Saline Water Conversion Corporation
Kingdom of Saudi Arabia

Evaluation of Chlorine Dioxide (ClO_2) Generation System for Disinfection in RO Product Water at SWCC Jubail Plant

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CONTENTS

BACKGROUND

- Recent studies have shown the formation of bromate in desalination-derived drinking water, especially when the desalinated water is treated with sodium hypochlorite solution produced by electrolyzing seawater.

Environmental Health Criteria 216, WHO (2000), Disinfectants and Disinfection By- products, *ISBN 9241572167, 30-31.*
http://www.who.int/ipcs/publications/ehc/ ehc_216/en/

BACKGROUND

Bromate formation in chlorinated water under special conditions has been explained by the following reaction.

Chlorine gas hydrolyses in water almost completely to form hypochlorous acid (HOCl):

$$Cl_2 + H_2O \longrightarrow HOCl + H^+ + Cl^- \quad (1)$$

$$HOCl \longrightarrow H^+ + OCl^- \quad (2)$$

The hypoclorous acid reacts in waters containing bromide ion to produce hypobromous acid

$$HOCl + Br^- \longrightarrow HOBr + Cl^- \quad (3)$$

$$OCl^- + Br^- \longrightarrow OBr^- + Cl^- \quad (4)$$

BACKGROUND

This reaction of hypobromous acid formation is irreversible. The presence of bromide in hypochlorite solutions can ultimately lead to the formation of bromate (BrO_3^-). Hypobromous acid is a weak acid (pk_a = 8.7); like hypochlorite, hypobromite is metastable. In alkaline solution, it decomposes to give bromate and bromide.

$$3OBr^- \longrightarrow BrO_3^- + 2Br^- \qquad (5)$$

1. Macalady, D. L.; Carpenter, J. H.; Moore, C. A. (1977), Sunlight induced bromate formation in chlorinated seawater. Science, 195(4284), 1335-1337.

2. Kumar, K.; Margerum, D. W., (1987), Kinetics and Mechanism of general – acid- assisted oxidation of bromide by hypochporite and hypochlorous acid. Inorg. Chem., 26(16), 2706-2711.

3. Margerum, D.W.; Huff Hartz, K.E., Role of halogen (I) Cation Transfer Mechnisms in water chlorination in the presence of bromide ion. J. Environ. Monit., 2002, 4, 20-26.

4. Beckwith, R. C.; Margerum, D. W., (1997), Kinetics of hypobromous acid disproportionation. Inorg. Chem., 36, 3754-3760.

5. Chao Liu, Urs von Gunten, and Jean-Philippe Croué, (2012), Environ. Sci. Technol., 46, 11054-11061.

BACKGROUND

In view of the above observations of enhanced bromate formation in water distribution systems containing bromide disinfected by chlorination under alkaline conditions, there appeared a need to choose an alternative to chlorine in curtailing the bromate formation.

BACKGROUND

If any disinfectant is to replace free chlorine as the most commonly used disinfectant, several criteria must be met, as follows:

1. It must be easily generated and be in wide use
2. It must be a good biocide.
3. It must provide an easily measured residual.
4. It must not produce or reduce undesirable byproducts than does free chlorine, and
5. It must be cost effective.

Chlorine dioxide

Based on a review of the literature chlorine dioxide was found to be the best alternative for the following:

1. It does not react with bromide to form hypobromites which could contribute to the formation of organo bromine compounds and bromate.
2. It is not a chlorinating agent and does not form halogenated organic compounds (i.e., THMs).
3. It is efficient over a wide pH range (5.0 to 9.5).
4. Very active against bacteria, viruses, algae, fungi and microorganisms.
5. Environmentally friendly.

- *Eva Agus, Nikolay V., David L. Sedlak, (2009), Disinfection byproducts and their potential impacts on the quality of water produced by desalination systems: A Literature Review, Desalination 237, p. 214-237.*
- *Chao Liu, Urs von Gunten, and Jean-Philippe Croué, (2012), Environ. Sci. Technol., 46, 11054-11061.*

BACKGROUND

- Chlorine dioxide exists almost entirely as monomeric free radicals. Concentrated chlorine dioxide vapour is potentially explosive, and attempts to compress and store this gas, either alone or in combination with other gases, have been commercially unsuccessful. Because of this, chlorine dioxide, like ozone, must be manufactured at the point of use.

