



Technologies to Remove DBPs in Drinking Water in Newfoundland and Labrador --- A Review

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List of abbreviations

AgNO₃: Silver nitrite
AgNP: Silver nanoparticle
BACF: Biological activated carbon filtration
BDCM: Bromodichloromethane
BWAs: Boil water advisories
Cfu: Colony-forming unit
DAF: Dissolved air flotation
DBCM: Dibromochloromethane
DBPs: Disinfection by-products
DMSO: Dimethyl sulfoxide
DOEC: Department of Environment and Conservation
EBCT: Empty bed contact time
GAC: Granular activated carbon
GCDWQ: Guidelines for Canadian Drinking Water Quality
HAAs: Haloacetic acids
MIOX: Mixed oxidants
NF: Nanofiltration
NOM: Natural organic matter
Ppb: Particles per billion
PSA: Poly sodium acrylate
QS: Quartz sand
RO: Reverse osmosis
THMs: Trihalomethanes
TOC: Total organic carbon
US: Ultrasound
UV: Ultraviolet
E. coli number: log/cfu

Executive Summary

Drinking-water security is now a worldwide issue. Microorganisms and chemicals in drinking water are difficult to remove through conventional water-treatment methods. Among the various pollutants in drinking water, disinfection by-products (DBPs), especially trihalomethanes (THMs) and haloacetic acids (HAAs), are now recognized as being potentially hazardous to human health under long-term exposure scenarios. They can potentially cause several kinds of cancers and mutagenic disorders. In Newfoundland and Labrador (NL), especially in rural areas, the concentration of THMs and HAAs are much higher than the Canadian drinking-water-quality guidelines of 100 µg/L and 80 µg/L, respectively (Health Canada, 2012). Most water treatment plants in NL use chlorine gas as disinfection. During this process, DBPs can be generated through reactions with natural organic matter (NOM) in the source water. In this report, advanced DBPs removal technologies, such as the advanced oxidizing method, ultrasound (US), quartz sand (QS) filtration, nanofiltration membrane, zirconium coagulation, and biological activated carbon filtration (BACF) are discussed in terms of their advantages and the feasibility of their application in rural areas.

1 Background

1.1 Current drinking-water-quality status in Newfoundland and Labrador

NOM is a major potential source of DBPs when chlorine is used as a disinfectant. According to the 2013 annual report (DOEC, 2014c) of the Government of Newfoundland and Labrador's Department of Environment and Conservation (DOEC), NOM concentration in drinking water in the province can be as high as 11 mg/L. Although the provincial government has taken action to improve drinking-water quality with measures such as source water protection and operators' education (e.g., the source-to-tap program [DOEC, 2001]), in 2013 there were still several communities with THM and HAA concentrations that exceeded the drinking-water-quality guidelines (DOEC, 2014c).

Monitoring DBPs in the province has focused on THMs and HAAs, as these are the most abundant DBPs formed by disinfecting water with chlorine. Out of approximately 480 sampled public water supply systems in the province, 134 displayed high levels of THMs, according to the Guidelines for Canadian Drinking Water Quality (GCDWQ) (DOEC, 2014b). Compared to the USEPA standard, however, approximately 159 out of 473 sampled public water supply systems in NL display high levels of HAAs (DOEC, 2014a). The majority of these exceedances occur in small, rural drinking-water systems, and usually in combination with other parameter exceedances, particularly colour (DOEC, 2009).

Despite the rising number of affected communities, the provincial government insists that high chlorination by-product levels are better than the risks associated with drinking untreated (e.g., chlorinated) water (DOEC, 2014). Currently, chlorine disinfection is a preferred and economical choice for small communities. Cost is a significant impediment to finding a more permanent solution to the problem in many areas.

DOEC's summary of THM and HAA distributions within the province is shown in Figure 1.1, which illustrated the THM distribution in 480 water supplies (DOEC, 2014b).

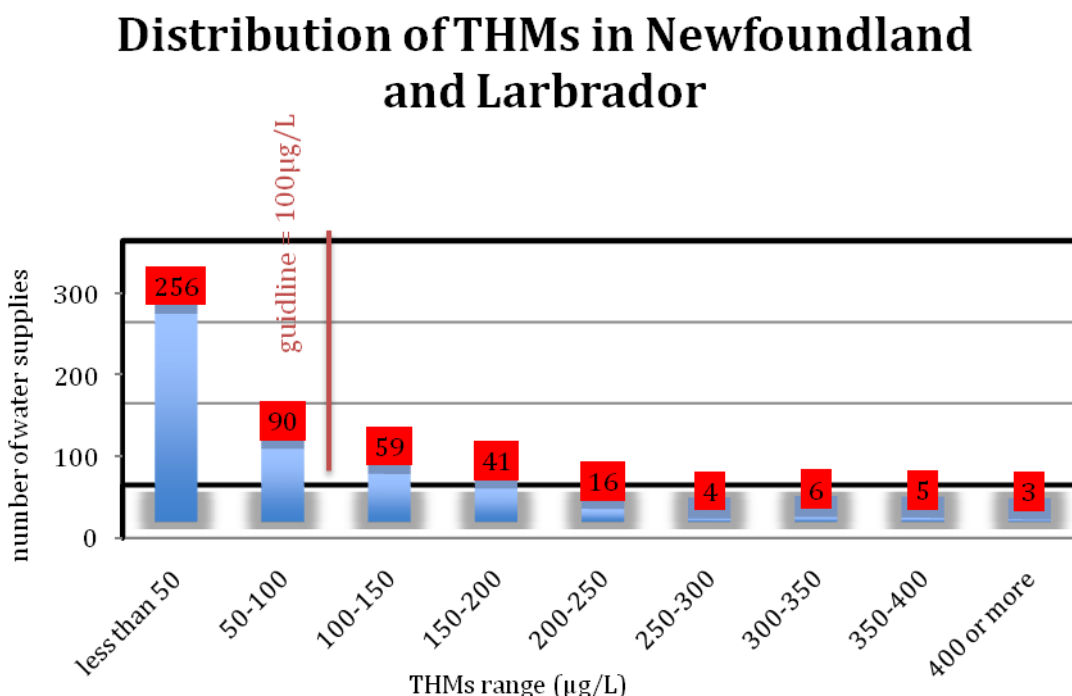


Figure 1.1 Distribution of THMs in Newfoundland and Labrador

As shown in Figure 1.1, 27.9% of the water utilities in NL have an exceedance of THMs, half of which are distributed in the 100–200 µg/L range.

The distribution of HAAs are listed below, and as Figure 1.2 (DOEC, 2014a) shows, in a total of 473 sampled public water supplies, 159 (or 33.6%) exceeded guideline-specified HAA concentrations. This illustrates that approximately one-third of the public water supplies cannot provide safe, potable water. When this is considered in conjunction with the summer of 2013 drinking-water-quality index, it can be inferred that most THM and HAA exceedances occurred in rural areas.

