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Management of hypochlorite solutions used for water treatment in small drinking water systems

Louis Coulombe, Christelle Legay, Jean Sérodes and Manuel J. Rodriguez*

NSERC Drinking Water Chair of Université Laval, Université Laval, Pavillon Félix-Antoine-Savard, 2325, rue des Bibliothèques, local 1612, Quebec City, G1 V 0A6, Province of Quebec, Canada

*Corresponding author. E-mail: manuel.rodriguez@esad.ulaval.ca

Abstract

Hypochlorite solutions (HSs), also called liquid chlorine, are widely used as disinfectants during drinking water treatment and distribution. However, the decomposition of the hypochlorite ion results in the formation of undesirable inorganic contaminants such as chlorite, chlorate, bromate and perchlorate. While HS decomposition cannot be completely avoided, it can be minimized through applying adequate practices during the purchasing, handling and storage of such solutions. This article presents the results of an investigation of the management of HS in water treatment plants (WTPs) in small municipalities. The data concerning HS management were acquired through field visits and semi-structured interviews with operators and managers of the small WTPs. The information gathered about HS management practices was compared to best management practice guidelines. Results show that practices involving HS differ between WTPs and that there are important gaps in the application of the existing HS management guidelines. The research revealed that the implementation of specific guidelines for the purchasing, handling and storage of HS is difficult for small WTPs due to the lack of human resources, expertise, and education, as well as a lack of infrastructure capacity.

Key words: best practices, contaminants, disinfection, drinking water, hypochlorite solutions, management, operators

INTRODUCTION

Hypochlorite solutions (HSs) are widely used as disinfectants in drinking water production for their oxidizing capabilities and their ability to maintain a residual level of disinfectant throughout the water distribution system (Asami *et al.* 2009; Snyder *et al.* 2009; Stanford *et al.* 2011). About one third of the drinking water treatment plants (WTPs) in the United States and close to 80% of Canadian WTPs use HSs in drinking water production (Snyder *et al.* 2009; Aranda-Rodriguez *et al.* 2014). There are several explanations for the popularity of HSs. HSs are easy to transport and store (Shah & Qureshi 2012), they can be handled without a high level of expertise and they are relatively safe compared to other disinfectant alternatives (Garcia-Villanova *et al.* 2010).

Despite its many advantageous features, HS comes with one major drawback. It is an unstable product that naturally decomposes over time (Gordon *et al.* 1993; Snyder *et al.* 2009). The decomposition of the hypochlorite ion results in the formation of regulated and unregulated undesirable contaminants during and after HS manufacturing. Chlorite, chlorate and perchlorate are decomposition products and contaminants of HS that are formed through the main path of decomposition of the hypochlorite ion. Chlorite formation occurs as a slow reaction between two hypochlorite ions. Chlorate formation results from the fast reaction between a hypochlorite ion and a chlorite ion. The formation of perchlorate occurs as a result of the reaction between a hypochlorite ion and a chlorate

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ion (Gordon *et al.* 1993). While chlorate and perchlorate concentrations in HS are known to increase during storage, the concentrations of chlorite are known to remain low and stable since the reaction leading to chlorate formation is faster than that of chlorite (Stanford *et al.* 2011). Bromate is another contaminant also found in HS. Its presence is due to the quick oxidization of bromide found in the raw salt used in HS manufacturing (Bouland *et al.* 2005; Snyder *et al.* 2009). Once the available bromide has been oxidized, bromate concentrations remain constant in HS (Stanford *et al.* 2011). HS decomposition also leads to a diminution of the available chlorine content, resulting in the need for higher amounts of HS in order to obtain the target residual chlorine during water treatment, which consequently leads to higher concentrations of inorganic contaminants in the finished drinking water (Garcia-Villanova *et al.* 2010). Several factors such as the ionic strength, pH, the presence of transition metal ions, hypochlorite concentration, exposure to sunlight, temperature and storage time are known to increase the decomposition of HS and the subsequent formation of contaminants (Snyder *et al.* 2009; Stanford *et al.* 2011).

