WEDC

MOBILE NOTE 7

Chlorination

Introduction

Chlorination is the most widely used method of disinfection of water supplies in developed and developing countries.

Originally published by WELL, the main focus of this note is the use of chlorination with small-scale water supplies in developing countries.

A number of references are listed towards the end of the note for readers seeking further comprehensive information on the topic.

Loughborough University

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This note highlights the following:

- health risks from disinfection using chlorine;
- chlorine-resistant micro-organisms;
- local production of sodium hypochlorite solutions from electrolysis of salt;
- ensuring that disinfection is effective; and
- using chlorine products for household-level treatment.

The basics

What is chlorine?

Chlorine is a poisonous gas which, when pressurized, forms a liquid. It is safer when combined with other chemicals in liquids (such as bleach) or solids (powders and tablets).

Why chlorinate?

Chlorination is used primarily to kill or inactivate disease-causing organisms (pathogens) in drinking water. This removes one of the major routes for transmission of diarrhoeal diseases.

Sometimes chlorination may also be used to oxidize certain unwanted chemicals.

How?

Chlorine, often in the form of a chemical compound (usually in solution), needs to be well mixed with raw water to kill or inactivate pathogens. Sufficient chlorine needs to be added so that, after completion of any reactions with organic matter or chemical substances in the water, there is enough free chlorine remaining to kill pathogens.

Where?

Chlorination can take place at community level (at the water source or in a treatment works, for example) or, on a simple scale, at household level.

When?

The treatment system needs to be sustainable so that water is never supplied untreated. Sufficient 'contact time' (typically 30 minutes) needs to be allowed after the chlorine is added for it to inactivate the pathogens before the water is consumed.

Some of the problems

- The water to be treated needs to be relatively free from organic or chemical substances that will react with the chlorine (unless this loss is allowed for). The presence of these in surface water will vary with rainfall, complicating their removal.
- Some pathogens found in surface water are resistant to normal doses of chlorine (although they are likely to be removed if appropriate treatment (e.g. fine filtration) is provided prior to chlorination).
- Chlorination needs a ready supply of a suitable source of chlorine and

the consumables used for testing the treated water.

- A trained person is needed to determine the right dose to add. They need suitable equipment to regularly measure the amount of active chlorine remaining after treatment. They must also have, and be able to maintain, suitable dosing equipment. Such equipment is complicated if it has to deal with variation in the flow rate of the water that is being treated.

Health impacts

Disinfection of water by chlorination appreciably reduces incidence of diarrhoea. Diarrhoea is a leading cause of illness and death in children less than 5 years old in the developing world.

Chlorination and safe water storage can make a significant contribution to reducing diarrhoeal diseases.

For example, a systematic review of the effect of point-of-use chlorination and other water disinfection methods in developing countries has shown their effectiveness in reducing the risk of diarrhoeal diseases by between 11 and 47 percent (Fewtrell et al., 2005).

One of the interventions to reduce HIV transmission from mother to child is the replacement of breast milk with infant formula milk. It is clearly important that safe water is used to prepare such formula or the child will be at great risk of numerous episodes of diarrhoeal diseases potentially leading to death.

Adverse health risks of chlorination by-products

In recent years there has been some opposition to the use of chlorine for disinfection because of perceived heath risks (primarily cancer) from certain disinfection by-products (DBPs) that can arise from the disinfection of water with chemicals. The World Health Organization's *Guidelines for Drinking-water Quality* (WHO, 2004, p.5) states that:

> " ... the risks to health from these by-products are extremely small in comparison with the risks associated with inadequate disinfection, and it is important that disinfection not be compromised in attempting to control such by-products."

Chlorine-resistant organisms

Two disease organisms (pathogens) found in water – *Giardia duodenalis* and *Cryptosporidium parvum* – are highly resistant to normal levels of chlorination. Fortunately, if appropriate pre-chlorination treatment stages such as sedimentation (particularly after coagulation and flocculation) and filtration are used in the water treatment process, there is little risk of these pathogens reaching the chlorination stage. In very simple treatment systems used in rural areas of developing countries, it is often not possible to include these necessary treatment stages and so some risk from these pathogens will remain if they are present in the raw water.

However, these organisms are unlikely to be present in groundwater if the collection point is properly protected and the water is hygienically handled.

Risks from contamination after treatment

Residual chlorine in water at the collection point will give some protection against subsequent contamination of the water, but users need to understand how to prevent subsequent contamination of the water or its quality may deteriorate, for example, through unhygienic practices used during collection, transportation, storage and withdrawal from storage. Many water-borne diseases are also carried by other routes.

For the best health impact, sanitation and hygiene practices in the household and community will need attention as well as the quality of the water.

