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Water Storage Tank Disinfection, Testing, and Maintenance

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Introduction

The use of fresh water storage tanks is common in rural areas of Arizona with limited or diminishing water resources. Homeowners living in remote areas with low-yield and seasonally dry wells or no wells must depend on water that is trucked in with tankers and stored on site to cover basic living necessities. Well owners with low-yielding wells may also rely on large holding tanks and booster pumps to collect well water before home delivery with the aid of a pressure tank. Emergency situations such as fires and water utilities shortages may also require the short-term storage of fresh water to cover the basic needs of dispossessed or displaced persons.

There are several reasons to clean and disinfect water storage tanks regularly including: to kill or prevent the survival of waterborne pathogens (bacteria, viruses, and other microorganisms) that can cause gastrointestinal and other diseases; to prevent the accumulation of scale and slime (biofilm), which can be sources of contaminants and can also harbor pathogens; and to control the accumulation of sediments and algal growth, which degrade the taste and odor of potable water.

This bulletin provides step-by-step methods to disinfect water storage tanks, tank descriptions, and maintenance tips. In addition, a review is provided of various methods of water testing for residual chlorine and water disinfection using chlorine chemicals, ozone, and ultraviolet (UV) light to assist anyone considering the purchase of a home water disinfection system.

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Figure 1. Above-ground steel water storage tank painted white to reflect light.

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Figure 2. Underground, polyethylene water storage tanks.

Types of Storage Tanks

Materials: Most of the traditional elevated storage tanks made of redwood and fed by windmills are long gone. Water storage tanks or domestic water systems in use today are typically made of steel (Fig. 1), fiberglass, or polyethylene (Fig 2). Today, thicker walled carbon steel tanks are made and sold for in-the-ground water storage, as are ribbed poly tanks (Fig. 2), and reinforced fiberglass tanks. Above-ground storage tanks are typically made out one of three materials: 1) thin-wall, welded, galvanized steel; 2) fiberglass blown around molds; and 3) extruded white, black, and green colored polyethylene.

Sizes: Custom metal shops can manufacture tanks locally and build them in custom made shapes and sizes. Only companies that have access to the proper polymer materials and special molds can manufacture extruded round polyethylene tanks in large quantities. Molded polyethylene tanks are relatively light in weight, but they are very bulky and difficult to package in quantity and transport very far. Tanks that can hold larger volumes of water are usually brought on site and permanently mounted in place. Tanks that are manufactured primarily for transporting potable water are often made of a translucent polyethylene with a white tint. The water level is clearly visible through the walls of the tank, which is convenient for knowing how much water is still available. These tanks are typically not baffled (no internal walls) and the water inside it can slosh around during transportation often making it difficult to control the vehicle transporting it. The translucent material of these tanks will also allow sunlight to penetrate and can facilitate the growth of algae inside the tank.

Openings: Water storage tanks must have openings for the entry and exit of water. The opening used to facilitate water entry is commonly located at the top of the tank to ensure the existence of an air gap that does not allow water to be siphoned back down the well. Water that is put into the tanks whenever it is available, and removed when it is needed can cause changes in shape (deformities) on the base and the sidewalls of the tanks. Seasonal changes in ambient temperature can cause expansion and contractions of storage tanks. For this reason special bulkhead fittings are used that are both strong and yet flexible enough to allow for the expansion and contraction or slight movements of the tanks. The seal around the inspection hatch is typically the hardest area to seal tightly, especially the tanks made of welded thin steel. Fiberglass and poly tanks typically have pre-manufactured coarse thread lids or bolted hatches incorporated into their walls forming tighter seals.

Above- or below-ground water storage tanks must also have a ventilation port that allows the air inside the tank to escape as the tank is filled with water, and to re-enter the tank as it is emptied. This ventilation port can double as the safety overflow relief port in case the tank is being overfilled with water. Screens over the ventilation port can keep out small animals, rodents, and most insects, but not fine dust and microorganisms. One of the most probable paths for dust and microorganisms to get inside any potable water storage tank is through one of the many openings.

