Development and evaluation of a small scale water disinfection system

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ABSTRACT

Provision of microbiologically safe drinking water for people living in the rural areas of developing countries remains a major challenge to date. A simple gravity-driven membrane point of use system was developed based on woven fabric microfiltration (WFMF) membranes. The WFMF is a loose type of membrane (0.45 μm). However, complete disinfection is not achieved with the WFMF, hence it was incorporated with two disinfectants. This study aimed to combine the WFMF with two disinfectants (WaterGuard and bromochlor tablets) to bring the water to the accepted quality for drinking. Four different types of water were sourced, considering two factors: E. coli and turbidity content. The WFMF demonstrated excellent filtration performance by producing permeates with turbidity less than 1 NTU for feed turbidity ranging between 10 and 200 NTU. There was 95–99.8% E. coli removal for raw feeds with influent E. coli ranging between 500 and 44,500 CFU/100 mL. Total disinfection was achieved with both disinfectants; however, the effectiveness of the chemical disinfectants in E. coli removal was affected by the quality of water to be disinfected. The study showed that turbidity plays a major role in disinfection performances by increasing chlorine demand on water sources with high turbidity levels.

INTRODUCTION

The provision of microbiologically safe drinking water to people living in rural areas of developing countries remains a major challenge to date (WHO 2011). The people in these areas are unable to access potable water mainly because existing water supply systems are already saturated due to increased population growth, the cost of installation and repairs of existing systems is high, or because of a shortage of water due to climate change. Other factors that affect rural water supply include rugged topography, lack of finance, dispersed settlement, lack of technological innovation and skills, and poorly designed existing systems (Peter-Varbanets et al. 2009).

Currently, several measures have been put in place to address the challenges of rural water supply. This is through the design and development of suitable technologies such as decentralized water treatment technologies, improvement of existing water treatment facilities and creation of awareness of newly designed systems for rural adaptation. There are three different categories of decentralized systems that are being used to help alleviate the supply of water in rural areas. These are point of use (POU), point of entry and small scale systems (SSS) (Sobsey 2002; Peter-Varbanets et al. 2009).

POU systems are used to provide safe water that is required by individuals, households and for emergency relief. According to Sobsey (2002), the system is often referred to as household water treatment. These systems are seen as a strategy for modifying hygiene behaviour amongst water consumers and as an improved sanitation facility. POU systems are also used to mitigate recontaminations that usually occur during transportation, distribution and household storage of potable water. The findings of Ahammed &
Chaudhuri (1999), Sobsey (2002) and Mwabi et al. (2011) have shown the effectiveness of POU systems, particularly in removing suspended particles in the form of turbidity and in disinfecting microbiological contaminants such as bacteria, viruses and sometimes protozoa, which has reduced the risk of diseases in the rural areas.

The most critical problem for POU systems is their lack of sustainability and the inability of the project to scale. In many cases, POU systems fail to achieve long term adoption. Their importance and acceptability does not go beyond the organization or public health initiative that promotes their usage. The findings by Sobsey et al. (2008) indicated that POU systems are not yet common in developing countries.

Membrane-based technologies, especially microfiltration (MF) and ultrafiltration (UF), can be incorporated into POU systems for the treatment of potable water. The advantages of membranes include the fact that the quality of the permeate is dependent on the nature of the membrane and not the skills of the operator, and they can be operated under gravity, thereby saving on the cost of pumping (Madaeni 1999). Several membrane based POU systems have been developed that are able to produce bacteriologically safe drinking water. Although these systems are excellent in their performance, three major set-backs have been identified that may affect the implementation of these systems in developing countries. These are cost, material of construction and operational life span (Sobsey 2002; Peter-Varbanets et al. 2009).

A POU system known as the Remote Rural Water Treatment System (RRWTS) was developed at Durban University of Technology (DUT). The system is made of a polyester based woven fabric microfiltration (WFMF) membrane that is sourced locally. It is made up of flat sheet modules that are assembled into a pack with a permeate outlet connected to a manifold using flexible pipes, and then a tap. It is a robust system that is gravity driven without requiring pumps or electricity.

