Curricular Unit

Subject Area(s)  
Physical Science, Physics, Chemistry

Curricular Unit Title  
Drinking Water Treatment Process

Grade Level  
11 (10-12)

Summary  
The development of drinking water treatment processes has greatly increased the standard of human health throughout the past century. Through a 3-lesson series complete with hands-on activities, students learn the importance of water treatment, the determining factors of what makes water safe to drink, and the details of the traditional drinking water treatment process, including: coagulation, flocculation, sedimentation, filtration, and disinfection. Each lesson discusses the full spectrum of engineering design options and treatment technologies, while focusing on the most widely used methods for treating surface water on a large scale. Students use this knowledge to design and treat a small amount of local lake or river water.

Engineering Connection  
Treating contaminated water to make it clean enough to drink has been the product of many years of engineering work. Civil and environmental engineers design systems that take water that is hazardous to drink and make potable by removing particles and pathogens. Although there are many engineered systems for drinking water treatment, the primary way engineers treat surface water is by coagulation, flocculation, sedimentation, filtration, and disinfection, which are engineered methods that closely emulate natural processes.

Engineering Category = 1  
Choose the category that best describes this unit’s amount/depth of engineering content:  
1. Relating science and/or math concept(s) to engineering  
2. Engineering analysis or partial design  
3. Engineering design process

Keywords  
coagulation, disinfection, drinking water treatment, environmental engineering, filtration, flocculation, sedimentation
Educational Standards
See the individual lessons and activities

Related Lessons & Activities
Related lessons:
1. Introduction to Drinking Water Treatment
2. Drinking Water Treatment: Coagulation, Flocculation, and Sedimentation
3. Drinking Water Treatment: Filtration and Disinfection

Related activities:
1. First Steps to Treating Surface Water
2. The Clean-Up Crew: Filtration

Time Required
1 week

Unit Overview
The first lesson and activity serve as background information in order to build a foundation of knowledge for the students to build off of when discussing the details of drinking water treatment. Lesson 2 discusses the processes of coagulation, flocculation, and sedimentation, which are used to destabilize the suspended particles in the source water. The 3rd lesson completes the story by describing the details of filtration and disinfection. These final steps are used to remove any remaining particles and neutralize any remaining biotic pathogens. Lessons 2 and 3 are correlated with activities 2 and 3, such that they students are participating in the processes that they are learning about in the lessons.

Unit Schedule

Summary Assessment
The main two assessments are the scientific paper and quiz that the students complete by the end of the unit. However, the students fill out worksheets that follow each lesson and activity throughout the unit to help the teacher assess the students’ understanding as well as resources for the students to use in preparing for their paper and quiz.

Attachments
- Drinking_Water_Treatment_Unit_Quiz.docx
- Drinking_Water_Treatment_Unit_Quiz_Solutions.docx
- Drinking_Water_Treatment_Unit_Presentation.ppx

Other

Redirect URL

Contributors
Bradley Beless, Jeremy Ardner

Supporting Program
University of Houston, National Science Foundation GK-12 and Research Experience for Teachers (RET) Programs
Drinking Water Treatment

by
Brad Beless
Outline

**Monday:** drinking water treatment overview
  – Write introduction paragraph

**Tuesday:** 1\(^{st}\) half of drinking water treatment process
  – Lab part 1

**Wednesday:** 2\(^{nd}\) half of drinking water treatment process
  – Lab part 2

**Thursday:** finish labs and discuss results
  – Write results and conclusions paragraph

**Friday:** quiz and wrap up
Opening Question

Where does the water from your tap come from?
Where is Earth’s Water?

- 0.007% of water on Earth is in lakes and rivers
- 0.76% of water on Earth is fresh ground water
Surface vs. Ground Water

Ground Water

- **Definition**: water contained in the pore spaces of the subsurface soils, called an aquifer.
- **Pros**: usually free of microorganisms and other pollutants.
- **Cons**: difficult to access and manage, can cause sequestration.
Surface vs. Ground Water

Surface Water

- **Definition** - water that is contained on the earth’s surface in lakes, rivers, swamps, etc.

