

Drinking Water Operator Certification Training Instructor Guide



Module 22: Inorganics Removal

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:
The Pennsylvania State Association of Township Supervisors (PSATS)
Gannett Fleming, Inc.
Dering Consulting Group
Penn State Harrisburg Environmental Training Center

A Note to the Instructor

Dear Instructor:

The primary purpose of this course, *Inorganics*, is to introduce participants to the basics of plant administration. This module has been designed to be completed in approximately 3 hours, but the actual course length will depend upon content and/or delivery modifications and results of course dry runs performed by the DEP-approved sponsor. The number of contact hours of credit assigned to this course is based upon the contact hours approved under the DEP course approval process. To help you prepare a personal lesson plan, timeframes have been included in the instructor guide at the Unit level and at the Roman numeral level of the topical outline. You may need to adjust these timeframes as necessary to match course content and delivery modifications made by the sponsor. Please make sure that all teaching points are covered and that the course is delivered as approved by DEP.

Web site URLs and other references are subject to change, and it is the training sponsor's responsibility to keep such references up to date.












Delivery methods to be used for this course include:

<ul style="list-style-type: none"> • Lecture • Discussion Questions • Calculations 	<ul style="list-style-type: none"> • PowerPoint slides • Class Activities • Exercises
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To present this module, you will need the following materials:

<ul style="list-style-type: none"> • One workbook per participant • Extra pencils • Flip Chart • Markers 	<ul style="list-style-type: none"> • Laptop (loaded with PowerPoint) and an LCD projector or overheads of presentation and an overhead projector • Screen
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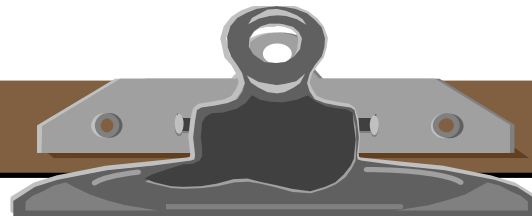
Icons to become familiar with include:

Participant Workbook	Instructor Guide
 Exercise/Activity	Same icons for Participant Workbook apply to the Instructor Guide. Ans: Answer to exercise, case study, discussion, question, etc.
 Case Study	
 Discussion Question	 PowerPoint Slide
 Calculation(s)	 Overhead
 Exercise	 Flip Chart
 Key Definition(s)	 Suggested "Script"
 Key Point(s)	

Instructor text that is meant to be general instructions for the instructor are designated by being written in script font and enclosed in brackets. For example:

[Ask participants if they have any questions on how to read the table. Answer any questions participants may have about how to read the table.]

If your module includes the use of a PowerPoint presentation, below are some helpful controls that you may use within the Slide Show.



PowerPoint Slide Show Controls

You can use the following shortcuts while running your slide show in full-screen mode.

To	Press
Advance to the next slide	N, ENTER, or the SPACEBAR (or click the mouse)
Return to the previous slide	P or BACKSPACE
Go to slide <number>	<number>+ENTER
Display a black screen, or return to the slide show from a black screen	B
Display a white screen, or return to the slide show from a white screen	W
Stop or restart an automatic slide show	S
End a slide show	ESC
Return to the first slide	Both mouse buttons for 2 seconds
Change the pointer to a pen	CTRL+P
Change the pen to a pointer	CTRL+A
Hide the pointer and button temporarily	CTRL+H
Hide the pointer and button always	CTRL+L
Display the shortcut menu	SHIFT+F10 (or right-click)
Erase on-screen annotations	E
Go to next hidden slide	H
Set new timings while rehearsing	T
Use original timings while rehearsing	O
Use mouse-click to advance while rehearsing	M

INSTRUCTOR GUIDE

INTRODUCTION OF MODULE: 5 minutes



Display Slide 1—Module 22: Inorganics Removal.

[Welcome participants to “Module 22 – Inorganics Removal.” Indicate the primary purpose of this course is to provide an overview of the inorganics removal process by identifying inorganics, their origins, their impact on drinking water, and their treatments.]

{Introduce yourself.}

[Provide a brief overview of the module.]



This module contains 3 units. On page i, you will see the topical outline for **Unit 1 – Overview of Inorganics** and for **Unit 2 – Inorganics Removal Standards**.

[Briefly review outline.]



If you turn the page, you will see the topical outline for **Unit 3 – Treatment Protocols**.

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[Continue to briefly review outline.]



Now turn the page again and you will see the end of the topical outline for Unit 3.

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[Finish reviewing the outline.]

INSTRUCTOR GUIDE

UNIT 1: 45 minutes



Display Slide 2—Unit 1: Overview of Inorganics.



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

- Define and identify sources of undesirable inorganic constituents that may be found in drinking water.
- Provide a brief historical perspective on inorganics removal treatment processes.



Display Slide 3—Unit 1: Overview of Inorganics.

- Define the following words:
 - Anions.
 - Cations.
 - Catalyst, as it pertains to treatment for soluble manganese.
 - Colloidal, as it pertains to iron and manganese.
 - Insoluble, as it pertains to metals.
 - Kinetics, as it pertains to oxidation.
 - Oxidation, as it pertains to treatment for soluble metals.
 - pH.
 - pE-pH.
 - Soluble, as it pertains to metals.
 - Solute.

