

Drinking Water Operator Certification Training



Module 22: Inorganics Removal Basics

Revised December 2015

This course module was developed by the Pennsylvania Department of Environmental Protection. Content sources are referenced at the end of every module unit.

(Note: Web links in the pdf version of this document are not hyper-linked directly to the web address.)

DISCLAIMER:

This module was designed as a training module for Pennsylvania drinking water operators to study prior to taking the drinking water subclass 9 ion exchange and greensand exam. The focus of this exam is the removal of inorganic constituents from drinking water using the treatment processes ion exchange or greensand filtration.

As a result, this training module focuses on the treatment methods of ion exchange units and greensand filters. In addition, there is a focus on the removal of some of the inorganic contaminants common in Pennsylvania groundwater systems: nitrates, iron, and manganese. Since arsenic, barium and mercury, may sporadically be found in Pa. groundwater, treatment options for these contaminants will also be mentioned in this module. Water softening is also discussed.

Note that since lead and copper treatment is covered in Module 20: Corrosion Control and Sequestering, treatment of those inorganic contaminants is not discussed in this module.

The 2006 version of the Pa. DEP Inorganic Contaminant Removal module has detailed advanced treatment information on this topic and can be obtained by e-mailing the Pa. DEP Safe Drinking Water Training Section at DEPWSTechtrain@pa.gov to request a copy. This advanced module has additional information on the removal of various inorganic contaminants as well as on oxidation, ion exchange, activated alumina and sequestration. The 2006 document also includes more detailed information on the inorganic contaminant treatments of GAC (granular activated carbon), coagulation/filtration, membranes, and lime softening. It includes the following information:

- Inorganic contaminant treatment selection considerations
- Advanced inorganic contaminant removal chemistry terminology
- Advanced inorganic contaminant removal chemistry explanations
- Conventional filtration and how it relates to inorganic removal
- Detailed information on treatments for iron and manganese removal
- Detailed information on treatments for hardness removal
- Detailed information on inorganic contaminant monitoring protocols
- Detailed tables on the following topics:
 - Sources of 26 inorganic contaminants
 - Common secondary standards with effects, inorganic contributors and indications
 - Various treatment technology options to consider for 24 inorganic contaminants
 - Potential forms of iron and manganese
 - Iron and manganese sampling procedures
 - Iron and manganese oxidant selection criteria
 - Iron and manganese theoretical (initial) dosing criteria
 - Potential treatments for less common inorganics
 - Potential treatments for miscellaneous trace metals

Unit 1: Inorganic Contaminant Basics

- I. Basic Inorganic Definitions
- II. Primary Inorganic Contaminants
- III. Secondary Contaminants

Unit 2 - Basic Math Review

- I. Complex Multiplication and Division
- II. Algebra Problems
- III. Unit conversions
- IV. Filter Surface Area
- V. Filter Volume

Unit 3 – Inorganic Removal Chemistry

- I. Basic Inorganic Removal Chemistry
- II. Inorganic Removal Chemicals
- III. pH Influence
- IV. Water Temperature Influence

Unit 4 –Inorganic Treatments

- I. Treatment Definitions
- II. Treatment Considerations
- III. Treatment Methods
 - A. Sequestration
 - B. Ion Exchange
 - C. Oxidizing Filters
 - D. Other Methods
- IV. Treatment Consideration Example

Unit 5 - Inorganic Filter Calculations

- I. Filter Loading Rate Calculations
- II. Filter Media Volume Calculations
- III. Ion Exchange Brine Calculation

Unit 6 – Inorganic Treatment Maintenance

- I. Ion Exchange Unit Maintenance
- II. Media Filter Maintenance

Appendices

Appendix A: Pennsylvania Safe Drinking Water Maximum Contaminant Level (MCL) List

Appendix B: Sources of Inorganic Contaminants

Appendix C: Treatment Technology Options

Appendix D: Inorganic Removal Pre-Test

(Note: The information in Appendices A, B, & C is important inorganic contaminant reference material. However, the information in these 3 Appendices is not on the exam.)

Unit 1 – Inorganic Contaminant Basics

Learning Objectives

At the end of this unit, you should be able to:

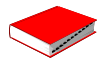
- Explain how a primary and a secondary inorganic contaminant are different.
- State a few primary inorganic contaminant concerns
- State a few secondary inorganic contaminant concerns
- Be able to reference the MCL list

Inorganic Removal Pre-Test

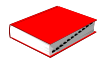
There is a 10 question pre-test at the end of the workbook in Appendix D. Please complete this pre-test now and then return to the lesson. The pre-test will help solidify a few introductory course concepts as well as review a few basic math concepts.

I. Inorganic Contaminant Definitions

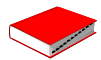
Let's start by defining a few inorganic terms.



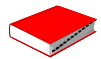
Inorganics are mineral-based compounds such as metals, nitrates, and asbestos that do not contain organic materials.



Maximum Contaminant Level (MCL) – The maximum permissible level of a contaminant in water which is delivered to a user of a public water system.



Primary Contaminant - A compound which is regulated in drinking water because of the potential to cause a health effect.



Secondary Contaminant – A compound which is generally not considered to cause a health effect but can cause aesthetic issues (e.g. taste, odor, color of water, etc.) or cosmetic issues (skin or tooth discoloration). As a result, this contaminant is monitored in drinking water and a maximum



contaminant level has been established. The word “secondary” indicates it is not a contaminant that generally causes an adverse health effect.

II. Primary Inorganic Contaminants

As stated in the definitions above, inorganic contaminants of concern in drinking water are separated into primary and secondary contaminants. The primary contaminants can have potential health effects, whereas the secondary inorganic contaminants are mainly considered to have aesthetic (e.g. taste, odor) or cosmetic (e.g. tooth staining) effects.

Maximum Contaminant Level List

The Federal EPA regulates more than 100 biological and chemical substances, and – based on EPA research findings on health impacts - additional contaminants are periodically being regulated. EPA sets the maximum level of a contaminant that is allowed in drinking water for each substance.

Pennsylvania’s MCL list, which is adapted from EPA, is in Appendix A of this document:

Primary Inorganic Contaminant (IOC) MCL List

Below is a screen shot of the **primary** inorganic contaminants from the MCL list in Appendix A:

Inorganic Chemicals (IOCs):

ANTIMONY	0.006	mg/L	FLUORIDE	2	mg/L
ARSENIC	0.010	mg/L	LEAD **	0.005	mg/L
ASBESTOS (Fibers longer than 10µm)	7	million fibers/L	MERCURY	0.002	mg/L
BARIUM	2	mg/L	NITRATE (as Nitrogen)	10	mg/L
BERYLLIUM	0.004	mg/L	NITRITE (as Nitrogen)	1	mg/L
CADMIUM	0.005	mg/L	NITRATE + NITRITE (as Nitrogen).....	10	mg/L
CHROMIUM	0.1	mg/L	SELENIUM	0.05	mg/L
COPPER **	1.0	mg/L	THALLIUM	0.002	mg/L
CYANIDE (free CN)	0.2	mg/L			

** The lead and copper primary MCLs are applicable only to bottled, vended, retail and bulk water hauling systems

Health Effects

Why should we care about the primary inorganic contaminants mentioned above and removing them from drinking water? The answer is because consuming drinking water that contains water with excessive levels of certain inorganic contaminants can potentially result in certain health effects.

Health effects that could potentially occur from many of the primary inorganic chemical contaminants are **chronic** in nature. Chronic effects occur when a person consumes contaminated water over a long period of time.

Nitrate and Nitrite are acute contaminants which may cause certain individuals who consume this contaminant to become ill in a short period of time.

Below are listed some of the health effects related to chronic ingestion of some of the primary inorganic contaminants on the MCL list that are more common to Pennsylvania waters:

- **Arsenic** - can potentially cause skin damage or problems with circulatory systems, and may cause an increased risk of cancer.
- **Barium** - may cause an increase in blood pressure.
- **Copper** – can potentially cause stomach and intestinal distress, liver or kidney damage.
- **Lead** – can potentially cause brain, red blood cell and kidney damage especially for young children and pregnant women.
- **Mercury** – can potentially cause kidney damage.
- **Nitrate (as Nitrogen) or Nitrite (as Nitrogen)** – For infants below the age of 6 months who drink water in excess of the MCL they can potentially become seriously ill and, if untreated, die. Symptoms include shortness of breath and blue-baby syndrome.

Later in this training module drinking water treatment methods for removal of arsenic, barium, mercury, nitrate and nitrite will be mentioned. For information on drinking water treatment methods for lead and copper, see Pa. DEP Module 20: Corrosion Control and Sequestering.

Inorganic Contaminant Drinking Water Monitoring

Pennsylvania has a *self-monitoring* program, which means that water suppliers are responsible for ensuring compliance samples are collected within the appropriate monitoring period, the samples are analyzed by an accredited lab, and the results are reported correctly.

More information about compliance monitoring requirements for inorganic contaminants (IOCs) can be found as follows:

- The Pa. DEP June 2010 General Update to Chapter 109 Water Supplier Training
- IOC monitoring waiver information can be found at the link below:
<http://www.dep.pa.gov/Citizens/My-Water/PublicDrinkingWater/Pages/Monitoring-Waivers.aspx>
- For more discussion on IOC requirements for your specific regulated water facility, contact your local Pa. DEP drinking water sanitarian

Sources

Inorganic contaminants can come from a variety of sources such as:

- **Natural** - Naturally occurring mineral weathering and leaching can cause some inorganics to find their way into the water supply. For example, the occurrence of arsenic, barium, mercury, nitrate and nitrite in drinking water can occur from the erosion of natural deposits.

- **Industrial** - Industrial discharges can also be a source of inorganic contamination. For example, runoff from glass & electronics production can contain arsenic. Discharge of drilling wastes can contain barium. Discharge from factories can contain mercury.
- **Agricultural** – Runoff from agricultural activities can contain inorganic contaminants. For example, runoff from fertilizer use can contain nitrate (as nitrogen) and nitrite (as nitrogen). Runoff from orchards can contain arsenic and runoff from croplands can contain mercury..
- **Drinking Water System and Household Plumbing Corrosion** - Lead and copper enter drinking water mainly from the corrosion of lead service lines or lead and copper plumbing materials.



Unit 1, Exercise #1 – Inorganic Contaminant Basics

Directions: Choose the correct answer.

1. _____ contaminants are regulated in drinking water because of the potential to cause a health effect. (*Choose the correct answer to fill in the blank.*)
 - a. Primary
 - b. Secondary
2. _____ contaminants are mainly considered to have aesthetic (e.g. taste, odor) or cosmetic (e.g. tooth staining) effects. (*Choose the correct answer to fill in the blank.*)
 - a. Primary
 - b. Secondary
3. The MCL is the _____ permissible level of a contaminant in water which is delivered to a user of a public water system. (*Choose the correct answer to fill in the blank.*)
 - a. minimum
 - b. maximum
4. The main concern about **primary** inorganic contaminants in drinking water is that they can cause aesthetic effects such as taste and odor problems.
 - a. True
 - b. False
5. The source of some inorganics is the erosion of natural deposits.
 - a. True
 - b. False

III. Secondary Contaminants

Secondary Contaminant MCL List

The MCL list also includes secondary contaminants. Secondary Contaminant list (also in Appendix A):

SECONDARY CONTAMINANTS

ALUMINUM	0.2	mg/L	MANGANESE	0.05	mg/L
CHLORIDE	250	mg/L	ODOR	3 T.O.N	
COLOR	15 color units		pH *	6.5 - 8.5	
CORROSIVITY	non-corrosive		SILVER	0.1	mg/L
FOAMING AGENTS	0.5	Mg/L	SULFATE	250	mg/L
IRON	0.3	Mg/L	TOTAL DISSOLVED SOLIDS	500	mg/L
			ZINC	5	mg/L

*The pH MCL represents a "reasonable goal for drinking water quality."

Secondary Contaminant Monitoring

Monitoring for secondary contaminants is required by the state of Pennsylvania. However, routine monitoring for the secondary contaminants is not required. These contaminants are monitored during sampling of a new source. If the secondary MCLs are exceeded, abatement is required via treatment or non-treatment (e.g. blending) methods. If the Pa. DEP has reason to believe secondary contaminants are being exceeded, routine monitoring can then be required.

Secondary Contaminant Effects

As mentioned earlier, the secondary contaminants are mainly considered to have aesthetic (e.g. taste, odor) or cosmetic (e.g. tooth staining) effects.

In addition to aesthetic effects, some secondary MCL exceedances have the potential to cause more serious adverse effects, including:

- Damage to water equipment
- Increased corrosion rates which may increase leaching of lead and copper and/or weaken distribution system pipes (i.e. more water line breaks).
- Reduced effectiveness of treatment for other contaminants
- Adverse health effects

For example, high total dissolved solids (TDS) levels increase corrosion rates, interfere with various treatment processes (e.g. membrane filtration) and may cause laxative-like effects in humans (e.g. loose stool and diarrhea).

Inorganics Common to Pennsylvania Waters

The following inorganic contaminants are common in Pennsylvania waters: lead, nitrates, and iron, plus those that contribute to corrosivity (which are copper, iron, manganese and zinc).

Arsenic may sporadically be found in Pennsylvania waters, whether from natural deposits or man-made activities, so treatment options for this contaminant will also be mentioned in this module.

Sources of Common Pa. Secondary Contaminants

The natural geology of Pennsylvania can be a source of iron and manganese. These two metals are especially common in Pennsylvania groundwater in the northern and western area of the state. Zinc can also be naturally occurring.

- **Aesthetic effects**

The aesthetic effects of the common Pa. secondary inorganic groundwater contaminants – when they occur in drinking water above the MCL - are as follows:

- **Iron** – rusty colored water; sediment; metallic taste; reddish or orange staining of plumbing fixtures, laundry, etc.
- **Manganese** – black to brown colored water; bitter metallic taste; black staining of plumbing fixtures, laundry, etc.
- **Zinc** - Metallic taste

- **Other effects**

Excess iron can also have other effects – such as corrosion - on water treatment and plumbing issues. It can also cause damage to water equipment and reduce effectiveness of water treatment for other contaminants.

Additional Inorganic Source Reference Table

Sources of additional inorganics are summarized in a reference table in Appendix B. This table may be helpful if your public water system is located in an area that has specific industrial (e.g. mining, petroleum, or factory related) or agricultural activities.



Unit 1 Exercise #2 – Inorganic Contaminant Basics

Directions: Choose the correct answer unless otherwise specified.

1. In Pennsylvania, who is responsible for ensuring that samples for inorganic contaminants are collected, analyzed, and that the results are reported?
 - a. The water supplier
 - b. Pennsylvania DEP
 - c. PA Dept. of Health
 - d. River Basin Commission
2. Excess iron in the drinking water can potentially cause which of the following aesthetic issues: *(Choose all that apply)*
 - a. Reddish or orange staining of laundry
 - b. Cancer
 - c. Metallic taste
 - d. Sediment
3. Typically, how often are community water systems in Pennsylvania required to monitor for secondary contaminants? *(Choose the best answer)*
 - a. Monthly
 - b. During sampling of a new source
 - c. Annually
 - d. Every 3 years
4. Excess manganese in the drinking water can potentially cause which of the following aesthetic issues: *(Choose all that apply)*

- a. Black to brown colored water
- b. Metallic taste
- c. Black staining of plumbing fixtures
- d. Reddish-orange staining of laundry

5. Excess iron in drinking water can also have “technical effects” on water treatment and plumbing issues. It can also cause damage to water equipment and reduce effectiveness of water treatment for other contaminants.

- a. True
- b. False



Unit 1 Key Points:

- ✚ Primary inorganic contaminants are monitored because they have the potential to cause health effects.
- ✚ Secondary contaminants are monitored because they can cause aesthetic or cosmetic issues.
- ✚ Excess nitrate or nitrite in water can immediately cause health effects for infants under 6 years of age.
- ✚ Excess iron and manganese in drinking water can give the water a metallic taste and can stain plumbing fixtures and laundry.

Unit 1 References:

Definitions:

- MCL definition taken from Pennsylvania Code, Title 25 Chapter 109 - §109.1 Definitions
- Primary contaminant definition by W. Lloyd from Pa. DEP
- Secondary contaminant definition by W. Lloyd from Pa. DEP; wording from the CDC site was also used from: <http://www.cdc.gov/healthywater/drinking/public/regulations.html> .

Primary IOC Health effects:

- Arsenic, barium, mercury, nitrate and nitrite health effects taken from Pa. DEP June 2010 General Update to Chapter 109 Water Supplier Training IOC table on pp. 2A-2 and 2A-3.
- Copper and lead health effects taken from the Pa. DEP Lead and Copper Quick Reference Guide; a link to this guide can be found at: <http://www.dep.pa.gov/Business/Water/BureauSafeDrinkingWater/DrinkingWaterMgmt/Regulations/Pages/Lead-and-Copper-Rule.aspx> (scroll down on page to LCR Reference Guide; web link working as of 12-2015)
- General comment about nitrate and nitrite health effects from Pa. DEP BSDW's D. Rotz.

- Source information on arsenic, mercury, nitrate and nitrite health effects taken from Pa. DEP June 2010 General Update to Chapter 109 Water Supplier Training IOC table on pp. 2A-2 and 2A-3.
- Lead and copper source information from Pa. DEP BSDW's D. Rotz.