- **Pros** - easy to access and manage

- **Cons** - contains microorganism and possibly other contaminants that can be harmful to humans
What Makes Water ‘Dirty?’
What Makes Water ‘Dirty?’

Common Contaminants

1. **Microorganisms**
   - bacteria
   - protozoa
   - virus
   - algae

2. **Parasites**

3. **Chemical**
   - inorganic
   - organic

4. **Radionuclides**

   - Cryptosporidium
   - E. coli
   - Arsenic
   - Hepatitis A
   - Polychlorinated Biphenyl
What Makes Water ‘Dirty?’

Contaminant Sources

• **Microorganisms/Parasites**
  - fecal contamination
    • Cholera, Typhoid, *E. coli*, *Giardia*, Salmonella
  - natural sources
    • soil bacteria and parasites

• **Chemical/Radionuclides**
  - human pollution
    • chemical spills or pest/herbicide application
  - natural sources
    • arsenic and uranium deposits
What Makes Water ‘Dirty?’

Measuring Water Quality

- **Microorganisms/Parasites**
  - turbidity: amount of light scattering particles
  - indicator organisms
    - Fecal Coliforms, *E. coli*, etc

- **Chemical/Radionuclides**
  - heavy metals
    - Atomic Absorption Spectroscopy (AAS)
  - organic contaminants
    - Gas Chromatography – Mass Spectroscopy (GC-MS)
What Makes Water ‘Dirty?’
## Drinking Water Standards

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>MCL or TT(^1) (mg/L)(^2)</th>
<th>Potential health effects from exposure above the MCL</th>
<th>Common sources of contaminant in drinking water</th>
<th>Public Health Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>OC Chlorodane</td>
<td>0.002</td>
<td>Liver or nervous system problems, increased risk of cancer</td>
<td>Residue of banned termicide</td>
<td>zero</td>
</tr>
<tr>
<td>D Chlorine (as Cl(_2))</td>
<td>MRDL=4.01</td>
<td>Eye/nose irritation; stomach discomfort</td>
<td>Water additive used to control microbes</td>
<td>MRDLG=4.01</td>
</tr>
<tr>
<td>D Chlorine dioxide (as ClO(_2))</td>
<td>MRDL=0.81</td>
<td>Anemia; infants &amp; young children: nervous system effects</td>
<td>Water additive used to control microbes</td>
<td>MRDLG=0.81</td>
</tr>
<tr>
<td>DBP Chlorite</td>
<td>1.0</td>
<td>Anemia; infants &amp; young children: nervous system effects</td>
<td>Byproduct of drinking water disinfection</td>
<td>0.8</td>
</tr>
<tr>
<td>OC Chlorobenzene</td>
<td>0.1</td>
<td>Liver or kidney problems</td>
<td>Discharge from chemical and agricultural chemical factories</td>
<td>0.1</td>
</tr>
<tr>
<td>IOC Chromium (total)</td>
<td>0.1</td>
<td>Allergic dermatitis</td>
<td>Discharge from steel and pulp mills; erosion of natural deposits</td>
<td>0.1</td>
</tr>
<tr>
<td>IOC Copper</td>
<td>TT(^7); Action Level = 1.3</td>
<td>Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage. People with Wilson’s Disease should consult their personal doctor if the amount of copper in their water exceeds the action level</td>
<td>Corrosion of household plumbing systems; erosion of natural deposits</td>
<td>1.3</td>
</tr>
<tr>
<td>M Cryptosporidium</td>
<td>TT(^3)</td>
<td>Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)</td>
<td>Human and animal fecal waste</td>
<td>zero</td>
</tr>
<tr>
<td>IOC Cyanide (as free cyanide)</td>
<td>0.2</td>
<td>Nerve damage or thyroid problems</td>
<td>Discharge from steel/metal factories; discharge from plastic and fertilizer factories</td>
<td>0.2</td>
</tr>
<tr>
<td>OC 2,4-D</td>
<td>0.07</td>
<td>Kidney, liver, or adrenal gland problems</td>
<td>Runoff from herbicide used on row crops</td>
<td>0.07</td>
</tr>
</tbody>
</table>