A detailed report by Pillay & Buckley (2003) and Pillay (2009) has been submitted to the water research commission of South Africa. It describes the development of the RRWTS and its performance, and outlines its various merits in bringing safe drinking water to poor rural communities of developing countries. This water treatment unit is able to remove suspended solids and colloids in the form of turbidity. Its permeate flow rate is 5–60 L/hr and the permeate turbidity is below 1 NTU. Separation in the RRWTS was achieved by size exclusion of materials. It is easy to use and maintain. Other factors such as cost and analysis and long term performance can be obtained from this report. The major finding and recommendation from that report was that though the system produced water of adequate quality for the target communities, its permeate did not meet international water standards. To attain international standards, it was recommended that a disinfection module must be added.

A study with regards to the incorporation of a disinfectant to the RRWTS was carried out by Mecha & Pillay (2014). The aim of the study was to combine the WFMF membranes with silver nanoparticles (AgNPs) using the modified chemical reduction method. They found that the coated membranes not only produce water with better quality (turbidity <1 NTU, zero E. coli and silver concentration <0.1 mg/L), but also greater quantity because of high permeability. Therefore, the membranes can be used as a standalone POU system to provide clean and safe water for poor people in remote rural areas. The methods of incorporating the silver particles was found to be laborious and therefore there is a need to explore other options.

The present study was aimed at evaluating the physical disinfection of the WFMF and chemical disinfection using two disinfectants, namely WaterGuard (WG) and bromochlor tablets (BRCH). WG is a 1% sodium hypochlorite disinfectant stored in 150 mL bottles. This disinfectant is sold at low prices in many stores in developing countries, and is also distributed as part of the poverty relief program in many rural areas of developing countries for treatment of drinking water (UNICEF 2006). The BRCH tablet is a chlorine-based solid disinfectant that is used mostly for large scale disinfection; however the tablet can be sized to suit SSS. Finally, membrane flux recovery was carried out after cleaning.

METHODS

Sample

The main contaminants of South African water are eutrophication of surface water, heavy metals, acid mine drainage, increased salinity, increased levels of suspended solids, bacterial and viral pathogens, pesticides or insecticides,
contaminants with oestrogen and oestrogens-mimicking substances, solid litter, oxygen depletion and radionuclides. However, rural areas are located far away from industrialisation, hence the main contaminants of their surface water are fecal pollution, colour and stability, salt concentrations, fluoride, sulphates and chlorides, and eutrophication (Statistics South Africa 2001). The feed samples were selected based on the above mentioned factors.

Four samples were used for this study: a highly contaminated feed with high *E. coli* and high turbidity; a medium feed with either the *E. coli* or turbidity high; and a low and easy river with low concentrations of both. Feed samples were classified this way to make up for the variations in different seasons, since the microbial population varies with the seasons. *E. coli* was spiked into tap water to make up the synthetic feed. The turbidity and *E. coli* of the feeds were 10–150 NTU and 400–45,500 count/100 mL, respectively. Table 1 shows the analytical equipment and methods used for analysis. The Colilert Quanti-tray method was used to determine *E. coli*. Colilert® is a commercially available enzyme-substrate liquid-broth medium (IDEXX Laboratories, Inc., Westbrook, Maine) that allows the simultaneous detection of total coliforms and *E. coli*. It is available in the most-probable number (MPN) or the presence/absence format. The MPN format was used for this study. Materials and apparatus used in this study were autoclaved and sterilized. All procedures and tests were carried out under sterilized conditions. Each experiment was repeated three times to allow for repeatability.

### Selection of indicator organism

Microbial indicators are microorganisms that are not pathogenic, however they indicate a potential threat to the microbiological quality of water, some of which are total coliforms, *E. coli* and fecal coliforms. *E. coli* is a commonly used bacterial indicator organism for pathogenic contamination, therefore it was chosen as the indicator for this study based on the following criteria: it is a strict indicator of fecal contamination; it is an organism, whereas total coliforms and fecal coliforms are groups; it is usually present when other pathogens are absent; it is amenable to rapid and accurate enumeration (WHO 2006; Cabral 2010; Mangayarkarasi et al. 2012). The WHO guidelines recommend a value of zero *E. coli* per 100 mL treated water as an indication of proper water treatment (WHO 2011).