INTRODUCTION TO INORGANICS: 20 minutes



Before we can discuss the removal of inorganics from the drinking water supply, we should first define the term and then discuss the sources of inorganics. So, let's start Unit 1 with a brief introduction to inorganics.

Definition of Inorganics



Review the definition of **inorganics**.

Sources of Inorganic Constituents



Where do these inorganics originate? How do they get into our water supplies? Let's examine those questions now.

Naturally Occurring

[Review the first and second bulleted point in the workbook].



This second point sounds a little confusing. It just means that there is dissolution and a subsequent release of iron and manganese from a lake or reservoir's bottom sediments.

[Finish reviewing information in the workbook.]

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The chart you see on this page is intended to give you an overview of the classic “world average” river, according to Livingstone. The highest concentrations are calcium and bicarbonate ions, both major components of “hard water.” This indicates that the bulk of rivers tend to be characteristically hard. Keep in mind that no one particular river is represented in this chart; it is a compilation of averages.

[Allow participants a minute or two to review the chart.]

Municipal and Industrial Discharge



Besides occurring naturally, inorganics are also introduced by people into the water supply. Municipal and industrial discharges can contribute to the problem.

[Ask participants to answer aloud the following question.]



What are some examples of municipal and industrial discharges that contribute inorganics to the water supply?

Ans: Phosphorous from municipal wastewater treatment plants contribute inorganics.
NOTE TO INSTRUCTOR: Various other answers are possible.

Non-point and Run-off

[Review information in the workbook. Ask the following question.]



What are some examples of non-point and run-off that contribute inorganics to the water supply?

Ans: Inorganics are contributed from nitrates due to run-off from fields to which fertilizer has been applied; sodium from salting icy roads; and iron from acid mine drainage.
NOTE TO INSTRUCTOR: Various other answers are possible.

Water in Contact with Piping

[Review information in the workbook. Ask the following question.]



What are some inorganics that find their way into the water supply via water in contact with piping?

Ans: Inorganics are found due to increased lead levels because of dissolution of lead-tin solder used in plumbing fixtures; “red water” is due to the corrosion of cast iron pipes; and asbestos in water is from leaching of asbestos-cement pipes.

NOTE TO INSTRUCTOR: Various other answers are possible.

Water Treatment By-products

[Review information in the workbook. Ask the following question.]



What are some examples of water treatment by-products that contribute inorganics in the water supply?

Ans: Contributions include aluminum residuals from overfeeding aluminum sulfate (alum), a water treatment plant coagulant; and bromate formation as a by-product of feeding ozone for disinfection to a raw water containing bromine.

NOTE TO INSTRUCTOR: Various other answers are possible.

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On pages 1-5 and 1-6, you will see a chart that shows some of the common metals that are found in drinking water, and some examples of their sources.

[Allow participants a few minutes to review the chart.]

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[NOTE TO INSTRUCTOR: The second page of the chart is located on page 1-6.]

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On page 1-7, you will see a similar chart that depicts inorganic ions and miscellaneous inorganics that are found in drinking water and the sources from which they come.

[Allow participants a few minutes to review the chart.]

INSTRUCTOR GUIDE

HISTORICAL PERSPECTIVES ON INORGANICS: 10 minutes



Since the early 20th century, the emphasis has been shifting from acute health issues to more chronic, long-term health effects due to the presence of trace quantities of organic, inorganic, and microbiological contaminants in drinking water supplies.

Chemical Perspectives



We will briefly review the timeline of chemical perspectives.

[Briefly review information in the workbook.]

Physical Perspectives



Earlier in history, if water was clear, it was assumed to be safe.

[Review information in the workbook.]

INSTRUCTOR GUIDE

GENERAL INORGANIC CHEMICAL AND TREATMENT TERMINOLOGY: 15 minutes



As we delve further into the subject of inorganics, their properties, and their treatments, you will encounter some words that may be new to you. We will review some of those terms now.



Review the definition of **anion**.



If anion is a compound with a negative charge, what do you suppose cation means?



Review the definition of **cation**.



Review the definition of **catalyst**.



Review the definition of **colloidal**.



Review the definition of **insoluble**.



Review the definition of **kinetics**.



Review the definition of **oxidation**.



What is one example of oxidation that many of us find on our cars?

Ans: Rust.



The next definition is probably familiar to many of you.



Review the definition of **pH**.



Review the definition of **pE-pH**.



Review the definition of **soluble**.



Review the definition of **solute**.



Now we have finished Unit 1. You can define inorganics and discuss some of their origins and how they are introduced into the water supply. You know the brief history and perspective of their treatments. And, we have introduced many terms.

We are ready to look more closely at the standards for inorganic constituents, which is the subject of Unit 2.

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UNIT 2: 25 minutes



Display Slide 4—Unit 2: Inorganics Removal Standards.



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

- State one reason for regulating some inorganic constituents by primary maximum contaminant level (PMCL) drinking water standards.
- Identify three inorganic constituents and describe their aesthetic effects in drinking water when exceeding secondary maximum contaminant level (SMCL) drinking water standards.

INORGANICS THAT OCCUR IN DRINKING WATER WITH PRIMARY DRINKING WATER STANDARDS: 10 minutes

Regulating These Constituents



Inorganics are regulated by various standards. One such set comes from the US EPA Safe Drinking Water Act Drinking Water Standards. These standards are concerned with the harmful or potentially harmful contaminants. MCL are always based on health concerns, whether acute or chronic.