Chemistry of chlorination

For full details of the chemistry of chlorination and use of chlorine for disinfection see relevant textbooks. Brief introductions to chlorination are provided in Skinner (2001, pp. 5-7), and Parr and Shaw et al. (1999).

Most chlorine is most likely to be used up through the oxidation of organic material and certain chemicals in the water. Enough chlorine must be added to oxidize all this material. The amount required to do this is known as 'chlorine demand'. There needs to be a sufficiently large surplus that a suitable amount of active chlorine (free residual chlorine) is available in the water after disinfection. The more impurities there are in the water, the greater the chlorine demand, though even apparently clean water is likely to have a chlorine demand of about 2 mg/litre .

Chlorination of dirty water will result in chlorine being wasted as what is used up will not be sufficient to disinfect the water.

WHO (2004, p. 194) states:

> “For effective disinfection, there should be a residual concentration of free chlorine of ⩾ 0.5mg/litre after at least 30 minutes contact time at pH <8.0”

Ensuring disinfection is effective

Sources of chlorine

The usual sources of chlorine (gas, liquids, solids and powders) and the typical chlorine content as a percentage by mass are shown in a number of references (including Skinner (2001, p.7)). The stability and ease of use of each compound differs. Proper storage before opening containers and between uses is essential to ensure chlorine compounds retain their effectiveness.

Even with good storage some have a fairly limited shelf-life. For instance, even if stored in sealed containers in a cool, dark place, lypochlorite can lose half its strength in a year.

Recent developments in the small-scale production of sodium hypochlorite from the electrolysis of salt solution now mean that decentralized local production is often feasible, in developing countries.

This approach has been used in some of the countries (e.g. Peru and Bolivia) where the Safe Water System has been promoted (see below).

Some suppliers of suitable equipment are listed in Skinner (2001, pp.43-45).

Determining the chlorine dose

Many books offer advice on the procedures for determining the required chlorine dose (see Skinner 2001, p.7).

The actual strength of the source of chlorine does not have to be known to determine an appropriate dose (see the 'Modified Horrocks' method described in Parr et al. (1999)).

It is important to realise that the chlorine demand of water sources will not necessarily remain constant. It will usually vary for surface water sources, depending on recent patterns of rainfall run-off contributing to the source, but pre-treatment stages to remove the additional suspended solids will limit the variation.

There are many factors that affect the efficiency of inactivation of microbial pathogens. The principal ones are the chlorine concentration around the organism; contact time (the period during which the chlorine is in contact with the pathogen); water temperature and pH. These and other factors that will affect chlorination, such as the nature and flow rate of the water; the availability and use of chlorine compounds and testing equipment; and the chlorinator and its operation are summarized by Skinner (2001, p.9).

Contact time

The efficiency of chlorine in inactivating various pathogens is often specified by a 'Ct value' which is usually related to the 99% inactivation of a particular type of organism. The Ct value is a product of the concentration of chlorine in mg/l and the contact time in minutes. It takes into account that lower chlorine concentrations for longer periods will have similar effectiveness to higher concentrations for shorter periods as long as the Ct values for each situation are the same.

After a chlorine compound is applied, the water needs to be held in a tank (contact tank) or pipe system for sufficient time (usually at least 30 minutes) for the organisms to be inactivated before the water will be safe to drink.

Where treated water is constantly flowing through a contact tank, the tank needs to be carefully designed to prevent water 'short circuiting' and passing through it faster than might be anticipated from the ratio between the volume of the tank and the flow rate of the water.

Checking the residual chlorine

Regular testing is essential to ensure that adequate free residual chlorine is still present in the treated water, whatever changes take place in the raw water or in the strength of the chlorine compound being used. Standard methods of field-testing for chlorine concentrations in water are well explained elsewhere and are briefly discussed in Skinner (2001, pp.14-15).

The DPD method is summarised in Parr et al. (1999).

Household-level chlorination

Under the right conditions, chlorination can take place at household level. The US Centers for Disease Control and Prevention (CDC) have for a number of years promoted the Safe Water System of household chlorination and safe storage of drinking water (CDC 2000). You can find out more about this from their website and the Safe Water System handbook.

Chapter 6, section 4, of Sobsey (2002) deals with the use of chemical disinfection at household level. It includes reports on the proprietary compounds that are a mixture of coagulant/flocculant and chlorine-based disinfectant.

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About this note

Author: Brian Skinner
QA: Patrick Moriarty, Jo Smet and Sandy Cairncross

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**Water, Engineering
and Development Centre (WEDC)
School of Civil and Building Engineering
Loughborough University
Leicestershire LE11 3TU UK**

Phone: + 44 (0) 1509 222885
Email: wedc@lboro.ac.uk
Website: wedc.lboro.ac.uk
Twitter: wedcuk
YouTube: wedclboro

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