Distribution of HAAs in Newfoundland and Labrador

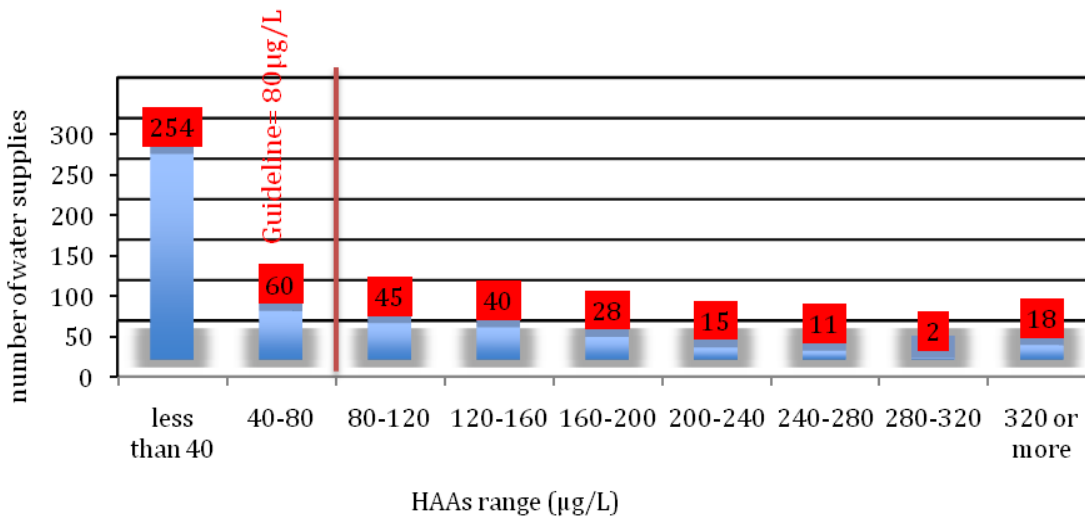


Figure 1.2 Distribution of HAAs in Newfoundland and Labrador

The Health Canada regulated guidelines for the concentration of THMs and HAAs in drinking water should be less than 100 µg/L and 80 µg/L, respectively (Health Canada, 2012).

The most severe exceedance occurred in New-Wes-Valley: the THM level was 380 µg/L and the HAA concentration over 600 µg/L. The HAA and THM concentrations in Marystown exceeded the current guidelines, at 113 µg/L and 100 µg/L respectively. Bonavista, which is sourced from Long Pond, has THM and HAA concentrations of 187 µg/L and 200.6 µg/L, which were higher than those from other water sources in the community. Channel-Port aux Basques, which is sourced from Gull Pond and Wilcox Pond, slightly exceeded the guidelines, with THM and HAA concentrations of 100 µg/L and 81 µg/L respectively (DOEC, 2013a).

Clarenville's water quality, on the other hand, has improved since 2007. According to previous research (Kar, 2000), THM and HAA concentrations in Clarenville's water supply were both around 400 µg/L in 2000. However, in the summer of 2013 THM and HAA concentrations were around 54 µg/L for both parameters (DOEC, 2013a).

Through the above investigation, small communities with very high levels of THMs and HAAs do not have proper water treatment in place and insufficient protection for their water sources. Water treatment facilities in these communities are only equipped with a prescreen, such as grates, to remove large pieces of organic matter, supplemented by a chlorine disinfection system, with no coagulation as pretreatment or any kind of filtration to remove the NOM. These communities generally use surface pond water or well water as their drinking-water source. In those communities, which use pond water, the water source is often surrounded by bushes and exposed to nature without any protection. When it rains, these ponds can be contaminated by sediments and organic matter in the soil.

1.2 Small community challenges in drinking-water treatment

The sparse geographical distribution of small communities in the province combined with populations of generally fewer than 1,000 people does not lend itself to easy solutions to drinking-water-quality issues. These communities simply do not have access to the same resources (human or financial) as larger systems do. They have a lower median household income and fewer businesses and industry; this results in a lower tax base. Populations in most small communities in Newfoundland and Labrador are aging and declining in size. These factors make it more difficult for them to afford the infrastructure and qualified operators necessary to provide high-quality drinking water to their populations if there are any water-quality issues (DOEC, 2009).

1.3 Objective and scope of work

In this literature review, the types, formation processes, and health impacts of DBPs will be discussed and advanced technologies introduced to determine the feasibility of deploying these technologies in rural areas¹, and, where applicable, at the household level.

2 Disinfection By-products (DBPs)

2.1 Occurrence of DBPs

Disinfection by-products, or DBPs, are generated during the disinfection period of drinking-water treatment. They are formed through reactions between NOM, naturally occurring in the source water, and the disinfectants used to treat this water (USEPA, 2009). Typical DBPs formations include THMs, HAAs, and others, including iodinated and fluoride by-products.

2.2 Key factors affecting the formation of DBPs

The formation of DBPs is affected by pH, temperature, season, and chlorine demand (Ahmad, 2013). DBPs concentrations vary seasonally. For instance, in winter the level of DBPs is relatively lower than it is in other seasons. This can also be understood in terms of lower temperatures, as the activities of microorganisms in the source water are reduced, and, therefore, less organic matter exists in the water. Source water is another concern for the formation of DBPs. Surface water, such as rivers, ponds, and lakes, is generally considered to contain more organic matter than groundwater. These organic matters are usually considered as the major source of DBPs.(Kar, 2000).

2.3 Current disinfection techniques in Canada and Newfoundland and Labrador

Most water treatment plants in Canada use chlorine for both primary and secondary disinfection purposes. For example, over 90% of the treatment plants in Newfoundland and Labrador use chlorine as the primary disinfectant. In another evaluation, the 2001–2004 Drinking Water Surveillance Program (DWSP) results showed that 165 of 179 (92%) treatment plants in Ontario use chlorine as their primary disinfectant. A 2005 survey of 3,590 drinking-water facilities located in nine provinces and territories indicated that sodium hypochlorite is the most common disinfectant being used in 78% of the plants, whereas 19% used chlorine gas, 1.4% calcium

¹Particularly in communities of 1,000 or fewer residents in NL.

hypochlorite, and less than 0.5% applied alternative disinfectants. Some water utilities use monochloramine, for example, as a secondary disinfectant (Canadian Health, 2006).

Similarly, Figure 2.1 and Figure 2.2 show over 90% of the drinking-water supply systems in NL utilize chlorination disinfection. Furthermore, over twenty chlorination disinfection systems came into operation from 2012 to 2013 alone—one fiscal year (DOEC, 2014c). Compared with other techniques, advanced oxidization is becoming more widely utilized in the province. The number of systems using this method in the province between 2010 (DOEC 2011b) and 2013 (DOEC 2014c) increased at the rate of one per year, rising from four in 2010 to seven in 2013.