[Review information in the workbook.]



Some treatment techniques have Action Levels (AL) associated with them. These are levels of contamination above which a public water supply is required to take remedial action, which is generally a treatment alteration or addition.

Commonly Found Inorganics with MCL



Table 2.1, on page 2-2, presents some commonly found inorganic contaminants and their maximum contaminant levels.

[Allow students a few minutes to review the table.]

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INORGANICS THAT OCCUR IN DRINKING WATER WITH SECONDARY DRINKING WATER STANDARDS: 10 minutes



Unlike primary standards, which are concerned with health effects, secondary standards are more concerned with aesthetic qualities of the water.

Effects of These Constituents

[Review information in the workbook.]

Commonly Found Inorganics with SMCL

The table on page 2-3 presents inorganic contaminants that have secondary maximum contaminant levels. The levels are set at concentrations below which minimal aesthetic impact should occur.

[Allow students a few minutes to review the table.]



Before you turn the page, think about the aesthetic qualities of drinking water. What are some qualities that you would not want to have in the water?

Ans: Students may mention the following: tastes; odors; color; tooth discoloration; staining; scaling; and sediments.

[NOTE TO INSTRUCTOR: Various other answers are possible.]

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Now that you have thought of the qualities that are important to your own drinking water, we will look at the chart on page 2-4. You will see the contributors to these effects and some ideas about what their presence may indicate.

[Allow students a few minutes to review the chart.]



Are there any questions about this information?

The final section of Unit 2 deals with the inorganic constituents that are not regulated, but may still require some treatment.

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INORGANICS NOT PRESENTLY REGULATED THAT MAY NEED TREATMENT: 5 minutes

Hardness



Hardness, in itself, does not create problems under the primary or secondary standards. However, it may require treatment, depending on the concentration. Let's look at some reasons for treating hardness.

[Review information in the workbook.]



What consequences could scale from hard water produce?

Ans: It can produce scale formation inside water conveyance pipes, which could lead to problems such as gradual restrictions in the pipe cavity, increased pumping expenses, and so on.

NOTE TO INSTRUCTOR: Various other answers are possible.

Hydrogen Sulfide

[Review information in the workbook.]



In this unit, you have learned that some inorganics cause health effects. These are regulated by primary maximum contaminant levels. Some inorganics have aesthetic effects that are not pleasant; these are secondary MCLs. Finally, some inorganics are not regulated but they can be harmful or displeasing to the customer or the equipment.

In Unit 3, we will examine some specific treatment methodologies.

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UNIT 3: 110 minutes



Display Slide 5—Unit 3: Treatment Protocols.



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

- List three conditions that may contribute to process selection for inorganics removal.
- Identify common treatments for iron and manganese.
- Identify common treatments for aluminum.
- Identify common treatments for hardness.
- Identify common treatments for nitrates.
- List a common treatment choice for three less common inorganics.

TREATMENT OVERVIEW: 12 minutes

Treatment Selection Considerations



We will be examining some common inorganics that require treatment and will look specifically at certain treatment options in this unit. Before we get into the specifics, though, we need to talk about some of the more general considerations that help us select the appropriate treatment for any particulates. You will want to keep these seven considerations in mind.

Contaminant Removal



Of course, the first consideration must be the contaminant you want to remove. Specific treatments work better for the removal of one contaminant than they might for another.

Source Water Quality and Variability



What are the typical levels and ranges of common water quality parameters such as pH in a source water? What are the levels of common inorganics such as iron, manganese, and hardness? These and other questions must be answered in order to determine the best treatment.

Existing Conditions



In most cases, the treatment selected should be able to be accommodated within the already existing water plant.

Flexibility



It is important to choose a treatment process that will be capable of meeting the goals of treatment under anticipated “worst case” source water conditions. While the consideration is primarily affected by the current water conditions, keep in mind that situations with water quality and quantity do change. Also keep abreast of current and future regulations so that planning can keep you from always trying to play catch-up with the requirements.

Utility Capabilities



Some treatments are more labor, cost, and energy intensive than others. The treatment must be compatible with the amount of personnel and funding available at your site.

Environmental Compatibility



Environmental laws must be followed, including environmental impacts of constructing a plant, operating it, and handling byproducts and waste.

Treatment Technology Options



The tables on pages 3-3 and 3-4 represent some of the inorganic contaminants that might be found in a water supply. It also notes which treatment processes are best suited to those contaminants. We will be focusing on several of these inorganics and their treatment processes in this unit. For now, just take a few minutes to familiarize yourself with the constituents and some of the treatment practices that are available.

The first table provides an overview of metals.

[Allow participants a few minutes to familiarize themselves with the table.]

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On this page, a similar table represents miscellaneous inorganic non-metals. Arsenic is by far the most commonly found inorganic in this group.

[Allow participants a few minutes to familiarize themselves with this table.]

INSTRUCTOR GUIDE

COMMON TREATMENTS FOR IRON AND MANGANESE: 20 minutes



Our discussions on iron and manganese are really the central components of the inorganics removal module. These constituents represent the most commonly experienced inorganics treatment problems experienced by water treatment plants. Manganese, which is the more difficult inorganic to remove, creates a special challenge.