### Design of the RRWTS

The RRWTS was designed having the WFMF as its major part. WFMF membranes were obtained from Gelvenor Consolidated Fabrics (PTY) Ltd in Durban, South Africa. The membrane pores were 0.45 μm. The unit consisted of a membrane pack of flat sheets (modules) made from woven polyester material. The module consisted of a fabricated rectangular PVC support frame with a permeate outlet incorporated in the inside. A total of 15 modules were inserted into the feed tank, Figure 1(a). The WFMF membrane sheets were then glued to both sides of the frame and a mesh spacer was inserted between the sheets to enhance permeate flow. A complete A4 size module and the manifold for permeate collection is shown in Figure 1(b) and 1(c). Figure 1(a) shows the POU system.

### Filtration performance with WFMF

Twenty litres of each feed sample was poured into the RRWTS and permeate was collected in a beaker after intervals of 30 minutes and analysed; the duration of each experiment was 3 hours. The efficiency of the WFMF was determined using the rejection equation, (Baker 2004).

\[
R(\%) = 100\times \left(1 - \frac{C_p}{C_f}\right)
\]

where \(C_f\) = feed concentration (g/L) and \(C_p\) = permeate concentration (g/L).

Pure water fluxes of the membrane modules (one at a time) were determined by filtering deionized water through the module in a dead end mode under gravity. The filtration unit
was flushed with deionized water, and the drainage valve and permeate outlet tap opened to drain the water. The drainage valve and permeate tap were then closed. The permeate outlet valve was opened and permeate collected in beakers. The volume of permeate collected with time was recorded. The permeate flux \( J \) was calculated using the equation:

\[
J = \frac{V}{AT}
\]

where \( V \) is the volume of permeate (L), \( A \) is the membrane filtration area (m²), and \( t \) is the time of collection of permeate (h).

### Disinfection using WG and BRCH

The chlorine residual is very important for drinking water; it is therefore necessary to apply accurate dosage at the right frequency (Momba & Brouckaert 2005). The chlorine dose, residual, as well as the contact time (CT) for each feed sample was determined before and after filtration. CT and agitation are some of the factors that are considered during disinfection. CT is used to determine the required time for direct contact between the organisms and chlorine, it is dependent on the quality of water to be treated and the concentration of chlorine (Momba et al. 2008).

Disinfection efficacy of the disinfectants was evaluated before MF and after. A calculated amount of WG was added manually to each sample to be treated, before then, the volume of the WG was converted to concentration using Equation (3). The RRWTS system was filled with the feed samples to be treated. The concentration of WG was varied from 10 to 50 mg/L. The desired amount of WG was poured into the RRWTS. The permeate valve Figure 1(a) was used to control the flow rate of the system between 1 and 45 L/h. The system was agitated for 20 seconds prior to opening of the valve to facilitate the mixing required for uniform distribution of the WG disinfectant. With respect to the BRCH, a mesh of 0.4 μm was placed in the tap (permeate) outlet, this was to hold the tablet to prevent it from falling off. The BRCH tablet was then placed on the mesh. Feed flow rate was controlled using a permeate valve. The reason for this was to enable contact between the feed and the BRCH so that disinfection takes place before permeate is collected:

\[
C = \frac{M}{V}
\]

where \( C \) is the concentration in milligrams per litre (mg/L), \( M \) is the mass in milligrams (mg) and \( V \) is the volume in litres (L).

Agitation was not necessary with the BRCH tablet, since disinfection occurred as soon as the feed came into contact with the BRCH tablets. The BRCH tablet size was varied between 0.1 and 0.8 g. The tests were repeated for the incremental amounts of WG and BRCH tablet sizes. The entire test
procedure was repeated for different feed samples. The samples were taken and tested for *E. coli* and chlorine residual after 30 minutes. Both disinfectants were stored in airtight containers.