Secondary contaminants:

- Secondary contaminant monitoring requirements taken from Pa. DEP June 2010 General Update to Chapter 109 Water Supplier Training 2A-14 and 2A-16.
- Secondary contaminant health effects taken from Pa. DEP June 2010 General Update to Chapter 109 Water Supplier Training 2A-15.
- Common Pennsylvania groundwater system inorganics information taken from Penn State Extension web site private water system FAQs at <http://extension.psu.edu/natural-resources/water/drinking-water/faqs> (scroll down on page to water quality question; web link working as of 8-2015)
- Prevalence of iron and manganese in N & W Pa. counties taken from Penn State Extension web site on iron and manganese in private water systems at:
- <http://extension.psu.edu/natural-resources/water/drinking-water/water-testing/pollutants/iron-and-manganese-in-private-water-systems> (see heading on sources of Fe and Mn; web link working as of 8-2015)
- Secondary contaminant aesthetic effects taken from Pa. DEP June 2010 General Update to Chapter 109 Water Supplier Training – table on 2A-15.
- Secondary contaminant source and water treatment effects taken from EPA's web site on corrosion and scaling in drinking water distribution systems (see individual left hand on iron at <http://www.epa.gov/nrmrl/wswrd/cr/> ; web link working as of 8-2015)

Maximum Contaminant List:

- MCL list taken from the Pa. DEP web pages at <http://www.dep.pa.gov/Business/Water/BureauSafeDrinkingWater/DrinkingWaterMgmt/Pages/default.aspx> (scroll down on page to Maximum Contaminant List; web link working as of 12-2015)

Unit 2 – Basic Math Review

Learning Objectives

At the end of this unit, you should be able to:

- Perform complex multiplication and division
- Perform basic algebra by solving for X
- Convert inches to feet (used in some filter calculations):
- Locate the correct formulas to perform the following filter surface area equations:
 - Calculate the area of a circle
 - Calculate the area of a rectangle
- Locate the correct formulas to perform the following filter volume equations:
 - Calculate the volume of a rectangular tank
 - Calculate the volume of a cylindrical tank

Note: If you took the pre-test in Appendix D and got questions 1, 5, and 9 correct, you can go directly to Unit 2, sections IV & V: Filter Surface Area and Filter Volume calculations.

I. Basic Math Review

Basic Rules for Performing Calculations

There are four general rules to remember when performing calculations:

- Rule 1: Perform calculations from left to right.
- Rule 2: Perform all arithmetic within parentheses prior to arithmetic outside the parentheses
- Rule 3: Perform all multiplication and division prior to performing all addition and subtraction.
- Rule 4: For complex division problems, follow the previous rules starting with parenthesis. Next perform all multiplication and division above the line (in the numerator) and below the line (in the denominator); then proceed with the addition and subtraction. Finally divide the numerator by the denominator.

Symbol Notes:

- A small "x" symbol denotes multiplication throughout this module.
- In the algebra segment and there-after, a capital "X" symbol denotes an unknown number.
- When 2 numbers have a backslash in between denoted by a "/" it means they are being divided (e.g. 10/2 means 10 is divided by 2.)

Basic Math Calculation - Example 1:

$$18 + 73 - 45 + 32 = 78$$

Simply calculate from left to right

Basic Math Calculations - Example 2:

$$(312 \times 4) + (27 \times 9) = 1248 + 243 = 1,491$$

Parentheses first, then add together

Basic Math Calculations - Example 3:

$$\frac{385 + (21/7) - (5 \times 13 \times 4)}{17 + 11 - (6 \times 4)} = \frac{385 + 3 - 260}{28 - 24} = \frac{128}{4} = 32$$



Unit 2, Practice #1: Basic Math Calculations:

1. $(85 \times 17) + (22 \times 12) =$

2. $\frac{(145 \times 9 \times 2) - (14 \times 9 \times 2) + 162}{(7 \times 5) - (10/2) + 150} =$

II. Algebra Problems

Algebra Problems – Solving for “X”



Algebra is a branch of mathematics that involves solving equations to determine an unknown value. Whereas arithmetic deals with specified numbers, algebra introduces quantities without fixed values, known as variables.

In this section we are reviewing basic algebra problems where we have to solve for an unknown which is X.

*Rules for Solving for an Unknown Variable (such as X)

1. X must be in the numerator.
2. X must be by itself (on one side of the equals sign).
3. Whatever you do to one side of the equation, you must do to the other side of the equation.

Let's look at an example:

$$7X = 42$$

- X is in the numerator in this equation.
- However, X is not by itself, so we need to isolate X on one side. To get rid of the 7 (which is supposed to be multiplied by the X), we divide by 7.

$$\frac{7X}{7} = \frac{42}{7}$$

- We must do the same thing to both sides of the equation, so we must divide both sides by 7. The 7's on one side of the equation than cancel out.

$$\frac{\cancel{7}X}{\cancel{7}} = \frac{42}{7} \longrightarrow X = \frac{42}{7} \longrightarrow X = 6$$

Calculating X - Example 1:

(Note: see Example #1 Question #1-#3 answers on the next page):

$$6X = 18$$

Example 1, Question #1: Is the **X** in the numerator? _____

Example 1, Question #2: Is the **X** alone on one side of the equation? _____

How do we get X alone on one side of the equation?

The answer is to divide both sides by "6" to get X alone and **treat both sides of the equation equally.**

$$\frac{\cancel{6}X}{\cancel{6}} = \frac{18}{6}$$

The 6's on the one side of the equation cancel out, so you are left with the following: $X = \frac{18}{6}$

Example 1, Question #3: What does X equal?

Answers for Example #1:

Example 1, Question #1: Is the **X** in the numerator? _____ (Answer: Yes)

Example 1, Question #2: Is the **X** alone on one side of the equation? _____ (Answer: No)

Example 1, Question #3: **X = 3**

Calculating X - Example Calculation 2

(Note: see Example #2 Question #1-#3 answers on the next page):

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

Rule 1, Example 2, Question #1: Is the **X** in the numerator? _____

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

The answer is to multiply both sides of the equation by **X**.

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

Example 2, Question #2: Once we move the **X** into the numerator on the other side of the equation, is **X then alone** on one side of the equation? _____

How do get **X** alone on one side of the equation?

The answer is to divide by 2.5 on each side of the equation so that the **X** is alone, but the equation keeps the same value.

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

The 2.5's on the one side of the equation cancel out, so you are left with the following: $X = \frac{1,000}{2.5}$

Example 2, Question #3: What does X equal?

Answers for Example #2:

Example 2, Question #1: Is the X in the numerator? _____ (Answer: No)

Example 2, Question #2: Once we move the X into the numerator on the other side of the equation, is X *then alone* on one side of the equation? _____ (Answer: No; 2.5 is still there too.)

Example 2, Question #3: $X = \underline{400}$



Unit 2, Practice #2 – Solving for X :

Directions: Solve for x in the following problems.

1. $\frac{X}{200} = 2.4$ $X = \underline{\hspace{2cm}}$

2. $10 = \frac{3000}{X}$ $X = \underline{\hspace{2cm}}$

Solving Word Algebra Problems: Finding the Correct Formula



The term “**Word problem**” is often used to describe any mathematical exercise where significant information about the problem is given as text rather than in mathematical form.

When faced with a word problem where you have to solve for X , there is usually a formula that can assist you. As a result, you don’t have to memorize standard equations, you just have to know where to locate them and how to switch them around to find what you are looking for.

Some recommendations for solving word problems (taken from Cuesta College in San Luis Obispo, CA) are as follows:

- 1- List the information you know and the information you don’t.
- 2- Search for a formula that has the items you know as well as those you don’t.
- 3- If you can change the formula around before plugging in the numbers for the item you need, do so. If not, plug in the numbers and then solve for the item you need.
- 4- Whatever is done to one side of the equation must be done to the other side of the equation. The unknown must end up on one side of the equation, by itself. If you have more than one unknown, then use the substitution or elimination method to solve the equations.
- 5- Put your answer back into the original equation to see if it is correct. If one side of the equation equals the other side of the equation, then you have the correct answer. If you do not have the correct answer, go back and try again.

III. Units of Measurement

Different formulas use different units of measurement. In solving a word problem it is important to not only determine the formula you need to use, but to also know how to convert between the units of measurement.

For example, many laboratory calculations use the metric system of weights and measures (e.g. meters for length, kilograms for weight, etc.)

The formulas we will use in the next section for calculating filter areas and volumes use the English System units of measurement as shown below. Note that these particular units of measurement are in a handout of "Formulas, Conversions, and Scientific Units" that are handed out with the Pa. drinking water and wastewater pre-certification exams. If you don't have a copy of this handout, e-mail the Pa. DEP Safe Drinking Water Training Section at DEPWSTechtrain@pa.gov to obtain a copy.

English Units
Length: foot (ft)
Area: square feet (sq ft or ft ²)
Volume: cubic feet (cu ft or ft ³)

The one conversion we will use in this training module is shown below

English Conversion
12 inches = 1 foot (12 in = 1 ft)

IV. Calculating Filter Surface Area



Area – The formula for calculation of the surface inside a particular shape

Area Formulas:

- Most filter tanks are cylindrical, square or rectangular.
- Formulas for calculating Area – final units are usually in sq. ft. or ft²:
- For a circular filter, we'll use the following formula:

$$\text{Area of a circle} = (0.785) (\text{Diameter}^2)$$

$$(\text{Note: You can also use } A = \pi r^2 \text{ which is Area} = (3.14)(\text{Radius}^2)$$

- If you are dealing with a square* or rectangular filter tank, you will use the following:

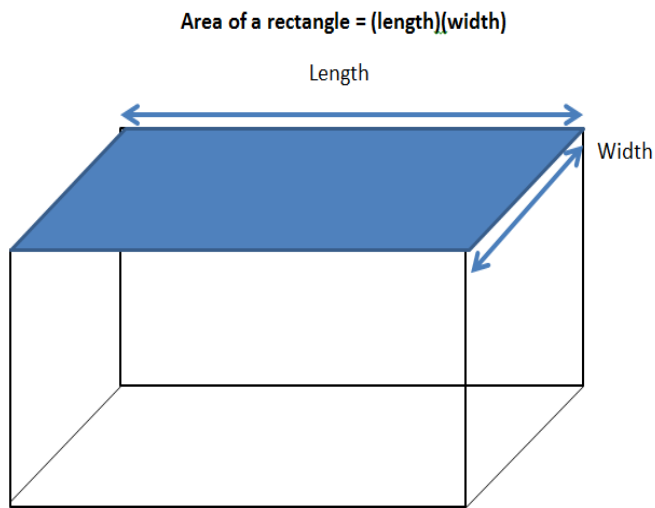
$$\text{Area of a Rectangle} = (\text{Length})(\text{Width})$$

**Note that since filters tend to be rectangular rather than square, the rest of this module will deal with the rectangular shape. In the rare case of a square filter, use the same formula you would use for a rectangle.*

Which formula do I use?

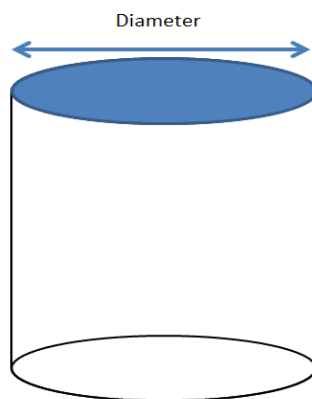
If you are given length and width to determine area, you have a rectangular filter.

In this case you are trying to find the two dimensional area in ft² of the surface of a rectangular filter (see rectangular diagram below)



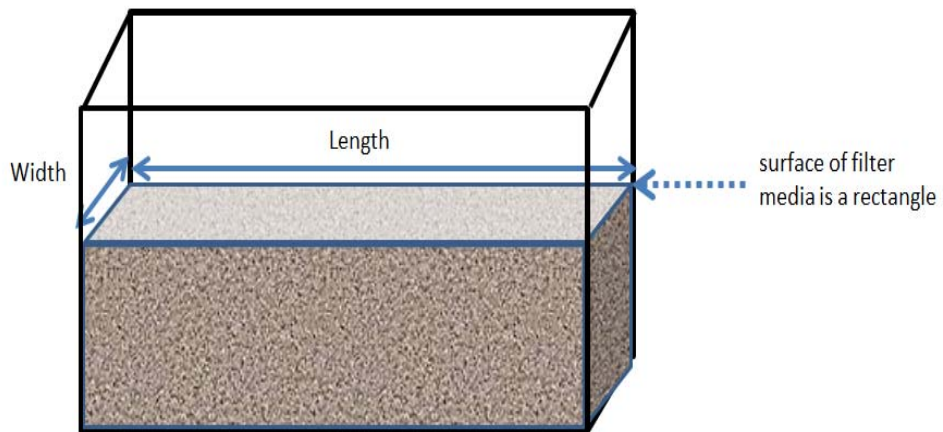
If you are given only a diameter to determine area, you have a cylindrical filter. In this case you are trying to find the two dimensional area in ft² of the 2-dimensional filter surface (see below) which would be a circle.

Area of a circle = (0.785)(Diameter²)



Filter Media Surface Area

- Calculating the surface area of filter media is the same as calculating area – final units are usually in sq. ft. or ft²:
- If you are dealing with the surface area of a rectangular filter, you will use the following:
Area of a Rectangle = (Length)(Width)
See the diagram below



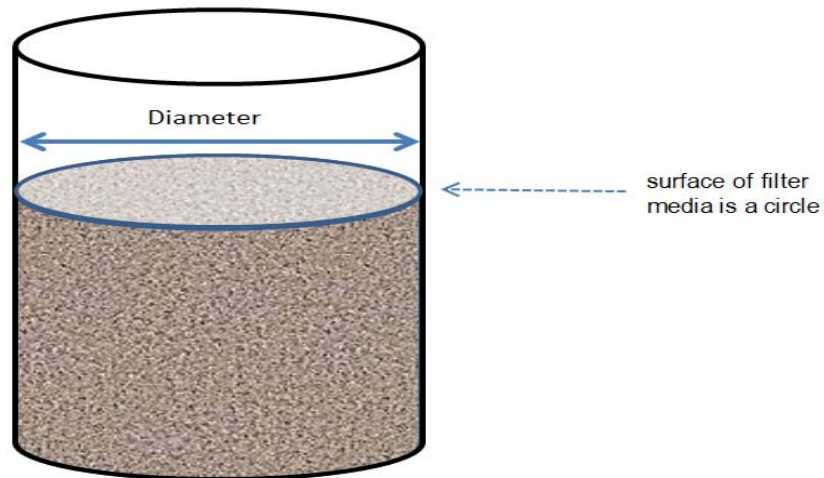
- For the surface area of media in a cylindrical filter, we'll use the following formula for a circle:

$$\text{Area of a circle} = (0.785) (\text{Diameter}^2)$$

(Note: You can also use $A = \pi r^2$ which is $\text{Area} = (3.14)(\text{Radius}^2)$)

See the diagram below

$$\text{Area of a circle} = (0.785)(\text{Diameter}^2)$$



Let's look at 2 examples.

Calculating Filter Surface Area - Example 1:

A greensand filter has a diameter of 12 feet. What is the filter surface area?

What we know:

- This problem gives us a diameter, so we know we are dealing with a circular shape.
- We need to find the surface area, which is in ft^2 .
- The formula that helps us find the area of a circle is as follows:

$$\text{Area of a circle} = (0.785)(\text{Diameter}^2)$$

We plug in the number we have:

$$\text{Area of a circle} = (0.785) [(12 \text{ feet})(12 \text{ feet})] \longrightarrow (0.785) (144 \text{ ft}^2) \longrightarrow 113 \text{ ft}^2$$

Calculating Filter Surface Area - Example 2:

A greensand filter has a length of 20 feet and a width of 35 feet. What is the filter surface area?

What we know:

- This problem gives us a length and a width, so we know we are dealing with a rectangular shape.
- We need to find the surface area, which for this filter is in ft².
- The formula that helps us find the area of a rectangle is as follows:

$$\text{Area of a rectangle} = (\text{length})(\text{width})$$

We plug in the numbers we have:

$$\text{Area of a rectangle} = (20 \text{ feet}) (35 \text{ feet}) \longrightarrow 700 \text{ ft}^2$$



Unit 2, Practice #3 – Filter Surface Area:

Directions: Choose the correct answer.

1. A greensand filter has a diameter of 20 feet. What is the filter surface area?
 - a. 40 ft²
 - b. 31.4 ft²
 - c. 314 ft²
 - d. 400 ft²
2. A mixed media filter has a length of 50 feet and a width of 456 inches. What is the filter surface area?
 - a. 80 ft²
 - b. 410 ft²
 - c. 1,900 ft²
 - d. 22,800 ft²

V. Calculating Filter Volume



Volume – The formula for calculation of the amount of a substance occupying a particular volume.

Volume Formulas

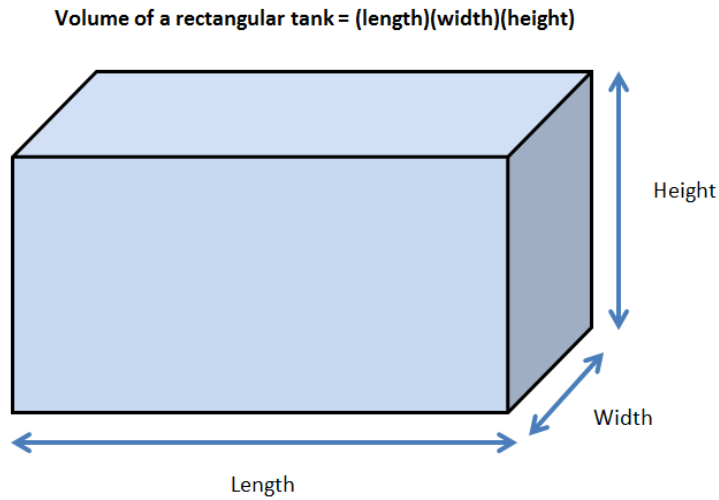
- In the switch from calculating area to calculating volume, we are literally adding a 3rd dimension. As a result, the formulas for calculating Volume have final units that are usually in cubic. ft. or ft³:

- As stated previously, most filter tanks are cylindrical or rectangular.