- **Standards set by the federal EPA**
  - sets Maximum Contaminant Levels (MCL) that are required by law
  - sets Maximum Contaminant Goals (MCLG) that are ideally obtained
Drinking Water Treatment

Point of Use
- home devices
  - Brita
  - RO filters
- camping filters

Large scale
- operated by the city or state
- operated by private companies
- Upwards of 200MGD
Drinking Water Treatment

Ground Water
- water softening or hardening and disinfection
- *rarely; heavy metal removal (arsenic)

Surface Water
- Conventional treatment
- membrane filtration

Saline Water
- reverse osmosis (RO)
- distillation
Why Does it Matter?

Infant Mortality
Source: World Health Organization (WHO), 2003

Access to Clean Water
Summary and Review

1. About what percent of the Earth’s water is usable for drinking water treatment?

2. What are pros and cons of using both surface or ground water?

3. What are the 4 main types of water contaminants?

4. What is turbidity?

5. Name a couple types of water treatment techniques
Drinking Water Treatment Processes: Coagulation, Flocculation, Sedimentation
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Opening Question

What is static electricity?
Conventional Drinking Water Process

- **Coagulation** - adding chemical agents to destabilize the particles in water
- **Flocculation** - mixing the water to allow the particles to collide and form flocs
- **Sedimentation** - keep the water calm and allow the flocs to settle to the bottom
- **Filtration** - remove the remaining flocs by passing the water through a media filter
- **Disinfection** - add a chemical agent (chlorine) that kills any remaining microorganisms
Coagulation

What does it mean to destabilize water particles?

• natural water particles almost always have a negative static charge

• this causes electrostatic repulsion between the particles

• the goal of coagulation is to eliminate the repulsive forces
Coagulation

How can we destabilize water particles?

1. **double layer compression**
   - add cations (Na\(^+\), Ca\(^{2+}\), Al\(^{3+}\))

2. **Adsorption and charge neutralization**
   - add charged polymers or cations with high valence charge or

3. **sweep flocculation**
   - add chemicals that form a precipitate

4. **inter-particle bridging**
   - adding charged polymers
Coagulation

What method is commonly used?

• Sweep flocculation is almost always the method used
  – The most ‘fool proof’ because the particles cannot be restabilized

• Iron [Fe] and Aluminum [Al] are the most common elements used

• Fe and Al form precipitates when at high enough concentrations
  – Al(OH) (s)
  – Fe(OH) (s)
Coagulation

- **Coagulation**- adding chemical agents to destabilize the particles in water
  - Water only spends a couple minutes passing through the coagulation process
  - Process called Rapid Mixing is used to evenly mix the coagulant
Flocculation

- Slow mixing designed to maximize the collisions between particles
  - Mix too weak and flocs might not become big enough
  - Mix too strong and the flocs formed might break apart
flocculation

3 mechanisms of floc formation
• Diffusion
• Shear mixing
• Differential settling
Conventional Drinking Water Process

• **Coagulation** - adding chemical agents to destabilize the particles in water

• **Flocculation** - mixing the water to allow the particles to collide and form flocs
  
  – Water spends 30 minutes to an hour in the flocculation basin
Sedimentation

- During sedimentation, the water is slowed down so that the large flocs can settle to the bottom
  - the flocs on the bottom are collected and treated elsewhere
  - the supernatant water passes over a weir and goes to filtration

