Agriculture and Agri-Food Canada
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Water Quality Matters

Chlorine disinfection of private water supplies for household or agricultural uses

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Description

Disinfection processes are used in the delivery of drinking water to reduce the risk of illness from disease-causing micro-organisms such as bacteria, viruses and parasites. Appropriately designed water treatment and disinfection processes will reduce exposure to pathogenic (disease-causing) micro-organisms or alter the organisms' DNA structure to prevent multiplication or reproduction in an animal's digestive system. The effectiveness of the *disinfection process* is determined by the nature of the organism, the chemistry and purity of the water, the disinfection dose and contact time. Disinfection is best achieved with clean water when properly applied after effective pre-treatment with filtration. Chlorination is one type of disinfection used in drinking water. Other common types of disinfection include chlorine dioxide, chloramines, ozone and ultraviolet light (UV). However, chlorination is one of the best disinfecting processes because it is possible to maintain and measure a residual level of chlorine in the distributed water. This allows for continual monitoring of the process and minimizes the potential for re-growth of pathogenic organisms throughout the distribution pipes. This fact sheet provides an overview of chlorination disinfection for applications on private water supplies.

Disinfection is necessary in order to provide safe drinking water, and is beneficial for many other agricultural applications, such as livestock watering.

Types of chlorine used in disinfection

Some community and public water supply systems use chlorine gas as a disinfectant; however, this method is too expensive and dangerous for home or small-scale agricultural uses. Household systems treating water obtained from private water supplies prefer to use liquid chlorine (sodium hypochlorite) or dry chlorine (calcium hypochlorite).

Liquid Chlorine:

- Household bleach (most common and suitable for potable water systems)
- Chlorine concentration ranges
  - 5% (domestic laundry use)
  - 12% (commercial laundry use), sodium hypochlorite
- More stable than dry chlorine
- Should be protected from heat and sun

Dry Chlorine:

- Chlorine concentration available 4%

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- Solution maintains strength for one week
- Soluble in water
- Powder is stable if stored properly
- Should be protected from heat and sun
- Flammable
- Produces sediment that clogs equipment

Safety Concerns

Chlorine is highly reactive with other chemicals, such as acids or ammonia, and extremely corrosive to certain materials. Accordingly, small-scale chlorination systems should not utilize highly concentrated chlorine chemicals that may be more common in water treatment plants. Appropriate precautions are necessary for chlorine storage and handling (use protective eyewear and rubber gloves). All materials used for the chlorine injection systems must be capable of withstanding the chlorine feed concentrations. Equipment, valves and piping will require periodic maintenance to ensure safety and effective operations.

Chlorine Reaction Processes

The primary goal in disinfection is to eliminate or inactivate pathogenic bacteria, viruses and parasites. Key factors affecting disinfection include water pH, temperature, the chlorine concentration and contact time with the water. Other factors such as water alkalinity and the presence of ammonia will affect the disinfection process.

In addition to being a disinfectant, chlorine is also a strong oxidant, and is sometimes used to precipitate dissolved minerals (e.g. iron) in a pre-treatment process. This fact sheet does not discuss the use of chlorine as a pre-treatment oxidant for precipitation of minerals.

Disinfection processes must address the issue of multiple reaction processes. Chlorine will react with organic substances in the water (e.g. dissolved organic carbon, tannins, lignins, etc.) and will oxidize a number of inorganic substances (e.g. dissolved iron, dissolved manganese, dissolved arsenic, hydrogen sulfide gas, nitrite, etc.). These reactions will interfere with the chlorine disinfection dose required to target pathogenic organisms. The chlorine disinfectant dosage must therefore be sufficient to satisfy all possible reactions in the water to leave a *chlorine residual* (unreacted chlorine) in the water after all water storage tanks or cisterns. Chlorine residuals need to be maintained throughout the entire distribution system. The chlorine residual should be 1.0 mg/L total chlorine and 0.2mg/L free chlorine at the point-of-use (POU) of the water (i.e. the faucets where the water is drawn from). [Health Canada, 2005]

Inexpensive test kits are available to test for total and free chlorine residuals. Chlorine dosing must not be too high, as excessive dosages of chlorine may result in objectionable taste and odour. Chlorine residuals should not exceed 4.0 mg/L. [USEPA, 2003]

A residual chlorine concentration will not necessarily ensure the water is free of disease-causing organisms as dirt may shield microorganisms from the chemical. Therefore, a multi-barrier approach to water treatment is important for disinfection. Multi-barrier water treatment relies on processing raw water through a series of stages to improve water quality before the final disinfection stage. Multi-barrier treatment is essential for all surface water sources and for any groundwater under the influence of surface water (e.g. shallow wells).

A small-scale surface water multi-barrier approach should include either coagulation and conventional filtration systems or a biological filtration system. A multi-barrier approach on small-scale groundwater systems will require proper well management (e.g. preventative measures such as shock chlorination to ensure proper disinfection) coupled with treatment processes to deal with any unique water quality problems in the ground water supply (e.g.

removal of iron, arsenic, hardness, etc.). Although shock chlorination of wells is an accepted and recommended preventive maintenance practice for wells, continuous chlorine or pellet chlorinators, injecting chlorine into wells, are not recommended because there is the potential to plug wells and severely interfere with the biological ecosystem of the developed well. Furthermore, the chlorine may corrode the well casing and pitless adaptor.