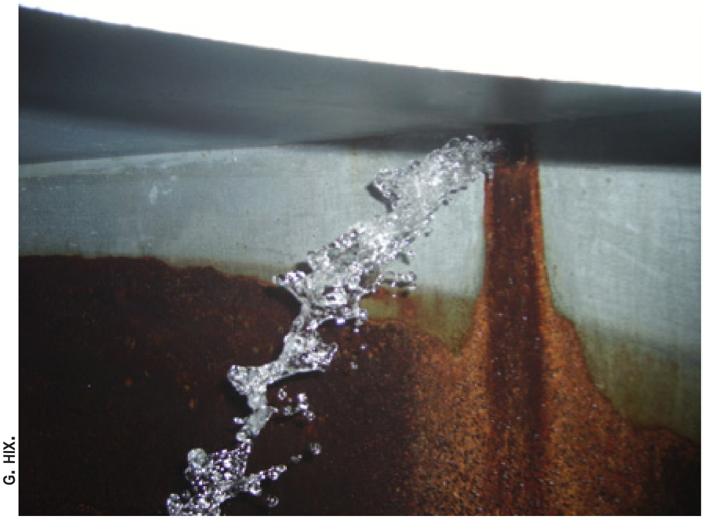

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Figure 3. Inside of a water storage tank with visible rust.

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Figure 4. Inside a water storage tank nearly empty, sediment and algae growth visible.

Potential Contaminants Present in Water Storage Tanks

Chemicals and Organic Matter: Warm water temperatures are commonly found inside water storage tanks. Warm water favors corrosion (Fig. 3), scale formation, and the growth of algae and other microorganisms. Over time, water storage tanks can accumulate organic (carbon-based) and inorganic residues and sediments, which can affect the taste, odor, and potability of the stored water. Sediments that accumulate at the bottom of well casings can be pumped to water storage tanks. These sediments come from the aquifer and are usually composed of fine sand, silt, and clay size particles. Although harmless, these soil materials can carry chemical contaminants and microorganisms (attached to them) into the storage tanks. Over time, changes in water oxygen content, pH, and temperature can produce new residues (from precipitation and corrosion) forming scale that damages storage tank components. These mineral crusts can trap or release contaminants into the water, depending on many factors such as water oxygen content, pH, and temperature changes.

Organic matter, found in the tissue of living and dead organisms, can be introduced to water storage tanks several ways including: from naturally-occurring organic matter in the aquifer water, from aquifer contamination (such as septic system seepage), from the growth of microorganisms inside the tank itself, and from air dust. Slime, often accompanying mineral residues, is produced by an overgrowth of bacteria and algae.

Microorganisms: Microorganisms usually enter water tanks carried by aquifer sediments and improperly sealed tank covers or breathing outlets improperly designed or not fitted with particle filters. Arizona's dusty environment often generates significant amounts of dust, which can enter water tanks and contaminate the water with several organisms including: green algae, bacteria, viruses, protozoa, fungi, pollen, and spores. Potable water often contains sufficient nutrients (nitrate, phosphate, and other minerals) to allow for growth of green algae (some light is needed) and filamentous bacteria, which produce slime (biofilm) (Fig 4). Although many bacteria that are naturally occurring in water are not usually harmful, pathogenic bacteria, viruses, and parasites can be found in water due to fecal matter contamination. This type of contamination is indicated with a water quality test that targets the presence of fecal indicator bacteria *Esherichia coli* or *E. coli*. If *E.coli* tests positive in the water, there is a high likelihood of fecal contamination and the possible presence of other pathogens. A pathogen is an organism that can make you sick. For example, some pathogenic types (strains) of bacteria can cause severe gastrointestinal problems to humans and livestock. In extreme conditions (e.g., overgrowth of slime and warm temperatures) pathogenic bacteria and even the dangerous parasite amoeba *Naegleria fowleri*, found in warm open waters such as lakes and ponds (Sifuentes, et al., 2011), can survive inside storage tanks rendering the water unsafe drink or bathe with (Biyela et al., 2012).