Perchlorate is considered a substance of concern because of its endocrine disruptor status which means it affects the production of thyroid hormones by inhibiting the iodine intake of the human thyroid gland (Greiner *et al.* 2008; Stanford *et al.* 2011; Shah & Qureshi 2012). While there is some concern about the health effects of chlorite and chlorate (WHO 2005), bromate is classified as a potentially carcinogenic substance (group B2) in humans by the United States Environmental Protection Agency (USEPA) (USEPA 2001). Under the drinking water regulations of the Province of Quebec (Canada), chlorite and chlorate concentrations in distributed drinking water must not be greater than 800 μg/L and those of bromate must not exceed 10 μg/L (Government of Quebec 2014). However, monitoring of chlorite and chlorate concentrations in distributed drinking water is only mandatory for WTPs using chlorine dioxide, and bromate monitoring is only required for WTPs using ozone. Perchlorate is currently not regulated in the Province of Quebec. While there has been state action addressing perchlorate standards, the USEPA announced perchlorate regulation under the Safe Drinking Water Act in 2011 but has not yet established the maximum level at which no known or anticipated adverse health effects would occur through drinking water exposure (USEPA 2017a).

While HS decomposition cannot be completely avoided, it can be minimized (Pisarenko & Gordon 2013). The way that HSs are managed can impact the presence of contaminants in the HS and consequently in the drinking water produced (Stanford *et al.* 2011). Following an investigation of the factors impacting the formation of contaminants in HS, an American Water Works Association (AWWA) research team developed a set of guidelines and recommendations for HS management (i.e. purchase, handling and storage) intended for the individuals who are involved in day-to-day operation with HSs in WTPs (Snyder *et al.* 2009). Table 1 presents a summary of the main recommendations issued by the AWWA for HS management aimed at WTPs that purchase HS from a supplier. Recommendations for WTPs that generate HS on-site are not addressed in this paper. Unless otherwise stated in Table 1, the AWWA recommendations have been identified in the B300a-11 document entitled: *Recommendation for the Handling and Storage of Hypochlorite Solutions* (AWWA 2011). Free of charge and accessible in English via the internet, this document is a supplement (Addendum) to ANSI/AWWA B300-10 Standard for Hypochlorites (AWWA 2010), which can only be accessed in the paid English version. However, the B300a-11 document is for information only and is not part of ANSI/AWWA B300-10. Recently, the B300a-11 document was translated into French by Health Canada and was made available as a public consultation document on bromate in drinking water (Health Canada 2015). Other recommendations relating to HS management such as *Drain and Flush Tanks Used for Storage* (Gordon *et al.* 1997; Purkiss 2011; Olin Corporation 2016) are also found elsewhere in the scientific literature.

Small municipalities often suffer from inadequate expertise and a lack of technical, financial and operational resources regarding drinking water production (Coulibaly & Rodriguez 2003; Flora

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Table 1 | Recommendations for HS management

Management step associated with guidelines	Sources: AWWA (AWWA 2011)	Quebec training document (Cégep de Saint-Laurent 2013)
Purchase	Purchase HS with verified pH values between 11 and 13	Not addressed
Purchase	Purchase filtered HS to control the removal of transition metal ions	Not addressed
Purchase	Purchase certified NSF/ANSI Standard 60[a,b]	Not addressed
Purchase	Not addressed	Analyze the concentration of the purchased HS
Purchase, Storage	Use fresh hypochlorite solutions when possible	Do not exceed a storage period of two months
Storage	Minimize the quantity of aged product in storage tanks prior to the delivery of new product	Not addressed
Storage	Dilute stored HS upon delivery	Not addressed
Storage	Store HS at low temperatures	Store HS above 30 °C Avoid freezing Store at temperatures between 10 and 15 °C
Storage	Store HS away from direct sunlight	Store away from direct sunlight
Storage, Handling	Control the pH of stored HS (maintain pH 11–13, even after dilution)	Not addressed
Storage, Handling	Using low-metal ion concentration dilution water	Not addressed
Storage, Handling	Not addressed	Periodically verify the concentration of diluted HS
Handling	Rotate stocks	Use the oldest products before newly received products

[a]The use of NSF/ANSI Standard 60 certified product is currently mandatory (since 08/03/2017) in the Province of Quebec but wasn't during the study period. This product ensures that large amounts of HS do not add unsafe levels of chemicals or contaminants to drinking water.
[b]Found in ANSI/AWWA B300-10 Standard for Hypochlorites (AWWA 2010).

