chapter 4: waterborne infections and disinfection

Infectious diseases caused by pathogenic bacteria, viruses, and protozoa or by parasites are the most common and widespread health risk associated with drinking-water.

Infectious diseases are transmitted primarily through human and animal excreta, particularly faeces. If there are active cases or carriers in the community, then faecal contamination of water sources will result in the causative organisms being present in the water. The use of such water for drinking or for preparing food, the contact during washing or bathing, and even inhalation of water vapour or aerosols may then result in infection. (WHO 1993)

4.1 Routes of exposure
For the faeco-oral pathogens, drinking-water is only one vehicle of transmission. Contamination of food, hands, utensils, and clothing can also play a role, particularly when domestic hygiene is poor. Because of this multiplicity of transmission routes, improvements in the quality and availability of water, in excreta disposal, and in general hygiene education are all important factors in achieving reductions in the diarrhoea morbidity and mortality rates.

While many faeco-oral pathogens have been shown to cause waterborne epidemics, none of them causes epidemics exclusively by this means. Neither the identification of a specific pathogen in drinking-water nor the occurrence of a common-source epidemic can therefore be taken as proof of waterborne disease transmission. To obtain confirmatory evidence, an epidemiological investigation is required. Those infections for which there is epidemiological evidence of waterborne transmission are listed in Table 4.1. The significance of the water route varies considerably both with the disease and with local conditions.

4.2 Orally transmitted infections of high priority (WHO 1993)
The human pathogens that can be transmitted orally by drinking-water are listed in Table 4.1 together with a summary of their health significance and main properties. Most of these pathogens are distributed world-wide. However, outbreaks of cholera and infection by the guinea worm *D. medinensis* are regional. The elimination of all these agents from water intended for drinking has high priority.

4.3 Opportunistic and other water-associated pathogens (WHO 1993)
Other pathogens are accorded moderate priority in Table 4.1 or are not listed, either because they are of low pathogenicity, causing disease opportunistically in subjects with low or impaired immunity, or because, even though they cause serious diseases, the primary route of infection is by contact or inhalation, rather than by ingestion.

Table 4.1: waterborne pathogens and their significance in water supplies (WHO 1993)
### Table: Environmental Techniques in Rural Areas

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Health significance</th>
<th>Main route of exposure</th>
<th>Persistence in water supplies</th>
<th>Resistance to chlorine</th>
<th>Relative infective dose</th>
<th>Important animal reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacteria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campylobacter jejuni, C. coli</td>
<td>High</td>
<td>O</td>
<td>Moderate</td>
<td>Low</td>
<td>Moderate</td>
<td>Yes</td>
</tr>
<tr>
<td>Pathogenic Enterobacteria</td>
<td>High</td>
<td>O</td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Salmonella typhi</td>
<td>High</td>
<td>O</td>
<td>Moderate</td>
<td>Low</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Other salmonellae</td>
<td>High</td>
<td>O</td>
<td>Long</td>
<td>Low</td>
<td>High</td>
<td>Yes</td>
</tr>
<tr>
<td>Shigella spp.</td>
<td>High</td>
<td>O</td>
<td>Short</td>
<td>Low</td>
<td>Moderate</td>
<td>No</td>
</tr>
<tr>
<td>Vibrio cholerae</td>
<td>High</td>
<td>O</td>
<td>Short</td>
<td>Low</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Yersinia enterocolitica</td>
<td>Moderate</td>
<td>I</td>
<td>May multiply</td>
<td>Moderate</td>
<td>High</td>
<td>No</td>
</tr>
<tr>
<td>Legionella</td>
<td>Moderate</td>
<td>C:IN</td>
<td>May multiply</td>
<td>Moderate</td>
<td>High(?)</td>
<td>Yes</td>
</tr>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>Moderate</td>
<td>O,C</td>
<td>May multiply</td>
<td>Low</td>
<td>High(?)</td>
<td>No</td>
</tr>
<tr>
<td>Aeromonas spp.</td>
<td>Moderate</td>
<td>I,C</td>
<td>May multiply</td>
<td>High</td>
<td>?</td>
<td>No</td>
</tr>
<tr>
<td>Mycobacterium, atypical</td>
<td>Moderate</td>
<td>O</td>
<td>?</td>
<td>Low(?)</td>
<td>Moderate</td>
<td>No(?)</td>
</tr>
<tr>
<td><strong>Viruses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adenoviruses</td>
<td>High</td>
<td>O, I,C</td>
<td>?</td>
<td>Moderate</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Enteroviruses</td>
<td>High</td>
<td>O</td>
<td>Long</td>
<td>Moderate</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Hepatitis A</td>
<td>High</td>
<td>O</td>
<td>Long</td>
<td>Moderate</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Hepatitis E</td>
<td>High</td>
<td>O</td>
<td>?</td>
<td>?</td>
<td>Low</td>
<td>Probable</td>
</tr>
<tr>
<td>Norwalk virus</td>
<td>High</td>
<td>O</td>
<td>?</td>
<td>?</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Rotavirus</td>
<td>High</td>
<td>O</td>
<td>?</td>
<td>?</td>
<td>Moderate</td>
<td>No(?)</td>
</tr>
<tr>
<td><strong>Protozoa</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entamoeba histolytica</td>
<td>High</td>
<td>O</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Giardia intestinalis</td>
<td>High</td>
<td>O</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Cryptosporidium parvum</td>
<td>High</td>
<td>O</td>
<td>High</td>
<td>Low</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Acanthamoeba spp.</td>
<td>Moderate</td>
<td>C</td>
<td>May multiply</td>
<td>High</td>
<td>?</td>
<td>No</td>
</tr>
<tr>
<td>Naegleria fowleri</td>
<td>Moderate</td>
<td>C</td>
<td>May multiply</td>
<td>Moderate</td>
<td>Low</td>
<td>No</td>
</tr>
<tr>
<td>Balantidium coli</td>
<td>Moderate</td>
<td>O</td>
<td>May multiply</td>
<td>Moderate</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Helminths</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dracunculus medinensis</td>
<td>High</td>
<td>O</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
<td>Yes</td>
</tr>
<tr>
<td>Schistosoma spp.</td>
<td>Moderate</td>
<td>C</td>
<td>Short</td>
<td>Low</td>
<td>Low</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Note:*

