FEBRUARY 2005

HOUSEHOLD DRINKING WATER SYSTEMS AND THEIR IMPACT ON PEOPLE WITH WEAKENED IMMUNITY

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List of Tables

List of Figures

1. Introduction

1.1 Drinking water and household treatment

It is now universally acknowledged by water and medical experts that the greatest risk associated with the ingestion of water is the microbial risk due to water contamination by human and/or animal feces (WHO, 2004a). In 2000, the lack of access to safe water remained a problem for over a billion people worldwide, and inadequate sanitation services affected at least 2.4 billion people (WHO and UNICEF, 2000; Mintz et al., 2001).

Poor water quality, sanitation and hygiene account for some 1.7 million deaths a year worldwide, mainly through infectious diarrhoea (Ashbolt, 2004). Diarrheal diseases, which are frequently transmitted by contaminated water is a leading cause of morbidity and mortality among children under 5 years of age in developing countries. Estimates of annual total mortality from diarrheal diseases ranges from 2.5 to 3.5 million and more than 80% are among children under 5 years of age (Kosek et al., 2003). Global morbidity is estimated at 4 billion episodes per year, of which 30% (1.2 billion episodes/year) are related to contaminated water (Ford, 1999).

There are several reasons for the persistence of these problems (Macy and Quick 2002)

- Population growth and shifts from rural to urban areas have stressed existing water and sanitary infrastructure and exceeded the capacity of many countries to keep up with demand for services.
- In many rural areas, water and sanitary infrastructures are inadequate or non-existent because of dispersed populations and poor transportation infrastructure.
- Large population dislocations caused by armed conflict and natural disasters have created enormous logistical problems in providing water and sanitation services.
- Inadequate maintenance of water and sanitation infrastructure has, in some instances, led to failures of technology.

Much of the global population now consumes untreated, non piped drinking water, usually consisting of small volumes (<40L/d) collected and stored in the home by users. Typically, people collect water from any available source and store it in a vessel in the home for domestic and potable use, often without treatment and protection from further contamination. In many cases, such collected household water is often heavily contaminated with faecal microbes and poses risks of exposure to waterborne pathogens and thus to infectious diseases (Sobsey et al., 2003).

On the basis of the epidemiological studies of Esrey et al. (1985;1991), it was previously concluded that the median reduction in diarrhoeal disease from improvements in water quality was low (15-17%) compared with improvements in sanitation, water quantity, or combined water and sanitation, hygiene. The methods and validity of these studies, designed to assess the health impact of such interventions, were recently seriously questioned by Clasen and Cairncross (2004). While improvements in both water quality and sanitation will have the greatest impact in reducing diarrhoeal and other infectious diseases, it is now clear that improvement in water quality alone has a beneficial effect on health. Sobsey, (2002) and Sobsey et al., (2003) mention that "there is now compelling evidence to document that improving microbiological water quality can appreciably reduce waterborne infectious disease risks, even in the absence of improved or adequate sanitation (excreta disposal). Simple, acceptable, low-cost interventions at the household and community level are capable of dramatically improving the microbial quality of drinking water and reduce the attendant risks of diarrhoeal disease and death". These observations were recently confirmed by Fewtrell and Colford, (2004). In the conclusion of their systematic review and meta-analysis on water, sanitation and hygiene in developing countries, they mention that "water quality interventions, in term of household (point-of-use) treatment seem to reduce diarrhoeal illness levels. This review suggests that water quality intervention may be more important than previously thought, as previous studies have suggested that such interventions are only effective where good sanitary conditions already exist."

A large variety of treatment methods exist to make water suitable for consumption at household level. They include chemical or physical ways to remove pathogens, chemicals and/or physical particles. All methods have their respective advantages, disadvantages and limitations in achieving water disinfection as well as on implementation in different contexts.

1.2 Drinking water and AIDS

The immune system provides an efficient line of defence against infection. During the life of an individual, the immune system develops, matures and eventually wanes. At birth, the immune system offers little protection against infection, but it develops rapidly in response to stimulants in the environment, infectious disease organisms and from contact with other people. After a few years, the body has acquired an elaborate system of immunity that can rapidly neutralize an infectious agent as well as set up as barrier against future infection by the same agent. Several factors, apart from age, can affect the effectiveness of the immune system: the individual level of nutrition, fitness, stress, use of drugs, infections, etc. Some infections can have a devastating impact on the immune system such as the human immunodeficiency virus (HIV) that severely impairs the host’s cellular immune system.

Infections that do not occur in healthy persons due to the low pathogenicity or concentration of the microorganisms are more likely to occur in immunocompromised patients. The infectious dose of an opportunistic pathogen is lower for them, specially if they are receiving antibiotic medication (which is the case in many immunocompromised patients for prophylactic or therapeutic reasons) (Glasmacher et al., 2003). Immunocompromised individuals also have a greater risk of mortality from normally benign infections (WHO, 2003). According to Engelhart et al., (2001), four groups of immunocompromised patients can be defined as well as respective protection measures (Table 1). This table also presents some different possible causes of immunosuppression, including AIDS.

Levels of immunosuppression	Causes of immunosuppression	Proposed protection measures
Level 1: mild immunosuppression	• Acute or chronic leukaemia, malignant lymphoma, childhood histicystosis X under maintenance therapy without neutropenia • Solid tumours (within 6 months of chemotherapy) • Long-term corticosteroid therapy with < 20 mg/day prednisone or equivalent • Autologous stem cell transplantation • AIDS with CD4+ cells 200-500/μl	• Avoid any circumstances with elevated infection risks (like drinking water from uncontrolled sources)
Level 2: moderate immunosuppression	• Acute or chronic leukaemia, malignant lymphoma, childhood histicystosis X, solid tumours under intensive treatment (expected duration of neutropenia <500/μl for <10 days) • Long-term corticosteroid therapy with > 20 mg/day prednisone or equivalent • Solid organ transplantation after intensive treatment phase • AIDS with CD4+ cells 50-200/μl	• Drinking water should have an additional antimicrobial barrier to tap water • Bathroom installations should be controlled for bacterial reservoirs
Level 3: severe immunosuppression	• Acute or chronic leukaemia, malignant lymphoma, childhood histicystosis X, solid tumours under intensive treatment (expected duration of neutropenia <500/μl for >10 days) • Solid organ transplantation under intensive treatment phase (induction or rejection therapy) • Allogeneic stem cell transplantation (6-12 months after engraftment) • AIDS with CD4+ cells<50/μl	• Any water for human use should have a very low bacterial count (use water filters/controlled carbonated water) • Strict control of bath installation and water for showering
Level 4: extreme immunosuppression	• Allogeneic stem cell transplantation (until engraftment)	• Only sterile fluids for drinking, mouth care and washing allowed.

Table 1: Levels of immunosuppression proposed for immunocompromised patients and proposed protection measures to prevent drinking-water-borne infections among them (Adapted from Engelhart et al., 2001; Torres and O'Brien, 2005, personal communication).

According to Torres and O’Brien, (2005) (personal communication) people with AIDS and CD4+ cells between 200 and 500 (level 1;Table 1) can be considered as belonging to the clinical stage II and III of the WHO classification (WHO, 2004b; see Annex 1). People with AIDS and CD4+ cells between 50 and 200 (level 2;Table 1) and lower than 50 (level 3; Table 1) can be considered as belonging to the clinical stage IV of this classification. Section 4 of this work presents the health impact of some pathogenic microorganisms on immunocompetent and on immunocompromised people. It must be stated that in this section 4, immunocompromised people of concern can be considered as belonging to the second and the third level of immunosuppression described in Table 1, and as a consequence belonging to the clinical stage IV of the WHO classification.

The total number of people living with the human immunodefiency virus (HIV) is still in progress and rose in 2004 to reach its highest level ever: an estimated 39.4 (+/- 3.5) million people are living with the virus. In 2004, 4.9 million people aquired HIV and the global AIDS epidemic killed 3.1 million people during the same period (UNAIDS, 2004). Public health systems in many high prevalence countries can no longer cope with the increased demand for health services. This reality, together with cultural preferences, contributes to the majority of AIDS patients being cared for within their local communities. Water is only one of the infectious risks to ambulatory (not present in hospital) HIV patients. Other important risk factors are food, air and household contacts.

Specific risk situation for infections from drinking water are drinking itself, accidental swallowing during daily dental care, mucosal lesions during tooth care, aspiration of aerosols during showers and the formation of reservoirs in bathroom utilities (toothbrush, showerheads). These risks are modified by the bacterial contamination of the drinking water on one side and more or less appropriate handling of bathroom installations and washing utilities on the other side.

The main objective of the water supply sector has always been to improve people's health by providing access to safe water supply and sanitation. The primary concept of controlling the risk of infection from drinking water for human use was founded on epidemiological studies and risk assessments based on highly infectious microbiological agents and a "normal" population. The growing number of immunosuppressed people, in the developed world, but also mainly in the developing countries (UNAIDS, 2004) makes it necessary to develop new concepts to protect these patients from infectious agents in drinking water (Glasmacher et al., 2003). With HIV/AIDS, this becomes even more urgent because diarrhoea and skin diseases are among the most common opportunistic infections.

Persistent and/or chronic diarrhoea is a major cause of morbidity and mortality in AIDS patients and, consequently, an important issue of public health, particularly in sub-Saharan Africa where more than 25 million people are living with HIV (Kelly et al., 2003; UNAIDS, 2004). Immunocompromised patients are as vulnerable for diarrhoeal disease as groups with an insufficient immunity system like the very young, the old and the sick. The difference is the vulnerability for HIV/AIDS related opportunistic diseases. In order for HIV infected people to remain healthy as long as possible and for people with AIDS to reduce their chances of getting diarrhoea and skin diseases, adequate water supply and sanitary facilities are of the utmost importance.

Good access to safe water and sanitation is indispensable for people living with HIV/AIDS and for the provision of home-based care to AIDS patients. Water is needed for bathing patients and washing soiled clothing and linen. Safe drinking water is necessary for taking medicines. Water is also needed to keep the house environment and latrine clean in order to reduce the risk of opportunistic infections. Water and sanitation provision increases the sense of dignity of both patients and caregivers.

Access to safe drinking water also takes another significance in countries with high HIV prevalence. Breastfeeding is a basic and extremely successful component in child survival. Although the mechanisms of transmission are not well defined, it is now known that HIV can be transmitted from mother to child via breast-feeding. If a mother is HIV positive, there is a one in three risk that she may transmit the virus to her baby through breastmilk, even if the child was born HIV negative. The 'obvious' solution would be to not breastfeed the child, but this has proven to be very difficult because of social, cultural and economic reasons, including the cost and availability of powdered milk, stigma and tradition. Moreover, the chance of a child dying from diarrhoea rises when formula feeds are not prepared with clean water, or when cleaning and water handling practices are not hygienic. Therefore, a mother with HIV infection must weigh the pluses and minuses of breast-feeding against alternative infant-feeding options.

2. Objective of the project

The objective of this project is to evaluate pre-selected household water treatment systems, their respective strengths and weaknesses and their potential impact on people with weakened immunity and on use in MSF project. As a result, this document is not considered as an exhaustive listing which presents all the existing household systems and their principles, but more as a critical evaluation of some pre-selected existing systems. Of the systems now available, the evaluated systems appear to be the most widespread and promising for further development, characterization, implementation and dissemination. These pre-selected water treatments include

- boiling,
- pasteurization (fuel, firewood, solar radiation or cooking),
- solar disinfection,
- UV lamps disinfection,
- chemical disinfection (chlorination, preceded or not by coagulation/floculation and/or filtration),
- ceramic filters in particular, other types of filters in general.

Each system is briefly described at section 3 and most of the relevant information is presented in tables showing what is removed and what is not removed as well as the respective advantages and disadvantages of each system. Results of existing epidemiological studies, if available, are also presented.

Since most of the household treatment systems studied are not perfect regarding the complete removal of pathogens and/or contaminants, the potential health effect of the identified not removed pathogens and/or contaminants on immunocompetent and also on immunocompromised people are presented at section 4. Two tables (25 and 26) summarizing the information presented in section 3 and 4 are located at the end of section 4. Conclusions are presented at section 5, under the form of a briefing paper with recommendations.

3. Evaluation of some pre-selected households water treatment systems

3.1 Heating water

3.1.1 Heating water by boiling.

Boiling water is probably the oldest and simplest method to remove pathogens from water. Some authorities recommend the water to be brought to a rolling boil for 1 to 5 minutes or even 10 minutes (CDC, 2001). Others recommend bringing the water to a rolling boil as an indication that a high enough temperature has been achieved (WHO, 2004a). WHO (2004a) considers that bringing water to a rolling boil is the most effective way to kill disease-causing pathogens, even at high altitudes and even for turbid waters. These requirements are likely to be well in excess of heating conditions needed to dramatically reduce most waterborne pathogens, but observing a rolling boil assures that sufficiently high temperatures have been reached to achieve pathogen destruction (Sobsey, 2002). Table 2 presents the effectiveness of boiling regarding the removal of pathogenic (micro)organisms and of some chemicals and components that can be present in drinking water. Table 3 presents the major advantages and disadvantages of heating water by boiling.

Table 2: Effectiveness of heating water by boiling regarding the removal of pathogenic (micro)organisms and of some chemicals and other components that can be present in drinking water

Adapted from Sobsey, 2002;Skinner and Shaw, 2004;WHO, 2004a		**Boiling**
(Micro)organisms	Viruses	4
	Bacteria	4
	Protozoan	4
	Helminth ova	4
Chemicals	Iron and manganese	-
	Arsenic	-
Other	Taste and odour	-
	Organic substances	-
	Turbidity	0

1-4 = increasing effectiveness; - = unknown effect; 0 = minimal if any effect

Table 3: Advantages and disadvantages of heating water by boiling

Adapted from Reiff et al., 1996; Burch and Thomas, 1998; Iijima et al., 2001; Sobsey, 2002; Colwell et al., 2003; Brick et al., 2004; Skinner and Shaw, 2004.	
	• Effective in destroying all classes of waterborne pathogens (viruses, bacteria, bacterial spores, fungi, protozoan, helminth ova), if correctly applied in terms of temperature and time. • Can be effectively applied to all waters, including those with high turbidity or dissolved constituents. • Rolling boil = indication easily identified (when temperature sensors are not available) of the efficiency of the treatment. • No particular equipment needed (with the exception of the energy source).

	• No need of high-skill labor and low level of training required.
	• Consumption of energy (fossil fuels/firewood): problems of availability, cost (50 to 150 US$ a year for 40 liters/day (requested volume for a family of 5)) and sustainability in a lot of regions. Risk of incomplete treatment with the objective of saving money. • No residual protection: risk for potential microbial recontamination (hands; utensils) during storage. Consumption must preferably occur within the same day. The use of lid is an asset* • People can be reluctant to boil. In this case, a strong promotional component could be required. • It takes time for the water to cool down: time between preparation and consumption can be long. • Risk of scalding (especially among children) • Boiling seems to affect the taste (but shaking the bottle will improve the taste)

*: storage aspect will be discussed in section 3.4

Epidemiological studies:

- Vanderslice and Briscoe, (1993) stated that boiling water was shown to eliminate the risk of diarrhea due to water source contamination for Filipino children
- Lehloesa and Muyima, (2000) studied a rural community in the Victoria district of South Africa using groundwater from boreholes. The brackish taste of the water has been the major complaint from the community, but the overall microbiological quality (heterotrophic bacteria, total coliforms, faecal coliforms and faecal streptococci) of the water was poor or unaceptable according to South African standards. Boiling the water for 5 minutes or household bleaching both succeeded in achieving the microbiological drinking water standards. Furthermore, boiling also slightly changed the salinity and total hardness by the precipitation of calcium carbonate.

Conclusions

Boiling (roiling boil during 1 to 5 minutes) is an extremely efficient and simple way to remove efficiently and completely all waterborne pathogens present in the water but problems exist regarding the

- availability, cost and sustainability in a lot of regions,
- absence of residual protection against recontamination,
- absence of impact on chemical and other components that can be present in drinking water.

3.1.2 Heating water to pasteurization temperatures

Although boiling is the preferred thermal treatment for contaminated water, heating to pasteurization temperatures (60-70°C) with fuel, firewood, solar radiation or solar cooking for periods of a few to tens of minutes will kill most waterborne pathogens. Heating at 55°C for several hours will dramatically reduce non-sporeforming bacterial pathogens as well as many viruses and parasites (including *Cryptosporidium parvum, Giardia lamblia, entamoeba histolytica* (Sobsey, 2002; Sobsey and Leland, 2001). For example, temperatures which cause approximately a 1-log decrease in viability within 1 min are:

55°C for protozoan cysts, 60°C for *E. coli*, enteric (related to the intestinal tract) bacteria, and rotavirus and 65°C for hepatitis A virus. Nevertheless, to ensure safe water pasteurization, the temperature-time relationships (see Figure 1) must be respected and a temperature of 70°C must be maintained for several minutes (10-15) to kill all the pathogens specially when immunodepressed populations are of concern. Compared to boiling, the risk of scalding during or after pasteurization is less and energy costs can be lower (if fuel or firewood are used), but when it is not possible to monitor the temperature, no indication of the treatment effectiveness can be obtained.

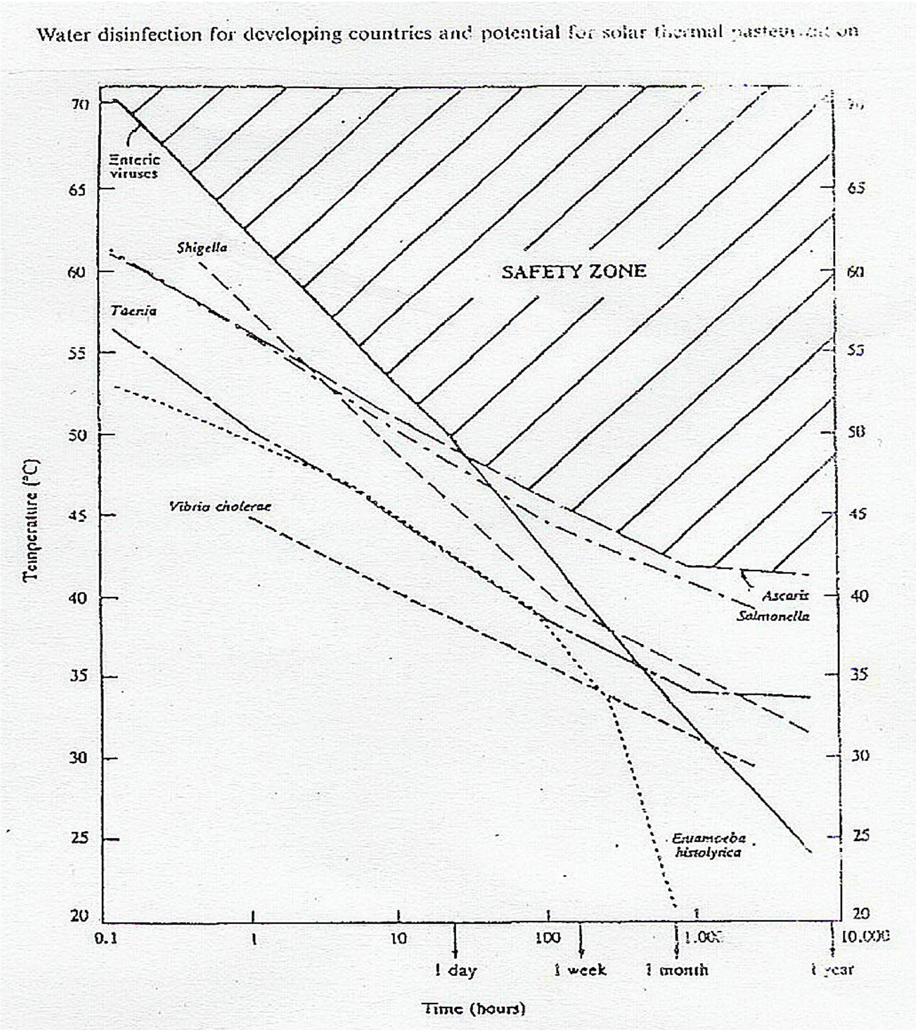

Figure 1: Temperature-time relationships for safe water pasteurization (adapted from Faechem et al., 1983). The hatched area is the safe zone for all common pathogens.

Heating water to temperatures lower than boiling temperature can also be reached by using solar radiation. In this case, the exterior of the vessel used is generally black or similarly capable of absorbing heat (metal containers). Only thermal effect occurs and temperatures can reliably reach 55 to more than 60°C (Joyce et al., 1996; Sobsey, 2002; Stanfield et al., 2003). At these temperatures, water can be pasteurized because most of the pathogens (enteric viruses, bacteria and parasites) are rapidly killed. By using two-sided solar reflectors or solar box cookers, temperatures of at least 65°C, up to 70°C, can be reached (Safapour and Metcalf, 1999; Stanfield et al., 2003;). This represents a pasteurization temperature capable of inactivating nearly all enteric pathogens within several tens of minutes to hours (Safapour and Metcalf, 1999; Skinner and Shaw, 2004). Nevertheless, and as when water is heated by fuel or firewood, the temperature-time relationships (see Figure 1) must be respected to ensure safe water pasteurization. Again a temperature of 70°C during several minutes (10-15) to kill all the pathogens must be considered as an objective especially if immunodeficient populations are of concern.

The impacts of pasteurization on chemicals (iron, manganese, arsenic) and on other parameters such as taste and odour, organic matter, turbidity, are weak and similar to those observed in the case of boiling (see Table 2). Table 4 presents the main advantages and disadvantages of pasteurization.

Table 4: Advantages and disadvantages of pasteurization

Adapted from Safapour and Metcalf, 1999; Sobsey, 2002; Stanfield et al., 2003	
	• Effective in destroying several classes of waterborne pathogens (bacteria, bacterial spores, fungi, protozoan, helminth ova), if the temperature-time relationships for safe water pasteurization are respected (see Figure 1). • Can be effectively applied to all waters, including those with high turbidity or dissolved constituents. • No need of high-skill labor and low level of training required • <u>In the case of solar pasteurization</u>: equipment needed is low cost (cardboard or aluminium foil can be used for solar reflectors or cookers)

	• Consumption of energy (if fuel or firewood is used): problems of availability, cost and sustainability in a lot of regions. Risk of incomplete treatment with the objective of saving money.
	• Can be less effective towards more heat-resistant pathogens if high temperatures are not reached
	• Need for water temperature indicators (thermometers or low cost reusable temperature indicators (WAPI)).
	• No residual protection: risk for potential microbial recontamination during storage.
	• It takes time for the water to cool down: time between preparation and consumption
	• <u>In the case of solar pasteurization</u>
	    • Cultural resistance to drink a water that normally is cold (groundwater).
	    • Need for good sunshine: variations according to the geographic location, season and daily conditions can result in important delays (hours or days).
	    • Only small quantities of the water can be treated daily (7-10L) with one system (water container + solar deflector), but can be increased by using several systems.
	    • Potential user objections due to the length of time to treat water.

<u>Epidemiological studies</u>

- After a first study in a coastal area of Kenya, Iijima et al., (2001) concluded that infectious bacterial diarrhoea was primarily transmitted by drinking water. Most of the residents of four tested villages had very low income levels and villages had no organized sanitation systems. Pasteurization of the water was applied in 1500 households (pots were placed on burning firewood until the color of the thermoindicator changed, indicating approximately 70°C, and were then removed. The water was kept in a clean container). The number of household which had no coliform bacteria in their drinking water increased from 11 to 43% after pasteurization implementation. The number of severe cases of diarrhoea was compared among people drinking pasteurized water (1779) and those drinking raw water (1641) during 4 months. 45 severe cases among the pasteurized group (2.5%) and 74 (4.5%) among the raw water group were noticed, representing a decrease of 44% in the severe cases of diarrhoea when water was pasteurized. Four years after the study, water was still pasteurized by 29% of households.

Conclusions

Heating water with fuel, firewood, solar radiation to pasteurization temperatures is an efficient way to kill all pathogens present in the water if temperatures between 60-70°C for periods of minutes to tens of minutes are respected. If those parameters are not respected (lower temperatures during insufficient periods of time), some pathogenic organisms more resistant to heat (see Figure 1), such as enteric virus in general (hepatitis A virus in particular) (see section 4.1.1 for a full description as well as a presentation of health impacts), bacterias such as *Shigella* and *Salmonella* (see section 4.1.2 and 4.1.3), Helminth ova (see section 4.1.7) may not be completely eliminated.

Furthermore, following problems exist regarding the

- availability, cost and sustainability in a lot of regions.
- absence of residual protection against recontamination
- need for the determination of water temperature (thermometers or low cost reusable temperature indicators (WAPI))
- absence of impact on chemical and other components that can be present in drinking water.

It must be mentioned that studies generally present the efficacy of household treatment systems through data of removals on some tested groups of (micro)organisms. Nevertheless, data showing that one or several groups of microorganisms are not removed are unfrequent. As a consequence, we had to use some indirect information from the litterature and linked to the properties of the (micro)organisms to estimate that, in some defavourable circumstances for the system tested, these organsims will probably not be removed. For example lower temperatures during insufficient periods of time, in the case of pasteurization, will allow to some groups of (micro)organisms more resistant to heat to survive. Same approach will be used in the case of the solar disinfection (resistance to heat and to UV radiation), UV lamp disinfection (resistance to UV radiation), ceramic candle filtration (size of the microorganisms lower than the size of pores, allowing them to pass through).

3.2 Disinfecting water

3.2.1 Solar disinfection

The second way in which solar radiation can be used to eliminate pathogens is through the effect of the natural UV irradiation. The effective component of solar radiation responsible for the inactivation of microorganisms is the UV-A spectrum (320 to 400 nm). UV light inactivates microorganisms by damaging their nucleic acids (deoxyribonucleic acids (DNA) or ribonucleic acid (RNA)), thereby preventing them from replicating (U.S. EPA, 2003)). This disinfection mechanism differs considerably from those of chemical disinfectants, such as chlorine or ozone, which inactivate microorganisms by destroying or damaging cellular structures, interfering with metabolism and hindering biosynthesis and growth.

In the case of solar disinfection, transparent bottles (or bottles painted in black on one side or lying on a dark surface allowing to collect and radiate heat) are used. Waterborne microbes are thus inactivated through the combined germicidal effects of both UV radiation and heating of the sunlight (Sobsey, 2002). In this type of bottle, water can be heated to temperatures of 50-55°C and even higher (60°C) when exposed to sunlight for several hours (Joyce et al., 1996; Wegelin, 2004).

Microbes differ in sensitivity to inactivation by heat and by UV radiation. Heat is more effective against vegetative bacteria, viruses and protozoan than against bacterial spores and helminth ova. UV radiation is more effective against vegetative bacteria and protozoan than against viruses and bacterial spores (Sobsey, 2002). A complementary effect exists thus between the two ways of action. Several authors (Wegelin et al., 1994; McGuigan et al., 1998; Rijal and Fujioka, 2001) also noticed that direct radiation of sunlight worked synergistically with solar heating of the water to disinfect the water. A greater inactivation than predicted, in adding up comparable levels of exposure to either one of the two agents alone, is thus obtained. According to Wegelin et al., (1994) and McGuigan et al., (1998), thermal inactivation is found to be important only at water temperatures above 45-50°C, at which point strong synergy between optical and thermal inactivation processes is observed. Therefore, achieving sufficiently high temperatures (55°C or higher for several hours) is an important factor for microbial inactivation by solar disinfection systems.

Laboratory and field studies (Wegelin et al., 1994; McGuigan et al., 1998; Reed, 1997; Reed et al., 2000; Rijal and Fujioka, 2001; Kehoe et al., 2004) have shown that various bacteria (faecal coliforms, faecal streptococci, *E. coli,* enterococci, *Clostridium perfringens* spores, *Shigella dysenteriae, Salmonella typhimurium*) and viruses (coliphage f2, rotavirus, Picornavirus (encephalomyocarditis virus), FRNA virus) are reduced by several orders of magnitude (from 2-log to more than 6-log) when exposed to sunlight (or to simulated overcast conditions at equatorial latitudes) for several hours and if sufficiently high temperatures are achieved. During these studies the impacts of turbidity, color, temperature, dose of solar radiation, relative impact of thermal and optical activation on the efficiency of the process were also studied.

Several solar treatment systems have been described, but one of the most technically simplistic, most practical and economical is the SODIS (Solar Water Disinfection) system. Basic using steps are as follows:

- Removing solids from highly turbid (>30NTU) water by settling or filtration if necessary
- Placing low turbidity water (<30NTU) in clear plastic bottles (discarded beverage bottles (1-2 L)) preferably painted black on one side and eventually placed on a corrugated iron (dark) roof.
- Oxygenating the water by vigorous shaking in contact with the air

- Exposing the filled, aerated bottles to full sunlight for about 5-6 hours (or more if only part sunlight). A solar radiation intensity of at least 500 W/m^2 is required during 6 hours for SODIS to be efficient. This is equivalent to 6 hours mid-latitude sunshine in summer.

Plastic bottles are preferable over glass because they are lighter, cheaper and less likely to break. PET (polyethylene terephthalate) bottles are preferable over PVC (polyvinylchloride) or other plastic bottles because unbreakable, chemically stable (no release of harmful constituents into the water) and they do not impart taste and odours to the water. Nevertheless, they have to be periodically replaced due to scratching or deformation if temperatures exceed 65°C.

According to Reed (1997), vigorously shaking (couple of minutes) bottles which are filled to ¾ of their capacity increases the oxygen content of the water before and during exposure to the sunlight, allowing a considerable improvement in effectiveness of solar disinfection. Reed et al. (2000) tested in India and South Africa 6 water sources with low levels of dissolved oxygen (at 13-40% of the air saturation value). Vigorous mixing followed by exposure to full-strength sunlight in transparent plastic containers (1-25L capacity) caused a rapid decrease in the counts of faecal indicator bacteria, giving complete inactivation within 3-6 hours with no evidence of reactivation.

Reactivation is a process linked to the capacity of repair by microorganisms. Those which have been exposed to UV light can still maintain some metabolic functions, and, in addition, some are able to repair the damage done by UV light and regain culturability and infectivity (U.S. EPA, 2003). Ways to repair such damages include photoreactivation (or photorepair) and dark repair mechanisms. In the first case, the enzyme responsible for nucleic acid repair must be activated by exposure to light, and in the second, the repair process does not need light but can occur in the presence of light. If in drinking water treatment plants and at the doses typically used in UV disinfection, microbial repair can be controlled (U.S. EPA, 2003), it can nevertheless probably not be the case during field applications of solar disinfection process, specially when high levels or color and/or turbidity interfere with sunlight penetration and thus with microbial inactivation.

Table 5 presents the effectiveness of the solar disinfection method regarding the removal of pathogenic (micro)organisms and of chemicals and components that can be present in drinking water. Table 6 presents the major advantages and disadvantages of the solar disinfection method

Table 5: Effectiveness of the solar disinfection method regarding the removal of pathogenic (micro)organisms and of chemicals and other components that can be present in drinking water

Adapted from Sobsey, 2002; Skinner and Shaw, 2004		**Solar disinfection**
(Micro)organisms	Viruses	2-3
	Bacteria	4
	Protozoan	4
	Helminth ova	2-3
Chemicals	Iron and manganese	-
	Arsenic	-
Other	Taste and odour	0

	Organic substances	-
	Turbidity	0

1-4 = increasing effectiveness; - = unknown effect; 0 = minimal if any effect

Table 6: Advantages and disadvantages of solar disinfection process.

Adapted from Joyce et al., 1996; Reed 1997; Safapour and Metcalf, 1999; Sobsey, 2002; Stanfield et al., 2003; Skinner and Shaw, 2004
• Complementary and synergistic effect of heat and UV radiation: effective in destroying most classes of waterborne pathogens. • Improved bacterial inactivation if aeration (mixing, agitation) is provided before or during sunlight exposure. • Equipment needed is simple and low cost (plastic (PET or PVC) bottles); procedure is simple • No need of high-skill labor and low level of training requested. • No chemical addition in the water (but possible leaching of chemical from some bottles).
• High levels of color and/or turbidity interfere with sunlight penetration and thus with microbial inactivation. A low turbidity (<30NTU) is required and a reduction by sedimentation and/or filtration could be necessary (as well as equipment to measure turbidity). • Need for good sunshine (variations according to the geographic location, season and daily conditions): from several hours in good conditions to two days in cloudy weather. • Only small quantities of the water can be treated (1-2L) per bottle (in the SODIS case) and several bottles are needed per household per day. It avoids the storage of large volumes of treated water and thus the risk of recontamination in the absence of residual protection. • Periodic bottle replacement needed and periodic cleaning to avoid biofilm development. • Determination of water temperature (thermometers or low cost reusable temperature indicators (WAPI)) is an asset. • Educational, socio-cultural, behavioral and motivational components could be important • Potential user objections due to the length of time to treat water • It takes time for the water to cool down: time between preparation and consumption

Epidemiological studies

Solar water disinfection (SODIS) process in clear bottles is an extensively tested method with several projects in different countries of South America, Africa, Asia (Wegelin, 2004). Nevertheless, only three epidemiological studies, using the solar water disinfection (SODIS) process were reported, all in Kenya.

- Conroy et al., (1996) presented the results of a 12 week randomized field trial of solar disinfection of drinking water in 206 Maasai children aged 5 to 16. Children whose mothers kept their drinking water on the roof of the family home in transparent plastic bottles in the sunlight had a 10% reduction in the incidence of all diarrhea and a 24%

reduction in the incidence of severe diarrhoea, compared with control children whose mothers kept their drinking water indoors;

- In the second (Conroy et al., 1999), 349 Maasai children younger than 6 years (mean age was 2,4 years) were randomized by alternate households (140) to drink water either left in plastic bottles exposed to sunlight on the roof of the house or kept indoors. All families were drinking water of poor quality (high levels of turbidity and bacterial contamination). The trial was run in Maasai by Maasai community elders. Children drinking solar disinfected water had a 16 % reduction in the incidence of severe diarrhoea, compared with control children whose mothers kept their drinking water indoors;
- In the third, Conroy et al., (2001) studied the impact of a cholera epidemic, in the same area in which the controlled trial of solar disinfection and diarrhoeal disease in children aged under 6 had recently finished. There were 131 households in the trial area, of which 67 had been randomized to solar disinfection. There was no significant difference in the risk of cholera in adults or in children older than 6 in households randomized to solar disinfection. However, there were only 3 cases of cholera in the 155 children aged under 6 years drinking solar disinfected water compared with 20 cases in the 144 control children (85% of reduction).

Unfortunately, these studies do not provide information regarding the microbial inactivation and reduction occurring during the trials and due to the exposition of the water to the sunlight. Therefore, the extent of pathogens reduction in waters is not known. Furthermore, some discrepancy exists between the results of the first two studies (16 to 24% reduction in severe diarrhoea) and of the third one (85 % reduction in cases of cholera) concerning the efficiency of the solar treatment. During the three studies, similar poor quality drinking water (high levels of turbidity (>200NTU) and bacterial contamination) was used by the families.

In these conditions, less than 1% of the total incident UV light penetrates further than a depth of 2 centimeters from the surface and thus can not be expected to have a significant germicidal effect beyond this distance in the liquid volume (Joyce et al., 1996). The potential germicidal effect of the treatment applied is thus probably linked to an increase in temperature occuring in the bottles exposed to the sunlight. As presented on Figure 1, *Vibrio cholerae* is highly sensitive to temperature. This could explain the high efficiency of the solar treatment observed during the study focusing on the cases of cholera and the lower efficiency observed during the two other studies focusing on more "general" diarrhoea events. These events being probably linked to the action of several pathogens harboring variable sensitivity regarding temperature.

Conclusions

Solar disinfection process can be effective in destroying most classes of waterborne pathogens. However, reaching this effective disinfection depends on several parameters:

- sensitivity of the microorganisms to inactivation by heat and by UV radiation
- cumulative UV dose transferred to the water and water temperature reached, depending on sunlight intensity in general and directly on the bottle in particular
- color and turbidity of the water
- type of material and volume of the bottle
- oxygen concentration in the water, depending on periodic agitation

Controlling these parameters and evaluating the real effectiveness of the treatment seems challenging, especially when measurement tools are absent. If turbidity is higher than 30NTU a reduction by sedimentation, filtration may be necessary (as well as equipment to measure turbidity).

According to the information presented in Table 5 and if non-optimal conditions are met (water has a high level of turbidity and/or colour, the sunshine is weak, insufficient time of exposition) we will consider that enteric viruses (4.1.1), helminth ova (4.1.7) due to their resistance to UV and heat, may survive and not be completely inactivated.

Other existing problems are:

- No residual protection against recontamination
- Absence of impact of this treatment on chemical and other components that can be present in drinking water.

3.2.2 UV lamps disinfection

Due to its efficacy regarding microorganisms (protozoan cysts and oocysts (*Giardia lamblia*, *Cryptosporidium parvum*), bacteria and viruses) inactivation (Parotta and Bekdash, 1998; Clancy et al., 2000; Shaw et al., 2000), coupled with the absence of bromate and halogenated by-products formation during its application as well as its cost-effectiveness, ultra violet (UV) irradiation (254 nm) is becoming a more and more widely used technique for disinfecting drinking water. The UV dose applied depends on the targeted microorganism and the log of inactivation required (from 2 mW.s/cm^2 for 0.5 log of inactivation of *Giardia* and *Cryptosporidium* to 185 mW.s/cm^2 for 4 log of virus inactivation) (U.S. EPA, 2003). As a consequence, the UV doses commonly used in disinfection will be in this range.

Full-scale drinking water applications generally use low-pressure, low-pressure high-output or medium-pressure mercury vapor lamps. The light emitted by the first two types of lamps is essentially monochromatic (at 254 nm) and is near the maximum of the microbial action spectrum. Medium-pressure lamps emit light over a wide range of wavelengths across the action spectra; however, they convert this power to germicidal light less efficiently. For UV disinfection of drinking water at the household level, the low-pressure lamps are entirely adequate because they operate at lower power, lower temperature and lower costs. Energy costs are lower than for boiling water using wood or charcoal, and solar or wind powered systems are feasible in some situations. These lamps can achieve UV radiation doses of 50-150 mW.s/cm^2 in high quality water, allowing disinfection of essentially all waterborne pathogens.

Nevertheless, the quality of the water and the property of the lamp sleeve surface will influence the effectiveness of the process and thus the microbial inactivation. As a consequence, an uncertainty of the magnitude of UV dose delivered to the water (unless a UV sensor is used) is still present. If the water quality (in terms of particulate or dissolved matter) is low or if the lamp sleeve surface is dirty, the dose could not be sufficient to completely inactivate the most UV-resistant microorganisms.

Adenoviruses are very resistant to UV disinfection (Meng and Gerba, 1996; Gerba et al., 2002, Thurston-Enriquez et al., 2003). They are likely the most resistant viruses to UV, probably due to the fact that they are double-stranded DNA. For example an UV dose of 160 mW.s/cm^2 is requested for 4 log of inactivation for an adenovirus type 2, against 31 mW.s/cm^2 for a Poliovirus 1, or 33 mW.s/cm^2 for a Coxsackievirus B3 (Gerba et al., 2002). Since low pressure lamps used at the community level can achieve a UV radiation dose of 50-150 mW.s/cm^2 in high quality water, a potential limitation exists in low quality water where an inactivation of adenoviruses lower than 3 or 4 logs is susceptible to occur.

Table 7 presents the effectiveness of UV lamps regarding the removal of pathogenic (micro)organisms and of chemicals and components that can be present in drinking water. Table 8 presents their adavantages and disdvantages for drinking water treatment.

Table 7: Effectiveness of the UV lamps regarding the removal of pathogenic (micro)organisms and of chemicals and other components that can be present in drinking water

Adapted from Sobsey, 2002; Servais et al., 2005		**UV lamps**
(Micro)organisms	Viruses	4
	Bacteria	4
	Protozoan	4
	Helminth ova	4
Chemicals	Iron and manganese	0
	Arsenic	0
Other	Taste and odour	0
	Organic substances	0
	Turbidity	0

1-4 = increasing effectiveness; - = unknown effect; 0 = minimal if any effect

Table 8: Advantages and disadvantages of UV disinfection with lamps.

Adapted from Meng and Gerba 1996; Sobsey, 2002; Stanfield et al., 2003; Servais et al., 2005.	

	• All waterborne enteric pathogens can be inactivated at sufficient high doses of UV radiation (adenoviruses are extremely resistant to UV disinfection, their level of inactivation will probably be lower than for other microorganisms).
	• No addition of chemicals to the water. Absence of formation of
	    • toxical disinfection by-products
	    • taste and odour
	• Simple to apply and to use, no need of high-skill labour and low level of training requested.

	• Quality of the water will influence microbial inactivation: particulate matter, dissolved organic matter, inorganic solutes (iron; sulfite, nitrites) in water will absorb UV radiation and shield microbes from UV radiation. A pre-treatment can be desirable. • Potential capacity of repair by microorganisms: sufficient UV dose to induce great damages must be provided • No residual protection: risk for potential microbial recontamination during storage. • Periodical cleaning of the lamp sleeve surface to remove deposits and maintain UV transmission • Uncertainty of the magnitude of UV dose delivered to the water (unless a UV

	sensor is used) • Energy requirements are low (several tens of watts per unit that can be supplied by a solar panel) but there is an essential need for an available and reliable source of electricity (dependence and risk of an interruption of power supply) and for a source of replacement lamps • Expensive at the household level (initial cost of 100-300$/household + power + lamp replacement (100$/household every 1-3 years). Most economic if the system is used at the community level.

Epidemiological studies

Even if UV lamps disinfection can be considered as a feasible technology for household water treatment, up to now, there are no epidemiological studies available describing a field application of the process in developing countries as well as its effect on illness rates.

Conclusions

UV lamps disinfection is effective in destroying all waterborne enteric pathogens at sufficient high doses of UV radiation. If the water quality (in terms of particulate or dissolved matter) is low or if the lamp sleeve surface is dirty, the dose may not be sufficient to completely inactivate the most UV-resistant microorganisms. In these conditions, adenovirures (4.1.1) are the most susceptible to be not inactivated.

Other existing problems include:

- Absence of residual protection against recontamination.
- Absence of impact of this treatment on chemical and other components that can be present in drinking water, at the doses commonly used in drinking water treatment.
- Expensive at the household level. The system can be used at the community level with lower costs.

3.2.3 Chemical disinfection (chlorination)

Today, chemical disinfection of drinking water is recognized as a safe and effective method of destroying pathogenic and other microbes in drinking water. Chemical disinfection is promoted and practiced at the community level as well as at the point-of-use (household level). Chlorine has been widely used for decades for disinfecting drinking water, at the community but also at the household levels. Chloramines, ozone, and chlorine dioxide are also frequently used as disinfectants, but essentially at the community level. Due mostly to difficulties in preparation and/or in use, they are not recommended for household water treatment and are thus rarely met at this level. Their application will thus not be discussed here.

3.2.3.1 Chlorination used alone

Chlorination is the most widely used method for disinfecting drinking water. Several different sources of chlorine exist for water treatment, including liquids (bleach (sodium hypochlorite)), solid (purpose-made HTH tablets (calcium hypochlorite)) or powders (bleaching powders (chloride of lime, a mixture of calcium hydroxide, calcium chloride and calcium hypochlorite). The concentration of these various chlorine products is thus different (Table 9). Concentrations will also vary with time: air-tightness, low temperature and absence of light are important during storage.

Table 9: Concentrations of various chlorine products

	Concentration (% active chlorine when fresh)
Sodium hypochlorite • Commercial • Household bleach • Javel water	 • up to 15% • up to 5% • about 1%
Chlorinated lime (bleaching powder)	• up to 35%
High Test Hypochlorite (HTH) tablets	• up to 70%

Dissolved organic matter concentration and composition, turbidity, pH (better efficiency at low than at high pH) and temperature (better efficiency at high than at low temperature) of the water will have an important impact on the efficiency of disinfection. A significant part of chlorine is consumed by the reaction with dissolved organic matter, particles and microorganisms present in the water (chlorine demand). Once this demand has been satisfied, any excess chlorine remains as a residual of chlorine. A sufficient concentration of chlorine can thus be added to ensure a free chlorine residual (between 0.3 and 0.5 mg Cl_2/L) in the treated water. The presence of this residual allows to verify the efficacy of the disinfection and to cope with any subsequent bacterial contamination.

Since organic matter composition and concentration, turbidity, pH and temperature vary from a water to another and according to time, leading to variations in chlorine demand, tests must be done and repeated frequently to ensure a permanent efficient disinfection. If possible at the community level or in a refugees camp, these manipulations are difficult or impossible to perform at the household level. At this level, chlorine is used under the form of a standard-dose product (SDP) such as tablet (Aquatabs®; each tablet containing the equivalent of 5 mg/L free available chlorine) or such as dilute solution of a fixed concentration (Clorin; Claro, Sur'eau (Center for Disease Control and Prevention-USA)). This dilute solution (sodium hypochlorite) can be commercially manufactured by a private company or can be produced on-site through electrolysis of salt water (Quick et al., 1996; Dunston et al., 2001). One tablet or a determined volume of the dilute solution is then added per volume of water. The objective is theoretically to reach a sufficient residual for all types of water met, but this objective is difficult to reach in practice. SDP can have non 100% effect or, at the opposite give a chlorine taste to the water.

Waterborne microbes also differ in their resistance to chemical disinfectant: protozoan cysts and oocysts, helminth ova > bacterial spores > acid-fast bacteria (notably Mycobacteria) > enteric viruses > bacteria (Sobsey, 2002). Within each group, there are different resistances between sub-groups, species or strains of microorganisms. Physical and physiological states of microorganisms can also influence their resistance as well as their aggregation in clumbs or embedding in other matrices such as biofilms or faecal matter that will protect them from the disinfectant action. All these factors are important regarding the efficiency of the process. A sufficient contact time, about 30 minutes, must be provided for chlorine to destroy the microorganisms.

Chlorine disinfection is effective against most waterborne pathogens including viruses. Nevertheless, even if correctly applied (in terms of concentration and contact time), it is not effective against protozoan such as *Cryptopdoridium parvum* (4.1.5) or *Cyclospora* *cayetanensis* (4.1.5) or against pathogenic environmental Mycobacteria species (4.1.4) (WHO, 2004a). To a lesser extent, helminth eggs (4.1.7), *Giardia lamblia* (4.1.6), some chlorine-resistant viruses like caliciviruses (notably Hepatitis E virus) or Hepatitis A virus (4.1.1) may also not be completely inactivated especially if chlorination is applied to turbid waters, and/or at high pH (>8) and/or at low temperatures.

The reactions of chlorine with organic matter and the subsequent formation of disinfection by-products (DBPs) have been in the forefront of water quality concerns for 30 years. A growing consensus is emerging about the levels of DBPs below which there are unlikely to be any significant or unacceptable risks. Concerns have recently shifted towards the potential adverse impacts of DBPs on early pregnancies (Bove et al., 2002), pregnancy outcome in susceptible populations (Infante-Rivard, 2004) and bladder cancer (Villanueva et al., 2003). The use of high chlorine dosage is, therefore, by itself not a guarantee of safe drinking water as it may result in high concentrations of DBPs.

Table 10 presents the effectiveness of chlorine disinfection method regarding the removal of pathogens (micro)organisms, chemicals and components that can be present in drinking water. Table 11 presents the major advantages and disadvantages of the use of chlorine.

Table 10: Effectiveness of the chemical disinfection (chlorination) regarding the removal of chemicals and other components that can be present in drinking water

Adapted from Heber, 1985; Sobsey, 2002; Skinner and Shaw, 2004		**Chlorine disinfection**
(Micro)organisms	Viruses	3-4
	Bacteria	3-4
	Protozoan	2-3
	Helminth ova	3-4
Chemicals	Iron and manganese	0
	Arsenic	-
Other	Taste and odour	1
	Organic substances	4
	Turbidity	0

1-4 = increasing effectiveness; - = unknown effect; 0 = minimal if any effect.

Table 11: Advantages and disadvantages of free chlorine treatment.

Adapted from Mintz et al., 2001; Macy and Quick, 2002; Sobsey, 2002; Souter et al., 2003; Ashbolt, 2004; Brick et al., 2004; Pedley et al., 2004; Skinner and Shaw, 2004; WHO, 2004a.	

	• If correctly applied (in terms of concentration and contact time), chlorine
	  • is effective against nearly all waterborne pathogens including viruses but at the exception of *Cryptopdoridium parvum, Cyclospora cayetanensis*, pathogenic environmental Mycobacteria species and in a lesser extent *Giardia lamblia and* helminth eggs.
	  • provides a stable residual lowering the risk for potential microbial recontamination during storage
	• Inexpensive (initial cost of 8$/household (special container for the water) + annual operating cost of 3$/household);
	• Proven and safe technology.

- Quality of the water will influence microbial inactivation
  - particulate, colloidal and dissolved constituents in water will react and consume chlorine. Efficiency is reduced in turbid water (>5 NTU)
  - pH and temperature of the water influence the efficiency of chlorine disinfection.

  The process must thus be adapted as a function of this quality and the free chlorine residual and/or microbial quality must be controled. These operations are impossible at the household level where standard-dose products (SDP) are used. SDP's can however have non-100% effect or at the opposite can give a chlorine taste to the water.
- Variable resistance of microorganisms regarding disinfection
- Potential production of disinfection by-products.
- Free chlorine residual measuring required.
- Cultural resistance regarding chlorine taste of the water; a strong promotional component is thus required.
- Dependence and risk of an interruption of disinfectant supply if not locally produced.

Epidemiological studies

There is considerable evidence that free chlorine effectively inactivates waterborne microorganisms and reduces the risks of waterborne diseases in point-of-use and household water supplies (Sobsey, 2002). This can be seen in Table 12, presenting the results of some intervention studies in developing countries during the last 6 years. Most of these studies included the use of fully articulated systems of chlorine production, distribution and dosing, a standardized household water storage container and the inclusion of a participatory education, motivation and behavior modification components. This global approach has been developed by the Center for Disease Control and Prevention (USA) under the name of Safe Water System. A low cost of adding chlorine to collected household water stored in a dedicated plastic container (preferably with a valved spigot) can typically reduce waterborne microbes as well as community diarrhoeal disease (see Table 12).

Conclusions

Chlorination usually takes place at a central treatment point in the drinking water treatment process, particularly in developing countries where there is a growing interest in applying it at the household level. If correctly applied (in terms of concentration and contact time), chlorine is effective against nearly all waterborne pathogens including viruses. Results of several epidemiological studies give a clear confirmation of its effectiveness. Chlorination has another important advantage: it provides a stable residual, lowering the risk for potential microbial recontamination during storage.

However, treating water by adding chlorine is not a simple process. To be efficient, the process must be adapted as a function of pH, temperature and chlorine demand due to the presence of dissolved organic matter and particles. The use of low dosage of chlorine may lead to unefficient disinfection and the use of high dosage of chlorine may results in high concentrations of disinfection by-products. Due to its complexity, this adaptation is difficult to implement at the household level. At this level, chlorine is generally used in the form of a tablet or as a dilute solution of a fixed concentration that must be added to a determined volume of water. Theoretically, the objective is to reach a sufficient residual for all types of water used, but, in practice, this objective is difficult to meet.

Furthermore, some organisms such as *Cryptopdoridium parvum*, *Cyclospora cayetanensis*, Mycobacteria species, and to a lesser extent *Giardia lamblia*, some viruses, helminth eggs are resistant to chlorine and are not significantly reduced even if chlorination is applied under proper conditions and when conventional CxT values (concentration x time of contact) are used. Other problems such as a cultural resistance regarding chlorine taste-and-odour of the water or the dependence of disinfectant supply if not locally produced are frequent. Furthermore, chlorine has no impact on chemicals and other components that can be present in drinking water, at the exception of organic substances that will be oxidated.

Location	Treatment	Microbial decrease	Disease reduction	Intervention	Reference
Uzbekistan	Free chlorine + special vessel	No statistical difference in faecal coliforms counts	84%, diarrhea	Water	Semenza et al., 1998
Guinea-Bissau	Free chlorine + special vessel (in oral rehydration solution-hospital)	Yes • 5 log in coliform bacteria • Mean *E. coli* from 6200 CFU*/100ml to 0/100 ml	No data	Water + sanitation and health intervention	Daniels et al., 1999
Bolivia	Free chlorine (+ other oxidants) from a MIOX unit + special vessel	Yes/*E.coli* positive samples/ from 95 to 21%	44%, diarrhea	Water + sanitation and health intervention	Quick et al., 1999
Pakistan	Free chlorine + special vessel	Yes/99.8% in thermotolerant coliforms	No data	Water + sanitation and health intervention	Luby et al., 2001
Zambia	Free chlorine (+ other oxidants) from a MIOX unit + special or local vessels	Yes/*E.coli* positive samples/ from 95 to 31%	48%, diarrhea	Water + sanitation and health intervention	Quick et al., 2002
Bolivia	Free chlorine (+ other oxidants) from a MIOX unit + special vessel	Yes • *E.coli* positive samples/ from 94 to 34% • *C. perfringens* positive samples/from 93 to 37% • Heterotrophic plate counts positive samples/from 98 to 58%	43%, diarrhea	Water	Sobsey et al., 2003
Bangladesh	Free chlorine + special vessel	Yes/*E.coli* positive samples/ from 55 to 13%	21%, diarrhea	Water	Sobsey et al., 2003

*CFU: Colony Forming Units.

Table 12: Effectiveness of chlorination and storage in a special container to disinfect household water.

3.2.3.2 Chlorination used in combination with another treatment

Purification of water at point-of-use using tablets or powders combining a coagulant-flocculent and a chemical disinfectant has also been described. These systems utilize a similar approach to that employed in conventional municipal water treatment facilities, namely coagulation, flocculation, sedimentation and disinfection for the removal of microorganisms. When used in combination for community water treatment systems in developed countries, these processes have been shown to dramatically reduce microbial contaminants in drinking water and produce water that meets international guidelines (Sobsey, 2002).

Kfir et al., (1989) presented removal of E. coli, various viruses and Giardia cysts from polluted waters in South Africa by using "chlor-floc" tablets. Rodda et al., (1993) presented successful removal of four pathogenic microorganisms (*Salmonella typhi*, *Sigella dysenteriae*, *Vibrio cholerae* and rotavirus) from simulated hard water of high organic content and colour by using the same tablets. The tablets can be used for the household and can be added to water in a 20L bucket. The mixture is stirred to dissolve the tablet and to flocullate, then allowed to stand unmixed to settle the floc. Supernatant water is then poured through a cloth filter into another bucket. Even if these tablets were successfully tested for reducing microorganisms, their effectiveness in reducing waterborne diarrhea and other disease were not reported through epidemiological studies. Furthermore, the product has been tested by MSF-Holland and MSF-Belgium and the conclusion were not extremely favourable for the product: the product seemed to be efficient under certain conditions (turbidity ≤100NTU) but not for waters with turbidity >200 NTU and with relatively high faecal contamination. Furthermore, important questions regarding the instructions of use, the impact of temperature and pH on the effectiveness of the process, the composition of the product and its innocuity stayed unresolved, despite requests addressed to the manufacturer.

Based on the same general principle, another system, the PuR® Water Purifier (Procter & Gamble, Cincinnati, Ohio, USA) has recently been evaluated. The product is supplied in individual sachets with a dose to treat 10 L of water. Its ingredients include a coagulant (ferric sulfate), an alkaline agent (sodium carbonate), a flocculent and flocculation aids (polyacrylamide, bentonite, chitosan) and a (timed-release) chlorine-based disinfectant (calcium hypochlorite) (Reller et al., 2003; Souter et al., 2003). Some worries can exist regarding the presence of residual acrylamide monomers in the water originating from polyacrylamide decomposition. Acrylamide is considered as a genotoxic carcinogen. According to the company, the level of polymer used in treating water with PUR is 3 mg/L, well within the typical use levels and therefore supported by the safety assessment process used to establish that this is safe for treating water. The polymer is approved for use and complies with Environmental Protection Agency (USA) requirements for percent monomer (acrylamide) and dose. The monomer is controlled at or below WHO accepted drinking water levels (0.5 ppb) (Allgood, 2005, personal communication).

The following procedure is recommended (Allgood., 2004) :

- The content of the sachet is added to 10L of water in a vessel and mixed vigorously in the water by continual agitation for 5 min.

- The floc is allowed to settle to the bottom of the container until the water appears clear and the floc has grown in size
- When the water is clear it is strained through a cloth filter into a safe storage vessel.
- The filtered water is allowed to stand for 20 minutes to complete the disinfection process.

Efficacy of the treatment was evaluated on different types of model and field waters covering large conditions in terms of quality, including conditions of highly contaminated waters presenting stringent conditions (high pH, high turbidity and high organic matter content, low temperature) for chlorine as a disinfectant (Souter et al., 2003, Allgood, 2004). Table 13 provides some examples of bacteria removals obtained on highly contaminated model waters by the PuR system. Tables 14 and 15 show the removal of viruses and protozoan oocysts obtained on highly contaminated model waters by the PuR system. These results are good, particularly concerning viruses removal. Nevertheless, additional tests evaluating the efficacy of the system against other viruses such as caliviruses (see 4.1.1), which are known to be resistant to chlorination, would be an asset.

Table 13: Bacteria removals obtained on highly contaminated model waters by the PuR system (adapted from Allgood, 2004)

Organism	Initial (N/L)	After treatment (N/L)	Log_{10} reduction
E. coli	2.1×10^{8}	<1	>8.32
10 common faecal bacteria	9.2×10^{9}	<1	>9.96
Salmonella typhi	2.1×10^{8}	<1	>8.20
Vibrio cholerae	1.2×10^{8}	<1	>8.08
Shigella sonnei	2.2×10^{8}	<1	>8.34
Klebsiella terrigena	2.8×10^{8}	<1	>8.45
Campylobacter jejuni	2.0×10^{8}	<1	>8.31

Table 14: Virus removals obtained on highly contaminated model waters by the PuR system (adapted from Allgood, 2004)

Organism	Initial viral counts/ml (log_{10})	Log_{10} reduction
Poliovirus	7.1	>5.00
Rotavirus	7.9	>5.00

Table 15: Protozoan cysts removals obtained on highly contaminated model waters by the PuR system (adapted from Allgood, 2004)

Organism	Initial counts (N/L)	Log_{10} reduction
Cryptosporidium parvum	1.76×10^{6}	4.00
Giardia lamblia	1.84×10^{6}	3.60

In numerous laboratory tests, samples artificially contaminated with model pathogens were effectively treated for bacteria, virus and parasite removal by the system. Even under conditions known to stress chlorine disinfection, the water treatment was effective. Water turbidity was reduced and free chlorine residuals were measurable 30 minutes after the disinfecting process (Souter et al., 2003). Field testing was carried out on drinking-water source samples (spring, lake, river, well, rain and tap water) collected and treated in five developing countries. Under "real-world" conditions, 320 drinking water samples that initially contained *E. coli* were devoid of measurable *E.coli* and coliforms post-treatment, suggesting that this treatment is effective and possible under a wide variety of conditions.

This water treatment was also effective in removing heavy metals, and especially arsenic from water artificially contaminated with arsenic and from water with naturally occurring arsenic contamination. The system removed 99.7% of arsenic that was added at levels of 500 to 1000 μg/L to laboratory and municipal water sources. Final mean arsenic concentrations for As5+ and As3+ were 0.8 and 1.2 μg/L respectively. Natural waters contaminated with arsenic from a region where there are currently health problems due to arsenic poisoning were also used. Eight samples of water collected from drinking water sources from Bangladesh were treated and tested for arsenic reduction. Mean pre-treatment arsenic levels were 229 μg/L (ranging from 49 to 430 μg/L). The mean post-treatment arsenic level in the eight samples was 1.2 μg/L representing a 99.5% removal. Three additional samples from other regions with low-level arsenic contamination also demonstrated effective removal.

Table 16 presents the effectiveness of chlorine disinfection used in combination with coagulation/flocculation (PuR system) for the removal of pathogens (micro)organisms, chemicals and components that can be present in drinking water. Table 17 presents the major advantages and disadvantages of this combined treatment system.

Table 16: Effectiveness of the combined treatment system regarding the removal of chemicals and other components that can be present in drinking water.

Adapted from Heber, 1985; Sobsey, 2002; Skinner and Shaw, 2004; Allgood, 2004		**Combined system**
(Micro)organisms	Viruses	4
	Bacteria	4
	Protozoan	4
	Helminth ova	4
Chemicals	Iron and manganese	N.A.*
	Arsenic	4
Other	Taste and odour	N.A.
	Organic substances	4
	Turbidity	4

1-4 = increasing effectiveness; - = unknown effect; 0 = minimal if any effect; *information non available.

Table 17: Advantages and disadvantages of combined treatment systems

Adapted from Sobsey, 2002; Reller et al., 2003; Souter et al., 2003; Allgood, 2004	
	• Highly effective against all waterborne pathogens. • Can be effectively applied to all waters, including those with high turbidity or dissolved constituents, high pH, low temperature. • Provide a stable residual lowering the risk for potential microbial

	recontamination and/or regrowth during storage. • Effective in removing arsenic from artificially or naturally contaminated samples. Same potential regarding lead, organics, pesticides. • No need of high-skill labour and moderate level of training required, but clear instruction must be given regarding the type of cloth filter used and the way to handle it (reuse, disposal of flocs) • Visual observation of the water quality improvement (turbidity reduction)
	• Expensive (initial cost of 5-10$/household for vessel + annual operating cost of 35-55$/household/year) • Important to be able to measure (observe) the turbidity decrease and/or chlorine residual • Filter cloth may not be appropriate and may leave the flocs going through • Potential production of disinfection by-products • Low capacity (10L/day/household) at the prize mentioned above • Cultural resistance regarding chlorine taste of the water. A strong promotional component could be required. • Dependence and risk of an interruption of coagulant-disinfectant supply. Regular disinfection is needed, since people who drink disinfected water lose their immunity to some disease. • A standard dose of chlorine is used. It can be to much/little according to the quality of water

Epidemiological studies

Five clinical studies have been completed with the Pur system, covering more than 2500 households (25000 people) in four countries. Diarrhea reduction was the objective in four studies (2 studies in a rural setting in Guatemala, one study in Kenya (turbid water) and one study in Pakistan (urban setting)), and arsenic removal was the objective in the fifth (Bangladesh).

- 492 households (2980 people) were enrolled in rural Guatemala (Reller et al., 2003). Weekly visits were done, during one year to determine diarrhea prevalence. Traditional practice (control) was compared to the use of PuR, PuR + adapted vessel, bleach, bleach + adapted vessel. During one year of observation, residents of control household had 4.3 episodes of diarrhea per 100 person-weeks. Incidence of diarrhea was 24% lower among residents of households using PuR, 29% lower among those using PuR + vessel, 25% lower among those using bleach and 12% among those using bleach + vessel. Even if, according to the authors, this study presents important limitations, intermittent use of home water treatment with flocculant-disinfectant decreased the incidence of diarrhea. The study also demonstrated that there is a specific challenge to preventing diarrhea among the youngest children with home water treatment.
- 514 households (3401 people) were enrolled in rural Guatemala (Allgood, 2004). Weekly visits were done, during four months to determine diarrhea prevalence. Traditional

practice (control) was compared to the use of PuR. Use of the PuR system led to a decrease of 40% in the percentage of total days of diarrhea.

- 600 households (6600 people) were enrolled in rural Kenya. Weekly visits were done, during 5 months to determine diarrhea prevalence. Traditional practice (control) was compared to the use of PuR and Bleach (Allgood, 2004). A 40% decrease in the percentage of weeks with diarrhea was measured among the children under 2 years of age drinking PuR treated water (20% decrease of among those drinking bleached water) by comparing to those drinking untreated water (control).
- 1300 households (9000 people) were enrolled in Karachi (Pakistan). Weekly visits over 10 months determined the prevalence of diarrhoea. Traditional practice (control) was compared to the use of PuR, Pur+soap, soap, and bleach (Allgood, 2004). In this case, reductions of 53% (PuR); 45% (Pur+soap), 38% (soap), and 45 % (bleach) in numbers of "person.weeks with diarrhea" were measured by comparing to control.
- 105 households using tubewells contaminated with arsenic were enrolled in Bangladesh. Arsenic in drinking water and urinary arsenic were determined each three weeks during a 12 weeks study. Arsenic in tubewells water was reduced by 85% and arsenic in urine was reduced by 37% (Allgood, 2004).

Conclusion

When applied in combination with a coagulation/floculation step (PuR system), chlorine disinfection is highly effective against all waterborne pathogens. Due to the effect of this additional step, all the waterborne pathogens (including viruses) that are normally not (completely) inactivated by chlorine when used alone will be previously physically removed from the water, even if water presents a high turbidity or dissolved constituents. Excellent disinfection results (>7-log bacterial, >4-log viral >3-log parasite reductions) across a variety of water types and under conditions that stress chlorine disinfection were obtained. Results of epidemiological studies available seem to confirm the fact that the PuR system has the potential to provide improved drinking water to households in developing countries. Arsenic seems also to be efficiently removed. Nevertheless, the system is expensive and has a low capacity, even for this price. A cultural resistance regarding chlorine taste of the water or the dependence of product supply may exist. Clear instruction must be given regarding the type of cloth filter to be used and the way to handle it (reuse, disposal of flocs). Production of potentially carcinogenic disinfection by-products can also occurs.

3.3 Filtering the water.

Filtration is a way to remove particles and at least some microbes from water. Several processes take place simultaneously during filtration

- Mechanical trapping
- Adsorption of suspended matter, chemical, microorganisms
- Biochemical proceses (biodegradation, grazing by protozoan, …)

A large variety of filters media and filtration processes are available for householod treatment of water as can be seen on Table 18 (adapted from Sobsey, 2002).

3.3.1 Rapid granular media filters

Filtration through sand or successive layers of anthracite coal and sand is the most widely used physical method for water treatment at the community level. Several granular media filters for household uses have been described. The size of particles that can be removed through deep-bed filtration can be much smaller than the pore size of the filter (Stanfield et al., 2003). This is due to electrostatic adhesion causing adsorption of particles that are in close proximity to the filter medium. These filters are typically able to reduce turbidity and enteric bacteria by as much as 90% and larger parasites (helminth ova) by more than 99%. However, due to their small size (see Figure 2), enteric viruses, unless associated with larger particles, will not be appreciably removed.

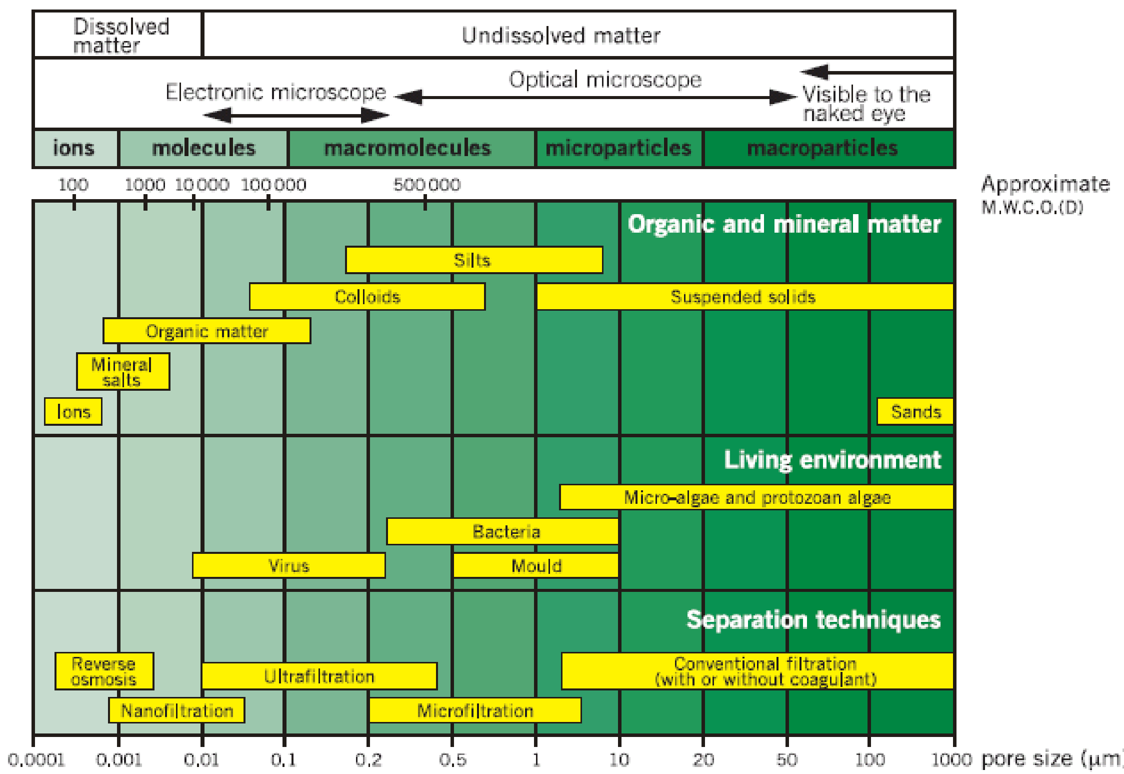

Figure 2: Filtration processes used in drinking water production classified according to their application domain and their removal characteristics with respect to living and non-living material (adapted from Servais et al., 2005).

Table 18: Filters and filtration media for treatment of household water; characteristics, advantages and disdvantages (Adapted from Sobsey, 2002)

Type of filter	Media	Availability	Ease of use	Effectiveness	Cost
Granular media, rapid rate depth filter	Sand, gravel, diatomaceous earth, other minerals	High	Easy to moderate	Moderate*	Low to moderate
Slow sand filter	Sand	High	Easy to moderate (community level)	High** in principle but often low in practice	Low to moderate
Vegetable and animal derived depth filters	Coal, sponge, charcoal,…	Medium to high	Moderate to difficult	Moderate	Low to moderate
Fabric, paper, membrane, canvas filter	Cloth, other woven fabric, synthetic polymers	Low to high	Easy to moderate	High to low (according to pore size and composition)	Low (natural) to high (synthetics)
Ceramic and other porous cast filters (see section 5.2)	Clay, other mineral	From high to low, with material availability and fabrication skills	Moderate (regular cleaning are needed)	From high to low (according to pore size and ceramic filter quality)	From high (imported) to moderate (local)
Septum and body feed filter	diatomaceous earth, other fine media	Varies	Moderate to difficult	Moderate	Varies

*: Moderate means 90-99% reductions of larger pathogens (helminth ova, larger protozoans) and solid associated pathogens, but low (<90%) reduction of viruses and free bacteria, assuming no pre-treatment. With pre-treatment (coagulation), pathogen reduction is typically >99% (high)

**: High means pathogen reduction >99%

Modified media have been developed to increase the removal of bacteria, viruses and turbidity by filtration (Ahammed and Chaudhuri, 1996). These modified media are positively charged and as a consequence are more effective for retaining the negatively charged virus and bacteria by electrostatic adsorption. Some results obtained from iron hydroxide-coated or iron and aluminium hydroxide-coated sand are presented in Table 19.

Table 19: Effectiveness of sand coated filtration regarding microorganisms and turbidity removal (adapted from Ahammed and Chaudhuri, 1996)

Type of filter and media	Filtration rate	Turbidity removal	Microorganisms removal
Rapid sand filter Iron hydroxide-coated or iron and aluminium hydroxide-coated sand. Short-duration test (1h)	1m/h	91%	82% HPC* 95% *E. coli* 80% poliovirus
Rapid sand filter Iron hydroxide-coated or iron and aluminium hydroxide-coated sand Long-duration test (2 months)	1m/h	96%	87% HPC 98% Faecal coliforms

*HPC: Heterotrophic Plate Counts

Nevertheless, the production of such modified media are beyond the capabilities of most household users, precluding their usage at this level. Their use are therefore more recommended for piped community water supply systems.

Due to their variable and potentially low microbe reductions (1 to 2 log reduction for larger pathogens, (helminth ova, larger protozoans) and solids-associated pathogens, less than 1log reductions of viruses and free bacteria), typical granular medium filters (not containing chemically modified media) are not recommended as a stand alone treatment for household water supplies, especially if immunocompromised people are of concern. They are best used as a pre-treatment, allowing for a reduction in turbidity and providing a water that is more amenable to pathogen reductions by other processes (Sobsey, 2002). If arsenic removal is the main objective, they seem to be efficient.

3.3.2 Slow sand filters

These filters are an appropriate, simple and low cost technology for community water treatment in developing countries. However, they are not recommended for individual household use because of their relatively large size (surface area) and the needs for proper construction and operation including regular maintenance (especially sand scraping, replacement and cleaning) by trained individuals. Such demands seems to be unrealistic because they are beyond the capacities and capabilities of most households (Sobsey, 2002).

3.3.3 Fiber, fabric and membrane filters

Some membranes and fiber filters (microfiltration, ultrafiltration) are able to efficiently remove parasites, bacteria and viruses (see Figure 2). Nevertheless, they require advanced fabrication methods, filter holders and the use of pressure to force the water through the filter media. These filters are not readily available and their costs preclude them for a widespread use to treat household water in many areas.

Typical fabric, paper, monofilament filters are not recommended for general treatment of household water. The pore sizes of this type of filter (20μm-200μm) are too large to appreciably retain viruses, bacteria and smaller protozoan parasites, especially if they are free and not associated with large particles or organisms (see Figure 2). When waterborne pathogens of concern are relatively large (cercariae of Schistosomes, guinea-worm larvae) or small but associated to large zooplankters (*Vibrio cholera*), the use of these filters can neverthelless give good results. Huq et al., (1996) and Colwell et al., (2003) mention for example that the use of inexpensive sari cloth, folded four to eight times, provide a filter of ≅20μm mesh size, small enough to remove all zooplankton, most phytoplankton and all V. Cholerae cells attached to plankton and particles >20μm. The use of this filter yielded to a 48% reduction in cholera when used and compared to the control population.

3.3.4 Diatomaceous earth filters

Diatomaceous earth and other fine media can be used to remove particulates and microbial contaminants from water. They can provide moderate to high removal of waterborne pathogens, but they are not practical for household use: specialized materials, construction and operations including maintenance are needed and dry material can pose a respiratory hazard. Commercial diatomaceous earth filters and medias are available in some countries but high costs and low availability may limit household use in other places. Due to these drawbacks, these types of filters are not likely to be widely use for household water treatment in many parts of the world and in many settings, and therefore, they are not recommended (Sobsey, 2002).

3.3.5 Porous ceramic filters

Porous ceramic filters (various types of clay, carved porous stone, diatomaceous earth,…) are in the forms of vessels or hollow cylindrical candles and are manufactured in a variety of pore sizes. Their effectiveness depends on the size of the pores. Good quality filters have micron or submicrons ratings (0.9 μm (absolute rating) for the Doulton® ceramic filter and 0.2 μm (absolute rating) for the Katadyn® ceramic filter) and are impregnated or coated with colloidal silver for additional bacteriostatic effect (to prevent biofilm formation on the filter and excesive bacterial numbers in the water). Insertion of adsorption media (activated carbon) in the candle can easily be done. Activated carbon filters have tremendous surface areas for contaminants to adhere to. They are effective at removing many contaminants that change the taste and odour of water, especially organic compounds. According to the manufacturers (Doulton and Katadyn), no major difference exists between the prices of ceramic candles with or without activated carbon. Due to the saturation of the adsorption sites and to the risk of bacterial regrowth in the carbon, recommended life expectancy is shorter (6 months) when activated carbon is present in the candle than when absent (12 months).

The filters (vessels or candles) are mounted in the top of a two compartment vessel. They are configured into gravity, in-line or hand pump systems. Water to be treated is placed in the upper compartment, flows through the candles and is stored as drinking water in the lower compartment. Pathogens are removed as contaminated water passes through the candles in the top compartment to the lower holding compartment, due to depth filtration and adsorption. The filtered water can only be accessed from this lower compartment by a tap or spigot, thus protecting it from the risk of recontamination prior to consumption (Clasen et al., 2004).

Ceramic filters are being produced in many parts of the world. Some of them are manufactured in developed or emerging countries under strict quality control constraints. They are extensively tested for efficacy in reducing various waterborne microbial contaminants (see Table 20). Ceramic filters can also be produced locally, in developing countries, but the extent to which they are tested for reduction of microorganisms stay uncertain at this time. Their performance evaluations for microbial reductions would provide valuable information and a basis for verifying the quality of the filters (Sobsey, 2002).

Table 20: Log reduction values (LRV) obtained on Katadyn® (Grade A) and on Stefani® (Grade B) ceramic candles (adapted from Clasen, 2004)

Ceramic filter	Organism	LRV*
Katadyn®	*E. coli*	>7.9
Katadyn®	*Shigella dysenteriae*	>6.9
Katadyn®	*Vibrio cholerae*	>4.0
Katadyn®	*Giardia lamblia* (cysts)	>6.5
Katadyn®	*Cryptosporidium parvum* (cysts)	>3.0
Katadyn®	*Entamoeba histolytica* (cysts)	>5.9
Stefani®	*E. coli*	=4.0
Stefani®	*Vibrio cholerae*	=4.0
Stefani®	*Streptococus faecalis*	=4.0
Further independent testing under way on viral reduction (estimation of LRV=2-3 for higher quality candles)		

*: (LRV=Log Reduction Value=log10 (untreated/treated)).

Due to their tiny size (0.1 to 0.01μm), virus are theoretically not removed with a 0.2μm or higher rated absolute filter. Nevertheless viruses have electrical surface charges that attach themselves to other larger particles. The tight pore-structure of any absolute sub-micron water filter can remove these attached viruses. However, due to many variables, no device should be relied upon for viral control (Doulton, 2005). Nevertheless, materials composing ceramic filters are capable of adsorbing viruses and in principle these filters can achieve high virus removal efficiencies. Due to the presence of competing adsorbents, adsorption sites for viruses become occupied and the virus adsorption efficiency will decrease with increased use and may become inefficient unless physical or chemical procedure can restore the virus adsorption sites (Sobsey, 2002). Clasen (2004) mentions that further independent testing are under way on viral reduction by ceramic filters and give an estimation of a log reduction value of 2-3 for higher quality candles. Additional information is clearly needed on this topic.

Table 21 presents the effectiveness of ceramic filters regarding the removal of waterborne pathogens, chemicals and components that can be present in drinking water and Table 22 the major advantages and disadvantages of the porous ceramic filtration method.

Table 21: Effectiveness of ceramic filters (manufactured according to high quality standards and coated with colloidal silver) regarding the removal of waterborne pathogens chemicals and other components that can be present in drinking water

Adapted from John and Ahammed, 1998; Skinner and Shaw, 2004; Doulton, 2005.		**Ceramic filtration**
(Micro)organisms	Viruses	2*
	Bacteria	4
	Protozoan	4
	Helminth ova	4
Chemicals	Iron and manganese	0
	Arsenic	0
Other	Taste and odour	0/4**
	Organic substances	2/4**
	Turbidity	4/4**

1-4 = increasing effectiveness; - = unknown effect; 0 = minimal if any effect; *: until additional information could be provided; **: ceramic filters without activated carbon/ ceramic filters with activated carbon.

Table 22: Advantages and disadvantages of ceramic filtration

Adapted from Sobsey, 2002; Fesselet, 2003; Tieche 2003; Clasen, 2004; Oude Vrielink, 2004; Skinner and Shaw, 2004
• Highly effective against most waterborne pathogens (bacteria, protozoa, helminth eggs) • Operate consistently regardless of turbidity, pH, temperature (high turbidity lead to quicker clogging: 15-20 NTU seems to be a maximum without a pretreatment). • No addition of chemicals to the water. Absence of formation of toxical disinfection by-products and/or taste and odours. • Easy to use (no mixing, batching, contact time) and maintain, minimal instruction or need for behavioural change • Visual observation of the water quality improvement (turbidity reduction) • High acceptability • Low cost, if produced locally : 3$ to 10$/household/year • Sustainable and transferable technology than can lead to local production and commercialization (rising problems of availability of trained workers, fabrication and distribution facilities; quality control measurements, including appropriate testing for proper pore size and microorganisms removals). • Insertion of adsorption media (activated carbon) in the candle to reduce taste and odour and organic contaminants such as pesticides is possible, but replacement must occurs more rapidly than when activated carbon is absent.

- Uncertain viral performance: additional studies needed.
- No residual protection, but due to the configuration of the system, risk for potential microbial recontamination during storage is low. Higher risk if drinking water containers are hand-made.
- Filtration effectiveness depends on pore size and presence/absence of colloidal silver coating.
- Relatively high cost if produced in developped countries: initial cost of 35$/household + 5-10$/year/household. Accessibility, affordability and sustainability for household use by the poorest people is thus uncertain.
- Low capacity (20L/day; 0.5-2L/h, depending on the filter and the turbidity of water).
- Breakage is possible (0.6%/month in long-term studies). Even if only slightly cracked, filter is unsuitable for microorganisms removal. The crack may be undetected during long periods. Simple and affordable method to test the quality, the integrity and the lifetime of the candles is missing.
- System requires regular cleaning (scrubbing-boiling) to remove accumulated materials and restore normal flow rate (each week or two weeks)
- Candles must be changed ((controversial) life expectancy of 6 months to 2 years or even 7 years).
- Distribution in developing countries (if not produced locally) is a challenge (bulky, low turnover, high capital).

Epidemiological studies

Filtration through porous ceramics filters is an extensively tested method with several projects in different countries of South America, Africa, Asia (Clasen, 2004). Results of some epidemiological studies, using this process were recently reported (see Table 23).

Conclusion

Ceramic candle filters are highly effective against most waterborne pathogens (bacteria, protozoa, helminth eggs). Nevertheless, due to their small size, and the potential decrease in adsorption sites available according to volume filtered, enteric viruses (4.1.1) are the microorganisms most susceptible to not be removed. This point of view can be considered as relevant until information regarding virus removal by ceramic candle filters is available. Additional studies to evaluate the effectiveness of the process regarding virus removal are however needed.

Results of epidemiological studies available seem to confirm that porous ceramic filters have the potential to provide improved drinking water to households in developing countries. Most of these results were, however, obtained on filters produced in developped or emerging countries and performance evaluations for filters produced in developing countries are still missing. Filters are highly effective against most waterborne pathogens and they can operate consistently regardless of turbidity (if <20NTU), pH, temperature. Furthermore, filters produced in developed or emerging countries, according to high quality standards, are highly effective, but their are expensive. Accessibility, affordability and sustainability for household use by the poorest people is thus uncertain. Filters produced in developing countries are less expensive, but questions exist about their effectiveness.

Table 23: Results of recent epidemiological studies regarding the effectiveness of porous ceramics filters

Location	Type of ceramic filter	Microbial decrease	Disease reduction	Intervention	Reference
Colombia (Magdalena Medio)	Pozzani candles, silver impregnated	Yes	Yes	Water + sanitation and health intervention	Fesselet, 2003
Zimbabwe and South Africa	British Berkefeld water filter (and Doulton ceramic filters)	Yes • *E. coli* geometric means from 15.5 MPN/100ml to 3.2/100 ml (at the tap) • *E. coli* geometric means from 22.3 MPN/100ml to 4.1/100 ml (in the cups)	• 80%, diarrhoea (all types) • 83%, diarrhoea (bloody diarrhoea) • 78%, diarrhoea (non-bloody diarrhoea)	Water + sanitation and health intervention	Du Preez, 2004
Cambodia	Locally produced ceramic-silver pot filter	No data	48%, diarrhoea	Water	Oude Vrieling, 2004
Bolivia (Charinco)	Katadyn Ceradyn® candles (0.2 µm porosity, silver impregnated) in locally-fabricated vessels	Yes • Thermotolerant coliforms positive samples/ from 84 to 0%.	• 70%, diarrhoea (all individuals) • 83%, diarrhoea (children<5years)	Water	Clasen et al., 2004
Bolivia (Chiñiri)	Katadyn Ceradyn® candles and Stefani®	Yes/Faecal coliforms mean/ • from 103 UFC/100 ml to 0 (stored tap water) • from 55 UFC/100 ml to 0 (stored surface water)	42%, diarrhoea	Water + sanitation and health intervention	Clasen, 2004

3.4 Collection and storage of the water

In developing countries, water storage is a necessity, both for those who are connected to a non-continuous water supply system and those who depend on drinking water sources located outside the household perimeter. The user must store the water to always have a sufficient amount of water available. Even if drinking water is obtained from a safe source or is correctly treated, it can become contaminated during or following collection (primarily through contact between water and contaminated hands) (Roberts et al., 2001; Jensen et al., 2002; Trevett et al., 2004) or storage. The storage of water during hours or days (Brick et al., 2004) allows the possibility of faecal contamination of otherwise good-quality drinking water inside the household. Children may, in particular, cause contamination when they put their faecally contaminated hands or ustensils into the household water container (Jensen et al., 2002).

From another point of view, even if water is correctly treated (at the community or at the household level), it can never be considered as sterile. In absence of residual disinfectant and in absence of recontamination, starved or injured bacteria are still present in the water. They can be at the origin of bacterial regrowth especially when the storage is long and occurs at elevated temperatures. This regrowth occurs in the bulk phase, but can also be at the origin of the formation of a biofilm on walls of the vessel. Some opportunistic pathogens (*Legionella*, mycobacteria, *Helicobacter pylori*) may then adsorb or even regrow in this biofilm, representing an additional source of contamination (WHO, 2003).

Some recent studies have illustrated this process of (re)contamination during the storage:

- Roberts et al., (2001) performed a randomized intervention trial in a Malawi refugee camp. They mention that the water flowing from the source wells had little or no microbial contamination although the water collectors quickly contaminated their water. Analysis of water samples demonstrated that there was a 69% reduction in the geometic mean of faecal coliforms levels in household water and 31% less diarrhoel disease in children under 5 years of age among the group using an improved bucket.
- Jensen et al., (2002) realized a field study in Pakistan aiming to investigate the relative importance of the domestic contamination of drinking water. Results showed that the domestic bacteriological contamination is important only when the water source is relatively clean (<100 *E. coli*/100ml). When the number of E.coli in the water source is above this value, intervention to prevent the domestic contamination would have a minor impact on water quality compared to an intervention at the source of water. Although the bacteriological water quality improved, elimination of direct hand contact with the stored water inside the household could not prevent the occasional occurrence of extreme pollution of drinking water at its source. This shows that extreme contamination values that are often thought to originate within the house have to be attributed to the public domain transmission ie filling and washing of the water pitchers.
- In the conclusion of his report on the implementation of ceramic candles filters in Colombia, Fesselet, (2003) mention that a clear output of the monitoring system was that maintenance of the drinking water container is critical to maintain a high quality

drinking water. The main recommendation given to users was to clean the drinking water container and the tap once a week with a chlorine solution

- Brick et al., (2004) mentioned that despite the requirements for provision of safe drinking water in municipal areas, in practice the water supplied in Vellore (South India) is contaminated and current households storage practices increased the level of contamination in at least two-thirds of households.
- In June 2004, an outbreak of shigellosis was confirmed in Abou Shouk camp in the Northern Darfour province of Sudan (Oxfam, 2004, personal communication). As water testing at the source showed no contamination, it was assumed that post-collection contamination was taking place. Containers quickly became contaminated once removed from the source and kept in the home. A mass cleaning and chlorination of all water containers was decided. Diarrhoea data showed a dramatic fall in cases following this cleaning campaign.

From a more general point of vue, Wright et al., (2004) realized a systematic meta-analysis of 57 studies measuring bacteria counts for source water and stored water in the home to assess how contaminations varied between settings. They concluded that most studies of change in the microbiological quality of water at source and point-of-use indicate a decline after collection, although there is significant variation between settings. This decline, measured in terms of faecal and total coliforms is proportionately greater where source water is largely uncontaminated: increased faecal and total coliforms counts in stored domestic water are especially found in urban areas with uncontaminated supplies. Nevetheless, they concluded that microbiological contamination of water between source and point-of-use is widespread and often significant. The percentage of point-of-use samples contaminated with faecal coliforms was also lower where households generally covered their water containers.

It can be concluded from this section that key factors in the provision of safe household water include the conditions and practices of water collection and storage and the choice of water collection and storage vessels.

4. Evaluation of the health impact of the microorganisms and of the chemical components not removed by some of the household water treatment systems.

4.1 Description and health impact of the non-removed waterborne pathogens

(Micro)organisms that are potentially not removed by one or by several pre-selected household drinking water systems are described in this section. Information regarding their respective negative impacts on immunocompetents and on immunocompromised people is also provided. Furthermore, Table 25, located at the end of this section 4 presents a summary of the hereunder information.

4.1.1 Enteric viruses

More than 140 different enteric viruses are known to infect man. They are excreted in the faeces of infected individuals and may directly or indirectly contaminate water intended for drinking. Once in the environment, they can survive for long periods of time. The enteric virus include the enteroviruses, rotaviruses, hepatitis A and E, Norwalk and Norwalk-like viruses, adenoviruses and reoviruses. They are transmitted by the faecal-oral route, infect the gastrointestinal or respiratory tracts and are capable of causing a wide range of illness, including diarrhea, fever, hepatitis, paralysis, meningitis, and heart disease.

Viral gastroentiritis occurs with two epidemiologic patterns, diarrhoea that is endemic in children and outbreaks that affect people of all ages. Viral diarrhoea in children is caused by the group A rotaviruses, enteric adenoviruses, astroviruses and the human caliciviruses (predominantly Noroviruses) (Ashbolt, 2004). The illness affects all children worlwide in the first few years of live, regardless of their level of hygiene, quality of water, food or sanitation or type of behaviour.

Rotaviruses

Rotaviruses are wheel-shaped, nonenveloped double-shelled viruses that cause intestinal illnesses. It is the most common cause of severe diarrhea among infants and children. The disease is characterized by vomiting, watery diarrhoea for 3-8 days, dehydration and fever and abdominal pain occur frequently (Abbaszadegan, 1999). They strike young children with similar frequency throughout the world, but the mortality rate is high in developing countries only, with some 870 000 per year. Rotavirus is one of the major cause of viral gastroenteritis worldwide and several waterborne outbreaks have been documented. The disease is more severe for the very young, the elderly and the immunocompromised. Case fatality rates in the United States are 0.01% in the general population, 1% in the elderly, and up to 50% in the immunocompromised (Gerba et al., 1996).

Adenoviruses

Adenoviruses are medium-size (90-100 nm), nonenveloped viruses containing double-stranded DNA. There are 49 immunologically distinct types that can cause human infections. Adenoviruses most commonly cause respiratory illness; however, depending on the infecting serotype, they may also cause various other illnesses, such as gastroenteritis, conjunctivitis, cystitis and rash illness (Crabtree et al., 1997; CDC, 2004). Symptoms of respiratory illness caused by adenovirus infection range from the common cold syndrome to pneumonia and bronchitis. Patients with compromised immune systems are especially susceptible to severe complications of adenovirus infection (CDC, 2004). According to Crabtree et al., (1997), adenovirus infections are usually acute and self-limiting with a greater severity of illness occuring in the immunocompromised. Enteric adenoviruses 40 and 41 cause gastroenteritis, usually in children and they cause mortalities as great as 50% in immunmocompromised people (Gerba et al., 2002). According to Hierholzer, (1992), adenoviruses are among the many pathogens and opportunistic agents that cause serious infection in the HIV-infected patients. Adenoviruses infections in these patients tend to become disseminated and severe. It has been estimated that adenoviruses cause active infection in 12% of AIDS patients and that 45% of these infections terminate in death within 2 months. In all immunocompromised patients, generalized illness involving the central nervous system, respiratory system, hepatitis and gastroenteritis usually have a fulminant course and result in death (Hierholzer, 1992).

Adenoviruses are very resistant and are very stable in the environment in general. They appear to be resistant to UV disinfection (Meng and Gerba, 1996; Gerba et al., 2002, Thurston-Enriquez et al., 2003), and also have a high thermal stability (Enriquez, 1999).

Caliciviruses (predominantly *Noroviruses*):

Among the known Caliciviruses pathogens of humans are the Noroviruses (previously known as Norwalk-like viruses) and the Sapporo-like viruses. For most of the enteric viruses, infection early in life provides immunity from severe disease upon re-infection. In contrast, epidemic viral diarhheoa is caused primarily by the *Norovirus* genus of the human caliciviruses. These viruses affect people of all ages and are often transmitted by faecally contaminated food or water. The tremendous antigenic diversity of caliciviruses and short-lived immunity to infection permit repeated episodes throughout life. The principal symptom is diarrheoa, additional symptoms include abdominal pain and cramping, low fever, headache, nausea. Human fatality is usually rare if the patients are otherwise in good health but the disease may be severe in immunologically compromised and elderly patients (Hurst, 1999).

Because they cannot be grown in cell cultures, very little is known about the survival of this type of virus in the environment. It has been shown that caliciviruses can pass through water purification filters and remain infectious even at standard levels of chlorine in drinking water : Keswick et al., (1985) mention that a 3.75 mg/L dose of chlorine (resulting in no free residual chlorine) was found to be effective gainst other viruses but failed to inactivate Norwalk virus. A dose of 10 mg/L (with a free chlorine residual of 6 mg/L Cl_2 measured after 30 minutes) was found to inactivate the same virus. According to Leclerc et al., (2002), enteric viruses such as caliciviruses and some protozoan agents, such as *Cryptosporidium* (see 4.4.5), are the best candidates to reach the highest levels of endemic transmission, because they are ubiquitous in water intended for drinking, being highly resistant to relevant environmental factors, including chemical disinfecting procedures.

Other waterborne enteric viruses of importance: that cause non-diarrhoeal diseases include Hepatitis A and E, enterovirus 71 and various enteroviruses (Polio, Coxsachie and ECHO viruses). Hepatitis A (HAV) and Hepatitis E (HEV) viruses are associated with inadequate water supplies and poor sanitation and hygiene, leading to infection and inflammation of the liver. Nevertheless, poor sanitation in developing countries results in early infection of HAV and lifelong protection from the severe ill effects seen in unexposed people.

HAV causes a disease known as infectious hepatitis, which is an acute inflammation of the liver. The mortality rate of hepatitis A is low, less than 0.3%in the US, but can be higher in more suceptible members of the population and in other countries where additional factors contribute to poor health (Sobsey, 1999). HAV is one of the more persistent enteric viruses in the environment. It is resistant to drying and dessication and also relatively resistant to high temperatures and can survive to some pasteurization conditions. Removal of HAV by coagulation-flocuculation and filtration is similar to that of other enteric viruses, with reduction up to 99%. Disinfection of water with chlorine or UV can achieve up to 99.99% inactivation under optimum conditions. If HAV is protected within organic matter or other particles, rates of inactivation can be dramatically reduced.

Hepatitis E virus (HEV) is a calicivirus. HEV also causes infectious hepatitis that is nearly indistinguishable from HAV and can also be waterborne. HEV seems responsible for the majority of cases of hepatitis that occur in Asian countries. For HEV, the mortality rate is usally low (from 0.1 to 4%), with an important variability that may be strongly strain-dependant. The illness may be very severe among pregnant women, (with mortality rates reaching 25%), as seen during outbreaks in China, Indian subcontinent, southeast and central Asia, the Middle East, parts of Africa and Mexico. Little information exists about the environmental stability of this virus. Tomar (1998) mentions that a free residual chlorine concentration of at least 0.5 mg/l for a minimum of 30 minutes is considered adequate to eliminate HEV and to provide good quality drinking water. However, according to internal MSF sources, concentrations of chlorine residual of 0.3 to 0.6 mg/L will not provide an efficient removal of the HEV virus. Concentration of 1.5 to 2.5 mg free chlorine residual are probably needed to sufficient to obtain this removal (Guthmann, 2004, personal communication).

4.1.2 *Shigella*

The genus *Shigella* is included in the family *Enterobacteriaceae*, a large and diverse group of bacteria found in soil, water, wastes, plants and the normal flora of animals. This genus consists of four species, causing acute gastroenteritis in humans by invading the intestinal mucosa. Shigellosis is characterized by diarrheoa, fever, nausea, vomiting and cramps. Illness ranges from mild, self limiting diarrheoa while complications may include sepsis, seizure, renal failure and haemolytic uraemia syndrome depending on the age and the immune status of the patient (Perdomo et al., 1994). Immunity from natural infection is short-lived and no effective vaccine is available.

Shigella infections are usually restricted to the intestine. Few cases of *Shigella* being isolated from the blood (named "bacteraemia") were reported and most of these are from children, usually in neonates and the malnourished (Trevett et al., 1993). In the small number of adult cases of *Shigella* bacteraemia which have been reported, there appears to be an association with underlying disease and immunosuppression, including AIDS (Baskin et al., 1987 ; Huebner et al., 1993 ; Trevett et al., 1993). According to Simor et al., (1989), patients with AIDS may be prone to developing chronic shigellosis because of impaired intestinal cell-mediated immunity. HIV-seropositive patients who develop *Shigella* infections may require prolonged treatment and/or suppressive therapy, similar to those infected with Salmonella (Kristjansson et al., 1994).

Transmission occurs primarily through direct or indirect faecal-oral contact with patients or carriers. Faecally contaminated food or water also transmit this disease. Shigelossis occurs worldwide and is most common in areas where sewage treatment and personal hygiene are poor to non-existent. Outbreak can occurs in day-care centers, nursing homes, refugee camps from contamination of food or water and by person-to-person contact. Waterborne outbreaks of Shigellosisi most commonly results from faecal contamination of water supplies. Outbreaks are also associated with recreational exposure to faecally contaminated swimming and wading pools, and polluted surface water such as lake and ponds. *Shigella* has been implicated in large epidemics in developing countries worldwide (Nel and Markotter, 2004). Despite scientific advances over the past century, the epidemiological characteristics, virulence and ability to develop drug resistance has led to renewed and increased incidence of *Shigella*.

Water and wastewater treatment processes incorporating disinfection are sufficient for inactivation of *Shigella*. *Shigella* are sensitive to chlorination at normal levels, and they do not compete favorably with other organisms in the environment. Nevertheless, on the basis of the information presented on Figure 1, *Shigella* is relatively resistant to temperature. According to the New Zealand Ministry of Health (2001), temperatures above 65°C must be used to rapidly inactivate this microorgansim.

4.1.3 *Salmonella*

The genus *Salmonella* is also included in the Family *Enterobacteriaceae*. This genus includes a wide variety of serotypes pathogenic for humans or animals and usually for both. Three clinically distinguishable forms of salmonellosis occurs in human including gastroenteritis, enteric fever and septicemia.

Gastroenteritis is an infection of the colon characterized by diarrhea, fever and abdominal pain. The infection is usually self-limiting, lasting two to five days. Enteric fever is caused by *S. typhi* (typhoid fever) and *S. paratyphi* (paratyphoid fever). Symptoms include sustained fever, diarrhoea, abdominal pain and may involve fatal liver, spleen, respiratory and neurological damage. Symptoms persist for two to three weeks. Enteric fever from *S. typhi* is more prolonged and has a higher mortality rate than paratyphoid fever. Septicemia is characterized by chills, high remitent fever, anorexia and bacteremia. Organisms may localize in any organ and produce lesions resulting in meningitis, endocarditis, pneumonia.

Reservoirs of Salmonella are domestic and wild animals. Humans also serve as a reservoir (convalescent carriers and those with asymptomatic infections). Infection occurs through ingestion of food or water contaminated with feces from infected hosts or by the ingestion of the infected meat products. Salmonella represents a major communicable worldwide disease problem. The annual occurrence of thypoid fever is estimated at 17 million cases with 600 000 deaths (Covert, 1999). Large numbers of Salmonella may be present in contaminated surface water and waste treatment plant influents and effluents.

Salmonellosis is estimated to be nearly 20 times more common and 5 times more often bacteremic in AIDS patients than in patient without AIDS (Celum et al., 1987 ; Sperber and Schleupner, 1987). In AIDS-infected patients, non-typhoidal salmonellosis is often life-threatening and relapsing. Jacobs et al., (1985) mention that salmonellosis in patients with AIDS was unusually severe, characterized by widespread infection, bacteremia and relapse, despite standard antibiotic treatment. Due to the difficulty in eradicating salmonella infection in these patients, long-term suppressive treatment with antibiotics seems warranted. Salmonellosis may occur in patients with an established diagnosis of HIV, or it may be manifestation of this disorder (Sperber and Schleupner, 1987 ; Glaser et al., 1985). *Salmonella* should be considered among the pathogens associated with HIV infection.

Chlorination is effective for inactivating *Salmonella* (this organism is as susceptible to chlorine disinfection as *E. coli*) in properly maintained distribution systems using conventional treatments. Nevertheless, on the basis of the information presented on Figure 1, *Salmonella* appears to be resistant to heating, up to 60°C.

4.1.4 Pathogenic Environmental Mycobacteria

Mycobacteria are a large group of microorganims that inhabit a diverse range of natural environments and some species are capable of infecting humans and animals. The *Mycobaterium tuberculosis* complex (*M. tuberculosis*, *M. bovis* and *M. Africanum*) includes the species pathogenic for humans and animals, and mycobacteria other than M. tuberculosis, include the formerly called atypical mycobacteria. Some of these non-tuberculosis mycobacteria are capable of causing disease. The most common among these include the *Mycobacterium avium* complex (*M. avium* and *M. intracellulare*). In contrast to tuberculous bacteria that live and grow in human tissue, non-tuberculous mycobacteria are free-living saprophytes that are widely distributed in the environment : water, soil, dust and aerosols. They have been recovered from many piped and treated drinking water sources throughout the world, where their high resistance to disinfection by chlorine contributes to their persistence in drinking water systems (Leclerc et al., 2004).

The concern about non-tuberculosis mycobacterial diseases has been completely changed by the emergence of the AIDS epidemic throughout the world. Before and still today, in immunocompetent people, non-tuberculous mycobacterial disease was primarily a pulmonary disease (caused by *M. kansasii*, *M. avium* and *M. intracellulare*) and in the absence of evidence of person-to person transmission, it was suggested that man is infected from environmental sources via aerosols. However, with the advent of the AIDS epidemic in the United states and Europe, in immunodeficient individuals, non-tuberculous mycobacterial disease is usually systemic with principally M. avium, isolated commonly from either blood or stool. In AIDS-patients, the infection is acquired predominantly through the gastrointestinal tract where it is able to translocate the intestinal mucosa, infect and replicate in the submucosal macrophages and cause bacteremia leading to dissemination of the organism.

The greatest increase in *Mycobacterium avium* complex (MAC) infections is seen in AIDS-patients. Approximately 25 to 50% of these patients suffer debilitating and life-threatening infection. (Le Chevallier, 1999). In the developing world, where the incidence of tuberculosis is high, the rate of non-tuberculous mycobacterial diseases in AIDS people is low, probably because patients die of other infections before they reach a stage at which the slow onset of *M. avium* disease develops (Leclerc et al., 2004).

There is a growing body of evidence to show that (drinking or bathing) water can be a significant vehicle for the transmission of these organisms, especially for people with HIV disease or in hospitals, but the epidemiological characteristics of these mycobacterial infections in HIV patients remain poorly understood, especially in terms of the mode of transmission. From a public health point of view, the occurence of bacteria of the *M. avium* complex in drinking water systems does not appear to pose any particular risk for the general population (Leclerc et al., 2004).

The biology and ecology of pathogenic environmental Mycobacteria render them highly resistant to chlorine (more species survive treatment with 1 mg/L free chlorine) and the other chemical disinfectant used in the treatment of drinking water. They are able to grow in water samples to which no additional nutrient substrate has been added and are able to colonize surfaces and form biofilms. Many sources of water, in particular surface water, will be contaminated with some species of pathogenic environmental Mycobacteria. Consequently, the early stages of water treatment (floculation, sedimentation and filtration) are the most important barrier to the transfer of pathogenic environmental Mycobacteria into the water to be drunk (Le Chevallier, 1999).

4.1.5 *Cryptosporidium parvum*

Cryptosporidium parvum, a leading cause of persistent diarrhoea in developing countries (Guerrant, 1997), is a most highly infectious enteric pathogen. This protozoa is found in untreated surface waters, in swimming and wade pools, day-care centers and hospitals. It is resistant to chlorine, small and difficult to filter and ubiquitous in many animals. Numerous potential animal and water sources have been found to be infected with *Cryptosporidium parvum*. Infection begins when a person ingests the chlorine-resistant, thick-walled oocysts. Infection may occur with ingestion of as few as 30 oocysts (some have occurred with just one oocysts) (Guerrant, 1997).

It is recognized as a cause of severe, life-threatening diarrhea in patients with AIDS as well as in previously healthy persons. The organism can cause illnesses lasting longer than 1 to 2 weeks in previously healthy persons. In persons with AIDS, it causes a prolonged, severe life-treatening diarrhoeal illness to which there is no effective treatment (Guerrant, 1997; Arag et al., 2003). Immunodeficient individuals, especially AIDS patients, may have the disease for life, with severe diarrhea and invasion of the pulmonary system contributing to death. Patients with late-stage AIDS are highly suceptible to cryptosporidiosis: several studies mention that the most common pathogen associated with diarrheoa in AIDS was Cryptosporidium (Manatsathit et al., 1996; Endeshaw et al., 2004). Table 24 presents the rates of Cryptosporidium infection among immunocompetent and HIV-positive persons in industrialized and developing areas.

Table 24: Rates of *Cryptosporidium* infection among immunocompetent and HIV positive persons in industrialized and developing areas.

Adapted from Guerrant, 1997		Patients with diarrhea	Controls without diarrhea
Immuno-competent	Industr. areas	2.2% (0.26-22)	0.2% (0-2.4)
	Developing areas	6.1% (1.4-40.9)	1.5% (0-7.5)
HIV-positive	Industr. areas	14% (6-70)	0% (0-0)
	Developing areas	24% (8.7-48)	5% (4.9-5.3)

Waterborne outbreaks of cryptosporidium infection can result in significant mortality, particularly among immunocompromised populations (Hoxie et al., 1997). Of the first 58 cases of cryptosporidiosis described in humans by 1984, 40 were in immunocompromised patients who contracted severe, often irreversible diarrheoa (lasting longer than 4 months). Of these 40 patients, 33 had AIDS. 55% of the 40 immunocompromised patients died. In two of 12 documented waterborne outbreaks in North America since 1985, mortality rates in the immunocompromised ranged from 52 to 68%.

Cryptosporidium also appears to be one of the leading causes of diarrhea, especially persistent diarrhea, among children in northeastern Brazil (Fang et al., 1995; Wuhib et al. 1994). In addition, the incidence of diarrhea has been nearly double for many months in young children after symptomatic cryptosporidial infections, suggesting that the disrupted barrier function in infected children leaves residual damage resulting in increased susceptibility of injured epithelium to additional diarrheal illnesses (Guerrant, 1997). This means that, in young children in developing countries, cryptosporidiosis predisposes them to substantially increased diarrheal illnesses.

Even if there is evidence that modes of transmission for *Cryptosporidium* other than drinking water exist, removal of cysts from the water to be treated is important. Due to the resistance of cysts to chlorination, their eradication from drinking water depends on adequate flocculation and filtration rather than chlorination.

A similar gastroenteritic disease to cryptosporidiosis is cyclosporiasis, also caused by a coccidian parasite: *Cyclospora cayetanensis*. Infections typically last an average of 7 weeks, up to four months in AIDS-patients. Symptoms mimic those caused by cryptopsoridiosis, including mild nausea, anorexia, abdominal cramping and watery diarrheoa (Ortega, 1999). Cyclosporiasis is most common in tropical and subtropical regions, but large outbreaks were recently reported in the Unites States, Canada and United Kingdom. Apart from faecally contaminated water, various types of fresh fruits or legumes have been indicated as a source of the parasite (Nel et al., 2004). *Cyclospora* oocysts, like *Cryprosporidium* oocysts are resistant to chlorine, but they are twice the size and may be more easily removed by floculation and filtration treatment methods. The emergence of this parasite was influenced by the AIDS epidemic, like in the case of *Cryptosporidium*.

4.1.6 *Giardia lamblia*

Giardia lamblia is a protozoan parasite that infects numerous mammals (domestic and wild animals), including humans. Giardia is found in the lumen of the small and large intestine, thus making it an enteric parasite. Once installed in the host’s intestinal tract, Giardia will produce a resisant, dormant transmission form, which is referred to as a cyst. Cysts are then defaeceted by the infected host. The cyst is round to oval with dimensions ranging from 8 to 18 μm long by 5 to 15 μm wide. It can survive for long periods outside the host, especially in cold water.

G. lamblia has a worldwide distribution and is indeed the most common intestinal parasite of humans worldwide (Marshall et al., 1997). The gathering of young children in day-care centres provides the ideal setting for transmission of infectious diseases. Bad hygiene is a major cause for this phenomenon. *G. lamblia* is transmitted as a faecal contaminant of food or water. Giardiasis is a major public health concern especially in developing countries, and waterborne outbreaks often occur. Furthermore, studies in a peri-urban shanty town in Lima, Peru, suggest that Giardia lamblia is hyperendemic in children (<10 years old) and despite treatment, 98% of the children became re-infected within 6 months (Ashbolt, 2004).

G. lamblia is known to produce gastrointestinal distress, including diarrheoa, weight loss, flatulence, cramps, vomiting, fatigue, mucus in the stool and bloody and foul smelling stool. It can produce a continuum of pathologies ranging from no symptoms to illness requiring hospitalization. The strain of parasite, along with the immune competency and health status of the host are important factors (Schaefer, 1999). The symptoms are especially severe in AIDS patients (Faubert, 1996). The prevalence rate of diarrhea caused by *Giardia lamblia* in AIDS-patients is higher than in those without AIDS, due to humoral immune defect in AIDS-patients (Moolasart, 1999).

Filtration processes, including diatomaceous earth filtration, slow sand filtration, and coagulation-filtration, when applied appropriately can remove *Giardia* cysts at levels of 99% or more. Chemical disinfectants such as free chlorine, are known to inactivate them, when appropriate conditions of pH, temperature, disinfectant concentration and contact time are used. A multiple-barrier approach to water treatment is the most prudent policy.

4.1.7 Helminths ova

Infection by intestinal parasitic worms is widespread throughout the world, affecting millions of people. Children are particularly susceptible and typically have the largest numbers of worms, which cause significant health problems.

Ascariasis is an infection of the small intestine caused by *Ascaris lumbricoides*, a large roundworm (nematode). *Ascaris lumbricoides* appears to be specific to humans. Recent estimates for the worlwide prevalence of acasriasis is 1275 millions infections. Infections are generally acquired during the first or second year of age, peak in children 5 to 15 years old. They then stabilize across the adult ages. The mean number of worms per person peaks in the 5-15-years olds and decline markedly in adults.

Symptoms (loss of appetite, distended and painfull abdomen, coughing, fever, vomiting, diarrhoea) can be due to migrating larvae, adult worms or both. Symptoms are more severe with more larvae or adult worms, or both. Pulmonary and intestinal infection, allergy to Ascaris allergens and other complications can all give rise to symptoms. Adult worms may produce mild abdominal pain. Ascaris is responsible for 35% percent of intestinal obstruction in endemic areas. Chronic ascariasis is widely recognized as a contributing factor impairing nutritional status

The eggs are found in soil contaminated by human faeces, sewages, sludge or in uncooked food contaminated by soil containing eggs of the worm. They have also been found in surface water, ground water and seawater. Asciariasis occurs with the greatest frequency in tropical and subtropical areas with inadequate sanitation and is linked to bad socioeconomic conditions. Ascaris ova are among the most environmentally resistant of intestinal pathogens (the embryo develops into the infective larva outside the body of the host and due to this, ova are well-suited to prolonged survivals in the environment). Effective coagulation and filtration processes remove Ascaris ova. Chlorine and chloramine are ineffective against ascaris ova (Smith et al., 1999). Exposure to UV light early in embryonation destroys the developing embryo.

Other important enteric helminths in developing countries include whipworms (*Trichuris trichiura*) and hookworms (*Ancylostoma duodenale and Necator americanus*) (Ashbolt, 2004). Hence there are a range of helminths potentially transmitted by water, but due to their large size (ova > 40 μmdiameter) they readily settle out in treatment ponds and are easily removed from drinking water by filtration when applied.

Many problems caused by these worms are chronic and long lasting (malnutrition, underweight, bowel obstruction, anaemia, retardation of mental and physical development), but can also lead to severe infections and death. Helminthic infections are common in vast regions of the world, especially in the developing countries, and they affect more than 1.5 billion people. In addition, millions of individuals in these countries also have other chronic infectious diseases such as malaria, tuberculosis and HIV. The constant and lifelong confrontation of these hosts with such infectious burden lead to a persistent activation of the immune system and unbalanced immune state. Vast populations on the globe, especially in africa and Asia are thus in a chronic immune-activation state (Borkow et al., 2000).

According to different authors (Bentwich et al., 2000; Borkow et al., 2000; Gopinath et al., 2000; Wolday et al., 2002), helminth infections that are endemic in Africa could have profound effects on the host immune system due to:

- the chronic immune activation that results in hyporesponsiveness and anergy
- this immune activation may diminish the capacity of these individuals to cope with infections and makes the host more susceptible for HIV infection. It increases the plasma viral load with infection and impairs cellular immunity
- together, they account for rapid spread and progression of HIV infection in helminth infested regions, and will probably undermine HIV vaccine success.

Table 25 presents a summary of the information described in sections 3 and 4.1, regarding the microorganisms most susceptible to be not removed by the different household water systems and their respective negative impacts on health of immunocompetent and immunocompromised people.

4.2 Description (and health impact) of the non-removed chemicals and other components

Table 26 presents a summary of the information described at section 3 regarding the effectivess of the different households drinking water treatment systems for the removal of some chemicals (iron and manganese, arsenic) and other "components" (taste and odour, organic substances and turbidity) that can be present in drinking water. At the exception of arsenic, these component do not have a direct effect on health, but their presence (absence) can be considered as a sign of the bad (good) quality of the water. Indeed, aesthetic (color (iron-manganese), presence of deposits (turbidity)) and organoleptic criteria (taste and odours) are the main, and often the only way in which the consumer evaluates the quality of drinking water. Drinking water must be acceptable to consumers from the aesthetic and organoleptic point of view. This acceptability relates indirectly to health, since the rejection of unacceptable water may lead consumers to use alternative waters that may be unsafe.

- Iron and manganese: these chemicals are not suspected of causing direct health effects through their presence in drinking-water. Nevertheless, they can cause severe discoloration of water and unpleasant metallic taste and odour, which may lead to consumers to turning to other, microbially unsafe sources of drinking-water.
- Arsenic is responsible for severe health effects due to exposure through drinking water in many countries. It can cause severe skin lesions and be at the origin of certain cancers (internal, skin) (Smith et al., 2000). Up to now, data mentioning a different impact of this contaminant on immunocompetent and immunocompromised people do apparently not exist.
- Taste and odour in drinking water may arise from biological sources (crustaceans, fungi, bacteria) or from chemical sources (disinfectant residuals, disinfection by-products, interaction between treated water and materials used in storage reservoirs or piping). Again, their presence in water which may lead to consumers to turning to other, microbially unsafe sources of drinking-water.

- Organic substances can be present under the dissolved or undissolved form in the water. They cover a wide range of compounds, which feature differing physical and chemical properties. The nature and properties of organic matter give rise to esthetic concerns, lead to the transport of contaminants, produce undesirable dysinfection by-products during oxidation processes. If not removed from drinking water, this organic matter can also serve as a substrate for the bacteria to grow.
- Turbidity can be defined as the reduction in transparency of a liquid due to the presence of undissolved matter. It can indicate the degree of physical pollution of water to be treated or the quality of water delivered for human consumption. Correlations are often drawn between turbidity and the suspended solid content.

Household process/system	Microorganisms not removed	Negative impacts on immunocompetents	Negative impacts on immunocompromised
Heating water by boiling	-	-	-
Heating water to pasteurization temperatures (fuel/firewood/solar)	Enteric viruses (B) (Hepatitis A virus is specially resistant)	Diarrhea, fever, hepatitis, meningitis, paralysis, respiratory illnesses, heart disease	Illness is, in most cases, more severe and can lead to death
	Shigella (B)	Shigellosis (diarrheoa; fever, nausea, vomiting, cramps)	Shigellosis more severe (bacteremia, may become chronic or fatal)
	Salmonella (B)	Salmonellosis, under three clinically dsitinguisable forms: gastroenteritis, enteric fever and septicemia	Salmonellosis more severe, widespread infection, bacteremia and relapse
	Helminth ova (B)	Chronic problems (malnutrition, underweight, anaemia,…), may lead to severe infections and death	Patients more susceptible for HIV infection, cellular immunity is impaired.
Solar disinfection	Enteric viruses (B)	Diarrhea, fever, hepatitis, meningitis, paralysis, respiratory illnesses, heart disease	Illness is, in most cases, more severe and can lead to death
	Helminth ova (B)	Chronic problems (malnutrition, underweight, anaemia,…), may lead to severe infections and death	Patients more susceptible for HIV infection, cellular immunity is impaired.
UV lamps disinfection	Adenoviruses (B)	Respiratory illnesses, gastroenteritis	Respiratory illnesses, gastroenteritis +severe complications
Chemical disinfection (chlorination)	Pathogenic mycobacteria (A)	Pulmonary disease	Bacteremia, disseminated infection of the organism. Debilitating and life-threatening infection.
	Cryptosporidium parvum (A)	Diarrheal illnesses (1-2 weeks)	Diarrheal illnesses (more severe/indefinitely)
	Cyclospora cayetanensis (A)	Diarrheal illnesses (7 weeks)	Diarrheal illnesses (4 months)
	Calicivirus (B)	Epidemic viral diarrhea	More severe disease
	Giardia lamblia (B)	Diarrheal illnesses. May lead to weight loss and dehydration	Diarrheal illnesses (more serious infection that can lead to severe illness or death)
	Helminth ova (B)	Chronic problems (malnutrition, underweight, anaemia,…), may lead to severe infections and death	Patients more susceptible for HIV infection, cellular immunity is impaired.
Chemical disinfection (chlorination) combined to a coagulation/flocculation	-	-	-
Ceramic candle filters (made according to high quality standards and silver coated)	Enteric viruses (C)	Diarrhea, fever, hepatitis, meningitis, paralysis, respiratory illnesses, heart disease	Illness is, in most cases, more severe and can lead to death

(A): Not removed by the system; (B): Probably not removed by the system when used in non-optimal conditions (see section 3 for what are those non-optimal conditions); (C): May not be removed : additional information needed on that subject.

Table 25: (Micro)organisms most susceptible to be not removed by the pre-selected households drinking water systems and their respective negative impacts on healt of immunocompetent and immunocompromised people.

Process	"Contaminant"	Removed	Added	**Negative impacts on health**
Heating water by boiling	• Iron and manganese • Arsenic • Taste and odour • Organic substances • Turbidity	• No • No • No • No • No		• - • Skin lesions, cancers (internal, skin) • - • - • -
	• Disinfection by-products		• No	•
Heating water to pasteurization temperatures (fuel/ firewood/solar)	• Iron and manganese • Arsenic • Taste and odour • Organic substances • Turbidity	• No • No • No • No • No		• - • Skin lesions, cancers (internal, skin) • - • - • -
	• Disinfection by-products		• No	•
Solar disinfection	• Iron and manganese • Arsenic • Taste and odour • Organic substances • Turbidity	• No • No • No • No • No		• - • Skin lesions, cancers (internal, skin) • - • - • -
	• Disinfection by-products		• No	
UV lamps disinfection	• Iron and manganese • Arsenic • Taste and odour • Organic substances • Turbidity	• No • No • No • No • No		• - • Skin lesions, cancers (internal, skin) • - • - • -
	• Disinfection by-products		• No	
Chemical disinfection (chlorination)	• Iron and manganese • Arsenic • Taste and odour • Organic substances • Turbidity	• No • No • No • Yes • No		• - • Skin lesions, cancers (internal, skin) • - • - • -
	• Disinfection by-products		• Yes	• Potentially carcinogenic (long-term impact)

Chemical disinfection (chlorination) combined to a coagulation/flocculation	• Iron and manganese • Arsenic • Taste and odour • Organic substances • Turbidity	• N.A. • Yes • N.A. • Yes • Yes		• - • - • - • - • -
	• Disinfection by-products		• Yes	• Potentially carcinogenic (long-term impact)
Ceramic candle filters (manufactured according to high quality standards and coated with silver); without activated carbon.	• Iron and manganese • Arsenic • Taste and odour • Organic substances • Turbidity	• No • No • No/Yes* • Yes (partially)/Yes* • Yes		• - • Skin lesions, cancers (internal, skin) • - • - • -
	• Disinfection by-products		• No	• -

N.A.: information non available; *: insertion of adsorption media (activated carbon) could be done to remove taste and odour and organic susbstances.

Table 26: Effectiveness of the different households drinking water treatment systems for the removal of some chemical and other components

5. Conclusion-briefing paper

MSF Holland Briefing Paper
on
Household Water Treatment

INTRODUCTION

In many of the areas in which MSF work, we are faced with beneficiaries who are immunocompromised, either as a result of malnutrition, illnesses, HIV infection, trauma or a combination of these factors. For those who are immunocompromised, drinking safe water is of the utmost importance due to an increased susceptibility to infections caused by viruses, bacteria and protozoa – and the increased risk of developing infections that are more severe and that can lead to death.

A large number of household water treatment methods are available to make water suitable for consumption. They include ways of chemically or physically removing pathogens, chemical and/or physical particles. All methods have advantages, disadvantages and limitations in achieving water disinfection, as well as strengths and weaknesses in their suitability for implementation in different contexts.

To determine the most suitable household water treatment method in the specific situations where we work with immunocompromised people, a literature study has been carried out by MSF-Holland that provides an overview of the relevant treatment methods, their advantages and disadvantages, as well as the effects that the pathogens and particles remaining after treatment are likely to have on immunocompromised people. This Briefing Paper presents a summary and the conclusions of this study. The full report is available on request.

The study revealed that slow sand filtration, sterilisation (using fuel, firewood, solar radiation or cooking) and disinfection by ultraviolet (UV) (sun) light are not feasible at the household level in the situations where MSF works. Boiling, disinfection by chlorine (in some conditions) and the use of ceramic filters have been shown to be feasible.
This Briefing Paper will now present a summarised analysis of the three most viable household water treatment methods, looking in turn at the advantages, disadvantages and effectiveness of each method.

HEATING WATER BY BOILING

Boiling (method: bring water to a ‘rolling’ boil for a period of 1 to 5 minutes) is an extremely effective and simple way to completely remove all waterborne pathogens. This method of treatment can be effectively applied to all waters, including those with high turbidity or dissolved constituents. The ‘rolling’ boil represents a simple and safe indication of the treatment taking place. Although several disadvantages exist (including the absence of impact on chemical and other components that can be present in drinking water - see Tables 1 and 2), consumption of water that has been boiled the same day can be considered as safe for consumers, even if they are immunocompromised. Boiling of water, in emergency and non-emergency situations, can therefore be considered a valuable solution to bacteriological water quality issues at the household level. In many regions, the decision of whether or not to implement this method will probably be linked to problems relating to the availability, cost and sustainability of accessing suitable fuel sources.

Table 1: Advantages and disadvantages of treating water by boiling

+	-
+ Effective (if correctly applied in terms of temperature and time) in destroying all classes of waterborne pathogens (viruses, bacteria, bacterial spores, fungi, protozoa, helminth ova). + Can be effectively applied to all waters, including those with high turbidity or dissolved constituents. + ‘Rolling’ boil = indication (when temperature sensors are not available) of the efficiency of the treatment. + No particular equipment needed (with the exception of the energy source). + No need for highly skilled labour, so low level of training required.	- Consumption of energy (fossil fuels/firewood): problems of availability, cost (50 to 150 US$ a year for 40 L/day -the required volume for a family of 5) and sustainability in a lot of regions. Leading to the risk of incomplete treatment to save money. - No residual protection, leading to a risk of microbial recontamination from sources such as hands, and utensils during storage. Consumption should therefore ideally occur during the same day as treatment - the use of a lid is an asset. - Absence of impact on chemical and other components that can be present in drinking water. - People can be reluctant to boil. In this case, a strong promotional component could be required. - It takes time for the water to cool down: time between preparation and consumption can be long. - Risk of scalding (especially among children). - Boiling seems to affect the taste (but shaking the bottle will improve the taste).

It should be stressed that, as with all types of household treatment methods, the conditions and practices of water collection and storage and the choice of water collection and storage vessels are key factors in the provision of safe household water.

Table 2: Effectiveness of treating water by boiling regarding the removal of pathogenic (micro)organisms and of chemical and other "components" that can be present in drinking water.

Household process/system	**(Micro)organisms or contaminants**	**Removed**	**Negative impacts on immunocompetent people**	**Negative impacts on immunocompromised people**
Treating water by boiling	All (micro)organisms	Yes	-	-
	Iron and Manganese	No	-	-
	Arsenic	No	Skin lesions, cancers (internal, skin)…	Skin lesions, cancers (internal, skin),
	Taste and odour	No	-	-
	Organic substances	No	-	-
	Turbidity	No	-	-

CHEMICAL DISINFECTION (CHLORINATION)

A distinction should be made between the effectiveness of chlorine applied alone to water, and chlorine applied in combination with coagulation and flocculation. This paper will examine each of these methods separately.

Chlorination applied alone

If correctly applied (in terms of concentration and contact time), chlorine is effective against most waterborne pathogens including viruses. The results of several epidemiological studies give a clear confirmation of this effectiveness. Chlorination can also provide a stable residual level of chlorine (free residual chlorine) lowering the risk of potential microbial recontamination during storage.

However, to be effective, levels of chlorination must be adjusted to take account of pH, temperature and chlorine demand (a factor influenced by the presence of dissolved organic matter and particles). Low dosages of chlorine may lead to ineffective disinfection and high dosages may results in taste, odour and high levels of disinfection by-products. Due to this complexity, effective chlorination is difficult at the household level. For this reason, household chlorination is generally conducted using tablets or a dilute solution of fixed concentration (also known as 'standard-dose products' - SDPs) added to a determined volume of water. The objective of these products is to reach a sufficient level of free residual chlorine for all types of water, but this objective is not always met in practice due to variations in pH, temperature and particulate matter. The advantages of SDPs include their low cost and simplicity of use (Table 3).

It should also be noted that some organisms such as *Cryptosporidium parvum*, *Cyclospora cayetanensis*, mycobacteria, and to a lesser extent *Giardia lamblia*, some viruses, and helminth eggs are resistant to chlorine and are not significantly reduced even if chlorination is correctly implemented (Table 5). The failure to remove these microorganisms represents a serious threat to immunocompromised patients, especially from *Cryptosporidium* spp, which are the most common pathogens associated with diarrhoeal disease (cryptosporididiosis) in people with AIDS. Indeed, immunocompromised people may have the disease for life, leading to severe diarrhoeal illness to which there is no effective treatment and a risk of invasion of the pulmonary system, a potentially fatal complication. In addition, other problems exist with chlorination such as cultural resistance to the taste and odour of chlorinated water, and/or dependence on chlorine generating products which may not be locally produced (see Table 3). Furthermore, chlorine has no impact on the removal of chemicals and other components that can be present in drinking water.

Despite these shortcomings chlorine used on its own is a very effective method of water treatment that can be recommended in the case of short-term emergency situations or for long term improvements in drinking water quality at the household level particularly for immunocompetent users. For immuncompromised users, water treatment with chlorine alone is not a sufficient means of water treatment.

Table 3: Advantages and disadvantages of water treatment using chlorine alone

+	-
+ If correctly applied (in terms of concentration and contact time), chlorine: ● is effective against most waterborne pathogens including viruses, with the exception of *Cryptosporidium parvum*, *Cyclospora cayetanensis*, pathogenic environmental mycobacteria species and to a lesser extent *Giardia lamblia and* helminth eggs; ● provides a level of free residual chlorine lowering of the risk of microbial recontamination during storage + Inexpensive (with an initial cost of US$8/household (for special container for the water) + annual operating cost of US$3/household). + Proven and safe technology.	- Quality of the water will influence the effectives of microbial inactivation: ● particulate, colloidal and dissolved constituents in water will react with and consume chlorine. The efficiency of chlorination is reduced in turbid water (>5 NTU) ● pH and temperature of the water influence the effectiveness of chlorine disinfection. - The process must thus be adapted to take account of these factors and the level of free residual chlorine and/or microbial quality must be checked. These operations are hard to achieve at the household level. As a consequence, standard-dose products (SDP) are used. SDP's may not have a 100% disinfecting effect or can give a chlorine taste to the water.

	- Variable resistance of microorganisms regarding disinfection. - Potential production of disinfection by-products. - Free chlorine residual measuring required. - Cultural resistance to chlorine tasting water: a strong promotional component is thus required. - Dependent on, and with a risk of an interruption of, chlorine generating product if not locally produced.

Chlorination applied in combination with coagulation/flocculation

When chlorine is applied in combination with coagulation/flocculation (e.g. PuR® system), chlorine disinfection is a highly effective method of treatment against all waterborne pathogens (see Table 5). All the waterborne pathogens (including viruses), that are not normally completely inactivated by chlorine when used alone, will be:

- physically removed from the water during coagulation/flocculation; and/or
- completely inactivated by the chlorine - once the organic matter and particles responsible for most of the chlorine demand have been removed during the coagulation/flocculation process, chlorine is more effective against microorganisms.

The use of chlorine combined with coagulation/flocculation is a very effective method of water treatment that can be recommended for short-term emergencies situations. It can also be used for long-term improvements to drinking water quality at the household level, as confirmed by the results of the epidemiological studies available. Due to the excellent disinfection results obtained across a variety of water types, the combination method can be recommended when immunocompetent people are involved and also when water consumers are immunocompromised. Arsenic also seems to be effectively removed by this method.

This method of treatment can be considered for long-term use, but some drawbacks exist: the products required are expensive and volumes of water treated are low (see Table 4). The process also requires the addition of chemicals to the water leading to the formation of taste and odour and of disinfection by-products that may be toxic (carcinogenic) in the long term. A cultural resistance to chlorine tasting water and a dependence on externally produced chlorine generating products and coagulants may also exist.

Table 4: Advantages and disadvantages of combined treatment systems.

+	-
• Highly effective against all waterborne pathogens. • Can be effectively applied to all waters, including those with high turbidity or dissolved constituents, with high pH, and low temperature. • Provides a residual level of free chlorine lowering the risk of potential microbial recontamination and/or re-growth during storage. • Effective in removing arsenic from artificially or naturally contaminated samples. • No need for highly skilled labour, so only moderate level of training required, but clear instruction must be given regarding the type of cloth filter used and the way to handle it (reuse of the cloth, disposal of flocs). • Visually observable improvement in water quality (turbidity reduction).	• Expensive (initial cost of US$5-10/household for vessel + annual operating cost of US$35-55/household/year). • Difficulties in measuring the decrease in turbidity and/or levels of free residual chlorine. • Filter cloth may not be appropriate and may allow flocs to go through. • Potential production of disinfection by-products. • Low production capacity (10L/day/household) at the price mentioned above. • Cultural resistance regarding chlorine taste of the water. A strong promotional component could be required. • Dependence on external materials with the risk of an interruption of coagulant and disinfectant supply. • A standard dose of chlorine is used. It can be too little/much, according to the quality of water.

Table 5: Effectiveness of chlorination used alone and combined with coagulation/flocculation, regarding the removal of pathogenic (micro)organisms and of chemicals and other "components" that can be present in drinking water.

Household process/system	(Micro)organisms or contaminants	Removed	Negative impacts on immunocompetent people	Negative impacts on immunocompromised people
Chemical disinfection (chlorination)	All (micro)organisms, with the exception of ↓	Yes	-	-
	Pathogenic mycobacteria	No	Pulmonary disease	Bacteremia, disseminated infection of the organism. Debilitating and life-threatening infection.
	Cryptosporidium parvum	No	Diarrhoeal illnesses (1-2 weeks)	Diarrhoeal illnesses (more severe/indefinitely)
	Cyclospora cayetanensis	No	Diarrhoeal illnesses (7 weeks)	Diarrhoeal illnesses (4 months)
	Calicivirus (Norwalk/ Norwalk like viruses)	No*	Epidemic viral diarrhoea	More severe disease
	Giardia lamblia	No*	Diarrhoeal illnesses. May lead to weight loss and dehydration	Diarrhoeal illnesses (more serious infection that can lead to severe illness or death)
	Helminth ova	No*	Chronic problems (malnutrition, anaemia), may lead to severe infections and death	Patients more susceptible due to HIV infection
	Iron and Manganese	No	-	-
	Arsenic	No	Skin lesions, cancers (internal, skin)…	Skin lesions, cancers (internal, skin)…
	Taste and odour	No	-	-
	Organic substances	Yes	-	-
	Turbidity	No	-	-
Chemical disinfection (chlorination) combined with coagulation/flocculation	All (micro)organisms	Yes	-	-
	Iron and Manganese	Information not available	-	-
	Arsenic	Yes	-	-
	Taste and odour	Information not available	-	-
	Organic substances	Yes	-	-
	Turbidity	Yes	-	-

*likely not to be completely removed when chlorination is applied in non-optimal conditions in terms of turbidity, dissolved organic matter, pH, temperature.

CERAMIC CANDLE FILTERS

Good quality ceramic candle filters have micron or submicronic ratings and are impregnated or coated with colloidal silver for additional bacteriostatic effect (to prevent biofilm formation on the filter). Ceramic candle filters are highly effective against most waterborne pathogens (bacteria, protozoa, helminth eggs). Additional studies to evaluate their real effectiveness regarding virus removal are however needed and in the absence of such results, we consider it safest to assume that these microorganisms are not removed by the filters (Table 7). The results of the epidemiological studies available seem to confirm the fact that porous ceramic filters have the potential to provide improved drinking water to households in developing countries. They also confirm the fact that these filters can operate consistently regardless of turbidity levels, pH and temperature. Visual observation of the improvement in water quality (through turbidity reduction) is important for the household user, allowing him/her to confirm that the water has been satisfactorily treated and can be consumed, including by immunocompromised people.

Most of these results were, however, obtained on filters produced in developed or emerging countries, in compliance to high standards of quality control. These filters are highly efficient but they are expensive (Table 6). Accessibility, affordability and sustainability for household use by the poorest people is therefore uncertain. Ceramic candle filters can, however, be considered a sustainable and transferable technology than can be locally produced and commercially sold, even if, up to now, unresolved questions exist about the real effectiveness of these lower quality, cheaper and locally produced filters.

Insertion of adsorption media (activated carbon) in the candle can easily be done. Activated carbon filters have large surface areas that contaminants can adhere to. They are effective at removing many contaminants that can influence the taste and odour of water- especially organic compounds (Table 7).

Treating water through the use of ceramic candle filters (with or without activated carbon) does not require the addition of chemicals to the water avoiding chemical taste and odour problems and the creation of disinfection by-products – many of which are considered toxic (carcinogenic) in the long term. This method of treatment can be recommended for long-term use, notably in a development approach.

Table 6: Advantages and disadvantages of ceramic filtration

+	-
+ Highly effective against most waterborne pathogens (bacteria, protozoa, helminth eggs). + Operate consistently regardless of turbidity (but high turbidity leads to quick clogging: 15-20 NTU seems to be a maximum without pretreatment), pH, and temperature. + No addition of chemicals to the water. Therefore absence of formation of toxic disinfection by-products and/or taste and odour. + Easy to use and maintain, minimal instruction or need for behavioural change. + Visual observation of the water quality improvement (turbidity reduction). + High levels of user acceptability. + Sustainable and transferable technology than can lead to local production and commercialisation. In this case, cost are low: US$3 to US$10/household/year. + Insertion of adsorption media in the candle can reduce taste, odour and organic contaminants such as pesticides.	- Uncertain viral performance: additional studies needed. - No residual protection, but due to the configuration of the system, risk for potential microbial recontamination during storage is low. Higher risk if drinking water containers are hand-made. - Filtration effectiveness depends on pore size and the presence/absence of colloidal silver coating. - Relatively high cost if produced in developed countries: initial cost of US$35/household + US$5-10/year/household. Accessibility, affordability and sustainability for household use by the poorest people is thus uncertain. - Low production capacity (20L/day, or 0.5-2L/h, depending on the filter and the turbidity of water). - Breakage is possible. Even if only slightly cracked, filter is unsuitable for the removal of microorganisms. The crack may remain undetected for long periods. - Systems require regular cleaning (scrubbing-boiling) to remove accumulated materials and restore normal flow rate (each week or two weeks). - Candles must be changed (life expectancy of 6 months to 2 years).

Table 7: Effectiveness of ceramic candle filters (coated with colloidal silver and manufactured according to high quality control standards), in the removal of pathogenic (micro)organisms and of chemicals and other "components" that can be present in drinking water.

Household process/system	**(Micro)organisms or contaminants**	**Removed**	**Negative impacts on immunocompetent people**	**Negative impacts on immunocompromised people**
Ceramic candle filters (manufactured according to high quality control standards and coated with silver), without activated carbon.	All (micro)organisms, at the exception of ↓	Yes	-	-
	Enteric viruses	No*	Diarrhoea, fever, hepatitis, meningitis, paralysis, respiratory illnesses, heart disease	Illness is, in most cases, more severe and can lead to death
	Iron and Manganese	No	-	-
	Arsenic	No	Skin lesions, cancers (internal, skin)…	Skin lesions, cancers (internal, skin)…
	Taste and odour	No	-	-
	Organic substances	Yes (partially)	-	-
	Turbidity	Yes	-	-
Ceramic candle filters (manufactured according to high quality control standards and coated with silver), with activated carbon.	All (micro)organisms, at the exception of ↓	Yes	-	-
	Enteric viruses	No*	Diarrhoea, fever, hepatitis, meningitis, paralysis, respiratory illnesses, heart disease	Illness is, in most cases, more severe and can lead to death
	Iron and Manganese	No	-	-
	Arsenic	No	Skin lesions, cancers (internal, skin)…	Skin lesions, cancers (internal, skin)…
	Taste and odour	Yes	-	-
	Organic substances	Yes	-	-
	Turbidity	Yes	-	-

*until information becomes available.

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Annex 1

WHO staging system for HIV infection and disease in adults and adolescents (Annex E). In Scaling up antiretroviral therapy in resource-limited settings: treatment guidelines for a public health approach. 2003 revision. World Health Organisation, Geneva, Switzerland.

Clinical Stage 1

1. Asymptomatic
2. Generalized lymphadenopathy

Performance scale 1: asymptomatic, normal activity

Clinical Stage 2

3. Weight loss < 10% of body weight
4. Minor mucocutaneous manifestations (seborrhoeic dermatitis, prurigo, fungal nail infections, recurrent orl ulcerations, angular cheilitis
5. Herpes zoster within the last five years
6. Recurrent upper respiratory tract infections (i.e. bacterial sinusitis)

And/or performance scale 2: symptomatic, normal activity

Clinical Stage 3

7. Weight loss > 10% of body weight
8. Unexplained chronic diarrhoea, > 1 month
9. Unexplained prolonged fever (intermittent or constant), > 1 month
10. Oral candidiasis (thrush)
11. Oral hairy leucoplakia
12. Pulmonary tuberculosis
13. Severe bacterial infections (i.e. pneumonia, pyomyositis)

And/or performance scale 3: bedridden < 50% of the day during last month

Clinical Stage 4

14. HIV wasting syndrome*
15. Pneumocystic carinii pneumonia
16. Toxoplasmosis of the brain
17. Cryptosporidiosis with diarrhoea > 1 month
18. Cryptococcosis, extrapulmonary
19. Cytomegalovirus disease of an organ other than liver, spleen or lymph node (e.g. retinitis)
20. Herpes simplex virus infection, mucocutaneous (> 1 month) or visceral.
21. Progressive multifocal leucoencephalopathy
22. Any disseminated endemic mycosis
23. Candidiasis of oesophagus, trachea, bronchi
24. Atypical mycobacteriosis, disseminated or pulmonary
25. Non-typhoid Salmonella septicaemia
26. Extrapulmonary tuberculosis
27. Lymphoma
28. Kaposi's sarcoma
29. HIV encephalopathy**

And/or performance scale 4: bedridden > 50% of the day during last month

*: HIV wasting syndrome: weight loss > 10% of body weight, plus either unexplained chronic diarrhoea (> 1 month) or chronic weakness and unexplained prolonged fever (> 1 month).

**: HIV encephalopathy: clinical findings of disabling cognitive and/or motor dysfunction interfering with activities of daily living, progressing over weeks to months, in the absence of a concurrent illness or condition, other than HIV infection, which could explain the findings.