 (to review Exercise answers)

Exercise for Unit 1 – Background and Properties

1. List and explain two uses of hypochlorite.

a.

b.

ANS: Answers may include disinfection, oxidation, and control of taste and odor.

2. Matching: Please match the chemical with the available chlorine by weight by drawing lines between the matches:

Chemical	Available Chlorine by Weight
Sodium hypochlorite	0.1 %
Household bleach	5.25%
Calcium hypochlorite	12 to 15%
	65 to 70%

3. Which of the following affect the stability of hypochlorite:

   a. Temperature
   b. Color
   c. Exposure to light
   d. How long it is stored

   Answer: a, c, and d.

4. Circle the choice that best fills in the blank:

   - The higher / lower the concentration of sodium hypochlorite, the more stable it is.
     - Answer = lower
   - Chlorine is less effective as the temperature decreases / increases .
     - Answer = decreases
   - Chlorine is less effective as the pH decreases / increases .
     - Answer = increases

5. Dry calcium hypochlorite will lose __3__ to __5__ percent available chlorine per year.

6. All hypochlorite solutions will release oxygen gas as the solution decomposes.

   a. True______ b. False______

Answer = True

Unit 2 – Chemical Handling, Storage and Safety

Display Slide 19 (Unit 2 Objectives)

Learning Objectives

- Explain proper handling and storage of hypochlorite
- Use the hypochlorite SDS sheet (formerly MSDS)
- Identify hypochlorite health and environmental hazards
- Identify personal protection equipment and first aid

Turn to page 2-2 and we'll begin our discussion on storage and handling facts.

Display Slide 20 (Storage and Handling)

Quantities

- Provide storage in separate rooms to avoid contact with organic material.
- Storage for a 30-day supply should be available.
- Sodium hypochlorite should not be stored longer than 45 days since its strength decomposes in storage.
- Store in a cool, dry atmosphere.

Types of Storage Containers

Sodium Hypochlorite

- Storage is available in 5, 15, 30 and 55 gallon drums.
- Bulk liquid should be stored in on-site bulk liquid storage tanks.

Calcium Hypochlorite

- Storage is available in 5, 15, 100, and 300 pound cans, and 415 and 800 pound barrels.
- It should be stored in shipping containers until it is used.
- After a container is opened, loss of chlorine will occur, particularly if exposed to moisture in the air.

Storage Rooms

Hypochlorite will spontaneously react with organic materials. As a result, it should be stored separate from all organic materials such as:

- Turpentine.
- Oils.

- Sugar.
- Fats.
- Paper Products
- Other oxidizable materials.

Temperature

- Maintain temperature of storage rooms between 60 and 70° F.

Ventilation

- Forced air ventilation should be provided.
- Operate fans when the room is occupied.

Light

- Prevent exposure to sunlight.

Materials of Construction

Hypochlorites are caustic; therefore, rubber, glass, PVC and other similar materials should be used when contact with hypochlorite solutions is necessary.

Containment

- Provide spill containment for bulk liquid storage facilities.
- Provide containment volume of 110% of the largest liquid vessel to be stored.

Turn to page 2-4 and we'll begin a discussion about how to handle hypochlorites safely.

Display Slide 21 (Safety)

Safety Data Sheets

A Safety Data Sheet, or SDS, is available from the chemical manufacturer/supplier for every chemical. For years, these sheets were commonly known as MSDS for Material Safety Data Sheet. However, the Occupational Safety and Health Administration (OSHA) Hazard Communication Standard of 2012 (HazCom 2012) mandates the use of a single format for safety data sheets featuring 16 sections. MSDS sheets can used by manufacturers until June 1, 2015, but many manufacturers are complying before this date.

You should read and understand the SDS for each chemical used in the plant. You should also maintain a personal copy for all hazardous chemicals that are used.

An SDS contains detailed assessments of chemical characteristics, hazards and other information relative to health, safety and the environment. The SDS includes:

- **Section 1, Identification**
- **Section 2, Hazard(s) identification**
- **Section 3, Composition/information on ingredients**
- **Section 4, First-aid measures**
- **Section 5, Fire-fighting measures**
- **Section 6, Accidental release measures**
- **Section 7, Handling and storage**
- **Section 8, Exposure controls/personal protection**
- **Section 9, Physical and chemical properties**
- **Section 10, Stability and reactivity**
- **Section 11, Toxicological information**
- **Section 12, Ecological information**
- **Section 13, Disposal considerations**
- **Section 14, Transport information**
- **Section 15, Regulatory information**
- **Section 16, Other information,** includes the date of preparation or last revision.

A sample SDS is located in the Appendix. Turn to page A-3 and we'll look at the health hazard information.

Display Slide 22 (Safety)

Hypochlorite Hazards

- Hypochlorite does not present the same hazards as gaseous chlorine, so it is safer to handle.
- All forms of chlorine can give off chlorine gas and fumes which could irritate one's respiratory system.
    - Chlorine gas is released when hypochlorite is exposed to high heat.
    - Chlorine fumes have a distinct chlorine smell, which can result in respiratory problems similar to those experienced with chlorine gas.
- Hypochlorite should be handled with clean, dry implements that are free of organic materials.

Spills

- Hypochlorite spills should be washed with large volumes of water to dilute it.

Health

- Hypochlorite can irritate both skin and eyes. It will cause discomfort and/or a rash.
- Immediately wash affected areas thoroughly with water, and flush eyes if hypochlorite has come into contact with them.

Environmental

- The effects of hypochlorite on animals are similar to the health effects it has on humans. It is toxic to aquatic life.

Turn to page 2-6 and we'll review the basic personnel safety protection equipment.

Advance Slide 22 (Safety)

Personnel Safety Protection

Basic Equipment

- Safety protection equipment for hypochlorite is similar to equipment used for other corrosive chemicals.
- Equipment must be used and maintained in strict accordance with manufacturers' recommendations and instructions.
- Protective clothing includes:
  - Eye protection.
  - Gloves.
  - Rubber aprons.
- Emergency showers and eye-wash stations should be provided.

Figure 2.1 An Emergency Shower

Figure 2.2 An Eye Wash Station

Q. Has anyone had any injuries with hypochlorite solutions? What were the injuries and what type of first aid did you provide?

Advance Slide 22 (Safety, Continued)

First Aid

Inhalation

- Remove the injured party and take person(s) to an uncontaminated outdoor area.
- Call for medical assistance.

Skin Contact

- Immediately shower with large quantities of water.
- Remove protective clothing and equipment while in the shower.
- Flush the skin with water for at least 5 minutes.
- Call for medical assistance.
- Keep the affected area cool.

Eye Contact

- Immediately shower with large quantities of water while holding eyes open.
- Call a physician immediately.
- Transfer person(s) promptly to a medical facility.

Ingestion

- Do not induce vomiting.
- Give large quantities of water.
- Call a physician immediately.
- Transfer person(s) promptly to a medical facility.

Display Slide 23 (Review Unit 2 key points on page 2-9)

Turn to page 2-9 and we'll review the key points for Unit 2.

Key points for Unit 2 – Chemical Handling, Storage and Safety.

- Temperature, ventilation, and light are important considerations when storing hypochlorite.
- Storage rooms should be kept separate and avoid contact with organic material.
- Storage for a 30 day supply is usually recommended.
- Don't store for more than 45 days since hypochlorite decomposes and loses potency.
- Hypochlorites are caustic. Use rubber, glass, PVC and other similar materials when storing hypochlorite.
- Provide spill containment for bulk liquid storage.
- Material Safety Data Sheets, or MSDS, should be readily available at the work site and reviewed by each worker.
- Hypochlorite should be handled with clean, dry implements that are free of organic materials.
- Since hypochlorites are corrosive to the skin, eyes, mouth and respiratory system, workers should be using appropriate protective clothing which includes eye protection, gloves, and rubber aprons. An emergency shower and an eye wash station should also be available.
- Each worker should thoroughly review and/or receive training in first aid procedures for hypochlorite accidents.

As a review of Unit 2, let's complete the questions on page 2-10 and we'll review the answers on the following slides.

Display Slides 24-28 (to review Unit 2 exercise answers)

Exercise for Unit 2 – Storage, Handling and Safety

1. Sodium hypochlorite should not be stored longer than ____45____ days since its strength decomposes in storage.
2. Calcium hypochlorite should be stored in its ___original___ containers until it is used.
3. Hypochlorites decompose and release ___chlorine gas___ into the air.
4. Forced air ventilation should be turned on whenever workers enter the hypochlorite storage or work area. a. True ___X____ b. False _________
5. MSDS is an abbreviation for Material Safety Data Sheet.
   a. Note: These are being changed to simply "Safety Data Sheets"
6. Typical information in a Safety Data Sheet includes:
   a. The product name and its synonyms.
   b. Fire and explosion hazard data.
   c. Toxicity data.
   d. First aid procedures.
   e. All of the above. This is the correct answer.
7. Hypochlorite spills should be washed with large amounts of ___water_____ to dilute it.
8. Hypochlorite will react spontaneously with organic material and should be kept separate from all organic compounds such as: fats, sugar, oils, turpentine, and other oxidizable materials.
   a. True __X___
   b. False ______
9. First aid procedures for skin contact with hypochlorite include showering with large quantities of __water____ and calling for medical assistance.
10. Hypochlorite should be stored so that it does not get direct exposure to answers could include water, heat, direct sunlight, and organic matter.

References

1 Further information about OSHA requirements can be obtained from:

www.osha.gov

or by phoning the

OSHA regional office in Philadelphia 215-861-4900

2 *Safety Practices for Water Utilities,* AWWA Manual of Water Supply Practices, M3, Sixth Edition, 2002.

Display Slides 29 and 30 (to review Unit 3 objectives)

Unit 3 – Math Principles and Process Control Calculations

Learning Objectives

- Describe math terms, principles and rules for solving equations.
- Review unit cancellation steps.
- Perform calculations for the following types of situations:
  - Calculating changing % concentrations of a chemical
  - Dosage/Feed Rate/Flow
  - Chlorine Demand or Dose
  - CT

Instructor Note: After listing the unit objectives and before reviewing the Unit 3 key points slide, there are only 2 slides that pertain to the math unit.

You will need blank overhead sheets, a white board, or flip chart paper to perform each type of math calculation within this unit.

When there are multiple steps, please show each step as a summary of the answer so that participants learn **how to perform the steps**, not just get the correct math answer.

When reviewing the Davidson Pie diagram for equations #2 and #3 on pages 3-27 and 3-29, use the Davidson Pie overhead and hide the flow segment of the pie for #2; then the dose segment for #3 to visually confirm the vertical format equation. More instructions are found on pages 3-27 and 3-29.

Before we introduce dosage calculations, let's start at the beginning with a review of math principles.

Turn to page 3-2.

Basic Math Principles for Solving Dosage Calculations

Here are some basic math terms and principles.

Fraction: A numerical expression containing a numerator and denominator that represents portions of a whole object. Fractions are used to represent ratios and represent division. For example, the fraction ¼ is used to represent the ratio 1:4 and 1 ÷ 4.

Parts of a Fraction

1. Numerator: The top number of a fraction that indicates how many parts are being considered.
2. Division Line: The line between the numerator and denominator that indicates that the numerator value is divided by the denominator value to convert a fraction into a decimal.

   Example: 1 ÷ 4 = 0.25 (as a decimal)
3. Denominator: The bottom number of a fraction that tells us how many equal parts into which the whole has been divided.

Fraction Written in Vertical Format:

$\frac{1}{4}$ (numerator) (denominator)

Class Activity

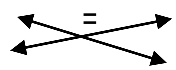
Write the following fractions in **vertical** format:

1/8 = $\frac{1}{8}$ (The numerator is: 1)

2/6 = $\frac{2}{6}$ (The denominator is: 6)

$\frac{8}{10}$ means that 8 is divided by 10

Rules for Solving for an Unknown Variable (such as *X*)
When solving for the unknown variable (*X*), there are 2 basic objectives: 1. *X* must be in the numerator, AND 2. *X* must be by itself (on one side of the equation).
To accomplish these objectives, **only diagonal movement of terms across the equal sign is permissible in multiplication and division problems.** $\frac{(5)}{(3)} = \frac{(3)}{(5)}$



Explanation of diagonal movement and an example.

An equation is a mathematical statement in which the terms or calculation on one side = the terms or calculation on the other side. To keep both sides equal, any multiplication or division done to one side, must be done to the other. This keeps the equation balanced.

Example 1:

5X = 20

Question #1 regarding Example #1: Is the *X* in the numerator? YES

Question #2 regarding Example #1: Is the *X* alone on one side of the equation? NO

How do we use diagonal movement to place *X* alone on one side of the equation?

Answer:

- Divide both sides by "5" to get *X* alone and **treat both sides of the equation equally**. Notice that the 5 was moved from the top of the left side to the bottom of the right side of the equation – a **diagonal move.**

$$\frac{\cancel{5}X}{\cancel{5}} = \frac{20}{5}$$

FINAL ANSWER: 20 ÷ 5 = 4

Turn to page 3-4 and we'll look at Example #2.

Example 2:

$$2.5 = \frac{1,000}{X}$$

Question #1 regarding Example #2: Is the *X* in the numerator? NO

How do we move the *X* into the numerator?

Answer:

- Multiply both sides of the equation by *X*. Or, you could think of it as simply moving the *X* diagonally from the denominator into the numerator.

$$X(2.5) = \frac{1,000\cancel{(X)}}{\cancel{X}} \qquad \text{OR} \qquad X(2.5) = \frac{1,000}{X}$$

Question #2 regarding Example #2: Is the *X* alone on one side of the equation? NO

How do we use diagonal movement to place *X* alone on one side of the equation?

Answer:

- Divide by 2.5 on each side of the equation so that the *X* is alone.

$$\frac{X\cancel{(2.5)}}{\cancel{2.5}} = \frac{1,000}{2.5}$$

$$X = \frac{1,000}{2.5}$$

FINAL ANSWER: 1,000 ÷ 2.5 = 400

Class Exercise Solving for *X*:

$$\frac{X}{200} = 2.4$$

$$X = 2.4(200)$$

$$X = 480$$

$$10 = \frac{3000}{X}$$

$$\frac{X\cancel{(10)}}{\cancel{(10)}} = \frac{3000}{10}$$

$$X = 300$$

There are a few rules for doing the various mathematical functions like multiplication, division, addition and subtraction.

Order of Operation for Multiplication, Division, Addition and Subtraction
To solve for *X* when multiplication and division as well as addition and subtraction of terms is indicated, use the following steps: 1. Simplify as many terms as possible, using the order of operation: • If **brackets or parentheses** contain any arithmetic, **simplify within these groups first** by: o Completing the multiplication or division, THEN o Complete the addition or subtraction. • Complete all **multiplication and division** from left to right, THEN • Complete all **addition and subtraction** from left to right. 2. Verify that the *X* term is in the numerator. If it is not, move the *X* term to the numerator, using a diagonal move. 3. Verify that *X* is by itself, on one side of the equation.

Explanation of the Order of Operation and an example.

Example 1:

$4\left(\frac{10}{2} + 3\right) + 6$

Step #1: Simplify terms **within parentheses** by **multiplying and dividing** from left to right.

= 4 (5 +3) + 6 (10÷2 = 5)

Step # 2: THEN simplify terms **within parentheses** by **adding and subtracting** from left to right.

= 4 (8) + 6 (5 + 3 = 8)

Step #3: Simplify terms **outside of parentheses** by **multiplying and dividing** from left to right.

= 32 + 6 (4 X 8 = 32)

Step #4: Simplify terms **outside of parentheses** by **adding and subtracting** from left to right.

= 38 (32 + 6 = 38)

Let's practice using the order of operation on example 2 on page 3-6.

Class Exercise: Explanation of the Order of Operation

Example 2:

(*X*)(2)(8.34) = 500

Step #1: Simplify terms by **multiplying and dividing** from left to right within parentheses.

(*X*)16.68 = 500

Step # 2: Verify that the X term is in the numerator. If it is not, move the *X* term to the numerator, using a diagonal move.

Is X in the numerator YES

Step #3: Verify that *X* is by itself, on one side of the equation. If it is not, divide both sides of the equation by the number on the *X* side of the equation.

Does this equation require a division? YES If so by what number? 16.68

(*X*)~~16.68~~ = 500

~~16.68~~ 16.68

FINAL ANSWER: 500 ÷ 16.68 = 29.97

Now let's discuss the concept of unit cancellation.

Problem Solving Using Unit Cancellation:

We give it that name because you cancel units until the problem is solved.

Unit cancellation involves canceling units in the numerator and denominator of unit fractions to obtain the desired units of measurement.

Unit cancellation can be used to make conversions or to solve problems.

There are three basic rules for using unit cancellation.

Turn to page 3-8.

Basic rules for using unit cancellation:

Unit fractions should be written in a vertical format. A unit fraction has one unit in the numerator (above the line) and one unit in the denominator (below the line).

1. A fraction is structured like this: $\frac{\text{numerator}}{\text{denominator}}$

   For example, gallons per minute (GPM) should be written as $\frac{\text{gal}}{\text{min}}$

2. Any unit which appears in the numerator of one unit fraction and the denominator of another unit fraction is canceled.

   The following is an example of how units are canceled:

$$20 \frac{\text{gal}}{\cancel{\text{min}}} \times 60 \frac{\cancel{\text{min}}}{\text{hr}} = 1200 \frac{\text{gal}}{\text{hr}}$$

3. It may be necessary to invert data and the corresponding units.

$$10 \frac{\text{gal}}{\text{min}} \text{ is the same as } \frac{1 \text{ min}}{10 \text{ gal}}$$

Example Problem: How many mL/min are in a flow of 5 gal/day?

We'll begin by setting up the problem:

Instructor Note: To set up the problem, write the known and unknown data on the white board or blank overhead sheet. Then write the 2 conversions needed.

Problem Set Up

List all known and unknown data.

Unknown: ? $\frac{\text{mL}}{\text{min}}$ Known: 5 $\frac{\text{gal}}{\text{day}}$

From this data, find units which need to be converted.

Volume units: gal to mL Time units: day to min

Find conversions from the conversion charts.

1 gal = 3,785 mL 1 day = 1,440 min

This is all the data we need to use in the problem.

Steps to solving problems using unit cancellation

Step 1: List unknown data including units in vertical format followed by an equal sign.

Example: Unknown data: $? \frac{mL}{min} =$

NOTE: You may need to invert data throughout the following steps.