Numbers of Chlorination Disinfection Systems from 2010 to 2013

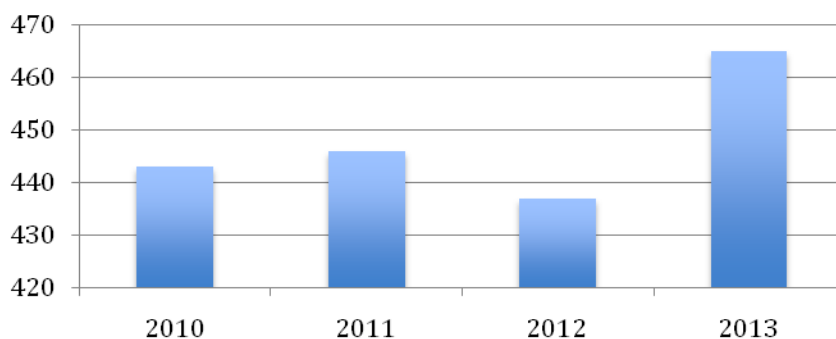


Figure 2.1 Number of Chlorination Disinfection Systems from 2010 to 2013

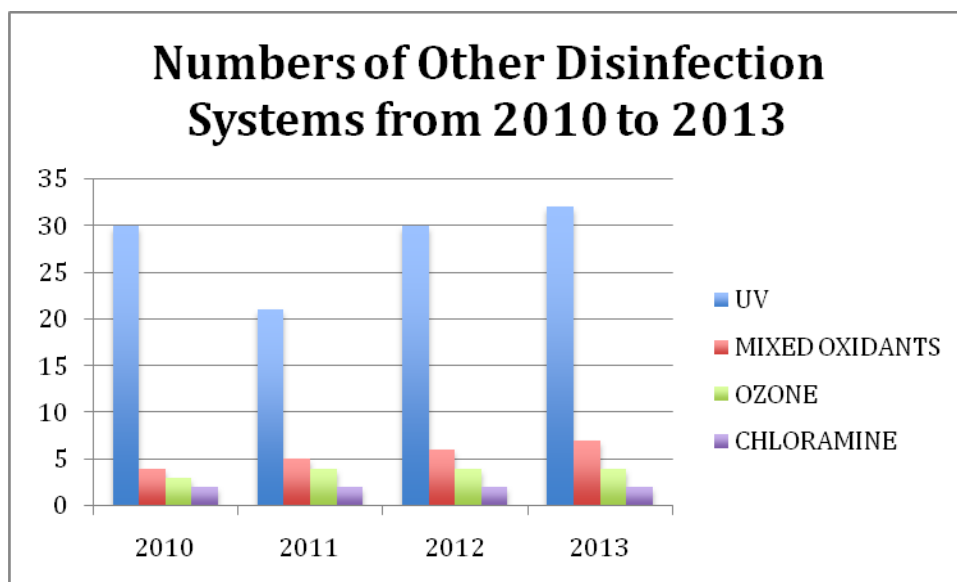


Figure 2.2 Number of Other Disinfection Systems from 2010 to 2013

Table 2.1 (DOEC, 2000) compares the techniques being utilized in NL on the basis of their disinfection efficiency, effect on water quality, and THM formation potential and cost-effectiveness relative to chlorine gas. Ozone showed the best performance as a disinfectant: it was the most effective in terms of microorganism removal and it had little DBPs formation; however, its high cost and requirement for well-trained operators restrict its utilization in rural areas.

The ultraviolet (UV) disinfection system performed less effectively than ozone on microorganism removal but achieved a DBPs production rate of zero and had no effect on pH. As illustrated in Figure 2.2, UV systems are the second most prevalent disinfection system in NL. UV can be used individually or combined with other disinfection systems, such as chlorine, to reduce the potential for bacteria regrowth in pipes. The cost of UV is the same as for ozone (Table 2.1). Mixed oxidants yield “good” and “very good” effectiveness ratings on microorganism removal and have a lower THM formation potential than chlorine (DOEC, 2000). Cost-effectiveness is an important factor in evaluating the feasibility of a water treatment system in rural areas. The cost of mixed oxidants ranges from 20% below to 50% higher than the cost of chlorine (DOEC, 2000). Mixed oxidant systems can produce similar effects at a similar cost to chlorine but with less DBPs formation, which may explain why these systems appear to be increasingly prevalent (Figure 2.2). The principle of disinfectant generation may help explain this increase. The MIOX Corporation is utilizing a combination of food-grade salt and water and passing this through an electrolytic cell to generate disinfectant. The following formula expresses this process:



A strong oxidant, sodium hypochlorite, is generated. Compared with conventional gaseous chlorine, this process is safer and easier to operate (MIOX, 2013).

Table 2.1 Comparison of Current Disinfectants and Applications

Comparison of Current Disinfectants and Applications					
Characteristics	<i>Chlorine</i>	<i>Chloramine</i>	<i>Ozone</i>	<i>Mixed Oxidants</i>	<i>UV</i>
Classification	Primary and Secondary	Secondary	Primary	Primary and Secondary	Primary
Effectiveness					
Bacteria	Very Good	Poor	Excellent	Very Good	Very Good
Viruses	Very Good	Poor	Excellent	Very Good	Very Good
Protozoa	Fair	Very Poor	Very Good	Good	Fair
Helminths	Good	No Information	Excellent	Good	No Information
Water Quality					
pH	Strong Effect	Strong Effect	Little Effect	Moderate Effect	No Effect
Turbidity	Strong Effect	Strong Effect	Strong Effect	Strong Effect	Strong Effect
Temperature	Strong Effect	Strong Effect	Strong Effect	Strong Effect	Strong Effect
Organic Matter	Strong Effect on Chlorine Demand	Little Effect	Ozone Demand	Less affected than Chlorine	No Effect
THMs	Can Develop with Precursors	Not Formed	Little Formation	Less than Chlorine	None
Cost of Other Disinfectants Compared to Chlorine Gas	1.00	3.4	3.5	0.8-1.5	3.5

3 Risk assessment of DBPs

3.1 Health impacts of long-term exposure

Of all possible DBPs, chlorinated and brominated (e.g., chloroform and bromoform) DBPs are considered to be major sources of risk to human health. With long-term exposure, they can cause bladder cancer, spontaneous miscarriages, and various birth defects (Matilainen & Sillanpää, 2010). Table 3.1 shows the possible health risks of DBPs under long-term exposure (Gopal et al., 2007; DOEC, 2009).

Table 3.1 Toxicological Effects of DBPs

Class of DBPs	Compounds	Health effects
Trihalomethanes (THM)	Chloroform Dibromochloromethane Bromodichloromethane Bromoform	Cancer, liver, kidney, and reproductive effects Nervous system, liver, kidney, and reproductive

		effects Cancer, liver, kidney, and reproductive effects Cancer, liver, kidney, and reproductive effects
Haloacetonitrile (HAN)	Trichloroacetonitrile	Cancer, mutagenic and clastogenic effects
Halogenated aldehydes and ketones	Formaldehyde	Mutagenic
Halophenol	2-Chlorophenol	Cancer and tumor promoter
Haloacetic acids (HAA)	Dichloroacetic acid Trichloroacetic acid	Cancer and reproductive and developmental effects Liver, kidney, spleen, and developmental effects

3.2 Cancer risks of DBPs

Ahmad (2013) researched the quality of Torbay and Pouch Cove drinking water to determine the presence of THMs and HAAs (Table 3.2). A risk assessment of life-time exposure was calculated in order to assess the cancer and non-cancer risk. By calculating different intake pathways (direct intake from drinking water; breath in steam and skin absorbance) of THMs and HAAs to find out the possibility of cancer risks of communities with high DBPs concentration. Comparison between large Canadian city (Ottawa) with full-scaled municipal water treatment system and Pouch Cove to illustrate the hazardous of high concentration DBPs in drinking water.

Table 3.2 Concentration of HAA and THM in Torbay and Pouch Cove in Newfoundland and Labrador

HAA components in tap water unit: µg/L									
MCAA	MBAA	DCAA	TCAA	BCAA	BDCAA	DBAA	CDBAA	TBAA	THAA
60.36	0	104.88	8.57	138.54	37.27	39.85	0	0	451.50
THM components in tap water unit: µg/L									
Chloroform		BDCM		DBCM		Bromoform			
132.50		9.89		2.10		0.22			

Total HI_{oral} (none carcinogen risk) for females was 0.504018182; males, 0.3465125. Total HI_{dermal} for females was 0.015947724; males, 0.01096406. Residents of Pouch Cove can be easily affected by non-cancer hazards; research on the hazardous nature of DBPs illustrated that they can possibly cause birth defects or miscarriages (WHO, 2005).

Total THM cancer risk in Pouch Cove was 2.78E-04 for females; 1.91E-04 for males. Thus, females have a higher risk of contracting cancer than males. Wang et al. (2007) conducted a cancer risk assessment of THMs in Ottawa, with full-scale water treatment plants, in Canada,

where chlorine-chlorine, ozone-chlorine, and chlorine-chloramine were applied in their disinfection systems. The risk to females and males was $1.44\text{E-}04$ and $1.18\text{E-}04$ respectively (Wang et al., 2007). Comparatively, residents living in communities with high levels of THMs and HAAs in their drinking water have almost twice the risk as those with access to well-treated drinking water. Chloroform, one common component of DBPs from chlorine disinfection systems, is volatile and potentially neurotoxic. Because chloroform occupied over 90% in the total THMs' concentration, the total risk of THMs could also be represented by the total chloroform risk. For communities that issued Boil water advisories (BWAs) due to high THM and HAA levels, boiling can help to remove the THMs from drinking water because of those compounds' volatility. However, boiling water is much less effective in removing HAAs, as indicated by a removal rate that varied from 17% to 23% (Ahmad, 2013).

