Drinking Water Treatment: Filtration and Disinfection

Yellow highlight = required component

Subject Area(s) chemistry, physics

Associated Unit **Drinking Water Treatment Process**

Lesson Title **Drinking Water Treatment: Filtration and Disinfection**

Header

Image 1
Image file: water_droplet_Lesson3.jpg
ADA Description: A water droplet falls splashes into a pool of water.

Caption: Clean water is necessary but must go through a treatment process before it is safe to drink.

Grade Level 10 (9-12)

Lesson # 3 of 3

Lesson Dependency
Lessons:

1. Introduction into Drinking Water Treatment
2. Drinking Water Treatment: Coagulation, Flocculation, and Sedimentation

Activities:

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

Time Required **30**

Summary
In this lesson students learn about the second half of a conventional surface water treatment plant: filtration and disinfection. They learn about the basic mechanisms by which particles in the water are removed when passing through a sand filter and the basic chemistry of how disinfected agents inactivate any remaining microorganisms. Students acquire knowledge about the specifics of these two processes, while reinforcing an understanding of how each process works within the overall design of water treatment.

Engineering Connection
Civil and specifically environmental engineers take water from the environment that is hazardous to human health and treat it so that it is safe to drink. Students will learn and understand the challenges faced by engineers when designing the last two processes of a conventional surface water treatment plant. They will learn to think about not just the science behind engineering, but the practicalities such as cost and feasibility.

Engineering Category = 1

Choose the category that best describes this lesson'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

chlorine, disinfection, filtration, water treatment

Educational Standards

National and State

Texas Essential Knowledge and Skills for Science, 2009, Environmental Systems 5(B): Identify source, use, quality, management, and conservation of water.

Texas Essential Knowledge and Skills for Science, 2009, Science Concepts: describe the unique role of water in chemical and biological systems.

ITEEA Educational Standard(s)

ITEEA, Standard 1, Grades 9-12, J. The nature and development of technological knowledge and processes are functions of the setting.

Pre-Requisite Knowledge

The basics of chemical reactions

Learning Objectives

After this lesson, students should be able to:

- **Describe the science behind the treatment processes filtration and disinfection.**
- **Explain how the processes of filtration and disinfection fit into the larger treatment scheme.**

Introduction / Motivation

In the previous two lessons we have learned that the primary sources for drinking water come from fresh ground or surface water and about the main types of contaminants are microorganisms, harmful chemicals, and parasites. Additionally, can anyone remind me what the first three processes are called when drinking surface water? (possible student answers: coagulation, flocculation, and sedimentation). Good, at this point the particles in the sources water: clay, silt, microorganisms, etc, have been destabilized with the addition of iron or aluminum so that they are able to collide and stick together, brought together in the flocculation basin to form large flocs, and given time for the large flocs to settle out in the sedimentation basin.

Today we are learning about the last two steps in the surface water treatment process, which are filtration and disinfection. The entire treatment process includes multiple barriers for the contaminants, and as we learned in the previous lesson, the first barrier was the combination of the first three steps. Filtration and disinfection are each additional barriers in the treatment process by which the threat by contaminants are decreases. Today we are going to learn how these two processes remove contaminants and help to further clean the water making it safe for humans to drink

Lesson Background & Concepts for Teachers

Filtration

The water exiting the sedimentation basin then comes to the filtration step. A majority of the flocs settled out of the water, yet there inevitably particles and flocs that remain in suspension that need to be removed. The method most commonly used in drinking water treatment plants is called rapid media filtration. Using this method, water passes through a media, typically sand, in the matter of 15-30 minutes, so that the remaining particles and flocs in the water are removed by the sand media. These media filters are designed for what is called ‘depth filtration,’ which simply means that the particles being filters should be retained throughout the depth of the filter and not just at the surface. To achieve effective depth filtration, it is important to control the size of the filter media because if the filter media is too small then all the water particles will be removed on the surface of the filter, but if the filter media is too large then the filter would not be as effective at removing the particles. For this reason, it is common that filters are designed to have two types of media, the larger size media on the top to capture the large incoming particles, and smaller sized media on the bottom of the filter to capture the remaining incoming particles. Using this dual media technique is an effective way to remove a maximum about of the particles while encouraging depth filtration.

More important than the size of the filter media, however, is the effectiveness of the coagulation process at the very beginning of the treatment plant. Filtration does not work well at all unless the initial water particles are properly destabilized during the coagulation process, meaning that if the source water was not destabilized at all and filtration was the first step of the treatment plan, there would be very little to no particle removal during filtration. To help explain this, use an imaginary illustration with bowling balls and a marble. If you fill up a room with bowling balls, representing the sand media, and drop a marble into the top of the pile, representing a water particle, the marble will bounce around in the spaces between the balls until it reaches the floor of the room. In comparison, if instead of using a marble, a piece of chewed gum was dropped into the pile of bowling balls it would most likely stick to one of the bowling balls as it moves downward. For this reason it is important that the particles that did not settle out and reach the media filter are properly destabilized so that they are sticky and can be retained by the sand when passing through. The illustration of the bowling balls and marble is especially appropriate because the size ratio between the bowling ball and the marble is similar to the ratio between the average size of sand media and the water particles that pass through the filter.