The disinfection efficacy, which is expressed as the log removal value, was determined by the use of Equation (4) (Baker 2004):

\[
L_{RV} = \log_{10} \left( \frac{C_f}{C_p} \right)
\]

(4)

where \( C_f \) = concentration of *E. coli* in the feed (CFU/100 mL); \( C_p \) = concentration of *E. coli* in permeate (CFU/100 ml). The log10 reduction value (LRV) is used to describe the bacterial removal efficiency.

**Membrane cleaning**

Cleaning was an essential part of the RRWTS, as membrane flux was to be restored after fouling. The membranes were dismantled from the pack of 15, soaked in 20 L water, and thereafter brushed with a soft scrubbing brush. Dish washing Sunlight soap was used to assist in the removal of dirt from the membrane surface. The membrane manifold and the tanks were rinsed with tap water several times to remove all traces of dirt, after which they were soaked in 3% sodium hypochlorite for 2 hours to inactivate any *E. coli* that may have clogged on the inside of the membrane matrix. The water flux recovery (WFR) was calculated using the WFR equation (Schäfer *et al.* 2004; Al-Amoudi & Lovitt 2007):

\[
WFR = \frac{J_c}{J_0}
\]

(5)

where \( J_c \) is the flux after cleaning and (LMH) and \( J_0 \) is the flux of the virgin membrane (LMH).

**RESULTS AND DISCUSSION**

**Chlorine residual and CT**

Residual chlorine is important in drinking water, especially water stored for later use. It is meant to protect against the re-contamination of the water that is already disinfected. The stipulated value for the chlorine residual according to SANS-241 (2005) is 0.2 mg/L for POU systems. The water quality that was used to measure the acceptable values for drinking water standards was according to the South African water quality guideline SANS 241 (2005). The obtained chlorine residual from the different rivers was compared to the tap water residual, which was used as a base case for this study. The Duzi and Umbilo rivers did not produce acceptable levels of chlorine residuals for either disinfectant. This indicated that the chlorine demand for Duzi and Umbilo rivers was higher, which then resulted in a low chlorine residual in the system. However, on increasing the amount of the WaterGuard and BRCH tablet size on the two rivers, the required chlorine residual was achieved.

The demand for the disinfectants depended on the quality of each water source. Residual chlorine was higher for waters with low contamination loads. Where the contamination load was low, the added chlorine then becomes available as free chlorine due to low chlorine demand. This was seen to be true with tap water and slightly with Town Bush River. It was therefore expected that by increasing the disinfectant concentration (WG and BRCH) the amount of chlorine residual also increased.

**Figures 2 and 3** show the concentrations of WG and BRCH tablets used to achieve chlorine residuals for each feed type. A greater chlorine residual was obtained for tap water and the Town Bush river, while less chlorine residual was obtained for the Duzi river because of the presence of high *E. coli* levels and other contaminants in the form of turbidity. Cheremisinoff (2002) and Momba *et al.* (2008) reported that the pollutants that use up much of the chlorine during disinfection are metals such as iron and manganese, organic matter, pathogens (i.e. *E. coli* and other microorganisms)
and turbidity. These organic matters were present in higher compositions in the Duzi and Umbilo rivers, which explains the high chlorine demand for these rivers compared to the others. The findings here signified that water with a high contamination level had a higher chlorine demand than less contaminated water to yield the required chlorine residual, as seen with the Duzi and Umbilo rivers.

According to Schoenen (2002) and Momba et al. (2008), water sources will not always have a constant chlorine demand; it varies from one water source to another. For surface water, the chlorine demand will depend on the recent pattern of rainfall run-off contributing to the source. Also, the amount and type of materials that are directly deposited or washed into such surface water will affect the chlorine demand. In instances where water to be treated is highly turbid, two things are bound to happen: (1) a larger amount of the chlorine will be wasted due to the chemical reaction with the suspended materials, particularly if there are organic substances; and (2) most of the micro-organisms will not be fully exposed to the germicidal activity of the chlorine because they are shielded by the suspended material. To achieve a high or complete disinfection rate and meet the standard for the chlorine residual, the feed quality must be free of contaminants. This will therefore mean that a small disinfectant concentration will be necessary to give the required chlorine residual on feed samples, as in the case of tap water and the Town Bush River.