- **O** = oral (ingestion); **I** = inhalation in aerosol; **C** = contact with skin; **IN** = ingestion in immunosuppressed patients.
- **?** = Not known or uncertain
- **a** Detection period for infective stage in water at 20°C: short = up to 1 week; moderate = 1 week to 1 month; long = over 1 month.
- **b** When the infective stage is freely suspended in water treated at conventional doses and contact times: resistance moderate, agent may not be completely destroyed; resistance low, agent completely destroyed.
- **c** Dose required to cause infection in 50% of healthy adult volunteers.
Opportunistic pathogens are naturally present in the environment and are not formally regarded as pathogens. They are able to cause disease in people with impaired local or general defence mechanisms, such as the elderly or the very young, patients with burns or extensive wounds, those undergoing immunosuppressive therapy, or those with acquired immunodeficiency syndrome (AIDS). Water used by such patients for drinking or bathing, if it contains large numbers of these organisms, can produce various infections of the skin and the mucous membranes of the eye, ear, nose, and throat. Examples of such agents are Pseudomonas aeruginosa and species of Flavobacterium, Klebsiella, Aeromonas, and certain “slow-growing” mycobacteria.

Certain serious illnesses result from inhalation of water in which the causative organisms have multiplied because of warm temperatures and the presence of nutrients. These include Legionnaires’ disease (Legionella spp.) and those caused by the amoebae Naegleria fowleri (primary amoebic meningoencephalitis) and Acanthamoeba spp. (amoebic meningitis, pulmonary infections).

Schistosomiasis (bilharziasis) is a major parasitic disease of tropical and sub-tropical regions, and is primarily spread by contact with water during bathing or washing. The larval stage (cercariae) released by infected aquatic snails penetrates the skin. If clean drinking-water is readily available, it will be used for washing. This will have the benefit of reducing the need to use contaminated surface water.

It is conceivable that unsafe drinking-water contaminated with soil or faeces could act as a carrier of other parasitic infections, and certain helminths. However, in most of these, the normal mode of transmission is ingestion of the eggs in food contaminated with faeces or faecally contaminated soil (in the case of Taenia solium, ingestion of the larval cysticercus stage in uncooked pork) rather than ingestion of contaminated drinking-water.

4.5 Nuisance organisms (WHO 1993)
There are a number of diverse organisms that have no public health significance but which are undesirable because they produce turbidity, taste and odour, support the growth of bacteria and fungi, or because they appear as visible animal life in water. As well as being aesthetically objectionable, they indicate that water treatment and the state of maintenance and repair of the system are defective. Examples include:

- seasonal blooms of cyanobacteria and other algae in reservoirs and in river waters, impeding coagulation and filtration and causing coloration and turbidity of water after filtration;
- in waters containing ferrous and manganous salts, oxidation by iron bacteria, causing rust-coloured deposits on the walls of tanks, pipes and channels, and carry-over of deposits in the water;
- microbial corrosion of iron and steel pipes (also stainless steel) by iron and sulfur bacteria
- production of objectionable tastes and odours, with a low threshold, e.g., geosmin and 2-methylisoborneol by actinomycetes and cyanobacteria;
- colonisation of unsuitable non-metallic fittings, pipes, jointing compounds and lining materials by microorganisms able to utilize leached organic compounds;
- microbial growth in distribution systems encouraged by the presence of biodegradable
and assimilable organic carbon in water (natural organic carbon, disinfection by-products), often produced by oxidative disinfectants (chlorine, ozone); this growth may include Aeromonas spp., which can produce false positive reactions in the coliform test; - infestation of water mains by animal life, feeding on microbial growth in the water or on biofilms, for example crustacea, *Asellus aquaticus*, snails, mussels, Nais worms, nematodes, and larvae of chironomids and mosquitos; in warm weather, slow sand filters can sometimes discharge chironomid larvae by draw-down into the filtered water.