Clarifier
Sedimentation

Stokes’ Law

\[
\nu_s = \frac{\rho_p - \rho_f}{\mu} R^2 g
\]

- \(\nu_s\) = settling velocity
- \(\rho_p\) = density of the floc
- \(\rho_f\) = density of the fluid (water)
- \(\mu\) = viscosity
- \(g\) = gravity
- \(R\) = radius of the floc

Sedimentation basins (clarifiers) are designed so that any particle larger than a specific \(R\) value settles out

- more time = smaller and smaller flocs settling out
Conventional Drinking Water Process

- **Coagulation**- adding chemical agents to destabilize the particles in water
- **Flocculation**- mixing the water to allow the particles to collide and form flocs
- **Sedimentation**- keep the water calm and allow the flocs to settle to the bottom
  - Water spends a couple hours in the sedimentation basin
Lab Procedures

• Get into groups of two
• Collect a 2L plastic soda bottle and cap
• Use tape to label the bottles with your names and period
• Fill the bottle with bayou water to the level demonstrated (about 1.5 liters)
• Write a sentence describing the water and what you observe
Lab Procedures

• add 1/8th teaspoon of Alum to your water

• cap the bottle tightly

• shake the bottle vigorously for 2-3 minutes (rapid mix)
Lab Procedures

• continue shaking the bottle, slowly rocking it back and forth for 15 minutes...!!!
Lab Procedures

- measure the pH of your water using pH paper
- write a sentence describing the water and what you observe
- carefully set your bottle in the closet and allow it time to settle over night
Drinking Water Treatment Processes: Filtration, Disinfection, Distribution
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Opening Question

What is diffusion?
Conventional Drinking Water Process

- **Coagulation**: adding chemical agents to destabilize the particles in water
- **Flocculation**: mixing the water to allow the particles to collide and form flocs
- **Sedimentation**: keep the water calm and allow the flocs to settle to the bottom
- **Filtration**: remove the remaining flocs by passing the water through a media filter
- **Disinfection**: add a chemical agent (chlorine) that kills any remaining microorganisms
Filtration

What are the filters made of?

- filters are most often made of sand and possibly a coal based material
- the size of the sand is designed to create depth filtration
  - flocs are removed throughout the media filter and not just the surface
- the media in the filters are called collectors
Filtration

3 mechanisms of floc removal
- diffusion
- interception
- gravity
Filtration

Stages of Filtration

• ripening
  – filter-to-waste

• pseudo-steady state
  – optimum floc removal

• backwash
  – cleaning the filter media
Conventional Drinking Water Process

- **Coagulation** - adding chemical agents to destabilize the particles in water
- **Flocculation** - mixing the water to allow the particles to collide and form flocs
- **Sedimentation** - keep the water calm and allow the flocs to settle to the bottom
- **Filtration** - remove the remaining flocs by passing the water through a media filter
  
  - Water spends around 15 – 30 minutes going through the filter
## Disinfection

### Types of Disinfection

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ozone</strong></td>
<td>• very reactive and effective</td>
<td>• expensive</td>
</tr>
<tr>
<td></td>
<td>• can be created on site</td>
<td>• complicated to use</td>
</tr>
<tr>
<td></td>
<td>• little microbe regrowth</td>
<td>• no residual</td>
</tr>
<tr>
<td><strong>Ultra Violet (UV)</strong></td>
<td>• none toxic</td>
<td>• high power cost</td>
</tr>
<tr>
<td></td>
<td>• works well under a wide range of water conditions</td>
<td>• Does not work well with turbid water</td>
</tr>
<tr>
<td></td>
<td>• minimum DBPs</td>
<td>• no residual</td>
</tr>
<tr>
<td><strong>Chlorine</strong></td>
<td>• reactive and effective</td>
<td>• expensive</td>
</tr>
<tr>
<td></td>
<td>• has residual</td>
<td>• toxic to humans</td>
</tr>
<tr>
<td></td>
<td>• eliminates odors and color as well</td>
<td>• forms DBPs</td>
</tr>
</tbody>
</table>
Distribution