What is Chlorine Demand?

Chlorine chemicals (Table 1) interact (react) with many things found in water, including: organic matter, metals, bromide, manganese, hydrogen sulfide, and ammonium. Chlorine chemicals will react with chemicals in solid forms (such as scale), dissolved in water, or attached to sediment particles. At the same time, chlorine chemicals will kill or inactivate microorganisms by chemically disrupting (oxidizing) their tissues. These chemical reactions occur together and create a chlorine (chemical) demand. Therefore, the chlorination process starts with an initial amount of chlorine added to water, it reacts with many things in the water until all the chlorine is used up or until all reactions are satisfied, and may leave some unused or partially used chlorine in the water called residual chlorine. This residual chlorine is divided into two forms: combined chlorine (composed mostly of nitrogen-chlorine chemicals such as chloramines, which are mild disinfectants) and free chlorine (available for additional disinfection if needed) (CDC, 2012).

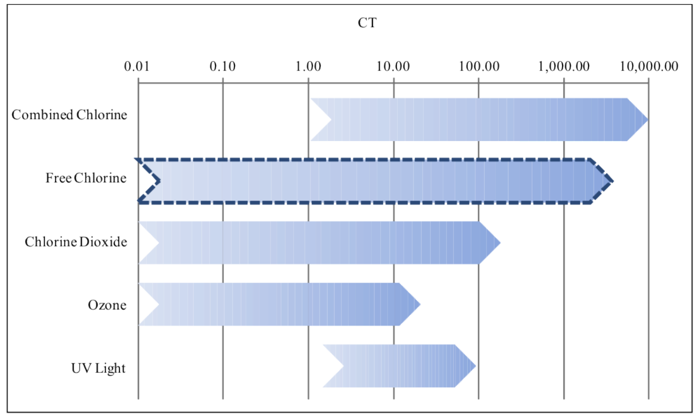

Figure 5. Disinfection requirements for 99% pathogen inactivation. Adapted from: *Water Treatment Principles and Design* (Crittenden, 2005)

How effective is chlorine disinfection?

As stated earlier, pathogens are a class of microorganism contaminants that can potentially cause health problems. Disinfection is typically used to inactivate pathogens, and five types of disinfection are typically used. These include combined chlorine, free chlorine, chlorine dioxide, ozone, and UV light. The effectiveness of these treatments is assessed in Fig. 5, which shows the ranges of required dose (CT) of each treatment to inactivate 99 percent of the pathogens in the water. The concentration (C) of the chemical is in parts per million (ppm) and the reaction time (T) in minutes. Thus, the dose of disinfectant is called CT, which is equal to C times T.

In general, chlorine-based disinfection is effective for most bacterial pathogens and some viruses, but requires higher dosage (CT) for protozoan parasites such as *Giardia* and *Cryptosporidium parvum*. For comparison purposes, ozone gas and UV light require a lower dose to kill (inactivate) the same parasites. This

Table 1. Characteristics of Five Common Disinfectants.

Disinfectant	Disinfection Byproducts*	Residual Stability	Cost	Operation and Safety
Combined Chlorine	Traces of THMs and HAAs**	Most stable residual	Low capital and operating cost	Chlorine gas and sodium hypochlorite solutions are hazardous
Free Chlorine	THMs and HAAs	Stable residual	Low capital and operating cost	Same as combined chlorine
Chlorine Dioxide	Chlorite and Chlorate ions	Stable residual	High operating costs	Chlorine and chlorite powder are hazardous
Ozone	Bromate	No residual – small reactors subject to short circuiting	Relatively high capital costs, and operating costs (electricity)	Avoids hazardous chemi-cals
UV	None	No residual – small reactors subject to short circuiting	Relatively high capital and operating costs (electricity)	Avoids hazardous chemi-cals

* Chemicals produced during disinfection, which are considered hazardous and regulated in public drinking water utilities by the U.S. EPA.