Table 4-1. Commercial Chlorine Dioxide Generators

GENERATOR TYPE	MAIN REACTIONS Reactants, byproducts, key reactions, and chemistry notes	SPECIAL ATTRIBUTES
ACID-CHLORITE: (Direct Acid System)	$4HCl + 5NaClO_2 \rightarrow 4ClO_{2(aq)} + ClO_3^-$ • Low pH • ClO_3^- possible • Slow reaction rates	Chemical feed pump interlocks required. Production limit ~ 25-30 lb/day. Maximum yield at ~80% efficiency.
AQUEOUS CHLORINE-CHLORITE: (Cl_2 gas ejectors with chemical pumps for liquids or booster pump for ejector water).	$Cl_2 + H_2O \rightarrow$ [HOCl / HCl] [HOCl/HCl] + $NaClO_2 \rightarrow$ $ClO_{2(g)}$ + H/OCl$^-$ + NaOH + ClO_3^- • Low pH • ClO_3^- possible • Relatively slow reaction rates	Excess Cl_2 or acid to neutralize NaOH. Production rates limited to ~ 1000 lb/day. High conversion but yield only 80-92% More corrosive effluent due to low pH (~2.8-3.5). Three chemical systems pump HCl, hypochlorite, chlorite, and dilution water to reaction chamber.
RECYCLED AQUEOUS CHLORINE OR "FRENCH LOOP"™ (Saturated Cl_2 solution via a recycling loop prior to mixing with chlorite solution.)	$2HOCl + 2NaClO_2 \rightarrow 2ClO_2 + Cl_2 + 2NaOH$ • Excess Cl_2 or HCl needed due to NaOH formed.	Concentration of ~3 g/L required for maximum efficiency. Production rate limited to ~ 1000 lb/day. Yield of 92-98% with ~10% excess Cl_2 reported. Highly corrosive to pumps; draw-down calibration needed. Maturation tank required after mixing.
GASEOUS CHLORINE-CHLORITE (Gaseous Cl_2 and 25% solution of sodium chlorite; pulled by ejector into the reaction column.)	$Cl_{2(g)} + NaClO_{2(aq)} \rightarrow ClO_{2(aq)}$ • Neutral pH • Rapid reaction • Potential scaling in reactor under vacuum due to hardness of feedstock.	Production rates 5-120,000 lb/day. Ejector-based, with no pumps. Motive water is dilution water. Near neutral pH effluent. No excess Cl_2. Turndown rated at 5-10X with yield of 95-99%. Less than 2% excess Cl_2. Highly calibrated flow meters with min. line pressure ~ 40 psig needed.
GASEOUS CHLORINE-SOLIDS CHLORITE MATRIX (Humidified Cl_2 gas is pulled or pumped through a stable matrix containing solid sodium chlorite.)	$Cl_{2(g)} + NaClO_{2(s)} \rightarrow ClO_{2(g)} + NaCl$ • Rapid reaction rate • New technology	Cl_2 gas diluted with N_2 or filtered air to produce ~8% gaseous ClO_2 stream. Infinite turndown is possible with > 99% yield. Maximum rate to ~1200 lb/day per column; ganged to > 10,000 lb/day.
ELECTROCHEMICAL (Continuous generation of ClO_2 from 25% chlorite solution recycled through electrolyte cell)	$NaClO_{2(aq)} \rightarrow ClO_{2(aq)} + e^-$ • New technology	Counter-current chilled water stream accepts gaseous ClO_2 from production cell after it diffuses across the gas permeable membrane. Small one-pass system requires precise flow for power requirements (Coulombs law).
ACID/PEROXIDE/CHLORIDE	$2NaClO_3 + H_2O_2 + H_2SO_4 \rightarrow 2ClO_2 + O_2 + NaSO_4 + H_20$	Uses concentrated H_2O_2 and H_2SO_4. Downscaled version; Foam binding; Low pH.

OBJECTIVES

- To evaluate the performance of ClO_2 generating system (Scotmas-UK represented by SENDAB, KSA) in RO product water of SWCC plant.
- To Study the purity and efficiency of ClO_2 product and the percentage yield.
- Optimization of the required Chlorine Dioxide dosage to disinfect the RO product water.
- To study the DBPs formation with the use of ClO_2 generating system..

EXPERIMENTAL

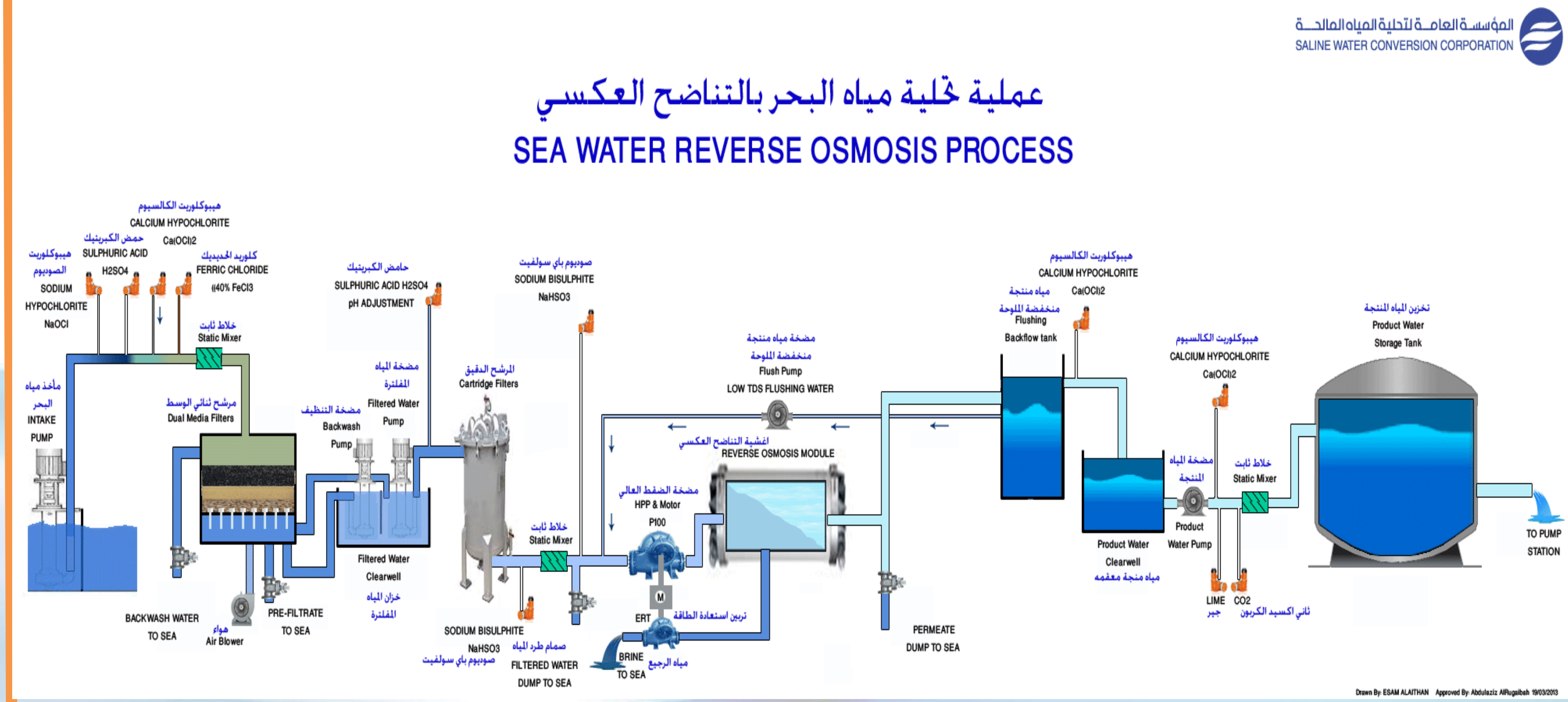
Pretreatment of RO plant

The existing pretreatment comprised rapid mix/coagulation using ferric chloride (40%), flocculation, sedimentation and dual granular media (sand and anthracite) filtration.