2004; Conestoga-Rovers & Associates 2010). According to the definition by USEPA, a small system is one that provides drinking water to less than 3,300 people (USEPA 2017b). Often, those systems include aging or inadequate infrastructure and deficient equipment and it can be difficult to recruit and retain qualified staff to manage those systems (USEPA 2016). As a result, small systems may be subject to difficulties associated with water treatment, operation and management including challenges in applying the best practices for routine management of HS. Furthermore, the relatively low consumption of HS in small systems could result in long storage times (Garcia-Villanova *et al.* 2010), which can then lead to greater HS degradation, as previously mentioned.

In the Province of Quebec, all duties related to the operation and monitoring of municipal drinking water serving residential customers must be carried out by a qualified and certified operator (Government of Quebec 2014). *Emploi-Québec* works as the government authority for professional qualifications including those in the field of drinking water. Anyone who wishes to be recognized as a qualified operator must hold a certificate of qualification issued by *Emploi-Québec*. The qualification profile and necessary skills vary depending on the type of raw water source and the characteristics of the WTP's treatment process with which an operator is required to work. The operator's qualifications must also periodically renewed by means of a document certifying that they have held a relevant job in the field of drinking water for at least six months over the last three years. If the certificate holder fails to meet this requirement, he/she is required to pass the exam associated with his/her previous training. Several training courses provide the skills required to be eligible for the certificate of qualification by *Emploi-Québec*. Among these are training programs offered directly by

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Emploi-Québec and are of variable duration. The training programs offered by *Emploi-Québec* are adapted to the different categories of WTPs and are mainly intended for people who are already in the labor market. The *Emploi-Québec* common core training course is 15 days long but does not apply to all the qualification profiles (the training program can be shorter or longer depending on the profile). These theoretical training programs are followed by an apprenticeship in the workplace under the supervision of a qualified operator. There are also several other training programs offered by different educational institutions that lead to diplomas, attestations and certificates which are generally of longer durations than the one offered by *Emploi-Québec*. In addition to the main recommendations issued by the AWWA for HS management, Table 1 also presents the recommendations listed in the training document (Cégep de Saint-Laurent 2013) provided during the *Emploi-Quebec* training course for operating WTPs supplied by groundwater sources with or without a filtration process. In the Province of Quebec, more than 70% of the municipal distribution systems are supplied by groundwater sources and serve fewer than 3,300 people (MDDELCC 2016).

To date, a very limited number of studies have addressed the handling and storage practices associated with HS in WTPs (Bolyard *et al.* 1993; Asami *et al.* 2009; Garcia-Villanova *et al.* 2010). In these studies, the handling and storage of HSs were not the main issues investigated. Moreover, none of the past studies specifically targeted small systems (i.e. serving below 3,300 people).

This article presents the results of an exploratory investigation of the management of HS in small municipal WTPs in the Province of Quebec. The study also aims to evaluate the feasibility of applying best practices associated with HS in the context of small municipal systems.

METHODOLOGY

Case study

The cases examined included WTPs from eight small municipalities (noted as 1 to 8 herein) located in the Province of Quebec (Canada) and that supply populations of 250 to 1,840 inhabitants. The WTPs were selected according to the following criteria: operate as a small municipal WTP (provide drinking water to less than 3,300 people), use HS for water disinfection, be located within a reasonable distance (maximum 200 km) from Université Laval (Québec City, Province of Quebec, Canada) to optimize the field work logistics, and agree to participate in the study. All WTPs were supplied by groundwater sources. The type of water treatments ranged from only chlorination to more complex treatments including pre-chlorination, potassium permanganate, aeration, polymer, different types of filtration, softener and post-chlorination. Based on the current drinking water regulations, the WTPs investigated were not required to monitor bromate, chlorite or chlorate in the distributed drinking water because of the types of water treatments they employed.