Although the raw water itself does not usually contain large numbers of nuisance organisms, problems may develop during the water-treatment process. Nuisance organisms become concentrated on the surfaces and inside the bed of filters, especially activated carbon filters.

The only positively identified health hazard from animal life in drinking-water arises with the intermediate stage of the guinea worm, *Dracunculus medinensis*, which parasites the water flea, *Cyclops*.

### 4.6 Persistence in water (WHO 1993)

The persistence of a pathogen in water is a measure of how quickly it dies after leaving the body. After leaving the body of their host, pathogens and parasites gradually lose viability and the ability to infect. The rate of decay is usually exponential, and a pathogen will become undetectable after a certain period. Pathogens with low persistence must rapidly find a new host and are more likely to be spread by person-to-person contact or faulty personal or food hygiene than by drinking-water. Because faecal contamination is usually dispersed rapidly in surface waters, the most common waterborne pathogens and parasites are those that have high infectivity or possess high resistance to decay outside the body. Persistence in water and resistance to chlorination are summarized in Table 4.1.

Persistence is affected by several factors, of which sunlight and temperature are among the most important. Decay is usually accelerated by increasing temperature of water and may be mediated by the lethal effects of ultraviolet radiation in sunlight acting near the water surface. Viruses and the resting stages of parasites (cysts, oocysts, ova) are unable to multiply in water. Conversely, relatively high amounts of biodegradable organic carbon, together with warm temperatures and low residual concentrations of chlorine, can permit growth of Legionella, opportunistic pathogens (*Pseudomonas aeruginosa*), and nuisance organisms during water distribution.

### 4.7 disinfection methods (Heber 1985)

As described before, it is essential that drinking water must be free of pathogenic/nuisance organisms. Storage, sedimentation, coagulation, flocculation and filtration of water both in each stage and in combination reduce the contents of bacteria in water to a certain extent. None of these methods can guarantee the complete removal of germs. Disinfection is the last stage of treatment. Water with low turbidity may even be disinfected without any previous treatment for bacteria removal.

Groundwater abstracted from deep wells (sandy soils) is usually free of bacteria.
Surface water, spring water from karstic areas and water obtained from shallow wells and open dug wells generally need to be disinfected. Water disinfection processes are designed to destroy disease-producing organisms by means of disinfectants. The degree or efficiency of disinfection depends on the method employed and on the following factors influencing the process:

- kind and concentration of microorganisms in the water,
- other constituents of the water (e.g. organic substances as humic acids) which may impede disinfection or render it impossible,
- contact time provided (important for chemical disinfectants, since their effect is not instantaneous, a minimum time of contact is necessary),
- temperature of the water (higher temperatures speed up chemical reactions).

Water disinfection can be accomplished by several means:

- physical treatment: removal of bacteria through slow sand filtration, straining of macroorganisms by means of microscreening, application of heat (boiling), storage, etc.
- irradiation with UV-light,
- metal ions, such as silver (and copper),
- chemical treatment, use of oxidants (halogens and halogen compounds, e.g. chlorine, chloramines, iodine, bromine, ozone, potassium permanganate, hydrogen peroxide, etc.).

A good chemical disinfectant should have the following abilities:

- destroy all organisms present in the water within reasonable contact time, the range of water temperature encountered, and the fluctuation in composition, concentration and condition of the water to be treated;
- accomplish disinfection without rendering the water toxic or carcinogenic (THM!);
- permit simple and quick measurement of strength and concentration in the water;
- persist in residual concentration as a safeguard against regrowth;
- allow safe and simple handling, application and monitoring;
- ready and dependable availability at reasonable cost.

Just as important as the proper choice of the disinfectant, applying the foregoing criteria, is that of the type of device to be used to add the agent to the water in a safe and controllable manner.

It cannot be emphasized strongly enough that there are potential hazards for the human organism associated with prolonged ingestion of chemicals. Nevertheless, the application of chlorine and its compounds for the purpose of water disinfection is the best and most tested compromise when evaluated according to the aforementioned criteria. The other methods differ significantly from each other in terms of their effect, the technological level and particularly in their applicability.