Coagulant was dosed at 2.0 to 3.5 ppm (mg/L) and pH was adjusted to 6.8 by adding sulphuric acid (98%).

Chlorine was dosed from the electro chlorinators of intake and the residual chlorine was kept in the range of 0.3 – 1.5 ppm. However, to compensate for deficiencies & shutdowns at intake chlorination, separate chlorination lines from calcium hypochlorite dosing system of RO plant have been provided. These dosing lines are located in the dosing pit upstream of dual media filters

EXPERIMENTAL



EXPERIMENTAL

SCOTMAS Bravo MX chlorine dioxide generating system was installed on the agreed location. Both reagents [sodium chlorite (31%) and hydrochloric acid (32%)] are reacted within a submerged chamber that is installed within a bypass line of the water to be treated.

$$5NaClO_2 + 4HCl \longrightarrow 4ClO_2 + 5NaCl + 2H_2O$$

EXPERIMENTAL

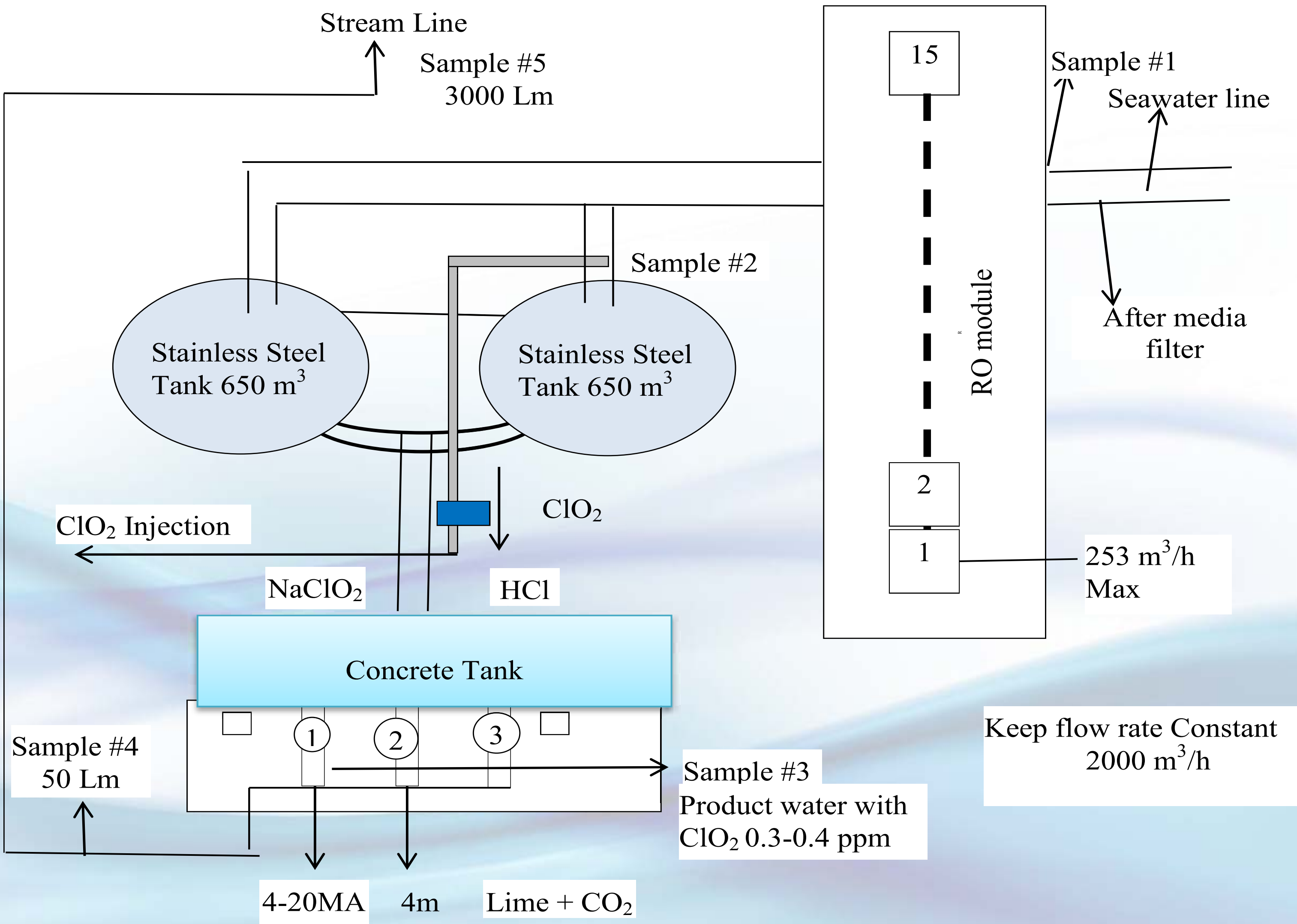
Dosing of ClO_2 with the flow of water was controlled by online analyzer and directly recorded on the screen by the operator. The sensors used are ion-specific amperometric 2-electrode systems, protected by a membrane, for accurate measurement of both chlorine dioxide and chlorite, and minimum detection limit is 0.05ppm.

EXPERIMENTAL

Agreed sample points are five as given below:

- Sample #1 : Intake seawater.
- Sample #2 : After RO (Before ClO_2 dosing)
- Sample # 3: 10 m after dosing of ClO_2 (before CO_2 & lime dosing)
- Sample # 4 : 50 m after RO (after CO_2 & lime dosing)
- Sample # 5: 3000 – 3500 m after dosing of ClO_2.