**Performance of WFMF on E. coli removal without disinfectants**

The WFMF was investigated to obtain its performance in the removal of turbidity and E. coli. According to the standards given by SANS-241 (2005) and WHO (2011), a POU system should be able to produce water with turbidities below 1 NTU with zero E. coli in 100 CFU/mL. Figure 4 shows E. coli removal by WFMF over a period of 120 minutes for the feed samples. Figure 5 shows the effect of an increase in operational time on flowrate using the WFMF.

**E. coli** rejection was achieved for all the rivers, but at different levels. The overall rejection for the period of experimentation for each water sample was 99.8, 99.6, 98.8 and 97.4% for Umbilo, Duzi, Town Bush and synthetic feed water, respectively. Therefore, the WFMF rejected E. coli with a minimum rejection rate of 97.4 and 99.8% maximum for the waters used in the study. The log removal was (>4-log) in each case. This is below the recommended value of (6-log) by SANS and WHO, hence the need for disinfection (SANS 2005; WHO 2011). According to Zhou et al. (2009), virus and bacteria removal is 3–6 log in MF and UF membrane systems and is about 8 log in the high pressure system. Figure 5 shows that the rejection profile starts off very strong in the first 20 minutes for all the rivers except the Town Bush, and then gradually slows down for the rest.
of the experimentation time. This was explained by the fact that pore blocking and narrowing of the microfilter happens very quickly in the first 30 minutes of filtration of the contaminated fluids, especially for water sources with high turbidity. Complete removal of *E. coli* by the WFMF was not achieved for all the rivers, implying that further optimization of the process was needed for complete removal of *E. coli*. According to Sobsey (2002), different studies have revealed that membranes are effective in producing water with reduced bacterial levels, but the retentivity depends on the magnitude of the organism concentration levels. This was observed when comparing the performance of the WFMF on *E. coli* removal on the Duzi river with the Town Bush river. The *E. coli* content after filtration differed, and this was due to the level of the incoming *E. coli* on the feed side despite the use of the same filter on both rivers. Nonetheless, the *E. coli* content on all the rivers was brought to levels that could be easily disinfected with a small disinfectant concentration.

**Performance of WFM on turbidity removal**

Figure 6 shows the turbidity profile of WFMF with time for different water sources.

Removal of turbidity is an important part of disinfection, as it helps in improving the appearance, taste and odour of the treated water. If required, it should be brought to levels where chemical disinfection can be easily and effectively achieved. According to Cheremisinoff (2002), Schoenen (2002) and Momba et al. (2008), complete disinfection is achieved when the feed is given some form of prior treatment such as filtration, or sedimentation is required before chlorination of unprotected surface water. According to SANS (2005), the stipulated standards for turbidity in potable water should be below 1 NTU. Turbidity hinders the effectiveness of chemical disinfection.

The turbidity removal profile in Figure 6 shows that as filtration time increases from 0 to 120 minutes, turbidity rejection also improves. The turbidity rejection showed a similar trend for all rivers. The highest turbidity rejection was observed in the first 30 minutes of filtration. Here, the permeate turbidities for all the river sources were generally below 1 NTU irrespective of the initial feed water turbidity. After 45 minutes of filtration, the filtration had reached its maximum and the addition of the depositing particulates no longer played a major role in the turbidity; as a result, no change in turbidity was observed. At 90 minutes, the rejection of turbidity no longer improved, particularly for the Duzi and Umbilo rivers. This was due to the formation of a cake layer on the membrane surface by microorganisms and particulates from the feed. These substances are responsible for the decrease in permeate flux, as seen after 30 minutes of filtration in Figure 5. For rivers with initially low turbidities such as the Town Bush and the synthetic feed, the start of saturation in the cake thickness actually took longer since there was less suspended matter to build up the cake layer.