The chlorination disinfection process for surface and groundwater supplies is positioned **after** the primary treatment devices to ensure disinfection of the purest and cleanest water possible. This allows for the greatest success in maintaining a chlorine residual throughout storage and the water distribution system. Figure 1 shows an example of disinfection of surface water.

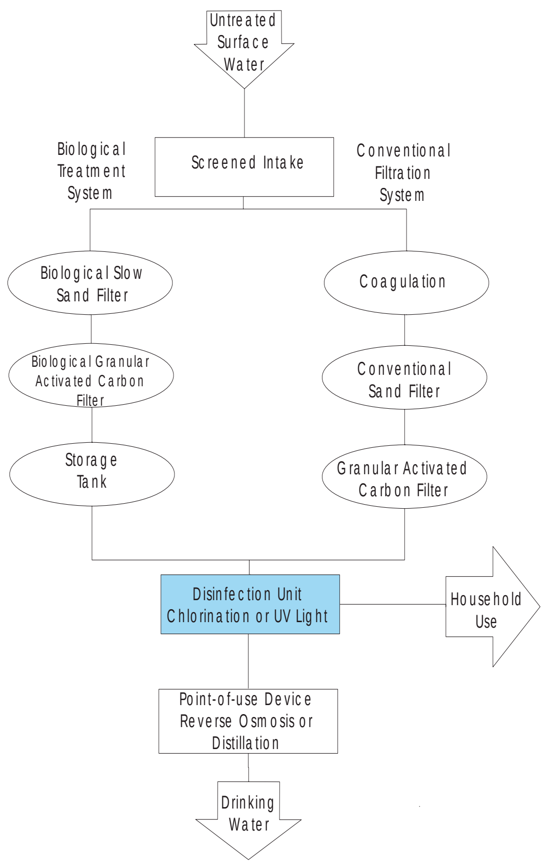

Figure 1: Disinfection After Primary Treatment

Concerns with Chlorine Disinfection

One disadvantage with chlorine is that it creates disinfection by-products when it reacts with water that has excessive amounts of organic material such as *dissolved organic carbon (DOC) or tannins*. Some disinfection by-products such as *trihalomethanes (THMs) and haloacetic acids (HAAs)* are potential cancer-causing. Disinfection by-products in drinking water must be kept below the Guidelines for Canadian Drinking Water Quality. Generally speaking, the greater the concentration of organic matter, the greater the potential to form higher concentrations of disinfection by-products. To manage this problem, the water treatment system should be designed to reduce the concentration of DOC before chlorination disinfection (ideally, reduce DOC to about 4 to 5 mg/L or less). Effective DOC reduction may be achieved with properly designed and maintained granular activated carbon (GAC) filtration, and/or biologically activated carbon (BAC) filters. Granular carbon filters used to remove DOC require frequent replacement of the granular carbon filter material. Biologically activated carbon filters require continuous flow and proper maintenance of adequate oxygen levels for effective DOC reduction. Another option involves the use of advanced coagulation processes (properly managed high doses) designed to reduce DOC concentrations.

Chlorination Dosing Procedures

Liquid chlorine is usually added to water after the initial stages of treatment (settling, coagulation, filtration, etc.). A pre-determined chlorine solution is mixed in a chemical storage tank. *Chemical injection pumps (Figure 2)* continuously pump the chlorine solution into the water through an in-line *venturi* device to mix the chlorine into pre-treated water. Sufficient contact time is required to allow the chlorine reactions to occur and to ensure that disinfection is achieved. Often small systems will incorporate a chlorine contact tank or possibly retention coils to achieve a desired chlorination contact time (often about 20 to 30 minutes depending on the design).

Figure 2: Chlorine Chemical Injection Pumps

Chemical injection or peristaltic feed pumps require the use of a flow meter to measure the quantity of water that is being disinfected. The amount of liquid chlorine solution injected depends on the quantity and quality of water treated and the desired chlorine residual, after a suitable contact time (usually determined by a trial-and-error process).

Operation and Maintenance Issues

If the quality of the water varies, the chlorine residual will need to be checked and adjusted. Frequent adjustment is therefore common on surface water sources. Well water quality remains fairly constant unless it is under the direct influence of surface water (typically wells less than 30 metres deep in pervious soil).

The *venturi* aspiration mixing technique uses an injection valve to introduce the chlorine into the water. It requires a constant flow of water through the *venturi valve* to work most effectively, and is therefore not ideal in start/stop modes of operation. Constant flow can only be achieved at certain locations in a water distribution system. Alternatively, injecting chlorine in front of a nonmetallic baffle or baffled tank will work better in start/stop modes of operation.