EXPERIMENTAL



EXPERIMENTAL

Samples were collected for analysis to check the agreed parameters as follows:

- ❖Residual ClO_2, chlorate, chlorite, residual chlorine, bromate, organics, THMs, and biological analysis.
- ❖Additional parameters; residual sodium bisulfite (SBS), residual free chlorine and pH at agreed locations.

ANALYTICAL TECHNIQUES

❖ ***Trihalomethanes (THMs) Analysis by GC/MS***

All samples were analyzed According to the Standard Methods based on the described procedures in APHA Standard Methods (APHA, 2003).

❖ ***Bromate and Chlorate Analysis by Ion Chromatography***

Bromate and chlorate in water was measured by ion chromatography using suppress conductivity detection according to U.S. EPA Method 300.1 B.

❖ ***Chlorine dioxide and Chlorite Analysis***

Residual Chlorine dioxide and Chlorite levels were measured by means of an online amperometric probe.

ANALYTICAL TECHNIQUES

Chlorine dioxide and chlorite concentrations were also measured by manual grab sampling and analysis as part of normal on site test procedures using DPD or a Palintest ChlordioX Plus portable monitoring instrument calibrated for chlorine dioxide.

ANALYTICAL TECHNIQUES

❖ ***Biological Analysis***

Water samples were withdrawn from the sampling points employing aseptic techniques and analyzed using “APHA Method 9215: Standard Methods for the Examination of Water Wastewater”

RESULTS AND DISCUSSIONS

Table shows Results from sampling point # 2 representative of permeate. Bromate, chlorite and chlorate were found to be negligible or nil for the whole evaluation period. Though some amount of THMs, predominantly bromoform (~40 ppb) was detected, the total THMs values (<1) were well below the regulated values (WHO=1).

S. No.	Sample Date	Sample Point	Chlorine Dioxide Residual Palintest	Chlorite (ClO_2^-) Palintest	Bromate (BrO_3)	Organics	Bromoform	THMs (total)	pH
			1	2	3	4	5	6	7
	UoM		mg/l	mg/l	µg/l	µg/l	µg/l		
1	21/4/16	2	0.01	0.02	NA*	NA	NA	NA	NA
2	23/4/16	2	0.01	0.02	NA	NA	NA	NA	NA
3	24/4/16	2	0.01	0.01	NA	NA	NA	NA	NA
4	25/4/16	2	0.01	0.01	<2	ND*	36	0.36	NA
5	26/4/16	2	0.01	0.01	<2	ND	34	0.34	NA
6	27/4/16	2	0.01	0.01	<2	ND	37	0.37	NA
7	28/4/16	2	0.01	0.01	<2	ND	34	0.34	5.45
8	30/4/16	2	0.01	0.01	NA	NA	NA	NA	NA
9	1/5/16	2	0.01	0.01	<2	ND	38	0.38	5.65
10	2/5/16	2	0.01	0.01	<2	ND	37	0.37	5.1
11	3/5/16	2	0.01	0.01	<2	ND	37	0.37	5.41
12	4/5/16	2	0.01	0.03	<2	ND	35	0.35	5.3
13	5/5/16	2	0.01	0.01	<2	ND	33	0.33	5.2
14	7/5/16	2	0.03	0.01	NA	NA	NA	NA	NA
15	8/5/16	2	0.01	0.01	<2	ND	39	0.39	5.33
16	9/5/16	2	0.01	0.01	<2	ND	40	0.4	4.9
17	10/5/16	2	0.01	0.01	<2	ND	29	0.29	5.3
18	11/5/16	2	0.01	0.01	<2	ND	27	0.27	5.29
19	12/5/16	2	0.01	0.01	<2	ND	30	0.3	5.3
20	14/5/16	2	0.01	0.01	NA	NA	NA	NA	NA
21	15/5/16	2	0.01	0.01	<2	ND	30	0.3	5.34
22	17/5/16	2	0.01	0.01	<2	ND	31	0.31	5.41
23	22/5/16	2	0.01	0.01	<2	ND	33	0.33	5.34
24	25/5/16	2	0.02	0.01	<2	ND	32	0.32	NA
25	1/6/16	2	0.01	0.01	NA	NA	NA	NA	NA
26	7/6/16	2	0.01	0.01	<2	ND	32	0.32	5.28
27	8/6/16	2	0.01	0.01	<2	ND	33	0.33	5.28
28	16/6/16	2	0.01	0.01	<2	ND	27	0.27	NA
29	20/6/16	2	0.01	NA	<2	ND	30	0.3	5.65
30	22/6/16	2	0.01	NA	<2	ND	34	0.34	5.39
31	27/6/16	2	0.01	NA	<2	ND	33	0.33	5.26
32	29/6/16	2	0.01	NA	<2	ND	29	0.29	5.3
33	4/7/16	2	0.01	NA	<2	ND	27	0.27	5.33
34	6/7/16	2	0.01	NA	NA	NA	NA	NA	5.33
35	11/7/16	2	0.01	NA	<2	ND	29	0.29	5.35
36	13/7/16	2	0.01	NA	<2	ND	27	0.27	5.46
37	18/7/16	2	0.01	NA	NA	NA	NA	NA	5.29
38	20/7/16	2	0.01	NA	NA	NA	NA	NA	5.21

RESULTS AND DISCUSSIONS

Tuning of the ClO_2 generating system

- Generally, to produce ClO_2 using acid-chlorite generation technologies a 1:1 volumetric ratio between sodium chlorite solution and acid solution precursors will be utilized
- Through intensive research and development, it was found that this excess of acid generally dosed is unnecessary and tuning can be carried out during commissioning and the initial operation of these systems to optimize ClO_2 generation.
- Tuning the generator, hydrochloric acid was dosed at approximately 30 -38% less compared to the sodium chlorite dose rate with the conversion efficiency within the range of 84% to 96%,