Step 2: Find data (known or a conversion) that has the same numerator unit as the unknown numerator. Place it to the right of the equal sign. Add a multiplication sign. This positions your numerator.

Instructor Note: Ask class to find data that contains mL in the numerator. Then circle numerator unit. This positions your numerator.

Example: $? \frac{mL}{min} = \frac{3,785\ mL}{1\ gal} \times$ ← *Conversion*

Step 3: To cancel unwanted denominator unit, find data (known or a conversion) that has the same numerator unit. Place it to the right of data used in Step 2. Place a multiplication sign between each piece of data.

Instructor Note: Cancel the gal units.

Example: $? \frac{mL}{min} = \frac{3,785\ mL}{1\ gal} \times \frac{5\ gal}{1\ day} \times$ ← *Known*

Step 4: Continue to place data (known or a conversion) into equation to systematically cancel all unwanted units until only the unknown denominator units remain.

Instructor Note: Continue to cancel units, circle denominator.

Example: $? \frac{mL}{min} = \frac{3,785\ mL}{\cancel{gal}} \times \frac{5\ \cancel{gal}}{1\ \cancel{day}} \times \frac{1\ \cancel{day}}{1,440\ min}$ ← *Conversion*

Note 1: All units must cancel, leaving only the units you are solving for in the unknown data. If all units except the unknown units are not crossed out, check the list of known data to see if all relevant known data was used to solve the problem and all necessary conversions were made.

Note 2: If you need to invert the known data or conversion values and units to cancel, remember to carry the value with the appropriate unit.

Step 5: Multiply the values of all numerators and place this value in the numerator of the answer. Multiply the values of all denominators and place this value in the denominator of the answer. Divide to calculate the final answer.

Important: Check the answer to verify that the value is reasonable.

Example: $? \frac{\text{mL}}{\text{min}} = \frac{18{,}925\ \text{mL}}{1440\ \text{min}} = 13.1\ \frac{\text{mL}}{\text{min}}$

Let's do this practice problem together on page 3-10.

Practice Problem:

How many hours will it take to empty a 55 gallon drum of sodium hypochlorite using a chemical feed pump that's pumping at a rate of 30 mL/min?

Solution:

Unknown Data: ? Hours Known Data: $\frac{55\ \text{gal}}{1}$ and $\frac{30\ \text{mL}}{1\ \text{min}}$

Positions the numerator | Known | Known

$$\frac{?\ \text{Hours}}{1} = \frac{1\ \text{hr}}{60\ \cancel{\text{mins}}} \times \frac{1\ \cancel{\text{min}}}{30\ \cancel{\text{mL}}} \times \frac{3785\ \cancel{\text{mL}}}{\cancel{\text{gal}}} \times \frac{55\ \cancel{\text{gal}}}{1} = \frac{208175}{1800} = 115.6\ \text{hrs.}$$

Conversion | Conversion

Note: The pump rate is rearranged to place the time unit in the numerator.

Display Slide 28 (to review positioning the numerator "hr" unit and cancelling the denominator units in known data and conversions. Emphasize the NOTE that the pump rate is rearranged to cancel the "min" unit)

Let's look at a dosage calculation problem on the bottom of page 3-10 in your workbook.

Instructor Note: Write out the cancellation steps on flipchart, whiteboard or overhead as you explain.

If a water treatment plant produces 3 million gallons per day, and uses chlorine gas, dosed at 7 mg/L, you can calculate how many pounds per day the plant will use.

Here are the unit cancellation steps

Unit Cancellation Steps:

Positions the numerator

Known **Known**

$$? \frac{\text{lbs}}{\text{day}} = \frac{1\ \text{lb}}{454\ \cancel{\text{g}}} \times \frac{1\ \cancel{\text{g}}}{1000\ \cancel{\text{mg}}} \times \frac{7\ \cancel{\text{mg}}}{\cancel{\text{L}}} \times \frac{3.785\ \cancel{\text{L}}}{1\ \cancel{\text{gal}}} \times \frac{1{,}000{,}000\ \cancel{\text{gal}}}{1\ \cancel{\text{MG}}} \times \frac{3\ \cancel{\text{MG}}}{1\ \text{day}} = \frac{79485\cancel{000}\ \text{lb}}{454\cancel{000}\ \text{day}} = \frac{175\ \text{lbs}}{\text{day}}$$

Conversions **Conversions**

Cancel unwanted units until you get to the denominator unit that you are solving the equation for. (in this example it's "day")

This is a very long set of steps that have been simplified by using a formula equation that we will introduce when we review dosage/feed rate calculations.

As a summary of hints and the unit cancellation steps, let's demonstrate one more conversion.

The following unit cancellation steps solve this problem. Let's take a look at the unit cancellation steps that are used to prove that the density of water is 8.34 lbs/gallon.

Unit Cancellation Steps

Step 1: List ? unknown data including units followed by an = sign

Step 2: Place data with same numerator unit to the right of the equal sign followed by a multiplication sign. This positions your numerator.

Step 3: To cancel unwanted denominator unit, next place data with same numerator unit.

Step 4: Continue to place data into equation to systemically cancel all unwanted units until only the unknown denominator units remain.

Step 5: Do the math (Multiply all numerator values, multiply all denominator values, then divide numerator by the denominator.)

Example:

The density of a liquid is 1 gm/mL in the Metric system. **What is the density in the English system (lbs/gal)?**

Notice that this conversion proves that the density of water = 8.34 lbs/gallon.

$$? \frac{lbs}{gal} = \frac{1\ lb}{454\ \cancel{gm}} \times \frac{1\ \cancel{gm}}{1\ \cancel{mL}} \times \frac{3785\ \cancel{mL}}{1\ gal} = 8.34\ \frac{lbs}{gal}$$

Helpful Hints:

$\frac{\text{Numerator}}{\text{Denominator}}$

Vertical format: 5 gal = $5\ \frac{gal}{1}$

1 gm = 1000 mg is written: $\frac{1\ gm}{1000\ mg}$ OR $\frac{1000\ mg}{1\ gm}$

"per" means divided by: Ex. 5 gpm = $5\ \frac{gal}{1 min}$

Inverting: $5\ \frac{gal}{1\ min} = 1\ \frac{min}{5\ gal}$

Now that we have reviewed math principles and unit cancellation steps, let's look at why we need those skills.

In order to calculate chemical dosage or feed rates, we need to perform math calculations.

Turn to page 3-12.

The first type of calculation involves calculating quantities when a chemical concentration changes.

Calculations for Changing % Concentrations of a Chemical

We purchase sodium hypo in 12%-15% strength, but we may have to dilute it (maybe our pump is just sized too big). Then we have to figure out how many gallons we are going to pump.

Instructor Note: Write out the math steps on flipchart, whiteboard or overhead as you explain.

Problem: In 12 hours, you feed 1.2 gallons of 12% hypochlorite solution. How many gallons would you have to use if the concentration is 5%?

Step 1: Set up math equation: Remember, in an equation, the terms or calculations on one side equal the terms or calculations on the other side. We can use this fact to put our problem in equation form.

1.2 gal x 12% = ? gal x 5%

Step 2: Divide both sides by 5% to get **? gal** alone on the right side of the equation (basic math rule)

$\frac{1.2\text{ gal} \times 12\not{\%}}{5\not{\%}} = \frac{?\text{ gal} \times \not{5\%}}{\not{5\%}}$

Step 3: Multiply 1.2 x 12 = 14.4 in the numerator (basic math rule)

Step 4: Perform the division: 14.4 (numerator) ÷ 5 (denominator) = 2.88 gallons (final basic math rule)

Vertical Format of Step 4: $\frac{14.4}{5}$

Note – the 12 hours was not important!

Let's practice this type of math problem.

Instructor Note: Read over the problem and then allow the class time to try the problem.

Practice Problem: You purchase a new pump. The old pump fed 5.5 gallons daily of 15% sodium hypochlorite. You need to change your concentration to a 6% solution. How many gallons can you now expect to use each day?

Step 1: Set up math equation: 5.5 gal x 15% = ? gal x 6%

Step 2: Divide both sides by 6% to get **? gal** alone on the right side of the equation

$$\frac{5.5\ \text{gal} \times 15\not\%}{6\ \not\%} = \frac{?\ \text{gal} \times \not{6\%}}{\not{6\%}}$$

Step 3: Multiply 5.5 x 15 = 82.5 in the numerator

Step 4: Perform the division: 82.5 (numerator) ÷ 6 (denominator) = 13.75 gallons

Vertical Format of Step 4: $\frac{82.5}{6}$

Turn to page 3-14 and we'll look at more process calculations that operators need to do.

In addition to calculating quantities when chemical concentrations change, operators also perform process calculations.

Process Calculations

There are three basic chlorination process calculations:

1. chlorine dosage or feed rate
2. chlorine demand
3. CT calculation

Chlorine Dosage/Feed Rate Calculation

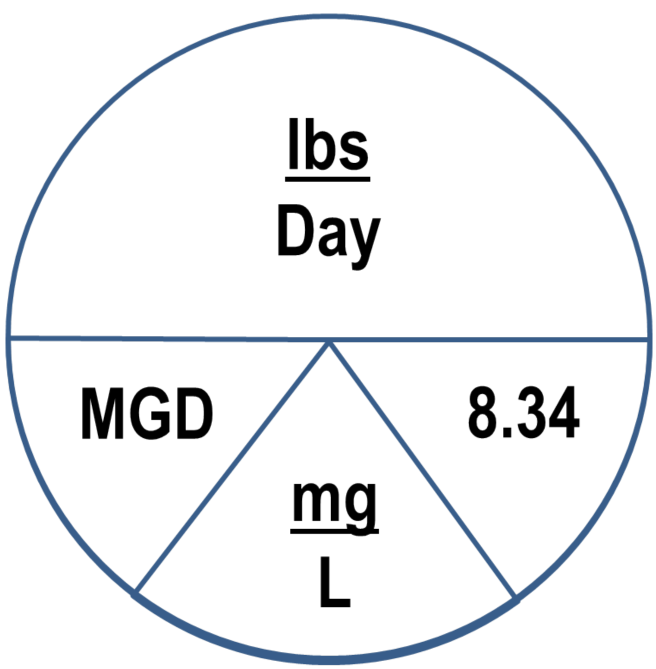
- To perform the calculation, you will need to know the amount of chlorine being added and the amount of water being treated.

Feed Rate, lbs/day = Flow (MGD) x Dosage (mg/L) x 8.34 lbs/gal

Display Slides 32 (Davidson Pie Diagram)

This formula is represented in the following diagram called the Davidson Pie which was created by Gerald Davidson, Manager, Clear Lake Oaks Water District, Clear Lake Oaks, CA.

Davidson Pie



Key Acronyms:

MG = million gallons
MGD = million gallons per day

Display Slides 32 -34 to show the following

Davidson Pie Diagram Interpretation and Formulas

This diagram can be used to solve for 3 different results: dosage, feed rate, and flow (or volume).

As long as you have 2 of those 3 variables, you can solve for the missing variable.

Davidson Pie Interpretation

Middle line = divided by (÷)
Bottom diagonal lines = multiply by (x)

In other words, here are the 3 equations that can be used with these variables:

1. Feed Rate, lbs/day = Flow (MGD) or Volume (MG) x Dosage (mg/L) x 8.34 (which is the density of water)

2. Flow (MGD) = lb/day ÷ (Dosage, mg/L x 8.34)

   Vertical Format: Flow(MGD) = <u>Feed Rate (lbs/day)</u>
   [Dosage (mg/L) x 8.34]

3. Dosage (mg/L) = lb/day ÷ (Flow, MGD x 8.34)

   Vertical Format: Dosage (mg/L) = <u>Feed Rate (lbs/day)</u>
   [Flow(MGD) x 8.34]

Turn to page 3-16.

Let's start with the first and most commonly used equation that solves for feed rate in lbs/day.

Instructor Note: As before, please write out the steps for the following problems on a flipchart, whiteboard or overhead as you explain each.

Equation # 1: Feed Rate Calculation Using Flow

Solving for Pounds/Day

Feed Rate, Pounds per day = flow(MGD) x dose(mg/L) x (8.34)

This equation alone (without extra steps) can be used to solve for feed rates of 100% strength chemicals, such as chlorine gas.

A water treatment plant produces 3 million gallons per day, and uses chlorine gas, dosed at 7 mg/L, how many pounds per day will the plant will use?

Feed Rate, Pounds per day = 3 x 7 x 8.34 = 175 pounds per day (same answer as the unit cancellation answer from earlier)

When we are using chemicals that aren't 100% strength, we need to factor in the active strength of the chemical into the calculation.

Active Strength is the percentage of a chemical or substance in a mixture that can be used in a chemical reaction. (also referred to as % purity)

Feed Rate Calculations Using Flow with a % Strength (i.e., % pure) Solution

Unlike chlorine gas, sodium and calcium hypochlorite solutions are not 100 percent pure. For example, the sodium hypochlorite typically used is 12.5% pure. That means that out of every gallon of hypochlorite, only 12.5% is the chlorine component, and the other material (87.5%) is not chlorine.

Problem: A water plant uses sodium hypochlorite (12.5%) to disinfect the water. The target dose is 1.2 mg/L. They treat 0.25 million gallons per day. How many pounds of sodium hypochlorite will need to be fed?

Step 1: Solve for pounds per day (feed rate) for 100 % pure chemical (no impurities).

Using the formula pounds per day = flow x dose x 8.34 = (0.25)(1.2)(8.34) = 2.5 pounds of chlorine is required.

Step 2: Calculate # of pounds of 12.5% solution needed to achieve Step 1 feed rate.

Since they are using hypochlorite, and only 12.5 % of the hypo is chlorine, we need to calculate how many pounds of hypo are required to get 2.5 pounds of chlorine. To do that we need to change the percent to a decimal, and divide that into the pounds required.

a) Convert % purity of solution into a decimal:

$$\frac{12.5\ \%}{100\%} = 0.125$$

b)Then divide the pounds needed (feed rate of 100% pure chemical) by the % purity of the solution (as a decimal).

$$\frac{2.5\ \text{pounds}}{0.125\ (\%\ \text{purity as a decimal})} = 20\ \text{pounds of } 12.5\ \%\ \text{hypochlorite.}$$

TIP: Answer will always be more pounds than Step 1 result because solution is not 100% pure.

Practice Problem: A water plant uses sodium hypochlorite (15%) to disinfect the water. The target dose is 1.6 mg/L. They treat 0.25 million gallons per day. How many pounds of sodium hypochlorite will need to be fed?

Step 1: Solve for pounds per day (feed rate) for 100 % pure chemical (no impurities).

Using the formula pounds per day = flow x dose x 8.34 = (0.25)(1.6)(8.34) = 3.3 pounds of chlorine is required.

Step 2: Calculate # of pounds of 15% solution needed to achieve Step 1 feed rate.

a) Convert % purity of solution into a decimal:

$$\frac{15\ \%}{100\%} = 0.15$$

b) Then divide the pounds needed (feed rate of 100% pure chemical) by the % purity of the solution (as a decimal).

$$\frac{3.3\ \text{pounds}}{0.15\ (\%\ \text{purity as a decimal})} = 22\ \text{pounds of } 15\%\ \text{hypochlorite.}$$

TIP: Answer will always be more pounds than Step 1 result because solution is not 100% pure.

Turn to page 3-18 and we'll look at the conversions you may have to do before using the feed rate formula.

When you have a flow in gallons per minute (GPM) or gallons per day (GPD), you will need to convert those values into million gallons per day (MGD) before using the feed rate formula.

Converting from GPM to MGD before solving with the formula

Problem: A water treatment plant operates at the rate of 75 gallons per minute. They dose soda ash at 14 mg/L. How many pounds of soda ash will they use in a day?

We'll use unit cancellation to show the steps involved in doing this math.

Instructor Note: *Under Step 1, emphasize setting up the equation with "gal" in the numerator to "position" the numerator and always have the data in the correct position. Reinforce this same idea under step 2 by starting with "MG" in the numerator.*

Step 1: Convert gallons per minute into gallons per day using unit cancellation.

$$? \frac{\text{gal}}{\text{day}} = 75 \frac{\text{gal}}{\text{minute}} \times \frac{60 \text{ minutes}}{\text{hour}} \times \frac{24 \text{ hours}}{\text{day}} = 108{,}000 \frac{\text{gallons}}{\text{day}}$$

Step 2: Convert gallons per day into million gallons per day (MGD) using unit cancellation.

$$? \frac{\text{MG}}{\text{day}} = \frac{1 \text{ MG}}{1{,}000{,}000 \text{ gallons}} \times \frac{108{,}000 \text{ gallons}}{\text{day}} = 0.108 \text{ MGD}$$

Positions the numerator

Step 3: Use MGD in feed rate formula to solve for lbs/day

Feed Rate, Pounds per day = flow(MGD) x dose(mg/L) x (8.34)

0.108 x 14 x 8.34 = 12.61 lbs/day

Steps 1 and 2 can be combined like this:

Step 1: Convert gallons per minute into million gallons per day (MGD) using unit cancellation.

$$? \frac{MG}{day} = \frac{1\ MG}{1,000,000\ \cancel{gallons}} \times \frac{75\ \cancel{gal}}{\cancel{minute}} \times \frac{60\ \cancel{minutes}}{\cancel{hour}} \times \frac{24\ \cancel{hours}}{day} = 0.108\ \frac{MG}{day}$$

You can also use the conversion of 1 day = 1440 mins (60 X 24) to remove 2 conversions. (minutes/hour and hours/day)

Step 1: Convert gallons per minute into million gallons per day (MGD) using unit cancellation.

$$? \frac{MG}{day} = \frac{1\ MG}{1,000,000\ \cancel{gallons}} \times \frac{75\ \cancel{gal}}{\cancel{minute}} \times \frac{1440\ \cancel{minutes}}{day} = 0.108\ \frac{MG}{day}$$

Converting from GPD to MGD before solving with the formula

Problem: If a water treatment plant is making water at the rate of 150,000 gallons per day, and the chlorine dose is 0.8 mg/L, how many pounds of chlorine will they use daily (assume 100% strength)?

Step 1: Convert gallons per day into million gallons per day (MGD) using unit cancellation.

$$? \frac{MG}{day} = \frac{1\ MG}{1,000,000\ \cancel{gallons}} \times \frac{150,000\ \cancel{gallons}}{day} = 0.15\ MGD$$

Step 2: Use MGD in feed rate formula to solve for lbs/day

Feed Rate, Pounds per day = flow(MGD) x dose(mg/L) x (8.34)

0.15 x 0.8 x 8.34 = 1 lb/day

Turn to page 3-20 and we'll look at problems that involve volume instead of flow calculations.

