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Improving Drinking Water Quality by Reducing Bromate Concentration in Drinking Water Networks in Kuwait

Mohammed Al Gallaf

وزارة الكهربـــاء والمـــاء
Ministry of Electricity & Water

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IMPROVING DRINKING WATER QUALITY BY REDUCING BROMATE CONCENTRATION IN DRINKING WATER NETWORKS IN KUWAIT

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INTRODUCTION

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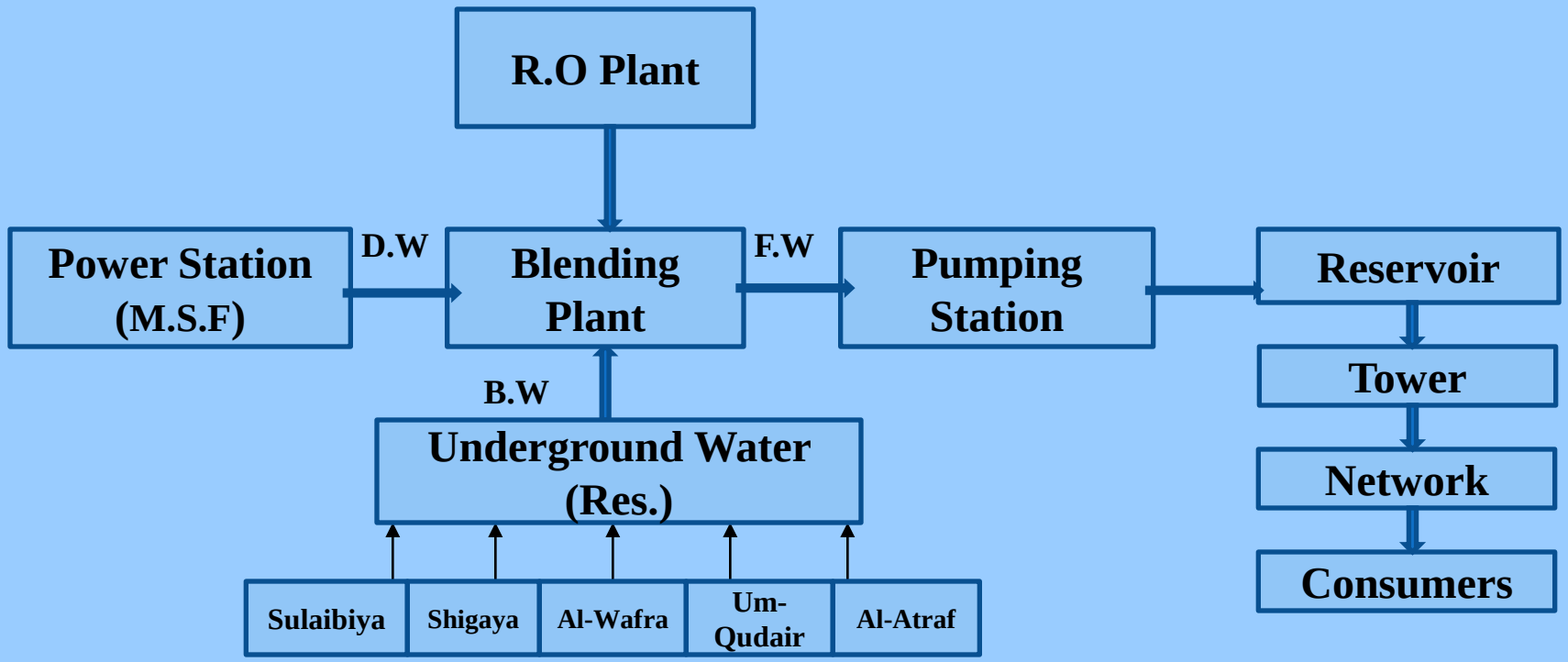
- The production of drinking water in Kuwait comes as a result of either from blending distilled water produced from Multi Stage Flash units (MSF) with brackish water produced from water well fields of Sulaibiya, Shigaya, Al-Wafra, Um-Qudair and Al-Atraf or form Reverse Osmosis (RO).
- The distribution networks consist of a main pumping and distribution lines and subsidiary networks, for supplying fresh water and brackish water to consumers.