Proper operation and maintenance of the chlorine batching process, chemical feed pumps and the venturi aspiration system are critical to achieve successful disinfection. Improperly batched chlorine solutions may negate effective chlorination, or cause too high of a chlorine residual. Chemical pumps may lose their prime and will not inject the chlorine solution even though they appear to be pumping. Plugged venturis will impair effective dosing of chlorine. Performance of venturi aspiration systems is particularly dependent on regular maintenance. If at all possible, the sodium hypochlorite solution should not be diluted with raw water, as this may introduce dirt, oxidized minerals, organisms, etc. which in turn can plug or foul the feed pump or the venturi device. Venturis are susceptible to encrustations of sodium hypochlorite causing significant change in their operational characteristics. Chlorine solution batches from dry granular chlorine are rarely particle free and may cause frequent plugging or fouling of chemical feed systems.

To achieve effective disinfection, small-scale chlorination systems must be designed to suit the water to be treated. The system must be properly operated and maintained, and equipment should be inspected daily. Chlorine residuals should be verified at least several times per week, by on-site monitoring and testing, recording, and tracking of actual chlorine residuals. If these steps are not followed, effective disinfection will not occur.

Disinfection Dosage and Contact Time

In order to work properly the chlorine must be allowed time to react with the water and the targeted disease-causing organisms. A chlorine *dosage* must be adequate to exceed the chlorine *demand* (the reactions caused by organic and inorganic matter), and leave behind a chlorine *residual*. Disinfection occurs during the *contact time* of the chlorine and the targeted organisms. The longer the contact time (within reason) the more effective the disinfection will be. As noted under "Concerns with Chlorine Disinfection", the formulation of chlorination disinfection by-products must be properly managed and controlled. A pre-determined chlorine concentration, C, is applied to the water for a specified length of contact time, T. The product is referred to as the CT value. The chlorine concentration C is the lowest continual chlorine residual in the treatment process, while the time T is the exposure time for that residual.

Disinfection effectiveness is reduced at higher pH levels and lower water temperatures. Therefore, higher CT values are required with higher pH, and/or lower temperature. In other words, chlorination disinfection is more effective at a lower pH (<6) and high temperature (>20°C).

Contact tanks with an air-vacuum release valve are available for closed systems. Small storage tanks work well with open systems. Contact time varies for the type of organism. Chlorination is not effective for parasites such as Giardia or Cryptosporidium - even with long contact times; these disease-causing parasites have strong shells that protect them from the chlorine chemical. This is another reason that effective pre-treatment processes must be used to remove these types of organisms, before the water is disinfected with chlorine.

Removal of Excess Chlorine

As a last step, when high residuals of chlorine are present in treated water, the chlorine is often removed with a granular activated carbon filter. However, despite the fact that the water has been disinfected and may contain some residual chlorine, carbon filters will develop substantial populations of heterotrophic bacteria and possibly other bacteria. This may exceed the Guidelines for Canadian Drinking Water Quality, and render the water unsatisfactory for drinking, cooking and brushing teeth. Carbon filters used in this fashion should be regularly monitored and replaced, and ultraviolet disinfection devices may be added after these carbon filters to control bacterial problems caused by the carbon filter.

Small Point-of-Use polishing treatment devices are designed for use on disinfected water. Even when the chlorine residual is normal, it must be reduced for such POU devices as reverse osmosis (RO) systems since the chlorine may damage the membrane over time. This is done by incorporating a small GAC filter that will require replacement on a regular basis. After the RO device, water may then be disinfected by a small ultraviolet light.

Other Types of Disinfection

There are four other main types of disinfection commonly used: chlorine dioxide, chloramine, ozonation and ultraviolet light. Chlorine dioxide and chloramine are not appropriate for rural household systems because they are expensive and dangerous. Ozonation is a powerful oxidant and much more corrosive than chlorine. However, it is a very effective disinfecting agent. It requires shorter contact time and a lower dosage for proper disinfection than chlorine. Ozone is a gas that must be created on-site using oxygen and electricity; safety concerns require testing for ozone gas. Because of the complexities related to ozonation, small-scale uses, particularly in households, are not common. Ultraviolet light disinfection uses a special lamp to inactivate reproduction of pathogens. UV radiation is easy to use, requires short contact times and the bulbs are readily available. One problem associated with UV radiation is the need for bulb replacement as organic material or mineral scales cling to the bulb. The bulb becomes less effective and it is recommended that the units have a dedicated power supply. UV systems are favored by some producers because they do not produce any odor or taste, but a key disadvantage is that there is no way to measure on-going effectiveness because there is no residual to monitor.

Summary

Disinfection, using chlorination, is the last step in a multi-barrier approach to providing safe water for rural household and agricultural uses. It is the most common disinfection method and is very effective if used correctly. With adequate pre-treatment, chlorine dosing, contact time and maintenance, chlorination effectively destroys many disease-causing bacteria and viruses. In addition chlorine is easy to control and is an inexpensive chemical to apply to rural surface or ground water treatment systems.

For more information on protecting and improving rural water supplies, contact your nearest Agriculture and Agri-Food Canada - PFRA office, or visit the Prairie Farm Rehabilitation Administration web site at www.agr.gc.ca/pfra.

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