THE EVALUATION OF A BROMINE-BASED PRODUCT AS PRIMARY DISINFECTANT FOR POTABLE WATER

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ABSTRACT

Not many references for the use of bromine as primary disinfectants for potable water treatment purposes can be found in literature. The most comprehensive single write-up on bromine-based disinfection is found in White (1). Given the scarcity of local and international literature to support the use of bromine as well as the decidedly negative tone found in some available literature a full gambit of tests and evaluations were performed on water from different water types, processes and distribution systems.

The study was made up of a number of separate investigations, using a commercial bromine-based product as disinfectant. After determining the composition of the product the potential for the formation of bromate and the likelihood of bromate formation if chlorine is added as secondary disinfectant later in the distribution network, was investigated.

This paper will deal with the subsequent studies to determine:

- *the efficacy of the product as a disinfectant (including decay rate) using chlorine as reference,*
- *possible health risks , and*
- *suitability for use in rural areas.*

INTRODUCTION

The Pudimoe Water Treatment Plant, owned and operated by the Naledi local municipality, is situated in the North West province approximately 50km from Vryburg. The raw water is supplied through the Vaal-Harts north canal. The delivery system, which is the responsibility of Sedibeng Water, consists of four reservoirs supplied from the Pudimoe reservoir and interconnected by about 32 kilometers of pipeline. The water could reach its final point, several weeks after leaving the plant, and provides many opportunities for bacterial re-growth along the way. The facility however exists to apply secondary chlorination in the network.

Water quality in general, was not complying with specifications due to operational difficulties at the plant and the decay of chlorine in the network. Chlorine, in the form of sodium hypochlorite (HTH) was added to reservoirs as a means of providing a disinfectant residual at point. This method of disinfection did not proof to be effective and consumers had to boil drinking water for long periods of time.

During 2003 the municipality used a bromine-based disinfectant, supplied by Aqua Africa, as an alternative to chlorine. The product, Aqua Treat 10/10, is made up of Sodium hypochlorite and Sodium bromide. As Sedibeng Water is responsible for point of use distribution, it was important to obtain information on the use of bromine as disinfectant. The emphasis was on the behavior of the product in the distribution network and the possible health risks associated with the presence of by-products.

The most comprehensive single write-up on bromine-based disinfection is found in White (1), who states that the use of free bromine in potable water is "probably non-existent". The compounds generally used can be divided into three categories namely free Bromine (Br_{2}), Bromine Chloride (BrCl) and Bromo-organic compounds. Although the poly-bromide resin systems seem to have found reasonable application in small systems such as single dwelling systems and swimming pools, no other inroads have been made by using bromide based compounds in the potable water industry.

Given the scarcity of local and international literature to support Aqua Africa's claims, as well as the decidedly negative tone found in some pieces of available literature, the Department of Scientific Services, Sedibeng Water, found it prudent to run a full gambit of tests and evaluations of the product. Bench scale investigations were conducted, including the potential for bromate formation. Acute oral LD 50 values were calculated, based on the data of the component chemicals. Results obtained indicated significant advantages over chlorination and no obvious health risks associated with the formation of bromates (5). It was then decided that an operations strategy was necessary as the plant was not under the jurisdiction of Sedibeng Water. A protocol was set up and in conjunction with the supplier, laboratory findings were verified on full scale.

OBJECTIVE OF THE STUDY

The objective of the study was to determine the disinfection capabilities of the product, the potential for the formation of harmful by-products in the network, the suitability for use in rural areas and the commercial viability of the product.

MATERIAL AND METHODS

Experimental work was designed to:

- maintain an initial disinfectant dosage to deal with the variable raw water input,
- provide sufficient residuals at the point of use
- maintain these residuals at the furthest point without having to apply dosing concentrations that will result in aesthetically unacceptable water at the nearest point of use
- have sufficient flexibility to allow for the rural type management situation

During the first phase of the investigation, Aqua Treat 10/10 was dosed at the plant, with no secondary dosing of chlorine. However, in order to investigate the possibility of bromate formation in the distribution network, chlorine was dosed as secondary disinfectant for a period of time. Aqua Treat 10/10 was dosed for three months and then compared with chlorine as primary disinfectant. Results were also compared with results obtained during the normal operation of the plant, when both primary and secondary chlorination were applied.