Data collection

The data concerning HS management was acquired mainly through two survey tools: semi-structured interviews and questionnaires. Semi-structured interviews are commonly used in qualitative research (Edwards & Holland 2013). They are open in comparison with classical structured interviews where questions are pre-established. Semi-structured interviews permit new questions (or sub-questions) and ideas that are motivated by the responses and reactions of the participants during the interview. In our study, the semi-structured interviews were carried out in the field with operators and/or managers in charge of each of WTP studied. With the exception of one WTP where two people were interviewed, one person was interviewed from each WTP (nine respondents in total). One objective of the interviews was to document the management and operational practices associated with the application

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of HS in the WTPs relative to the various HS management recommendations made by the AWWA and in the Quebec training document. The other objective was to highlight the difficulties faced by operators in the implementation of these recommendations. The main topics covered during the interview were the purchase of the HS, the quality of the HS purchased, the storage conditions and the operation regarding the use of HS for water treatment. Interview grids were adapted to the characteristics of each WTP investigated according to water treatment specificities and involved about 50 questions. The interviews were designed to last approximately 45 minutes. Some of the questions asked included several sub-questions depending on the response previously obtained. Following the interview, a questionnaire was distributed to each respondent. The purpose of the questionnaire was to examine the personal assessment of the respondents about the various aspects related to HS covered during their theoretical training and during the apprenticeship in the workplace (if applicable). The questionnaire included 17 questions with the following options for answers: do not know, not addressed, addressed but not sufficiently, sufficiently addressed. The training document referred to in Table 1 was consulted and used for the design of the interview grids and the questionnaire.

The data obtained from the interviews and questionnaires were analysed based on conventional qualitative and quantitative methods. Qualitative analysis considered principally the content analysis technique (Hsiu-Fang & Shannon 2005), whereas quantitative analysis was based on frequency analysis.

RESULTS AND DISCUSSION

Respondent profiles

The nine operators interviewed in this study have different qualification profiles. Seven operators completed qualification programs issued by *Emploi-Québec* and two completed other training courses not issued by *Emploi-Québec*. One completed a *Diploma of Collegial Studies in Water Sanitation* (includes three full years of study) and the other obtained an *Attestation of Collegial Studies in Water Management Techniques* (includes approximately 1.5 years of study). The operators who were trained by *Emploi-Québec* completed apprenticeships in relevant workplaces following their theoretical training. The operators who followed training courses from other institutions did not complete apprenticeship programs. The two operators who received training outside of *Emploi-Québec* have full-time roles performing drinking water related tasks. Among the seven operators that completed qualification programs issued by *Emploi-Québec*, six also perform professional tasks not related to drinking water such as maintenance of roads and paths, wastewater management and maintenance and repair of various types of municipal equipment. The other works full time performing drinking water related tasks for more than one municipal WTP. The time spent on drinking water related tasks by operators surveyed varied between 40 to 160 hours per month. The number of years of experience that each of the respondents had working with drinking water ranged from three to 22 years. With the exception of one operator for whom the employer is a private organization, all other operators were municipal employees.

Characteristics of the purchased HS

Interview results show that the AWWA recommendation for the purchase of pH-controlled HS (Table 1) was followed by all of the WTPs investigated. For five WTPs investigated, information about the filtration of the purchased HS was not available. In all cases where the information was available, the purchased HS was filtered, as recommended by the AWWA. As recommended by the AWWA (Table 1), all of the HSs purchased by the eight WTPs were NSF/ANSI Standard 60 certified.

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However, none of the respondents knew the meaning of NSF/ANSI Standard 60. In addition to being unaware of the standard, eight out of the nine respondents did not know that the HS purchased met the criteria for that certification. This suggests that this recommendation may be applied inadvertently.

The quantity of HS purchased per order and the frequency of orders varied between the investigated WTPs. The quantity of HS purchased and the purchase frequency associated with each WTP is presented in Table 2.