Introduction

Common Sources of Iron and Manganese



There are four ways that iron and manganese find their way into the water supply.

Review information in the workbook. You may need to notify participants that “thermocline” refers to the boundary in a body of water where the aerobic and anoxic (anaerobic) layers meet.

INSTRUCTOR GUIDE

Definitions



As we review the definitions on page 3-6 of your workbook, keep in mind that some of these words are being defined for your future reference. As you work with the inorganics removal process, you will certainly encounter these words. We will not necessarily use all of them in our session today.



Review the definitions.



Continue to review the definitions.

Common Treatments



There are four common treatments for iron and manganese removal. We will discuss each in detail.

[Review information in the workbook.]

Oxidation/Filtration



The first treatment is oxidation, which is followed by filtration. Oxidation converts dissolved iron and manganese into solid particles so that "downstream" treatment processes, such as filtration with or without coagulation, can remove these contaminants.

Oxidation generally precedes coagulation which causes the oxidized particles to "clump together" into larger solids. Filtration will always follow oxidation or coagulation; therefore, oxidation and coagulation are pretreatments for filtration.

Oxidation



For oxidation, there are many different parameters that require consideration. In a new supply, an engineer and/or pilot testing would be involved; however, in an existing plant that has several types of oxidation chemicals on site, an operator might make this call based on the results of sampling, which will be discussed on the next page. The first thing you need to establish is, "What forms are the iron or manganese in the source water?" The forms will be identified only following specific sampling protocols and subsequent receipt of the laboratory analyses. The table in your workbook gives you some ideas about the forms you may find.

Monitoring and Sampling Procedures



In order to make the determination, you will have to acquire samples of raw water.

[Review information in the workbook.]



Here on page 3-9, you will find a table that details the collection protocols.

Allow participants a few minutes to review the table. Indicate that the table is informational only and does not require in-depth explanation. State that it allows participants to be aware of on-site sampling requirements in order to define the forms of iron and manganese which, in turn, define the treatment requirements.

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Criteria for Selecting the Oxidant

[Review information in the workbook.]



On the next few pages you will see a table that details the type of oxidant appropriate for various conditions. Specific characteristics—the category headings, such as pH—may have an important impact on the kinetics, or speed of the oxidation reaction, which in turn may be significant in determining which oxidant(s) may be most effective at a particular plant. Some oxidants, for example, may react too slowly for the amount of contact time available at the plant.

Also note that cold water impacts the reaction time of some types of oxidation, such as the first two—aeration/DO and Chlorine.

Another important consideration is the competitive demands in the water. In other words, you are not just considering the iron and manganese removal, but also the other qualities of the water that might help determine the type of oxidant used. Significant DOC, which you will recall is dissolved organic carbon, can actually produce an ineffective treatment, even if all the other parameters seem to point to one methodology.

Finally, note the last two columns. Here we are reminded that oxidation alone may not always remove the target inorganic.

[Allow participants a few minutes to review the table.]

INSTRUCTOR GUIDE

[NOTE TO INSTRUCTOR: The table continues on this page.]

INSTRUCTOR GUIDE

[NOTE TO INSTRUCTOR: The table continues on this page.]

Initial Dosing



Now that you know what type and form of inorganic contaminant is in the water, and you have a good idea of the kind of oxidant that is required, how do you determine how much oxidant to add? Theoretical doses, or initial doses, are the starting point for this determination. Initial dosing is not a hard and fast rule; it is just an idea of where you can start. Remember that many factors make this determination.

[Review information in the workbook. Remind participants to use the table as a reference tool.]

Filtration



There are two common types of media used for the filtration process.

[Review information in the workbook]

Manganese Greensand

[Review the bulleted points in the workbook, including their sub-bullets. You may need to note that ion exchange, the properties of which are mentioned in this section, will be more fully explained in a subsequent section.]



Air wash is important in conjunction with water wash due to the “sticky nature” of iron and manganese precipitates. Otherwise, the media grains tend to stick together. Air wash helps to maintain the filter media in a free, loose condition, which results in longer runs due to the reduction of media cementing. Air wash also tends to slow the growth of the media due to metal precipitates, which would otherwise reduce the media surface area.

[Review the advantages and disadvantages of manganese greensand.]



KMnO₄ is the formula for potassium permanganate, and is also commonly used as an abbreviation for this chemical. It is a chemical oxidant that is added at the plant.

One consideration here is that the media could lose its coating completely if not used according to the supplier's operating instructions. This is different than exhausted media, which can be regenerated on-site. A media stripped of its *factory coating* would have to be replaced; this would be an unusual circumstance having to do with an inappropriate chemistry coming in contact with the media. However, even if the supplier's instructions for use are closely followed, media does have a lifespan. That lifespan is site-specific, depending on issues such as frequency of backwashing, which will gradually break down the media.

Anthrasand



It is very interesting to note that conventional filter media can develop into media having the treatment characteristics of anthrasand if it is exposed to the oxidation conditions for a site-specific period of time. Individual media grains actually "grow" due to the manganese dioxide coating that slowly accumulates on them. (Sand will turn black from this coating.) Some plants with newly installed anthracite/sand will seed the bed with "old" media that already has the coating in order to speed up this process; otherwise it may take months for it to happen naturally.