	Dose Rate (Lhr^{-1})		
Date	31 % Sodium Chlorite	32% Hydrochloric acid	Volumetric Ratio
25/4/16	3.24	2.25	0.69
27/4/16	3	2.13	0.71
05/5/16	2.77	1.93	0.70
08/5/16	2.63	1.83	0.70
09/5/16	2.38	1.65	0.69
21/5/16	2	1.34	0.67
22/5/16	1.9	1.27	0.67
23/5/16	1.8	1.2	0.67

		Equivalent ClO_2 Concentrations(mgL^{-1})		
Date	31 % Sodium Chlorite (Lhr^{-1})	Theoretical	Actual	Conversion Efficiency (%)
01/5/16	3	0.44	0.32	72.13
02/5/16	2.92	0.43	0.39	92.33
03/5/16	2.92	0.43	0.39	90.94
04/5/16	2.92	0.43	0.38	89.98
05/5/16	2.77	0.40	0.38	94.55
07/5/16	2.77	0.40	0.31	75.59
08/5/16	2.63	0.38	0.29	76.14
09/5/16	2.38	0.35	0.33	96.37
10/5/16	2.38	0.35	0.30	85.27
11/5/16	2.38	0.35	0.29	84.49
12/5/16	2.38	0.35	0.27	78.17
14/5/16	2.38	0.35	0.23	66.69

RESULTS AND DISCUSSIONS

Optimization of ClO_2 Dose Rate

The dosing control for chlorine dioxide was monitored at sample point # 3. A dosage of ClO_2 with a residual in the range of 0.3 to 0.4ppm was controlled as per the requirement for initial disinfection.

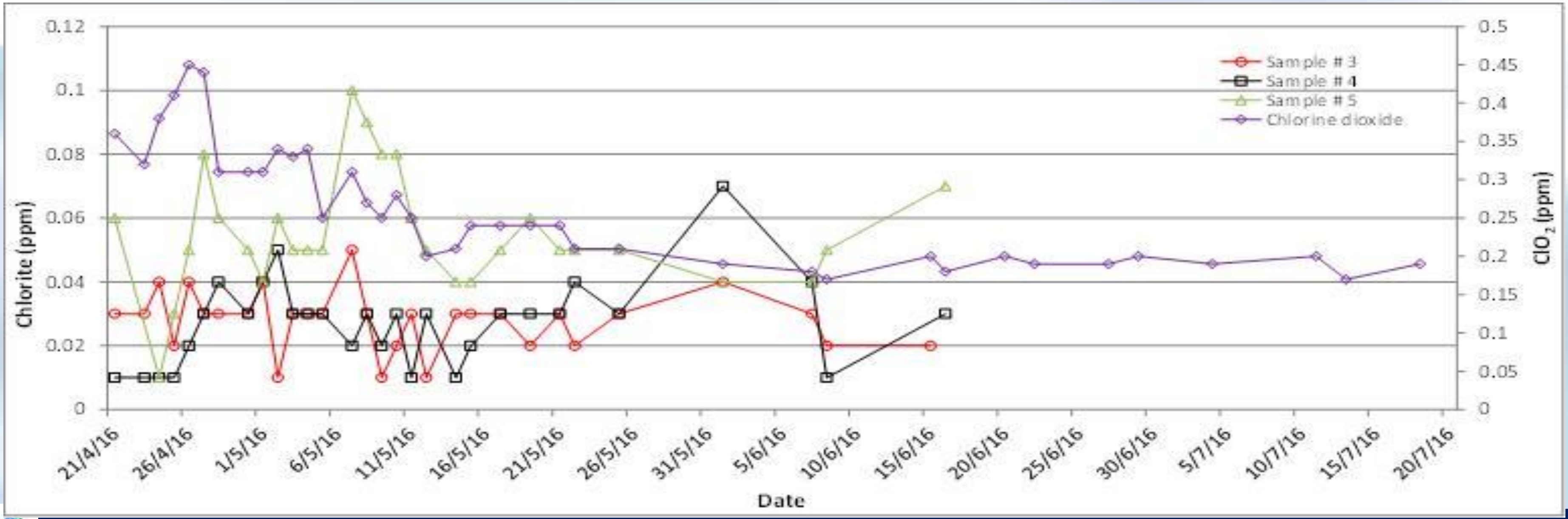
A dose rate in the range of 0.18 – 0.20 ppm of residual ClO_2 was found to be optimum dose rate and the test was continued with this rate and monitoring the microbiological analysis the performance was evaluated.