4.7.1 Chlorination (Heber 1985)

Chlorination is the most widely used method for drinking water disinfection. It is effective and economical. Its use requires some knowledge about the complex processes that take place during chlorination. Those processes will be briefly summarized in the following paragraphs.
The Action of Chlorine and its Range of Application

Chlorination is known as the addition of chlorine gas or some other oxidizing chlorine compound (sodium or calcium hypochlorite, chlorinated lime) to the water to be treated. The actual agent is hypochlorous acid (HOCl) which forms when chlorine is added to water:

$$\text{Cl}_2 + \text{H}_2\text{O} \leftrightarrow \text{HOCl} + \text{HCl}^-$$

Hypochlorous acid also forms subsequent to dissociation, when chlorinated lime or hypochlorites are added:

$$\text{NaOCl} \leftrightarrow \text{Na}^+ + \text{OCl}^-$$
$$\text{Ca(OCl)}_2 \leftrightarrow \text{Ca}^{2+} + 2\text{OCl}^-$$

The following chemical equilibrium

$$\text{HOCl} \leftrightarrow \text{H}^+ + \text{OCl}^-$$

depends on pH and temperature. At pH levels between 3 and 6, hypochlorous acid dissociates poorly, Chlorination is most effective in that range of pH. At pH levels greater than 8, hypochlorite ions predominate or exist almost exclusively. Hence the disinfecting effect drops off rapidly as the level increases above 8 pH.

Simultaneously with the dissociation, hypochlorous acid partly breaks up, forming monatomic oxygen, which contributes to the oxidizing effect:

$$\text{HOCl} \rightarrow \text{HCl} + \text{O}$$

The fraction that becomes effective as an oxidizing agent when chlorine or some of its compounds is added to raw water is called “free available” or “active” chlorine.

Small amounts of chlorine, due to its ability to penetrate cells of microorganisms, are sufficient to destroy many different strains of bacteria. Similarly, many types of viruses and macro-organisms such as schistosoma larvae can be killed. A contact time of at least 30 minutes is required, at the end of which the residual chlorine concentration in the water must still be between 0.1 and 0.5 mg/l (= ppm). Amoebic cysts and spores with resistant cell membranes require higher doses and longer contact times.

Chlorine also reacts with many other oxidizable water constituents such as iron and manganese compounds, ammonia, and compounds thereof (forming -chloramines), as well as numerous types of organic substances. The presence of these substances reduces the germicidal effect considerably. Sufficient chlorine must be added to the water to make sure that there is a residual concentration to prevent recontamination/ regrowth.

It is advisable to remove or reduce prior to chlorination, those substances by means of sedimentation and/or filtration which would impede disinfection. Through such pre-treatment helminth eggs (parasitic worms) can be removed, which are insensitive to chlorination.

In recent times it was found that through chlorination, certain undesirable side effects may occur. Particularly in industrialized areas, synthetic organic compounds may enter the hydrologic cycle in high concentrations. The presence of chlorine enhances the danger of the formation of carcinogenic compounds (e.g., chloroform and other trihalomethanes THM).
Chloramines
Especially in the USA chloramines are used to germinate surface waters with strong contents of organic substances. During the dosage of Chlorine, also ammoniac (NH$_3$) is added to the water, chloramines are formed.

\[
\text{NH}_3 + 3\text{Cl}_2 \rightleftharpoons \text{NCl}_3 + 3\text{H}^+ + 3\text{Cl}^- 
\]

Chloramines reduce germs, but they affect not a chlorination of organic constituents of the water. So, the formation of chlorphenol (bad taste) can be prevented.

In Germany the chloramin-method is not allowed, because chloramines seem to be a risk for human health.

Chemicals
Chlorine gas and chlorine dioxide are widely used in water treatment on account of their high efficiency and ease of application. Handling and transport, however, are considered too demanding and hazardous for the purposes described in this manual (explosive, toxic, instable).

Several chlorine compounds which have various active chlorine contents (table 4.2) are more easily applicable. In some form or another they are available virtually anywhere.

<table>
<thead>
<tr>
<th>Table 4.2: strength of various chlorine preparations (Heber 1985)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% active Chlorine</td>
</tr>
<tr>
<td>Sodium Hypochlorite</td>
</tr>
<tr>
<td>household Bleach</td>
</tr>
<tr>
<td>Javelle Water</td>
</tr>
<tr>
<td>chlorinated Lime</td>
</tr>
<tr>
<td>HTM</td>
</tr>
</tbody>
</table>

Sodium hypochlorite (NaOCl), commonly known as bleach or Javelle water:
This is generally available in dissolved form. Its commercial strength in terms of active chlorine is between 1 and 15%. It is stored in dark glass or plastic bottles. The solution loses some of its strength during storage. Prior to use, the active chlorine content should be tested. Sunlight and high temperatures accelerate the deterioration of the solution. The containers therefore should be stored in cool darkened areas. The stability of the solution decreases with increasing contents of available chlorine. Even though hypochlorite solutions are less hazardous than chlorine gas, every precaution should be taken to avoid skin contact.

The solution contains 10% NaOH for chemical stabilisation. In this case a dosage also increases the pH-level of the drinking water. It must be controlled, that the pH-level is not higher than 8 pH (see above).