تقرير عن نوعية المياه فى مجمعى توزيع المياه بالشويخ والدوحة خلال شهر مارس 2014

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No.	DATE	SHUWAIKH P.S.				DOHA P.S.				DOHA West				DOHA East			
		Fresh Water				Fresh Water				DISTILLED WATER				DISTILLED WATER			
		Cond (µs/cm)	TDS (mg/l)	pH	Cl_2 (mg/l)	Cond (µs/cm)	TDS (mg/l)	pH	Cl_2 (mg/l)	Cond (µs/cm)	TDS (mg/l)	pH	Cl_2 (mg/l)	Cond (µs/cm)	TDS (mg/l)	pH	Cl_2 (mg/l)
1	02/3/2014	517	274	7.56	0.33	208	109	8.1	Nil	96	50	7.7	Nil	8	4	7.8	Nil
2	03/3/2014	524	276	7.70	0.34	202	106	8.1	0.40	100	53	8.3	Nil	8	4	8.1	Nil
3	04/3/2014	506	268	7.73	0.33	187	98	8.4	0.40	88	46	8.1	Nil	7	4	7.4	Nil
4	05/3/2014	492	261	7.72	0.32	191	100	8.5	0.40	93	49	8.0	Nil	7	4	8.1	Nil
5	06/3/2014	470	249	7.74	0.42	184	97	7.7	0.20	88	46	8.5	Nil	7	3	8.0	Nil
6	09/3/2014	391	207	7.73	0.35	210	110	8.1	0.30	97	51	8.2	Nil	10	5	7.6	Nil
7	10/3/2014	397	211	7.72	0.32	196	103	8.1	0.25	92	48	8.1	Nil	7	3	7.8	Nil
8	11/3/2014	369	195	7.63	0.35	199	105	8.4	0.28	98	51	8.1	Nil	9	4	8.1	Nil
9	12/3/2014	391	207	7.66	0.38	209	110	8.1	0.21	105	55	8.3	Nil	8	4	7.7	Nil
10	13/3/2014	359	190	7.64	0.35	192	101	8.1	0.60	107	56	8.5	Nil	7	4	8.3	Nil
11	16/3/2014	455	241	7.82	0.30	205	107	8.1	0.40	96	50	8.3	Nil	10	5	8.4	Nil
12	17/3/2014	455	241	7.76	0.32	207	109	8.3	0.30	101	53	8.3	Nil	12	6	8.5	Nil
13	18/3/2014	339	179	7.74	0.35	202	106	8.3	0.40	96	51	8.4	Nil	9	5	8.5	Nil
14	19/3/2014	284	150	7.76	0.42	190	99	8.2	0.50	103	54	8.4	Nil	8	4	8.2	Nil
15	20/3/2014	286	151	7.7	0.43	211	111	8.3	0.20	99	53	8.4	Nil	10	5	8.3	Nil
16	23/3/2014	245	130	7.76	0.25	155	82	7.3	0.20	103	54	7.4	Nil	11	6	6.4	Nil
17	24/3/2014	228	121	7.68	0.25	216	113	8.1	0.40	84	44	7.4	Nil	9	5	8.0	Nil
18	25/3/2014	318	168	7.50	0.45	208	109	8.1	0.40	83	43	8.3	Nil	23	11	8.2	Nil
19	26/3/2014	315	167	7.75	0.40	223	117	8.2	0.50	89	47	7.9	Nil	11	6	7.8	Nil
20	27/3/2014	317	168	7.74	0.35	219	115	8.0	0.40	81	42	8.3	Nil	9	5	7.9	Nil
21	30/3/2014	245	130	7.65	0.30	215	113	7.2	0.30	76	40	8.1	Nil	9	4	7.6	Nil
22	31/3/2014	251	133	7.70	0.25	198	104	7.4	0.40	91	47	7.8	Nil	9	5	7.7	Nil
Notes		MSF + R.O MIXED No Brackish Water Addition Average of Bromate Conc (8.0 ppb)				With Brackish Water Addition Average of Bromate Conc (2.0 ppb)				With Carbonation Before Blending				Without Carbonation Before Blending			