** See list of abbreviations below.

is due to the fact that parasites tend to have a thicker protein coating that can be quite resistant to disinfection. Therefore, to be safe, it is recommended that the upper range of the CT values (as shown by the arrow heads) be used to disinfect drinking water.

Illustration of CT using information from Figure 5 and Table 2. For example, to disinfect a 1000-gallon water tank using free chlorine from bleach, Figure 5 (bordered dashed arrow) shows that the recommended upper CT value is about 5,000. Table 2 (top right bordered dashed box) indicates that to raise the concentration of free chlorine up to 20 ppm in 1000 gallons of water, 1.5 quarts of bleach are needed.

Question: How long will it take to kill 99% of the pathogens in the water?

Answer: If CT = 5,000 and C = 20 ppm, then the contact time needed T = CT/C = 5,000/20 = 250 minutes or about 4 hours. **Note that the 4-hour contact time is valid if the concentration of chlorine remains at this level for 4 hours**. In practice, when a low concentration of free chlorine is used to disinfect water, its level drops over time due to chlorine demand and other factors. Therefore, in the example above the contact time necessary to disinfect a 1000-gallon tank with 20 ppm of bleach should be at least 3-4 times the original estimate or 12-16 hours.

Note that the dose requirement alone should not dictate which disinfection method to use. Other important factors to consider include the creation of hazardous chemicals (also known as disinfection byproducts), the residual disinfectant stability, cost, ease of use or equipment operation, and safety. Table 1 lists five disinfection processes and discusses these factors.

Disinfection is necessary to provide pathogen-free water, and many factors should be considered when selecting a method. In addition to disinfection, a residual (see What is Chlorine Demand? Section) is often needed to prevent growth or re-growth of pathogens or nuisance biofilms in water storage and distribution systems. Often a single technology may not be enough to guarantee water potability and more than one process is used. Since ozone or UV does not provide chlorine residual in the water storage tanks or in the distribution system, chlorine or chloramines are commonly added to provide supplemental chlorine residual.

Options and Steps to Disinfect Water Storage Tanks

The following Boxes provide two step-by-step guides to disinfecting water storage tanks. Option A (Box 1) may be more suitable for small tanks with very limited access and small openings. It requires longer periods of chlorine contact time and uses two or more volumes of tank water. Option B (Box 2) is faster, better suited to large, outdoor tanks, but requires full access to the tank's inner surface for scrubbing using a strong chlorine solution.

Box 1.

Potable Water Storage Tank Disinfection using Household Bleach--Option A

1. Scrub and wash internal surfaces of tank with soapy water and a brush, taking care to remove any visible, gray, green, brown, or black residues.

2. Thoroughly rinse out all the soap and flush out all bottom sediments and residues.
   Note: Disinfection of a dirty tank will require more disinfectant due to an increase in chlorine demand.

3. Fill the tank to ¼ (with fresh water) and for a 1000-gallon tank; pour one to two quarts of fresh (unopened) household bleach.
   Note: one to two quarts of bleach will add about 13 to 26 ppm of free chlorine to 1000 gallons of water.

4. Fill the tank to the top with fresh water, cap it, and let stand for about 12 to 24 hours, depending on the amount of bleach added (one or two quarts).
   Note 1: Adding more bleach requires less waiting (shorter contact time).
   Note 2: At the end of the ~12-24-hour period, you should still smell chlorine in the water.

5. Drain all the chlorinated water. Refill with potable water.
   Note: Drained water with residual chorine may be used to irrigate native shrubs and trees, but should not be given to animals.

Metric conversions: 1gallon=3.8 liters, 1 quart=0.95 liters, 1 ounce=29.6 milliliters.
Acronyms: ppm=parts per million, which are equivalent to milligrams per liter (mg/L). L=liter, ml=milliliter.

Box 2.