4 Alternatives to chlorine disinfection

In this section nano-sized silver coated particle disinfectant, CDC-recommended household disinfection technologies, and MIOX are discussed as alternatives to chlorine disinfection. These technologies will generate lower DBPs (and in some cases no DBPs), are relatively easy and safer to operate, and cost less than chlorine.

4.1 Nano-sized silver coated particle filtration

Antibacterial surfaces are common in the medical field (i.e., on medical implants to prevent infection), yet some researchers have also used this technique to purify contaminated water. Various surfaces (including stainless steel and copper) can be coated with particles like silver for bacterial/biofilm removal/reduction from drinking water (Lalley et al., 2014).

Silver has been used as a water disinfectant since the times of the ancient Greeks (about 150 B.C.). Although the exact process of silver disinfection remains unclear, it is believed to result from silver (Ag) atoms binding to thiol groups (-SH) in enzymes, which subsequently causes enzyme deactivation. Other theories postulate that Ag^+ ions enter the cell, intercalate between purine and pyrimidine base pairs (which disrupts the hydrogen bonding between the two anti-parallel strands), thus denaturing the DNA molecule. Though many metals are effective at bacterial inactivation (e.g., copper [Cu], zinc [Zn], iron [Fe], lead [Pb], aluminum [Al], gold [Au]), silver is the most efficient, has the lowest hazard potential, and, therefore, is the most commonly investigated disinfecting metal nanoparticle. The oligodynamic effect of silver is quite strong for bacterial cells, yet relatively non-toxic to mammalian cells. With the advent of nanotechnology, silver is again being considered as a potential water decontaminator and a replacement for current chemical (and DBPs-forming) disinfectants. Numerous surfaces can serve as supports for such decontaminating silver particles (Lalley et al., 2014).

Conventional chlorine disinfection has the potential to form DBPs and drug-resistant bacteria; however, it requires operators who have a strong technical background. Nano-sized silver particle disinfection has been widely proposed and employed as a potential alternative disinfection technology. Silver ions (Ag^+) have been utilized as an effective disinfection material in the medical field. They can penetrate or destroy bacteria cells to critically damage DNA and RNA functions (Mpenyana-Monyatsi et al., 2012). Species such as *Cryptosporidium* (a

microscopic parasite that causes diarrhea cannot be efficiently inactivated by chlorine disinfection.

In some developing countries, water scarcity and safety are major concerns. Because residents cannot access safe drinking water or treated water, there is an urgent need for cheap point-of-use methods to purify this water. The use of silver in disinfecting harvested rainwater has shown to be efficient at removing various species, including *E. coli* and *P. aeruginosa*; it is also an inexpensive alternate water disinfection technique (Lalley et al., 2014). For example, in Mexico, where local water supplies are not always safe, especially in rural areas, a colloidal silver product called Microdyn has been used for decades to keep residents safe from contaminated drinking water. Silver has also been widely used in Europe as a drinking-water disinfectant, but its utilization in the U.S. is limited, due to the possibility of silver leaching (CDC, 2013). Extensively researched, nano-sized silver particle coated materials are a new trend for point source and decentralized water treatment plant disinfection systems (Mpenyana-Monyatsi et al., 2012). The application of AgNPs-functionalized ceramic filters, hydrogels, ion-exchange materials, papers, polyurethane foam, and polymeric spheres as bioactive components in flow-through or column systems for point-of-use water disinfection have already been tested (Loo et al., 2013).

Paper, as a common product, contains a large amount of fiber and hollows, which could provide sufficient support for bound between paper and AgNPs coating. It has been shown to be a potential material to be coated by nano-sized silver particles. In a percolation system with paper coated by nano-sized silver particles, pathogens are deactivated when they pass through the paper; this ensures that the leaching of silver is within the acceptable range.

Comparison tests among natural zeolite, sand, fiberglass, anion resin, and cation resin have been conducted to determine the best material for Ag coating. (Mpenyana-Monyatsi et al., 2012). The results in Table 4.1 indicate that during 90-minute tests the Ag/cation resin performed best in *E. coli* removal. This experiment also showed that, with the regrowth of *E. coli* in treated water, only the Ag/cation resin showed no regrowth in the treated water. Other filtration systems showed more or less the regrowth of *E. coli* (Mpenyana-Monyatsi et al., 2012).

Table 4.1 Removal efficiency of silver coating on different materials

Material/ concentration	0.01 mM (log cfu/100 mL)	0.03 mM (log cfu/100 mL)	0.05 mM (log cfu/100 mL)	0.1 mM (log cfu/100 mL)
Ag/Zeolite	0.5	0.5	1.0	1.5
Ag/Sand	1.0	1.0	2.0	2.5
Ag/Fiberglass	1.2	2.5	3.5	4.3
Ag/Anion	2.0	4.0	4.0	4.5
Ag/Cation resin	3.5	4.5	5.5	>7.0

Silver ion elution is another important parameter in AgNPs coated systems. During the 120-minute 0.1 mM Ag/substrate test, the lowest Ag⁺ release was detected from the Ag/cation filter system and the highest from the Ag/zeolite system. The initial released level of the Ag/cation system was below 0.1 mg/L, while 1.8 mg/L was released from Ag/zeolite. However, after the

90-minute process, no free silver ions were detected in the filtered water from the various filtration systems.

Mpenyana-Monyatsi et al. (2012) illustrate that cation resin coated with AgNPs can obtain a high removal rate of pathogens, meanwhile there would be a relatively low elution of Ag^+ silver ions. Ion resin exchange is a widely recognized technique in water and wastewater treatment processes, especially for arsenic and mercury removal and for softening processes.

Porous carbon foam, proposed by Karumuri et al. (2013), increased the contact area of the AgNP with the source water compared to other cost-efficient materials (Karumuri et al., 2013).

Synthesis of AgNP on support structures:

Among the established methods to synthesize AgNP, the most suitable and cost-effective for small-scale products is the chemical reduction of silver salts in the presence of reducing and stabilizing agents. Karumuri et al. used silver nitrate (AgNO_3) as the original compound, which reacted with a tri-sodium citrate reduction agent in the presence of dimethylsulfoxide (DMSO). This involved a two-step process: deposition of AgNO_3 on support structures followed by an in-situ chemical reduction in the DMSO-citrate solution.

Bactericidal effectiveness of the AgNP-foam:

The antibacterial properties of AgNP-foam were tested, as explained earlier. From the rotation test, it was observed that the percentage of bacteria survival gradually decreased with time and more than 99% of the initial bacteria were degraded in 40 minutes. On the other hand, less than 10% of the bacteria was degraded when treated with as-received foams. From filtration tests, it was observed that almost 90% degradation in bacteria loading was achieved within two percolations of 5 minutes each, and complete degradation by three filtrations.

Durability of AgNP attached carbon surfaces:

The microstructure and elemental composition of AgNP-foam were monitored before and after water flow. No microstructural changes were apparent. Initial Ag concentrations remained unchanged after both types of tests. Durability studies of AgNP grown by this method on various carbon substrates have been conducted in the past. Some tests performed under harsher test conditions involving high power ultrasonic agitation have shown no change in AgNP densities or particle size distributions. Therefore, it is not surprising that these particles remain attached within the range of tests performed here. Long-term field-testing involving more forceful water flow or years of operation may be needed before detectable degradation occurs in these samples (Karumuri et al., 2013).

