

High pH Chlorination: Is Bromination an Advantage?

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Introduction

Over the past two decades, the water treatment industry has gained extensive knowledge concerning the ecology of biofilms and the problems they cause in cooling water systems. Twenty years ago if one involved in the water treatment industry were to espouse the importance of biofilms in the formation of mineral scales, many would look upon this person with great doubt as to his or her sanity. Today, due to our collective exponential growth in biofilm related knowledge, we no longer feel this way as an industry. We are well informed of how biofilms can influence corrosion, fouling, the formation of mineral scales, and be critical in the amplification of pathogens such as certain species of *Legionellae*.

With the increasing liability concerns surrounding cooling water pathogens, more water treatment companies are incorporating oxidizing microbicides as the mainstay of their cooling water biofilm control programs. These programs are often supplemented with biodispersants and non-oxidizing microbicides for a more comprehensive biofilm control approach. Many companies have moved completely away from using alternating non-oxidizing microbicide programs so popular in the past. This shift in philosophy may be in part because “best practices” documents for *Legionella* control either recommend or suggest the use of oxidizing compounds and the knowledge that oxidizing compounds may be more effective in the destruction of biofilm components such as extracellular polysaccharides and proteins than are non-oxidizing microbicides. (1,2)

Both chlorine and bromine chemistries are and have been used extensively for the control of microorganisms and microbial biofilms in industrial and commercial cooling water systems. Both chlorine and bromine containing compounds come in a variety of forms including gas, liquid, and solid forms all offering different features and advantages with regard to safety, cost, and efficacy. The use of bromine as an oxidizing compound became popular in the 1980's in part due to utility and industrial oxidant discharge limitations and a move towards high pH cooling water. Both the use of bromochlorodimethylhydantoin (BCDMH) and bleach activated sodium bromide were and continue to be popular choices with sodium bromide activated by bleach the most cost effective method of application. More recently, single component liquid stabilized bromine products such as Stabrex[®] and Stabrom[®] have become popular especially in smaller systems where convenience can outweigh the high cost of use.

The purpose of this discussion is not to review the various characteristics of or provide an extensive comparative efficacy study of these oxidant forms, but to help provide insight into the question of whether bromination offers a significant advantage over chlorination and if chlorination can still be an effective method for microbial control in cooling water systems at high pH. This paper will attempt to answer the questions posed by including discussions on observation and experience, field test data on five operating cooling water systems, and laboratory data.

Background

Much of the knowledge water treatment professionals have about the performance of a water treatment program approach is gained through actual field application, experience and results. When the performance of chlorine at the elevated pH typically found in most cooling water systems is discussed in some circles it is often regarded as ineffective. This industry wide dogma is primarily based on the dissociation chemistry (Fig. 1) and short term disinfection studies. It is often not based on real application experience or at least real experience when the programs are properly applied. The dissociation chemistry of chlorine and bromine indicates at elevated pH a greater percentage of bromine is in the more lethal hypohalous acid form and short term disinfection studies often support this(3) However some studies also contradict this. McCoy and Wireman compared the effectiveness of both NaOCl and BCDMH against *Legionella pneumophila* and found them both to be effective in short term studies even at pH 8.5.(4) In a study by Liermann et al, it is shown the pH within a biofilm may be significantly lower than in the bulk water.(5) If this were the case more OCl⁻ would shift to the more lethal HOCl form compared to the bulk water surroundings and result in a greater degree of efficacy. A search of the literature not only finds evidence showing bromine to be a more effective microbicide than chlorine at elevated pH, but also to support chlorine can be effective. It is important to mention that good overall microbial control relies not only on killing the bacteria in the bulk water but more importantly reducing the number of organisms contained in the biofilm and then removing the biofilm from the surface. Both chlorine and bromine based microbicides should be effective in providing both functions. Characklis demonstrated the effect of biofilm removal by hypochlorite at elevated pH.(6) Multiple references in the literature point to increased resistance of biofilm organisms to low level chlorination. Other studies indicate combined chlorine such as monochloramine may be more effective in reducing biofilm bacteria populations than free chlorine.(7,8) LeChevallier et al, reported chloramines did not react with extracellular polysaccharides which may account for the improved efficacy of chloramines against biofilm organisms.(9) There is much to be found in the literature and one is encouraged to perform their own search in the quest for knowledge but to be cautious about formulating a firm stance based on one study