Potable Water Storage Tank Disinfection using Household Bleach--Option B

1. Scrub and wash internal surfaces of tank with soapy water and a brush, taking care to remove visible, green, brown, or black residues.
2. Thoroughly rinse out all the soap and flush out all bottom sediments and residues.

   Note: Disinfection of a dirty tank will require more disinfectant due to an increase in chlorine demand.

   CAUTION!

   -Perform next step outside or in a well-ventilated area

3. Prepare 1-4 gallons of strong 200-ppm (mg/L) chlorine solution using **fresh (unopened)** household bleach using a clean 5-gallon bucket. **Add ½ ounce of bleach for every gallon of water in the bucket.**

   CAUTION!

   -Do not climb down a tank or perform the next tasks in a closed area.

   -Wear gloves, eye protection, and old clothes.

   -Avoid skin contact with strong chlorine solutions.

   -Avoid breathing chlorine vapors.

4. Use a hand sprayer with an extended nozzle or long, soft brush to wet all the inside surfaces of the tank with the strong, 200ppm chlorine solution.
5. After about 1 hour, wash chlorine solution off the tank walls using a water hose, taking care not to contaminate the tank with dirt residues and drain the wash water off the tank.

   Note: This tank wash water should not be used to irrigate any kind of vegetation, come in to contact with anyone or animals (pets, fish, wildlife), or be discharged into a septic system.

6. Repeat wash and drain step (5) at least one more time.

Metric conversions: 1gallon=3.8 liters, 1 quart=0.95 liters, 1 ounce=29.6 milliliters.
Acronyms: ppm=parts per million, which are equivalent to: mg/L=milligrams per liter, ml=milliliter, L=liter

Additional Notes

- **After disinfection it is recommended that the potable water stored in the tank be tested for total coliform bacteria and *E. coli*. Repeat cleaning or add additional chlorine if the tests are positive.**
- **Disinfection of large tanks (and wells) is best left to professionals who are trained to handle concentrated oxidants such as hypochlorite-based liquids that can cause skin damage and throat and eye irritations.**

  WARNING: Do not use chlorine solutions in combination with other chemicals such as strong acids or strong alkaline solutions (ammonia-containing).

Table 2. Chemicals and UV Light used for water disinfection for home, pool, and other (industrial) uses. Note that only liquid bleach and calcium hypochlorite powder are recommended for use in disinfection of water storage tanks by homeowners.

Chemical	Sodium Hypochorite %	Active Chlorine %	To Prepare 10 gallons with 200 ppm Chlorine Add	To Prepare 100 gallons with 200 ppm Chlorine Add	to Prepare 1000 gallons with 20 ppm Chlorine Add	To Prepare 1000 gallons with 1 ppm Chlorine Add
Liquid Bleach (Fresh*, Plain, Unscented) ($NaClO$) *Use New bottle of Bleach	5.25	4.90	5 liquid ounces (15 milliliters)	48 liquid ounces (1.5 quarts) (1.4 Liter)	48 liquid ounces (1.5 quarts) (1.4 Liter)	2.5 liquid ounces (75 milliliters)
			or	or	or	or
Calcium Hypochlorite Powder (High Test) ($Ca(ClO)_2$)		65-76	0.4 ounces (12 grams)	4 ounces (120 grams)	4 ounces (120 grams)	0.2 ounces (6 grams)
Bleaching Powder-Chlorinated Lime ($CaCl(ClO).4H_2O$)		20-35	Industrial Bleaching Agent/Pool Disinfection Not Recommended for Home Use			
Lithium Hypochlorite ($LiClO$)		35	Pool Disinfection ONLY Do Not Use to Disinfect Water Tanks or Drinking Water			
Chlorine gas (Cl_2)		100	Used by Drinking Water & Wastewater Treatment Utilities DANGEROUS! Not Available for Home Use			
Chlorine Dioxide gas (ClO_2)		263	Industrial/Medical use ONLY DANGEROUS! Not Available for Home Use			
Chloramine gas, liquid (NH_2Cl)		0	Residual Disinfectant ONLY, not for Home Disinfection Added to Public Water Distribution Systems			
Ozone Gas (O_3)			Very Strong Oxidant, No Residual Disinfection Commercial and Pool Use ONLY			
Bromine, Bromide: Chemicals			Pool/Jacuzzi Disinfection ONLY. Do Not Use to Disinfect Water Tanks or Drinking Water			
Iodine: Liquid, tablets			Emergency Disinfection of Small Volumes of Drinking Water			
UV light (Not a Chemical. Cell-damaging Radiation)			Very Strong Oxidant, No Residual Disinfection In-line Water Disinfection for Commercial and Home Use			