Much like flocculation, there are three main mechanisms by which destabilized water particles are removed when they pass through a media filter: Brownian motion, sedimentation, and interception. To understand these mechanisms, it is easiest to consider a single sand grain as water flows around it from top to bottom. Very small particles will generally follow the path of the water flow, but can deviate from that path due to the bombardment of water particles causing to move outside the natural flow path. Due to this addition movement outside of the flow path, these small particles which would no naturally collide with the sand grain could collide and stick. Additionally, for the larger water particles that are following the natural flow lines around the sand grain, their large mass and momentum can cause them to settle onto the sand grain as the flow of water bends around the outside of the sand grain. Lastly, interception occurs when any water particle that is following the flow of water around the sand grain naturally collides with the sand.

Based on the three mechanism explained above, the size of the water particles plays a large role in how they are removed in the media filter. Against most people’s intuition, the very small particles are removed well, while the medium size particles that do not diffuse or settle well are removed the least. For this reason, if it there is an option of investigating the particle leaving the filter, it is important to focus on the particles that fall into the medium size range (diameters of 1 – 5um).

While the scientific understanding of how particles are removed is important, it is also important to understand the practical requirements to operating a media filter. It is desirable to use a media filter for many years, but if particles are continually being removed throughout the filter, the filter will eventually become so full of particles that it will clog and water will no longer pass easily through. For this reason, each media filter is designed to go through a washing cycle. At the beginning of the cycle is a clean media filter which has to be ripened. Interestingly, the clean media does not the best job at removing water particles; it is not until there is an initial layer of particle already retained in the filter that the filter begins operating at its best level. To help understand this, the illustration with the bowling balls and gum can once again be used. The bowling balls themselves are not sticky, but simply provide a surface for the gum to stick to. If enough pieces of gum are dropped through the bowling balls, they will begin to be coated with the gum, provided a stickier surface for the incoming pieces of gum to attach to. For this reason, the ripening period is allowing the clean media to be coated with destabilized water particles to enhance the filters ability to remove the incoming particle. After the filter has been ripened, it begins to operate at its optimal efficiency, meaning that the filter removes the maximum percent of incoming particles. It is only during this time that the water leaving the filter is collected and sent to be disinfected. After some time (usually 1 – 3 days), the water will not easily move through the filter or some of the retain particle stare breaking off of the media and coming out the bottom of the filter. At that point the filter its cleaned using a process called backwashing. During backwashing, some of the previously filtered water is pumped from the bottom of the filter to the top at fast enough of a rate that the media particles are suspended and bumped around. During the backwashing, the particle that were collected by the filter media are knocked off and lifted by the water away from the media, leaving a clean media filter to be once again ripened.

Disinfection

Once the water passes through the filter, a large percentage of the original particles have been removed, but there is still a potential that microorganisms remain in the water. The process of disinfection is to treat the water in a way that kills or inactivates the remaining microorganisms in the water. There are numerous chemicals that can be used as a disinfectant, the most common being chlorine and ozone. Additionally, ultra violet (UV) radiation can be used as a disinfectant, but is primarily used in waste water plants and not in drinking water facilities. The mechanisms by which chlorine and ozone disinfect are quite similar, yet the method at which they are applied is quite different. A primary difference between the two disinfectants is that chlorine can be used to leave a residual whereas ozone does not. What this means is that when chlorine is added to water, a portion of it is consumed in reaction with microorganisms and the remaining chlorine remains in the water as a residual and acts as a deterrent towards the regrowth of any microorganisms. In comparison, when ozone is added to water, a portion of it is consumed in reactions with microorganisms and the remaining ozone quickly deteriorates because of its unstable nature. Ozone is a more powerful disinfectant than chlorine, but chlorine is the most widely used disinfectant due to the importance of the residual concept. It is important for the engineers designing the treatment plant to not only consider what might be the cheapest and most effective way to kill the microorganisms, but also how to be most protective with the water as it moves through the distribution system.

Chlorine in general acts as an oxidant, which reacts with other atoms and molecule by stripping an electron from the other atom or molecule. There are two main forms that chlorine can exist in: free chlorine and combined chlorine. Free chlorine, such as hypochlorite (OCl^-) and hypochlorous acid (HOCl), is a much more powerful oxidant and therefore a more effective disinfectant but does not have a long residual time in water. Combined chlorine, such as monochloramine (NH_2Cl), is a less powerful oxidant and therefore less effective disinfectant but has a much longer residual time. In order to best utilize the disinfecting and residual properties of chlorine, what is often done is that free chlorine is used in the treatment plant to kill the microorganisms and then converted to combined chlorine by the addition of ammonium before the water enters the distribution system.