Chlorinated Lime or Bleaching Powder (CaO $\cdot$ 3 CaOCl$_2$ $\cdot$ 3 H$_2$O):
In general, the powder is readily available and inexpensive. It is stored in corrosion resistant cans. When fresh, it contains 35% active chlorine. Exposed to air, it quickly loses its...
effectiveness. It is usually applied in solution form which is prepared by adding the powder to a small amount of water to form a soft cream. Stirring prevents lumping when more water is added. When the desired volume of the solution has been prepared, it is allowed to settle before decanting. Solutions should have concentrations between 5 and 1% of free chlorine, the latter being the most stable solution. Some 10% of the chlorine remains in the settled sludge. The same precautions for the NaOCl solution pertain also to the storage of dissolved chlorinated lime.

High Test Hypochlorite (HTH) is a stabilized version of calcium hypochlorite (Ca(OCl)₂) containing between 60% and 70% available chlorine. Under normal storage conditions, commercial preparations will maintain their initial strength with little loss. Even though HTH is expensive, it may be economical, thanks to its properties. It is available in tablet or granular form (commercial names: Stabothlor, Caporit or Para-Caporit). These chemicals must be handled with great caution. They are caustic, corrosive and sensitive to light. They should be stored in tightly closed containers and in darkened spaces, accessible only to authorized personnel. When handling the material, contacts with skin, eyes and other body tissues must be avoided. Chlorine corrodes metal and to a less extent, wood and some synthetic materials. Metal parts which come in contact with the chemicals should be resistant.

Determination of Chlorine Dose
Chlorine of any type must be added to water in closely controlled concentrations which depend on the characteristics of the water. As the use of dry chemicals doesn’t always permit sufficient accuracy of dosing, solutions are preferred. Chlorine is usually added to the water for disinfection at the end of the treatment process. This allows the most effective treatment at the lowest level of chlorine application.

In the field, the chlorine demand of water of a given quality can be determined as follows: One litre samples of the water are taken. Chlorine solution of a known concentration is added and mixed with the water. After 30 minutes of contact time, the residual chlorine content is measured. The difference to the amount added then yields the chlorine consumption.

\[
\text{Chlorine demand} = \text{chlorine consumption} + \text{desired residual}
\]

Usually 1% chlorine solutions are applied. The chlorine flow is set such that a chlorine residual level of between 0.1 and 0.3 mg/l is obtained. Higher levels are recommended if rapid recontamination is likely.

Calculation of the required amount of chlorine:
Given the amount or flow of water to be chlorinated, the chlorine demand and the strength of the chlorine solution to be used, the necessary amount of solution can be calculated as follows:

\[
\text{chlorine demand} \times \text{amount of water to be treated} = \text{required amount of active chlorine per hour (g/h)}
\]
required amount of chlorine solution per hour (l/h)  
= required active chlorine per hour (g/h) divided by active chlorine per litre of solution (g/l)

It must be noted that the manufacturers usually express the available chlorine content in terms of percent weight (g/100 g). In the field, however, it is often expressed in terms of percent volume (g/100 ml of solution). Since the density of chlorine solutions is higher than that of water, the percent weight measure for a given solution is lower than the percent volume measure.

**Example:**

strong contaminated surface water
amount of water: 735 inhabitants 30l/d ==> 1 m³ /h
using HTH (1%) for desinfection

Chlorine demand = 0.9 + 0.3= 1.2 mg/l  (maximum possible in Germany)

required amount of active chlorine =1.2*1.0=1.2 g/h

required amount of chlorine solution: = 1.2 / 15 = 0.08 l/h

**Practical Application**

Aside from using commercially available chlorine feeder instruments, it is quite possible to manufacture a simple dosing apparatus for a constant feed rate. The most difficult part is the setting of the proper rate of delivery. Reliable operation and regular maintenance must be provided. Sufficient contact time for the chlorine must be ensured.

Chlorination should never be performed prior to slow sand filtration (residual chlorine destroys biological agents). Sedimentation and filtration preceding chlorination enhance the disinfection effect. The lower the turbidity, the smaller the amount of chlorine necessary for effective disinfection.

The chlorine solution can either be added to a batch of water (non-continuous or diffusion chlorination) or alternatively, it can be fed continuously to a constant flow of water.

**Batch Chlorination**

Where tanks are used for storage of drinking water, the required amount of chlorine can be added to the tank periodically. It is advantageous to alternate between two tanks (see Fig. 4.1). While one tank is in use, the other one is refilled and treated with chlorine. The water can be used after a minimum of 30 minutes contact time. This procedure allows uninterrupted supply.

If the water quality of a given source varies, the chlorine demand must be re-evaluated from time to time. Before a tank is used the first time for storing water, it must be cleaned carefully and disinfected (application of chlorinated water with between 50 and 100 ppm active chlorine). Once the water has been disinfected, recontamination must be carefully prevented. Tanks should be covered with controlled air in- and outlets.
Chlorine Tablets
In certain situations, e.g., while travelling, chlorine tablets can be used. They are available from various companies. They are used for periodic chlorination of small batches of water.