Loo et al. (2013) developed a point-of-use poly sodium acrylate (PSA) cryogel coated by silver nanoparticles (PSA/AgNP). The media of the disinfectant is PSA, a superabsorbent gel that can absorb hundreds of times its own weight of water; silver was dispersed uniformly on the media's surface. The preparation of PSA/AgNP can be briefly described as follows: allow 1 g of dried PSA cryogels to swell in a 250 mL solution of 1, 5, or 10 mM of AgNO_3 ; shake the suspension at 120 rpm on a shaker for 24 h; immerse the cryogels in a 250 mL solution of NaBH_4 to form silver nanoparticles; thoroughly wash the resultant nanocomposites by immersing in Milli-Q water, followed by vacuum filtration. PSA/AgNP can provide a good internal connection

between AgNP and PSA; AgNP and pores within PSA, to increase the interaction area. A column scale experiment conducted by Loo et al. indicated that PSA/AgNPs could achieve an average of 84.5% water recovery. Total Ag loss after 24 hours ranged from 0.03% to 1.79%; the total Ag in disinfected water ranged from 36.4 µg/L to 76.6 µg/L. The World Health Organization's (WHO) guideline for acceptable levels of soluble silver compounds when used as a disinfectant is 150 µg/L; the average soluble silver level in drinking water treated by silver is about 50 µg/L (WHO, 2014). Therefore, the total silver levels detected in the disinfected water treated by PSA/AgNPs proposed by Loo et al. (2013) are acceptable. PSA/AgNPs showed excellent disinfection efficiency on *E. coli* and *B. subtilis*; they showed a reduction from 5.4 to 7.0 logcfu/100 mL after 15 seconds of disinfection (Loo et al., 2013).

4.2 Household UV disinfection systems

Small-scale household water treatment systems currently available on the market can generally be attached to the tap or under the sink, or they can be installed in an indoor pipeline system. The most commonly utilized commercial systems are a combination of an UV lamp as the disinfectant, with activated carbon filtration, or reverse osmosis (RO) filtration to remove turbidity, colour, odour, and organic and inorganic chemicals. A visible or audible UV lifetime indicator is often installed to alert consumers to change the UV lamp and filtration cartridge. For cost of UV systems please see feasibility Table 6.1 (Rainfresh, 2009; Harris & Park, 2010).

4.2.1 eSpring® water purification system

A commercially available product from eSpring®, a UV lamp plus a carbon cartridge home device for treating water, is designed to be used with any municipally treated drinking water source or well water (Harris & Park, 2010). One market product announced by eSpring® was comprised of a UV light as the disinfectant and activated carbon as the filtration system. As shown in Table 2.1, a UV lamp with a germicidal wavelength can achieve disinfection with zero chemical additives and no bio-resistance (the ability of microbes to withstand doses of chemicals). Unlike chemical approaches to water disinfection, UV irradiation provides rapid, effective inactivation of microorganisms through a physical process. When bacteria, viruses, and protozoa are exposed to the germicidal wavelengths of UV light, they are rendered incapable of reproducing and infecting. UV light has a demonstrated efficacy against pathogenic organisms, including those responsible for cholera, polio, typhoid, hepatitis, and other bacterial, viral, and parasitic diseases. In addition, UV light (either alone or in conjunction with hydrogen peroxide) can destroy chemical contaminants such as pesticides, industrial solvents, and pharmaceuticals through a process called UV oxidation. A terminal side treatment system, eSpring®, has been proved to remove 99% of DBPs, odour, colour, and chlorine taste.

4.2.2 Rainfresh Whole House Ultraviolet (UV) Water Disinfection System

This system is comprised of a fine pore size (5 µ) filtration system and a UV lamp (Rainfresh, 2009). It can be installed on the main waterline before it is divided into cold and hot water and it operates 24 hours a day to provide protection for the home. An audible and visible UV lifetime alarm is available for UV lamp monitoring (Rainfresh, 2009). Installed in the main waterline hooked up to the house, Rainfresh can reduce contamination in both hot and cold water.

4.3 CDC-recommended household disinfection technologies

The Centers for Disease Control and Prevention (CDC) provide several easy-to-operate water-treatment technologies for those developing countries with no access to treated water. Ceramic

filtration, slow sand filtration, flocculants, and disinfectant powder are all prominent examples of technologies that have been introduced to these countries.

Currently, the most widely implemented ceramic filter design is Potters for Peace: a flowerpot-shaped design with a designated water capacity of 8-10 liters. To use the ceramic filters, families fill the top receptacle or the ceramic filter itself with water, which flows through the ceramic filter or filters into a storage receptacle. The treated water is then accessed via a spigot embedded within the water storage receptacle. The filters can be produced locally at ceramics facilities and then immersed in colloidal silver to ensure the complete removal of bacteria in treated water and prevent the growth of bacteria within the filter itself. Any locally made and commercial ceramic filters are widely available in developed and developing countries (CDC, 2012).

A slow sand filter, another filter adapted for household use, is more commonly known as a Biosand filter; “Biosand” is a specific trademarked system, whereas the slow sand filter mentioned by CDC is the most commonly used technology. The most widely implemented version consists of layers of sand and gravel in a concrete or plastic container approximately 0.9 m tall and 0.3 m². The water level is maintained at 5-6 cm above the sand layer by setting the height of the outlet pipe. This shallow water layer allows a bioactive layer to grow on top of the sand, which contributes to the reduction of disease-causing organisms. A diffuser plate prevents disruption of the biolayer when water is added. To use the filter, simply pour water into the top and collect finished water out of the outlet pipe into a bucket. Over time, especially if the source water is turbid, the flow rate can decrease. Users can maintain the flow rate by cleaning the filter by agitating the top level of sand, or by pretreating turbid water before filtration (CDC, 2012).

Slow sand filtration works through a combination of biological and physical-chemical interactions. The biological layer of the filter, or *schmutzdecke*, is important for the effective removal of microbial pathogens. Precoat filtration was initially developed as a portable unit to remove *Entamoeba histolytica*, a protozoan parasite. In this process, water is forced under pressure or by a vacuum through a uniformly thin layer of filtering material, typically diatomaceous earth. As with granular media filtration, proper chemical conditioning of the water improves the treatment efficiency of precoat filtration. In contrast, membrane filtration removes microbial pathogens primarily by size exclusion (without the need for coagulation) and is effective in removing microbes larger than the membrane pore size (CDC, 2012).

The Procter & Gamble Company (P&G) developed the PUR™ Purifier of Water in conjunction with CDC. PUR™ sachets are now centrally produced in Pakistan and sold to non-governmental organizations (NGOs) worldwide at a cost of US\$0.035 per sachet. The small sachet contains powdered ferric sulfate and calcium hypochlorite. To treat water with PUR™, open the sachet, add the contents to an open bucket which contains 10 liters of water, stir for 5 minutes, let the solids settle to the bottom of the bucket, strain the water through a cotton cloth into a second container, and wait 20 minutes for the hypochlorite to inactivate the microorganisms (CDC, 2012).

4.4 MIOX®

Mixed oxidants is a new and popular disinfection technology, one of which is MIOX®. The MIOX Corporation combines salt, water, and power to generate cost-effective disinfectant chemistries on-site. The scale of MIOX generator varies from 1-2 lb/day to over 3,000 lb/day.

The capacity of MIOX varies from 10,000 gal/day to 100,000,000 gallons/day (MIOX, 2013). With the same dosage, MIOX can achieve 50% less DBPs than conventional chlorine disinfection. It has been applied in many rural communities of developing countries (MIOX, 2013).