[Review information in the workbook.]

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[Continue reviewing information on Anthrasand in the workbook].



For your information only, I will mention that there is another type of media that is called pyrolusite. It is a naturally-occurring manganese dioxide ore. It has been the filter media of choice for iron and manganese in Great Britain for many years.

Now that we have discussed the two most common types of media used specifically for iron and manganese removal, let's take a minute to summarize this media.



Display Slide 6—Granular Media Summary.

[Review information on the slide.]



Display Slide 7—Granular Media Summary.

[Review information on the slide.]

Coagulation/Filtration



In addition to oxidation of soluble iron and/or manganese, another important pretreatment step—especially for surface water supplies—is coagulation of the precipitated colloidal metal oxides.

You will recall that earlier I mentioned that coagulation, like oxidation, must be followed by filtration to remove particulates. In fact, coagulation generally follows oxidation and then goes through the filtration process.

Coagulation

[Review information in the workbook.]

Filtration



Other types of filtration processes sometimes used for removing iron and/or manganese are the membrane processes, microfiltration and ultrafiltration. These processes would generally require pretreatment with oxidation followed by coagulation.

[Review information in the workbook.]

Sequestration



Sequestration is almost always a stand-alone treatment process. The reason this process is used, where suitable, is to avoid the expense of constructing a filter plant.

[Review information in the workbook, noting the importance of the key point.]

Ion Exchange



Ion exchange is generally a stand-alone treatment process, although sometimes it is used as a post treatment process. This is a site specific determination.

Now let's look at some specific details about ion exchange for iron and manganese removal.

[Note the importance of the key point and review the next two bulleted items in the workbook.]



Zeolite is primarily a softening media, which also removes iron and manganese. It is often referred to as manganese-zeolite softening when the primary objective is iron and/or manganese removal. An important consideration when using this media is not to precede it with any oxidation; otherwise, the media will become plugged.

[Review information pertaining to manganese-zeolite softening in the workbook.]



You will note that a 1.0 mg/L limit for iron and manganese was suggested for large municipal suppliers. This has to do with the fact that larger plants require rather efficient treatment processes; these high production requirements would require minimal downtime, which leads to longer filter run times between backwashing.

Other Treatments



There are other treatment options available for iron and manganese removal. Four are listed in your workbook.

Biological Filtration

[Review information in the workbook.]

Membranes

[Review information in the workbook.]



This topic will be explored further in the section on water hardness.

Softening Precipitation

[Review information in the workbook.]



You will also see more information about this topic in the section on water hardness.

Treatment at the Source

[Review information in the workbook.]



That finishes the section on types of iron and manganese removal processes. Aluminum is another inorganic that may require removal from drinking water supplies. Let's look now at some information on aluminum. You will recognize one of its standard treatment protocols, as well as one of the causes for high aluminum—coagulation.

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COMMON TREATMENTS FOR ALUMINUM: 8 minutes



Aluminum sulfate, commonly referred to as alum, is a coagulant that causes small particles to clump together into larger particles so downstream processes can more effectively remove them. An overdose of this chemical, as well as improper pH and/or cold water temperatures, are the most common reasons for aluminum residuals to appear.

pH Adjustment



pH adjustment can be a simple solution to the aluminum problem.

[Review information in the workbook.]

Coagulation/Filtration



You will remember that coagulation is the addition of a chemical compound, such as alum, to the water in order to destabilize colloidal and suspended particles. This results in particle aggregation into flocs that can be more readily removed by clarification and/or filtration processes.

[Review the key point in the workbook.]



Chemical pretreatment is often essential for downstream physical treatment processes such as clarification and/or filtration.

[Review the remaining bullet and the first three sub-bullets in the workbook.]



Streaming current detectors measure very weak electrical charges in water; particles in water are generally negatively charged, which keeps them dispersed. Coagulant addition adds positively charged particles, which causes the negatively charged particles to come together (or clump, as indicated above). Actually the proper terminology to use is floc, rather than clump.

SCDs are normally located just downstream of the coagulation addition point to detect the relative strength of positive or negative charges in the treated water; therefore, determination of an underdose or overdose of the coagulant is possible.

[Review the sub-bullet pertaining to SCD.]



Using a set of square jars—preferably Plexiglas—and one gang stirrer, a series of chemical doses is tested in a jar test. This is most commonly used to screen coagulant doses to determine the best dose for the existing source water quality conditions at a water treatment plant.

[Review the remaining sub-bulleted information in the workbook.]

INSTRUCTOR GUIDE

COMMON TREATMENTS FOR HARDNESS: 15 minutes



Hardness is a common problem in water; it stems from metallic cations—especially calcium—in the water because minerals have dissolved from geologic formations by natural waters.

Let's review some of the terminology that applies to this condition and its treatment. If you work with hard water, you will probably encounter these words.



Review the definition of **alkali**.



Review the definition of **alkalinity, total**.



Total alkalinity is the measure of how much acid must be added to a liquid to lower the pH to 4.5, using a titration procedure, which we will define in a few minutes.



Review the **definition of alkalinity, bicarbonate (HCO_3^-)**.



Review the **definition of alkalinity, phenolphthalein**.



Review the **definition of buffer**.



Review the **definition of buffer capacity**.



Review the **definition of calcium carbonate equivalent (CaCO_3)**.