Diffusion Chlorination
Open wells are often bacteriologically contaminated because of non hygienic methods for lifting the water, or due to careless use of the surroundings of the well. CPHERI and NEERI (India) respectively, experimented with simple devices that would allow providing water in a well or in a tank with a sufficient amount of chlorine over a certain period of time (see Fig. 4.2 and 4.3).

In Figure 4.3, three types are mapped:
Type I is a clay jar (12 to 15 l volume), filled nearly half-way with a mix of 1.5 kg bleach powder and 3 kg coarse sand (grain size 1.4 to 1.6 mm). It has two holes above the sand surface. The jar is covered with a plastic foil. The jar is suspended approximately 1 m below the water surface in the well. The chlorine can thus diffuse through the two holes into the well water. Range of application: Wells of 9 to 13 m³ volume of water, daily removal some 10% (0.9 to 1.3 m³ ); Effectiveness: 1 week at a residual chlorine content of between 0.2 and 0.8 mg/l.
Type II also consists of a clay jar (volume 7 to 10 l). It has 6 to 8 holes in the bottom. These are, covered with stones on top of which a layer of gravel is placed. On top of that is put a mix of 1.5 kg bleaching powder and 3 kg of coarse sand. Stones are filled to the rim of the jar, which is then lowered into the water. Range of application: same as before. Effectiveness: Two weeks at a residual chlorine content of between 0.2 and 1.0 mg/l. For larger wells and higher rates of water use, two jars should be used which are refilled interchangeably.

Type III: For small household wells, a double jar is recommended which releases less chlorine per time unit. The inner jar contains, a mix of 1 kg bleaching powder and 2 kg coarse sand. The diffusion openings are provided as shown in Fig. 4.3. Range of applications: Wells
environmental techniques in rural areas

with 4.5 m volume of water and daily removal of between 360 to 450 l.
Effectiveness: Two to three weeks at a residual chlorine content of between 0.15 and 0.5 mg/l.
As these devices are not fit for large variations in water use, insufficient chlorination may occur at higher rates of water use.

Continuous Chlorination
Simple chlorine dosing instruments can be installed in piped water supply systems. Chlorine is fed to the water in proportion to the flow rate. Fig. 4.4 shows a water supply scheme including continuous chlorination. A pipeline transmits the water from the source to the reservoir, passing through some sort of pre-treatment (e.g., coagulation/flocculation and sedimentation). Before entering the reservoir, the water is passed through a mixing chamber where a dosing apparatus introduces droplets of chlorine into the water.

Figure 4.4: Diagram of a water supply scheme with continuous chlorination by a dripping dosing device (Heber 1985)

In the following paragraphs, some examples of drip dosers are discussed:
– Glass or plastic bottles. Through a tap near the bottom, the chlorine is released into the water. The tap also serves as a coarse control of the delivery rate (Fig. 4.5 a,b). A constant head H provides fine control of the delivery rate. This head H is measured either between the faucet and the fine bore air inlet tube (b) or between the two tubes which pass through the rubber cap (c, d).
– 200 l metal drum. The drum (Fig. 4.6), painted inside with bituminous paint to protect the metal from corrosion, holds the hypochlorite solution. A floating bowl (plastic, glass or ceramics – two versions are shown in Fig. 4.6) which is anchored and stabilized in the tank, controls the delivery rate. The solution enters the bowl via a small bore glass inlet tube. From there, it leaves the bowl through a wide bore delivery tube. The flow rate is controlled by the head difference H (between the upper end of the glass tube and the level of the liquid in the tank) and the diameter of the fine bore inlet tube. The flow rate is given by the following expression (based on Bernoulli’s equation):

\[ Q = \sqrt{2gH \cdot Cd^2 / 4} \]

where Q = flow rate, g = gravitational acceleration, H = head difference, C = empirical discharge coefficient (approx. 0.6), d = diameter of small bore inlet tube.
From the above expression, it can be seen that the delivery rate is proportional to the second power of the tube diameter and to the square root of the head difference. That is to say, the smaller $H$ or $d$, the smaller is the flow rate. Hence, the flow rate is independent of the level of the solution in the tank: As the level drops, so does the floating bowl. To stop the delivery completely, the bowl must be lifted at least a distance $H$, so as to stop the gravitational driving force of the doser. The outlet (wide bore tube) must not be closed or else the bowl will gradually fill up and sink to the bottom, possibly suffering damage.