- In recent years, bromate has become known as a contaminant of potable water & it is not normally found in water.
- Because bromate is potentially carcinogenic, according to World Health Organization guidelines (WHO, 2011) & also European Union (EU), the maximum contaminant level (MCL) is 10 μg L^{-1}.
- Moreover, bromate is stable, and there is currently no economically feasible technology to remove it once it is formed.
- In kuwait, now-a-days the fresh water is disinfected by chlorine gas, resulting in the formation of bromate as byproduct in distribution networks with different concentration levels.
- Subsequently, both distilled water and brackish water contain bromide ions with different concentrations. And also, the fresh Reverse Osmosis (RO) water produced from shuwaikh and Az-Zour power stations has bromide ions concentration.
- The path-way and rate of decomposition are related to factors, such as pH concentration of the source water, temperature, ionic strength and light which lead to formation of bromate.

Studies on Bromate in Drinking Water

- Most oxidizing chemical disinfectants can oxidize bromide to bromate, however it is very dependent on the mode of action of the individual disinfectant.
- Considerable bromate was formed from the chlorinated water, when exposed to sunlight has been investigated by Macalady *et al.* (1977).
- Furthermore, bromate was also formed in the dark, by cross-oxidation reaction ions between hypobromite and hypochlorite during Chlorinated water was explained Haag (1981) respectively.
- In the presence of ammonia, residual chlorine may exist as monochloroamine will react with hypobromite to form bromate has been proposed by Bousher et.al., (1990).
- Other oxidant like, UV and hydrogen peroxide are likely to result in the oxidation of bromide lead to bromate formation by Richardson e. al., (1981)
- Therefore, it is theoretically possible for chlorination during the treatment of drinking water to result in the formation of bromate as by-product.
- Hence, the purpose of this study to find a solution to overcome the formation of bromate as byproduct from bromide concentration in potable water network in Kuwait.

Chemical Reaction Lead to Formation of Bromate

❖ Chlorine Gas

- In Kuwait, Ministry of electricity & water is producing Fresh water by blending distilled water with brackish water in order to cover the consumption demand of potable water.
- Here, chlorine used as disinfectant in water distribution network at different stations in order to contact the fresh water quality parameter to W.H.O standard.
- Chlorine gas under normal pressure and temperature, can be compressed to a liquid and stored in cylindrical containers (i.e.) as pressure-liquefied gas.
- The following equation presents the hydrolysis reaction:

$$Cl_2\,(g) + H_2O \longrightarrow HOCl + H^+ Cl^-$$

- Here, disinfection plays an important step in eliminate pathogens that exists in water distribution system and ensuring that water is safe to drink.
- Consequently, the quality of potable water in the distribution system through different areas is checked and the water samples are randomly collected for the chemical analysis during 2013.

- From the chemical analysis report we find that chlorine disinfectant process produced disinfection byproducts of Trihalomethanes, Haloacetic acid & bromate formation.
- In fact upon chlorination water, enhanced formation of bromate was described by the following reaction scheme:

$$HOCL + Br^- \rightarrow Cl + HOBr$$
$$HOCL + HOBr^- \rightarrow Cl^- + HOBr$$
$$HOCL + HBrO_2^- \rightarrow Bro_3^- + 2H^+ Cl^-$$

- Although these reaction takes place when reaction rates increase with decrease pH, it has been suggested that the ionic species can also react via,.
- So, the higher risk factor was deemed acceptable based on additional considerations such as the potential risk associated with a decrease in current levels of microbial protection and risks from increases in levels of disinfection by-products from the chlorine disinfectant.
- In order to overcome from these byproducts, now-a-days alternative water disinfection method is considered for the development of disinfection byproducts (DBPs) in potable water.
- To avoid this by products, in current year chlorine dioxide disinfection technique will be applied.