Notice that you can also use this first equation and substitute volume for flow. Let's look at a problem that uses volume instead of flow. In addition, the feed rate is determined in pounds, rather than pounds per day.

Feed Rate Problem Using Volume instead of Flow with a % Strength Chemical

Your storage tank has been taken out of service for cleaning. The 50,000 gallon tank must be properly disinfected before you can return it to service. The consulting firm recommends you use 25 mg/L of 68% calcium hypochlorite. How many pounds of calcium hypochlorite do you need to add to the water?

Step 1: Convert volume (in gallons) into MG so that the feed rate formula can be used.

$$?MG = \frac{1\ MG}{1{,}000{,}000\ \not{gal}} \times 50{,}000\ \not{gal} = 0.05\ MG$$

Step 2: Solve for pounds (feed rate) for 100 % pure chemical (no impurities).

? lbs = volume(MG) x dose(mg/L) x 8.34 = (0.05)(25)(8.34) = 10.4 pounds of chlorine is required.

Step 3: Calculate # of pounds of 68% solution needed to achieve Step 2 feed rate.

Since they are using hypochlorite, and only 68 % of the hypo is chlorine, we need to calculate how many pounds of hypo are required to get 10.4 pounds of chlorine. To do that we need to change the percent to a decimal, and divide the pounds required by the purity of the solution (as a decimal).

a) Convert % purity of solution into a decimal:

$$\frac{68\%}{100\%} = 0.68$$

b) Then divide the pounds needed (feed rate of 100% pure chemical) by the % purity of the solution (as a decimal).

$$\frac{10.4\ \text{pounds}}{0.68\ (\%\ \text{purity as a decimal})} = 15.3\ \text{pounds of hypochlorite.}$$

Instructor Note: Read over the problem and then allow the class time to try the problem.

Practice Problem #1

Calculate the amount of calcium hypochlorite to dose a 500,000 gallon storage tank to a dose of 25 mg/L using granular calcium hypochlorite that indicates it is 65% chlorine.

Step 1: Convert volume (in gallons) into MG so that the feed rate (lbs) formula can be used.

$$?MG = \frac{1\ MG}{1{,}000{,}000\ gal} \times (500{,}000)\ gal = 0.5\ MG$$

Step 2: Solve for pounds per day (feed rate) for 100 % pure chemical (no impurities).

? lbs = volume(MG) x dose(mg/L) x 8.34 = (0.5)(25)(8.34) = 104.25 pounds of chlorine is required.

Step 3: Calculate # of pounds of 65% solution needed to achieve Step 2 feed rate.

a) Convert % purity of solution into a decimal:

$$\frac{65\%}{100\%} = 0.65$$

b) Then divide the pounds needed (feed rate of 100% pure chemical) by the % purity of the solution (as a decimal).

$$\frac{104.25\ pounds}{0.65} = 160.39$$ pounds of 65% calcium hypochlorite.

Let's try a problem that has a **slight twist**. Read practice problem #2 on page 3-22.

Instructor Note: Read over the problem and then allow the class time to try the problem.

Practice Problem #2:

Calculate the amount of chlorine required for a dosage of 1 mg/L in a 600,000 gallon storage tank. The tank is **¾ full**. (Assume 100% strength)

Step 1: Calculate volume of tank that is not 100% full by multiplying the volume by the fraction (or its equivalent decimal.)

$600{,}000 \times \frac{3}{4} = 450{,}000$ gallons **OR** $600{,}000 \times 0.75 = 450{,}000$ gallons

Step 2: Convert volume (in gallons) into MG so that the feed rate (lbs) formula can be used.

$?MG = \frac{1\ MG}{1{,}000{,}000\ \not{gal}} \times 450{,}000\ \not{gal} = 0.45\ MG$

Step 3: Solve for pounds per day (feed rate) for 100 % pure chemical (no impurities).

? lbs = volume(MG) x dose(mg/L) x 8.34 = (.45)(1)(8.34) = 3.75 pounds of chlorine is required.

Here's summary of the feed rate calculation steps we use when we have either a volume or a flow. **This will always be used when solving for POUNDS or POUNDS/DAY. So, whenever you see a problem that asks to solve for an amount in pounds, use these steps!**

Summary of Steps for Solving Feed Calculations (in lbs/day) for % Strength (i.e., % Purity) Solutions (using either volume or flow rate)

Example: Calculate the amount of calcium hypochlorite required to dose a 500,000 gallon storage tank to a dose of 25 mg/L using granular calcium hypochlorite that indicates it is 65% chlorine.

Step 1: Convert volume (in gallons) into MG <u>or</u> flow in gallons (per day or per minute) into MGD so that the feed rate (lbs or lbs/day) formula can be used.

$$?MG = \frac{1\ MG}{1{,}000{,}000\ \cancel{gal}} \times \text{volume of tank } (\cancel{gal}) \text{ OR}$$

$$?MGD = \frac{1\ MG}{1{,}000{,}000\ \cancel{gal}} \times \frac{\text{volume of flow } (\cancel{gal})}{1\ day} \text{ OR}$$

$$?MGD = \frac{1\ MG}{1{,}000{,}000\ \cancel{gal}} \times \frac{\text{volume of flow } (\cancel{gal})}{1\ \cancel{min}} \times \frac{1440\ \cancel{min}}{day}$$

Step 2: Solve for pounds per day (feed rate) for 100% pure chemical (no impurities). (104.25 pounds for this example)

? lbs = volume(MG) x dose(mg/L) x 8.34 = pounds of chlorine that are required.

Step 3: Calculate # of pounds of % solution needed (in this example, 65%) to achieve Step 2 feed rate.

a) Convert % purity of solution into a decimal:

$$\frac{65\%}{100\%} = 0.65$$

b) Then divide the pounds needed (feed rate of 100% pure chemical) by the % purity of the solution (as a decimal).

$$\frac{104.25 \text{ pounds}}{0.65} = 160.39 \text{ pounds of 65\% calcium hypochlorite.}$$

TIP: Answer will always be more pounds than Step 2 result because solution is not 100% pure.

Turn to page 3-24 and we'll talk about how we use specific gravity to convert lbs into gallons.

How do we convert pounds of a solution into gallons of that same solution?

Solving for Gallons/Day

Calculating "Active Ingredient" Weight

In addition to knowing that solutions are not 100% pure (i.e. 100% active), we also need to determine the weight of the active strength ingredients within that solution.

Active ingredient weight is the number of pounds of "active ingredient" per gallon of a % solution that cause a chemical reaction.

- This "active ingredient" weight value is then used in a calculation with the 100% pure "lbs/day" feed rate to determine the "gal/day" feed rate.

We need the specific gravity of the solution which is found on the MSDS sheet to calculate the weight of a solution.

Calculating the Weight of the "Active Ingredient" of a % Solution Chemical

EXAMPLE: How many pounds of chlorine are there in a gallon of sodium hypochlorite that is 12.5% pure that has a specific gravity of 1.15?

Step 1: Solve weight equation (lbs/gal) for 1 gallon of chemical

Weight, lbs/gal = (Specific gravity of substance) x (weight of a gallon of water)

$$1.15 \times 8.34 \frac{\text{pounds}}{\text{gallon}} = 9.59 \frac{\text{pounds}}{\text{gallon}}$$

Step 2: Determine the "active ingredient" weight of the solution based on the % purity of solution

a) Convert % purity of solution into a decimal:

$$\frac{12.5}{100} = 0.125$$

b) Multiply the weight of a gallon (from step 1) by the % purity of the product (as a decimal).

$$9.59 \frac{\text{pounds}}{\text{gallon}} \times 0.125 = 1.2$$ pounds of available chlorine in a gallon of 12.5 % sodium hypochlorite

This active ingredient weight provides the pounds of available chlorine that is found in each gallon of 12.5% sodium hypochlorite solution. Within the 9.59 pounds of 12.5% sodium hypochlorite, there are 1.2 pounds of available chlorine (i.e., active ingredient).

Now that we know the active ingredient weight of the solution, we can use this information to determine how many gallons we need to feed. We'll use unit cancellation to determine the number of gallons/day from the lbs/day feed rate.

Using "Active Ingredient" Weight to Convert Feed Rate from lbs/day to gal/day

Example: A water plant uses sodium hypochlorite (12%) to disinfect the water which provides 1.2 lbs/gal of available chlorine ("active ingredient" weight). The required dosage is 2.5 mg/L. They treat 118,000 gallons per day. How many gallons of sodium hypochlorite will need to be fed?

Step 1: Convert flow in gallons (per day) into MGD so that the feed rate (lbs/day) formula can be used.

$$? \text{ MGD} = \frac{1 \text{ MG}}{1{,}000{,}000 \ \cancel{\text{gal}}} \times \frac{118{,}000 \ (\cancel{\text{gal}})}{1 \ \text{day}} = 0.118 \text{ MGD}$$

Step 2: Solve for pounds per day (feed rate) for 100% pure chemical (no impurities).

Using the formula pounds per day = flow x dose x 8.34 = (0.118)(2.5)(8.34) = 2.46 pounds of chlorine is required.

Step 3: Use "active ingredient" weight with unit cancellation steps to convert lbs/day to **gals/day**

Active Ingredient Weight of 12% hypo solution

Feed Rate of 100% pure chlorine

NOTE: Inverted weight so that gallon unit was in numerator to position the numerator

$$? \frac{\text{gal}}{\text{day}} = \frac{1 \text{ gallon}}{1.2 \text{ lbs}} \times \frac{2.46 \text{ lbs}}{\text{day}} = 2.05 \frac{\text{gal}}{\text{day}}$$

NOTE: When you are given the "active ingredient" weight of a solution to solve a feed rate problem, you do not need to use the % purity factor because it was used in the weight calculation.

Turn to page 3-26 and we'll practice this type of problem.

Instructor Note: Read over the problem and then allow the class time to try the problem.

Practice Problem: A water plant uses sodium hypochlorite (12.5%) to disinfect the water which provides 1.2 lbs/gal of available chlorine ("active ingredient" weight). The chlorine dosage is 1.6 mg/L. They treat 600,000 gallons per day. How many gallons of sodium hypochlorite will need to be fed?

Step 1: Convert flow in gallons (per day) into MGD so that the feed rate (lbs/day) formula can be used.

$$? \text{ MGD} = \frac{1 \text{ MG}}{1{,}000{,}000 \not{\text{gal}}} \times \frac{600{,}000 \not{\text{(gal)}}}{1 \text{ day}} = 0.6 \text{ MGD}$$

Step 2: Solve for pounds per day (feed rate) for 100 % pure chemical (no impurities).

Using the formula pounds per day = flow x dose x 8.34 = (0.6)(1.6)(8.34) = 8 pounds of chlorine is required.

Step 3: Use "active ingredient" weight with unit cancellation steps to convert lbs/day to **gal/day**

Active Ingredient Weight of 12.5% hypo solution

Feed Rate of 100% pure chlorine

$$\frac{?\text{gal}}{\text{day}} = \frac{1 \text{ gallon}}{1.2 \text{ lbs}} \times \frac{8 \text{ lbs}}{\text{day}} = \frac{6.67 \text{ gal}}{\text{day}}$$

NOTE: When you are given the "active ingredient" weight of a solution to solve a feed rate problem, you do not need to use the % purity factor because it was used in the weight calculation.

We've covered the many situations in which you use the feed rate equation, now let's move the 2nd equation that we can use that solves for flow.

Tip: Two Different Paths for Solving

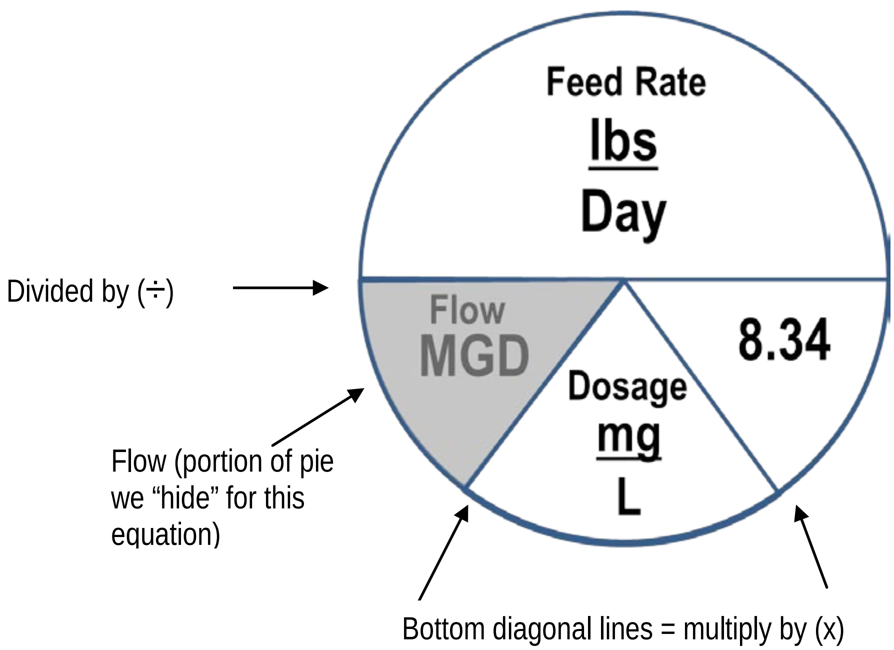
If the problem **asks for pounds or pounds per day**, solve the equation using the feed rate formula and dividing by the percent solution. We'll call this **Path 1** (steps are summarized on page 3-23)

If the problem **asks for gallons or gallons per day**, solve the equation using the feed rate equation and available chlorine (or active ingredient weight). We'll call this **Path 2** (steps summarized are shown on page 3-25

Equation #2: Solving for Flow Using the Feed Rate Formula

We will continue to use the Davidson Pie Feed Rate/Dosage Formula.

Display Slides 33 to show the following (advance once)



Remember: Middle line represents a division sign (÷)
Bottom diagonal lines = multiply by (x)

Vertical Format: Flow, MGD = $\frac{\text{Feed Rate, lbs/per day}}{\text{(Dose, mg/L)(8.34)}}$

Problem: A water treatment plant uses 14 pounds of chlorine to treat their water daily. The chlorine dose is 1.5 mg/L. What is their flow rate in MGD?

Step 1: Set up the variables in vertical format and insert known values

? Flow (MGD) = $\frac{\text{Feed Rate, lbs/day}}{\text{(Dose)(8.34)}} = \frac{\text{14 lb/day}}{(1.5)(8.34)}$ ← **Known feed rate**

↑ **Known Dose**

Step 2: Multiply 1.5 x 8.34 in the denominator = 12.51 (basic math rule)

Step 3: Perform the **FLOW** division: 14 (numerator) ÷ 12.51 (denominator) = 1.1 MGD

Turn to page 3-28 and practice using equation #2.

Practice Problem: A water treatment plant uses 8 pounds of chlorine daily and the dose is 17 mg/L. How many gallons are they producing?

Step 1: Set up the variables in vertical format and insert known values

$$? \text{ Flow (MGD)} = \frac{\text{Feed Rate, lbs/day}}{(\text{Dose})(8.34)} = \frac{(\,8\,)\text{ lb/day}}{(17)(8.34)}$$

Step 2: Multiply 17 x 8.34 in the denominator = 141.78 (basic math rule)

Step 3: Perform the **FLOW** division: 8 (numerator) ÷ 141.78 (denominator) = 0.056425 MGD

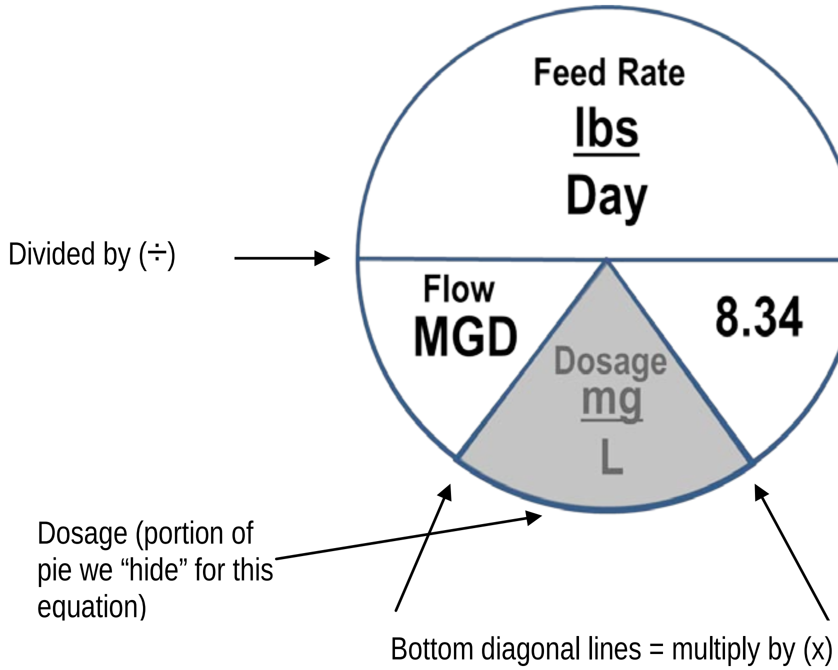
Unit Cancellation Steps to solve for gallons/day

$$? \frac{\text{gallons}}{\text{day}} = \frac{1{,}000.000 \text{ gallons}}{1 \ \cancel{\text{MG}}} \times \frac{.056425 \ \cancel{\text{MG}}}{\text{day}} = 56{,}425 \frac{\text{gallons}}{\text{day}}$$

Finally, the 3rd equation we can use solves for dosage.

Equation #3: Solving for Dose Using the Feed Rate Formula

Display Slides 34 to show the following (advance once)



Vertical Format: Dose, mg/L = $\dfrac{\text{Feed Rate, lbs/per day}}{\text{(Flow, MGD)(8.34)}}$

Example: A water treatment plant is producing 1.5 million gallons per day of potable water, and uses 38 pounds of chlorine each day. What is the chlorine dose at that plant?

Step 1: Set up the variables in vertical format and insert known values

? Dose (mg/L) = $\dfrac{\text{Feed Rate, lbs/day}}{\text{(Flow, MGD)(8.34)}} = \dfrac{\text{38 lb/day}}{(1.5)(8.34)}$ ← **Known feed rate**

↑ Known Flow (MGD)

Step 2: Multiply 1.5 x 8.34 in the denominator = 12.51 (basic math rule)

Step 3: Perform the DOSE division: 38 (numerator) ÷ 12.51 (denominator) = 3.03 mg/L

Turn to page 3-30 and practice using equation #3.