Disinfectant dosing concentrations at the plant were aimed at providing sufficient residual (approximately 0.2 mg/l) at point of use. Both Sedibeng Water and Waterlab tested samples twice a week for bacteriological quality. Crop Pro, Agrichemical Consultant, calculated the Acute oral LD 50 values. Umgeni Water Services determined bromate formation potential. Disinfectant residuals were measured daily. At the plant residuals were measured, at a minimum of two-hour intervals. This was done to ensure that the disinfectant concentration in the water leaving the plant was kept as constant as possible.

The EPANET hydraulic model was used to calculate the expected residual concentrations and to perform an age analysis of the water in the network.

FULL SCALE INVESTIGATION: RESULTS AND DISCUSSIONS

<u>Water quality</u>

Figure 1 shows the bromine concentrations (Br_2 mg/l) at different points in the network, as obtained by means of the EPANET hydraulic model.

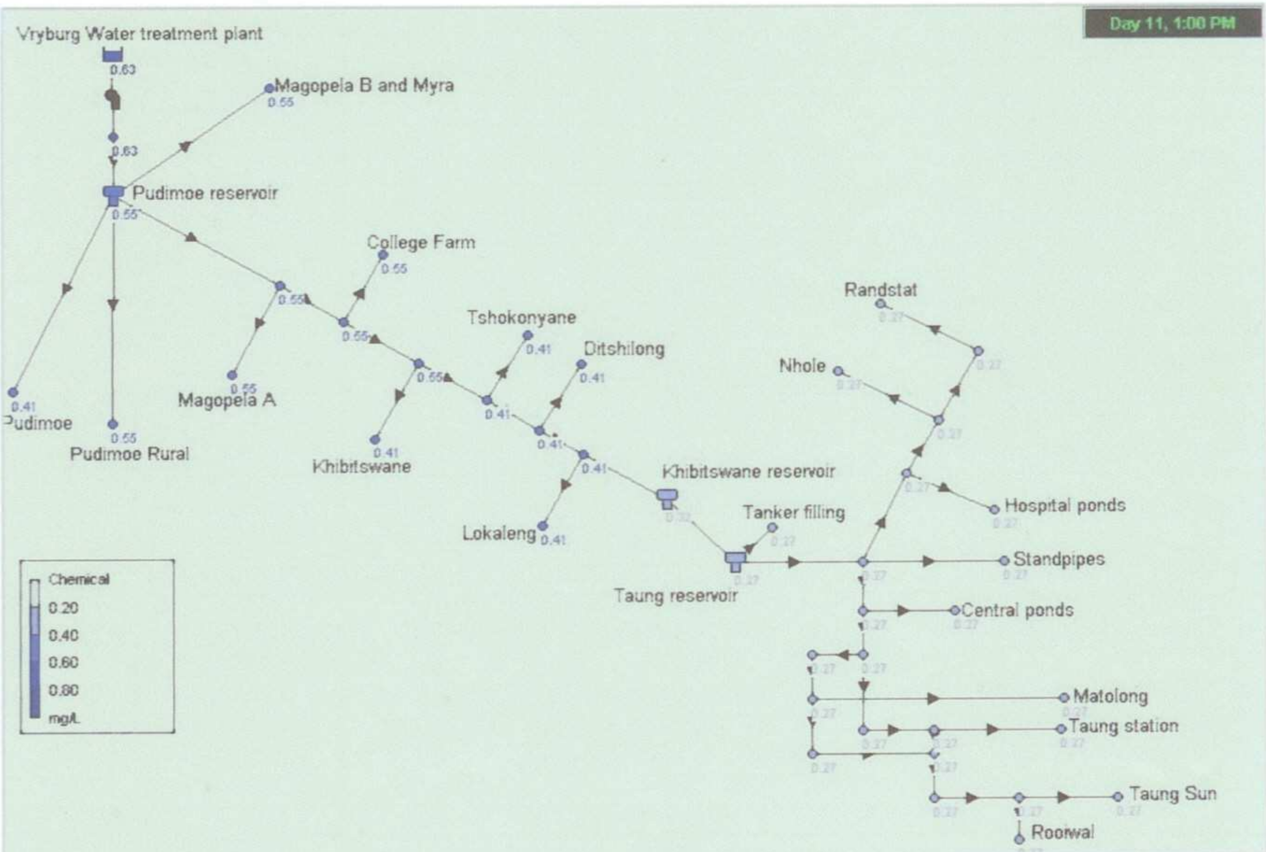

Figure 1: Residual bromine concentrations calculated by means of the EPANET hydraulic model.