Review the **definition of gram equivalent weight**.



Review the **definition of hardness, total**.



Supersaturated concentrations of these dissolved minerals that are components of hardness may result in scaling of distribution systems, hot water heaters, heaters, boilers, and so forth.



Review the **definition of hardness, calcium**.



Review the **definition of hardness, carbonate**.



Continue to review the definitions.



Review the last two definitions.

Ion Exchange



The two most common municipal types of softening are ion exchange and lime-soda ash. You have already been introduced to the concept of ion exchange, so let's start with that process.

Remember that ion exchange is "filter media," referred to as resin, that functions by removing an undesirable ion, such as calcium, which is a major component of hard water. In order for the calcium to be removed by the resin, a less strongly held ion already on the resin is replaced, or exchanged. Typically the ion replaced is sodium, as in table salt, which is sodium chloride. Eventually the resin must be regenerated with very strong sodium chloride solution. This is how domestic water softeners work.

[Review information in the workbook, noting that a cation-based resin is used to remove hardness; remind participants to note that they will see some ion exchange treatments that rely on anion-based resins as the unit progresses.]

Lime Softening

[Review information in the workbook, including information under the following headings.]

Chemical Precipitation

Remind students of the definition of precipitation, as this is an important concept. They may wish to refer to page 3-7 of the workbook to find the definition.

Lime/Soda Ash Softening

[Review information in the workbook.]

Reactions of Lime/Soda Ash Softening

[Review the first paragraph in the workbook.]



The five reaction steps in your workbook represent the details for chemical precipitations to occur using the lime/soda ash method of softening. You will see the calcium ions being removed as calcium carbonate on the right side of the equation. If magnesium ions are being removed, you will see them removed as $\text{Mg}(\text{OH})_{2(s)}$.

[Review the first reaction step that details neutralization of naturally-occurring carbon dioxide existing as carbonic acid.]



To neutralize carbon dioxide with precipitation of calcium carbonate, an increase in pH with lime addition causes calcium carbonate to exceed its solubility, resulting in precipitation of excess calcium carbonate.

[Review second reaction step that details reduction of calcium carbonate hardness by precipitation of excess calcium carbonate.]



The addition of soda ash downstream of the lime addition allows the calcium associated with noncarbonates to react with the carbonates in soda ash to precipitate out as calcium carbonate. Let's look at that reaction step.

[Review third reaction step that details reduction of calcium noncarbonated hardness.]



Removal of magnesium carbonate hardness occurs by the addition of more lime to increase hydroxide ion concentration and pH until the solubility product constant is exceeded for magnesium hydroxide.

[Review fourth reaction step that details precipitation of magnesium carbonate hardness.]



Finally, precipitation of magnesium noncarbonate hardness also occurs as a result of the lime addition above.

[Review fifth step that details precipitation of magnesium noncarbonate hardness.]

Stability

[Review the two-stage process for stability reactions.]

Lime Softening

[Review information in the workbook].

Reactions of Lime Softening



To soften using lime, calcium carbonate is precipitated. First, as with our previous reactions, neutralization occurs. Then a three-step process occurs in which lime is added each time to induce a specific chemical change.

[Review information in the workbook.]

Softening Membrane Filtration



Membrane filtration, with pretreatment, can remove the components of hardness. Filtration relies on a thin film of synthetic material that is permeable to water but, depending on the size of the membrane's pores, not permeable to some minimum size of suspended particles, colloidal particles, and ions.

[Review information in the workbook.]

Pretreatment Requirements

[Review information in the workbook.]



Reverse osmosis would work here, too, but would probably be much more expensive than nanofiltration. Unless there were also other contaminants that NF would not remove, RO would not be used. It is important to remember, therefore, that there are always other considerations in selecting the most suitable treatment processes, besides the main contaminant you are trying to remove.

Sequestration



As explained under the section on iron and manganese removal, sequestration stabilizes the primary components of hardness, namely calcium and magnesium, to prevent their precipitation.

INSTRUCTOR GUIDE

COMMON TREATMENTS FOR NITRATES: 5 minutes



Ion exchange and membrane filtration are the recommended choices for nitrate treatment. You are familiar with both of these processes, so let's look at their specific applications for nitrates.

Ion Exchange

[Review information in the workbook. Note that anion-based resins are used for nitrate treatment, as opposed to the cation-based resins that were used in the treatment of hardness.]

Membrane Filtration



Another concept with which you are familiar, membrane filtration, can be used for nitrate treatment. Let's review those specifics.

[Review information in the workbook.]

COMMON TREATMENT FOR TOTAL DISSOLVED SOLIDS, SULFATES: 5 minutes



The treatment for TDS, or total dissolved solids, can be removed with either RO or NF—nanofiltration—types of membrane filtration. In common with most membrane processes, there is one input, or feed, and two outputs, which are permeate (the treated water) and concentrate (the reject or wastewater per membrane module).

Membrane Filtration

[Review information in the workbook.]



Note the point that, in addition to membrane filtration, ion exchange using an anion-based resin is a type of treatment process for TDS.

INSTRUCTOR GUIDE

COMMON TREATMENTS FOR LESS COMMON INORGANICS: 10 minutes



While we have covered the most commonly found inorganic constituents in some detail, it is important to remember that there are a host of less common inorganics that can be found in drinking water, and they may require treatment as well.