Practice Problem: A water treatment plant produces 150,000 gallons of water every day. It uses an average of 2 pounds of permanganate for iron and manganese removal. What is the dose of the permanganate?

Step 1: Set up the variables in vertical format.

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34)}$$

Step 2: Convert gallons per day into MGD and insert known values into equation.

$$?\frac{\text{MG}}{\text{day}} = \frac{1 \text{ MG}}{1{,}000{,}000 \text{ ~~gallons~~}} \times \frac{150{,}000 \text{ ~~gallons~~}}{\text{day}} = 0.15 \text{ MGD}$$

$$? \text{ Dose (mg/L)} = \frac{\text{Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34)} = \frac{(2) \text{ lb/day}}{(0.15)(8.34)}$$

Step 3: Multiply 0.15 x 8.34 in the denominator = 1.25 (basic math rule)

Step 4: Perform the **DOSE** division: 2 (numerator) ÷ 1.25 (denominator) = 1.6 $\frac{\text{mg}}{\text{L}}$

We are finished with our feed rate/ dosage calculation examples.

Let's discuss the second type of process control calculation: chlorine demand.

Display Slide 35

Chlorine Demand or Dose Calculation

- A sufficient amount of chlorine must be added so that the chlorine demand is met and the desired chlorine residual is provided.

  Chlorine Demand (mg/L) = Chlorine Dose (mg/L) – Chlorine Residual (mg/L)

  OR

  Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual

Example #1: The chlorine demand of water is 2.1 mg/L. If a chlorine residual of 0.6 mg/L is desired, what is the required chlorine dosage in mg/L?

Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)

? Dose = 2.1 + 0.6
= 2.7 mg/L

Example #2: The chlorine dosage is 2.9 mg/L. If the chlorine residual is 0.6 mg/L, what is the chlorine demand in mg/L?

Chlorine Demand (mg/L) = Chlorine Dose (mg/L) – Chlorine Residual (mg/L)

? Chlorine Demand = 2.9 – 0.6
= 2.3 mg/L

Turn to page 3-32 and we'll look at a variation on the dose/feed rate calculations. What if we only want to calculate a dose and feed rate for a time period that is **less than a full day?**

Let's begin with calculating a feed rate for a work shift.

Calculating feed rate for a work shift (less than 24 hours)

Problem: You must maintain 0.5 mg/L chlorine residual in the finished water with a chlorine demand of 1.5 mg/L. The pumping rate is 500 gpm. How many pounds of 68% calcium hypochlorite will be fed during the first shift (8 hours)?

Step 1: Calculate the dose using the formula

Chlorine Dose (mg/l) = Chlorine Demand (mg/l) + Chlorine Residual (mg/l)

Dose = 1.5 + 0.5
= 2.0 mg/L

Step 2: Convert gpm to MGD

$$\frac{?\text{MG}}{\text{day}} = \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} \times \frac{500\text{ gal}}{\text{min}} \times \frac{1440\text{ min}}{\text{day}} = 0.72\text{ MGD}$$

Step 3: Use Feed Rate calculation to solve for lbs/day

? lbs/day = flow x dose x 8.34 = (0.72)(2.0)(8.34) = 12 pounds of chlorine is required.

Step 4: Calculate # of pounds of 68% solution needed to achieve Step 3 feed rate.

a) Convert % purity of solution into a decimal:

$$\frac{68\%}{100\%} = 0.68$$

b) Then divide the pounds needed (feed rate of 100% pure chemical) by the % purity of the solution (as a decimal).

$$\frac{12\text{ pounds}}{0.68} = 17.6\text{ pounds of 68\% calcium hypochlorite.}$$

Step 5: Calculate pounds needed for an 8 hour shift

$$?\text{lbs} = \frac{17.6\text{ lbs}}{\text{day}} \times \frac{1\text{ day}}{24\text{ hrs}} \times \frac{8\text{ hrs}}{1} = 5.8\text{ lbs in an 8 hour shift}$$

Let's practice this calculation by doing the problem on page 3-33.

Practice Problem: You must maintain 0.5 mg/L chlorine residual in the finished water with a chlorine demand of 1.5 mg/L. The pumping rate is 300 gpm. How many **pounds** of 65% calcium hypochlorite will be fed during 12 **hours**?

Step 1: Calculate the dose using the formula

Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)

Dose = 1.5 + 0.5
= 2.0 mg/L

Step 2: Convert gpm to MGD

$$?\frac{MG}{day} = \frac{1\ MG}{1{,}000{,}000\ \not{gal}} \times \frac{300\ \not{gal}}{\not{min}} \times \frac{1440\ \not{min}}{day} = 0.432\ MGD$$

Step 3: Use Feed Rate calculation to solve for lb/day

? lbs/day = flow x dose x 8.34 = (0.432)(2.0)(8.34) = 7.2 pounds of chlorine is required.

Step 4: Calculate # of pounds of 65% solution needed to achieve Step 3 feed rate.

a) Convert % purity of solution into a decimal:

$$\frac{65\%}{100\%} = 0.65$$

b) Then divide the pounds needed (feed rate of 100% pure chemical) by the % purity of the solution (as a decimal).

$$\frac{7.2\ pounds}{0.65} = 11$$ pounds of 65% calcium hypochlorite.

Step 5: Calculate pounds needed for 12 hours

$$?lbs = \frac{11\ lbs}{day} \times \frac{1\ day}{24\ hrs} \times \frac{12\ hrs}{1} = 5.5\ lbs$$ in 12 hours

Turn to page 3-34.

We learned how to convert the lbs/day feed rate to gals/day back on pages 3-25 and 3-26. Now let's use that same concept and apply it to a problem that first requires us to **solve for the dose** and then ultimately convert to **gals/day**.

Calculating Feed Rate and Converting to gallons per day (again)

Problem: How many gallons of 12.5% sodium hypochlorite are required to treat 116,000 gpd with a desired residual of 0.5 mg/L and a chlorine demand of 2.0 mg/L? NOTE: 12.5% sodium hypochlorite – 1.2 lb/gallon available chlorine ("active ingredient" weight).

Remember, the problem asks you to solve for gallons and the available chlorine is given. This is what we called Path 2 in our Tip on Page 3-26.

Step 1: Calculate the dose using the formula

Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)

Dose = 2.0 + 0.5
= 2.5 mg/L

Step 2: Convert gpd to MGD

$$\frac{116{,}000}{1{,}000{,}000} = 0.116 \text{ MGD}$$

Step 3: Use Feed Rate calculation to solve for lb/day

? lbs/day = flow x dose x 8.34 = (0.116)(2.5)(8.34) = 2.42 pounds of chlorine is required.

Step 4: Use "active ingredient" weight with unit cancellation steps to convert lbs/day to gallons/day

Active Ingredient Weight of 12.5% hypo solution

Feed Rate of 100% pure chlorine

$$\frac{?\text{gal}}{\text{day}} = \frac{1 \text{ gallon}}{1.2 \text{ lbs}} \times \frac{2.42 \text{ lbs}}{\text{day}} = \frac{2.0 \text{ gal}}{\text{day}}$$

Let's practice these steps by doing the problem on page 3-35.

Practice Problem: How many gallons of 12% sodium hypochlorite are required to treat 150,000 gpd with a desired residual of 0.8 mg/L and a chlorine demand of 0.6 mg/L? NOTE: 12% sodium hypochlorite = 1.2 lb/gallon available chlorine ("active ingredient" weight).

Step 1: Calculate the dose using the formula

Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)

Dose = 0.8+ 0.6
= 1.4 mg/L

Step 2: Convert gpd to MGD

$$\frac{150,000}{1,000,000} = 0.15 \text{ MGD}$$

Step 3: Use Feed Rate calculation to solve for lb/day

? lbs/day = flow x dose x 8.34 = (0.15)(1.4)(8.34) = 1.75 pounds of chlorine is required.

Step 4: Use unit cancellation to convert lbs/day to gallons/day

Active Ingredient Weight of 12% hypo solution

Feed Rate of 100% pure chlorine

$$\frac{?\text{gal}}{\text{day}} = \frac{1 \text{ gallon}}{1.2 \text{ lbs}} \times \frac{1.75 \text{ lbs}}{\text{day}} = \frac{1.46 \text{ gal}}{\text{day}}$$

The last process control calculation relates to CT. Turn to page 3-36.

CT

Display Slide 36

CT – The product of residual disinfectant concentration (C) measured in mg/L in a representative sample of water prior to the first customer, and disinfection contact time (T) in minutes; that is "C" x "T."

CT = disinfectant concentration x contact time = C (mg/L) x T (minutes)

Therefore, the *units of CT are expressed in mg-min/L*.

Example #1: If a free chlorine residual of 1.8 mg/L is measured at the entry point of the system, after 120 minutes of detention time in the clearwell, what is the CT value in mg-min/L?

CT = disinfectant concentration x contact time

1.8 mg/L x 120 minutes = 216 mg-min/L

Example #2: If a free chlorine residual of 3.0 mg/L is measured at the end of the clearwell after 5 hours of detention time, what is the CT value in mg-min/L?

Step 1: Convert 5 hours of detention time to minutes (CT must be in minutes)

$$\text{Min} = 60\ \frac{\text{min}}{\text{hr}} \times 5\ \text{hr} = 300\ \text{minutes}$$

Step 2: Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = disinfectant concentration x contact time

CT = 3.0 mg/L x 300 min = 900 mg-min/L

Let's practice using the CT equation on page 3-37.

Practice Problem: If a free chlorine residual of 2.5 mg/L is measured at the end of the clearwell after 4 hours of detention time, what is the CT value in mg-min/L?

Step 1: Convert detention time from hours to minutes.

$$? \text{ Min} = \frac{60 \text{ min}}{\text{hr}} \times 4 \text{ hr} = 240 \text{ minutes}$$

Step 2: Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = disinfectant concentration x contact time

CT = 2.5 mg/L x 240 minutes = 600 mg-min/L

What if you have to determine detention time? Here's the equation to calculate theoretical detention time.

Calculating Theoretical Detention Time

$$\text{Theoretical Detention Time (minutes)} = \frac{\text{Volume of Tank (gallons)}}{\text{Influent Flow (gpm)}}$$

Notice the units:

Volume = gallons
Time = minutes

All calculations must be converted to those units before you do the math.

Example #3: A sedimentation tank holds 50,000 gallons and the flow into the plant is 500 gpm. What is the detention time in minutes?

$$\text{Detention Time (time)} = \frac{\text{Volume}}{\text{Flow}} \quad \frac{50{,}000 \text{ gallons}}{500 \text{ gpm}} = 100 \text{ minutes}$$

Turn to page 3-38 and we'll practice calculating detention time.

Practice Problem: What is the detention time (in min) of a tank that has a volume of 150,000 gallons with a plant flow rate of 2.5 MGD? (hint convert the flow rate to gpm, then plug into DT)

Step 1: Convert flow rate from MGD to gpm

$$\frac{?\,gal}{min} = \frac{1{,}000{,}000\ gal}{1\ \cancel{MG}} \times \frac{2.5\ \cancel{MG}}{\cancel{day}} \times \frac{1\ \cancel{day}}{1440\ mins} = \frac{1736\ gal}{mins}$$

Step 2: Calculate detention time using the formula:

$$\text{Detention Time (time)} = \frac{Volume}{Flow} \qquad \frac{150{,}000\ gallons}{1736\ gpm} = 86\ minutes$$

Now we are ready to combine this information with the CT calculation in a problem.

Example #4: A plant is set at a flow rate of 5 MGD. Water enters into a clearwell that has a volume of 75,000 gallons. The chlorine residual of the outlet end of the tank is 1.2 mg/L. What is the CT in mg-min/L?

Step 1: Convert flow rate from MGD to gpm

$$\frac{?\,gal}{min} = \frac{1{,}000{,}000\ gal}{1\ \cancel{MG}} \times \frac{5\ \cancel{MG}}{\cancel{day}} \times \frac{1\ \cancel{day}}{1440\ mins} = \frac{3472\ gal}{mins}$$

Step 2: Calculate detention time using the formula:

$$\text{Detention Time (time)} = \frac{Volume}{Flow} \qquad \frac{75{,}000\ gallons}{3472\ gpm} = 21\ minutes$$

Step 3: Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = disinfectant concentration x contact time

CT = 1.2 mg/L x 21 minutes = 25 mg-min/L

Let's practice both equations by doing the problem on page 3-39.

Practice Problem: A plant is set at a flow rate of 3 MGD. Water enters into a clearwell that has a volume of 50,000 gallons. The chlorine residual of the outlet end of the tank is 1.6 mg/L. What is the CT in mg-min/L?

Step 1: Convert flow rate from MGD to gpm

$$?\frac{gal}{min} = \frac{1{,}000{,}000\ gal}{1\ \cancel{MG}} \times 3\frac{\cancel{MG}}{\cancel{day}} \times \frac{1\ \cancel{day}}{1440\ mins} = \frac{2083\ gal}{mins}$$

Step 2: Calculate detention time using the formula:

$$\text{Detention Time (time)} = \frac{Volume}{Flow} \qquad \frac{50{,}000\ gallons}{2083\ gpm} = 24\ minutes$$

Step 3: Insert disinfection residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = disinfectant concentration x contact time

CT = 1.6 mg/L x 24 minutes = 38 mg-min/L

Congratulations, we are done working math problems and now we need to summarize this unit with key points on page 3-40.

Display Slide 37

Key points for Chemical Feed Dosage, Chlorine Demand and CT Calculations

- Remember to perform math calculations using the order of operation steps listed in this unit.
- You can use unit cancellation steps to solve for the units you are seeking. Be sure to begin with the numerator unit and cancel unwanted units until only the unknown denominator units remain.
- The Davidson Pie diagram can be used to solve for feed rate (lbs or lbs/day), flow (MGD) or dosage (mg/L) by using the following formulas:

  1. Feed Rate, lbs/day = Flow (MGD) or Volume (MG) x Dosage (mg/L) x 8.34 (which is the density of water)

  2. Flow (MGD) = $\frac{\text{Feed Rate (lbs/day)}}{[\text{Dosage (mg/L)} \times 8.34]}$

  3. Dosage (mg/L) = $\frac{\text{Feed Rate (lbs/day)}}{[\text{Flow(MGD)} \times 8.34]}$

- In order to use any of these formulas, all flows or volumes must be converted to either million gallons per day (MGD) or million gallons (MG).
- If you are calculating a feed rate for a solution that is not 100% pure chlorine (like sodium hypochlorite and calcium hypochlorite), remember to:
  1. Calculate the feed rate as if it's 100% pure,
  2. Then divide the feed rate of 100% pure chemical by the percent purity of the solution (as a decimal).
- Specific gravity is used to calculate the "active ingredient" weight of a solution which provides you with the available lbs of chlorine/gallon of solution. Once you have the available lbs of chlorine/gallon of solution(i.e., "active ingredient" weight), you can use unit cancellation steps to determine the number of gallons you need to feed.
- You can use the following equation to calculate chlorine dose, chlorine demand or chlorine residual.
  - Chlorine Dose (mg/L) = Chlorine Demand (mg/L) + Chlorine Residual (mg/L)
- To calculate CT values, use the following formulas:
  - CT = disinfectant concentration x contact time = C (mg/L) x T (minutes)
  - Theoretical Detention Time (minutes) = $\frac{\text{Volume of Tank (gallons)}}{\text{Influent Flow (gpm)}}$
  - Remember to convert flow into **gpm** and volume into **gallons**
  - Remember to convert hours into **minutes** before using the formulas.

Instructor Note: Handout "Basic Math Principles" job aid as a summary of the Unit 3 math calculations.

Here's a job aid that contains a sample problem for each type of situation we covered in Unit 3. You may want to use it when you complete the Unit 3 exercise or if you want to complete additional math practice problems that are found in the Appendix.

Instructor Note: Allow the students a few minutes to try the Unit Exercise problems before reviewing them.

Display Slides 38 - 41 (to review Unit 3 exercise answers)

Exercise for Unit 3 – Chemical Feed Dosage, Chlorine Demand and CT Calculations

1. In order to use the Feed Rate formula which is lbs/day = Flow or Volume x Dosage x 8.34, name the units of measurement for the flow or volume:

   a) MGD or MG

   b) gpm or gallons

   c) gpd or gallons

   d) All of the above units can be used

2. If you have calculated the feed rate for a solution as if it's 100% pure; but, your solution is a 65% calcium hypochlorite, what value do you use to represent the percent purity (as a decimal)? In other words, what value are you dividing by?

   a) 65

   b) 6.5

   c) 0.65

   d) 0.0065

3. You have determined that you need to feed 100 lbs/day of chlorine. You are using 15% sodium hypochlorite which provides 1.2 lbs/gal available chlorine. In order to convert the "lbs/day" feed rate into "gallons/day," what math step do you use?

   a) 100 lbs/day X 1.2 lbs/gal

   b) 100 lbs/day X 0.15

   c) 100 lbs/day ÷ 1.2 lbs/gal

   d) 100 lbs/day ÷ 0.15

4. When calculating a CT value, what units are used in the detention time calculation?

   a) Volume (MG) ÷ Flow (gpm)

   b) Volume (Gal) ÷ Flow (gpm)

   c) Volume (MG)÷ Flow (MGD)

   d) Volume (Gal) ÷ Flow (MGD)

Additional practice math problems are located in the Appendix.

Reference

Joanne Kirkpatrick Price, *Basic Math Concepts for Water and Wastewater Plant Operators*.

Display Slide 42 to review Unit 4 objectives

Unit 4 – Chemical Feed

Learning Objectives

- Explain the disinfection regulatory requirements.
- Explain breakpoint chlorination.
- Identify chemical feed equipment and explain important operation and maintenance considerations

Turn to page 4-2 and we'll begin this unit with a review of some of the regulatory requirements.

Regulatory Requirements

Display Slide 43 and explain the following

All community water systems (CWSs) are required to provide continuous disinfection. Also, CWSs must meet the disinfection byproducts MCLs. The following regulatory requirements address both disinfection and their associated byproducts with treatment technique requirements, MCLs, and MRDLs.

Q. How many of you operate a surface water treatment plant? Have you had a filtration plant performance evaluation (FPPE)? Did you review the log inactivation requirements listed below?