If you are dealing with a rectangular filter tank, you will use the following:

$$\text{Volume of a Rectangular Tank (ft}^3\text{)} = (\text{Length})(\text{Width})(\text{Height})$$

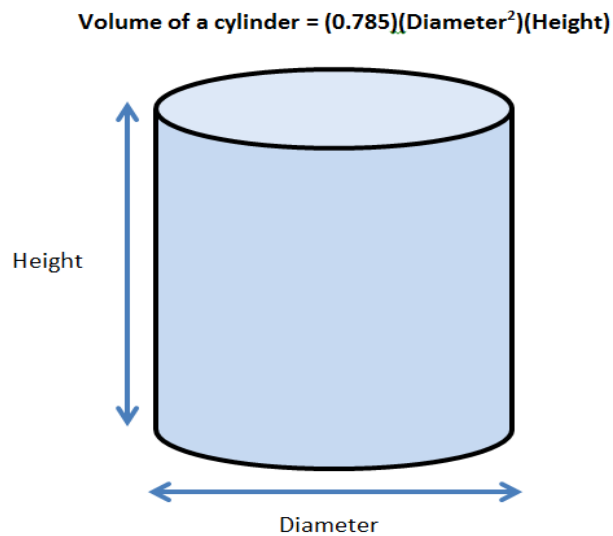
Note: In filter equations, the terms "height" and "depth" are interchangeable.



- For a cylindrical filter tank (which is a circle with a 3rd dimension added), we'll use the following formula:

$$\text{Volume of Cylinder (ft}^3\text{)} = (0.785) (\text{Diameter}^2)(\text{Height})$$

(Note: You can also use $V = \pi r^2 H$ which is Area = (3.14)(Radius²)(Height)



Which formula do I use?

If you are given length, width, and height, you have a rectangular filter.

If you are given a diameter and a height, you have a cylindrical filter.

Let's look at 2 examples.

Calculating Filter Volume - Example 1:

A mixed media filter has a length of 30 feet, a width of 10 feet and a height of 25 feet. What is the volume of the filter?

- a. 65 ft³
- b. 6,000 ft³
- c. 7,500 ft³
- d. 58,875 ft³

What we know:

- This problem asks for volume and the answer is in ft³.
- This problem gives us a length, a width, and a height, so we know we are dealing with a rectangular tank.
- The formula that helps us find the volume of a rectangle is as follows:

Volume of a rectangular tank (ft³) = (length)(width)(height)

We plug in the numbers we have:

$$\text{Volume of a rectangular tank (ft}^3\text{)} = (30 \text{ feet}) (10 \text{ feet})(25 \text{ feet}) \longrightarrow = 7,500 \text{ ft}^3$$

Calculating Filter Volume - Example 2:

A greensand filter has a diameter of 15 feet and a height of 30 feet. What is the volume of the filter?

- a. 6,750 ft³
- b. 5,299 ft³
- c. 450 ft³
- d. 353 ft³

What we know:

- This problem asks for volume and for the answer to be in ft³.
- This problem gives us a diameter, so we know we are dealing with a circular shape.
- The formula that helps us find the volume of a cylinder is:

Volume of a cylinder (ft³) = (0.785)(Diameter²)(Height)

We plug in the numbers we have:

$$\begin{aligned} \text{Volume of a cylinder} &= (0.785) [(15 \text{ feet})(15 \text{ feet})] (30 \text{ feet}) \longrightarrow (0.785) (225 \text{ ft}^2) (30 \text{ feet}) \\ &= 5,299 \text{ ft}^3 \end{aligned}$$

Calculating Filter Volume – Example 3:

A mixed media filter measures 20 feet by 15 feet by 420 inches. What is the volume of the filter?

- a. 1,050 ft³
- b. 10,500 ft³
- c. 126,000 ft³
- d. 420,000 ft³

What we know:

- This problem asks for volume and for the answer to be in ft³.
- The three measurement items indicate we are dealing with a rectangle.
- The formula that helps us find the volume of a rectangle is as follows:

Volume of a rectangular tank (ft³) = (length)(width)(height)

- One of the items is in inches, so we need to convert that to feet before proceeding further.

Step 1: Convert 420 inches into X feet, using the conversion of 12 inches = 1 foot. Let's review conversion principals:

Unknown: X feet =

$$X \text{ feet} = \frac{1 \text{ foot}}{12 \text{ inches}} \quad \leftarrow \text{Conversion}$$

$$X \text{ feet} = \frac{1 \text{ foot}}{12 \text{ inches}} \times 420 \text{ inches} \quad \leftarrow \text{Known}$$

$$X \text{ feet} = 0.0833 \text{ feet} \times 420 = 35 \text{ feet}$$

Step 2: The formula that helps us find the volume of a rectangular tank is as follows:

Volume of a rectangular tank = (length)(width)(height)

We plug in the numbers we have:

$$\text{Volume of a rectangular tank} = (20 \text{ feet}) (15 \text{ feet}) (35 \text{ feet}) \longrightarrow = 10,500 \text{ ft}^3$$



Unit 2, Practice #4 – Filter Surface Area and Volume:

Directions: Choose the correct answer.




1. A greensand filter has a length of 50 feet, a width of 30 feet and a height of 300 inches. What is the volume of the filter?
 - a. 2,355 ft³
 - b. 18,000 ft³
 - c. 37,500 ft³
 - d. 450,000 ft³

2. A greensand filter has a length of 40 feet and a width of 30 feet. What is the filter surface area?
 - a. 70 ft²
 - b. 700 ft²
 - c. 942 ft²
 - d. 1,200 ft²

3. A manganese greensand filter has a diameter of 10 feet and a height of 35 feet. What is the volume of the filter?
 - a. 2,748 ft³
 - b. 18,000 ft³
 - c. 37,500 ft³
 - d. 450,000 ft³



Unit 2 Key Points:

-  Remember to perform all arithmetic within parentheses prior to arithmetic outside the parentheses and to perform all multiplication and division prior to performing all addition and subtraction.
-  Units are important; if you have the correct math but the wrong units, the answer is wrong.
-  Most algebraic formulas can be located – you just need to practice using the formulas you need in order to solve for X.

✚ Work to get X alone on one side of the equation!

✚ For filter calculations, if you are given a diameter or a radius, then you need to use the formula for calculation of a circle (for area) or a cylinder (for volume).

Unit 2 References:

- "Basic Rules for Performing Calculations" was taken from the Pa. DEP "Overview of Basic Math" Module #28 workbook: pp. 1-8, 1-9
- Rules for solving for X taken from the following:
 - Price, Joanne Kirkpatrick. "Basic Math Concepts for Water and Wastewater Plant Operators" Lancaster: Technomic Publishing Company, Inc., 1991. Print. pp. 11-12
 - *Algebra Lab (Mainland HS Daytona Beach, FL) Solving One Step Equations" at http://www.algebralab.org/lessons/lesson.aspx?file=Algebra_OneVariableOneStep.xml*
- Laboratory Unit Conversion and Unit Cancellation Section:
 - Definitions:
 - Unit Conversion relationship concept taken from Brady, James E. and Humiston, Gerard E. "General Chemistry Principals and Structure - 3rd edition." New York: John Wiley & Sons Inc. 1982. Print. pp. 10-11 and Phoenix College Chemistry (Phoenix, AZ) web page at <http://www.pc.maricopa.edu/data/GlobalFiles/file/chemistry/lee/Unit%20Equality.pdf>
 - Vertical Format Concept taken from Pa. DEP 2013 Revised Hypochlorite Module 25 (edited by Pa. DEP's D. Rotz) pp. 3-8 and 3-9.
 - Metric System Definition and Base Unit information and table taken from Wikipedia
 - Vertical format conversion factor table created by Pa. DEP's B. McNamara
 - Steps for using unit cancellation to convert laboratory units taken from Pa. DEP 2013 Revised Hypochlorite Module 25 (edited by D. Rotz) pp. 3-8 and 3-9 and modified by B. McNamara to apply to laboratory calculations.
 - Unit conversion /unit cancellation examples and problems created by Pa. DEP's W. Lloyd. Steps for solving unit conversion /unit cancellation examples and problems taken from Pa. DEP 2013 Revised Hypochlorite Module 25 (edited by D. Rotz) pp. 3-8 and 3-9 and modified by B. McNamara to apply to laboratory calculations.
- Area and Volume:
 - Some of the definition of the term "Area" is from Merriam Webster at <http://www.wordcentral.com/cgi-bin/student?book=Student&va=area> (link working as of 8-2015); the rest was from W. Lloyd at Pa. DEP.
 - Circular area and volume calculations checked at calculateme <http://www.calculateme.com/cArea/AreaOfCircle.htm>
 - Rectangular area calculations checked at calculateme <http://www.calculateme.com/cArea/AreaOfRectangle.htm>

- Rectangular volume calculations checked at Calculator.net at:
<http://www.calculator.net/volume-calculator.html>
- Some of the definition of the term "Volume" is from Merriam Webster at <http://www.merriam-webster.com/dictionary/volume> (link working as of 8-2015); the rest was from W. Lloyd at Pa. DEP.
- Drawings and explanations of volume and area from W. Lloyd at Pa. DEP.
- Some calculations checked
at:http://www.convertme.com/en/convert/flow_rate_volume/gallon_min.html

Unit 3 – Inorganic Removal Chemistry

Learning Objectives

At the end of this unit, you should be able to:

- Match basic inorganic removal chemistry terms with definitions
- Give examples of basic types of inorganic contaminant removal chemistry processes
- Answer general questions on optimal pH levels for removal of iron and manganese based on treatment type
- Answer general questions on optimal water temperature for removal of iron and manganese based on treatment type

I. Inorganic Contaminant Removal Chemistry

Ion Exchange Chemistry

Let's start by looking at some ion exchange chemistry definitions.



Ion – An atom or a group of atoms with an electrical charge.

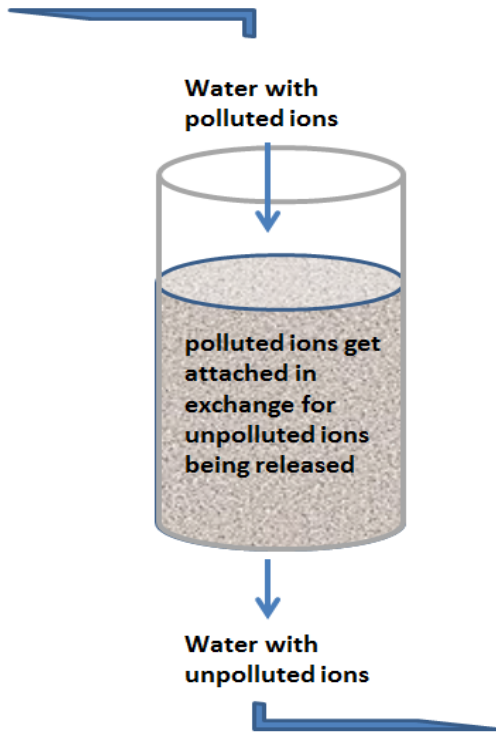
- Anions are atoms or a group of atoms with a negative electrical charge.
- Cations are atoms or a group of atoms with a positive electrical charge.



Ion Exchange – The exchange of ions between two electrolytes or between an electrolyte solution and a complex. In this module the term is used to denote the process whereby inorganic pollutants are removed from water by attaching to a polymeric resin that attracts pollutant ions in exchange for non-pollutant ions.

Below is a diagram showing the general principal of ion exchange.

Diagram showing general principle of what happens in an ion exchange unit



Example

An example of a process where ion exchange is used is water softening.

- When ion-exchange is used for water softening, the fresh resin beads have sodium ions attached.
- As "hard water" containing magnesium and calcium ions passes through the resin that has sodium ions, the magnesium and calcium ions stick to the resins and replace the sodium ions, which are then released into the water.

This has been a quick introduction to the chemistry involved in the process of ion exchange; we will discuss this treatment in more detail in this module.

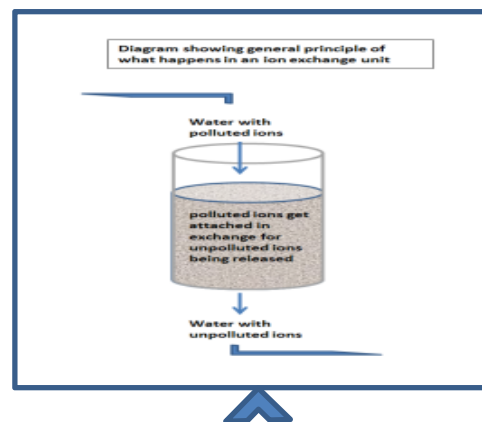


Question: The ion exchange units look like filters and have media in them, so why aren't they called filters? Also, the same container can have manganese greensand in it and be called a filter, so why isn't an ion exchange unit a filter?

Answer: The process of filtration involves the physical straining of a contaminant. In the ion exchange unit, pollutant ions with a charge are exchanged for non-pollutant ions, so since the treatment process is one of attachment and not straining, it is not technically considered a filtration process.

Note that the Wikipedia page on filtration states that "Ion exchange units are commercially called filters even though filtration is not their principal function."

Class - here's a diagram of the ion exchange process - reminds me of how some mornings I choose a tie to wear. While I'm busy my wife replaces it with one she considers more suitable!



General Inorganic Removal Chemistry

Let's start by looking at some inorganic removal chemistry definitions.



Oxidizing agent – A chemical species which either removes an electron from another chemical species or that transfers oxygen to a substrate. The oxidation of certain inorganic contaminants can make them easier to remove from drinking water because it causes them to precipitate out of solution prior to filtration.



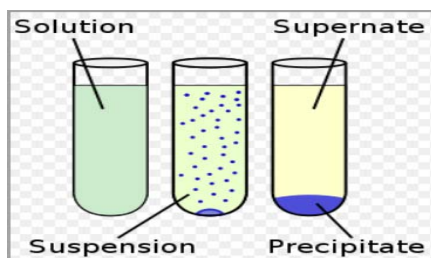
Saturation Point – The point at which a solution of a substance can dissolve no more of that substance and additional amounts will appear as a separate phase (such as a precipitate if it is a solid or effervescence if gaseous).



Sequestration – The action of forming a bound metal ion, bound atom or other stable compound with an ion, atom, or molecule so it's no longer available for reactions. For example, polyphosphates sequester some contaminants so they stay in solution.



Precipitation – In chemistry, the term precipitation is the creation of a solid in a solution; when the chemical reaction occurs in a solution, the solid formed is called the "precipitate." See a simple sketch of this process below.



Sketch of precipitation process from ZooFari at [https://en.wikipedia.org/wiki/Precipitation_\(chemistry\)](https://en.wikipedia.org/wiki/Precipitation_(chemistry))

Examples of Inorganic Removal Chemistry

Now let's look at some examples of how the previously mentioned chemical processes are used in removing inorganic contaminants from drinking water. The next unit of this module will build upon this information in further detail.

Sequestration

Polyphosphates are sequestering agents since they keep iron, manganese, and calcium in solution.



Question: Since the treatment process of sequestration does not actually remove inorganics (instead it keeps them in solution), why is this treatment included in a module about inorganic contaminant removal?

Answer: All the other types of treatment addressed in this module deal with the removal of the contaminants, so that is why the module is called "Inorganic Removal." Just keep in mind that the sequestration treatment is not removing anything.

Oxidation

Oxidizers are used to precipitate an inorganic during filtration, so these two treatment processes are often used in conjunction with one another.

An example of a strong oxidizer is potassium permanganate which can be used to oxidize iron and manganese into a precipitate form for removal.

Another example of a strong oxidant is chlorine. This chemical is commonly used in drinking water disinfection. However, it can also be used as an oxidant to remove iron, manganese, and arsenic. The formation of corrosive products can be a limitation when using chlorine as an oxidant for removal of certain inorganics.

The treatment process of aeration can be used as an effective oxidizer. However, aeration requires careful control of the flow of water through the process. Too little flow causes oxygen saturation which results in corrosive water.

Ozone can also be used as an oxidizer.



Unit 3, Exercise #1 – Inorganic Removal Chemistry

Directions: Match the lettered item with the correct numbered definition:

- a. sequestration b. precipitate c. saturation point d. ion exchange
1. _____ A solid that develops within a liquid solution.
 2. _____ Precipitation occurs when a chemical is added to a solution past this maximum amount.
 3. _____ Inorganic pollutants are removed from water by attaching to a polymeric resin that attracts pollutant ions in exchange for non-pollutant ions.
 4. _____ Metal ions are bound by added materials to form a stable compound, so they are no longer available for reactions.

II. Inorganic Contaminant Removal Chemicals

Definitions

Let's start by defining some of the chemicals that aid in the removal of inorganic contaminants.

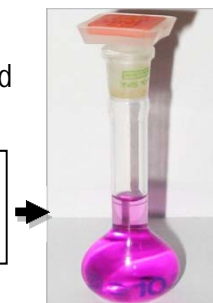


Polyphosphates – Any of a class of inorganic polymers containing linked phosphate groups. Some polyphosphates are used in corrosion control and/or water softening. Polyphosphates sequester inorganic contaminants (i.e. keep them in solution).



Potassium Permanganate – An inorganic chemical that is produced from manganese dioxide; it is a salt that consists of K^+ and MnO_4^- ions. Potassium permanganate is a strong oxidizer which is often used to precipitate out iron and manganese.

A picture of potassium permanganate solution in a volumetric flask from MaterialsScientist at https://en.wikipedia.org/wiki/Potassium_permanganate#Water_treatment_and_disinfection
Note the pink color!



Examples

Now let's look at the chemistry of how specific chemicals may be used to remove inorganic contaminants from drinking water.

Some of these chemicals are used as stand-alone treatments. Other chemicals are used as a pre-treatment prior to another treatment step that follows. For example, they may act as "filter aids" prior to the water passing through a filter.