-Similar instruments of different sizes are shown in Fig. 4.7 The solution enters a glass or copper pipe through an inlet hole somewhat below the surface. The pipe is connected to a rubber hose which runs to the outlet. A float again provides a constant head difference between the liquid level and the inlet hold. The delivery rate is controlled by the size of the hole and its distance below the surface.
environmental techniques in rural areas

Figure 4.6: Drip dosing devices with floating bowl. (Heber 1985)

Figure 4.7: Drip dosing device made from a 20l plate canister. (Heber 1985)
4.7.2 Iodine (Heber 1985)

Iodine is an excellent disinfectant, effective against bacteria, amoeba cysts, cercerea and some viruses. It is added to the water mostly in the form of an aqueous solution. WHO recommends the application of 2 droplets per litre of water of a 2% iodine tincture. Iodine preparations are also available in tablet form. In comparison to chlorination, the use of iodine has the following advantages:

- effectiveness over a wider range of pH values (up to pH 10), except at very low temperatures;
- ammonia and organic nitrogenous compounds have little effect on germicidal efficiency because they do not form substitution compounds with iodine;
- action depends less on contact time and temperature;
- effectiveness against more pathogenic organisms within short times;
- use and handling is simpler.

Since operating costs are too high, the use of iodine is not expected to ever become an important disinfectant. The applicability is limited due to following disadvantages:

- higher concentrations than chlorine (on a ppm basis) are necessary for effective action;
- muddy or turbid water substantially affect germicidal action;
- iodine is about 20 times as expensive as chlorine per unit of germicidal effectiveness;
- taste and slight colour produced by the iodine affect palatability and aesthetic quality;
- physiological effect of prolonged use of iodine (especially in children) is suspected.

Allergies were ascertained.

In view of these economic and health implications, the use of iodine for disinfection is recommended only for occasional application (e.g., in case of catastrophe or while travelling). Aside from that, iodine is a highly effective and technically widely applicable disinfectant.

4.7.4 Ozonation (Heber 1985)

Ozone (O$_3$) is one of the most effective disinfectants. As a powerful oxidant, it reduces the contents of iron, manganese, and lead, and eliminates most of the objectionable taste and odour present in water. Its effectiveness does not depend on the pH value, temperature or ammonia content of the water. Since ozone is relatively unstable, it is generated almost invariably at the point of use. Ozone is obtained by passing a current of dried and filtered air (or oxygen) through between two electrodes (plates or tubes) subjected to an alternating current potential difference. A portion of the oxygen is then converted into ozone.

This principle of ozone production has been used in Europe for a long time, since it has the advantage of being applicable under a wide range of conditions. It leaves no chemical residuals behind in the treated water. On the other hand, no lasting protection against recontamination is provided either. Capital costs for the instrumentation of ozone production and feeding, as well as operating costs due to the electrical energy requirements, are very high. Moreover, operation of ozonizers requires continuous and skilled monitoring. The operational requirements therefore exceed the resources available in rural areas of most developing countries.
4.7.5 Potassium Permanganate (Heber 1985)

Potassium permanganate ($\text{KMnO}_4$), a powerful oxidant, is rarely applied in water treatment for the purpose of disinfection. It is sufficiently effective against cholera bacteria, but not against other pathogenic germs. A dose of 1 to 5 ppm $\text{KMnO}_4$ is recommended for application. It must be noted, that it creates a purple-brown precipitate which coats the walls of the tank. It cannot be removed easily. In recent years, potassium permanganate has gained steadily in the application in pretreatment since it has proved effective at:

- removing objectionable odour and taste by means of oxidation of organic material, hydrogen sulfide;
- preventing algal growth;
- removing iron and manganese compounds by means of oxidation and subsequent separation by filtration.

4.7.6 Disinfection by Silver (Heber 1985)

Preparations containing silver may be used to reduce the germ count of water. The products are commercially available, either as a liquid or a powder. They are readily soluble in water and can be dosed easily. The effectiveness of silver can be explained by the oligodynamic properties of silver ions (silver nitrate or salt compounds). Even minute concentrations (0.03 to 0.04 ppm) are notably effective. The silver ions curb the growth of germs. After contact of between 30 minutes and 6 hours, depending on the level of bacteriological contamination, water of a very low germ content may be obtained. Odor and taste of the water are not affected by the application of silver. Disinfection by silver is a simple and very effective method. Its major advantage is that it provides already treated water with long-lasting protection against recontamination by germs.

The effect of silver and other metals has been known to many peoples for a long time. The tradition of storing drinking water in silver vessels is still maintained in wealthier Hindu families. Although there is a tendency at present to exchange the metallic containers for plastic ones, even simple Indian villagers can still be seen fetching water from the well in brass or copper vessels. The metallic vessels are believed to have antiseptic qualities. Silver preparations are also used in ceramic filters.

Major disadvantages of silver for the purpose of disinfection are the costs of treatment (about 200 times higher than gaseous chlorine), relatively long contact periods are required, organic substances and iron, sulphur, etc., inhibit action, thus limiting the applicability of the technique. If combined with chlorine, silver preparations are more widely applicable (direct disinfection and protection against recontamination).