Display Slide 44 and explain the following

Surface Water Supplies

- The disinfection process must achieve 99.9 percent (3 log) inactivation of Giardia cysts and 99.99 percent (4 log) inactivation of enteric viruses. Chlorination equipment must be capable of maintaining a chlorine residual, which achieves a minimum of 1 log Giardia cyst inactivation following filtration.
- This must be determined by CT factors and measurement methods established by EPA. Refer to EPA's *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*.

Q. How many of you are ground water systems? Have you submitted your 4-log treatment demonstration form? Are you taking the entry point residual disinfectant samples yet?

Advance Slide 44 and explain the following

Groundwater Supplies

- Community groundwater systems are required to provide continuous disinfection and at least 4-log treatment of viruses (99.99% removal and/or inactivation).
- Community groundwater systems are required to maintain at each groundwater entry point a minimum residual disinfection concentration approved by DEP to provide 4-log treatment of viruses.
- This applies to groundwater supplies <u>not</u> under the influence of surface water intrusion.
- A minimum of 20 minutes of contact time must be provided.

Look at the chlorine residual information on page 4-2 and answer some questions.

(Instructor Note: Please go through each of the questions below and allow the class to answer each before proceeding. They will use the information on page 4-2 and 4-3 to answer the questions. There are not any PowerPoint slides for this portion. You should ask students to underline or highlight the answers within the workbook.).

Q What is the minimum entry point residual value number for surface water systems?
A. 0.2 mg/L

Q What is the minimum detectable distribution system residual value number for surface water systems?
A. 0.02 mg/L

Q. At what locations do you take chlorine residuals?
A. (entry point and distribution)

Q. Specifically, where in the distribution system do you take chlorine residuals?
A. (Same locations as TCR samples at representative points within the distribution system)

Q. Are the chlorine samples taken at the same time as the TCR samples?
A. Yes

Q. Have any of you ever needed to collect a Heterotrophic Plate Count (HPC) sample at a sampling point that had no residual?

Q. Was that HPC sample less than 500/mL?

Chlorine Residual Requirements

- For surface water systems:
  - Minimum free, combined or chlorine dioxide residual entering the distribution system (i.e., **entry point**) may not be less than 0.2 mg/L for more than 4 hours, and be maintained as a minimum detectable (0.02 mg/L or greater) residual throughout the distribution system.
  - Samples are taken at the same locations at representative points within the distribution system and at the same time as the total coliform samples.
    - NOTE: Sampling points with nondetectable disinfectant residuals which have heterotrophic plate count (HPC) measurements of less than 500/mL are deemed to be in compliance with the minimum detectable residual requirement.

Notice that **groundwater** systems also have to sample chlorine residual at the entry point.

Q. What is your approved minimum residual for your entry point?

Q. Do groundwater systems have the same chlorine residual sampling requirements in their distribution systems as surface water systems?
A. *(Yes, same locations and same time as TCR sites)*

- For groundwater systems:
  - o Minimum free chlorine entering the distribution system (i.e., **entry point**) no less than 0.40 mg/L or its equivalent as approved by DEP or other minimum residual approved by DEP to provide 4-log treatment of viruses.
  - o A disinfectant residual acceptable to DEP shall be maintained through the distribution system of the community water system sufficient to assure compliance with the microbiological MCLs.
  - o DEP will determine the acceptable residual of the disinfectant considering factors such as type and form of disinfectant, temperature and pH of the water, and other characteristics of the water system.
  - o Chlorine residual samples are taken at the same locations at representative points within the distribution system and at the same time as the total coliform samples.

Display Slide 45 and explain the following

- Chlorine added to water containing organic and inorganic chemicals reacts with these materials to form chlorine compounds. Maximum Contaminant Levels (MCLs) have been established for these disinfection byproduct compounds.

Maximum Contaminant Levels

Maximum contaminant levels (MCLs) regulations are issued by the USEPA and in Pennsylvania by the DEP. The MCLs list a variety of organic and inorganic chemicals, disinfection by products (DPBs), radionuclides, microbiological contaminants, and turbidity levels that pertain to drinking water. Some example MCLs are listed below.

Maximum Residual Disinfectant Level

The maximum residual disinfectant level (MRDL) is the maximum permissible level of a disinfectant added for water treatment that may not be exceeded at the consumer's tap without an unacceptable possibility of aderse health effects.

Contaminant	MCL or MRDL
Total Trihalomethanes (TTHMs), a DBP	0.080 mg/L
Haloacetic Acids (HAA5), a DBP	0.060 mg/ L
Bromate, a DBP	0.010 mg/ L
Chlorite, a DBP	1.0 mg/L
Benzene	0.005 mg/ L
Diquat	0.02 mg/ L

- Chlorine (as Cl2) — 4.0 mg/ L as maximum residual disinfectant level (MRDL)

Turn to page 4-4 and we'll look at a few secondary contaminants.

Secondary contaminant levels are also included since these may affect taste and odor. Some examples are shown below.

Contaminant	MCL
Sulfate	250 mg/ L
Iron	0.3 mg/ L
pH	6.5 – 8.5

In order to keep disinfection byproducts below their MCLs, here are ways to minimize TTHM formation.

Display Slide 46 and explain the following

Minimizing Total Trihalomethane (TTHM) Formation

Drinking water systems can reduce TTHM formation in several ways:

1. Reduce the organic material before chlorinating the water. Treatment techniques, such as coagulation, sedimentation, and filtration can remove most of the organic materials. However, activated carbon can be used to remove greater amounts of organic material than can be removed by other techniques.
2. Optimize chlorine usage.
3. Change the point of chlorine addition in the treatment series. If the point of chlorine addition is moved to a location <u>after</u> sedimentation or filtration, TTHM production can be reduced as these processes remove part of the organic material.
4. Use alternative disinfection methods. Using a mixture of chlorine and ammonia (chloramine) reduces THM formation.

Q. Have you had to implement any of these options to reduce your TTHM levels? If so, which one did you do?

The next topic we'll discuss involves chlorination terminology.

Chlorination Mechanics and Terminology

- The exact mechanism of chlorine disinfection action is not fully known.
  - One theory is that chlorine directly destroys the bacterial cell.
  - Another theory is that chlorine inactivates the enzymes which enable the cells to use food, thus starving the organisms.

Display Slide 47 and explain the following

Chlorine demand is the amount of chlorine required to react with all the organic and inorganic material.

- In practice, the chlorine demand is the difference between the amount of chlorine added and the amount remaining after a given contact time.
- Some reactive compounds have disinfecting properties while others do not.

Advance Slide 47 and explain the following

Chlorine residual (or Total Chlorine) is the total of all compounds with disinfecting properties and any remaining free chlorine.

Chlorine Residual (mg/L) = **Combined Chlorine Forms** (mg/L) + **Free Chlorine** (mg/L)

> **Combined Chlorine:** When chlorine is added to water, some of the chlorine reacts with nitrate to form chlorine-ammonia compounds. This is referred to as combined chlorine.
>
> **Free Chlorine:** Chlorine available to inactivate disease-causing organisms

- The presence of measurable chlorine residual indicates that all chemical reactions have been satisfied and that sufficient chlorine is present to kill or inactivate the microorganisms.

- Note: The chlorine residual is not impacted by changes in water temperature.

Chlorine dose is the amount of chlorine needed to satisfy the chlorine demand plus the amount of chlorine residual needed for disinfection:

Chlorine Dose (mg/L) = **Chlorine Demand** (mg/L) + **Chlorine Residual** (mg/L)

Display Slide 48 (Breakpoint chlorination curve)

Breakpoint Chlorination

Breakpoint chlorination is the addition of chlorine until all chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. Breakpoint chlorination determines how much chlorine is required for disinfection.

A residual in the form of free available residual chlorine needs to be provided. This has the highest disinfecting ability.

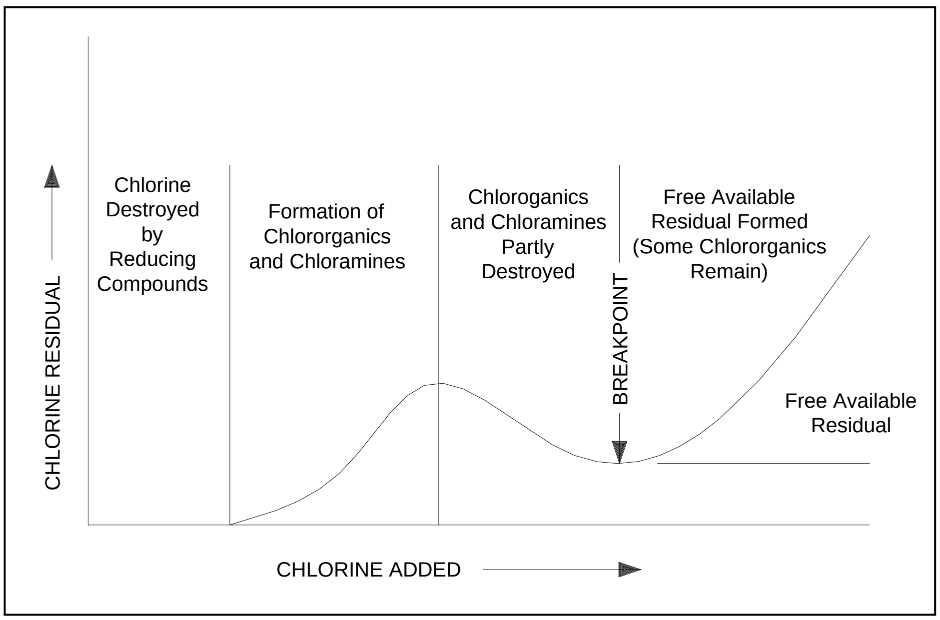


Figure 4.1 Breakpoint Chlorination Curve

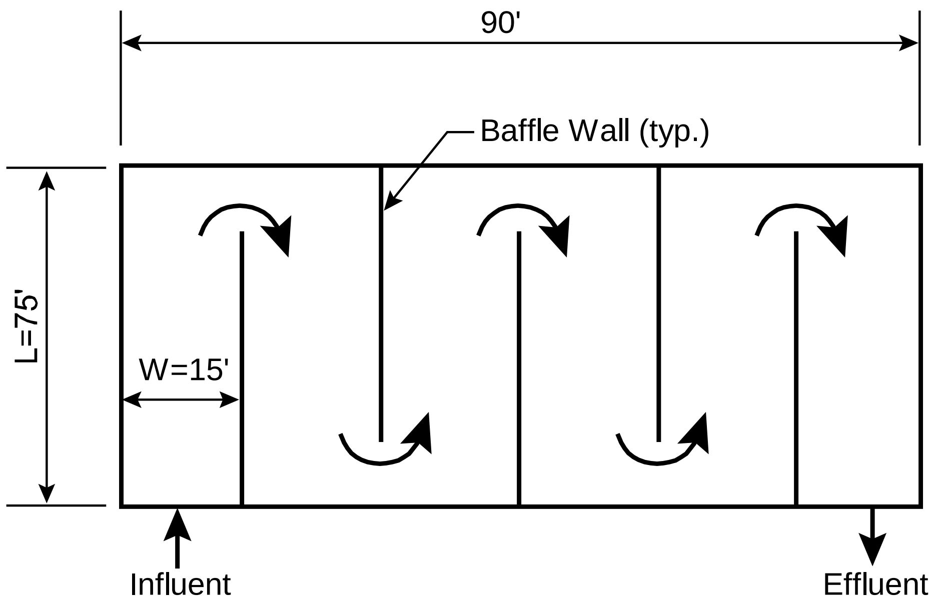
In addition to knowing how to provide the highest disinfecting residual, it's important to design a chlorine contact tank properly.

Look at the design on page 4-7.

Chlorine Contact Tank Design

Display Slide 49 and explain the following

- The chlorine contact basin design is of critical importance to maximize the effective detention time through the basin, and minimize short-circuiting. Baffling within the basins help minimize short-circuiting and aids in mixing. Note that the length to width ratio of 25:1 or greater should result in effective storage or baffling efficiencies of 70% or greater.



L:W = $\geq$ 25

for 70% Baffling Efficiency

$$\frac{6 \times 75}{15} = 30 \geq 25$$

Figure 4.2 Chlorine Contact Basin.

Q. Have you had to install baffles to increase your chlorine contact time to meet the groundwater rule 4-log treatment of viruses requirement?

Now let's discuss feed system designs. Turn to page 4-8 and we'll start with sodium hypochlorite.

Sodium Hypochlorite

- Sodium hypochlorite is supplied only in solution form.
- It is ready for use as received.
- Sodium hypochlorite is usually fed neat (i.e., at the strength received) if 12.5% strength or less. If the solution strength is greater than 12.5%, it may need to be diluted.

Figure 4.3 shows a typical bulk sodium hypochlorite feed system schematic diagram.

Display Slides 50 and 51 (bulk sodium hypochlorite feed system and sodium hypochlorite drum feed system)

Figure 4.4 depicts a schematic diagram of a typical sodium hypochlorite drum feed system.

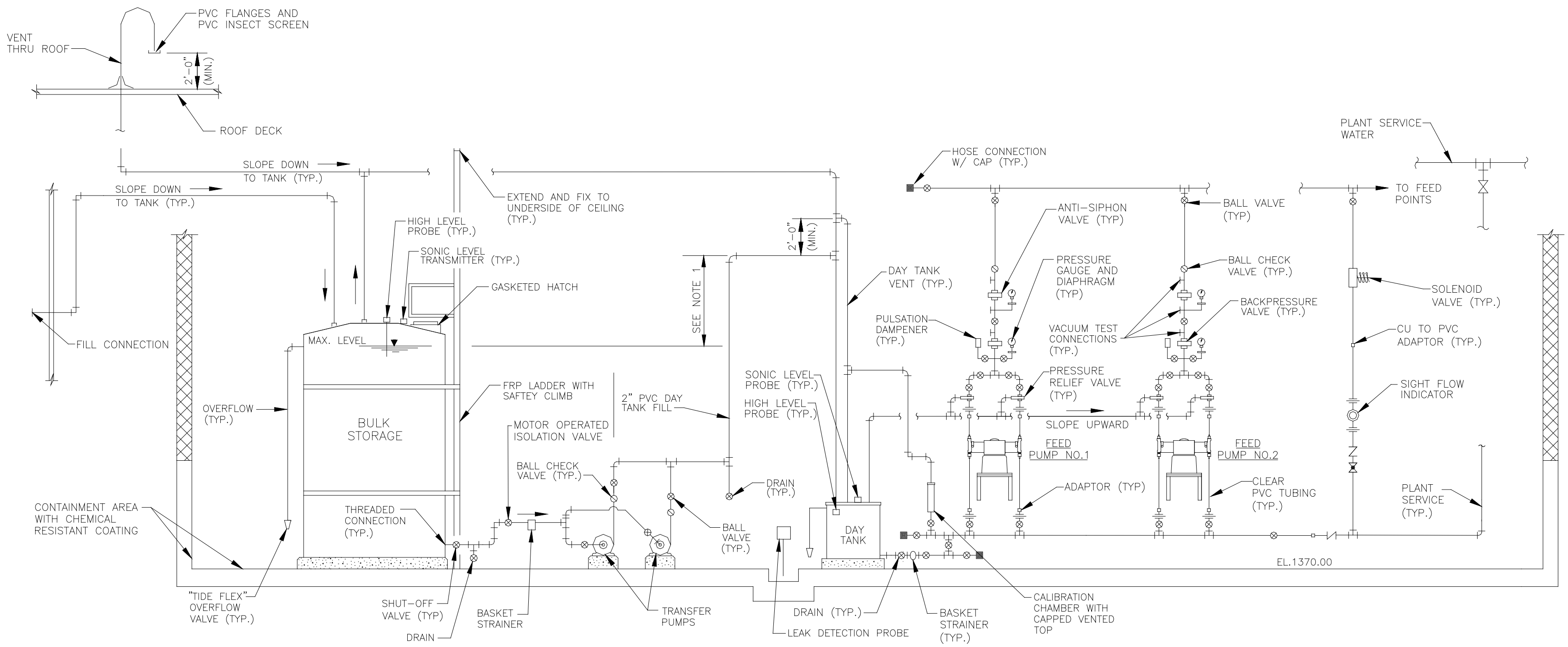


Figure 4.3 Typical Bulk Sodium Hypochlorite Feed System Schematic

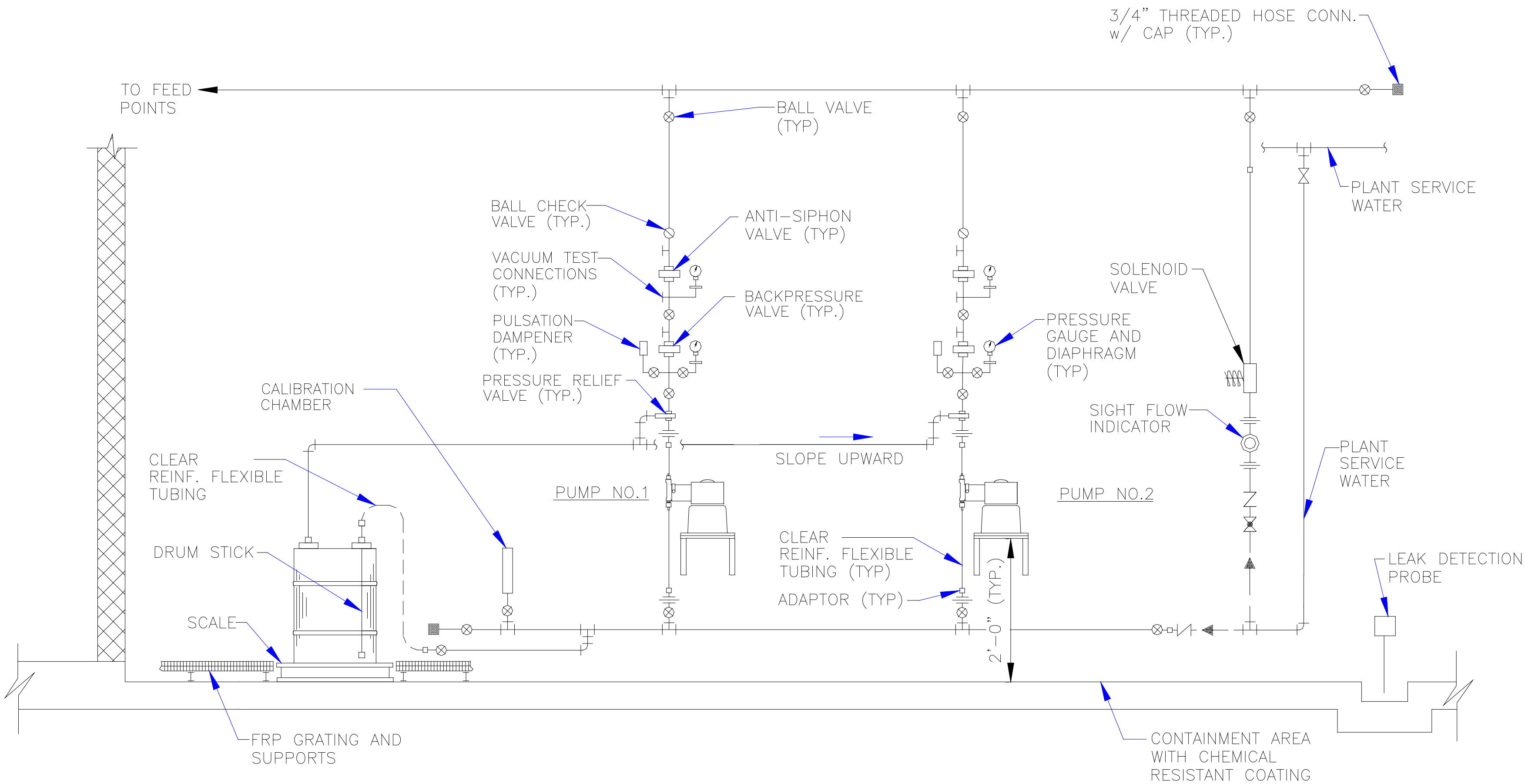


Figure 4.4 Typical Sodium Hypochlorite Drum Feed System Schematic

Turn to page 4-11 and we'll look at the major components of the feed equipment.