Sample Date	Sample Point	Chlorine Dioxide Residual Palintest	Chlorine Dioxide Residual Online	Chlorite (ClO_2^-) Palintest	Chlorite (ClO_2^-) Online	Chlorate (ClO_3^-)	Bromate (BrO_3^-)	Organics	Bromo form	THMs (total)	Biological Analysis	pH
		1	2	3	4	5	6	7	8	9	10	11
	UoM	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l			
21/4/16	3	0.36	NA	0.03	0.03	NA	<2	ND	NA	NA	Negative	NA
23/4/16	3	0.32	0.34	0.03	0.03	NA	<2	ND	NA	NA	Negative	NA
24/4/16	3	0.38	0.33	0.04	0.03	NA	<2	ND	NA	NA	Negative	NA
25/4/16	3	0.41	0.34	0.02	0.02	NA	<2	ND	38	0.38	Negative	NA
26/4/16	3	0.45	0.33	0.04	0.03	NA	<2	ND	35	0.35	Negative	NA
27/4/16	3	0.44	0.39	0.03	0.03	NA	<2	ND	37	0.37	Negative	NA
28/4/16	3	0.31	0.29	0.03	0.03	NA	<2	ND	35	0.35	Negative	8.55
30/4/16	3	0.31	0.32	0.03	0.03	NA	<2	ND	NA	NA	Negative	NA
1/5/16	3	0.31	0.3	0.04	0.03	NA	<2	ND	40	0.4	Negative	7.48
2/5/16	3	0.34	0.32	0.01	0.03	NA	<2	ND	38	0.38	Negative	8
3/5/16	3	0.33	0.31	0.03	0.03	0.07	<2	ND	38	0.38	Negative	8
4/5/16	3	0.34	0.33	0.03	0.03	0.05	<2	ND	35	0.35	Negative	7.9
5/5/16	3	0.25	0.3	0.03	0.04	0.07	<2	ND	33	0.33	Negative	NA
7/5/16	3	0.31	0.32	0.05	0.04	NA	<2	ND	NA	NA	Negative	NA
8/5/16	3	0.27	0.31	0.03	0.07	0.05	<2	ND	39	0.39	Negative	7.8
9/5/16	3	0.25	0.3	0.01	0.07	0.08	<2	ND	40	0.4	Negative	NA
10/5/16	3	0.28	0.29	0.02	0.04	0.05	<2	ND	32	0.32	Negative	8.5
11/5/16	3	0.25	0.26	0.03	0.05	0.06	<2	ND	27	0.27	Negative	7.55
12/5/16	3	0.2	0.23	0.01	0.05	0.03	<2	ND	32	0.32	Negative	7.22
14/5/16	3	0.21	0.22	0.03	0.04	0.02	<2	ND	NA	NA	Negative	NA
15/5/16	3	0.24	0.22	0.03	0.04	NA	<2	ND	32	0.32	Negative	7.2
16/5/16	3	NA	NA	NA	NA	NA	NA	ND	NA	NA	Negative	NA
17/5/16	3	0.24	0.22	0.03	0.04	0.01	<2	ND	33	0.33	Negative	NA
19/5/16	3	0.24	0.2	0.02	0.05	NA	<2	ND	NA	NA	Negative	NA
21/5/16	3	0.24	0.2	0.03	0.05	NA	<2	ND	NA	NA	Negative	NA
22/5/16	3	0.21	0.18	0.02	0.05	0.01	<2	ND	35	0.35	Negative	7.82
25/5/16	3	0.21	0.21	0.03	0.05	0.01	<2	ND	34	0.34	Negative	NA
1/6/16	3	0.19	0.2	0.04	0.05	0.01	<2	ND	34	0.34	Negative	NA
7/6/16	3	0.18	0.16	0.03	0.07	0.01	<2	ND	33	0.33	Negative	7.5
8/6/16	3	0.17	0.17	0.02	0.07	0.05	<2	ND	27	0.27	Negative	NA
16/6/16	3	0.2	0.21	0.02	0.06	0.02	<2	ND	30	0.30	Negative	8.53
20/6/16	3	0.18	0.19	NA	0.07	0.01	<2	ND	34	0.34	Negative	5.53
22/6/16	3	0.2	0.19	NA	0.07	0.01	<2	ND	33	0.33	Negative	5.36
27/6/16	3	0.19	0.2	NA	0.08	0.01	<2	ND	31	0.31	Negative	5.25
29/6/16	3	0.19	0.21	NA	0.08	0.01	<2	ND	27	0.27	Negative	5.27
4/7/16	3	0.2	0.15	NA	0.08	0.01	<2	ND	25	0.25	Negative	5.31
11/7/16	3	0.19	0.2	NA	0.08	0.01	<2	ND	28	0.28	Negative	5.3
13/7/16	3	0.2	0.15	NA	0.08	NA	<2	ND	NA	NA	Negative	5.34
18/7/16	3	0.17	0.19	NA	0.07	NA	<2	ND	NA	NA	Negative	5.31
20/7/16	3	0.19	0.2	NA	0.09	NA	<2	ND	NA	NA	Negative	5.20

RESULTS AND DISCUSSIONS

Disinfection By-products (Chlorite)

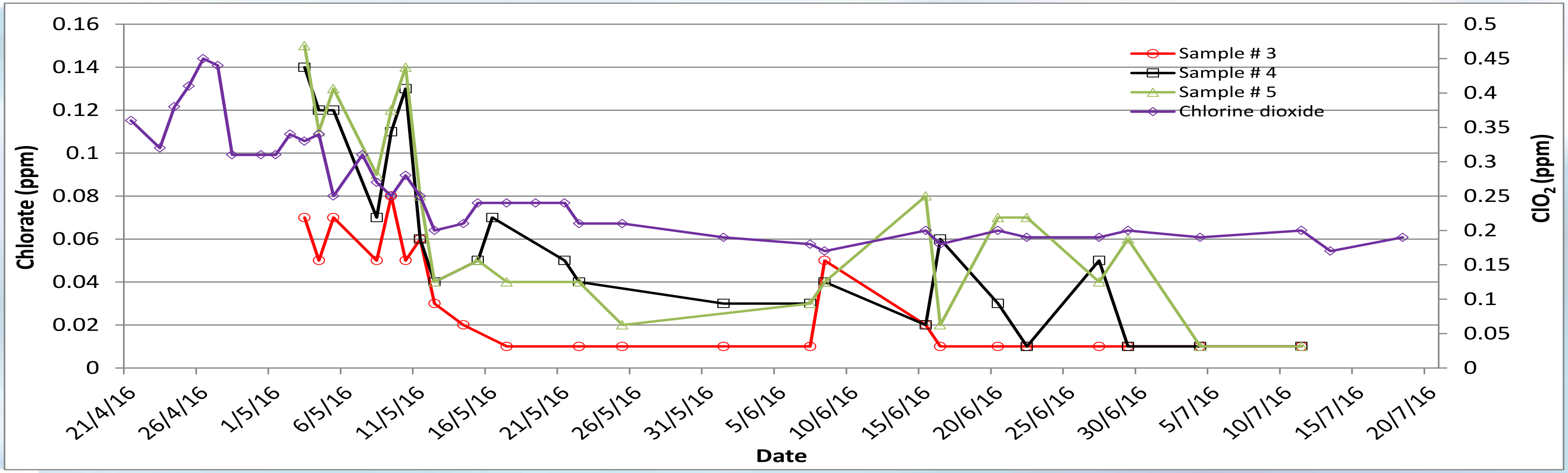
The concentration of the chlorite for all the sampling points was found to be well below the regulation value (0.7 ppm, WHO), moreover, the values were very low (0.01 – 0.04 ppm) except for the sampling point # 5 the values were a little higher (0.04 – 0.1 ppm), which is known to occur due to disproportionation of chlorine dioxide upon increasing pH. However, it was interesting to note that there was no significant effect on the formation of chlorite with adjustment of the ClO_2 dose.