- **Sequestering Agents**

- **Polyphosphates** are sequestering agents; they keep iron, manganese, and calcium in solution, thereby preventing the formation of precipitates that could deposit scale or cause discoloration.

- **Oxidizers**

- **Potassium Permanganate** is highly reactive under conditions found in the water industry and will oxidize a wide variety of organic and inorganic substances.
 - It is a dry granular powder typically put into solution prior to feeding.
 - A primary use of permanganate is iron and manganese removal. It oxidizes iron and manganese into precipitate form.
 - Potassium permanganate is a better oxidizer of manganese than chlorine.
- **Chlorine**
 - Chlorine can be used as an oxidant.
 - Location of chlorine addition should be considered since TTHM's may form if organic matter is present in the water.
 - Chlorine is usually fed upstream of filtration to give precipitates time to form.
- **Ozone**
 - Ozone is generated on-site as a result of a reaction between an electric arc and oxygen.

Note that aeration is also an oxidizer. It was not included here because it is a process and not a chemical.



Unit 3, Exercise #2 – Inorganic Removal Chemicals

Directions: For the first three problems, choose the correct action for each description.

1. The common reaction polyphosphates have on iron and manganese to keep them in solution.
 - a. Sequester

- b. Oxidize
2. The common reaction potassium permanganate has on iron and manganese that creates a precipitate.
 - a. Sequesters
 - b. Oxidizes
 3. Even though chlorine is commonly used to disinfect drinking water, it also reacts in this way to remove iron, manganese, and arsenic.
 - a. Sequesters
 - b. Oxidizes
 4. Chlorine is a better oxidizer of manganese than potassium permanganate.
 - a. True
 - b. False
 5. The formation of corrosive products can be a limitation when using chlorine as an oxidant.
 - a. True
 - b. False
 6. Circle all the oxidizers (choose all that apply)
 - a. Ozone
 - b. Chlorine
 - c. Sodium hexametaphosphate
 - d. Potassium permanganate
 - e. The treatment process of aeration

II. pH and Inorganic Contaminant Removal

Let's review a few pH terms.



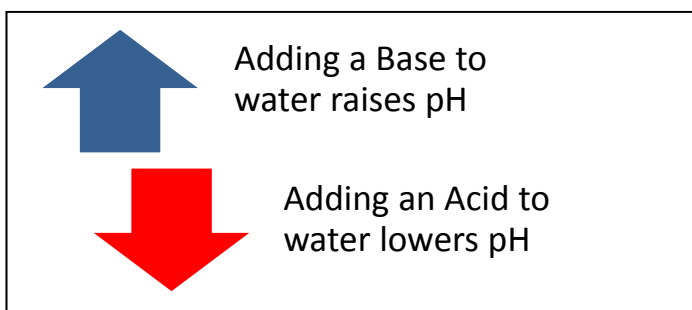
An **Acid** is a substance that produces hydrogen ions in water. Acids can usually be recognized by the "H" at the beginning of the chemical formula (although some do not have this at the beginning.) For example, the chemical formula for hydrochloric acid is HCl.



A **Base** is a substance that produces hydroxide ions in water. Bases can usually be recognized by the "OH" at the end of their chemical formula (although some do not have this ending.) For example, the chemical formula for sodium hydroxide is NaOH.



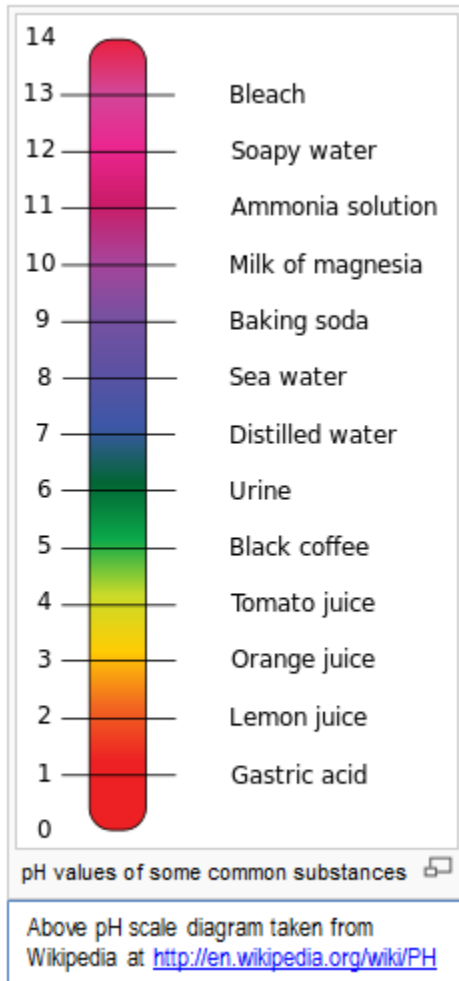
pH - In chemistry, **pH** is a measure of how acidic or basic an aqueous solution is. Solutions with a pH of less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkaline.



Adding an acid to pure water upsets the hydrogen-hydroxide ion balance. The water now has more hydrogen ions and the pH decreases.

If you add a base to pure water, there will be more hydroxide ions than hydrogen ions and the pH will increase.

The pH scale ranges from 0 (most acidic) to 14 (most basic).



Common Bases:

Calcium Hydroxide – Ca(OH)_2 – known as slaked lime

Sodium Carbonate – Na_2CO_3 – soda ash

Sodium Hydroxide - NaOH – used to make drain cleaner

Common Acids:

Acetic Acid – CH_3COOH - found in vinegar

Hydrochloric Acid - HCl – used in household cleaning

Sulfuric Acid – H_2SO_4 - found in car batteries

Optimal pH for Iron and Manganese Removal

pH can play a role not only in the type of inorganic being removed but also in the method of inorganic removal being used.

Since iron and manganese commonly cause aesthetic problems in Pennsylvania waters, let's look at the optimal pH for removal of iron and manganese using different oxidation treatment methods:

- **Iron:**
 - Iron removal by aeration: best at a pH of 8.0 – 9.0
 - Iron removal by potassium permanganate: best at a pH of 6.0 – 9.0
 - Iron removal by chlorine: fast at any pH
 - Iron removal by chlorine dioxide: instantaneous at any pH

- **Manganese:**
 - Manganese removal by aeration: best at a pH of 10.0
 - Manganese removal by potassium permanganate: best at a pH of 5.5 – 9.0

- Manganese removal by chlorine: best at a pH over 9.5
- Manganese removal by chlorine dioxide: instantaneous at a pH of 6.0 – 9.0



Unit 3, Exercise #3 – Effect of pH on Iron & Manganese Removal:

Directions: Choose the correct answer.

1. If Hydrochloric Acid – HCl - is added to water, will it raise or lower the pH?
 - a. Raise the pH
 - b. Lower the pH

2. If Calcium Hydroxide – $\text{Ca}(\text{OH})_2$ – (known as slaked lime) is added to water, will it raise or lower the pH?
 - a. Raise the pH
 - b. Lower the pH

3. Another term for a basic solution with a pH greater than 7 is to say the solution is _____
 - a. alkaline
 - b. acidic
 - c. neutral

4. If you want to remove iron and manganese by aeration, which is the **best** pH for the water to be?
 - a. A pH of 10 - 12
 - b. A pH of 8 - 9
 - c. A pH of 6 - 7

5. If you want to remove iron and manganese using potassium permanganate, which is the **best** pH for the water to be?
 - a. A pH of 10 - 12
 - b. A pH of 6 - 8
 - c. A pH of 3 – 5

III. Water Temperature

Water temperature may have an influence on inorganic contaminant removal, especially when treating for iron and manganese.

- Iron removal:
 - Cold water slows removal of iron using aeration
 - Cold water slows removal of iron during treatment with chlorine
 - Water temperature has a minimal effect on potassium permanganate treatment
 - Water temperature has a minimal effect on chlorine dioxide treatment
 - Water temperature has a minimal effect on ozone (O₃)(aq) treatment
- Manganese removal:
 - Cold water slows removal of manganese using aeration
 - Cold water slows removal of manganese during treatment with Chlorine
 - Cold water slows removal of manganese during treatment with potassium permanganate - below 35°F requires a reaction time of greater than 2 minutes.
 - Water temperature has a minimal effect on chlorine dioxide treatment
 - Water temperature has a minimal effect on ozone (O₃)(aq) treatment

Note above that cold water slows the removal of iron and manganese when using aeration and during treatment with chlorine.



Unit 3, Exercise #4 – Effect of Water Temperature on Iron & Manganese Removal

Directions: Choose the correct answer from the right hand column:

Chemical	Effect if water is cold?
Iron removal using aeration	a. Yes b. No
Manganese removal using aeration	a. Yes b. No
Iron removal – in water below 35°F- using potassium permanganate	a. Yes b. No
Manganese removal – in water below 35°F- using potassium permanganate	a. Yes b. No
Iron removal using chlorine	a. Yes b. No
Manganese removal using chlorine	a. Yes b. No



Unit 3 Key Points:

- ✚ Polyphosphates are sequestering agents; they keep iron, manganese, and calcium in solution
- ✚ Potassium permanganate oxidizes iron and manganese to form precipitates.
- ✚ pH can play a role not only in the type of inorganic being removed but also in the method of inorganic removal being used.
- ✚ Adding a base to water raises the pH; adding an acid to water lowers the pH.
- ✚ Cold water slows the removal of iron and manganese when using aeration and during treatment with chlorine.

References:

- Unit 3 references are grouped with the Unit 4 references at the end of Unit 4.

Unit 4 – Inorganic Treatment

Learning Objectives

At the end of this unit, you should be able to:

- Match basic inorganic treatment terms with definitions
- Give examples of how inorganic treatments are used
- Review reference tables on inorganic treatments

I. Definitions

Let's first look at some inorganic treatment terms.



Aeration – Exposure of the process flow to a large amount of air. During inorganic contaminant removal, aeration is often used as an oxidizer to precipitate out a contaminant prior to filtration.



Greensand – A sedimentary deposit that consists largely of dark greenish grains of glauconite (see picture below) often mingled with clay or sand. In water treatment, a manganese coated greensand filter media is often used to oxidize and absorb inorganic contaminants.



Picture of Glauconite mineral (a main component of Greensand)
from Helix84 at <https://en.wikipedia.org/wiki/Glauconite>



Filtration – The mechanical or physical operation which is used for the separation of solids from fluids (liquids or gases) by interposing a medium through which only the fluid can pass.



Water Softening – The removal of positively charged ions (i.e. cations) in water that has a high mineral content (i.e. “hard water”). A common method of water softening is to use ion exchange resins to replace ions like calcium with sodium or potassium ions. Another softening method is to use lime softening.

II. Treatment Considerations

Determining what type of inorganic treatment to use is dependent on several factors, including:

- Whether you are treating ground water or surface water
- Contaminant to be removed
- Form of contaminant present
- Levels of contaminant present
- Amount of water to be treated
- Whether your existing treatment will remove the necessary contaminants

The purpose of this module is to familiarize you with some of the basics of inorganic contaminant treatment. However, when you are dealing with the removal of an existing or new contaminant at your treatment plant, it is best to consult with someone with advanced expertise (such as a drinking water chemical engineer) since there are many factors to consider.

III. Treatment Methods

The following contains information on of some inorganic treatments and examples of how they are used to remove inorganic contaminants from drinking water, including:

- Sequestration
- Ion exchange
- Oxidizing filters

Sequestration

Sequestration uses a chemical, generally a polyphosphate compound, to keep metals such as iron and manganese dispersed in water, preventing the tendency of these contaminants to otherwise precipitate and create aesthetic problems.

- Note that sequestration may work best on lower levels of some contaminants.
 - The maximum soluble iron level that can be practically and economically treated is around 1.0 mg/L.
 - The maximum soluble manganese level that can be practically and economically treated is around 2.0 mg/L.
- The sequestrant is typically a polyphosphate product such as sodium hexametaphosphate or tripolyphosphate.
- The sequestrant must be fed prior to the addition of any oxidant. For example, metaphosphate sequestering must be given time to occur prior to any chlorine oxidation of iron in solution.

- Chlorine residuals must be maintained in the distribution system when feeding one of these products.

◆ Ion Exchange

Ion exchange involves passing water through a container filled with resins (usually composed of small beads such as the resin beads picture below) that are fabricated from an organic polymer. It is a type of treatment device, but one that involves a chemical exchange as the beads attract contaminant ions in exchange for giving off other ions, thus the term “ion exchange.”

Most ion exchange systems are containers of ion exchange resin operated on a cyclic basis. Water is treated as it flows through the resin container (see the ion exchanger picture below).



Picture of Ion Exchange Resin Beads from https://en.wikipedia.org/wiki/Ion_exchange_resin



Picture of Ion Exchanger from Brackenheim at https://en.wikipedia.org/wiki/Ion_exchange

The resin is considered exhausted when water leaving the exchanger contains more than the desired maximum concentration of the ions being removed.

In water treatment, ion exchange is primarily used for softening; however, it is being used more frequently for the removal of other dissolved ionic species. For example, ion exchange treatment may be useful in removing arsenic, barium, nitrate and nitrate, iron and manganese. The tables in Appendix C include more information about what contaminants may be removed by ion exchange technology.

Ion exchange treatment devices are backwashed to remove contaminant chemicals, such as iron and manganese. Backwashing the resin bed removes accumulated solids by flushing removed ions from the resin.

More information on ion exchange unit backwashing and recharge is in Unit 6.

- **Water Softening Example**

As mentioned previously, one type of ion exchange treatment that is common is softening. This process uses a resin that has ions attached – such as sodium – that will be exchanged with the hardness ions of calcium or magnesium.

Since it is so common and a good example of the ion exchange process, let's look at it in more detail.

The presence of certain minerals in drinking water (e.g. calcium or magnesium) creates “hard water”, which causes scale build-up. Removal of minerals like calcium or magnesium is known as “softening” the water and can be done by either ion exchange resins or lime softening.

- ▶ When ion-exchange is used for water softening, the fresh resin beads have sodium ions attached.
- ▶ As “hard water” containing magnesium and calcium ions passes through the resin, the magnesium and calcium ions stick to the resins and replace the sodium ions, which are then released into the water.
- ▶ Resin can be recharged through washing it with a solution that contains a high concentration of sodium ions (e.g. that has large amounts of common salt - NaCl - dissolved in it.)
- ▶ More about resin recharge is discussed in Unit 6.

◆ Oxidizing Filters

Oxidizing filters have a coating of a substance that oxidizes the contaminant to aid in the filtration process.

An example is the use of potassium permanganate coated greensand (aka, manganese coated greensand) in a pressure filter. This method of filtration is a type of dual treatment that occurs simultaneously since the potassium permanganate coating oxidizes as the greensand filters.

- A consideration when using oxidizing filters is the amount of organic material that is present in the water. Significant amounts of phosphate and organic material can result in fouling of the filters and the reduction of filter efficiency.
- Another consideration when using oxidizing filters is the location of the chlorine addition point. Potential formation of TTHM and ferric chloride need to be considered.

Let's look at examples of this type of treatment.

➤ Greensand Filtration

A manganese coated greensand filter media is used in well water treatment systems to removed dissolved iron and manganese with the addition of an oxidant, usually potassium permanganate, under controlled pH conditions.

➤ Other Oxidizing Filter Medias

Anthracite sand or zeolite media may be used by themselves or in a mixed media (with each other, with greensand, etc.) An oxidizing coating (such as potassium permanganate) may be present to assist in the filtration processes.

Oxidizing of an inorganic filtration media may occur through aeration by air injection during filtering.

◆ Other Inorganic Removal Treatment Methods

Various types of inorganic contaminants and the recommended treatments can be found in Appendix C.

Now let's just touch on the methods of Coagulation/Filtration, Membrane Filtration, and Lime Softening. More detailed information on these methods can be found in the 2006 version of the Pa. DEP Inorganic Contaminant Removal which can be obtained by e-mailing the Pa. DEP Safe Drinking Water Training Section at DEPWSTechtrain@pa.gov to request a copy.

- **Coagulation/Filtration:**

- ▶ Coagulation is the use of a coagulant chemical to promote aggregation (or clumping) of small and colloidal particles into larger particles. The coagulant chemical neutralizes the electrical charge on the surface of the small particles, resulting in destabilization of the colloidal suspension.

- ▶ In the coagulation/filtration treatment process, coagulation is used as a pretreatment process for removal of some inorganics prior to filtration.

- **Membrane Filtration:**

- ▶ A membrane is a semi-permeable thin layer of material capable of separating contaminants as a function of their physical/chemical characteristics.

Certain types of membrane filtration may be useful for removing arsenic, barium, mercury, nitrate and nitrite, and zinc.

- ▶ Reverse osmosis (RO) and nanofiltration (NF) can be effective for removal of soluble iron and manganese, provided that an acid is fed prior to the membranes to prevent manganese precipitation.

- ▶ Microfiltration (MF) and ultrafiltration (UF) can be effective, provided that preoxidation and/or coagulation steps occur prior to the membranes.

- **Lime Softening:**

- ▶ Lime Softening softens water through the addition of slaked lime (calcium hydroxide) to remove hardness (calcium and magnesium) ions by precipitation.

Lime softening may be useful for removing arsenic (with pre-oxidation), barium, iron, manganese, mercury, and zinc.

- ▶ Soda Ash (aka sodium carbonate) may also be used along with lime softening since soda ash also competes with the magnesium and calcium ions in hard water.

IV. Treatment Consideration Example

Let's look at iron and manganese as an example of treatment considerations:

- Considerations:
 - ▶ Treatments for groundwater may not be practical for surface water
 - ▶ Iron can be present in various forms (dissolved, colloidal, particulate, dissolved organic carbon-complexed.)
 - ▶ When iron has combined with natural organics, it can be more challenging to remove from drinking water.
 - ▶ The levels of iron and manganese present might help determine the best treatment.