By Definition:

Chlorine Solutions are as Active Chlorine (mg Cl_2/L) or ppm of Cl_2 [mg=milligram, ppm=parts per million]

100% Active Chlorine ~ 14.5 moles/L of ClO^- chemical (assuming 1kg=1L) [kg=Kilogram, L=liter]

Disinfecting chemicals:

Good Disinfectant: Hypochlorite Ion (ClO^-)

Best Disinfectant: Hypochlorous Acid ($HClO$)

Best Water pH Range and Temperature for Chlorination are:

pH=5.5-7.5, Temperature~ above 65° F [F=Fahrenheight]

To Favor the Presence of HClO, Water with pH Above 8 Should be Acified to Lower the pH Before Chlorination

USE food-grade sulfuric acid (CAUTION! Strong acid, handle with extreme care). DO NOT USE: citric, acetic, phosphoric, nitric or hydrochloric acids

- **Color Wheels** (Initial low cost, easy to use, not always reliable, lack calibration/standardization)
- **Test-tubes** (Initial low cost, easy to use, usually reliable but lack calibration/ standardization)
- **Digital Colorimeters** (Initial high cost, very accurate and precise if used properly)

Figure 6. Free chlorine test kit. Hach® (no endorsement implied)

Testing your Stored Water for Free Residual Chlorine

The water safety and potability of stored water can be maintained with periodic testing and chlorination. The residual levels of free chlorine should be kept at between 0.2 to 1.5 ppm. However, this is often difficult since chlorine chemicals decompose and volatilize, losing their strength over time and with changing environmental conditions. Water storage tanks that hold a known initial volume of water may be initially chlorinated to insure water potability. However, over time, as water is being used, the addition of progressively smaller amounts of chlorine chemicals may be needed to maintain safe levels of residual chlorine.

Water stored in overflow storage tanks, used for example in low-yield wells, is seldom chlorinated as the water volumes vary daily and turnover rates are variable. Note, however, that periodic cleaning and disinfection of overflow tanks and supporting equipment (pumps, pipe systems) is necessary and recommended to prevent the growth of opportunistic pathogens such as the bacteria *Legionella sp.* and *Mycobacterium*. These bacteria are commonly found in water environments and tend survive in biofilms. More recently they have been found to grow at rapid rates in distribution systems or storage tanks that are not regularly disinfected or properly maintained (Rock un-published data).

Once water is chlorinated, following the steps shown above, the level of residual free chlorine may be tested using a variety of methods that use chemicals ranging from test strips, calibrated color scales, to portable colorimeters. The user should be aware that some chlorine test kits do not measure free chlorine (recommended for water potability). Test kits used for pool chlorination (based on the OTO method) measure total chlorine, not free chlorine and are therefore not recommended for use in testing potable water storage tanks.

Tests kits that use the DPD-1 method are recommended to test free chlorine in potable water. There are three types of kits that can be used to measure total (not recommended) or free residual chlorine (recommended) (CDC, 2012) in order of increasing cost:

Additional Notes

- To prevent user errors, all kits must be used carefully following manufacturer instructions. **One common user error is testing with expired chemicals.**
- Chemicals (powder bags or tablets) purchased from one manufacturer may not be used in other manufacturers' test kits).
- Chlorine test kits vary in price, ranging from about $40 to over $400 (Fig. 6). Once the kit is purchased, the only expendables needed are the chemicals in the form of powder or tablets, which usually cost less than $0.10 / test, and replacement batteries for portable colorimeters.