Hypochlorite Feed Equipment

With the exception of the type of chemical storage/solution preparation, the equipment for feeding the two forms of hypochlorite is similar. The major components and the purpose of each follow.

Display PowerPoint Slide 52. The slide is animated for each bulleted item.(click to display each topic)

Storage/Solution Preparation

- The bulk storage tank provides a container for the storage of a 30-day minimum supply of sodium hypochlorite solution. The bulk storage tank should provide a minimum volume of 110% of the maximum chemical delivery quantity to minimize the potential for overflowing the tank during chemical deliveries.

- The solution preparation tank provides containers for preparation of a minimum 1-day supply of calcium hypochlorite solution. Two containers are suggested: one in service and one with solution aging to facilitate settling of insoluble compounds.

Scales

- Scales provide an indication of the quantity of chemical remaining, which is useful for chemical inventory control.

Transfer Pumps

- Transfer pumps are used for the transfer of sodium hypochlorite from the bulk storage tank to day tanks.

Day Tank

- The day tank stores daily chemical required for delivery by feeders, and also monitors chemical usage and provides inventory control.

Chemical Feeder

- The chemical feeder uses positive displacement diaphragm pumps such as the mechanical diaphragm type, the hydraulic diaphragm type, or an electronic solenoid pump. Some chemical feeders are vacuum eductor-type feeders.

Chemical Feed Piping

- The backpressure valve maintains a constant backpressure on the feed pump discharge.
- The anti-siphon valve prevents backsiphonage of process water into the chemical feed system.
- The pressure relief valve limits the discharge pressure of the feed pump and protects the feed piping.
- The isolation valves permit maintenance of various system components without the need to remove the entire feed system from operation.

Calcium Hypochlorite

Most plants manually prepare stock batch solutions. Figure 4.5 depicts a typical Calcium Hypochlorite Feed System.

- Usually a one-day supply of 1 to 3 % strength is prepared.
- The proper quantity of HTH is dissolved in a sufficient quantity of water.
- The batch solution should be prepared in a separate container.
  - Allow the solution to stand for 8 to 24 hours before actual use.
  - Pour or siphon the clear solution into the day tank supplying the feeder.

Display Slide 53 (calcium hypochlorite drum feed system)

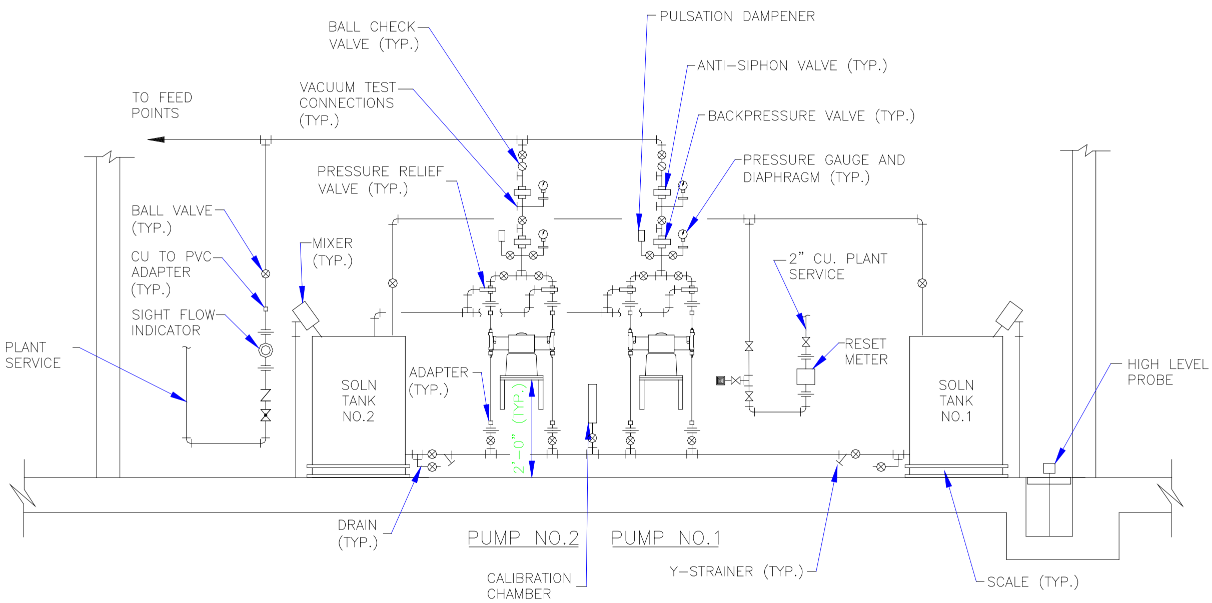


Figure 4.5 Typical Calcium Hypochlorite Feed System

On-Site Generated Sodium Hypochlorite

Typical sodium hypochlorite generation process layout is shown in the following figure.

Display Slide 54 (on-site hypochlorite generation process)

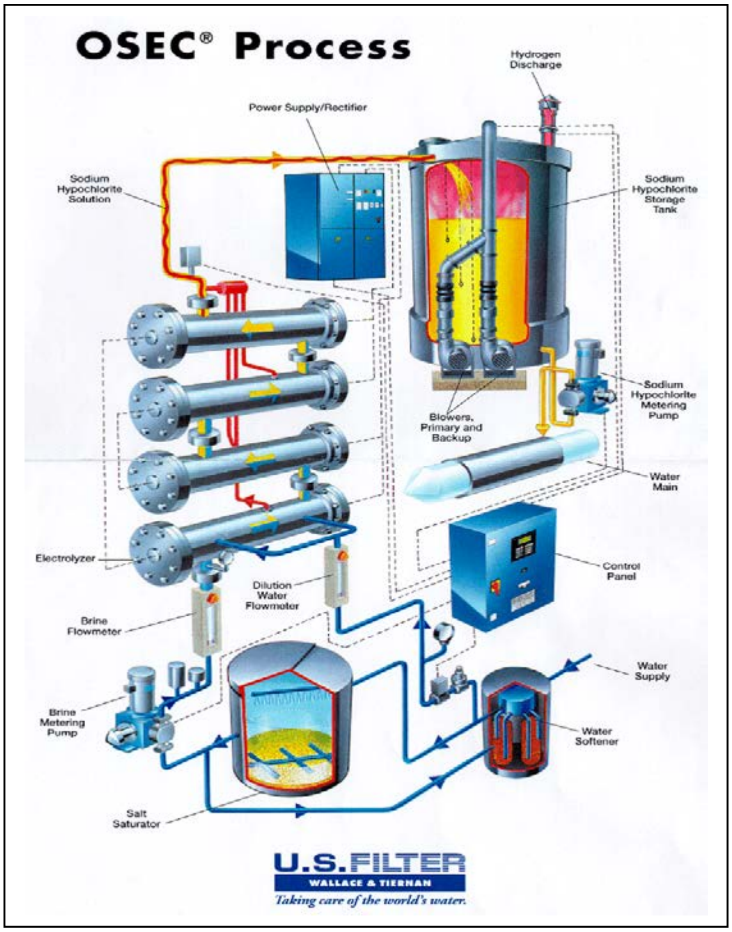


Figure 4.6 On-Site Hypochlorite Generation Process[1]

Turn to page 4-14 and we'll look at the components for the on-site generated sodium hypochlorite.

System Components

- The brine storage vessel stores salt and softened water where concentrated brine solution is made and stored. (Noted as Salt Saturator in Figure 4.6.)
- The water softener reduces the hardness of the water supply to less than 17 mg/l total hardness.
- The hypochlorite generators are reaction vessels where electrical charge is applied to the brine solution, resulting in the formation of sodium hypochlorite. (Noted as Electrolyzer in Figure 4.6.)
- The control system or panel controls the hypochlorite production cycle.
- The storage tanks store hypochlorite solution. Hydrogen is released from the process.

Chemical Feed Settings

Feed Rate is the quantity or **weight** of chemical delivered from a feeder over a given period of time. The chemical feed pump must be calibrated to **deliver the selected dosage**. A feed rate can have different units of expression, such as lb/hr, lbs/day, mL/min, or gal/day. Often, determining a feed rate involves time and weight conversions.

- Feed pumps are calibrated with the use of a pump calibration curve.
- A new pump calibration curve should be constructed:
  - At least once per year.
  - If troubleshooting points to the need for a new pump calibration.
  - If any maintenance is performed on the pump.

Turn to page 4-15 and we'll look at the steps in developing a pump calibration curve.

Display Slide 55

Steps in Developing a Pump Calibration Curve

Step 1: Determine actual feed pump output.

- Operate feed pump over full operating range
- Determine actual pump output

Here's an example of the type of data you would collect for each stroke setting (20 – 100%)

LIQUID FEED PUMP CALIBRATION TABLE

% Stroke: __________

PUMP SETTING	VOLUME (mL)	TIME (min)	FEED RATE (mL/min)
20			
40			
60			
80			
100			

Here's an example of a completed liquid feed pump calibration table.

Pump Setting (%)	Alum Pumped (ml)	Time (sec)	Feed Rate (ml/min)	Feed Rate (gal/min)
0	0.0	30	0.00	0.000
20	65.6	55	71.56	0.019
	141.9	59	144.31	0.038
60	249.1	61	245.02	0.065
80	195.2	32	366.00	0.097
100	267.4	35	458.40	0.121

Figure 4.7 Liquid Feeder Pump Calibration Table

Instructor Note: If someone asks about how to convert mL/min into gal/min in the last column in 4.7:

$$\frac{?\,gal}{Min} = \frac{1\ gal}{3.785\ L} \times \frac{1\ L}{1000\ mL} \times \frac{71.56\ mL}{min} = \frac{0.019\ gal}{min}$$

Turn to page 4-16 and look at step 2.

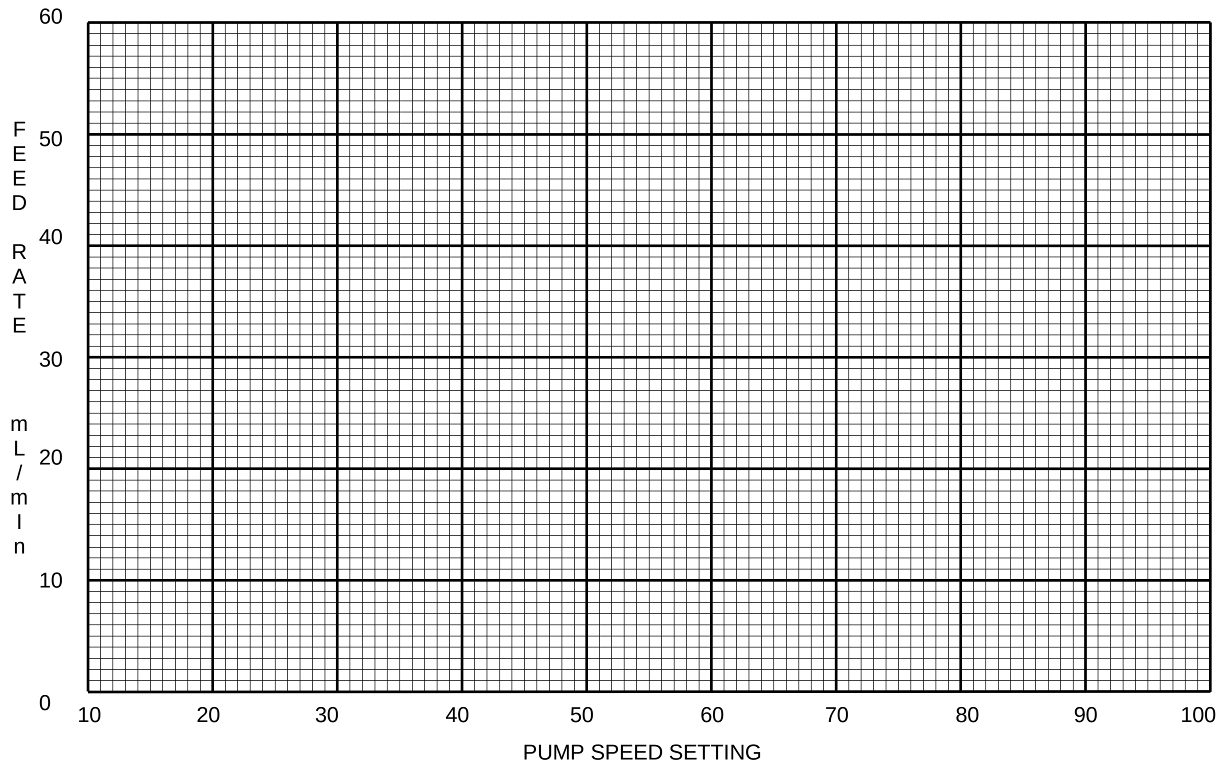
Display Slide 56

Step 2 – Develop feed pump calibration curve.

- Plot each **Feed Rate (mL/min)** vs. **Pump Speed setting** on the graph.
- Connect each of the points together with a straight line.

PUMP: ______________________________ PUMP CALIBRATION CURVE DATE: ____________________

% Stroke: ____________________________



Here's an example of a Dry Feeder Calibration Curve.

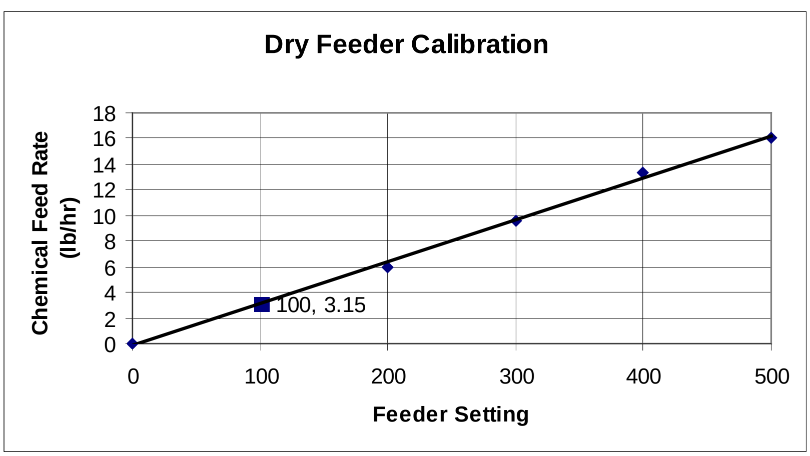


Figure 4.8 – Feeder Calibration Curve

In addition to developing a pump calibration curve, there are some activities that operators must do on a daily, weekly and monthly basis.

Hypochlorite Feed System Operation

Normal Operation

Normal operation of the hypochlorite feed system requires regular observation of the facilities and equipment, and a regular preventative maintenance program recommended in the manufacturer's specifications. Exact operating procedures will depend on the type of hypochlorite in use at the facility and on the equipment that is installed at the facility.

Look at the activities listed below.

Q. Which ones do you do?

Q. Are you doing them at the suggested frequency?

The general procedure is as follows:

Daily

- Visually inspect the storage and feed areas.
- Verify operation of chemical transfer pumps.
- Read scales, charts or meters at same time each day to determine actual chemical usage. Be sure to record readings for water pumped and actual chemical usage.
- Check chlorine residual in the system and adjust chlorine feed rate as necessary. Verify the proper operation of chemical feed pumps.
- Prepare calcium hypochlorite solution as necessary.
- Look for leaks.

Weekly

- Check the chemical dose by verifying proper pump calibration and computing the actual weekly chemical dosage.
- Check the entire system for problems.
- Clean the area.

- Verify the chemical supply on-hand and order as necessary.

Monthly

- Clean and lubricate equipment in accordance with manufacturer's recommendations.

Turn to page 4-18 and we'll look at a few troubleshooting tips.

Abnormal Operation

In the event of an abnormal operation, be sure to inform your supervisor of the problem.

Low Chlorine Residual

- Determine the actual chlorine residual in the laboratory and compare with the residual analyzer reading. Then recalibrate the analyzer appropriately.
- If the analyzer is properly calibrated, check the following:
    - The sample pump operation.
    - The feed pump operation.
    - The control system, if it is on automatic control. Operate in manual control mode if necessary.
    - The water chlorine demand. Increase the feed rate if necessary. Add additional feed pumps on line if demand is higher than can be provided by a single unit.

Chemical Pump Not Operating

- Verify the hypochlorite supply availability.
- Start the spare pump to maintain system chlorination.
- Check the electrical supply equipment, such as electrical connections, circuit breakers and control equipment.
- Check for blockages:
    - In the solution tank.
    - In the valves, both manual and electrically controlled.
    - In feed lines such as the feed pump suction lines and feed pump discharge lines.

Display Slide 57 (to review Unit 4 key points on page 4-19)

Key points for Unit 4 – Chemical Feed.