**Performance of WaterGuard alone without WFMF**

Figure 7 shows the effect of WaterGuard concentration on *E. coli* removal for different rivers.
For all the rivers, irrespective of the contamination level, increasing WG concentration resulted in a decline in *E. coli*. The improvement in disinfection on increasing WG concentration is expected, because for the same number of bacteria the concentration or strength of the disinfectant is then increased, resulting in improved disinfection. This is in agreement with the findings of Cheremisinoff (2002), which showed that when chlorine dosage is increased, the amount of available chlorine to be used for oxidation or deactivation of bacteria is also increased. This study revealed that initial concentrations of 7.26 and 14.52 mg/L resulted in a greater impact on disinfection than on increasing concentration from 21.78 to 50.8 mg/L. The reason for this occurrence was however not further verified; nonetheless, the presence of other contaminants in the feed was behind the reduction of the disinfectant efficacy as earlier stated during the determination of the chlorine residual. A study by Cheremisinoff (2002) revealed that the initial amount of chlorine dosed gets used up for oxidation by metals such as iron and manganese and the organic matter present in the water before disinfection of bacteria occurs. The Duzi river proved to be more difficult to disinfect by WG, followed by the Umbilo, and the easiest was the Town Bush river. The difficulty in disinfecting the Duzi river was due to high turbidity, organic matter and other pathogens competing for chlorine. WG at 50.82 mg/L was able to completely disinfect the Duzi river water. This dose was high compared to other rivers that contained fewer contaminants. According to Cheremisinoff (2002), the high dosages of chlorine will need to be removed by activated carbon in order for the water to be palatable, which may lead to further cost. Also, the residual chlorine was high. The ease of disinfecting the Town Bush river was linked to the absence of turbidity and organic matter in that water. One of the factors considered for the adaptation of a POU system for use with regards to chlorine dosage is the residual dosage, which was stated earlier. Furthermore, a high dosage of chlorine will give the treated water a taste and an odour.

**Performance of water BRCH without WFMF**

BRCH tablets were tested on all the water sources by varying the sizes and flow rates. The effect of tablet size was studied by varying the tablet size between 0.1, 0.3, 0.5 and 0.75 g whilst keeping a constant flow rate of 20 L/hr. The effect of flow rate was determined by keeping a constant tablet size of 0.3 g and varying flow rates. The flows investigated were extremely low flows of 1 and 5 L/hr and high flow rates of 20 and 45 L/hr, see Figure 8. Figure 9 shows the effect of BRCH tablet sizes on *E. coli* removal; log removal values for the permeate were 2-log. The results show that increasing the tablet size improved disinfection for all the rivers. This was because an increase in the tablet size increased the surface area of the tablet that came into contact with contaminated water, which
resulted in the release of more chlorine. The increased contact between tablet and water being disinfected results in collision between the disinfectant and the contaminant. This collision is necessary before any disinfection occurs. The flow rate affects residence time or CT and mixing. Figure 10 shows that at low flow rates more disinfection is achieved. Again, this is due to an increase in CT, which facilitates collision, and also most of the fluid comes into contact with the tablet. Although a high flow rate facilitates mixing, the increased flow rate reduces CT and much of the fluid does not come into contact with the tablet, so no disinfection occurs. This explains why less disinfection was achieved at high flow rates for highly contaminated feed water. Hence, for optimum disinfection to occur, the size of disinfectant, flow rate and quality of feed to be treated played a vital role. Similarly, like WG, the LRV for all the feed samples was 2-log.
Performance of RRWTS with chemical disinfectants

The RRWTS's (combined filtration and disinfection) performance was evaluated on the basis of total removal of E. coli from the water as shown in Figures 10 and 11.