Storage Tank Maintenance

Electrical Components: Water storage tanks, when used in conjunction with domestic water wells, typically have some form of liquid level control device to automatically turn on the well pump when the tank reaches a prescribed water level and turn it off when it becomes full. This is typically done with micro switches inside plastic housings that float on the water inside the tank. A second micro switch is often submerged lower in the tank to shut off the booster pump if the water level in the tank becomes too low. Electrical switches operating daily on or under water can fail and must be replaced from time to time.

Homeowners are not advised to troubleshoot or replace these electrical components themselves, but to rely upon qualified, licensed water well contractors. While they may look the same, and serve the same purpose, there are liquid level control float switches that use a small bubble of liquid mercury to open and close the electrical contacts; these models are never approved for use in drinking water systems.

Tank Openings: Inspection hatches on top of the storage tanks are there for providing access to liquid level indicators and control devices, access to submersible booster pumps inside the tanks, and for visual inspection of the water level and sediment accumulation on the bottom of the tank.

The access hatches of underground storage tanks are typically sealed with a gasket and multiple bolts to maintain air tight and watertight seals close to the ground. Opening these hatches can easily provide an opportunity for dirt, debris, and bacteria to get inside the tank anytime the seal is broken.

Access hatches on aboveground storage tanks can be ten feet or more in the air and require standing on a ladder for inspection. Visually seeing what is down inside a dark tank full of water can be difficult. When inspecting a water storage tank in bright sunlight, a mirror to reflect sunlight may be better than a flashlight for peering into the tank and through the water.

Leaks: Many galvanized water storage tanks are initially coated with a thin layer of bees wax to delay the oxidation and corrosion of the galvanized steel. Hot water, or steam cleaning, of the inside of these tanks could remove this protective coating and allow more rapid corrosion of the metal. Steel storage tanks that have been in service for a few years may already have partial corrosion of the steel walls as indicated by slightly rusted spots on the outside of the tank. These areas often indicate very thin zones of metal and iron oxide precipitates made by microorganisms. Aggressive scrubbing or removal of iron oxides outgrowths (tubercles)(Fig. 3) inside or outside of the tank can cause pinhole leaks that must be repaired by welding on patches. Alternatively, epoxy-based compounds are can be used to make these minor repairs in metal and fiberglass tanks. Leak repairs in plastics tanks may require the use of specialty kits provided by tank manufacturers.

Conclusions

Homeowners living in remote areas need fresh water storage tanks to meet their water needs. Emergency situations may also require the short-term storage of fresh water to cover the basic needs. Potable water tanks should be cleaned and disinfected regularly to kill waterborne pathogens that can cause gastrointestinal and other diseases and to prevent the accumulation of other contaminants that can also make the water unsafe to drink and degrade its taste.Homeowners using chlorine chemicals such as bleach may safely disinfect storage tanks.Tanks should be cleaned thoroughly with detergents and any sediments or debris should be removed before chlorination to reduce chlorine demand and the formation of toxic disinfection byproducts.

The potability of water stored in large water tanks may be maintained with residual chlorine and regular water testing. Modern ozone and UV light water disinfection methods are safe to use but are more expensive and do not provide protection (in the form of residual disinfection) to stored water.

Abbreviations used in the publication

cfu	Colony Forming Units
CDC	Center for Disease Control
CT	defined as: chemical Concentration(mg/L) X contact Time(minutes)
DPD-1	N,N-diethyl-p-phenylenediamine (chemical used to test free chlorine in water)
HAAs	Haloacetic Acids (disinfection byproducts formed during chlorination)
kg/L, mg/L	Kilograms per Liter, milligrams per Liter
OTO	Orthotolidine (chemical used to test total chlorine in water)
ppm	Parts per Million, equivalent to mg/L
THMs	Trihalomethanes (disinfection byproducts formed during chlorination)
UV	Ultraviolet Light

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