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Disinfection of Fresh Water by Chlorine Di oxide (Az-Zour Project)

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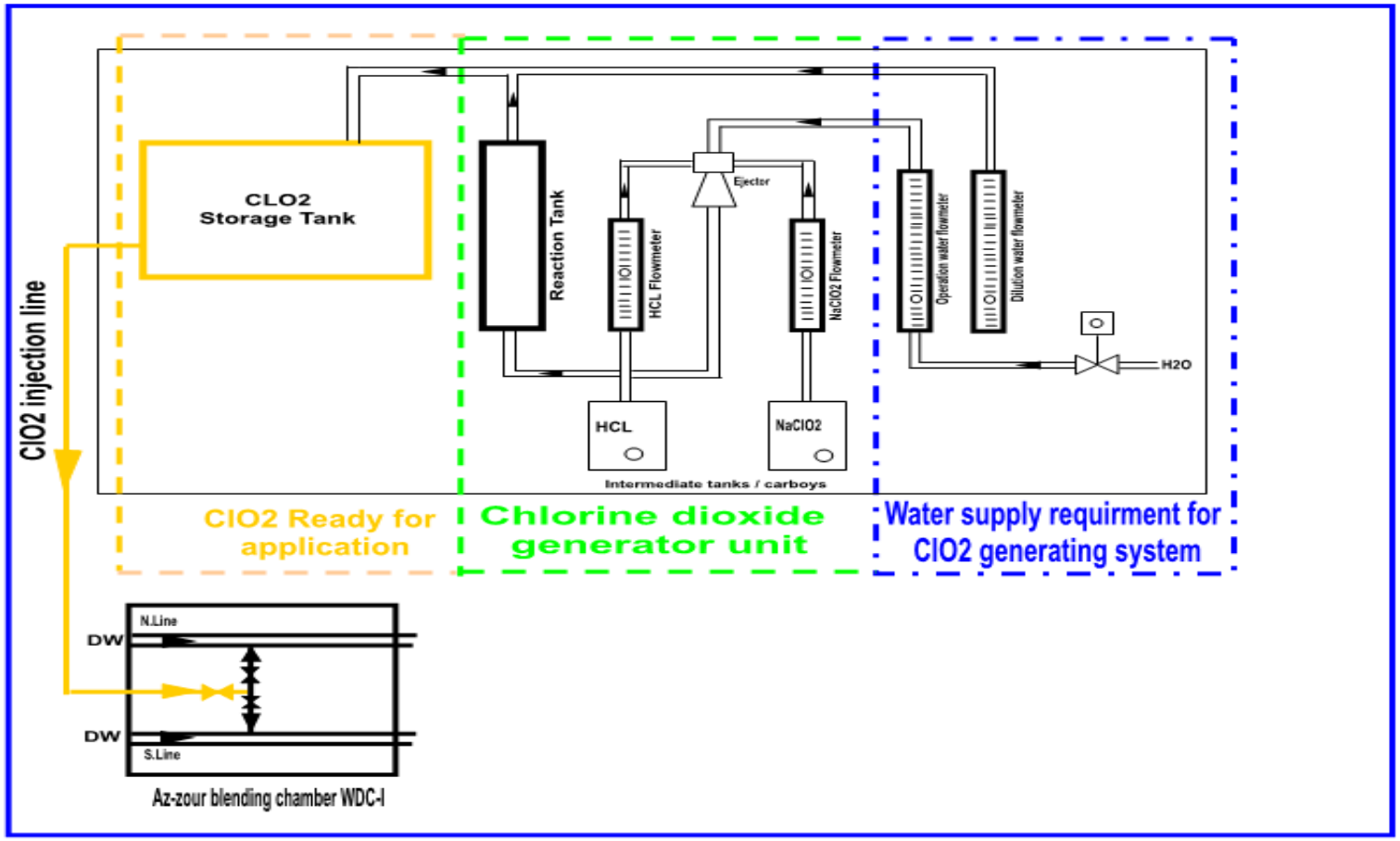
- It's a new method which will be applied in a part of the network this year.
- Chlorine dioxide is used as disinfectant for fresh water treatment.
- Under Vacuum, Chlorine dioxide can generate or applied by two techniques.
- According to the following Chemical reaction:

  (i) $5NaClO_2 + 4HCl \longrightarrow 4ClO_2 + 5NaCl + 2H_2O$ (1st Technique)

  (ii) $2NaClO_2 + Cl_2 \longrightarrow 2ClO_2 + 2NaCl$ (2nd Technique)
- The Above Project will use the 1st Technique
- For, portable water ClO_2 is generate from NaCl (24.5%) & HCl solution (32%) with these two chemical are injected to generator Via., dosing pump.
- The chemical features of ClO_2 gas is soluble in water strong oxidizing agent.
- It's activities not depend on pH, while chlorine pH depended.
- Very low formation of in-organic ions chlorine dioxide improves the quality of drinking water ,it neutralize odor, remove color.
- It is better than Cl_2 for removing iron & manganese.
- Because, chlorine dioxide is a very effective bacterial disinfectant and it is even more effective than chlorine for the disinfection of water that contains viruses.
- Chlorine dioxide removes and prevents bio film. It is much less corrosive than chlorine and does not hydrolyse to form an acid.

Chlorine dioxide process diagram for disinfection of fresh water Az-Zour.



Comparision Table For Chlorine & Chlorine Di oxide

CHLORINE		CHLORINE DIOXIDE	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Chlorination is a well-established technology. • Chlorination has flexible dosing control • Oxidizes soluble iron, manganese & sulfides • Enhances taste and odor • May enhance coagulation and filtration of particulate contaminants • It is an effective biocide • Is the easiest and least expensive • disinfection method, regardless of system size • Is the most widely used disinfection method and therefore, the best known • Provide a residual.	• formation of dissolved organic substances & halogen-substituted byproducts • Finished water could have taste and odor problems, depending on the water quality and dosage • Chlorine gas is a hazardous corrosive gas • It is less effective at high pH • Forms oxygenated byproducts that are biodegradable and which can enhance subsequent • Biological growth if chlorine residual is not maintained.	• Chlorine dioxide is more effective than chlorine and chloramines for inactivation of viruses, Cryptosporidium and Giardia. • The required contact time for ClO_2 is lower • Chlorine dioxide oxidizes iron, manganese and sulfides. • Chlorine dioxide may enhance the clarification process. • Taste and odors resulting from algae and decaying vegetation, as well as phenolic compounds, are controlled by chlorine dioxide. • Under proper generation conditions (i.e., no excess chlorine), halogen-substituted DBPs are not formed. • Chlorine dioxide is easy to generate. • Biocidal properties are not influenced by pH. • Chlorine dioxide provides residuals. • Chlorine dioxide has better solubility	• The chlorine dioxide process forms the specific byproducts chlorite and chlorate. • Disinfection efficiency is reduced significantly at low temperatures • Costs associated with training, sampling, and laboratory testing for chlorite and chlorate are high. • Equipment is typically rented, and the cost of the sodium chlorite is high. • Measuring chlorine dioxide gas is explosive, so it must be generated on-site. • Chlorine dioxide decomposes in sunlight. • Can be explosive at high temperatures and pressures • Can lead to production noxious odors in some systems.

Safety Precaution for Chlroine Di Oxide Generating System

- Avoid storage & handling of combustible or reactive material such as acid or organic material in sodium chlorite area.
- Raw chemicals storage tanks should be with vent to atmosphere.
- Chlorine dioxide solution concentration in storage tanks should not exceed more than 4% for temperature 40°C.
- Leakage for raw chemicals ($NaClO_2$ & HCl) is not possible in under vacuum system.
- If leakage in pipe-works, ClO_2 generating system will be shut off automatically (by interlock) for safety reason.
- If Chlorine dioxide solution leaks in ClO_2 storage tank, ClO_2 generating system will be shut off automatically .
- If motive water fails for any reeasons, ClO_2 generating system will be shut off automatically .

❖ <u>Safety Steps for Personnel's</u>

- In case of ClO_2 solution leaks, ClO_2 leak detector will function and gives alarm/ indication & buzzer to take care before entering the plant. Ventilation take action on leak alarm.
- Wear gas mask, breathing apparatus.
- Safety googles & face protector like chlorine.