- Community water suppliers have both **minimum and maximum chlorine residual requirements** to meet according to their source water classification. The minimum and maximum levels are listed here:
    - Minimum **entry point and distribution system requirements for surface water systems:** Surface water suppliers are required to have a minimum free, combined or chlorine dioxide residual entering the distribution system (i.e., **entry point**) that may not be less than 0.2 mg/L for more than 4 hours. Additionally, surface water suppliers are required to maintain a minimum detectable (0.02 mg/L or greater) residual throughout the distribution system.
    - Minimum **entry point and distribution system requirements for groundwater systems:** Groundwater suppliers are required to have a minimum free chlorine residual entering the distribution system (i.e., **entry point**) no less than 0.40 mg/L or its equivalent as approved by DEP or other minimum residual approved by DEP to provide 4-log treatment of viruses.
        - Additionally, groundwater suppliers are required to maintain a disinfectant residual acceptable to DEP throughout the distribution system sufficient to assure compliance with the microbiological MCLs. DEP will determine the acceptable residual of the disinfectant considering factors such as type and form of disinfectant, temperature and pH of the water, and other characteristics of the water system.
    - Maximum **residual disinfectant level requirements within the distribution system for all system types:** Surface water and groundwater suppliers are required comply with a maximum residual disinfectant level no greater than 4.0 mg/L as chlorine. Compliance is based on a running annual average, computed quarterly, of monthly averages of all samples collected within the distribution system.

- Drinking water systems can reduce THM formation in several ways:
    - Reduce the organic material before chlorinating the water. Treatment techniques, such as coagulation, sedimentation, and filtration can remove most of the organic materials. However, activated carbon can be used to remove greater amounts of organic material than can be removed by other techniques.
    - Optimize chlorine usage.
    - Change the point of chlorine addition in the treatment series. If the point of chlorine addition is moved to a location **after** sedimentation or filtration, THM production can be reduced as these processes remove part of the organic material.
    - Use alternative disinfection methods. Using a mixture of chlorine and ammonia (chloramine) reduces THM formation.

- Chlorine demand is the amount of chlorine required to react with all the organic and inorganic material.

- Chlorine residual is the total of all chlorine compounds with disinfecting properties and any remaining free chlorine.

- Chlorine dose is the amount of chlorine needed to satisfy the chlorine demand plus the amount of chlorine residual needed for disinfection.

- Breakpoint chlorination is the addition of chlorine until all chlorine demand has been satisfied. It is used to determine how much chlorine is required for disinfection. At this point, further additions of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint.

- The chlorine contact basin design is of critical importance to maximize the effective detention time through the basin, and minimize short-circuiting. Groundwater systems now required to provide 4-log treatment of viruses may need to install baffles within the chlorine contact tanks to increase detention time and reduce short-circuiting.

- Sodium hypochlorite is supplied in solution form and typically it is used as received.

- Sodium hypochlorite can be generated on site by using special equipment to supply an electric charge to a brine solution.

- After a chlorine dosage has been calculated, it's important to develop a chlorine feed pump calibration curve that determines the chlorine delivery feed rate as it relates to the pump setting. This calibration process assures that the pump is delivering the proper chlorine dosage.

- Hypochlorite feed system equipment should be inspected daily for proper operation. Follow the maintenance recommendations that the pump manufacturer provides.

- Check the chlorine residual in the system daily and adjust chlorine feed rate as necessary.

Display Slides 58-64 (to review Unit 4 exercise answers)

Exercise for Unit 4 – Chemical Feed

1. The disinfection process for surface water supplies must achieve 99.9 percent (3 log) inactivation of Giardia cysts and 99.99 percent (4 log) inactivation of enteric viruses.

2. Chlorine residual samples are taken at representative points within the distribution system. These samples are taken at the same time and at the same location as the coliform samples are taken.

   a. __X____ True
   b. ______ False

3. The maximum residual disinfectant level (MRDL) is the maximum permissible level of a disinfectant added for water treatment that may not be exceeded at the consumer's tap without an unacceptable possibility of aderse health effects.

4. List one way a water supplier can reduce THM formation:

Any of the following:

- Reduce the organic material before chlorinating the water. Treatment techniques, such as coagulation, sedimentation, and filtration can remove most of the organic materials. However, activated carbon can be used to remove greater amounts of organic material than can be removed by other techniques.
- Optimize chlorine usage.
- Change the point of chlorine addition in the treatment series. If the point of chlorine addition is moved to a location **after** sedimentation or filtration, THM production can be reduced as these processes remove part of the organic material.
- Use alternative disinfection methods. Using a mixture of chlorine and ammonia (chloramine) reduces THM formation.

5. Explain what breakpoint chlorination is.

   Breakpoint chlorination is the addition of chlorine until all chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. Breakpoint chlorination determines how much chlorine is required for disinfection.

6. The breakpoint chlorination curve can be used to determine how much chlorine is required for disinfection.

7. Chlorine dose = chlorine demand (mg/L) + chlorine residual (mg/L).

8. A day tank stores daily amounts of chemical required for delivery by feeders.

9. Calcium hypochlorite solutions are typically prepared with a 1 to 3 % strength.

10. A pump calibration curve plots feed rate delivery versus the pump setting.

11. In the event of an abnormal operation, be sure to inform your Supervisor about the problem.

There are additional practice math problems that begin on page A-8.

Instructor Note: *Offer to e-mail the answer key or the link below where operators can access the answer key to the practice problems.*

A Module 25 answer key is available at the following website link:

- http://www.depweb.state.pa.us/operatorcenter/
- In the right hand menu click "Education and Training", then "Training Modules"

[1] Courtesy of U.S. Filter, Wallace & Tiernan Products (18 June 2003).

Full Group Course Review Activity

Display Slides 65-116 (Module 25 review questions)

As a full group activity, ask class to answer, and then click for correct answer animation

A Typical Chlorine MSDS Sheet

```
OLIN CORPORATION               -- SODIUM HYPOCHLORITE,7-15 %,CPE 622680
=======================================================
MSDS Safety Information
=======================================================
FSC: 6810
NIIN: 01-029-5565
MSDS Date: 04/23/1997
MSDS Num: BVFLX
Product ID: SODIUM HYPOCHLORITE,7-15 %,CPE 622680
MFN: 02
Responsible Party
Cage: 99530
Name: OLIN CORPORATION
Address: 501 MERRITT 7
Box: 4500
City: NORWALK (FORMALLY IN STAMFORD,CT) CT 06856-4500
Info Phone Number: 203-750-3000/203-750-3543
Emergency Phone Number: 800-654-6911/203-356-2000
Preparer's Name: UNKNOWN
Review Ind: Y
Published: Y
=======================================================
Contractor Summary
=======================================================
Cage: 03JX8
Name: ENVIROTROL INC (504-736-9041)
Address: UNKNOWN
Box: UNKNOW
City: UNKNOWN NK 00000
Phone: UNKNOWN
Cage: 99530
Name: OLIN CORPORATION
Address: 501 MERRITT 7
Box: 4500
City: NORWALK CT 06856-4500
Phone: 203-750-3000/800-511-MSDS
Cage: 0STM5
Name: VOPAK USA INC
Address: 6100 CARILLON POINT
City: KIRKLAND WA 98033-7357
Phone: 425-889-3400/425-889-3617
=======================================================
Item Description Information
=======================================================
Item Manager: S9G
Item Name: SODIUM HYPOCHLORITE SOLUTION
Specification Number: NONE
Type/Grade/Class: NONE
Unit of Issue: DR
Quantitative Expression: 00000000055GL
UI Container Qty: 0
Type of Container: DRUM
```

```
=======================================================
Ingredients
=======================================================
Cas: 7681-52-9
RTECS #: NH3486300
Name: SODIUM HYPOCHLORITE (CERCLA); AVAILABLE CHLORINE 5%
% Wt: 7 - 15
Other REC Limits: NONE RECOMMENDED
OSHA PEL: NOT ESTABLISHED
ACGIH TLV: NOT ESTABLISHED
EPA Rpt Qty: 100 LBS
DOT Rpt Qty: 100 LBS
------------------------------
Cas: 1310-73-2
RTECS #: WB4900000
Name: SODIUM HYDROXIDE (CERCLA)
% Wt: 0.5-2.5
Other REC Limits: NONE RECOMMENDED
OSHA PEL: 2 MG/M3
ACGIH TLV: C 2 MG/M3; 9596
EPA Rpt Qty: 1000 LBS
DOT Rpt Qty: 1000 LBS
------------------------------
Cas: 7647-14-5
RTECS #: VZ4725000
Name: SODIUM CHLORIDE
% Wt: 5 - 11
Other REC Limits: NONE RECOMMENDED
OSHA PEL: NOT ESTABLISHED
ACGIH TLV: NOT ESTABLISHED
------------------------------
Cas: 7732-18-5
RTECS #: ZC0110000
Name: WATER
% Wt: BALANCE
Other REC Limits: NONE RECOMMENDED
OSHA PEL: NOT RELEVANT
ACGIH TLV: NOT RELEVANT
```

===
Health Hazards Data
===
LD50 LC50 Mixture: LD50 (ORAL, RAT) 3000-5000 MG/KG
Route Of Entry Inds - Inhalation: YES
Skin: NO
Ingestion: YES
Carcinogenicity Inds - NTP: NO
IARC: NO
OSHA: NO
Effects of Exposure: TARGET ORGANS:EYES, SKIN, RESPIRATORY AND GASTROINTESTINAL TRACTS. ACUTE- CORROSIVE. MAY CAUSE EYE AND SKIN IRRITATION & BURNS. VAPORS ARE IRRITATING TO UPPER RESPIRATORY TRACT. MAY CAUSE BURNS. HARMFUL IF INHALED/SWALLOWED. MAY CAUSE GASTROINTESTINAL TRACT BURNS. CHRONIC- MAY CAUSE LUNG DAMAGE, SKIN ULCERATION.
Explanation Of Carcinogenicity: NONE
Signs And Symptions Of Overexposure: SEVERE IRRITATION, TEARING, NAUSEA, VOMITING, WHEEZING, SHORTNESS OF BREATH, CHEST PAIN, CORNEAL DAMAGE, TISSUE DESTRUCCTION, SWELLING
Medical Cond Aggravated By Exposure: ASTHMA, RESPIRATORY AND CARDIOVASCULR DISEASES
First Aid: GET MEDICAL HELP IF SYMPTOMS PERSIST. INHALED:MOVE TO FRESH AIR. PROVIDE CPR/OXYGEN IF NEEDED. EYES/SKIN:IMMEDIATELY FLUSH WITH WATER FOR 15 MINUTES. HOLD EYELIDS OPEN. ORAL:DO NOT INDUCE VOMITING. IF CONSCIOUS, DRINK PLENTY OF WATER. SEEK IMMEDIATE MEDICAL ATTENTION. IF VOMITING OCCURS, KEEP HEAD BELOW HIPS. DO NOT GIVE ANYTHING BY MOUTH TO AN UNCONSCIOUS PERSON.
===
Handling and Disposal
===
Spill Release Procedures: FLUSH TO SEWER WITH LARGE AMOUNT OF WATER IF PERMITTED. OTHERWISE, ABSORB SPILL WITH INERT MATERIAL SUCH AS VERMICULITE. PLACE IN A CONTAINER FOR DISPOSAL. CLEAN AREA THOROUGHLY TO REMOVE RESIDUAL CONTAMINATION.
Neutralizing Agent: WEAK ACIDS
Waste Disposal Methods: DISCHARGE, TREATMENT OR DISPOSAL IS SUBJECT TO FEDERAL, STATE OR LOCAL REGULATIONS. FLUSH TO SEWER WITH LARGE AMOUNT OF WATER, IF ALLOWED. SINCE EMPTIED CONTAINERS RETAIN PRODUCT RESIDUE, FOLLOW LABEL WARNINGS EVEN AFTER CONTAINER IS EMPTIED.
Handling And Storage Precautions: STORE IN A COOL PLACE AWAY FROM DIRECT SUNLIGHT AND INCOMPATIBLE MATERIALS.
Other Precautions: DO NOT GET IN EYES, ON SKIN OR ON CLOTHING. AVOID INHALATION OF VAPORS OR MISTS. KEEP OUT OF REACH OF CHILDREN. OBEY HAZARD WARNING LABEL. USE WITH ADEQUATE VENTILATION. DO NOT CONTAMINATE ENVIRONMENT.

===
Fire and Explosion Hazard Information
===
Flash Point Text: NONE
Lower Limits: NOT RELEVANT
Upper Limits: NOT RELEVANT
Extinguishing Media: SMALL FIRE:DRY CHEMICAL, CARBON DIOXIDE, WATER SPRAY. LARGE FIRE:WATER FOG IN FLOODING AMOUNT.
Fire Fighting Procedures: WEAR PROTECTIVE CLOTHING AND NIOSH-APPROVED SELF-CONTAINED BREATHING APPARATUS. COOL FIRE -EXPOSED CONTAINER WITH WATER SPRAY.
Unusual Fire/Explosion Hazard: MAY EMIT CHLORINE GAS.
===
Control Measures
===
Respiratory Protection: NONE NORMALLY NEEDED. IF WORKING IN CONFINED AREAS, IF EXCESSIVE MISTING IS EXPECTED, WEAR NIOSH-APPROVED RESPIRATOR (REFER TO 29 CFR 1910.134)
Ventilation: MECHANICAL (GENERAL/LOCAL EXHAUST)
Protective Gloves: RUBBER
Eye Protection: SAFETY GLASSES WITH SIDE SHIELD/GOGGLES
Other Protective Equipment: EYE WASH STATION, QUICK DRENCH SHOWER AND IMPERVIOUS CLOTHING
Work Hygienic Practices: OBSERVE GOOD INDUSTRIAL HYGIENE PRACTICES AND RECOMMENDED PROCEDURES. WASH AFTER HANDLING AND BEFORE EATING OR DRINKING.
Supplemental Safety and Health: FORMULA CHANGED. FOR PREVIOUS FORMULATION, SEE PNI A, SAME NSN.
===
Physical/Chemical Properties
===
HCC: B1
NRC/State LIC No: NOT RELEVANT
Vapor Pres: UNKNOWN
Vapor Density: UNKNOWN
Spec Gravity: 1.08 - 1.26
PH: >11
Viscosity: UNKNOWN
Evaporation Rate & Reference: UNKNOWN
Solubility in Water: MISCIBLE
Appearance and Odor: GREENISH-YELLOW LIQUID; CHLORINE ODOR
Percent Volatiles by Volume: 88- 95
Corrosion Rate: UNKNOWN
===
Reactivity Data
===
Stability Indicator: YES
Stability Condition To Avoid: HIGH HEAT, SUNLIGHT, ULTRA-VIOLET LIGHT
Materials To Avoid: ACIDS, OXIDIZING AGENTS, IRON, COPPER, AMMONIUM COMPOUNDS, ORGANICS
Hazardous Decomposition Products: CHLORINE GAS
Hazardous Polymerization Indicator: NO
Conditions To Avoid Polymerization: NOT RELEVANT
===
Toxicological Information
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Ecological Information
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===
MSDS Transport Information
===
===
Regulatory Information
===
===
Other Information
===
===
Transportation Information
===
Responsible Party Cage: 99530
Trans ID NO: 100231
Product ID: SODIUM HYPOCHLORITE,7-15 %,CPE 622680
MSDS Prepared Date: 04/23/1997
Review Date: 01/27/1998
MFN: 2
Radioactivity: NOT RELEVANT
Net Unit Weight: 468-546 LBS
Multiple KIT Number: 0
Review IND: Y
Unit Of Issue: DR
Container QTY: 0
Type Of Container: DRUM
Additional Data: PROPER SHIPPING NAME, HAZARD CLASS, UN ID NUMBER AND
PACKAGING GROUP PER MSDS. REPORTABLE QUANTITY (RQ) 100 LBS
===
Detail DOT Information
===
DOT PSN Code: HNU
DOT Proper Shipping Name: HYPOCHLORITE SOLUTION
Hazard Class: 8
UN ID Num: UN1791
DOT Packaging Group: III
Label: 8
Special Provision: B104,N34,T7
Packaging Exception: 154
Non Bulk Pack: 203
Bulk Pack: 241
Max Qty Pass: 5 L
Max Qty Cargo: 60 L
Vessel Stow Req: B
Water/Ship/Other Req: 26

```
=======================================================
Detail IMO Information
=======================================================
IMO PSN Code: IKL
IMO Proper Shipping Name: HYPOCHLORITE SOLUTION
IMDG Page Number: 8186
UN Number: 1791
UN Hazard Class: 8
IMO Packaging Group: II/III
Subsidiary Risk Label: -
EMS Number: 8-08
MED First Aid Guide NUM: 741
=======================================================
Detail IATA Information
=======================================================
IATA PSN Code: NYC
IATA UN ID Num: 1791
IATA Proper Shipping Name: HYPOCHLORITE SOLUTION +
IATA UN Class: 8
IATA Label: CORROSIVE
UN Packing Group: III
Packing Note Passenger: 819
Max Quant Pass: 5L
Max Quant Cargo: 60L
Packaging Note Cargo: 821
=======================================================
Detail AFI Information
=======================================================
AFI PSN Code: NYC
AFI Proper Shipping Name: HYPOCHLORITE SOLUTIONS
AFI PSN Modifier: WITH MORE THAN 5% BUT LESS THAN 16% AVAILABLE CHLORINE
AFI Hazard Class: 8
AFI UN ID NUM: UN1791
AFI Packing Group: III
Special Provisions: P5, N34
Back Pack Reference: A12.3
```

===
HAZCOM Label
===
Product ID: SODIUM HYPOCHLORITE,7-15 %,CPE 622680
Cage: 99530
Company Name: OLIN CORPORATION
Street: 501 MERRITT 7
PO Box: 4500
City: NORWALK CT
Zipcode: 06856-4500
Health Emergency Phone: 800-654-6911/203-356-2000
Label Required IND: Y
Date Of Label Review: 12/09/1997
Status Code: C
MFG Label NO: UNKNOWN
Label Date: 12/09/1997
Year Procured: 1998
Origination Code: G
Eye Protection IND: YES
Skin Protection IND: YES
Signal Word: WARNING
Respiratory Protection IND: YES
Health Hazard: Moderate
Contact Hazard: Moderate
Fire Hazard: None
Reactivity Hazard: None
Hazard And Precautions: TARGET ORGANS:EYES, SKIN, RESPIRATORY & GI TRACTS. ACUTE- CORROSIVE. MAY CAUSE EYE & SKIN IRRITATION & BURNS. VAPORS IRRITATING TO RESPIRATORY TRACT. HARMFUL IF INHALED/SWALLOWED. MAY CAUSE GI TRACT BURNS. CHRONIC- MAY CAUSE LUNG DAMAGE. STORE AWAY FROM INCOMPATIBLES. ABSORB SPILL WITH VERMICULITE. PLACE IN A CONTAINER FOR DISPOSAL. CLEAN AREA TO REMOVE RESIDUAL CONTAMINATION. FIRST AID- GET MEDIC AL HELP IF SYMPTOMS PERSIST. INHALED:MOVE TO FRESH AIR. PROVIDE CPR/OXYGEN IF NEEDED. EYES/SKIN:IMMEDIATELY FLUSH WITH WATER FOR 15 MINUTES. HOLD EYELIDS OPEN. ORAL:DO NOT INDUCE VOMITING. IF CONSCIOUS, DRINK PLENTY OF WATER. CALL PHYSICIAN AT ONCE.
===