4.7.7 Boiling (Heber 1985)

Boiling water is a very effective though energy-consuming method to destroy pathogenic germs: bacteria, viruses, spores, cercerea and amoeba cysts, worm eggs, etc.

The presence of turbidity or other impurities has little effect on germicidal effectiveness. If boiling is the only type of treatment available, it is recommended to let the water settle before, and decant it or filter it through a fine-meshed cloth so as to remove coarse impurities and suspended particles. The water, is then brought to a strong boil which is maintained for at least five, preferably twenty minutes (one minute of extra boiling time
should be added for every 1000 metres height). For storing, it must not be transferred to a different vessel, but left in the former one and covered, so as to protect it from recontamination.

Boiling, together with the associated release of gases, especially $\text{CO}_2$, alters the taste of water. But through stirring while boiling and by letting the water sit in the partially filled vessel for a few hours afterward, the water picks up air and loses its bland taste. To improve the taste of the water, flavouring plant materials may be added during boiling. If done properly, boiling is a very effective and simple disinfection method. Since it requires a significant amount of energy, this method is only recommended in exceptional cases.

4.7.8 Ultra-violet Radiation (Heber 1985)

The germicidal effect of UV rays had been known long before the first experiments were carried out to harness it for water disinfection. In principle, the effect of sunlight on surface water is imitated in a more intense and controllable way. The most commonly used source of UV-radiation is a low pressure quartz mercury vapour lamp which emits invisible light at a wavelength in the range between 200 and 300 nm with part of the energy in the spectral region of 2537 Å.

The germicidal effect depends on the electric power of the lamp and on the time of exposure of the water to the radiation. It decreases with increasing distance between water and lamp. Also, many substances present even in pretreated water (e.g., small amounts of dissolved iron) absorb UV light. Other constituents (turbidity, suspended matter) inhibit or prevent the transmission of radiation. A disinfection unit is built such that the water is made to flow through a pipe in a thin film around the lamp, which is located at the pipe’s centre, emitting radiation. The flow rate is adjusted as required. The water must be pre-filtered.

Disinfection by UV radiation is a “clean” process, since no chemical additives are used. Residual matter doesn’t occur, and tastes and odours are neither produced in the water nor altered. Due to some severe disadvantages of this type of treatment, it is not expected to find any consideration for application in the areas targeted by this manual:

- commercially available devices are relatively expensive,
- there is a dependence on steady power supply,
- the lamp’s powers of penetration are limited; thin water films are necessary,
- turbidity and impurities reduce the effectiveness notably,
- the lamps gradually lose their radiation power, accelerated by a coating of dirt. The lamp’s average life is 1000 to 5000 hours,
- disinfection occurs rather quickly and effectively (up to 99.9%), though no protection for recontamination is provided.

4.7.9 Solar water disinfection

The lack of water treatment plants or the poor performance of existing ones often requires disinfection at household level to prevent the spread of waterborne diseases. Water chlorination is unfortunately not always possible (lack of chemicals, unpleasant taste etc.) Solar water disinfection (SODIS) is a simple water treatment process, based on locally available resources (sunlight and plastic bottles).
Most human pathogens transmitted through contaminated water are vulnerable to heat and UV-A radiation. It basically uses two components of sunlight: ultraviolet light to directly irradiate microorganisms and infrared light to heat the water.

The raw water is filled in black coloured plastic bottles (see figure 4.8) and exposed to sunlight. The turbidity has to be lower than 30 NTU, so that sunlight can pass through the entire water layer. To reduce E.coli by 99.9% requires about five hours exposure at lower temperatures, but only about one hour if the threshold water temperature of 50°C is reached. No regrowth or revival of E.coli has been found even after water samples treated with SODIS and stored over two weeks. Also the concentration of vibrio cholerae is reduced significant.

With this method a possible arsenic contamination of the water can also be reduced (50-90%). Therefore the adsorption of arsenic ions to ferric oxide flocks (FE III) is used. To support photo-oxidation of iron, a few µl/l citron-juice are mixed with the water. After a sunlight expose of 4 hours the flocks deposit. The results can be seen in table 4.3.

![Figure 4.8: concept of SOLARIS (Wegelin)](image1)

![Figure 4.9: concept of SORAS (Wegelin)](image2)

### Table 4.3: arsenic reduction with SORAS (Wegelin)

<table>
<thead>
<tr>
<th>As(III)</th>
<th>As(II)</th>
<th>As(V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>max.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>min.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DOC</th>
<th>Mango</th>
<th>Ananas</th>
<th>Citrat</th>
<th>Zitron</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mg/l</td>
<td>1.5 g/l</td>
<td>500 µl/l</td>
<td>50 µl/l</td>
<td>200 µl/l</td>
</tr>
</tbody>
</table>

### Literatur


Wegelin, M. "Zurück zum Haushalt-auch in der Wasseraufbereitung." *EAWAG news* 48: