

Review on Slow Sand Filtration in Removing Microbial Contamination and Particles from Drinking Water

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Abstract The improvement of water quality is closely associated with man-environment relationships. There should be a dialogue between all actors and the community when undertaking water and sanitation activities. For positive results and better sustainability, the community should be involved and participate at all stages of water development and environmental sanitation schemes. A combination of safe drinking water, adequate sanitation and hygiene practices like hand washing is a pre-requisite for morbidity and mortality rate reduction, especially among under five years old children in developing countries. To reduce the incidence and prevalence of diarrhoeal diseases, improvements in the availability, quantity, and quality of water, improved sanitation, and general personal and environmental hygiene are required. The majority of people in developing countries do not have access to piped drinking water and must carry; transport and store water within their homes and in the process the quality of water may deteriorate. Therefore, slow sand filtration has been recognized as an appropriate technology for drinking water treatment in rural areas, and is recognized as a suitable filtration technology for removing water borne pathogens and reducing turbidity. It is capable of improving the physical, chemical, and microbiological quality of water in a single treatment process without the addition of chemicals, and can produce an effluent low in turbidity and free of bacteria, parasites and viruses.

Keywords: bacteria, drinking water, slow sand filter, treatment, turbidity

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1. Introduction

Water is the essence of life and access to safe drinking water is a fundamental human need and, therefore a basic human right essential to all. Supply of safe water of appropriate quality is important to the well-being of mankind and development of any country because it supports public health and, therefore, ensures economic growth. The provision of water, sanitation and good hygiene services is vital for the protection and development of human resources (Devadas, 1984).

Approximately over one billion people world-wide lacks access to adequate amounts of safe water and rely on unsafe drinking water sources from lakes, rivers and open well. Nearly all of these people live in developing countries, especially in rapidly expanding urban fringes, poor rural areas, and indigenous communities (Gundry et al., 2004; Bartram et al., 2005). Much of the global population now consumes untreated, non piped drinking water, usually consisting of small volumes <40 lpcd (liter per capita per day) 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 heavily contaminated with faecal microbes and possess risks of exposure to water borne pathogens and thus to infectious diseases (Sobsey, 2003).

The greatest risk associated with the ingestion of water is the microbial risk due to water contamination by human and/or animal feces. The effects of drinking contaminated water result in thousands of deaths every day, mostly in children under five years of age in developing countries (WHO, 2004a). Diseases caused by consumption of contaminated water, and poor hygiene practices are the leading causes of death among children world wide, after respiratory diseases (WHO, 2003). Thus lack of safe drinking water supply, basic sanitation and hygienic practices are associated with high morbidity and mortality from excreta related diseases. Diarrhea remains a major killer in children and it is estimated that 80 % of all illnesses in developing countries is related to water and sanitation; and that 15 % of all child deaths under the age of five years in developing countries result from diarrheal diseases (WHO, 2000, WHO, 2004a; Thompson and Khan, 2003).

Because of the magnitude of the health problems associated with water of inadequate quality and quantity, substantial efforts have focused on how to evaluate and maximize the health benefits derived from improved water supplies. In many developing countries, the high incidence of water borne diseases and wide-spread use of untreated

and often highly polluted water sources necessitate the accurate assessment of faecal contamination of water.

Regular examination of water quality for the presence of pathogenic/indicator organisms, chemicals, and other physical contents provides information on the level of the safety of water. Frequent examinations of faecal indicator organisms remain the most sensitive way of assessing the hygienic conditions of water. Indicator organisms of faecal pollution include the coliform group as a whole and particularly *Escherichia coli*, *Enterococcus faecalis* and some thermotolerant organisms such as *Clostridium perferingens* (WHO, 1984). The overall concepts adopted for microbiological quality is that no water intended for human consumption shall contain *E.coli* in 100ml sample (WHO, 2004b).

Bacteriological tests for the detection of faecal pollution of water have developed using indicator bacteria (non-pathogenic groups of bacteria) selected on the basis of the following criteria; numerous in feces but not other materials, counted by means of simple reliable test, more resistance than pathogens to physical and chemical inactivating agents and unable to grow in conditions outside intestine (WHO, 1984).

The coliforms are in the family Enterobacteriaceae and include the genera *Escherichia*, *Citrobacter*, *Klebsiella*, and *Enterobacter* (Clark and Pagel, 1977). Because several of these species are regularly found in unpolluted soils and water, the standard tests for them can not be said to indicate specific faecal pollution. *Escherichia coli* are almost exclusively faecal microorganisms and constitute over 90 % of the coliform flora of the human intestine. It is easily distinguished from other coliforms on the basis of its growth at 44°C on media normally used for coliform determination. The faecal coliform test must therefore taken as the most sensitive, reliable and specific indicators of faecal pollution (WHO, 1984; Abebe, 1986).

In order for a household water treatment technology such as SSF to achieve widespread sustainable use among the poor, it must meet the "criteria of the poor" (Duke and Baker, 2005).

- Effective in cleaning the water and improving its taste, smell and appearance.
- Easy to operate and maintain.
- Affordable and durable, with little or no recurring costs.
- Manufactured using local skills and materials.
- Does not use chemicals or energy.

Slow sand filtration process provides treatment through physical filtration of particles and biological removal of pathogens and organics in the upper biologically active layer of the sand bed known as biofilm. It has been recognized as an appropriate technology for drinking water treatment in rural areas, and is recognized as a suitable filtration technology for removing water borne pathogens and reducing turbidity. It is capable of improving the physical, chemical, and microbiological quality of water in a single treatment process without the addition of chemicals, and can produce an effluent low in turbidity, bacteria and viruses. In fact, Wegelin (1988) states, "no other single treatment process can improve the physical, chemical, and bacteriological water quality of surface water better than slow sand filtration". In addition, the USEPA (1997) states, "when used with a source water of appropriate quality, slow sand filtration may be the

most suitable filtration technology in small systems" These two statements elucidate the important role of slow sand filtration for treating surface water in small systems.

Slow sand filters can be constructed from local materials, mainly from properly graded sand/gravel, concrete/clay, and standard piping, can operate without the use of specialized equipment, and is much less labor intensive than rapid filters. Also slow sand filters operate under gravity flow conditions, and energy, its on-going energy demand is minimal. Thus, slow sand filtration is an attractive treatment alternative for local communities. Finally, there is very little water wastage during cleaning of the filters and the production of sludge is much less than rapid sand filters. The sludge can subsequently be handled in its dry state, preventing recontamination of surface water; and can be used to improve agricultural fertility (Huisman and Wood, 1974).

Slow sand filtration is a sustainable technology for rural water treatment because it is low cost and simple to operate. In addition, it is able to produce excellent effluent quality without the use of treatment chemical. In fact, under good source water conditions, Cleasby et al. (1984a) found that slow sand filtration achieved better treatment than coagulation followed by direct filtration. In addition to the potential health hazard of long-term chemical exposure, treatment chemicals are also costly to manage in rural water systems. Due to lack of availability in rural areas, the transportation costs of importing chemicals can be a major concern for small systems. In addition, the use of chemicals requires more maintenance and monitoring from skilled personnel, as the chemical dosing-process is highly sensitive to fluctuations in raw water quality such as pH. Thus the on-going operational costs of a conventional treatment system that uses chemicals can be overwhelming for a small community.

Therefore, this review article reviews the efficiency of slow sand filtration in removing microbial load and turbidity from drinking water.

2. Slow Sand Filtration Process

2.1. Brief History of Slow Sand Filtration

Slow sand filtration dates back to 1829 in Paisley, Scotland, where John Gibb supplied water to the city from the slow sand filter (SSF) at his bleachery (Baker, 1948). However, the current model for slow sand filtration originated from a one-acre slow sand filter designed by Jams Simpson for the Chelsea water company in London in 1852, which treated surface water from the Thames River (Barrett et al., 1991). After John Snow linked the outbreak of disease such as cholera and typhoid to waterborne contamination, slow sand filter became a legal requirement for all potable water extracted from the River Thames from 1892 (Huisman and Wood, 1974). Further convincing proof of the effectiveness of SSF at controlling waterborne diseases was provided in 1894 by the experience of two neighboring cities, Hamburg and Altona, which delivered drinking water from the River Elbe. The former delivered drinking water from the river untreated, while the later filtered the whole of its supply. When the river water became infected with cholera organisms, Hamburg suffered from a cholera epidemic while Altona

did not. SSF was the sole method of water treatment until the advent of rapid sand filtration at the end of 19th century (Brink and Parks, 1996). Currently, the USEPA recognized slow sand filtration as an acceptable water treatment technology, which provides safe water for human consumption.

2.2. Characteristics of Slow Sand Filtration

The basic components of a slow sand filter are: supernatant water layer, sand bed (fine and coarse sand), gravel and outlet hose. The supernatant water layer provides a head of water that is sufficient to drive the water through the filter bed, whilst creating a retention period of several hours for the water. Sand is the usual filter medium because of its low cost, durability and availability. The sand has a relatively fine grain size (effective size 0.15-0.3mm). The gravel provides an unobstructed passage for treated water from the filter bed, which prevent sand from clogging the under-drain piping and supports the filter sand bed. Water percolates slowly through the porous sand medium, and inert particles, organic material, and microorganisms such as bacteria, viruses and cysts of *Giardia* and *Cryptosporidium* enteroparasites are removed (Ellis, 1985; Fogel et al., 1993). Organic and inorganic particulate matter and pathogenic microorganisms are removed by physical filtration and biological degradation in the sand bed. Most of the treatment occurs at the top of sand bed where deposits of particulate and algal matter, combined with the dense growth of biomass, form a surface layer known as the biofilm. However, significant additional treatment also occurs throughout the rest of the sand bed. The literature reveals some variation in the recommended design parameters for slow sand filters (Table 1).

Table 1. Characteristics of Slow Sand Filters

Design Criteria	Recommendations		
	Ten states standards USA (1987)	Huisman and wood (1974)	Visscher <i>et al.</i> (1987)
Bed depth (m)	0.8	1.2	0.9
Effective media size (mm)	0.3-0.45	0.15-0.35	0.15-0.3
Filtration rate (m/h)	0.08-0.24	0.1-0.4	0.1-0.2
Support bed (m)	0.4-0.6	Not reported	0.3-0.5
Supernatant waters (m)	0.9	1-1.5	1

Source: Galvis *et al.* (2002).

2.3. Mechanisms of Filtration

Filtration is used primarily for removal of suspended particulates, including pathogens, in the production of potable water. Table 2 lists the variety of particles found in raw waters. Particle removal efficiencies in the range of 99% to 99.9% are reported in the literature for biologically matured slow sand filters (Bellamy et al., 1985a), particularly from surface water of relatively low turbidity.

An important factor affecting removal mechanisms of slow sand filtration is filtration rate. In particular, sedimentation and biological mechanisms are dependent on filtration rate (Ellis, 1985). As expected, Poynter and Slade (1977) found that removal of viruses decreased with increased filtration rate. In addition, Muhammad et al. (1996) found that color removals, which depend mostly on

sedimentation, were significantly decreased at higher filtration rates. This confirms that biological treatment and sedimentation are indeed influenced by filtration rate. Interestingly, Huisman (1977) reported that a higher filtration rate increases the organic loading rate, which results in higher substrate availability and forces microorganisms to live deeper than 300-400 mm in the sand bed, leading to potential breakthrough of bacteria. In some cases, however, filtration rate does not have an effect on bacteria removals. For example, Poynter and Slade (1977) found that increasing the filtration rate from 0.2 m/h to 0.4 m/h had no effect on removals of coliform bacteria and *E. coli*.

Table 2. Particles found in raw waters.

Category	Group/name	Size (µm)
Mineral	Clays (colloidal)	0.001-1
	Silicates	No data
	Non-Silicates	No data
Biological	Viruses	0.001-0.1
	Bacteria	0.3-10
	Algae, unicellular	30-50
	<i>Giardia</i> cysts	10
	Parasite eggs	10-50
	Nematode eggs	10
Other particles	<i>Cryptosporidium</i> oocysts	4-5
	Amorphous debris, small	1-5
	Organic colloids	No data

Source: Bellamy *et al.* (1985a).

Also another important factor affecting removal mechanisms of slow sand filtration is bed depth. The minimum depth for good turbidity and coliform bacteria removal is 300mm, but 600mm is necessary for removal of all viruses (Ellis, 1985). Bellamy et al. (1985c) found good removals of bacteria with reduced bed depth. Where coliform removals dropped from 97% to only 95% by reducing the bed depth from 0.97 m to 0.48m. This is because most of the biomass and biological treatment occurs in the upper portion of the sand bed. In fact, Williams (1987) found that all bacteria reduction occurred in the top 20cm of the filter bed, where a 1 log removal of faecal coliforms was achieved after 5cm depth and another 1.3 log removal after 20cm depth, for a total of 2.3 log removal (99.5%). Overall, bed depth is more important for removal of smaller particles, including viruses, colloidal matter, and color, and less significant for removal of bacteria.

In general, filtration occurs by physical (transport) and chemical mechanisms (attachment). Additionally, biological processes are important purification mechanisms operating in slow sand filtration (Huisman and Wood, 1974).

2.3.1. Physical-chemical Mechanisms of Removal in Slow Sand Filtration

Physical-chemical mechanisms of filtration are divided in to two categories: transport mechanism and attachment mechanism. Transport mechanism governs the transport of particulate matter to the filter media (otherwise referred to as collectors) and attachment mechanisms govern the attachment of particles to the media.

One of the major types of transport mechanisms in slow sand filtration is straining or screening, where particles larger than the pore size of media are physically removed. However, as the pore size of the media progressively

decrease due to particle deposition and biofilm growth; straining will become more efficient in capturing particles that are even smaller in size (Weber-Shirk and Dick, 1997b).

There are particles in surface water that are much smaller than the pore size of the media, such as bacteria (0.01 to 10 μ m), viruses (0.01 to 0.1 μ m), and colloidal particles (0.001 to 1 μ m) (Montgomery, 1985). These particles penetrate deeper into the bed, where other mechanisms of transport (inertia, sedimentation, interception, hydrodynamic action and diffusion) become important. Impaction occurs when the inertia of the particle approaching the collector is greater than the hydrodynamic force that is carrying the water past the collector (Montgomery, 1985). The particle will deviate from the flow path and impact the collector. Hydrodynamic forces that result from changes in flow velocity and changes of pore size may also transport particles to the surface of the collector (Montgomery, 1985).

Sedimentation occurs when the mass density of a particle is much greater than that of water and its settling velocity causes the particle to deviate from the flow path and settle on to the media surface. Ellis (1985) reported that sedimentation is probably more important with suspended particulates between 4 and 20 μ m in size.

Interception occurs when deposited particles accumulate on the media surface, gradually reduce the pore size, and act as additional collectors for subsequently passing particles. It is generally known that as the ratio of the particle size to media size increase, interception also increases (Montgomery, 1985). Particles in the colloidal range (less than 1 μ m in diameter) are influenced by diffusion and will deviate from flow paths toward the filter media, depending on the electrostatic interaction between the particles and the media (Montgomery, 1985). As particles are transported to the filter media, attachment mechanisms will act to capture the particle resulting in a successful collision. Such attachment mechanisms include mass attraction (van der Waals force) and electrostatic attraction between oppositely charged particles (Montgomery, 1985). The effects of van der Waals forces, however, are only significant if the particle can overcome any electrostatic repulsion barrier and reach the surface of media (Haarhoff and Cleasby, 1991). Mc Connell (1984) suggests the possibility of multivalent cations acting as a bridge between negatively charged surfaces and negatively charged particles. This theory was confirmed by the finding that "virus adsorption on sand is enhanced with increasing ionic strength and with higher concentration of higher valence cations in solution" (Galvis et al., 1998).

Adsorption of particles to the media is another important attachment mechanism. Microorganisms such as algae and bacteria will colonize the filter bed and form a sticky zoogeal biofilm on the sand grains to which particles can become attached to. Ellis (1985) suggests that adsorption is more important for smaller particles.

Detachment of particles is another important phenomenon of filters. As particle deposits and growth of biofilm reduce the pore size of the media, the interstitial velocity in the pores increases. This causes an increase in the hydrodynamic shear force on particle deposits and may cause particles to become detached. Shearing forces are expected to be highest in the biofilm (Weber-shirk and

Dick, 1997b). Increased detachment may also occur with sudden increases in the influent solids concentrations. Detached particles can then penetrate deeper in to the filter bed and may ultimately break through the filter. For example, Ellis and Aydin (1995) found that particulate deposits decreased rapidly with depth; however were still present at depth of 400mm. This highlights the importance of maintaining consistent operational conditions, and avoiding sudden fluctuation in influent or flow water quality.

2.3.2. Biological Mechanisms of Removal in Slow Sand Filtration

Pathogenic microorganisms including bacteria and viruses, and cysts of enteroparasites may be effectively removed by SSF (Burman, 1962; Poynter and Slade, 1977). This is partly explained by the slow filtration rate of water and fine sand used, but also attributed to biological mechanisms in the biofilm and within the upper layers of the sand bed (Huisman and Wood, 1974). Among the several biological mechanisms operating in slow sand filters, predatory activities associated with the maturity of the filter bed are suggested as the main process responsible for removing and inactivating microbial pathogens during SSF.

Haarhoff and Cleasby (1991) concluded from a review of published literature that predation of algae and bacteria, scavenging of detritus by aquatic worms found mainly in the deeper region of the bed, natural death, inactivation, metabolic breakdown (i.e. reduction of organic carbon), and adsorption to the sticky zoogeal surface of the sand are the principal biological mechanisms responsible for particle removal by SSF. For example, bacteria removal in SSF has been attributed to grazing by protozoa. Burman (1962) examined the bacterial condition of water before, during and after filtration at the Walton treatment works, in London. This showed that coliform and *E. coli* counts decreased in the supernatant water during the hydraulic retention time above the sand. This was attributed to bacterial grazing by protozoa or other predators migrating from the filter surface. Coliform counts increased at the sand surface, but lower *E. coli* counts were found, suggesting that growth of coliform bacteria may occur in the filter mat on the sand surface but there was no evidence for the growth of *E. coli* in the filter as an able to grow outside intestine. In another study at Walton on colonization of a resanded slow sand filter, the numbers of *E. coli* bacteria in the filtered water were inversely related to the size of numbers of flagellate and ciliate populations in the filter, suggesting that protozoa were important agents for bacteria removal (Weber-Shirk and Dick, 1999).

Weber-Shirk and Dick (1997a) suggest that predation of bacteria is the most important of all these mechanisms, and adsorption is the least significant. However, at a lower water temperatures, it is suggested that adsorption to biomass is the dominating mechanism, due to reduced biological activity (Welte and Montiel, 1996).

Duncan (1988) provides a survey of the common organisms that can be found in the sand bed. These include aerobic bacteria, flagellates, ciliates, rotifers, flatworms (Microturbellaria), gastrotriches, nematode (round worms), annelida (segmented worms) and arthropods (haracticids). Of all these, the predominant organisms are gram-negative pigmented bacteria such as *Pseudomonas* and *Aeromonas*

as well as algae, protozoa, and higher order eukaryotes (Eighmy et al., 1993). Bacteria that are typically present in biological process are generally classified as oligotrophs (Rittman and Huck, 1989). Oligotrophs are "characterized by their ability to simultaneously and efficiently utilize a wide array of substrates present at low concentrations." (Moll and Summers, 1996).

The larger microorganisms such as protozoa either feed on suspended particles or bacteria, or are predators of other inhabitants of the sand bed. This is confirmed by Weber-Shirk and Dick (1999) who state, "predators that graze on attached bacteria potentially free up sites for future bacteria attachment while suspension feeding predators directly remove particles from the mobile phase". A proven species to be implicated as a bacterial predator is Chrysophyte (Weber- Shirk, 2002). Other predacious fauna include meiofaunal species (0.1 to 1mm in size), which feed on individual bacterial or algal cells, suspended particles, or other species (Duncan, 1988). Some eukaryotes are known to be predators to bacteria, while some microorganisms simply produce substances that are toxic to enteric bacteria (Lloyd, 1973; Huisman and Wood, 1974).

Aerobic oligotrophic bacteria grow on the sand media to form a dense biofilm. This sticky biofilm, sometimes referred to as zoogloea, is known to adsorb colloidal material. Some researchers postulated that filtration efficiency was partially a function of particle adsorption to the sticky biofilm (Huisman and Wood, 1974). Bacteria such as *Pseudomonas aeruginosa* are known to produce extra-cellular polymeric substances (EPS), polysaccharides and proteins, which serve to anchor bacteria to surfaces (Dai et al., 2002). Bellamy et al. (1985b) suggested that the polymers acted to flocculate organisms and destabilize clay and bacteria to facilitate attachment. Wheeler et al. (1988) suggested that these extra- cellular polymers could also provide binding sites for viruses. Removal of viruses is achieved through microbial predation and adsorption to biomass (Wheeler et al., 1988). Due to the relatively small size of viruses; physical mechanisms of removal are of less importance. Wheeler et al. (1988) found that biomass concentration is just as important for the removal of viruses (e.g. rotavirus) as it is for the removal of pathogenic bacteria. In fact, they found similar patterns of removal between viruses and bacteria with respect to depth in the filter.

The term 'bioantagonism' has been used by a few authors to explain a mechanism of removal where by incoming pathogenic bacteria are either 'out competed' or 'inactivated' by autochthonous (naturally occurring) bacteria in the sand bed. For example, in the natural environment, Sattar et al. (1999) found that survival of *Cryptosporidium* declined in the presence of autochthonous microorganism, and this phenomenon was referred to as bioantagonism. Although no specific microorganism was determined responsible for oocyst decay and the actual mechanisms of bioantagonism were unclear, autochthonous bacteria could similarly be responsible for oocyst decay in slow sand filters. This assumption is supported by the research of Uhl (2000), which indicates that pathogens in biofilters decrease, rapidly in the presence of autochthonous bacteria. The reasoning is that pathogenic bacteria, or autochthonous bacteria, are accustomed to high concentrations of organic matter where they thrive and experience a high growth rate. However, at low concentrations of organic matter, their growth rate is low. In contrast, the growth rate of autochthonous bacteria is still high even at low concentrations of organic matter (less than 1mg/L) of carbon, thus out competing pathogens (Uhl,2000).

The term, 'inactivation', is used to describe the removal of enteric microorganisms due to predation or bioantagonism (Datta and Chaudhuri, 1991). Each layer of the sand bed has its own inactivation potential depending on the vertical distribution of biomass. For example, Prokaryotes and Eukaryotes were active through out the filter bed in inactivating enteric microorganisms (*E. coli*); however inactivation potential was highest near the surface of filter bed (Datta and Chaudhuri, 1991).

3. Performance of Slow Sand Filtration

Slow sand filtration produces an effluent low in turbidity, free of impurities and more importantly, virtually free of bacteria, entero-viruses and protozoa (Galvis et al. 1998). Galvis et al. (1998; 2002) found typical removal efficiencies for slow sand filter as shown in Table 3. Most of the results are from slow sand filters operating at temperatures above 50C, filtration rates between 0.04 and 0.2 m/h, bed depths above 0.5 m, and effective media diameters between 0.15 and 0.3mm.

Table 3. Typical Removal Efficiencies for Slow Sand Filtration

Parameter	Effluent or Removal Efficiencies	Comments
Turbidity	<1NTU	Treatment efficiency depends on quantity, nature and distribution of particles.
Coliform bacteria	>99%	Treatment efficiency mostly depends on the biological maturity of the filter.
Entero bacteria	90-99.9%	Treatment efficiency affected by temperature, filtration rate, media size, bed depth and cleaning.
Entero viruses and <i>Giardia</i>	99-99.9%	Effect of cleaning practices on removal efficiency in a biologically mature bed is minimal.
True color	25 to 40%	Color is associated with organic material and humic acids. Average 30% removal.
Total organic Carbon (TOC)	<15-25%	Mean 16%
Dissolved organic carbon (DOC).	5-40%	Mean 37%
Biodegradable dissolved Organic carbon (BDOC)	46-75%	Mean 60%
Assimilable organic carbon (AOC)	14-40%	Mean 26%
UVabsorbance (254nm)	5-35%	Mean 16-18%
Trihalomethane (THM)	<25%	
Iron and Manganese	30 to 90%	Fe levels> 1mg/L reduce filter run length due to precipitation and filter clogging.

Source: Galvis et al. (1998; 2002).

3.1. Removal of Bacteria

It is suggested that slow sand filtration can achieve between 99 and 99.9% of pathogenic bacterial removal (Van Dijk and Ooman, 1978). However, removal efficiencies may be somewhat site specific as there is some variation in the findings from several authors. The variation in bacteria removals can be attributed to differences in source water quality conditions and filter operational conditions. This highlights the importance of onsite pilot testing to determine treatment performance under the prevailing water quality and operational conditions.

3.2. Removal of Viruses

Slow sand filtration can achieve very good removal of viruses. Typically virus removals in slow sand filtration range from 2 to 6 logs (Trojan and Hansen, 1989), and generally increase with increasing bed depth and decreasing filtration rate and increasing water temperature. Poynter and Slade (1977) found 99.9% removal of

poliovirus I with a bed depth of 600 mm and filtration rate of 0.2 m/h. Removal efficiencies decreased with lower bed depth and higher filtration rates, and were only slightly affected by temperature. For example, 99.9% removal was achieved at a temperature of 11 to 120 C but decreased only slightly to 99% at 60C. Yahya et al. (1993) studied the removal of bacteriophages MS-2 and PED-I which represent human enteric viruses because they are similar in shape and size (25nm and 62 nm, respectively) and they absorb poorly to sand. Removal of MS-2 and PRD-1 was 99% and 99.9%, respectively.

3.3. Removal of Parasites

Slow sand filtration is very efficient in removing parasites such as *Giardia* and *Cryptosporidium*. A summary of removals reported by several authors is presented in Table 4. In general *Cryptosporidium* is more difficult to remove than *Giardia* because of its smaller size and has lower collector efficiency than *Giardia* (Hsu et al., 2001).

Table 4. Removal of *Giardia* and *Cryptosporidium* in Slow Sand Filters

Author	<i>Giardia</i>	<i>Cryptosporidium</i>	Comments.
Bellamy <i>et al.</i> (1985a)	>98%	-	-
Schuler <i>et al.</i> (1988)	99.8 to 100%	100%	-
Schuler <i>et al.</i> (1991)	-	3.9 to 7.11log	-
Fogel <i>et al.</i> (1993)	Average of 93%	-	-
Logsdon <i>et al.</i> (1993)	93.7 to 99.9%	-	-
USEPA (2001)	-	99.9 to 99.9%	-
Timms <i>et al.</i> (1995)	-	99.9%	Influent spike of 4,000oocyst/L, Filtration rate of 0.3 to 0.4 m/h
Loganetal.(2001)	-	>3 to 41og	Influentspikeof65,000oocyst/L, Less removal with larger media

Overall, slow sand filtration can achieve excellent removals of bacteria, viruses, *Giardia* and *Cryptosporidium*, suspended particulates or turbidity, so it provides drinking water that is consistently safe for human consumption.

4. Operational Factors Affecting Removal in Slow Sand Filtration

4.1. Removal Efficiency of Slow Sand Filtration

Slow sand filtration is proven to achieve excellent removals of pathogenic bacteria, protozoa, viruses, suspended solids, and turbidity. However, removal efficiency is highly dependent on physical and operational characteristics of the filter including the media size, bed depth, filtration rate, biological maturity of the filter, and cleaning practices.

Generally, there are similarities in the findings of many authors, who report a decrease in filter efficiency with increased media size, increased filtration rate, decreased bed depth, and decreased biological maturity of the sand bed. A smaller media is favored due to its increased filtration efficiency. Ellis (1985) reports improved bacteria removals with smaller media. Although, the impact of media size on filter performance largely depends on the size distribution and surface chemistry of the particulate matter in the source water. For example, if there is a high proportion of a solid in the water with a relatively large particle diameter, these solids are more likely to be removed, even in large media. Vander Hoek et al. (1996) document a varied response from several authors

regarding the effect of media size on slow sand filter performance. Interestingly, Bellamy et al. (1985c) reported that an increase in effective sand size did not necessarily result in poor filter performance. An increase in effective media diameter from 0.128 mm to 0.615mm resulted in only a small decrease in bacteria removals from 99.4% to 96%.

4.2. Cleaning of Slow Sand Filtration

Cleaning must be performed at the end of a filter run. Typically, filter run times range from 30 to 60 days, but could reach more than 100 days (Ellis, 1985). The traditional method of cleaning slow sand filters involves draining the water level down to just below the sand surface and scarping off the top 1 or 2 cm of biofilm. The biofilm is where the highest concentration of biomass exists, hence the region where most biological treatment is achieved. Thus, pathogen removal may be compromised for a couple of days after cleaning until biofilm maturity is reestablished. In some cases, however, cleaning may have no effect on treatment efficiency. For example, Fox et al. (1984) found that bacteria removal was unaffected by scraping, and Poynter and Slade (1977) found that scraping had little effect on the removal efficiency of viruses.

Burman (1962) found that cleaning of the slow sand filter led to a reduction in the removal of *E. coli* from 99 to 94%, although removal of coliform bacteria was unaffected. Burman (1962) also found that removal of chlorine resistant spore-forming bacilli ranged from 81 to 88%, and after cleaning these removals dropped from 81 to 73%. Bellamy et al. (1985a) found that cleaning or

replacing the sand resulted in a 1 log decrease in bacteria removal efficiency.

Basically, if the length of filter run is short and cleaning is frequent, the biological layer will never have enough time to reestablish equilibrium and maturity. Cleasby (1984b) found that the removal of coliform bacteria increased from 95% to greater than 99% as the filter matured. Likewise Bellamy et al. (1985a) found that *Giardia* removal was 98% in new sand, where as in biologically mature sand, removal was 3 to 4 log. Thus, the importance of lengthy filter runs, which allow plenty of time for maturation, can not be over stated.

Eighmy and Collins (1988) reported using an alternative method of cleaning known as "harrowing" where the sand is raked by a comb harrow, which penetrates 30cm in to the sand bed and detaches particulate debris. The debris is then washed away by a continuous flow of water across the top of the sand bed.

Generally, cleaning times are significantly lower with the harrowing method than the scraping method, and filters could be put back on line within days instead of weeks. Also this method results in minimal or no sand loss, thus re-sanding of the filter after many years of operation is not an issue. But most importantly, Eighmy and Collins (1988) found that very little biomass was lost during cleaning and biomass populations penetrated deeper in to the sand bed, providing more biological contact time and improving removals of non-purgeable dissolved organic carbon.

An additional advantage of harrowing is that it is an in-situ cleaning method, and it is not necessary to drain the water level down to expose the sand. Lloyd (1996) found that some protozoa such as spiratichs, which graze on incoming bacteria, are particularly susceptible to desiccation when the sand is exposed. Thus, in-situ methods of cleaning are preferred to maintain the viability of the biomass ecosystem in the sand bed.

5. Contamination of Drinking Water in Home Storage Containers

Most water sources in developing countries are polluted by chemical and biological agents. Feachem (1980) noted that in developing countries, water sources sometimes show indicator bacteria concentrations, equivalent to those of weak untreated sewage. These contaminated water sources can be vehicles for the transmission of pathogens (Esrey et al., 1985). According to Ngoma (1992) more than one-third of deaths in developing countries are caused by drinking water from these highly contaminated sources.

In their study on water borne transmission of cholera in Trujillo, Peru, Swerdlow et al. (1992) tested the variation of water quality at the source (i.e. well water), and later in the household (i.e. stored water). In this study, progressive deterioration of water quality was observed during distribution and storage at home. Consequently, the mean coliform counts were higher (20 faecal coliforms and 794 total coliforms per 100ml) in water sample from household storage container and lower (1 faecal coliform and 1 total coliform per 100ml) in city well water (Swerdlow et al., 1992).

The risk of diarrhoeal disease due to contamination of drinking water during household storage was noted in surveys conducted by different researchers. Pinfold and

Horan (1991) stated that there is higher risk of ingesting faecal micro-organisms with water that is contaminated during collection and storage than with water from the source.

Swerdlow et al. (1992) in a case-control study indicated that stored water contamination during hand washing and scooping was strongly associated with cholera illness. The stored water has become contaminated with *Vibrio cholera* and coliform bacteria (Swerdlow et al., 1992). Mintz et al. (1995) summarized some investigations in which recognized enteropathogens were identified from stored water. *Escherchia coli*, *Vibrio cholera* 01, *Strongyloides*, and *Ascaris* were repeatedly isolated from the home storage water samples (Mintz et al., 1995).

The majority of faecal bacteria found in stored water are, most likely transferred from environment through water related activities by way of water handling practices (Pinfold and Horan, 1991). The practices include method of collection from the sources, transport to the house, drawing of water from storage container, keeping the water container clean, and washing hands before collecting (Pinfold and Horan, 1991).

Several researchers, Pinfold and Horan (1991), Swerdlow et al. (1992), Bartram and Johns (1988) and Kelly (1990) stressed the need for hygiene education to the community on the contamination of water during collection and storage in home. In communities where household storage of water is common, hygiene education is considered the most effective means to quality improvement. Guidelines for hygiene education (Boot, 1987) and for cholera control (WHO, 1993) also emphasized on the prevention of contamination of water borne diseases.

6. Summary

The improvement of water quality is closely associated with man-environment relationships. There should be a dialogue between all actors and the community when undertaking water and sanitation activities. For positive results and better sustainability, the community should be involved and participate at all stages of water development and environmental sanitation schemes.

A combination of safe drinking water, adequate sanitation and hygiene practices like hand washing is a pre-requisite for morbidity and mortality rate reduction, especially among under five years old children in developing countries. To reduce the incidence and prevalence of diarrhoeal diseases, improvements in the availability, quantity, and quality of water, improved sanitation, and general personal and environmental hygiene are required. The majority of people in developing countries do not have access to piped drinking water and must carry; transport and store water within their homes and in the process the quality of water may deteriorate.

Therefore, slow sand filtration has been recognized as an appropriate technology for drinking water treatment in rural areas, and is recognized as a suitable filtration technology for removing water borne pathogens and reducing turbidity. It is capable of improving the physical, chemical, and microbiological quality of water in a single treatment process without the addition of chemicals, and

can produce an effluent low in turbidity and free of bacteria, parasites and viruses.

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