4.5 Chlorine Dioxide

Chlorine dioxide has been known as a powerful disinfectant (see Table 6.1 for costs). The first use of it can be traced back to 1900s in Belgium. During the 1950s, it was widely used in drinking water disinfectant (EPA, 1999). It is found that in dark cool environments, chlorine dioxide will not react with bromide, which with chlorine disinfection will react to generate bromoform, one of the THMs. Thus chlorine dioxide can reduce the formation of DBPs (WHO, 2000).

Chlorine dioxide cannot be compressed stored due to its explosive under pressure. There is no commercial compressed cylinder of chlorine dioxide (WHO, 2000). If utilized in a municipal drinking water treatment plant, it has to be generated onsite. However, due to its high reactivity and explosive nature, the accumulation of 10% volume in air will cause an explosion (EPA, 1999). If it is applied in small communities, with limited generation space, any leaking of chlorine dioxide will possibly lead to an explosion and injury to the water operator.

5 DBPs removal technologies

5.1 Zirconium coagulation

Zirconium coagulation technology is a recent innovation to improve coagulation efficiency to meet the higher standards of wastewater effluent and drinking-water quality. It can also be effectively employed in membrane pre-filtration applications where technologies such as ultrafiltration or microfiltration currently utilize enhanced coagulation techniques to improve operating efficiency (Jarvis et al., 2012).

The coagulant zirconium oxychloride contains 20% weight equivalent ZrO_2 , consisting of cationic hydroxylated zirconium. The specific gravity of this coagulant is 1.34 and it has a low pH value. Fig 5.1 shows the pilot scale scheme of the procedure. The pilot plant used in the experiments consisted of a rapid mix tank, two flocculator tanks in series, dissolved air flotation (DAF), and sand filtration (Figure 5.1). This configuration simulates a typical flow sheet used at full scale for treating high organic content water of this type. In this procedure, raw water is first fed to the rapid mixer, which contains prepared coagulant solution, and the pH is adjusted by adding NaOH solution to the preferred level for coagulation. The raw water is mixed with the coagulation solution at 200 rpm for two minutes, and the mixed water then is fed to the flocculators for flocculation. The rotation speed of the flocculators is 5 rpm to allow the formation of floc. Dissolved air flotation is followed by a saturator to pump out the sludge. Water from the floatation is pumped into sand filtration (Jarvis et al., 2012).

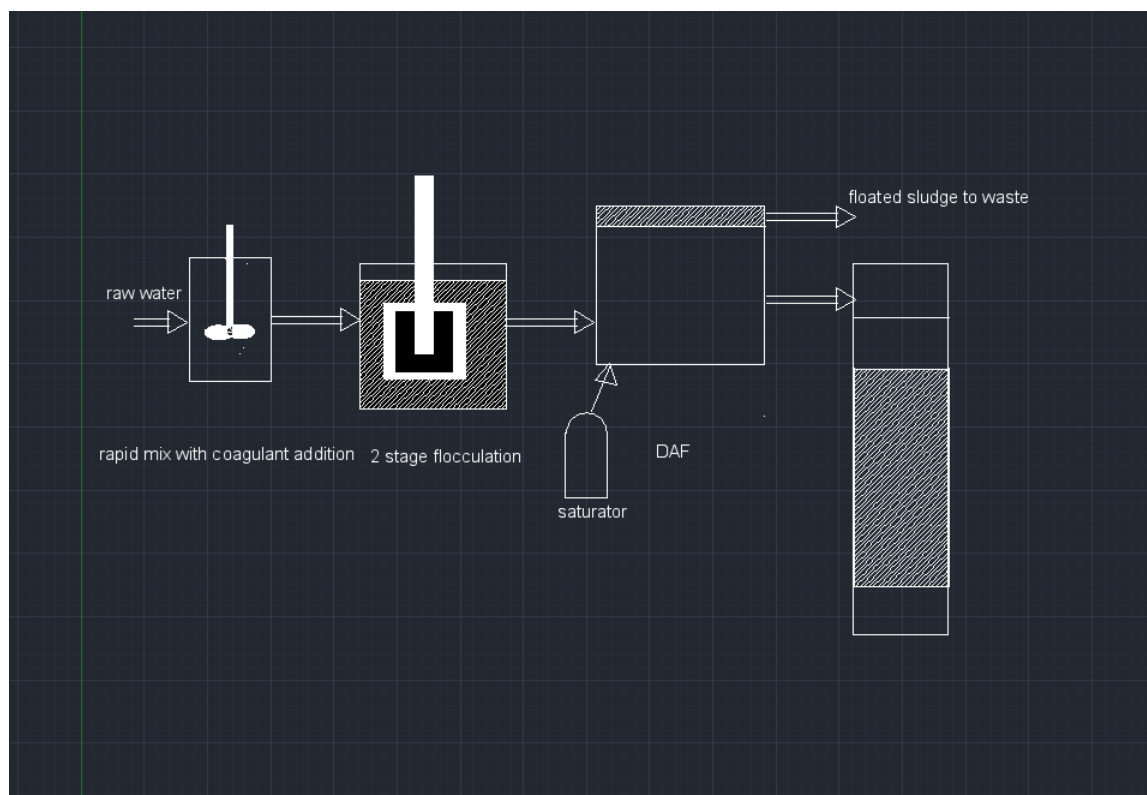


Figure 5.1 Scheme of zirconium coagulation water treatment system

5.2 Activated carbon adsorption

Granular activated carbon (GAC), a potential treatment technology that was calculated to be very effective when it was theoretically introduced to the St. John's water supply, exhibits a theoretical DBPs removal efficiency of 68% (Sadiq et al., 2001).

Activated carbon can be operated either as fixed beds of granular product or the addition of powdered carbon to an agitated tank. This technology is well known for its effectiveness in removing organic matters and is considered the best available treatment for many targeted organics as well as for the removal of taste, odour, and colour (Roy, 2009).

Biological activated carbon, a recently introduced efficient and effective technology for removing THMs and HAAs, is an enhanced GAC filtration system. As research shows, biological activated carbon can remove 49% of THMs in 50 minutes and 90% of HAAs in 40 minutes (Lou, 2014).

The preparation of biological activated carbon uses GAC as a media for microorganism growth and water from a water treatment plant as protein for these microorganisms. The water was poured into the GAC to allow the microorganisms to evenly form a biofilm on the surface of the GAC (Lou, 2014).

5.3 Nano membrane filtration

Nano membrane filtration is a pressure driven separation process for the removal of submicron particles. It could be recognized as a low pressure RO membrane. The pore size ranges from 0.001 μm to 0.005 μm . Due to its pore size, nano membrane filtration is capable of removing cyanobacteria, which is also known as green-blue algae, and Giardia. The primary drawbacks of nano filtration and biological membrane treatments are membrane fouling; when the concentration of NOM increases, they can become polluted.

Patterson et al. (2012) studied the Fyne process, a type of nano filtration (NF) considered a practical process for small communities (populations of 25-500), to research the filtration's ability to reduce the pathogen and formation of potential DBPs precursors, provide low-cost treatment alternatives with easy operation and maintenance, and improve water quality to reduce complaints. A pilot study conducted in the U.S. with real field-testing contained two 3-foot modules, with only 2.5 m^2 membranes for the flow rate smaller than 10 gpm. Pilot unit testing conducted by Patterson et al. showed that the Fyne process can achieve a total organic carbon (TOC) removal rate of over 96%, which can greatly reduce the formation potential of DBPs. The pathogen removal rate was tested by *B. subtilis* as a bacteria indicator that reached 4.3 log/100 mL cfu to complete. The process can also provide colour removal efficiency over 90% and 99.5% efficiency of removing 2-3 μm particles (Patterson et al., 2012).