Analysis of Bromide & Bromate in Drinking Water Using IC with Suppressed Conductivity Detection

- The target anion (i.e. bromate) was determined in drinking water samples during the year 2013. So, we have collected the samples from RO line fresh water network around shuwaikh area in Kuwait as suggested.
- For analysis the drinking water samples were collected in Amber brown bottle containers directly from the faucet (after thorough rinsing).
- After collecting samples were kept immediately in an ice cooler until they reached the lab where they were transferred to the refrigerator. All water samples were stored at 4°C until analysis.

Bromide & Bromate ion Concentration in Shuwaikh RO Line Water

- From the chart, even we have high or low concentrations level of bromide & conductivity shows bromate ion is < 1 µg/L during the year 2013, respectively.
- The analyzed RO Line water was checked before chlorine injection. As a result we get <1 µg/L of bromate concentration in water analysis test.
- From this result we can confirm that before chlorine injection there was no bromate ions in RO Line water.
- The Bar graph shown in Fig (1) & Fig (2) respectively.

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Bar Graph For Maximum & Minimum Bromide Concentration in Shuwaikh RO Line During 2013

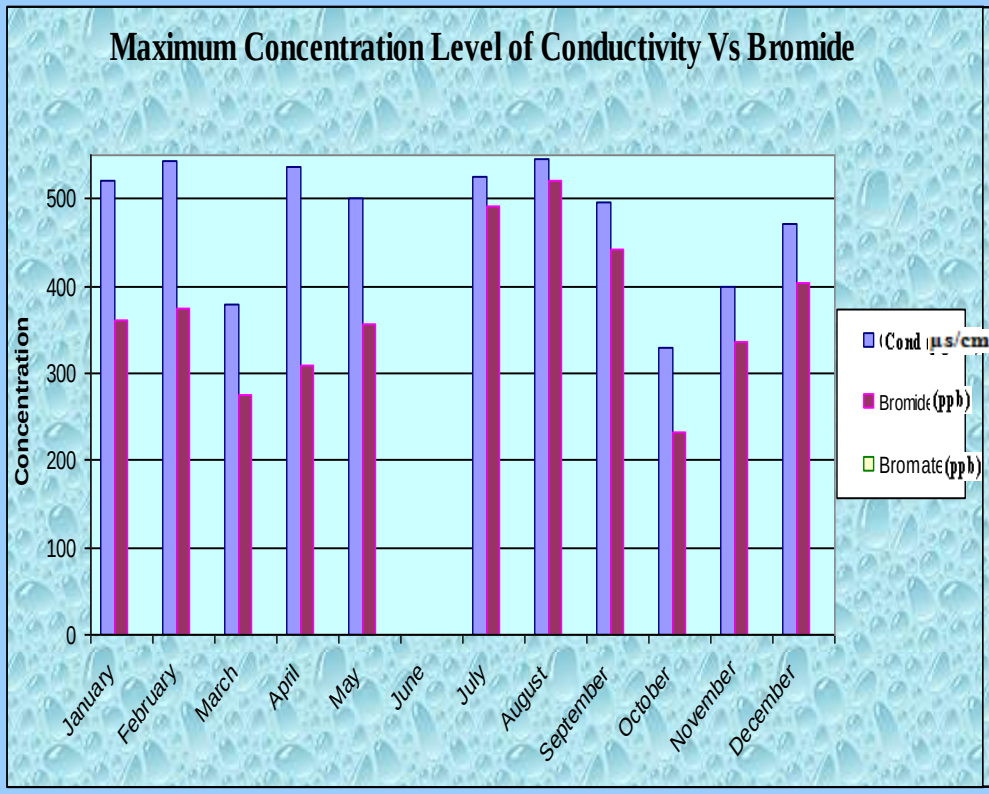

Fig (1)