RESULTS AND DISCUSSIONS

Chlorate

The concentration of the chlorate for all the sampling points # 3, 4 and 5 during the optimization and for the duration of test with the optimized dose rate was found to be well below the regulation value (0.7 ppm, WHO). Initially at a higher dose rate of ClO_2, Chlorate concentrations were found to be a little higher (0.05 – 0.14 ppm). But as the dose rate of ClO_2 were reduced and at the optimum dose rate of 0.19 ppm ClO_2, the chlorate values for sampling point # 4 and # 5 were reduced and found to be in the range of 0.02 – 0.06 ppm whereas for sampling point # 3 the values were almost consistent at 0.01ppm.



RESULTS AND DISCUSSIONS

Bromate

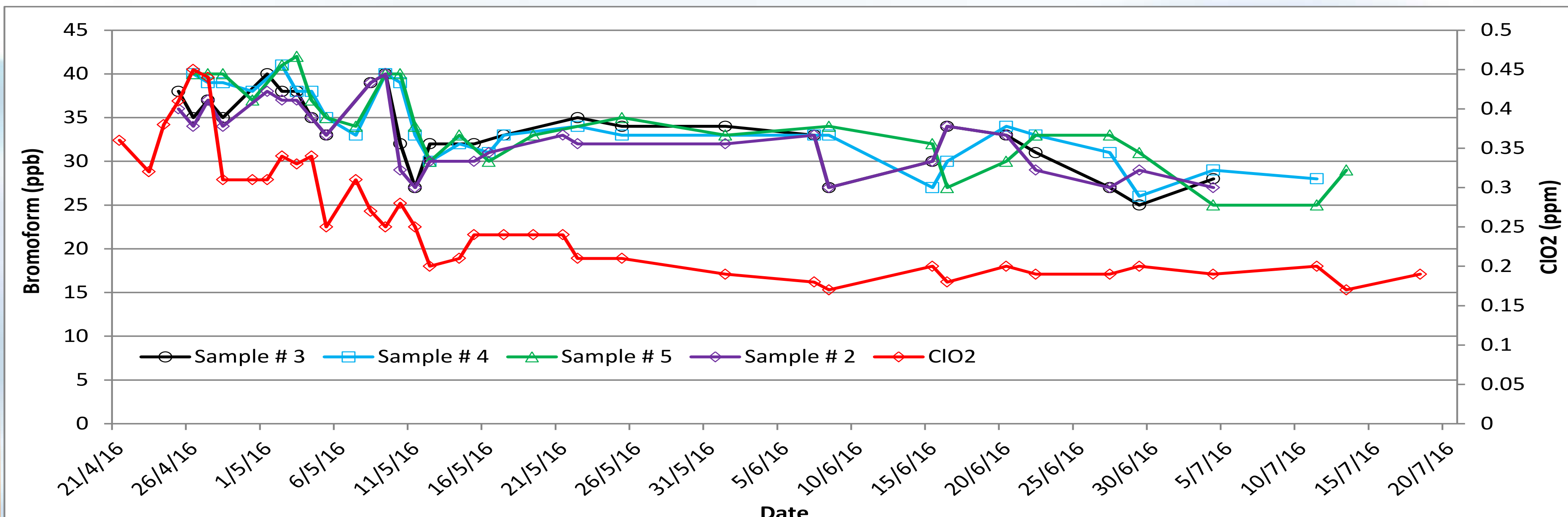
Bromate concentrations determined were found to be <2 ppb for all the sampling points indicating negligible or no bromate formation with ClO_2 treatment during the whole trial period. Bromate concentrations for each sample point throughout the trial