The Fyne process uses a physical foam ball cleaning technique to scour the inner tube wall of the nano filter to reduce pressure drops and maintain system flow. During filtration, the inside walls of the membrane tube slowly become coated with a foulant layer, and raw water contaminants accumulate inside the membrane tube and recirculation loop. The Fyne process periodically and automatically performs a foam ball clean. A nominal 12.7 mm diameter foam ball is placed in one of the raw water connections on each module. The flow direction of the raw water in the module is reversed. This flow reversal causes the foam ball to pass through each of the 72 membrane tubes inside the module, cleaning the inside wall of the membrane tube while simultaneously discharging the concentrated raw water and drawing fresh water into the recirculation loop. Small perforated plates installed in the module inlet and outlet lines called "foam ball catchers" retain the foam balls in the system. The foam ball cleaning technique typically results in a low frequency of chemical cleaning. The design concept, however, allows for a chemical clean to be done by using a small cleaning tank (Patterson et al., 2012).

Uyak et al. (2008) studied THM removal by a nano filtration membrane and found that, with THM levels below 80 $\mu\text{g/L}$, a nano membrane can achieve a removal rate of 99%. When the concentration is greater than 80 $\mu\text{g/L}$, however, the nano filtration membrane cannot properly remove THMs; the concentration did not show significant change after the process was completed (Uyak et al., 2008).

5.4 Regenerative magnetic TiO_2

Highly adsorptive and regenerative magnetic TiO_2 is a newly developed technology for NOM removal in drinking water. Its power source could be solar energy and it has been shown to have a high performance removal rate. Research indicates that after five-time regeneration (reuse), the removal performance did not decrease. The NOM removal rate was 86%, and the UV_{254} removal

rate 78% (Ng et al., 2014). This technology has been utilized for column tests, and its real site application needs more research.

5.5 Ultrasound and quartz sand

In sonolytic treatment experiments, the ultrasound (US) was generated and transferred into the water sample via an immersible titanium alloy probe at a constant electrical power output of 150 W. The probe was immersed approximately 3 cm below the water surface. The sample vessel was placed in a water bath at a constant temperature of $20 \pm 0.5^{\circ}\text{C}$ during the irradiation period (Yang et al., 2014).

In quartz sand (QS) adsorption experiments, 2 g of QS was immersed into a 200 mL tap water with spiked DBPs. The sample vessel was placed in a thermostatic magnetic stirrer set at 20°C and 200 rpm (Yang et al., 2014).

Experiments with combined US and QS were carried out to evaluate the combination's removal efficiency for DBPs. The 200 mL tap water with the spiked DBPs mixtures and 2 g QS was exposed to 20 kHz US (Yang et al., 2014). The QS adsorption alone reached around a 40% removal rate of total THMs, and US alone reached 83% and 99% removal rate for TCAN and TCNM and cannot degrade other THMs. Combined US and QS adsorption achieved a THM removal rate of over 50% (Yang et al., 2014). A pilot-scale experiment is still required for the preparation of a real site application.

5.6 Boiling water and household filter systems

Carrasco-Turigas et al. (2013) conducted research on the use of different household devices for water boiling and filtration to determine their relative THM removal capability. The highest removal rate was found by microwave boiling: it achieved a 97% THM removal rate. This may be because microwave does not have a steady boiling temperature, temperature can be raised in seconds, so the sudden boiling situation can cause the agitation of water, which could cause the high removal of THM (Carrasco-Turigas et al., 2013). By comparison, THM removal rates were 66% when water was boiled in a saucepan, and 48% when boiled in a kettle. RO reached a 99% removal rate of total THMs and an average of 80% removal was achieved by activated carbon pitcher-type filters (Carrasco-Turigas et al., 2013).

6 Feasibility of utilization in rural areas

As illustrated above, many water treatment systems are currently available in the market. Among these, eSpring[®] had the best performance and cost-effectiveness. It utilizes an activated carbon filter and UV oxidation for purification. Laboratory and field tests showed that the eSpring[®] could provide around 99% removal of THMs and HAAs. Besides the removal of DBPs, the activated carbon cartridge can also adsorb certain hazardous materials, such as mercury and arsenic. The major disadvantage of this system, however, is that it cannot remove particles and inorganic contaminants. Another minor disadvantage of eSpring[®] is that it is designed to be installed and attached to a tap or under a counter. Therefore, residents cannot be protected from

THM and HAA exposure during showers or baths. Because THMs and HAAs already exist in water when it is distributed to households, these compounds can enter the body through inhalation and dermal contact when showering or bathing. Therefore, people living in communities with contaminated distributed water can significantly mitigate their risk of contracting cancer by ingestion through installing an eSpring[®] water treatment system, but they cannot avoid the other two pathways (inhalation and dermal contact).

Another major concern is the overall economy of this system. The initial cost of eSpring[®] is \$1,024 for a capacity of 1,320 gallons, which would be enough to meet a six-person household's consumption demands for a year. The activated carbon filter requires replacement annually at a cost of \$200. Based on 1,320 gallons usage per household, the cost for the first year is \$0.70 per gallon, decreasing to \$0.15 per gallon in the second year.

A Rainfresh whole house UV water disinfection system is designed by a Canadian company and is currently available to Canadian consumers. It takes approximately 60-75 minutes to install, and the equipment, which costs around \$400, is much less expensive than eSpring[®], while still providing the same one-year capacity. The difference between Rainfresh and eSpring[®] is that eSpring[®] can be attached to a tap and equipped with an LED indicator that alerts customers of its remaining UV lifetime, whereas Rainfresh must be installed on the main cold-water line, which makes its indicators less obvious to users. Accordingly, although the Rainfresh UV light is assembled with audible and visible indicators to illustrate its UV life, users could more easily forget to check the life of the lamp.

The advantage of a Rainfresh water-treatment system is that it includes a sediment adsorption system which can screen out small particles and heavy metals. Because Rainfresh can be directly installed in the pipeline system, this significantly increases its potential to be combined with other similar products to achieve better treatment effects.

According to the DOEC's Drinking Water Quality Index Spring 2013, in most rural NL areas, communities on long-term BWAs are on these advisories because these communities either had no disinfection, or their disinfection system was undergoing maintenance (DOEC, 2014). A better choice for residents in these areas would be the installation of a household water treatment system. When the low population density of these areas is considered, the total life-cycle cost of a full-performance water-treatment plant would be too high for the local community to sustain with its current tax base.

For residents living in areas with BWAs that are in place due to no disinfection or because a disinfection system was under maintenance, the optimal solution depends on the population density of each community. If a community is too small to justify the installation of a centralized water-treatment system, or if it was too difficult to distribute water from other neighboring communities, point-source disinfection or small-scale household disinfection systems could be a better choice. Besides eSpring[®] and Rainfresh, super absorbent cryogel decorated silver nanoparticles developed by Loo et al. could be a viable option. The disinfectant can be made as small as a standard pill and it is highly reusable (Loo et al., 2013). In areas where people are periodically unable to access disinfected water, this small and easy-to-store disinfectant would be an ideal option. As mentioned in Section 4.1, this Ag⁺ is a fast disinfectant; the product

manufactured by Loo et al. can reach a 3 log reduction of bacteria in 15 seconds. Another advantage of this disinfectant is its reusability. Loo et al. verified this characteristic of the product by reusing it five times and testing the bacteria residue after disinfection. The result showed that the efficiency was not reduced even after the fifth reuse (Loo et al., 2013). This high reusability is due to the principle of how silver ions kill bacteria. Once a silver ion kills one bacterium, it will leave the dead cell and seek the next one. Thus, the procedure does not affect silver ion activity.