Table 1 shows a comparison between residual disinfectant concentrations as measured at the sampling points in the distribution network, when using chlorine and Aqua Treat 10/10 alternatively. The results indicate that when dosing Aqua Treat 10/10, acceptable levels of disinfectant could be detected at the furthest point in the network. These results confirm the results obtained with the EPANET model (Fig. 1), indicating that a bromine concentration of 0.27mg/l could be expected after approximately 85 h, should the water leave the plant with a concentration of approximately 0.63mg/l (Br_2). An age analysis done on the water in the system indicated that water could reach some points in the network up to four days after leaving the plant.

Table 1: Comparison of residuals measured in the network, using Aqua Treat 10/10 (Br_2 mg/l) and chlorine (mg/l).

	Final	Police station	Hospital	Casino
Age of water (h)		32	85	85
Aqua treat 10/10 34 l/Ml = 0.8mg/l (Br_2)	0.63	0.41	0.21	0.33
	0.52	0.41	0.35	0.25
	0.58	0.26	0.24	0.32
	0.73	0.36	0.19	0.30
	0.33	0.18	0.05	0.16
Chlorine 4.7mg/l	0.58	0.18	0.00	0.05
	2.50	0.14	0.03	0.03
	2.75	0.14	0.00	0.06
	2.50	0.16	0.06	0.18
Chlorine 3. 0 mg/l	1.60	0.10	0.00	0.02
	0.65	0.09	0.00	0.00
Chlorine, 3,0 & 1.5 mg/l	1.5	0.10	0.14	0.05
	1.3	0.09	0.10	0.06

The results furthermore show that even with high residual free chlorine concentrations being measured in the product water leaving the plant, the levels detected at point of use were either zero or approaching zero. Long retention times, confirmed by the age analysis, probably contributed to the decay of chlorine in the network. The application of secondary disinfection at the Taung reservoir did not provide the required residual concentrations at these sampling points (Table 1).

The results of bacteriological analyses performed on water samples obtained from the various sampling points, as shown in Table 2, illustrate the effect of low residual concentrations on the quality of water at point of use. Although the application of secondary chlorination at the Taung reservoir did improve the quality of the water at the two sampling points feeding from the reservoir, the results from bacteriological analyses performed were still not satisfactory. It is clear from these results that a better bacteriological quality could be maintained through out the distribution network when Aqua Treat 10/10 was used as disinfectant.

Table 2: Comparison of bacteriological quality, using Aqua Treat 10/10 and chlorine.

	Police station			Hospital			Casino		
	SPC /100 ml	TC /ml	FC /ml	SPC /100ml	TC /ml	FC /ml	SPC /100ml	TC /ml	FC /ml
Aquatreat 1010 34 l/Ml = 0.8 mg/l (Br2)	77	0	0	86	0	0	76	0	0
	55	0	0	65	0	0	86	0	0
	80	0	0	82	0	0	55	0	0
	64	0	0	76	0	0	70	0	0
	232	0	0	204	2	0	104	0	0
Cl_2 4.7 mg/l	228	0	0	1534	9	3	445	1	0
	304	0	0	876	3	0	1020	3	1
	198	0	0	1364	7	2	168	0	0
	223	0	0	543	2	0	108	0	0
Cl_2 3.0 mg/l	186	0	0	968	2	0	864	1	0
	200	0	0	2800	10	4	1480	4	0
Cl_2 3.0 & 1.5mg/l	155	0	0	160	0	0	158	2	0
	135	0	0	174	1	0	175	1	0

Health Aspects

To facilitate easy interpretation of the calculated LD 50 values (2) based on the technical product, the formulated product and the product as dosed, the classification of hazardous pesticides in South Africa is presented in Table 3.

Table 3: Hazardous classification of pesticides (acute oral LD 50 values, mg/kg body weight) in South Africa (3)

	Solids	Liquids
Extremely hazardous	5 or less	20 or less
Highly hazardous	5 to 50	20 to 200
Moderately hazardous	50 to 500	200 to 2000
Slightly hazardous	Over 500	Over 2000
Acute hazard unlikely in normal use	Over 2000	Over 3000

For perspective, a typical toxicity rating based on official rankings in South Africa is shown in Table 4.

Table 4: Known LD 50 values, mg/kg body weight (3).