Because chlorine is a power oxidant, there are many things in addition to microorganism that can react with chlorine, therefore consuming chlorine that would preferably be reacting with microorganisms. Some of the ways that chlorine can be consumed is through reactions with reduced metals such as ferrous oxide (Fe^{+2}), reaction with ammonium, natural decomposition driven by UV light from the sun, and reactions with microorganisms. The main objective with the addition of chlorine is of course to react with the microorganisms, but enough chlorine must be added to satisfy the other consuming factors so that enough chlorine is left to effectively disinfect the microorganisms. This is again another example of why the idea of chlorine residual is important, because if enough chlorine is added so that there is a residual, then it assures that there was enough to react with the microorganisms.

The mechanisms by which chlorine kills the microorganisms is still not well understood, but there are a few processes thought to be the main methods by which chlorine kills the microorganisms. Due to the reactive properties of chlorine, the addition of chlorine can rupture the cell walls or membranes of the microorganisms. Additionally, chlorine can interfere with the metabolic process of the microorganisms such that they cannot get the energy they need to grow and multiply. Unfortunately, there are some microorganisms that are very resistant to the destructive power of chlorine and have historically been the most problematic microorganisms for treatment plants to remove. Two examples are *Giardia* and *Cryptosporidium*, both of which have a protective cell which protects the microorganisms from degradation by chlorine. For this reason, it is important that the first four steps of the treatment process are working well so that less importance is place on killing microorganisms at the end of the process.

Although the disinfection of microorganisms is the primary purpose of adding a chlorine, there are other benefits that secondary to the disinfection of microorganisms. For example, chlorine eliminates molecules that cause color in water as well as provides a standard taste and odor to water. Additionally, as mentioned before, chlorine reacts with reduced metals so that they are not a hazard to the finished water. Unfortunately, the downfall to the addition of chlorine, and other disinfectants as well, is the formation of disinfection by products (DBPs). The DBPs are recently being discovered and addressed as chemicals that could cause chronic sicknesses if consume at high levels for long periods of times. For this reason, it is important to balance the amount of chlorine so that a high percent of the microorganisms are disinfected, but not too much as to minimize the formation of DBPs.

Image Insert Image # or Figure # here [use Figure # if referenced in text]

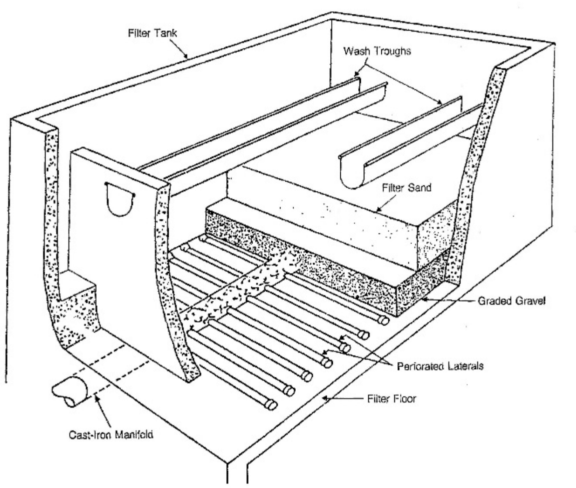

Figure 1

Image file: rapid_sand_filter_Lesson3

ADA Description: The image is a drawn design diagram of a rapid flow sand filter. The diagram depicts cut out sections of the filter, showing the sand and gravel media, as well as all the piping and structural aspect of the filter.

Source/Rights: By US Environmental Protection Agency [Public domain or Public domain], via Wikimedia Commons

URL:http://commons.wikimedia.org/wiki/File:Rapid_sand_filter_EPA.jpg

Caption: Example design of a rapid sand filter that could be used in a drinking water treatment plant.

Vocabulary / Definitions

Word	Definition
media filtration	The use of media, such as sand or activated carbon, to remove suspended particles from water
disinfection	The addition of a chemical or radiation to kill or deactivate microorganisms in the water

Associated Activities

The Clean-Up Crew: Filtration and Disinfection

Lesson Closure

There you have it, the secret to taking contaminated surface water and turning it into water that is safe to drink. Each of the steps are important and act as a barrier to the potential of contaminants passing through to the product water. In coagulation the particles are destabilized so they can stick to each other and eventually to the media grains in the filter. The flocculation basin forms large flocs that can be settled to the bottom. The sedimentation basin allows time for the large flocs to settle to the bottom so they do not unnecessarily clog up the filter. Media filtration polishes of the water of a majority of the remaining particles. Lastly, the addition of disinfection is the last barrier against any microorganisms that might have made it through the system.

The drinking water treatment process is very effective at removing contamination, yet it of course not a perfect system. As mentioned in the first lesson, the main threat in surface water is microorganisms, which is why this process focuses on removing microorganisms, but additional treatment might be necessary if there are harmful chemicals present. Fortunately the Environmental Protection Agency (EPA) require water treatment plants to monitor for those harmful chemicals to make sure they are not present and do not present a threat to the consumers safety.

I hope through what you have learned you can go home and feel good about drinking the water from your tap!

Assessment

Lesson Extension Activities

Additional Multimedia Support

References

Attachments

Lesson3_guided_notes_and_Activity2.docx

Other

Redirect URL

Contributors

Brad Beless and Jeremy Ardner

Supporting Program

University of Houston, National Science Foundation GK-12 and Research Experience for Teachers (RET) Programs

Acknowledgements