The cost of one pill-sized disinfectant would be around \$0.05. Considering that one pill can disinfect a glass of water, and is reusable, it is suitable for residents who will periodically be unable to access safe water due to a lack of disinfectant or chlorine or a power outage, or a power outage.

Nano-sized silver disinfection technology appears to be a safe and efficient alternative technique compared to conventional disinfection methods. However, there are still several major concerns with this technology, such as how to prevent heavy metal leaching and the cost of materials. Lalley et al. (2014) illustrated that the silver layer would be rapidly eroded if the silver surface was not smooth enough; the rougher the surface, the faster the erosion. This erosion will cause the silver to leach, which can be potentially hazardous to humans (Lalley et al., 2014).

Bay Bulls Water Treatment Plant and the Windsor Lake Water Treatment Plant in St. John's are two good examples of areas that have sufficient budgets and trained operators. The Bay Bulls facility is a conventional plant with flocculation as its primary treatment, followed by filtration and ozone disinfection, and chlorination. This system can eventually reduce DBPs formation and keep free residue in the distribution system for long-term disinfection. The Windsor Lake plant, on the other hand, was assembled with an advanced membrane filtration system as its primary treatment and UV light as primary disinfection, followed by chlorine gas as a secondary treatment and free residue provider. Both systems significantly reduce the formation of DBPs by different technologies. However, the capital and operation cost of either system is much higher than the cost of chlorination (Table 2.1). In addition to being quite expensive, both systems require well-trained operators.

Nano membrane filtration is a widely used advanced filtration technology. It can provide substantial efficiency as a primary filtration system relative to other alternatives. The Windsor Lake Water Treatment Plant utilizes membranes as its primary filtration after pre-screening, and, as such, it can already filter a large amount of microorganisms. Meanwhile, even if the plant does utilize chlorine disinfectant, without any other treatment such as coagulation, after nano filtration, the formation of DBPs could be vastly reduced. The nano membrane can even filter protozoa such as *Giardia*. However, nano membrane fouling has been a significant concern, as this can significantly shorten a membrane's lifetime while also lowering filtration efficiency. Since many communities use surface water as their source water, these communities generally do not have sufficient protective methods in place to protect the source water. When heavy rain occurs, soil can be directly flushed into the source water and leaves and branches may fall into the water; this results in high NOM in the source water and, consequently, high DBPs formation after chlorination. Although the nano membrane can prevent most NOM leaving the filtration into disinfection system, the high concentration of NOM can easily cause fouling of the nano

membrane. This fouling will not only sharply reduce the efficiency of the filtration but it will also raise the expense to clean or change the membrane units. Controlling membrane fouling is a critical factor in the success of a membrane application. Fouling is generally defined as the accumulation of material on the surface or in the pores of a membrane that inhibits the passage of water, decreasing NF productivity (USEPA, 2005). Membrane fouling is dependent on the water quality and on the membrane's properties and construction. Steric and polar interactions strongly influence NOM removal.

The Fyne process (

Figure 6.1) is often chosen as the primary treatment in small communities because of its minimal pretreatment and chemical cleaning requirements, as well as its unique mechanical cleaning feature. The system requires no pretreatment of feed water other than a coarse (3 mm) screen to prevent the entry of large solids. The Fyne process uses a tubular semi-permeable membrane to allow clean filtered water to pass through the membrane while retaining microbial contaminants and most of the colour-producing organic material is dissolved in water, thus reducing the potential for the formation of DBPs after chlorination. The whole system could be designed on a small scale for seasonal resort use; it can be operated without maintenance for a summer operation with no chemical or pretreatment required. The Fyne process would be a good choice for small communities in NL (Patterson et al., , 2012), although pilot testing may be required to determine the type of membrane needed.



Figure 6.1 Fyne process plant

Granular media filtration is widely used in drinking-water treatment. It removes microbes through a combination of physical-hydrodynamic properties and surface and solution chemistry. Under optimal conditions, the combination of coagulation, flocculation, sedimentation, and granular media filtration can result in 4 log/100 mL cfu or better removal of protozoan pathogens. However, without proper chemical pretreatment, this type of rapid rate filtration works as a simple strainer but it is not an effective barrier to microbial pathogens (CDC, 2012).

PUR flocculants/disinfection powder is manufactured in Pakistan, and is specially offered to developing countries without access to treated water. At its current price of \$0.035 per pack, it is very inexpensive on a per-use basis, but it is not easy to operate and requires multiple containers to filter the flocculation and disinfection residue. PUR is good for emergency or camping use because it can reduce colour and microorganisms by flocculation and achieve disinfection as well. However, if it is utilized for house purposes, the capacity of the container limits its efficiency. Because PUR requires stirring of the mixture to provide sufficient contact between

water and the PUR, filtering is required after flocculation and disinfection to remove the flocculant.

QS and US combined filtration systems are relatively inexpensive in terms of capital and operation costs, but the removal rate of DBPs varies from 12% to 60% by QS alone. By sonication alone, THMs even at a ppb (particles per billion) level can be degraded; more than 20% THMs can be degraded after 60 minutes sonication. Combined QS and sonication can reach a removal rate of 51%.

The price of QS is approximately \$150-\$200/metric tonne. Compared with other technologies, the price is relatively inexpensive. In small NL communities, where populations are often less than 1,000, both conventional treatment and membrane filtration are more expensive than QS.

Roy (2009) studied the cost of different disinfection and filtration systems; his results are summarized in Table 6.1.

Table 6.1 Estimated cost for different disinfection and organic removal systems

	1 MegaGallon/Day	Capital costs	Operation and maintenance costs	Annual cost (Based on 10 Year Life Cycle)
Disinfection systems	Chloramine	\$ 62,608	\$ 4,861	\$ 11,122
	Chlorine Dioxide	\$ 47,531	\$ 21,217	\$ 25,970
	UV Disinfection	\$ 359,359	\$ 10,855	\$ 46,791
	Ozone	\$ 974,973	\$ 91,862	\$ 189,359
Filtration systems	Granular Activated Carbon	\$ 863,696	\$ 61,531	\$ 147,900
	Nano filtration	\$ 1,057,344	\$ 133,392	\$ 239,126
	Microfiltration/Ultrafiltration	\$ 1,786,445	\$ 78,573	\$ 257,218

7 Conclusion

Among all technologies that have been introduced or are currently being utilized, choosing the most appropriate technology is highly dependent on the size of the community and its budget. For small communities with populations of less than 200, it would be more economically efficient and feasible to either install a small-scale filtration system that would fit within their limited budgets or put greater emphasis on source water reservoir preservation. Properly protected source water would be more ideal for those communities using simplified treatment to remove NOM before disinfection, and it can also effectively reduce the formation of by-products after disinfection. Household water treatment systems are an alternative method. Under this option, municipal departments can keep the same facilities without installing extra treatment systems, which could save more money on capital and operational expenses. In communities of

1,000 or less the capital and operation costs of a full-scale water treatment plant would be much more expensive than if the municipality/local service district purchased household water treatment systems for households and later replaced the filters. In the meantime, the preservation of source water is important for municipal departments.

The Fyne process nano filtration membrane proved to be effective in the removal of TOC, which can subsequently reduce DBPs formation potential, and the cost is relatively low. This process could be an alternative water treatment system for small communities with populations below 1,000.

Besides updating technologies to remove NOM and/or DBPs, regional approaches to centralize water treatment and distribution systems for small communities could help provide well-protected source water, as well as full-scale, well-maintained water treatment systems. Such approaches could help many communities that currently lack sufficient funding to improve their water quality.

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