COMPOUND	LD 50 value, mg/kg body weight
Table salt	3 320
Aspirin	1 240
Strychnine	1 to 25

Table 5: Toxicity data of water treatment chemicals (4).

COMPOUND	DERMAL LD 50 VALUE mg/kg body weight	ORAL LD 50 VALUE mg/kg body weight
Sodium hypochlorite	> 5 000	> 7 700
Sodium bromide	> 5 000	8 200
Chlorine 100%		293

When compared with the hazardous classification of pesticides (Table 3), the values presented in Table 5 indicate that Aqua Treat 10/10, with reference to sodium bromide, poses only a slight hazard. Chlorine gas, however, could be classified as highly hazardous. Oral LD 50 values (Table 5) also compare favourable with the values of known products as presented in Table 4. When dosed at concentrations as used during the full-scale investigation, the calculated toxicity of the water treated with Aqua Treat 10/10 is less than that of the chlorinated water (Table 6).

Table 6: Theoretical toxicity of treated water at point of treatment (4).

COMPOUND	ACUTE ORAL LD 50 VALUE mg/kg body weight
Chlorine gas	
Toxicity of treated water (dosed at 4.7 mg/l of water)	124 680.85
Aqua treat 1010	
Toxicity of treated water (product dosed at 34 l/Ml of water)	2 211 933.21

Table 7 shows that, even where secondary chlorination was applied at reservoirs in the network, the formation of bromates was of no concern. Maximum bromate levels for potable water are not specified in the South African Bureau of Standards (SABS) 241-2001 (5). World Health Organisation (WHO) standards (6), however, indicate maximum levels of 10.0 μg/l for human consumption.

Table 7: Results on bromate formation in the distribution network.

Point of Use	Bromate as mg BrO^{3-}/l
Taung reservoir	< 0.025
Casino	0.054

Cost comparison

Table 8: Cost comparison between chlorine and Aqua Treat 10/10

CHLORINE			AQUA TREAT 10/10
4.7 mg/l	3.0 mg/l	3.0 mg/l (prim)+ 1.5 mg/l (sec)	34 l/Ml = 0.8 Br_2 mg/l
6.33 c/kl	4.04 c/kl	5.1 c/kl	7.0 c/kl

Secondary chlorination was only applied at the Taung reservoir and the cost calculation is therefore based on the volume of water being supplied from that reservoir. Although the treatment cost for Aqua Treat 10/10 was found to be higher than that of chlorine, it must be pointed out that:

- Historical data on analytical results of the system indicates that chlorination has to be applied at additional points in the network in order to provide sufficient residual at point of use,
- Additional chlorination in the network will incur additional costs related to installation of chlorinators and increased use of chlorine. The installation cost for chlorine will be approximately between R 70 000 and R 100 000 (7) in comparison with installation costs of approximately between R 31 000 and R 36 000 for Aqua Treat 10/10 (8).
- Aqua Treat 10/10 is not yet commercially available and further research could result in more competitive pricing (8).

Safety aspect

It is known that the leakage of chlorine gas requires immediate evacuation; it could cause serious damage to people, animals and the environment. Installation, storage and transport should be in terms of the guidelines and instructions for safe and effective handling, available from suppliers (9).

In the case of Aqua Treat 10/10 safety measures will also apply with regard to the handling, transport and storage of the product. Where leakages or spillages occur, these will be easily contained by means of the specific storage construction and would therefore not pose any risk to people and the environment (8).

CONCLUSIONS

Although the varying raw water quality could have impacted on the residuals measured in the network and therefore affected the comparison between the two products, the results obtained with chlorination during the study are in confirmation with historical data from plants owned and operated by Sedibeng Water. Full-scale results were also in confirmation with laboratory investigations.

From results obtained during the full-scale study, and from bench scale experiments to determine decay rates, it can be concluded that it will most likely be possible to maintain a sufficient disinfectant residual in the network when using Aqua Treat 10/10.
Compared with LD 50 values of known compounds, AquaTreat 10/10 is unlikely to pose any health risk when used in water treatment for potable purposes.

The distribution, handling and application of Aqua Treat 10/10 will offer significant advantages. The direct hazard to the local population will also be less.

Full-scale investigations at the Pudimoe Water Treatment Plant therefore indicated that Aqua Treat 10/10 could be used as a cost effective alternative to chlorination. Research will in future be aimed at developing market specific products.

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