Filtrates from the WFMF were disinfected using WG and BRCH tablets. The result in Figure 10 shows that less than 20 mg/L of WG was required to achieve total disinfection, thereby achieving an LRV of 4-log disinfection on all the feed samples tested. Similarly, less than 0.2 g of BRCH tablet was required for complete disinfection, see Figure 11. The need for extra disinfectant dose and CT was eliminated as total disinfection was achieved immediately and at minimal disinfectant concentration. This was obtainable on all the rivers. The combination of the WFMF together with the disinfectants met the (4-log) inactivation of microbial contaminants by (WHO 2011) and SANS 241 (2005).

The WFMF reduces the contaminants in the feed samples that could hinder disinfection and also slow the process. The presence of colloids and suspended matter reduces the efficiency of disinfection, increases the demand for disinfectants and can lead to the formation of disinfection by-products. Also, many pathogens and indicator organisms can be protected from being disinfected when the water has high turbidity, as the organisms are shielded from having direct contact with the used disinfectant.

The WFMF therefore eliminated the need for disinfection kinetics, which could be time consuming and costly in some cases. It also reduced the formation of disinfection by-products, as well as the taste and odour associated with going above the stipulated chlorine residual in the permeate, as was in the case when disinfecting the feeds without prior pre-treatment. There are three aesthetic factors that determine the reaction of water consumers at all levels: taste, odor and appearance. Most will prefer to drink odorless, tasteless and bright-looking water that is not treated than to consume treated water with odor or taste. Permeates from the RRWTS met these criteria and hence can be easily accepted by the consumers. Other POU systems have, however, failed to meet these criteria. Therefore, the findings in this study confirm that of Schoenen (2002), which showed that filtration should be carried out prior to chemical disinfection to eliminate other unwanted particles that may shield the pathogen.

Effect of cleaning and recovery of the WFMF

Cleaning of the membrane was carried out after 150 hours of filtration, this was to give room for the observation of the effects of fouling on the membranes. Fouling is a major setback for the application of membrane technology. It is defined as the reduction in permeate flow in a membrane with time due to the accumulation of organic and inorganic particles. The pure water flux of the virgin membrane was found to be 60 LMH for each module, this will be used as a basis for comparison with the cleaned and fouled membrane.

Cleaning of the membrane removes the fouling layer, which in turn assists in the recovery of flux during filtration.
Figure 12 shows the effect of cleaning and flux recovery. The Duzi river had the highest flux decline of 65% after 150 hours of filtration, followed by the Umbilo with 60%, while the Town Bush had the least at 63%. Cleaning of the membranes resulted in a recovery of more than 80% of the membrane flux irrespective of the feed type. Most membrane manufacturers recommend a flux recovery of more than 80%. A study by Bessiere et al. (2009) on the effect of natural organic matter (NOM) on fouling has shown that NOM are responsible for the rapid but reversible fouling on the membrane. These components get adsorbed on the membrane material and are not easily detached from the membrane.

The advantage that the RRWTS has over the POU system is the fact that the system does not require expertise to clean and recover its flux after it has fouled. Also, most membranes are susceptible to chlorine attacks, but not in the case of the RRWTS.

CONCLUSIONS

Flat sheet woven fibre MF membranes were used for this study, with the overall focus on disinfection using the membranes and disinfectants. Turbidity and other particulate matter were a major hindrance to complete disinfection using the disinfectants alone. However, it helped to improve the WFMF effectiveness in E. coli removal due to pore blocking, narrowing and cake filtration, which in turn improved disinfection by the WFMF. The LRV of both disinfectants and WFMF when applied alone for disinfection was (2-log) while an LRV of (4-log) was obtained on combining the WFMF and disinfectants. Therefore, it was concluded that the major benefit derived from integrating the WFMF with chemical disinfection was that it yielded a great reduction in the use of huge amounts of chemicals because small quantities of disinfectants were required to disinfect the water and hence eliminate the possibility of taste and odour in the treated water, and finally, complete deactivation of microbial agents.

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REFERENCES


Cheremisinoff, N. P. 2002 Handbook of Water and Wastewater Treatment Technologies. 1st edn, Butterworth Heinemann, Boston, USA.


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