Hypochlorite Practice Math Problems

1. **In 24 hours, 4.2 gallons of 12% hypochlorite solution is fed. How much (in gallons) would you have to use if the concentration was 7%?**
   a. 2.4 gallons
   b. 5 gallons
   c. 7.2 gallons
   d. 10.1 gallons

Step 1: Set up math equation: 4.2 gal X 12% = ? x 7%

Step 2: Divide both sides by 7% to get **? gal** alone on the right side of the equation

$$\frac{4.2 \text{ gal}}{7\%} \times 12\% = ? \text{ gal} \times \frac{\cancel{7\%}}{\cancel{7\%}}$$

Step 3: Multiply 4.2 X 12 = 50.4 in the numerator

Step 4: Perform the division: 50.4 ÷ 7 = 7.2 gallons See 3-12 WB for complete explanation

2. **In 10 hours, you feed 3.5 gallons of 12.5% hypochlorite solution. How many gallons would you have to use if the concentration is 6%?**
   a. 7.3 gallons
   b. 3.7 gallons
   c. 1.4 gallons
   d. 0.9 gallons

Step 1: Set up math equation: 3.5 gal X 12.5% = ? x 6%

Step 2: Divide both sides by 6% to get **? gal** alone on the right side of the equation

$$\frac{3.5 \text{ gal}}{6\,\cancel{\%}} \times 12.5\cancel{\%} = ? \text{ gal} \times \frac{\cancel{6\%}}{\cancel{6\%}}$$

Step 3: Multiply 3.5 X 12.5 = 43.75 in the numerator

Step 4: Perform the division: 43.75 ÷ 6 = 7.3 gallons

See 3-12 WB for complete explanation

3. **A plant flow is set at 2.2 MGD. The chlorine dose needs to be 2.0 mg/L. How many pounds of 12.5% sodium hypochlorite can the system expect to use each day?**
   a. 294 pounds
   b. 37 pounds
   c. 0.3 pounds
   d. 30 pounds

Step 1: Solve for feed rate of 100% pure chemical by using lbs/day = (2.2) (2.0) (8.34) = 36.69
Step 2: Calculate # of pounds of 12.5% by dividing Step 1 feed rate by purity as a decimal:

$$\frac{36.69 \text{ pounds}}{0.125} = 293.5 \text{ pounds}$$ of 12.5% sodium hypochlorite.

See 3-17 WB for complete explanation

4. **A system needs to determine how many pounds of 12.5% sodium hypochlorite they will use when the plant is set at a flow of 375,000 gpd. They need to maintain a chlorine dosage of 1.5 mg/L**.
   a. 4.7 pounds
   b. 47 pounds
   c. 37.5 pounds
   d. 3.8 pounds

Step 1: Convert gpd to MGD: 375,000 ÷ 1,000,000 = .375 MGD
Step 2: Solve for feed rate of 100% pure chemical by using lbs/day = (.375) (1.5) (8.34) = 4.69
Step 3: Calculate # of pounds of 12.5% by dividing Step 2 feed rate by purity as a decimal:

$$\frac{4.69 \text{ pounds}}{0.125} = 37.5 \text{ pounds}$$ of 12.5% sodium hypochlorite.

See 3-19 WB for complete explanation

5. **A tank contains 575,000 gallons of water. This water is to receive a chlorine dose of 2.2 mg/L. How many pounds of calcium hypochlorite (65% available) will be required for this disinfection**?
   a. 16.2 pounds
   b. 10,550 pounds
   c. 10.55 pounds
   d. .162 pounds

Step 1: Convert gpd to MGD: 575,000 ÷ 1,000,000 = .575 MGD

Step 2: Solve for feed rate of 100% pure chemical by using lbs = (.575) (2.2) (8.34) = 10.55

Step 3: Calculate # of pounds of 65% by dividing Step 2 feed rate by purity as a decimal:

$\frac{10.55 \text{ pounds}}{0.65}$ = 16.2 pounds of 65% calcium hypochlorite

See 3-20 WB for complete explanation

6. **Calculate the amount of chlorine required to dose an 800,000 gallon storage tank to a dose of 5 mg/L. You believe it is best to use granular calcium hypochlorite and the product information indicates it is 68% chlorine.**
   a. 25 pounds
   b. 33 pounds
   c. 49 pounds
   d. 60 pounds

Step 1: Convert gpd to MGD: 800,000 ÷ 1,000,000 = 0.8 MGD

Step 2: Solve for feed rate of 100% pure chemical by using lbs = (0.8) (5) (8.34) = 33.36

Step 3: Calculate # of pounds of 68% by dividing Step 2 feed rate by purity as a decimal:

$\frac{33.36 \text{ pounds}}{0.68}$ = 49 pounds of 68% calcium hypochlorite.

See 3-20 WB for complete explanation

7. After cleaning, a system needs to disinfect a 750,000 gallon storage tank. The system has decided on a dose of 25 mg/L. How many pounds of 68% calcium hypochlorite would they need to purchase for the job?

a. 30 pounds
b. 75 pounds
c. 156 pounds
d. 230 pounds

Step 1: Convert gpd to MGD: 750,000 ÷ 1,000,000 = .75 MGD

Step 2: Solve for feed rate of 100% pure chemical by using lbs = (.75) (25) (8.34) = 156.37

Step 3: Calculate # of pounds of 68% by dividing Step 2 feed rate by purity as a decimal:

$\frac{156.37 \text{ pounds}}{0.68}$ = 229.9 pounds of 68% calcium hypochlorite.

See 3-20 WB for complete explanation

8. How many pounds of chlorine would be needed to disinfect a 700,000 gallon tank that is $^{2}/_{3}$ full? It has been determined it needs dosed to 5 mg/l.

a. 19.5 lbs
b. 29.2 lbs
c. 9.7 lbs
d. 39.5 lbs

Step 1: Calculate volume of tank that is not 100% full by multiplying volume by the fraction (or its equivalent decimal):

700,000 X $\frac{2}{3}$ = 466200 gallons OR 700,000 x 0.66 = 466200 gallons

Step 2: Convert gpd to MGD: 466200 ÷ 1,000,000 = 0.4662 MGD

Step 3: Solve for feed rate of 100% pure chemical by using lbs = (0.4662) (5) (8.34) = 19.4 lbs

See 3-22 WB for complete explanation

9. **A treatment plant uses sodium hypochlorite (12%) to disinfect the water. The target dose is 0.8 mg/L. They treat 250,000 gpd. How many pounds of sodium hypochlorite will they need to feed?**
   a. 14 pounds
   b. 10 pounds
   c. 4.3 pounds
   d. 1.7 pounds

Step 1: Convert gpd to MGD: 250,000 ÷ 1,000,000 = 0.25 MGD

Step 2: Solve for feed rate of 100% pure chemical by using lbs/day = (0.25) (0.8) (8.34) = 1.67

Step 3: Calculate # of pounds of 12% by dividing Step 2 feed rate by purity as a decimal:

$\frac{1.67 \text{ pounds}}{0.12}$ = 13.9 pounds of 12% sodium hypochlorite.

See 3-23 WB for complete explanation

10. **A treatment plant uses 12.5% hypochlorite to disinfect the water. The required hypochlorite dosage is 2 mg/L and the plant flow is 300,000 gpd. How many gallons of 12.5% hypochlorite are required (12.5% hypo has 1.25 lbs/gal available chlorine)?**
    a. 5.1 gallons
    b. 4 gallons
    c. 12 gallons
    d. 400 gallons

Step 1: Convert gpd to MGD: 300,000 ÷ 1,000,000 = 0.30 MGD

Step 2: Solve for feed rate of 100% pure chemical by using lbs/day = (0.30) (2.0) (8.34) = 5 lbs/day

Step 3: Convert to gallons using the available chlorine (unit cancellation):

$\frac{\text{? gallons}}{\text{Day}} = \frac{\text{1 gal}}{\text{1.25 lbs}} \times \frac{\text{5 lbs}}{\text{day}}$ = 4 gallons/day

See 3-25 WB for complete explanation

11. The chlorine demand of the water is 1.4 mg/L. If the desired chlorine residual is 0.5 mg/L, what is the desired chlorine dose, in mg/L?

a. 0.9 mg/L
b. 1.3 mg/L
c. 1.5 mg/L
d. 1.9 mg/L

Step 1: Dose = demand + residual (.5 + 1.4) = 1.9 mg/L

See 3-31 WB for complete explanation

12. At a flow rate of 375 gpm, how many pounds of 67% calcium hypochlorite would be required to maintain a 0.8 mg/L chlorine residual in the finished water if the chlorine demand is 0.8 mg/L?

a. 3.6 pounds
b. 5.4 pounds
c. 7.2 pounds
d. 10.8 pounds

Step 1: Calculate dose by adding demand + residual (0.8 + 0.8) = 1.6 mg/L

Step 2: Convert gpm to MGD

$$\frac{?\text{MG}}{\text{day}} = \frac{1\text{ MG}}{1{,}000{,}000\text{ gal}} \times \frac{375\text{ gal}}{\text{min}} \times \frac{1440\text{ min}}{\text{day}} = 0.54\text{ MGD}$$

Step 3: Solve for feed rate of 100% pure chemical by using lbs/day = (0.54) (1.6) (8.34) = 7.2

Step 4: Calculate # of pounds of 67% by dividing Step 3 feed rate by purity as a decimal:

$$\frac{7.2\text{ pounds}}{0.67} = 10.8\text{ pounds}$$ of 67% calcium hypochlorite.

See 3-32 WB for complete explanation (step 5 not needed)

13. A system needs to maintain a chlorine residual of 0.8 mg/L. The chlorine demand is 1.2 mg/L and the plant flow is set at 500 gpm. How many pounds of 65% calcium hypochlorite would the system expect use in 8 hours?

a. 12 pounds
b. 6 pounds
c. 9 pounds
d. 11 pounds

Step 1: Calculate dose by adding demand + residual (1.2 + 0.8) = 2.0 mg/L

Step 2: Convert gpm to MGD

$$?\frac{MG}{day} = \frac{1\ MG}{1{,}000{,}000\ gal} \times \frac{500\ gal}{min} \times \frac{1440\ min}{day} = 0.72\ MGD$$

Step 3: Solve for feed rate of 100% pure chemical by using lbs/day = (0.72) (2) (8.34) = 12

Step 4: Calculate # of pounds of 65% by dividing Step 3 feed rate by purity as a decimal:

$\frac{12\ pounds}{0.65}$ = 18.4 pounds of 65% calcium hypochlorite.

Step 5: Calculate pounds needed for 8 hours

$$?lbs = \frac{18.4\ lbs}{day} \times \frac{1\ day}{24\ hrs} \times \frac{8\ hrs}{1} = 6.1\ lbs\ in\ 8\ hours$$

See 3-32 WB for complete explanation

14. How many gallons of 15% sodium hypochlorite (1.4 lbs/gal available chlorine) are required to treat 750,000 gpd with a desired chlorine residual of 0.8 mg/L and a demand of 0.6 mg/L?

a. 2 gallons
b. 4 gallons
c. 6 gallons
d. 8 gallons

Step 1: Calculate dose by adding demand + residual (0.8 + 0.6) = 1.4 mg/L

Step 2: Convert gpd to MGD: 750,000 ÷ 1,000,000 = 0.75 MGD

Step 3: Solve for feed rate of 100% pure chemical by using lbs/day = (0.75) (1.4) (8.34) = 8.76

Step 4: Use unit cancellation to convert lbs/day to gallons/day

Density of 15% hypo solution

Feed Rate

$$\frac{?\,gal}{day} = \frac{1\ gallon}{1.4\ lbs} \times \frac{8.76\ lbs}{day} = \frac{6.25\ gal}{day}$$

See 3-34 WB for complete explanation

15. How many gallons of 12½% sodium hypochlorite are required to treat 750,000 gpd with a desired residual of 1.2 mg/L and a chlorine demand of 0.5 mg/L? (note, 12½% has 1.2 lbs/gal available chlorine)

a. 7 gal/day

b. 9 gal/day

c. 11 gal/day

d. 13 gal/day

Step 1: Calculate dose by adding demand + residual (0.5 + 1.2) = 1.7 mg/L

Step 2: Convert gpd to MGD: 750,000 ÷ 1,000,000 = 0.75 MGD

Step 3: Solve for feed rate of 100% pure chemical by using lbs = (0.75) (1.7) (8.34) = 10.63

Step 4: Use unit cancellation to convert lbs/day to gallons/day

Density of 12.5% hypo solution

Feed Rate

$$\frac{?\,gal}{day} = \frac{1\ gallon}{1.2\ lbs} \times \frac{10.63\ lbs}{day} = \frac{8.8\ gal}{day}$$

See 3-34 WB for complete explanation

16. A plant is set at a flow rate of 3 MGD. Water enters into a clearwell that has a volume of 55,000 gallons. The chlorine residual of the outlet end of the tank is 1.4 mg/L. What is the CT in mg-min/L?

a. 25

b. 180

c. 37

d. 203

Step 1: Convert flow rate from MGD to gpm

$$\frac{?\,gal}{min} = \frac{1{,}000{,}000\ gal}{1\ MG} \times \frac{3\ MG}{day} \times \frac{1\ day}{1440\ mins} = \frac{2083.3\ gal}{mins}$$

Step 2: Calculate detention time using the formula:

Detention Time (time) = Volume / Flow = 55,000 gallons / 2083.3 gpm = 26.4 minutes

Step 3: Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = disinfectant concentration x contact time

CT = 1.4 mg/L x 26.4 minutes = 36.9 mg-min/L

See 3-38 WB for complete explanation

17. A free chlorine residual of 1.7 mg/L is measured at the end of the clearwell after 4 hours of detention time, what is the CT value in mg-min/L?

a. 6.8 mg-min/L
b. 80 mg-min/L
c. 240 mg-min/L
d. 408 mg-min/L

Step 1: Convert 4 hours into minutes (4 X 60) = 240 mins

Step 2: Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = disinfectant concentration x contact time

CT = 1.7 mg/L x 240 minutes = 408 mg-min/L

See 3-36 WB for complete explanation

18. A plant is set at a flow rate of 2 MGD. Water enters into a clearwell that has a volume of 50,000 gallons. The chlorine residual of the outlet end of the tank is 0.9 mg/L. What is the CT in mg-min/L?

a. 11 mg-min/L
b. 22.5 mg-min/L
c. 32 mg-min/L
d. 44.5 mg-min/L

Step 1: Convert flow rate from MGD to gpm

?gal / min = 1,000,000 gal / 1 ~~MG~~ x 2 ~~MG~~ / ~~day~~ x 1 ~~day~~ / 1440 mins = 1388.8 gal / mins

Step 2: Calculate detention time using the formula:

Detention Time (time) = Volume / Flow = 50,000 gallons / 1388.8 gpm = 36 minutes

Step 3: Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = 0.9 mg/L x 36 minutes = 32.4 mg-min/L See 3-38 WB for complete explanation

19. If the free chlorine residual of 1.8 mg/L is measured at the end of the clearwell after 3 hour of detention time, what is the CT value in mg-min/L?

a. 5 mg-min/L
b. 75 mg-min/L
c. 176 mg-min/L
d. 324 mg-min/L

Step 1: Convert 4 hours into minutes (3 X 60) = 180 mins

Step 2: Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = disinfectant concentration x contact time

CT = 1.8 mg/L x 180 minutes = 324 mg-min/L

See 3-36 WB for complete explanation

20. If the free residual of 1.8 mg/L is measured at the entry point of the system, after 5 hours of detention time, what is the CT value in mg-min/L?

a. 16 mg-min/L
b. 95 mg-min/L
c. 275 mg-min/L
d. 540 mg-min/L

Step 1: Convert 4 hours into minutes (5 X 60)= 300 mins

Step 2: Insert disinfectant residual concentration and contact time (in minutes) into CT equation and multiply the values.

CT = disinfectant concentration x contact time

CT = 1.8 mg/L x 300 minutes = 540 mg-min/L

See 3-36 WB for complete explanation

21. In 18 hours, you use 6 gallons of 15% sodium hypochlorite. How much (gallons) would you have to use if the concentration is 7%.

a. 3 gallons
b. 10 gallons
c. 13 gallons
d. 16 gallons

Step 1: Set up math equation: 6 gal X 15% = ? x 7%

Step 2: Divide both sides by 7% to get ? gal alone on the right side of the equation

$$\frac{6\ \text{gal} \times 15\%}{7\%} = ?\ \text{gal} \times \frac{\cancel{7\%}}{\cancel{7\%}}$$

Step 3: Multiply 6 X 15 = 90 in the numerator

Step 4: Perform the division: 90 ÷ 7 = 12.8 gallons

See 3-12 WB for complete explanation

22. A system is using 12.5% sodium hypochlorite to disinfect at a dose of 1.5 mg/L. When the plant flow is set at 550,000 gpd, how many pounds of sodium hypochlorite should they expect to use?

a. 7 pounds
b. 35 pounds
c. 55 pounds
d. 155 pounds

Step 1: Convert gpd to MGD: 550,000 ÷ 1,000,000 = 0.55 MGD

Step 2: Solve for feed rate of 100% pure chemical by using lbs/day = (0.55) (1.5) (8.34) = 6.89

Step 3: Calculate # of pounds of 12.5% by dividing Step 2 feed rate by purity as a decimal

$$\frac{6.89}{0.125} = \text{55 lbs of 12.5\% sodium hypochlorite.}$$

See 3-23 WB for complete explanation

A Module 25 answer key is available at the following website link:
http://www.depweb.state.pa.us/operatorcenter/

In the right hand menu click "Training", then "DEP Training Modules"