Take a look at the table on page 3-31. It shows some of these inorganic constituents and their potential treatment processes. The processes are graded for their effectiveness; the legend is at the bottom of the table.

[NOTE TO INSTRUCTOR: You may first want to review the abbreviations used for the treatment processes before encouraging participants to review the table. These are found at the bottom of the table.]

[Allow participants a few minutes to familiarize themselves with the table. Ask for questions.]

Arsenic



You might need to treat for arsenic; about 8% of water systems generally having groundwater source of supply have arsenic levels exceeding the standard for this contaminant.

[Review information in the workbook.]

Treatment Processes

Precipitation without Preoxidation

[Review information in the workbook.]

Adsorption

[Review information in the workbook.]

Ion Exchange

[Review information in the workbook, noting the importance of the key point.]



Ideally, there should be very little sulfate in the raw water; otherwise, shorter run times will be noticed due to sulfate competition, resulting in reduced capacity for arsenic.

Membrane Filtration

[Review information in the workbook.]

Hydrogen Sulfide



You will not find sulfur in surface water. In this section we will find out why that is so and will learn a little about the water quality issues surrounding hydrogen sulfide and its potential treatments.

Sulfate compounds may be converted to hydrogen sulfide under reducing conditions. Oxidation of organic matter caused by bacteria uses sulfate as an electron acceptor, resulting in hydrogen sulfide production. Sulfur reducing bacteria, known as SRB, chemically change naturally occurring sulfates into hydrogen sulfide (H₂S). SRB use sulfur as an energy source, while living in an oxygen deficient, or anaerobic, environment. Hydrogen sulfide is not noticeable in cold water because SRB do not grow in the presence of oxygen.

Hot water tanks are an ideal environment for SRB due to the heat and anaerobic conditions.

[Review information in the workbook.]

H₂S Water Quality Issues

[Review information in the workbook.]

H₂S Treatment Alternatives

[Review information in the workbook.]



On page 3-35, there is a table that highlights some of the trace metals and the effectiveness of certain treatments. We will not go into this in detail; the table is read the same way as the previous one.

The most common method of removing trace metals is precipitation by increasing pH to the maximum insolubility of the specific trace metal, which depends primarily on the solubility of the complexes that are formed. Metals are cations in water, many of which form both hydroxides and carbonates as solid forms that subsequently settle out in a treatment process.

Coagulation can also be an effective removal process for many trace metals, particularly if ferric chloride is used as the coagulant.

[Inform participants that they do not need to review the table at this time; it can be studied at a later time for their information.]

MONITORING PROTOCOL: 12 minutes

Parameters and Equipment Commonly Used for Monitoring the Effectiveness of Oxidation Processes



Now that you are familiar with some of the more common and less common inorganic contaminants that are found in water, and you have learned about the most effective treatment options for them, let's take a look at some general information about the protocols for monitoring inorganics and their treatment. In this section, you will also receive a general overview of the types of equipment used for monitoring.

We start the study by examining the water quality parameters and equipment used with the oxidation processes we previously discussed.

Water Quality Analyses

Iron and Manganese

[Review information in the workbook.]



Remember, again, that other constituents in the water—such as organic matter—also may have an oxidant demand.

Free Chlorine Residual

[Review information in the workbook.]



It is important to analyze the samples immediately because of the propensity of chlorine to dissipate quickly. Also remember that any residual measurements listed here do not represent other chlorine requirements, such as disinfection requirements.

Permanganate Residual

[Review information in the workbook.]

Analytical Equipment



The analytical equipment mentioned here and in the next few sections are relatively standard to most facilities. Some of the more costly or accurate equipment may not be found in smaller plants. The analytical methods are generally simple, following step-by-step procedures provided by the equipment manufacturer. This training session is not designed to teach you how to use any of this equipment; simply be aware that they are valuable instruments for assessing the quality of source and treated water quality at a treatment plant site.

Field test kits typically use a color comparator, which consists of a small case containing a plastic color disc having a color range that is the same color as the sample following the addition of a reagent. The operator views this disc while adjusting it until there is a match with the color intensity in the reacted water sample. After the colors match, a concentration reading from the case can be interpolated.

A portable colorimeter uses the basics of color intensity, similar to the color comparator test kit, to determine the concentration of a contaminant; however, it generates a direct reading as a number rather than requiring an interpolation.

Portable spectrophotometers are similar to colorimeters, although they can usually do more types of analyses.

[Review the first bulleted point and its sub-bullets.]



Bench equipment typically uses the same methodologies as the equipment's field counterparts. The equipment is obviously not as portable as the field versions, but the bench equipment may have greater capabilities and may have a higher resolution for a particular analytical procedure.

[Review the second bulleted point and its sub-bullets.]



On-line analytical equipment provides real-time analytical results of any operational changes that may be required, such as a change in oxidant dosing. Many plants have built-in automation so that a signal from the on-line analyzer to process equipment, such as the oxidant feed pump, causes an automatic adjustment in feed rate to maintain a preset level of a particular water quality constituent to occur as necessary.

[Review the third bulleted point and its sub-bullets.]