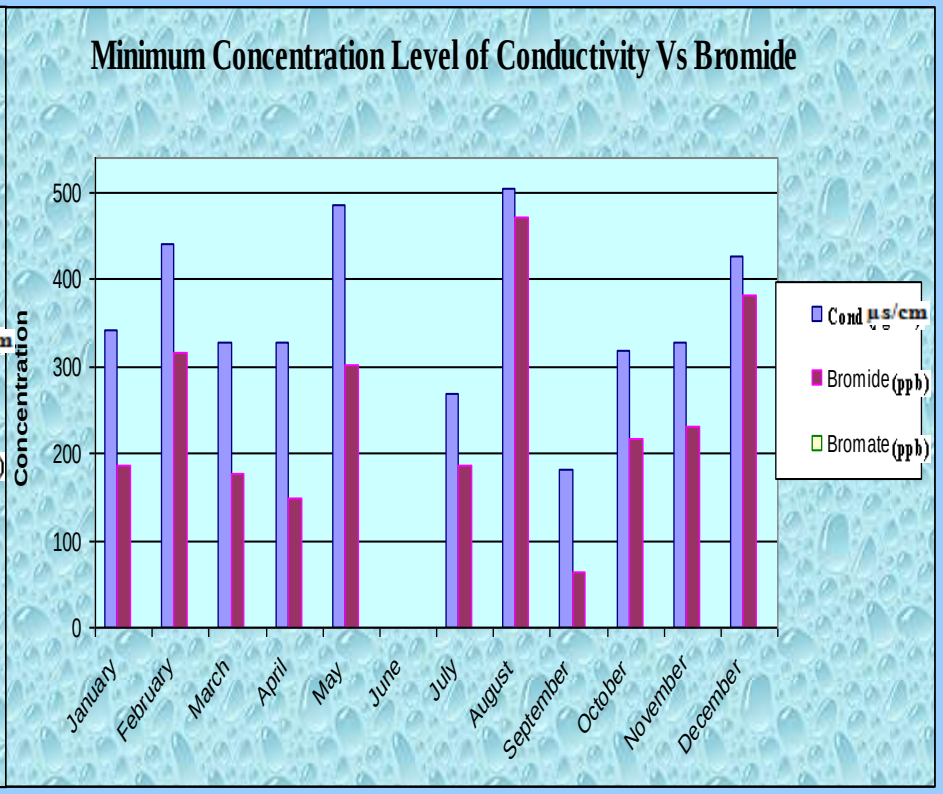

Fig (2)

CONCLUSION

- This study shows that if bromide is present in the water sample and disinfection is applied, there is definite probability of forming bromate in drinking water.
- Also, in coastal areas, there are high levels of bromide present due to seawater and ground water intrusion in drinking water.
- According to the data during 2013, our results show that increasing total dissolved solids (TDS) will increase bromide concentration to form bromate.
- These are the following factors which will affect bromate formation such as bromide ion concentration, pH of the source water, temperature and the reaction time in the distribution network.
- As per water analysis results, there are significant high concentrations of bromide ions in water samples randomly collected, and also showed detectable amount of both bromide and bromate concentration level in drinking water.
- To overcome the formation of bromate as byproduct, we apply the following procedure to minimize the level of bromate concentrations in the water network
- By either reducing the total dissolved solids (TDS) to less than 120 ppm.
- to mineralize the MSF water with lime stone to make it potable water and in the same time to minimize as much as possible using brackish water for blending (blending ratio).
- decreasing the injection of chlorine gas as much as possible without effecting the quality of the drinking water

- Even so after all these steps, the result show detectable amount of bromate concentration in drinking water.
- So, in order to avoid this, now-a-days alternative water disinfection method will be considered for the elimination of disinfection byproducts (DBPs) in potable water.
- By comparing the advantages and disadvantages of chlorine disinfectant, we can conclude that chlorine dioxide gas is easy to generate and maintain water disinfection level in water distribution system.
- Theoretically the use of chlorine dioxide instead of chlorine gas prevents the formation of harmful halogenated disinfection byproducts, for example trihalomethanes and halogenated acetic acids and expected no bromate formation.
- According to the World Health Organization (WHO, 2011) the maximum contaminant level (MCL) of chlorine dioxide (ClO_2) is 0.7 mg/l to make drinking water safe to drink.

THANK YOU