Table 2 | Characteristics of the purchased HS

WTP		Quantity per purchase	Purchase frequency (approximately)
1		32 drums of 20 L	6 weeks
2		~600 L (bulk)	2 weeks
3		2 drums of 20 L	2 weeks
4		32 drums of 20 L	6–7 weeks
5		20 drums of 20 L	1 month
6		1,500–1,600 L (bulk)	5 weeks
7	A[a]	1,000 L (bulk)	3 months
	B[a]	3 drums of 55 L	2–3 weeks
8		30 drums of 10 L	4 to 6 months

[a]WTP 7 performs pre-chlorination and post-chlorination. HSs used for pre-chlorination and post-chlorination were purchased from different suppliers. 'A' corresponds to pre-chlorination and 'B' to post-chlorination.

As a safety measure, it is important to keep a certain amount of HS in inventory at all times, in case of unforeseen events (i.e. an out-of-stock supplier, storms, labor disputes, etc.). WTPs that use HS in drum format usually have a number of drums left over from the previous order when a new supply is received. For these WTPs, inventory from the previous order are indeed used before the newly acquired ones. This is consistent with the recommendations in both the AWWA and the Quebec training document: rotate stocks; use the oldest products before the newly received products (Table 1). Because of these circumstances, in the investigated WTPs using HS in drum format, the maximum storage time for HS stocks may be greater than the purchase frequency values presented in Table 2. For WTPs using bulk HS, there is in general a residual volume of HS remaining in the tanks at the time of receipt of a new supply. This will be discussed later in the text.

The assessed WTPs do not generate their HS on site. Therefore, there is a time delay between the manufacturing of the HSs and their delivery at the WTPs. This amount of time can vary from one WTP to another depending on the number of intermediaries between the HS manufacturer and the WTP. This issue is discussed by Asami *et al.* (2009) who identified two different 'distribution channels': direct routes from the manufacturer to large WTPs, and indirect routes involving one or more intermediaries (and thus longer durations) for smaller WTPs. Our survey indicates that for the WTPs in this study, there are four indirect routes involving one intermediary and five indirect routes involving two intermediaries. The distribution channels with two intermediaries were all associated with WTPs using HS in drum format. Although no information was available about the time-delay between HS manufacturer and the arrival of HS at the WTPs, it is reasonable to assume that for WTPs with two intermediaries in their distribution routes the time between HS manufacture and delivery is long.

The AWWA recommendation for HS storage time (Table 1) is vague and does not specify a maximum recommended storage time. Consequently, it is impossible to discern which of the WTPs in this study have safe storage practices. Therefore, the recommendation in the Quebec training document

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(storage period does not exceed two months; Table 1) was used to assess which WTPs meet the recommended storage time. Based on the frequency of HS purchases presented in Table 2, two of the nine HS stocks used in the investigated WTPs are stored for periods of time that clearly exceed the recommendation. The reason for these high storage times is that the suppliers require the purchase of a minimum volume of HS per order that exceeds the volume that these two WTPs consume in two months.

Storage conditions

The AWWA recommendation on storage temperature is vague (Table 1). The interview responses by operators on air temperature at the sites where HSs are stored were nonspecific and imprecise. Storage temperatures of HSs are higher in summer than in winter for most WTPs under study. The variability of storage temperature from WTP to WTP is higher in winter than in summer. Storage temperatures in summer vary from 12–15 °C to 21–22 °C according to the WTP. In winter, storage temperatures vary from 8–10 °C to 20–22 °C according to the WTP. However, no precise conclusion could be derived from these data about the application of the Quebec training document recommendation that HS be stored at temperatures between 10 and 15 °C. The Quebec training document recommendations to avoid freezing HS and to not expose HS to temperatures exceeding 30 °C during storage appeared to be complied with at all eight of the WTPs. All of the HS storage sites were devoid of air-conditioning equipment. However, with the exception of one particular case (where HS was stored in another building), all of the HS was stored in areas where the passage of water within the WTP infrastructure created natural air-conditioning (all WTPs studied are supplied by groundwater which tends to be relatively cool during summer) contributing to a decrease in the ambient air temperature during summer. In winter, temperatures in WTPs are controlled by heating equipment in order to obtain temperatures that are comfortable for working and/or to avoid frost and equipment breakdown. None of the operators mentioned that the temperature control in winter was specifically intended to avoid HS freezing. Based on the testimonies, it was clear that despite having the ability to control the temperature during winter, material constraints (lack of air-conditioning equipment) would have made it difficult to achieve the recommendations of storage temperature during summer.