Parameters and Equipment Commonly Used for Monitoring Coagulation and Flocculation Processes

Water Quality Indicators



Certain conditions are monitored either because indicators provide information about the water quality or as a result of indicators that gave information about the water quality. For example, temperature, particularly less than 40° F, slows coagulant reaction time with certain coagulants, resulting in delayed floc formation. Let's take a minute to review some of these indicators.

[Review information in the workbook.]

Analytical Equipment



By now you are familiar with most of the equipment that is used. Listed in your workbook are some of the field, bench, and on-line analytical equipment used in conjunction with coagulation and flocculation treatment processes.

[Review information in the workbook.]

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[Finish reviewing this section in the workbook.]

Parameters and Equipment Commonly Used for Monitoring Clarification and Conventional or Membrane Filtration



The final section of this unit deals with clarification and filtration indicators and instrumentation.

Water Quality Indicators

[Review information in the workbook.]



If aluminum or iron levels are too high, excessive alum or ferric coagulant doses are being used; coagulant feed rates should be reduced. The aluminum or iron levels are most accurately measured on-site with a colorimeter or spectrophotometer.

Analytical Equipment

[Review information in the workbook.]

INSTRUCTOR GUIDE

[Finish reviewing information in the workbook.]



That concludes Unit 3 and concludes the instructional part of this session. Are there any questions?

Now it is time to try the review questions for this training module. On the next two pages you will find an exercise; see how many answers you know. I will give you about 15 minutes to answer the questions; then we will discuss the answers in class.

[Allow participants 15 minutes to complete the review. Then ask for volunteers to answer each question. Be sure to correct any misinformation. The questions pertain to the learning objectives set forth at the beginning of each unit.]

INSTRUCTOR GUIDE

REVIEW: 23 minutes



Exercise

Match the letter of the definition to the word it describes.

- | | |
|----------------------------|--|
| 1. <u>D</u> Solute | A. A chemical reaction between an oxidant chemical, such as chlorine, and a soluble constituent, such as manganese, that results in the constituent being converted into its solid form. |
| 2. <u>E</u> Supersaturated | |
| 3. <u>G</u> Precipitation | B. An elemental atom or compound with a negative charge. |
| 4. <u>A</u> Oxidation | C. A water whose chemical makeup neutralizes any acids or bases added, without a significant change in pH. |
| 5. <u>B</u> Anion | D. The dissolved component of a solution. |
| 6. <u>F</u> Cation | E. Unstable condition in water, whereby a substance is contained at a concentration greater than the saturation concentration for that substance. |
| 7. <u>C</u> Buffer | F. An elemental atom or compound with a positive charge. |
| | G. The separation from a solution of a substance made insoluble as the result of a chemical reaction. |

Write your answer below each question.

8. Name three sources of inorganic constituents.

Ans: Any three of the following are acceptable: naturally occurring; municipal and industrial discharges; non-point and runoff; water in contact with pipe materials; water treatment by-products.

9. What do MCL drinking water standards protect?

Ans: Primary Maximum Contaminant Levels protect acute and chronic health concerns.

10. What do SMCL drinking water standards protect?

Ans: Secondary Maximum Contaminant Levels protect against aesthetically unpleasant characteristics.

11. List three conditions that may contribute to process selection for inorganics removal.

Ans: Any three of the following are acceptable: target contaminant to be removed; source water quality and variability; reliability of the treatment process; existing conditions; flexibility; utility capabilities; and environmental compatibility.

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12. How can in-plant sources contribute to high levels of iron and manganese?

Ans: Accumulated solids in sedimentation basins can become anoxic (anaerobic) and “go septic,” which results in the conversion of particulate iron and/or manganese into their soluble forms, with subsequent release to the process flow; downstream filtration may not be able to remove these contaminants.

13. Identify three common treatments for iron and manganese.

Ans: Any three of the following may be acceptable (site specific): oxidation/filtration; coagulation/filtration; ion exchange; and sequestration.

14. Identify two common treatments for aluminum.

Ans: pH adjustment/coagulation/filtration and coagulant dose adjustment/filtration are treatments.

15. Identify two common treatments for hardness.

Ans: Any two of the following may be acceptable (site specific): ion exchange; lime softening; membrane filtration; and sequestration.

16. Identify one common treatment for nitrates.

Ans: Any one of the following is acceptable: ion exchange or membrane filtration.

17. List two less common inorganics and one treatment for each.

Ans: Any treatment from the following list is acceptable for the specific inorganic: arsenic (precipitation; adsorption; ion exchange; membrane filtration); hydrogen sulfide (GAC; oxidizing filter; manganese greensand; aeration/filtration; chemical oxidation with chlorine/filtration; chemical oxidation with potassium permanganate/filtration; chemical oxidation with ozone/filtration).

18. Should ion exchange be used for surface or groundwater sources?

Ans: Ion exchange is used for groundwater sources.

19. Which treatments are actually pretreatment techniques for filtration?

Ans: Oxidation and coagulation are pretreatments for filtration.

20. Explain how ion exchange works.

Ans: In ion exchange, a chemical process is used to reversibly transfer ions between synthetic media (referred to as a resin with the ion exchange process) and the water being treated. The specific type of resin used has a selective affinity for the ions of one element over another; ions of the element saturated onto the resin are replaced with the target (undesirable) ions of another element due to preferential selection for this ion by the resin. Depending on the desired element to be treated, an anion- or cation-based resin is used.