- Contaminant Levels:

Let's look at what might be considered for a small one-building water system that has low-water use (e.g. a small church):

- Very low levels of dissolved iron and manganese might be easily sequestered by phosphate compounds to be kept in solution.
 - Lower levels of dissolved iron and manganese might be removed using an ion exchange water softening unit.
 - Moderate levels of dissolved iron and manganese may require an oxidizing filter treatment system. A filter with manganese greensand or zeolite coated with manganese oxide may be necessary.
 - High levels of dissolved iron and manganese may need to be changed to a solid form by being oxidized through mixing with air through aeration before being put through a filter. However, this method is not recommended for organic forms of iron since they may cause clogging of the aerator and/or filter.
 - High levels of dissolved or oxidized iron and manganese might also be treated by first oxidizing the water (via chlorine, potassium permanganate, or ozone) to precipitate the contaminants out and then pass them through a filter.
- Combined Treatments:

If different inorganic treatments are combined, how they impact one another is a consideration.

- ▶ In the treatment of iron, the feeding of a sequestering agent must occur prior to the addition of any oxidant. For example, metaphosphate sequestering of iron must be given time to occur prior to any chlorine oxidation of iron in solution.



Unit 4 Exercise – Inorganic Treatment Methods

Directions: Choose the correct answer.

1. The presence of which mineral in drinking water can make it “hard water.”
 - a. potassium
 - b. sodium
 - c. calcium

2. When iron has combined with natural organics, it can be easier to remove from drinking water.
 - a. True
 - b. False

3. Sodium hexametaphosphate is used to oxidize iron and manganese.
 - a. True
 - b. False

4. A common treatment method to soften water is by ion exchange
 - a. True
 - b. False

5. Potassium permanganate sequesters manganese to aid in removal through filtration.
 - a. True
 - b. False

6. During water softening the “hard water” _____ and _____ ions stick to the resins and replace the _____ ions, which are then released into the water. *(Choose the best answer to fill in the blanks.)*
 - a. sodium and calcium, magnesium
 - b. calcium and magnesium, sodium
 - c. potassium and magnesium, calcium

7. The feeding of a sequestering agent must occur _____ the addition of any chemical that has oxidant properties. For example, where would sodium metaphosphate sequestration treatment occur in relationship to chlorine treatment? (*Choose the best answer to fill in the blanks.*)

- a. before
- b. after

8. Aeration can be a useful treatment for removing low levels of hydrogen sulfide from drinking water; it is also a useful treatment for removing radon from drinking water. Aeration can also be used to _____ iron by causing it to precipitate out prior to filtration. (*Choose the best answer to fill in the blanks.*)

- a. sequester
- b. oxidize



Unit 4 Key Points:

- ✚ The contaminant to be removed, the form and level of the contaminant present, as well as the type of source water and amount of water to be treated are all factors to be considered in choosing an inorganic treatment method.
- ✚ Some common methods of inorganic treatment are sequestration, ion exchange and oxidizing filtration.
- ✚ Ion exchange units contain resin beads which trap ions in exchange for giving off other ions, thus the term "ion exchange."
- ✚ A manganese coated greensand filter media is often used to oxidize and absorb inorganic contaminants as well as filter them.
- ✚ Removal of minerals like calcium or magnesium is known as "softening" the water.

Unit 3 & 4 References:

Aeration:

- Aeration definition taken from information in Pa. DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB p. 3-10.
- Aeration as a useful process for removing hydrogen sulfide from drinking water taken from Wikipedia article on Hydrogen Sulfide at https://en.wikipedia.org/wiki/Hydrogen_sulfide#Removal_from_water
- Aeration as a useful process for removing radon from drinking water taken from Wikipedia article on Radon at https://en.wikipedia.org/wiki/Radon#In_drinking_water

Treatment Methods:

- Order of treatment methods taken from Us Dept of Agriculture Iron and Manganese in Drinking Water Engineering Tech Tips web page at <http://www.fs.fed.us/eng/pubs/html/99711308/99711308.html>

Sequestration:

- Sequestering information from Pa. DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB p. 3-21.

Ion Exchange:

- Ion definition created by using wording from [http://www.thefreedictionary.com/ion+\(chemistry\)](http://www.thefreedictionary.com/ion+(chemistry)) which references The American Heritage® Dictionary of Student Science, Second Edition. Copyright © 2014 by Houghton Mifflin Harcourt Publishing Company. Published by Houghton Mifflin Harcourt Publishing Company. All rights reserved. Also added were statements from Pa. DEP's W. Lloyd.
- Anion and cation definitions created from Pa. DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB p. 1-9.
- Ion Exchange diagram created by Pa. DEP's W. Lloyd.
- Ion Exchange usage statement from EPA's Drinking Water treatability database – Ion exchange web page at <http://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?treatmentProcessId=263654386>

Iron:

- Iron treatment considerations from Pa. DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB p. 3-9.
- Treatment levels: <http://www.water-research.net/index.php/iron> and <http://extension.psu.edu/natural-resources/water/drinking-water/water-testing/pollutants/iron-and-manganese-in-private-water-systems>
- Ion Exchange as a treatment method for barium taken from EPA's web site on Drinking Water: Basic Information about Regulated Drinking Water Contaminants on Barium at <http://water.epa.gov/drink/contaminants/basicinformation/barium.cfm#eight>

Definitions:

- Backwashing definition taken from Wikipedia article on Backwashing at [https://en.wikipedia.org/wiki/Backwashing_\(water_treatment\)](https://en.wikipedia.org/wiki/Backwashing_(water_treatment))
- Coagulation definition taken from DEP DW Operator Training Module #14 (Conventional Filtration) WB p. 1-3.
- Filtration definition taken from Wikipedia article on Filtration at <https://en.wikipedia.org/wiki/Filtration>
- Greensand definition is taken from Merriam Webster at <http://www.merriam-webster.com/dictionary/greensand>
- Ion Exchange definition taken from Wikipedia article on Ion Exchange at https://en.wikipedia.org/wiki/Ion_exchange and IOC/SOC/VOC Treatment Fact Sheet on Ion Exchange written by E. Rawski for the 1999 Pa. DEP Advanced Staff Handbook (ASH) Training.
- Lime Softening definition taken from Wikipedia article on Lime Softening at https://en.wikipedia.org/wiki/Lime_softening
- Oxidizing agent definition is taken from Wikipedia article on Oxidizing Agents at https://en.wikipedia.org/wiki/Oxidizing_agent

- Saturation Point definition is taken from Wikipedia article on Saturation (chemistry) at [https://en.wikipedia.org/wiki/Saturation_\(chemistry\)](https://en.wikipedia.org/wiki/Saturation_(chemistry))
- The pH definition was taken from the Wikipedia page about pH at <http://en.wikipedia.org/wiki/pH>
- The pH arrow sketch was done by W. Lloyd from Pa. DEP.
- Acid and base definitions and information was taken from Module 2 of Pa. DEP's 1998 Corrosion Control Treatment Training for Operators.
- The pH definition and chart were taken from the Wikipedia page about pH at <http://en.wikipedia.org/wiki/pH> Information about acids and bases – including chemical formulas and uses - were taken from acid and base hyperlinks in that article.
- Polyphosphate definition from Wiktionary at <https://en.wiktionary.org/wiki/polyphosphate>
- Potassium Permanganate definition from Wikipedia article on Potassium Permanganate at https://en.wikipedia.org/wiki/Potassium_permanganate#Water_treatment_and_disinfection and incorporated oxidation explanation from https://en.wikipedia.org/wiki/Oxidizing_agent
- Precipitation definition and sketch taken from Wikipedia article on Chemical Precipitation at [https://en.wikipedia.org/wiki/Precipitation_\(chemistry\)](https://en.wikipedia.org/wiki/Precipitation_(chemistry))
- Soda Ash definition from Wikipedia article on Soda Ash at https://en.wikipedia.org/wiki/Soda_ash
- Sequestration definition taken from Memidex Free On-Line dictionary at <http://www.memidex.com/sequestration+chemistry>; includes definition for chelate taken from the same site at <http://www.memidex.com/chelate>
- Slaked Lime definition taken from Wikipedia article on Calcium Hydroxide at https://en.wikipedia.org/wiki/Calcium_hydroxide Slaking definition from Wiktionary at <https://en.wiktionary.org/wiki/slake>
- Water Softening definition taken from Wikipedia article on Water Softening at https://en.wikipedia.org/wiki/Water_softener

Explanations:

- Oxidation explanation of chlorine taken from EPA Drinking Water Treatability database article on chlorine at <https://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?treatmentProcessId=-1118142891>
- Ion exchange explanation and picture taken from Wikipedia article on Ion Exchange at https://en.wikipedia.org/wiki/Ion_exchange
- Ion exchange resin recharge explanation taken from Wikipedia article on Ion Exchange Resin at https://en.wikipedia.org/wiki/Ion_exchange_resin
- Oxidizing Filter explanation taken from U.S. Dept of Agriculture Iron and Manganese in Drinking Water Engineering Tech Tips web page at <http://www.fs.fed.us/eng/pubs/html/99711308/99711308.html> with some wording added by Pa. DEP's W. Lloyd.
- Greensand Filtration explanation is taken from EPA's table on "Removing Multiple Contaminants from Drinking Water" at http://water.epa.gov/scitech/drinkingwater/dws/treatment/upload/2007_12_17_treatment_poster_treatment_technologies.pdf plus a Wikipedia article on Greensand at <https://en.wikipedia.org/wiki/Greensand>

- Polyphosphate explanation taken from DEP DW Operator Training Module #20 (Corrosion Control and Sequestering) WB p. 1-2.
- Potassium Permanganate explanations taken from
 - DEP DW Operator Training Module #21 (Chemical Addition) WB p. 1-12.
 - EPA Guidance Manual on Alternate Disinfectants and Oxidants
 - http://water.epa.gov/lawsregs/rulesregs/sdwa/mdbp/upload/2001_01_12_mdbp_alter_chapt_5.pdf
- Membrane Filtration definition taken from DEP DW Operator Training Module #19 (Membrane Filtration) WB p. 1-2.
- Membrane Filtration explanation taken from DEP's 2006 DW Operator Training Module #22 (Inorganic Removal), WB p. 3-24.
- Treatment of Membrane Filtration explanation taken from DEP's 2006 DW Operator Training Module #22 (Inorganic Removal),
- Treatment of arsenic, barium, iron, manganese, mercury, and zinc using lime softening taken from DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) pp. 3-3 and 3-4
- Treatment of arsenic, barium, mercury, nitrate and nitrite, and zinc using membrane filtration taken from DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) pp. 3-3 and 3-4

Unit 5 – Inorganic Filter Calculations

Learning Objectives

At the end of this unit, you should be able to:

- Calculate the loading rate of a high rate trickling inorganic filter
- Calculate the media volume of an inorganic filter
- Calculate the gallons of brine solution needed to regenerate an ion exchange unit

Before we go on to solving filter word problems, let's look again at our Word Problem Solving Steps from Unit 2.

Steps to Solving Word Problems:

Step 1: Make a list of what you know and what you don't

Step 2: Find the formula you will use.

Step 3: Determine if the units are consistent throughout the calculation. If they are not, but can be converted, use unit conversion to obtain the necessary units.

Step 4: Plug the information into the equation and work to isolate the unknown item on one side.

Step 5: Cancel out the units and calculate the answer.

(Hint: When finished, you should be able to plug your answer back into the original equation and have both sides equal each other.)

I. Filter Loading Rate Calculation

First let's define filter loading rate:



Filter Loading Rate – The rate of water flow through the filter. The flow rate of the water being added to the filter is divided by the filter surface area as follows:

$$\text{Filter Loading Rate (gpm/ ft}^2\text{)} = \frac{\text{Flow Rate (gpm)}}{\text{Surface Area (ft}^2\text{)}}$$

Sometimes this equation uses gallons per **day**:

$$\text{Filter Loading Rate (gpd/ ft}^2\text{)} = \frac{\text{Flow Rate (gpd)}}{\text{Surface Area (ft}^2\text{)}}$$

The calculation depends on a few factors:

- Filter surface area units are in ft² (aka sq. ft.); the surface area formula used depends on the filter structure (retangular or circular) as noted in Unit 2 section IV. of this module.
- Flow rate units are usually in gpm or gpd; use the specific formula based on what you are calculating
- The filter loading rate may also be called the “hydraulic surface loading rate”



Formula to Remember: Filter Loading Rate

The certification exam formula sheets show the Filter Loading Rate equation with gpd instead of gpm; remember that these formulas look almost exactly the same.

$$\text{Filter Loading Rate (gpm/ ft}^2\text{)} = \frac{\text{Flow Rate (gpm)}}{\text{Surface Area (ft}^2\text{)}}$$

Filter Loading Rate - Example: You have a cylindrical filter that is 5 feet in diameter that is designed to treat 25 gallons a minute. What is the filter loading rate of this filter in gpm/ft²?

Step 1: Let's make a list of what we know and what we don't.

Circular filter diameter = 5 feet
Filter flow rate = 25 gpm
Filter loading rate = unknown
Surface area = unknown

Step 2: Find the formula you will use. To determine the filter loading rate we will use that formula (choosing the one that has the flow rate in gpm):

$$\text{Filter Loading Rate (gpm/ft}^2\text{)} = \frac{\text{Flow Rate (gpm)}}{\text{Surface Area (ft}^2\text{)}}$$

Step 3: Make sure the units are equivalent. In this case, they are not (we need ft², which we will get when we determine the surface area) and we need to perform the following calculation.

Determine the filter surface area in ft². For a circular filter, we use the following equation:

$$\text{Area of Circle} = (0.785) (\text{Diameter})^2$$

Let's plug in our circular filter diameter:

$$\text{Area of Circle} = (0.785) (5 \text{ feet})^2$$

$$\text{Area of Circle} = (0.785) (25 \text{ ft}^2) \longrightarrow 19.63 \text{ ft}^2$$

Here is our new list of what we know and what we don't:

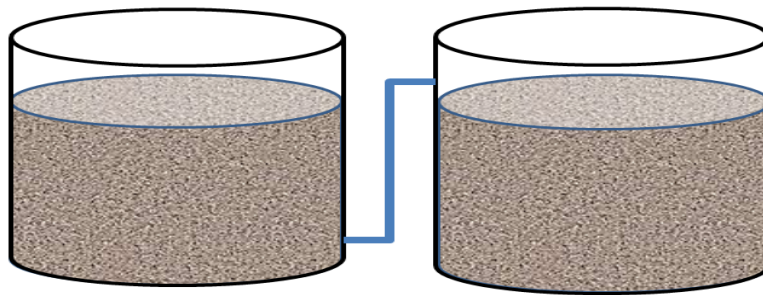
Flow rate = 25 gpm
Cylindrical filter surface area = 19.63 ft²
Filter Loading rate = unknown

Now we can go ahead and plug our numbers into the filter loading rate formula:

$$X \text{ gpm/ft}^2 = \frac{25 \text{ gpm}}{19.63 \text{ ft}^2} \longrightarrow 1.27 \text{ gpm/ft}^2 \text{ is the filter loading rate}$$

Filter Loading Rate – Example 2: You have two cylindrical filters – that are set up in series - that are each 5 feet in diameter that are each designed to treat 25 gallons a minute. What is the filter loading rate of these filters in gpm/ft²?

Below is a diagram of filters set up in series (i.e., water passes through one and then the other.) As a result, in this case, the filter loading rate would be the same as one individual filter, which still means that **1.27 gpm/ft² is the filter loading rate of these filters.**



II. Filter Media Volume Calculations

Filter Media Volume

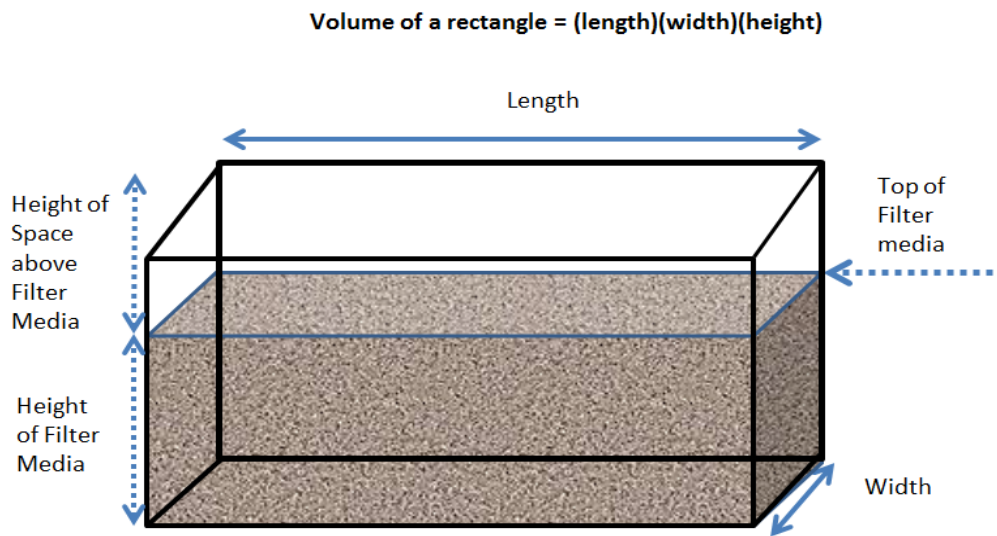
As we discussed in Unit II. Part IV.on area and volume, if you are given length, width, and height, you have a rectangular filter. Previously we discussed the calculation to find the total volume of what the rectangular filter can contain which is:

$$\text{Volume of a Rectangle (ft}^3\text{)} = (\text{Length})(\text{Width})(\text{Height})$$

Note: In filter equations, the terms “height” and “depth” are interchangeable.