Sample Date	Sample Point	Chlorine Dioxide Residual Palintest	Chlorine Dioxide Residual Online	Chlorite (ClO_2^-) Palintest	Chlorite (ClO_2^-) Online	Chlorate (ClO_3^-)	Bromate (BrO_3^-)	Organics	Bromo form	THMs (total)	Biological Analysis	pH
		1	2	3	4	5	6	7	8	9	10	11
	UoM	mg/l	mg/l	mg/l	mg/l	mg/l	µg/l	µg/l	µg/l			
21/4/16	3	0.36	NA	0.03	0.03	NA	<2	ND	NA	NA	Negative	NA
23/4/16	3	0.32	0.34	0.03	0.03	NA	<2	ND	NA	NA	Negative	NA
24/4/16	3	0.38	0.33	0.04	0.03	NA	<2	ND	NA	NA	Negative	NA
25/4/16	3	0.41	0.34	0.02	0.02	NA	<2	ND	38	0.38	Negative	NA
26/4/16	3	0.45	0.33	0.04	0.03	NA	<2	ND	35	0.35	Negative	NA
27/4/16	3	0.44	0.39	0.03	0.03	NA	<2	ND	37	0.37	Negative	NA
28/4/16	3	0.31	0.29	0.03	0.03	NA	<2	ND	35	0.35	Negative	8.55
30/4/16	3	0.31	0.32	0.03	0.03	NA	<2	ND	NA	NA	Negative	NA
1/5/16	3	0.31	0.3	0.04	0.03	NA	<2	ND	40	0.4	Negative	7.48
2/5/16	3	0.34	0.32	0.01	0.03	NA	<2	ND	38	0.38	Negative	8
3/5/16	3	0.33	0.31	0.03	0.03	0.07	<2	ND	38	0.38	Negative	8
4/5/16	3	0.34	0.33	0.03	0.03	0.05	<2	ND	35	0.35	Negative	7.9
5/5/16	3	0.25	0.3	0.03	0.04	0.07	<2	ND	33	0.33	Negative	NA
7/5/16	3	0.31	0.32	0.05	0.04	NA	<2	ND	NA	NA	Negative	NA
8/5/16	3	0.27	0.31	0.03	0.07	0.05	<2	ND	39	0.39	Negative	7.8
9/5/16	3	0.25	0.3	0.01	0.07	0.08	<2	ND	40	0.4	Negative	NA
10/5/16	3	0.28	0.29	0.02	0.04	0.05	<2	ND	32	0.32	Negative	8.5
11/5/16	3	0.25	0.26	0.03	0.05	0.06	<2	ND	27	0.27	Negative	7.55
12/5/16	3	0.2	0.23	0.01	0.05	0.03	<2	ND	32	0.32	Negative	7.22
14/5/16	3	0.21	0.22	0.03	0.04	0.02	<2	ND	NA	NA	Negative	NA
15/5/16	3	0.24	0.22	0.03	0.04	NA	<2	ND	32	0.32	Negative	7.2
16/5/16	3	NA	NA	NA	NA	NA	NA	ND	NA	NA	Negative	NA
17/5/16	3	0.24	0.22	0.03	0.04	0.01	<2	ND	33	0.33	Negative	NA
19/5/16	3	0.24	0.2	0.02	0.05	NA	<2	ND	NA	NA	Negative	NA
21/5/16	3	0.24	0.2	0.03	0.05	NA	<2	ND	NA	NA	Negative	NA
22/5/16	3	0.21	0.18	0.02	0.05	0.01	<2	ND	35	0.35	Negative	7.82
25/5/16	3	0.21	0.21	0.03	0.05	0.01	<2	ND	34	0.34	Negative	NA
1/6/16	3	0.19	0.2	0.04	0.05	0.01	<2	ND	34	0.34	Negative	NA
7/6/16	3	0.18	0.16	0.03	0.07	0.01	<2	ND	33	0.33	Negative	7.5
8/6/16	3	0.17	0.17	0.02	0.07	0.05	<2	ND	27	0.27	Negative	NA
16/6/16	3	0.2	0.21	0.02	0.06	0.02	<2	ND	30	0.30	Negative	8.53
20/6/16	3	0.18	0.19	NA	0.07	0.01	<2	ND	34	0.34	Negative	5.53
22/6/16	3	0.2	0.19	NA	0.07	0.01	<2	ND	33	0.33	Negative	5.36
27/6/16	3	0.19	0.2	NA	0.08	0.01	<2	ND	31	0.31	Negative	5.25
29/6/16	3	0.19	0.21	NA	0.08	0.01	<2	ND	27	0.27	Negative	5.27
4/7/16	3	0.2	0.15	NA	0.08	0.01	<2	ND	25	0.25	Negative	5.31
11/7/16	3	0.19	0.2	NA	0.08	0.01	<2	ND	28	0.28	Negative	5.3
13/7/16	3	0.2	0.15	NA	0.08	NA	<2	ND	NA	NA	Negative	5.34
18/7/16	3	0.17	0.19	NA	0.07	NA	<2	ND	NA	NA	Negative	5.31
20/7/16	3	0.19	0.2	NA	0.09	NA	<2	ND	NA	NA	Negative	5.20

RESULTS AND DISCUSSIONS

❖ *Trihalomethanes (THMs)*

Negligible or very small amount of THMs were detected, bromoform (~40 ppb) being the predominant. It should be noted here that the THMs values are the carryover from the chlorination of sea water and intermittent chlorine dose before the membranes and that the values were consistent as found in the sampling point # 2. This indicated that ClO_2 had no effect on the THMs formation. TTHMs were also found to be in good control for all the sampling points (<1) and well below the WHO regulated values of 1.



CONCLUSIONS

- A dose rate in the range of 0.18 – 0.20 ppm as residual ClO_2 was found to be optimum dose rate on the performance of disinfection observed from the microbiological analysis.

- Biological analyses showed total Coliforms & E.Coli in all the sampling points was negative indicating ClO_2 to be very efficient in killing the bacteria and therefore a suitable alternative to chlorination.

- Residual ClO_2 at the sampling point # 4 and # 5 were found to be in the range of 0.1– 0.16 ppm.

CONCLUSIONS

- Disinfection byproducts chlorite and chlorate formed at the ClO_2 control point (sampling point # 3) were found to be in the range of 0.01 – 0.04 ppm which are well below the WHO regulation values of 0.7 ppm.

- The combined ClO_2, chlorite and chlorate concentrations did not exceed the maximum limit of $1 mgL^{-1}$ currently recommended by USEPA.

CONCLUSIONS

- Bromate concentrations determined were found to be <2 ppb for all the sampling points indicating negligible or no bromate formation with ClO_2 treatment.

- Negligible or very small amounts of THMs were detected throughout the trial even through adjusting ClO_2 dose. Bromoform (~40 ppb) being the predominant THM detected, was found to be carryover from the chlorination of sea-water and intermittent chlorine dose due to its presence before the RO membranes with no significant change after ClO_2 injection. TTHMs were found to be well below the WHO regulated values of ≤1 throughout the whole of the trial.

CONCLUSIONS

The consistent values of disinfection by-products (TTHMS) recorded, resulting from the chlorination of sea-water before and after treatment with ClO_2 has proven that these results could be avoided by use of the SENDAB (SCOTMAS-UK) ClO_2 generating system.

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Date 11th November 2011

Dear Mr Callachan

APPROVAL GIVEN UNDER REGULATION 31(4)(a) OF THE WATER SUPPLY (WATER QUALITY) REGULATIONS 2000 No. 3184 & THE WATER SUPPLY (WATER QUALITY) REGULATIONS 2001 (WALES) No.3911

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