How it works

• large pumps are used to pressurize the water pipes

• water towers are used to store water and energy
Conventional Drinking Water Process

• **Coagulation**- adding chemical agents to destabilize the particles in water

• **Flocculation**- mixing the water to allow the particles to collide and form flocs

• **Sedimentation**- keep the water calm and allow the flocs to settle to the bottom

• **Filtration**- remove the remaining flocs by passing the water through a media filter

• **Disinfection**- add a chemical agent (chlorine) that kills any remaining microorganisms
Lab Procedures

- discuss as a group how you want to design your filter

- draw a diagram of your filter with the different types of media labeled

- as a group, go to the station with the filter media and construct your filter
Lab Procedures

• retrieve your bottle from the day before, be VERY CAREFULL not to shake or mix the water

• write a sentence describing the water and what you observe
Lab Procedures

• one partner hold the filter above a catchment container
• the other partner slowly and carefully pour the water from your bottle through your filter, allowing it to drain into the catchment container
• once you have poured half of your water through the filter, begin collecting the filtered water with an additional cup
• write a sentence describing the filtered water and what you observe
Lab Procedures

• once finished filtering, set your used filter in a separate bin and set your bottle aside

• take your filtered water to the spectrometer be measured

• discard the water and use any remaining time to work on your lab report
Drinking Water Treatment Quiz

1. _____ (T/F) Water that seems ‘cloudy’ or ‘murky,’ like the water from Buffalo Bayou has a low turbidity.

2. _____ (T/F) Water particles in natural waters are considered ‘stable’ because they have a positive electrical charge, causing them to repel one another and avoid forming flocs.

3. _____ (T/F) The main concern when treating surface water is microorganisms that can cause sickness.

4. _____ (T/F) The main source of chemical contamination of water is natural oil deposits leaking into the groundwater.

5. _____ (T/F) The purpose of a media filter is to strain out the remaining flocs on the surface of the filter.

6. The measure of light scattering particles is defined as___________.
   a. pH
   b. Turbidity
   c. Salinity
   d. Color

7. When using a clean sand filter it is important to...
   a. Allow the filter to ripen before collecting usable drinking water
   b. Collect the initial water that comes out in order to conserve resources
   c. Backwash the filter before every use
   d. Add Alum to the filtered water

8. What percentage of the Earth’s water is accessible for use as drinking water?
   a. 96.5%
   b. 75%
   c. 2.5%
   d. <1%

9. All of these are benefits of access to clean drinking water except...
   a. Infant mortality rates decrease with access to clean drinking water
   b. It improves overall quality of life
   c. Infant mortality rates increase with access to clean drinking water
   d. It provides water that is tasty and fresh

10. What chemical is used in the disinfection stage of the conventional drinking water process?
    a. Chlorine
    b. Flouride
    c. Bourine
    d. Uranium
11. What was the purpose of adding the Alum powder to the bayou water in the overall drinking water treatment process? Use the vocabulary words you learned during the lectures.

12. Name each step of the conventional drinking water treatment process and briefly describe each step.
Drinking Water Treatment Quiz

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Alum is used as a coagulant to destabilizes the natural water particles, allowing them to collide together and form flocs. Alum also forms a precipitate, which helps the destabilized particles form bigger and more dense flocs.

12. Name each step of the conventional drinking water treatment process and briefly describe each step.

Coagulation: destabilize the natural water particles

Flocculation: mix the water in order to allow the destabilized particles to collide and from flocs

Sedimentation: stop any mixing and allow the flocs to settle to the bottom

(media) Filtration: filter the remaining particles/flocs with sand and coal collectors

Disinfection: deactivate any remaining microorganisms by adding chlorine or ozone

(bonus) Distribution: Store and distribute the clean drinking water through a network of pipes