Look at the diagram below and the following three dotted arrows: the arrow pointing to the top of the filter media surface, the height arrow indicating the height of the space above the filter media, and the height arrow indicating the height of the filter media.

- If you are asked to determine the volume that the filter media is currently occupying, in your volume calculation you would use the height from the top of the filter media surface to the bottom of the filter.
- If you are asked to determine the volume of the space above the filter media, in your volume calculation you would use the height from the top of the filter media to the top of the filter.
- If you are asked to determine part of the volume of the remaining space above the filter media that might need to have filter media added, in your volume calculation you would use the height of the segment of that space.



Calculating Filter Media Volume – Example:

A sand filter measures 20 feet by 15 feet. If the unit needs 4 inches of additional sand ordered, how many cubic feet of sand must be ordered?

What we know:

- This problem asks for the answer to be in ft³ so we know we need to determine volume.
- Also, the three measurement items indicate we are dealing with a rectangle.
- One of the items is in inches, so we need to convert that to feet before proceeding further.

Step 1: Convert 4 inches into X feet, using the conversion of 12 inches = 1 foot. Let's review conversion principals:

Unknown: X feet =

$$X \text{ feet} = \frac{1 \text{ foot}}{12 \text{ inches}} \quad \leftarrow \text{Conversion}$$

$$X \text{ feet} = \frac{1 \text{ foot}}{12 \text{ inches}} \times 4 \text{ inches} \quad \leftarrow \text{Known}$$

$$X \text{ feet} = 0.0833 \text{ feet} \times 4 = 0.333 \text{ feet}$$

Step 2: The formula that helps us find the volume of a rectangle is as follows:

$$\text{Volume of a rectangle} = (\text{length})(\text{width})(\text{height})$$

The height we will use is the height of the segment of the area above the filter that needs to be filled.

We plug in the numbers we have:

$$\text{Volume of a rectangle} = (20 \text{ feet}) (15 \text{ feet})(0.333 \text{ feet}) \longrightarrow = 99.9 \text{ ft}^3$$

As mentioned previously, if you are given a diameter and a height, you have a cylindrical filter. Previously we discussed the calculation to find the three dimensional volume in ft³ of what the cylindrical filter can contain:

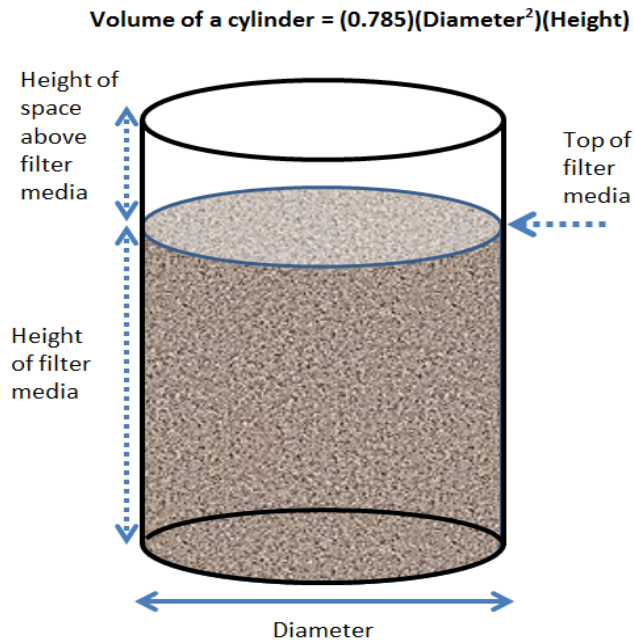
$$\text{Volume of Cylinder (ft}^3\text{)} = (0.785) (\text{Diameter}^2)(\text{Height})$$

(Note: You can also use $V = \pi r^2 H$ which is $\text{Area} = (3.14)(\text{Radius}^2)(\text{Height})$)

Look at the diagram below and the following three dotted arrows: the arrow pointing to the top of the filter media surface, the height arrow indicating the space above the filter media, and the height arrow indicating the height of the filter media.

- ✚ If you are asked to determine the volume that the filter media is currently occupying, in your volume calculation you would use the height from the top of the filter media surface to the bottom of the filter.
- ✚ If you are asked to determine the volume of the space above the filter media, in your volume calculation you would use the height from the top of the filter media to the top of the filter.
- ✚ If you are asked to determine part of the volume of the remaining space above the filter media that might need to have filter media added, in your volume calculation you would use the height of the segment of that space.

Note: In theory, if your cylinder ends in a conical shape on top, you would calculate the volume of the cone and add it to the cylinder volume. In reality, space is needed for filter bed expansion, so check with the filter manufacturer to determine if any of this area would even be filled with media.





Unit 5 Practice #1:

1. You have a filter that is 45 feet long by 30 feet wide that treats 60 gpm. What is the filter loading rate?
 - a. 81,000 gpm/ ft²
 - b. 22.5 gpm/ ft²
 - c. 0.23 gpm/ ft²
 - d. 0.044 gpm/ ft²

2. A sand filter measures 40 feet by 30 feet. If the unit needs 15 inches of additional sand ordered, how many cubic feet of sand must be ordered?
 - a. 1.25 ft³
 - b. 9.3 ft³
 - c. 1,500 ft³
 - d. 18,000 ft³

3. You have two cylindrical filters – that are set up in series - that are each 20 feet in diameter that are each designed to treat 60 gallons a minute. What is the filter loading rate of these filters in gpm/ft²?
 - a. 0.15 gpm/ft²
 - b. 0.191 gpm/ft²
 - c. 2.3 gpm/ft²
 - d. 5.23 gpm/ft²

III. Ion Exchange Brine Recharge Calculation

When an ion exchange unit needs to be recharged, a specific type of brine solution that is of a certain active strength must be used.

We will be determining the gallons of a brine solution that are required for recharge.

In solving this types of problem, there is some given information you will start with:

- **Salt concentration strength (lb/gal):** For all the ion exchange recharge calculations we will be performing, we will be using a salt concentration that has an active strength of 1 lb/gal of 10% salt solution.

- **Salt regeneration dosage (lbs/ft³):** The salt regeneration dosage is usually a given number for each ion exchange unit
- **Ion exchange resin volume (ft³):** The volume of resin that is contained in the ion exchange unit

We will be using a formula that you will need to remember:



Formula to Memorize: Pounds of Salt Needed Calculation*

You are expected to know the formula for calculating the pounds of salt (lb) needed. The formula* we will use is:

$$B = SxVx1/C$$

B = Brine (gal)

S = Salt dosage (lbs/ft³)

V = Volume of resin (ft³)

C = Concentration of brine solution (lb/ gal of % salt solution)

**Formula from the Alberta Canada Public Works Department*

Let's look at how to use the aforementioned given information to determine the gallons of salt solution needed to recharge an ion exchange unit. We'll look an an example on the next page.

Calculating Ion Exchange Brine Recharge – Example:

An ion exchange unit contains 700 ft³ of ion exchange resin. Each cubic foot of resin requires 3 lbs of salt to recharge the resin. What is the minimum amount of gallons of 10% salt solution needed to achieve regeneration? The salt solution has an active strength of 1 lb/gallon.

Step 1: Let's make a list of what we know and what we don't.

Salt dosage = 3 lbs/ft³

Volume of resin = 700 ft³

Concentration of brine solution = 1 lb/ gal of 10% salt solution

Step 2: Find the formula you will use. Since we are looking for the volume (in gallons) of brine recharge solution needed, we will use the following formula:

$$B = SxVx1/C$$

Here's how the above problem would look:

Brine (gal) = unknown

Salt dosage (S) = 3 lbs/ft³

Volume of resin (V) = 700 ft³

Concentration of brine solution (C)= 1 lb/ gal of 10% salt solution

Now we can go ahead and plug our numbers into the equation:

$$B = SxVx1/C$$

$$B \text{ (gal)} = \frac{3 \text{ lbs/ft}^3 \times 700 \text{ ft}^3 \times 1}{1 \text{ lb/ gal of 10\% salt solution}} = 2,100 \text{ gal}$$

Note – A gallon in the division in the denominator is equivalent to it being in the numerator.



Unit 5 Practice #2:

An ion exchange unit contains 300 ft³ of ion exchange resin. Each cubic foot of resin requires 1.5 lbs of salt to recharge the resin. What is the minimum amount of gallons of 10% salt solution needed to achieve regeneration? The salt solution has an active strength of 1 lb/gallon.

- Approximately 150 gallons
- Approximately 450 gallons
- Approximately 1,500 gallons
- Approximately 4,500 gallons



Unit 5 Key Points:

- If you need to determine part of the volume of the remaining space above the filter media that might need to have filter media added, in your volume calculation you would use the height of the segment of that space.
- If you need to determine the filter loading rate for filters set up in series (i.e., water passes through one and then the other), the filter loading rate would be the same as for one individual filter.
- Use the Filter Loading Rate rate formula to determine the loading rate of a filter.
- Use the Pounds of Salt Needed and Ion Exchange Brine Recharge formulas to determine the gallons of brine needed to recharge an ion exchange unit.

Unit 5 References:

Filtration Rate Formulas compared and taken from the following:

- Pa. DEP Water and Wastewater certification exam handout of formulas, conversions and scientific units – under water and wastewater heading see hydraulic surface loading rate formula and surface loading rate formula
- The West Virginia Bureau for Public Health and West Virginia Rural Water Association 2009 Advanced Math Handbook for Class III and IV Water Operators – see filtration rate formula on pg. 7 at: http://www.wvdhhr.org/oehs/eed/swap/training&certification/documents/advanced_math_handbook.pdf
- All volume filter drawings and problems created by W. Lloyd from Pa. DEP.
- Filter loading rate problem created by W. Lloyd from Pa. DEP.
- Ion Exchange Pounds of Salt Needed Formula from E. Rawski, Pa. DEP P.E.
- Ion Exchange Brine Calculation Formula from the April 19th 1995 Alberta Canada Public Works Department document on Softener Performance from their Water Treatment Coordinator's Meeting created by G.F. Yuzwa, P. Eng. H2O Engineering LTD Calgary, Alberta - p. 8 at <http://www.infrastructure.alberta.ca/content/doctype306/production/techpres22.pdf>

Unit 6 – Inorganic Treatment Maintenance

Learning Objectives

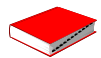
At the end of this unit, you should be able to:

- Answer additional questions about ion exchange units, such as:
 - Define ion exchange terms
 - List types of ion exchange resins
 - Explain resin regeneration
 - Name the piece of monitoring equipment used to evaluate an ion exchange unit
- Answer additional questions about media filtration, such as:
 - Define common filter terms
 - List types of filter media
 - Answer questions about backwashing a media filter
 - Name the piece of monitoring equipment used to evaluate a media filter

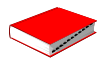
I. Ion Exchange Unit Maintenance

In Unit 4 we looked at the ion exchange treatment process which involves passing water through a container filled with resins. Let's examine ion exchange units in more depth.

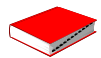
We'll start by defining a few more terms.



Conductivity – In regards to electrolyte solutions, conductivity is the measure of the ability of an electrolytic solution to conduct electricity.



Exhaustion – The ion exchange resin beads become saturated with the contaminant(s) they are removing and available replacement ions / attachment sites decrease for the target pollutant.



Regeneration – The “reloading” of an ion exchange resin bed with a concentration of the original non-pollutant ions to make the resin bed ready for service once again.

- For example, ion exchange softeners are regenerated with a salt (NaCl) solution.
- The terms “recharge” or “reactivation” are used interchangeably with the term “regeneration”



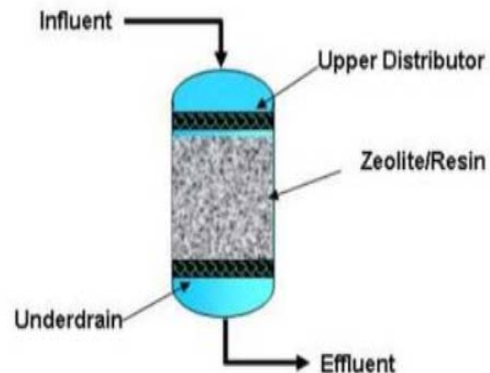
Zeolite – A group of naturally occurring microporous minerals that, in the drinking water industry, are commonly used in ion exchange beds. Their structure allows them to accommodate a wide variety of cations. Zeolite can also be industrially produced.

Resins

In ion exchange units the resin contains attachment sites which have either a positive or negative charge, and which attract ions of opposite charge. The ions on the resin attract pollutant ions in exchange for giving off other non-pollutant ions which are then released into the treated water (thus the term “ion exchange.”)

Resin selection is based on the contaminant to be removed. For example, in softening, a cation-based resin is used to exchange sodium ions for calcium ions. Anion-based resins are used to remove arsenic and nitrates.

Resins are frequently composed of resin beads (as pictured in Unit 4). Another commonly used ion exchange resin is zeolite.



Typical Ion Exchange Unit Configuration from
EPA Drinking Water Treatability Database – Ion exchange web site at:
<http://iaspub.epa.gov/tdb/pages/treatment/treatmentOverview.do?processId=263654386>

Regeneration

The ion exchange resin bed becomes exhausted as the number of resin attachment sites available for the target pollutant decreases. An exhausted resin bed is “regenerated” with a concentrated solution of the original non-pollutant.

Depending on the type of unit, the regeneration process can involve several steps, including backwashing, brining, and rinsing.

Let's look at an example of the 4-step regeneration process that is used in some ion exchange units that is often set up to occur automatically based on time or how much water the unit has processed. For any given ion exchange unit, the manufacturer's instructions need to be consulted for proper regeneration procedures.

- Step 1: Backwash – Water is passed backwards through the unit to expand the media and wash away suspended solids.
- Step 2: Brine Introduction – A regenerant brine solution of a certain concentration is passed onto and through the filter for a certain period of time to regenerate the resin.
- Step 3: Slow Rinse – The slow rinse is passed through the filter to remove excess brine solution.
- Step 4: Fast Rinse – The fast rinse occurs through the filter at the normal flow rate to remove additional excess brine.

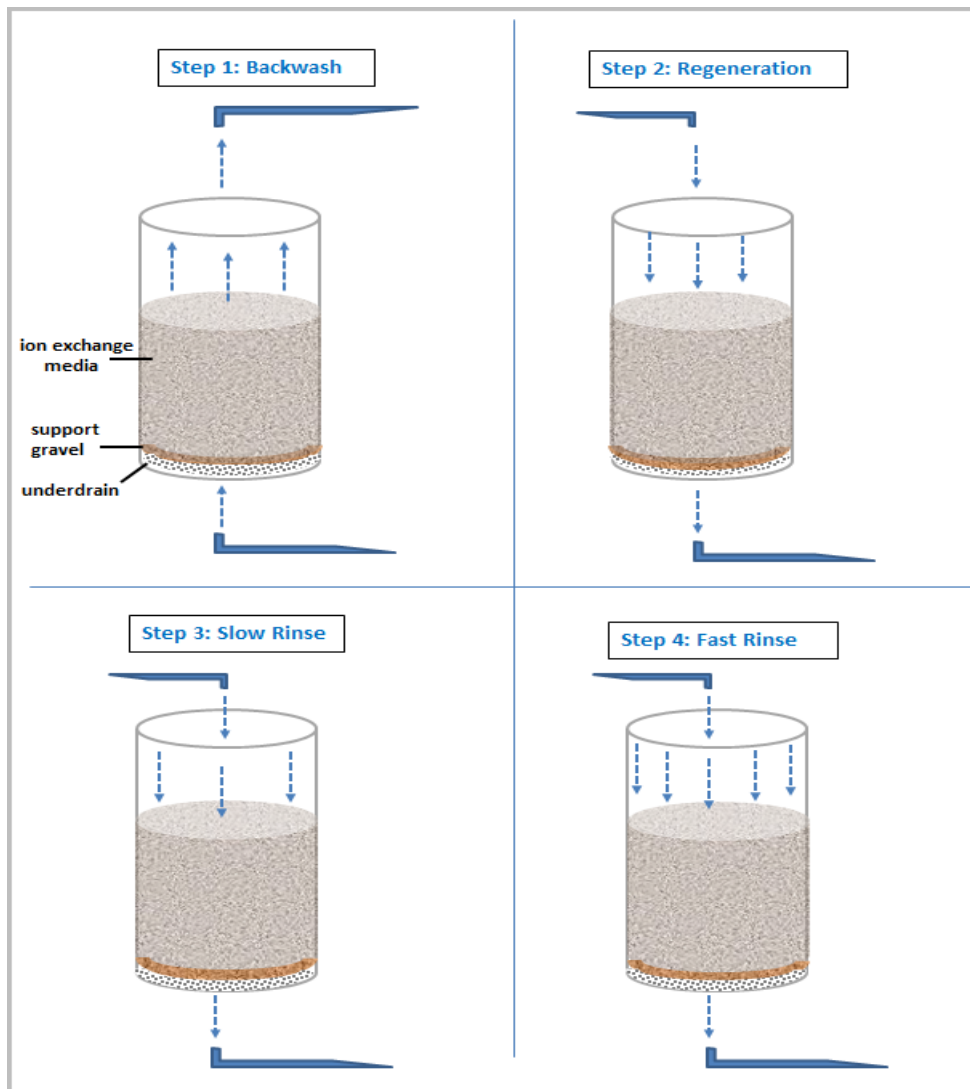


Diagram of Common Ion Exchange Regeneration Steps

Wastewater Disposal Considerations

The resin regeneration process produces a waste solution with an elevated level of the contaminant plus the regenerate brine solution. Do not dispose of backwash water into the storm drain system. Check with your local wastewater facility to determine if you will be in compliance in disposing of your ion exchange backwash water in the sanitary sewer system.

Flow Rate Considerations

During design and initial operation, a maximum flow rate of 100% will be determined for the unit.