The sites where HS is stored have varying sunlight exposure profiles. Some of these sites have windows while others do not. Among the sites with windows, there are those where HSs are stored in places without direct exposure to sunlight (four) and others that do have direct exposure (three). As a result, the latter do not comply with the recommendations provided by the AWWA or the Quebec training document regarding exposure to direct sunlight (Table 1). Unlike the technical constraints associated with temperature management, the reduction of direct sunlight exposure can be achieved relatively easily, which suggests that operators are not sufficiently aware of the risks associated with this issue.

Handling

The AWWA recommends (Table 1) minimizing the mixing of aged and newly received HS stocks. However, as previously discussed, it is recommended that a certain amount of HS be kept available at all times, as a safety precaution. The surveyed WTPs that use bulk HS have only one HS tank, which can complicate the ability to comply with that recommendation. Among the three WTPs that use bulk HS, only one (WTP 7A) does not mix aged HS with newly acquired HS. However, this is not done in this particular WTP for the purpose of meeting that recommendation. The operators empty the remaining volume of HS from the tank (the drums are then used for post-chlorination in WTP 7B) before the delivery of the new HS stock. This is necessary so that they

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are able to receive the minimum purchase volume of HS per order imposed by their supplier (lower volume orders lead to additional costs).

Four of the nine HSs used in the WTPs studied were not diluted prior to use in water treatment. Of the five WTPs using diluted HS during treatment, none diluted HS stocks upon delivery as recommended by the AWWA (Table 1). The respondents reported that it would be impossible to apply this recommendation using the current equipment because of the size of the tanks. These tanks are too small to accommodate the dilution of all HS stocks from the same order. At those same WTPs, the HS is diluted directly in the tanks feeding the dosing pumps and is prepared just before use. In all cases, the HS is diluted with treated water. For the HS dilution, it is recommended that softened or deionized water be used in order to avoid the introduction of catalyzing impurities that may accelerate the degradation of HS (AWWA 2011). Moreover, given that the dilution process has the potential to disturb the pH stability of HS and result in faster degradation rates (Black & Veatch Corporation 2010), pH should also be controlled after dilution as recommended by the AWWA (Table 1). Survey results show that none of the respondents verify the pH of the purchased HS or the diluted HS and consequently, they do not take any steps to control the pH during storage as recommended by the AWWA (with addition of sodium hydroxide). Given the WTPs studied are not equipped with softened or deionized water or sodium hydroxide, it seems that it may not be practicable for these WTPs to follow the specific recommendations associated with dilution, under current conditions (Black & Veatch Corporation 2010). It should be noted that the acquisition of the equipment necessary to adequately meet that recommendation would not only lead to extra costs for municipalities but also to additional time investments by the operators.

Two of the nine HSs used in the WTPs studied were subjected to analyses of the chlorine content as recommended in the Quebec training document (Table 1). Occasional verifications were made prior to the utilization and the dilution of HS at one WTP, while verifications were performed twice per inventory roll (i.e. once upon receipt of an order and a second time when half of the inventory from that order had been used) at the other WTP. For the other WTPs, no verifications of chlorine content are made for the purchased HS since operators believe that this practice is irrelevant because they trust that their suppliers provide HS with the proper chlorine content. Some respondents also mentioned that no one had ever asked them to do this verification, and that the procedure is too complex or takes too much time to complete. In the case of diluted HSs, none of the WTPs analyzed the concentration of the solution, as recommended in the Quebec training document. Operators reported the same reasons as those given for the purchased HS.

Respondents' appreciation for their training

Table 3 presents the opinions of the respondents interviewed about notions related to HS addressed during their training. These results suggest that some relevant information about HS and HS management may not be sufficiently considered in the training received. Furthermore, some respondents who have completed training through *Emploi-Québec* reported weaknesses in the training received. The

Table 3 | Distribution of respondent's opinions about topics related to HS addressed during theoretical training (left columns: nine respondents) and during apprenticeship in workplace (right columns: seven respondents)

Respondent's opinion	Quality control on receipt of stocks		Inventory management[a]		Recommended storage conditions		Degradation and consequence on treatment		Factors influencing degradation	
Not addressed	2	1	1	0	0	0	0	0	0	0
Addressed but not sufficiently	3	3	0	2	2	2	6	3	3	3
Addressed sufficiently	4	3	7	4	7	5	3	4	6	4

[a]One respondent could not recall if this aspect was addressed during his training.