Manufacturing instructions as well as daily operation will determine the optimum flow rates for the unit. Increasing flow rate (for example, from 40 % to 60%) will result in more contaminant removal for a set period of time, so the effluent will have less of the contaminant present. However, problems that may occur (as per the next section below) as well as the required frequency of regeneration need to be considered.

Ion Exchange Unit Monitoring

Conductivity can be a quick and inexpensive way to measure the performance of certain water treatment systems. Since ions carry a charge, an electrical conductivity meter may be used to determine when an ion exchange unit needs to be recharged.



Electrical conductivity meters measure the electrical conductivity in a solution. This type of meter (pictured on the left) may be used to determine when an ion exchange unit needs to be recharged.

Conductivity meter photo from Nuno Nogueira at

http://en.wikipedia.org/wiki/File:Electrical_conductivity_meter.jpg

Troubleshooting

If an ion exchange unit starts to have problems, there are various factors to be considered, a few of these are:

- Possible fouling of the resin from source water organics
- Improper resin regeneration
- Extended service run time resulting in additional needed regeneration time
- Flow rates that are too high or too low that cause premature resin exhaustion

- Leaky valves which can cause longer regeneration times
- Leaky valves which can cause poor water quality for the effluent leaving the unit
- Excessive backwashing which causes resin loss
- Instrumentation problems; for example, a conductivity meter that needs calibration

Excellent training information that includes details on troubleshooting can be found on various manufacturer ion exchange training web sites. Two of these (that are working as of 2015) are:

- GE Power & Water – Handbook – Chapter 8 on ion exchange:
http://www.gewater.com/handbook/ext_treatment/ch_8_ionexchange.jsp
- DOW Company – Ion Exchange Answer Center:
http://dowac.custhelp.com/app/answers/detail/a_id/439/~dow-ion-exchange-resins---troubleshooting
- Sacramento California Water Treatment Plant Operation Volume II, p. 102



Unit 6 Exercise #1 – Ion Exchange Unit Maintenance

Directions: Choose the correct answer.

1. What type of meter may be used to determine when an ion exchange unit needs to be recharged?
(choose the best answer)
 - a. Chlorine meter
 - b. Turbidimeter
 - c. A conductivity meter
 - d. pH meter

2. In order to decrease the amount of hardness ions present in the effluent leaving an ion exchange softener, the flow rate should be _____.
 - a. increased
 - b. decreased
 - c. kept the same

3. If the regeneration process is not properly performed on an ion exchange unit, it may result in the unit becoming _____ efficient at removing contaminants.

a. more

b. less

4. You are troubleshooting why your ion exchange unit seems to need a longer regeneration time; possible factors could be (check all that apply):

a. You have been decreasing your service run times

b. Your system has leaky valves

c. You have been extending your service run times

5. Ion exchange units are easy to completely recharge, so it's not critical whether or not you follow the manufacturer's recommendations for proper regeneration procedures.

a. True

b. False

II. Media Filter Maintenance

As stated previously, the process of drinking water filtration involves a physical straining of contaminants from the drinking water. Since the use of filters that contain media can be used to remove inorganic contaminants, let's look at media filters in more detail.

Media Containing Filter Types

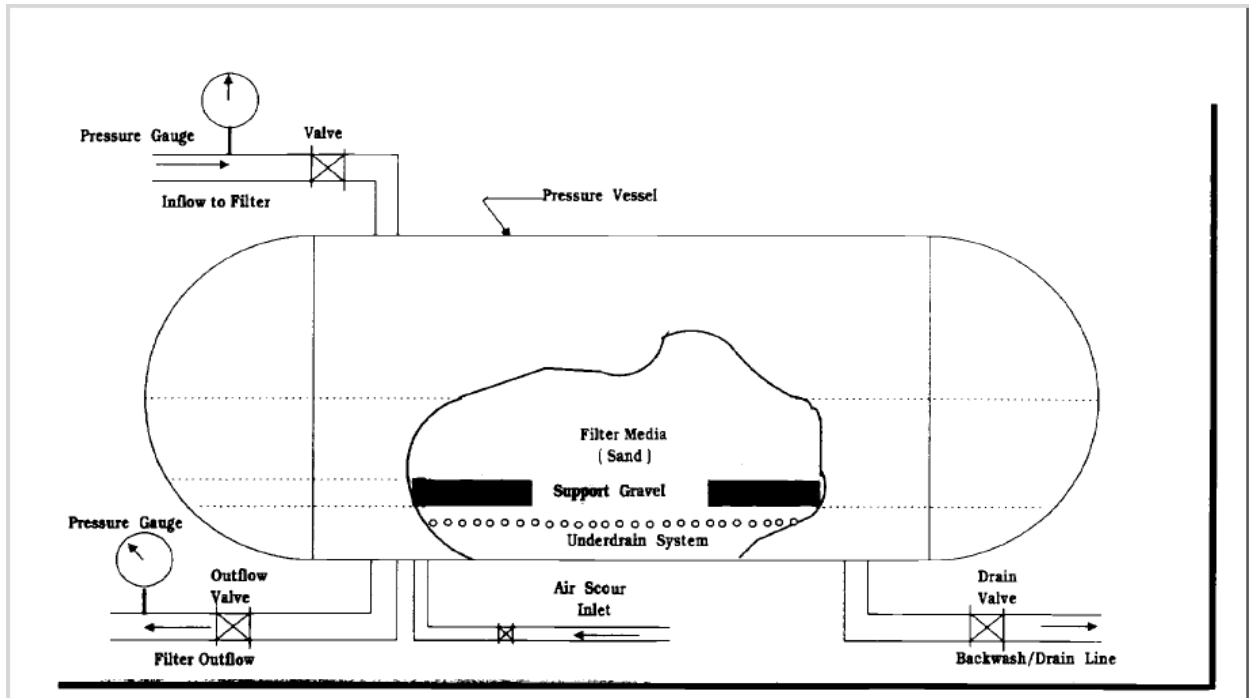
There are different types of filters that are used to treat large amounts of drinking water for the public in water treatment plants. The type of source water and the amount of water to be treated often determines the type of filter that will be used. As a result, the type of filtration that is used for removing inorganic contaminants may be either an open, gravity flow filter or a pressure filter.

In some plants, a filter is part of a treatment train of several types of treatment to remove various contaminants (that include inorganics). An example might be a mixed media filter that is present in a conventional or direct filtration treatment plant. In other plants, in addition to disinfection treatment, a filter may be the only other type of treatment present to target a specific inorganic contaminant. An example might be a small groundwater treatment plant that has liquid hypochlorite disinfection and a manganese greensand pressure filter to remove iron and manganese.

Filter names may be based on the type of media that they contain and/or whether the water flows through the filter by gravity or is forced through in a pressurized flow.

Let's look at two examples.

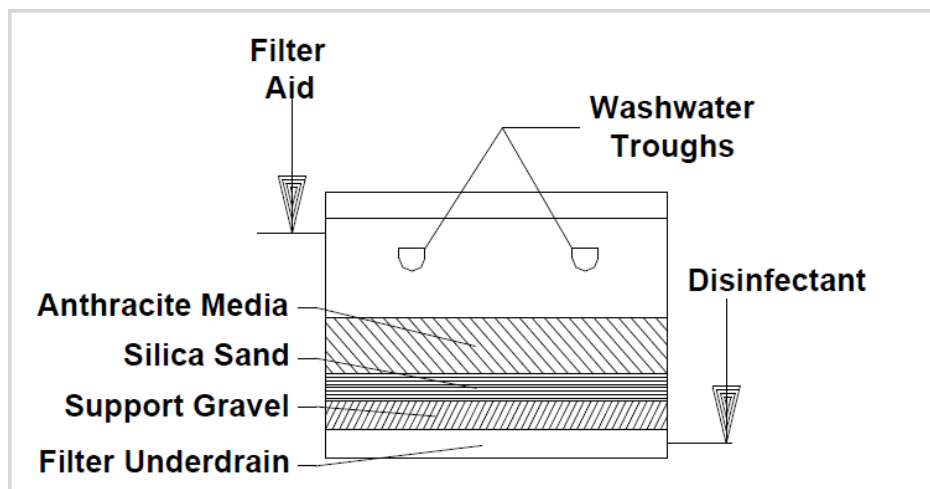
- **Pressure Filters** have media that is contained in a closed vessel. Instead of the water flowing through the filter by gravity, a pump or high-pressure water source causes the filter to be operated under pressure. See an example schematic of a pressure filter below.



Closed pressure filter schematic

from the 1995 Ireland EPA Water Treatment Manual on Filtration pg. 25 at:
https://www.epa.ie/pubs/advice/drinkingwater/EPA_water_treatment_manual_%20filtration1.pdf

- **Mixed Media Filters** have a mixture of media to filter out contaminants of various sizes. For example, the open mixed media filter shown below contains anthracite media and silica sand on top of support gravel and an underdrain. See an example schematic of an open mixed media filter below.



Open mixed media filtrater schematic

from Pa DEP Drinking Water Training Module #14 (Conventional Filtration) pg. 4-2 at:
http://files.dep.state.pa.us/Water/BSDW/OperatorCertification/TrainingModules/dw-14_conv_filtration_wb_final.pdf

More than one filter is often present at a treatment plant so that one can be shut down for cleaning while the other is in use or maintenance is occurring. Also, water may flow from one filter to another in series.

Source Water

If a filter is used to remove inorganic contaminants from drinking water, the source water and the amount of water to be treated often determines the type of filter that will be used.

- Open filters are typically used for surface water supplies.
- Pressure filters (tanks) are typically used for groundwater treatment.

Filter Terms

Let's define a few filter terms



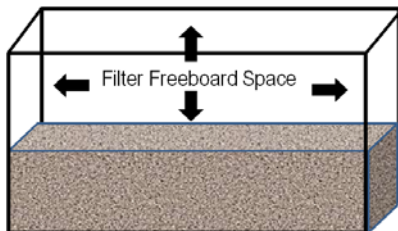
Backwashing – In water treatment, this refers to pumping water backward through the filter media in order to clean it.



Filter Effluent – Treated water that flows out of a filter.



Freeboard – The term used for the space between the top of the filter and the top of the filter tank that allows for filter media expansion.



Headloss – A measurement of the solids accumulation in the filter bed. This is the resistance to flow as water passes through the filter.

Filter Media

Typical conventional filtration plant filters may contain anthracite coal and silica sand on top of support gravel. A layer of garnet (a natural non-metallic mineral) may also be present on top of the gravel.

However, filters that are specific for inorganic removal may be open gravity or closed pressure filters and may contain a single type of media or a mixed media. Anthracite, silica sand, and zeolite media may be used by themselves or in a mixture.

Manganese greensand is commonly used in inorganic removal filters.

- **Manganese Greensand**

- Manganese greensand is greensand that is coated with manganese oxide that is used to remove iron and manganese under controlled pH conditions.
- Manganese greensand is commonly used for groundwater sources containing levels of iron and/or manganese that require treatment.
- Greensand filters typically have an anthracite media cap (12 inch to 24 inch depth) that serves to remove iron, thereby reducing fouling and clogging of the greensand.
- Greensand filters are sometimes referred to as “iron filters” because they are commonly used to remove iron. (Note: Sometimes the term “iron filter” also refers to an ion exchange softener that is also removing iron, so this term has various meanings.)
- Soaking and cleaning greensand filters in an acidic solution will increase the ion exchange efficiency of the filter. (Note: see the question below for more discussion about the use of the term “ion exchange” in discussing this type of filter).



Question: Since manganese greensand is said to be used in filters, can this process ever be considered to be an ion exchange process?

Answer: Manganese greensand treatment is primarily an oxidation and filtration chemical process. There are some technical articles on-line that indicate that this process also has ion exchange properties. That explanation is beyond the scope of this module.

Filter Backwashing

During the filtration process, contaminant particles become trapped in the media. As media expansion takes place and the flow through the filter slows down, this is an indication that the filter needs to be backwashed.

Backwashing of a filter occurs as water is pumped back up through the filter media (sometimes in conjunction with the intermittent use of compressed air).

Rapid sand filters and pressure filters can be backwashed.

The backwash process may be triggered automatically after a set amount of time or based on head loss measurements. For some filters, the backwash requirements may be based on when the contaminant (for example, such as iron and/or manganese) begins to break through the filter. A backwash can also have a turbidity-based trigger.

- ✦ The freeboard, the space above the filter media, allows for the media bed expansion during the backwash process.
- ✦ Air wash is important in conjunction with water wash.
- ✦ Insufficient backwashing causes the thickness of the filter media to increase. This can cause problems such as:
 - decreased flow through the filter media,
 - failure to remove additional insoluble iron and manganese,
 - decreased filter run times
- ✦ Excessive backwash flow rate can cause a loss of filter media.



Disposal Considerations

The backwash process produces a waste solution with an elevated level of the contaminant. Check with your local wastewater facility to determine if you will be in compliance in disposing of your filter backwash water in the sanitary sewer system.

During the permitting phase (with Pa DEP's clean water program as well as with any pertinent local WW authority), it is good to verify that there are no relevant permit compliance issues which might be associated with day-to-day operation of the DW facility.

Flow Rate Considerations

During design and initial operation, a maximum flow rate of 100% will be determine for the unit.

Manufacturing instructions as well as daily operation will determine the optimum flow rates for the filter. Increasing flow rate (for example, from 40 % to 60%) will result in more contaminant removal for a set period of time, so the effluent will have less of the contaminant present.

Problems that may occur if flow rates are too low or too high need to be considered. For example, if the finished water has a turbid appearance, the flow through the unit may need to be decreased.

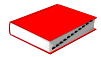
The calculation of filter loading rate is important because if too much contaminated water is “loaded” onto an inorganic filter, “fouling” or clogging of the filter can occur.

Drinking Water Filter Monitoring

Depending on the quality of the source water and the amount of water being treated, there are various types of treatment that may be used at a public water system. As a result, different types of monitoring equipment may be present to determine if the finished water is meeting certain standards. For example, pH meters and chlorine monitors may be present to monitor water corrosivity and disinfection levels.

One way to determine if a filter is adequately removing certain inorganic contaminants is to monitor the finished water using targeted testing. However, since frequent targeted testing of certain inorganics can be impractical due to analytical time and cost, more generalized testing is used. Since a sand or mixed media filter is often removing more than just inorganics, a turbidimeter may be used to assess the turbidity of the water effluent to assess the functioning of the unit.

Sand or Mixed Media Filter Monitoring



Turbidity – In drinking water treatment, this is the cloudiness of the water that is measured by passing a light beam through the water to measure how much of the light is reflected by the particles in the water.

Turbidimeters measure the turbidity of water before filtration and following filtration with a sand or mixed media (sand, gravel and anthracite coal) filter.

A turbidimeter is used to measure water clarity.



Turbidimeter photo from Z22 at <https://en.wikipedia.org/wiki/Turbidity>



Unit 6 Exercise #2 – Media Filter Maintenance

Directions: Choose the correct answer.

1. Should the freeboard space of a filter be totally filled?
 - a. Yes, the more filter media there is in a filter, the more contaminants that can be removed
 - b. No, because it allows for media bed expansion during the backwashing process

2. Filter backwash is required when contaminants (such as iron or manganese) begin to build up in and break through the filter
 - a. True
 - b. False

3. Insufficient backwashing causes the thickness of the filter media to increase. For iron and manganese removal, this can cause problems such as (choose all that apply):
 - a. increased flow through the filter media,
 - b. failure to remove additional insoluble iron and manganese
 - c. better cleaning of media during the backwash process.
 - d. decreased filter run times







4. The backwash process on an iron and manganese filter produces a waste solution with an elevated level of these contaminants. Backwash water can be disposed of into the storm drain system that leads to a nearby body of water.
 - a. True
 - b. False

5. As media _____ takes place and the flow through the filter _____, this is an indication that the filter needs to be backwashed.
 - a. contraction, speeds up
 - b. expansion, slows down
 - c. coloring, gets cloudy

6. If the finished water from your filter has a turbid appearance, the flow through the filter may need to be _____.
- increased
 - decreased
7. The term "iron filter" usually refers to an oxidizing filter where iron is oxidized by the special coating of manganese oxide that is attached to the _____ in the filter .
- greensand
 - polyphosphates
8. Soaking and cleaning greensand filters in an acidic solution will increase the ion exchange efficiency of the filter.
- True
 - False



Unit 6 Key Points:

-  An electrical conductivity meter may be used to determine when an ion exchange unit needs to be recharged.
-  Ion exchange units must be periodically recharged.
-  A common type of granular media used for iron and manganese removal is and manganese greensand
-  The freeboard, the space above the filter media, allows for the media bed expansion during the backwash process.
-  Filter backwash is required when headloss reaches a predetermined endpoint, or when iron and/or manganese begin to break through the filter.
-  Consult your local wastewater facility to discuss the processing of backwash water after it is released into the sanitary sewer.