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weaknesses mentioned were that a large amount of information was taught in a short time period, that some concepts were difficult to absorb/understand thoroughly, and that the training is directed at people with previous knowledge of drinking water issues. Some people also mentioned their interest in having periodic refreshers covering some of the concepts taught during their training.

Implementation of the recommendations

An analysis of the Quebec training document (Cégep de Saint-Laurent 2013) contents revealed that, apart from the brief description of the various decomposition and combustion products of HS (i.e. hydrogen chloride, irritating and toxic gases and vapors, sodium chlorate, oxygen and hydrogen), there is no mention of the occurrence of contaminants in HS (chlorite, chlorate, etc.) and their possible impact on drinking water quality. Although it is possible that this issue was addressed orally by the training instructors, it is justifiable to ask whether operators who completed the training are aware of this issue.

As shown in Table 1, several AWWA recommendations for the proper management of HS do not appear in the Quebec training document. The purchase of HS certified NSF/ANSI Standard 60 was one of these recommendations. However, in March of 2017, the purchase of products certified NSF/ANSI Standard 60 used for the drinking water treatment became mandatory in the Province of Quebec (Government of Quebec 2014).

This study highlights the fact that some AWWA recommendations lack the precision necessary to provide operators with adequate knowledge for managing HS (i.e. store HS at lower temperatures; use fresh hypochlorite solutions when possible). Moreover, in the context of small WTPs, the application of some AWWA recommendations (i.e. dilute stored HS upon delivery; control the pH of stored HS at pH 11–13 even after dilution; using low-metal ion concentration dilution water) are likely to be compromised by the lack of equipment required and by supplier limitations. This study also identified other factors that restrict the application of several recommendations, such as the operator's level of motivation, the diversity of tasks the operators are responsible for beyond just drinking water related tasks, and a lack of time. Given that the surveyed WTPs have several differences between them and often face different operational and management realities, the factors that limit the ability to implement the recommendations likely vary from one WTP to another.

In light of these findings, it appears that recommendations for HS management must also be adapted to the realities and capacities of small WTPs. To that end, the recommendations would therefore benefit from being adaptable or flexible. Moreover, in order to better prepare future operators in the Province of Quebec, the theoretical training should be improved in order to present the issues associated with HS in a more rigorous manner. It is essential that operators be more aware of the potential impact of HS stock management on water quality. In addition to updating the theoretical training document, it would be beneficial to create continuing education tools that review HS management recommendations and address the issues related to HSs and their potential impact on water quality, in order to reach the operators who have already completed their training.

Finally, most recommendations given to WTPs are also directed to HS suppliers, including control of storage conditions (temperature and exposure to light) and reduction of time between the moment of solution production and the moment of its delivery to the WTPs. Other strategies conducted by suppliers, such as measuring HS chemical characteristics before delivery, will also improve the quality control process and reduce potential HS contamination.

CONCLUSIONS

This exploratory study allowed for documentation of the purchase, handling and storage practices related to HS implementation in small municipal WTPs in the Province of Quebec. The following

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main observations were made: HS management practices differ between WTPs and there are gaps in the application of the existing HS management recommendations (e.g., by the AWWA, in the Quebec operator training materials). The survey with WTP operators revealed that the application of the recommendations for proper HS management is sometimes difficult, particularly in small WTPs due to the lack of human resources, infrastructure capacity, knowledge and sensitization.

This study has noteworthy limitations which must be considered. Firstly, a relatively small number (eight) of WTPs were assessed. Additionally, although the WTPs studied are small, they are located near major cities (maximum 155 km). It is likely that the application of HS management recommendations is even more challenging in WTPs that are geographically isolated from large urban centers.

Future work is needed to document the management and use of HS solutions for disinfection at WTPs in remote communities. Also, it will be important to investigate the possible impact of HS management practices on the actual presence of inorganic contaminants (bromate, chlorite, chlorate and perchlorate).

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