Unit 6 References:

Ion exchange:

- Ion exchange recharge explanation and definition from the following:

- IOC/SOC/VOC Treatment Fact Sheet on Ion Exchange written by E. Rawski for the 1999 Pa. DEP Advanced Staff Handbook (ASH) Training.
- Ion exchange exhaustion definition combined from the following:
 - IOC/SOC/VOC Treatment Fact Sheet on Ion Exchange written by E. Rawski for the 1999 Pa. DEP Advanced Staff Handbook (ASH) Training.
 - CT Department of Public Health *Publication 10: Ion Exchange Treatment of Private Drinking Water Systems*, April 2009 at: http://www.ct.gov/dph/lib/dph/environmental_health/pdf/ion_Exchange_Treatment_of_PDWS.pdf
- Ion exchange recharge definition IOC/SOC/VOC Treatment Fact Sheet on Ion Exchange written E. Rawski as referenced above.
- Ion exchange resin examples from DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB pp. 3-28, 3-32, and 3-36.
- Zeolite definition created from information taken from Wikipedia article on Zeolite at <https://en.wikipedia.org/wiki/Zeolite>
- Ion exchange backwash water disposal information taken from http://cfpub.epa.gov/safewater/radionuclides/radionuclides.cfm?action=Rad_Ion%20Exchange
- Ion exchange regeneration steps summarized in a compilation of information from the following web sites:
 - WQP (Water Quality Products) Newsletter article "Resin Regeneration Fundamentals" by Frank Desilva at <http://www.wqpmag.com/resin-regeneration-fundamentals>
 - New Zealand Institute of Chemistry article entitled "Ion Exchange Resins" by David Alchin (Service Chemist, Drew New Zealand) with summary by Heather Wansbrough at <http://nzic.org.nz/ChemProcesses/water/13D.pdf> - pg. 5

Filtration:

- Manganese greensand definition taken from Wikipedia article on Greensand at <https://en.wikipedia.org/wiki/Greensand>
- Backwashing definition and explanation taken from Wikipedia article on Backwashing at [https://en.wikipedia.org/wiki/Backwashing_\(water_treatment\)](https://en.wikipedia.org/wiki/Backwashing_(water_treatment)) Types of filters that can be backwashed also taken from this web article.
- Headloss definition is taken from DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB p. 3-17.
- Filter backwash information is taken from DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB p. 3-17.
- Iron Filter meaning compiled by Pa. DEP's W. Lloyd from Googling the term "iron filter" and reading various web sites.
- Conventional filter media information from DEP's DW Operator Training Module #14 (Conventional Filtration) WB p. 4-2.
- Filter effluent definition created by DEP's W.Lloyd.
- Conductivity definition is taken from Wikipedia article on Conductivity (electrolytic) at [https://en.wikipedia.org/wiki/Conductivity_\(electrolytic\)](https://en.wikipedia.org/wiki/Conductivity_(electrolytic))
- Comic strip characters from clip art that comes with the programs licensed to DEP; wording by Pa. DEP's W. Lloyd.

Appendix A: MCL List

(Note: As of the 2015 editing of this module, this 2006 Pennsylvania Maximum Contaminant Level (MCL) is still current.)

**PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF DRINKING WATER MANAGEMENT
MAXIMUM CONTAMINANT LEVELS (MCLs)
MAXIMUM RESIDUAL DISINFECTANT LEVELS (MRDLs)**

PRIMARY CONTAMINANTS

Volatile Organic Chemicals (VOCs):

BENZENE	0.005	mg/L	MONOCHLORO BENZENE	0.1	mg/L
CARBON TETRACHLORIDE	0.005	mg/L	STYRENE	0.1	mg/L
o-DICHLORO BENZENE	0.6	mg/L	TETRACHLOROETHYLENE	0.005	mg/L
para-DICHLORO BENZENE	0.075	mg/L	TOLUENE	1	mg/L
1,2-DICHLOROETHANE	0.005	mg/L	1,2,4-TRICHLORO BENZENE	0.07	mg/L
1,1-DICHLOROETHYLENE	0.007	mg/L	1,1,1-TRICHLOROETHANE	0.2	mg/L
cis-1,2-DICHLOROETHYLENE	0.07	mg/L	1,1,2-TRICHLOROETHANE	0.005	mg/L
trans-1,2-DICHLOROETHYLENE	0.1	mg/L	TRICHLOROETHYLENE	0.005	mg/L
DICHLOROMETHANE	0.005	mg/L	VINYL CHLORIDE	0.002	mg/L
1,2-DICHLOROPROPANE	0.005	mg/L	XYLENES (Total)	10	mg/L
ETHYLBENZENE	0.7	mg/L			

Synthetic Organic Chemicals (SOCs):

ALACHLOR	0.002	mg/L	GLYPHOSATE	0.7	mg/L
ATRAZINE	0.003	mg/L	HEPTACHLOR	0.0004	mg/L
BENZO(a)PYRENE	0.0002	mg/L	HEPTACHLOR EPOXIDE	0.0002	mg/L
CARBOFURAN	0.04	mg/L	HEXACHLORO BENZENE	0.001	mg/L
CHLORDANE	0.002	mg/L	HEXACHLOROCYCLOPENTADIENE	0.05	mg/L
2,4-D	0.07	mg/L	LINDANE	0.0002	mg/L
DALAPON	0.2	mg/L	METHOXYCHLOR	0.04	mg/L
DIBROMOCHLOROPROPANE (DBCP)	0.0002	mg/L	OXAMYL (Vydate)	0.2	mg/L
DI(2-ETHYLHEXYL) ADIPATE	0.4	mg/L	PCBs	0.0005	mg/L
DI(2-ETHYLHEXYL) PHTHALATE	0.006	mg/L	PENTACHLOROPHENOL	0.001	mg/L
DINOSEB	0.007	mg/L	PICLORAM	0.5	mg/L
DIQUAT	0.02	mg/L	SIMAZINE	0.004	mg/L
ENDOTHALL	0.1	mg/L	2,3,7,8-TCDD (Dioxin)	3 x 10 ⁻⁸	mg/L
ENDRIN	0.002	mg/L	TOXAPHENE	0.003	mg/L
ETHYLENE DIBROMIDE (EDB)	0.00005	mg/L	2,4,5-TP (Silvex)	0.05	mg/L

Disinfection Byproducts:

TOTAL TRIHALOMETHANES (TTHMs)	0.080	mg/L
(Chloroform, Chlorodibromomethane, Bromoform & Bromodichloromethane)		
HALOACETIC ACIDS (HAA5)	0.060	mg/L
Monochloroacetic Acid, Dichloroacetic Acid, Trichloroacetic Acid, Monobromoacetic Acid, & Dibromoacetic Acid)		
BROMATE	0.010	mg/L
CHLORITE	1.0	mg/L

Disinfectants (MRDLs): *Note 2*

CHLORINE (as Cl ₂)	4.0	mg/L
CHLORAMINES (as Cl ₂)	4.0	mg/L
CHLORINE DIOXIDE (as ClO ₂)	0.8	mg/L

MRDL = Maximum Residual Disinfectant Level

Inorganic Chemicals (IOCs):

ANTIMONY	0.006	mg/L
ARSENIC	0.010	mg/L
ASBESTOS (Fibers longer than 10µm)	7 million fibers/L	
BARIUM	2	mg/L
BERYLLIUM	0.004	mg/L
CADMIUM	0.005	mg/L
CHROMIUM	0.1	mg/L
COPPER **	1.0	mg/L
CYANIDE (free CN)	0.2	mg/L

Radionuclides:

GROSS ALPHA	15	pCi/L
COMBINED RADIUM (226 + 228)	5	pCi/L
BETA PARTICLE & PHOTON ACTIVITY	4	mrem/yr
Gross Alpha MCL excludes Radon and Uranium particle activity.		
Beta Particle & Photon Activity MCL is for man-made radionuclides.		
URANIUM	30	µg/L

FLUORIDE	2	mg/L
LEAD **	0.005	mg/L
MERCURY	0.002	mg/L
NITRATE (as Nitrogen)	10	mg/L
NITRITE (as Nitrogen)	1	mg/L
NITRATE + NITRITE (as Nitrogen)	10	mg/L
SELENIUM	0.05	mg/L
THALLIUM	0.002	mg/L

** The lead and copper primary MCLs are applicable only to bottled, vended, retail and bulk water hauling systems

Microbiological Contaminants: PRESENCE OR ABSENCE OF TOTAL COLIFORMS BASED ON NUMBER OR PERCENTAGE OF TOTAL COLIFORM POSITIVE SAMPLES/MONTH OR FECAL COLIFORM OR E.COLI POSITIVE ROUTINE OR CHECK SAMPLES

Turbidity 1 NTU (applicable only to unfiltered surface water sources)

**PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION
DIVISION OF DRINKING WATER MANAGEMENT
MAXIMUM CONTAMINANT LEVELS (MCLs)**

SECONDARY CONTAMINANTS

ALUMINUM	0.2	mg/L	MANGANESE	0.05	mg/L
CHLORIDE	250	mg/L	ODOR	3	T.O.N
COLOR	15	color units	pH *	6.5 - 8.5	
CORROSIVITY	non-corrosive		SILVER	0.1	mg/L
FOAMING AGENTS	0.5	Mg/L	SULFATE	250	mg/L
IRON	0.3	Mg/L	TOTAL DISSOLVED SOLIDS	500	mg/L
			ZINC	5	mg/L

*The pH MCL represents a "reasonable goal for drinking water quality."

Notes:

mg/L = milligrams per liter = parts per million; µg /L = micrograms per liter = parts per billion;
pCi/L = picocuries per liter (particle activity); mrem/yr = millirems/yr (annual dose equivalent)
µm = micrometers; T.O.N. = threshold odor number

Chapter 109, Safe Drinking Water Regulations, defines MCL and MRDL as follows:

MCL (Maximum Contaminant Level) – the maximum permissible level of a contaminant in water which is delivered to a user of a public water system, and includes the primary and secondary MCLs established under the Federal Safe Drinking Water Act, and MCLs adopted under the act. For MCLs incorporated into this chapter by reference, the term refers to the numerical value and the means of determining compliance with that value and does not refer to the EPA applications to specific types of public water systems or sources.

MRDL (Maximum Residual Disinfectant Level) – 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 adverse health effects. The consumer’s tap means the entry point for bottled water and vended water systems, retail water facilities and bulk water hauling systems.

Appendix B: Sources of Inorganic Contaminants Important to Drinking Water

The following chart displays examples of common sources of inorganic contaminants (metals) that are of importance to drinking water.

Parameters	Metals				
	Naturally Occurring	Industrial Discharges	Storm Water Run-off	Distribution System Pipe Corrosion	Water Treatment By-product
Antimony		Petroleum refineries; fire retardants; ceramics; electronics; solder			
Barium	Erosion of natural deposits	Drilling wastes; metal refineries; brick and ceramic manufacturers			
Beryllium		Metal refineries; coal burning factories; electrical, aerospace, and defense industries			
Cadmium	Erosion of natural deposits	Metal refineries; waste from electroplating	Runoff from waste; batteries; paint	Galvanized pipe corrosion	
Chromium (total of valence states III and IV)	Erosion of natural deposits	Steel and pulp mills; waste from electroplating; garbage; fossil fuel combustion			
Lead	Erosion of natural deposits			Corrosion of distribution system lead pipe; household plumbing systems	
Copper	Erosion of natural deposits			Corrosion of household plumbing systems	Copper salts used for algae control in reservoirs
Mercury, Total (inorganic)	Erosion of natural deposits	Refineries; factories	Runoff from landfills and croplands		
Nickel	Erosion of natural deposits				

Parameters	Metals				
	Naturally Occurring	Industrial Discharges	Storm Water Run-off	Distribution System Pipe Corrosion	Water Treatment By-product
Thallium		Leeching from one-processing sites; electronics, glass, and drug factories			
Iron	Erosion of natural deposits; bacteria converting solid ferric hydroxide (FeOH) soluble ferrous ion (Fe ⁺)	Acid mine drainage		Corrosion of distribution pipe	Overdose of iron salt coagulant
Manganese	Erosion of natural deposits; in aquatic environment, anaerobic bacteria convert solid manganese dioxide (MnO ₂) to soluble manganous ion (Mn ⁺)	Discarded batteries; steel alloys; agricultural products			
Aluminum	Erosion of natural deposits				Overdose of alum coagulant
Silver					Some domestic treatment systems
Sodium	Erosion of natural deposits	Many industrial wastes			Sodium hypochlorite, caustic soda, soda ash
Zinc	Erosion of natural deposits			Corrosion of galvanized pipe	Some phosphate-based corrosion inhibitors

The following chart displays examples of common sources of inorganic contaminants (anions and miscellaneous inorganics) that are of importance to drinking water.

Parameters	Inorganic Anions & Miscellaneous Inorganics				
	Naturally Occurring	Industrial Discharges	Storm Water Run-off	Distribution System Pipe Corrosion	Water Treatment By-product
Arsenic	Erosion of natural deposits	Glass and electronics production wastes; smelting of nonferrous metal ores (especially copper)			
Asbestos	Erosion of natural deposits	Mining discharge		Asbestos decay; cement pipe	
Chloride	Erosion of natural deposits				
Sulfate	Erosion of natural deposits				
Nitrate (as N)	Erosion of natural deposits		Leaching from septic tanks; farm fertilizers; feed lots; sewage		
Nitrite (as N)			Leaching from septic tanks; sewage		
Nitrate + Nitrite (both as N)	Erosion of natural deposits		Leaching from septic tanks; farm fertilizer; feed lots; sewage		
Fluoride	Erosion of natural deposits		Fertilizer; aluminum factories; leaching from septic tanks; sewage		Water additive to promote strong teeth
Selenium	Erosion of natural deposits	Petroleum refineries; discharge from mines			
TDS (Total Dissolved Solids)	Erosion of natural deposits				

References:

Appendix B Tables taken from Pa. DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB pp. 1-5 through 1-7

Appendix C: Treatment Technology Options

The following tables present inorganic contaminants that may potentially be found in drinking water supplies and the feasible treatment options for each contaminant.

Table C.1 Treatment Technology Options for Metals

Parameter	GAC	Oxidation	Coagulation/ Filtration	Ion Exchange	Membranes	Lime Softening	Activated Alumina	Corrosion Control	Sequestration
Antimony			X		X				
Barium				X (Cation)	X	X			
Beryllium			X	X	X	X			
Cadmium			X	X (Cation)	X	X		X	
Chromium ⁽⁺³⁾			X	X (Cation)	X	X			
Chromium ⁽⁺⁶⁾			x	X (Anion)	X	X			
Copper								X	
Iron		X	X	X (Cation)	X	X		X	X
Lead								X	
Manganese		X	X	X (Cation)	X	X		X	X
Mercury	X		X		X	X			
Molybdenum				X (Anion)	X				
Nickel				X (Cation)	X	X			
Thallium				X (Anion)			X		
Zinc				X (Cation)	X	X		X	

⁽¹⁾ **Membranes**

NF Nanofiltration (membranes containing slightly larger diameter pores than RO; used primarily for softening hard water and for removing disinfectant by-product precursors, or organics)

RO Reverse osmosis (membranes primarily used for desalination of seawater and for removal of salts from brackish water; also capable of removing synthetic organic chemicals)

ED Electrodialysis/Electrodialysis Reversal (membrane process primarily used to demineralize brackish water and seawater, and to soften hard water; limited to removing ionic contaminants; not effective for removing pathogens and organics)

GAC Granular Activated Carbon

Table C.2 Treatment Technology Options for Inorganic Anions and Miscellaneous Inorganics

Parameter	GAC	Oxidation	Coagulation/ Filtration	Ion Exchange	Membranes ⁽¹⁾	Lime Softening	Activated Alumina	Corrosion Control	Sequestration
Arsenic (+3)			X (w/preoxidation)	X	X	X (w/preoxidation)	X	X	
Arsenic (+5)			X	X	X	X (w/preoxidation)	X	X	
Boron				X	X	X			
Nitrate				X	X				
Nitrite				X	X				
Nitrate and Nitrite				X	X				
TDS					X				
Chloride					X				
Sulfate				X	X				
Selenium (+4)			X	X (Anion)	X	X	X		
Selenium (+6)				X (Anion)	X	X	X		
Fluoride					X		X		
Calcium & Magnesium Hardness				X (Cation)	X	X			X

⁽¹⁾ Membranes

NF Nanofiltration (membranes containing slightly larger diameter pores than RO; used for softening hard water and for removing disinfectant by-product precursors, or organics)

RO Reverse osmosis (membranes primarily used for desalination of seawater and for removal of salts from brackish water; also capable of removing synthetic organic chemicals)

ED Electrodialysis/Electrodialysis Reversal (membrane process used to demineralize brackish water and seawater, and to soften hard water; limited to removing ionic contaminants; not effective for removing pathogens and organics)

GAC Granular Activated Carbon

References:

- Appendix C Tables taken from Pa. DEP's 2006 DW Operator Training Module #22 (Inorganic Removal) WB pp. 3-3 & 3-4

Appendix D: Inorganic Removal Pre-Test

1. Solve the following equation: $\frac{385 + (21/7) - (5 \times 13 \times 4)}{17 + 11 - (6 \times 4)} =$

- a. 9
- b. 7
- c. 31
- d. 32

2. The following is NOT an inorganic contaminant:

- a. Arsenic
- b. Benzene
- c. Copper
- d. Lead

3. Potassium permanganate:

- a. Will color water green if too much is added
- b. Is a strong oxidizer
- c. Is the typical name given to sodium carbonate

4. Adding a base to water _____ the pH; adding an acid to water _____ the pH

- a. lowers; drops
- b. raises; spikes
- c. lowers; raises
- d. raises; lowers

5. Solve for X in the following equation: $2.5 = \frac{1,000}{X}$

- a. $X = 0.0025$
- b. $X = 2,500$
- c. $X = 400$
- d. $X = 1,000$

6. Excessive iron in the water can cause:

- a. The water to have a rust or orange color
- b. The water to have a sweet taste
- c. The water to stain plumbing fixtures black

7. The use of coagulant chemicals promotes:
- medium particles to stay the same size
 - small particles to clump together into larger particles
 - larger particles to break down into smaller particles
8. A cylindrical inorganic filter has a diameter of 20 feet. What is the filter media surface area?
(Hint: The formula for area of a circle = $(0.785)(\text{Diameter}^2)$)
- 7.85 ft²
 - 17 ft²
 - 314 ft²
 - 177 ft²
9. The presence of which mineral in drinking water can make it "hard water."
- potassium
 - sodium
 - calcium
10. 54 inches is how many feet? (Hint: 1 foot = 12 inches)