Experience

In working with numerous cooling water systems utilizing only sodium hypochlorite and operating in a pH range of 8.0 to 9.0, it is the author's experience that little or no difference in performance has been observed when compared to the large number of brominated systems also treated. This evaluation is based primarily on cleanliness of the tower fill, overall algae control, the lack of condenser fouling and deposition, and *Legionella* test results. Almost without exception, these halogen programs are supplemented with either a biodispersant or a non-oxidizing microbicide. The majority of these systems utilize an amine acetate type biodispersant. The system pictured (Fig.2) is a 7,500 ton HVAC condenser water system which utilizes sodium hypochlorite and operates at a pH of 8.6 – 8.7. Sodium hypochlorite is applied daily for 7 hours based on ORP control. Typical residuals for this system are 0.2 – 0.7 ppm free chlorine. In addition, a polyquat is applied weekly at a level of 4 ppm active to assist with overall control. The system has been operating this way for several years with no tower fill fouling, no algae problems, and no condenser fouling.

Figures 3 and 4 show chlorine residual data collected over an extended period using an internet based service log which compiles both operator and service representative data in a single database. The systems are HVAC condenser water with 6,000 and 2,600 ton capacities. The system in figure 3 averaged a total residual of 1.35 and a free residual of 0.59 over the three month period recorded. This is slightly higher than desired but shows a trend down to a more favorable control range. In figure 4, the system operated with an average total chlorine residual

of 0.63 and a free residual of 0.31 over the 8 month period recorded. This is within target residuals desired for the system. This system shows a trend upward likely due to the winter months requiring a lower residual for algae control. Both systems, in addition to sodium hypochlorite, apply a weekly addition of a biodispersant for enhancing cleanliness. No non-oxidizing microbicide is used. Both systems have operated for several years on this program and show no indication of problems due to biofilm.

In the majority of the successfully treated chlorinated or brominated systems the author has observed in the field, the halogen is either applied continuously to maintain a low residual or applied 4 – 7 days per week for several hours at a somewhat higher residual. The low continuous residuals are typically 0.2 – 0.5 ppm free chlorine and 0.5 – 1.5 ppm total chlorine with the higher residual intermittent programs using 0.5 – 1.0 ppm free chlorine and 1.0 – 2.0 ppm total chlorine. The author has also observed numerous unsuccessful halogen programs where the frequency of addition and the residuals achieved were not enough to control biofilm.

Legionella Testing

A large number of cooling water systems using either sodium hypochlorite or hypochlorite/sodium bromide are tested frequently for *Legionella*. The data shown in figure 5 show both approaches to be effective. Systems 2 – 10 indicate a high number of positive results from 9/02 – 12/02. During this period, these systems were using BCDMH fed 3 times weekly from a brominator. The systems were transitioned to bleach and a biodispersant and improvements in both overall fouling and pathogen control were made. Subsequent testing on these systems yielded less number of positive results for *Legionella*. Most of the systems in figure 5 have ORP based control for halogen. Systems 2, 9, and 10 do not currently have ORP control and the result is a program with less effective control of halogen residuals.

Field Data Comparison

Five systems currently operating on a bleach/bromine program were selected for a short term field test to compare the effects of changing from the bromination program to a chlorination program. The short term test would look for any changes in operating efficiency, tower fill fouling, bacterial populations, ATP levels, and visual algae growth.

System A operates with an average load of 10,000 tons HVAC. The feed of halogen is controlled by an internet accessible cooling water controller with ORP control capabilities. The system is set to continuously control halogen to a set point of 420 mv. The system is also programmed to spike the ORP two times weekly to an ORP of 550 mv. The system feeds a supplementary microbicide once a week with this function disabled for the duration of the test. System B has a total capacity of 1500 tons HVAC and is equipped with the same feed and control equipment as System A. System B is set up to control similarly to system A. Systems C, D, and E are smaller systems of approximately 500 tons each with identical control equipment to systems A and B and similar control settings. Systems B – E also feed a supplementary biodispersant which was disabled for the duration of the study.

The systems were monitored for a period of 46 days (7/12/04 – 8/27/04). During this period all supplemental microbicides and biodispersants were discontinued. The control systems were programmed to provide a weekly data log automatically sent to the author's computer to monitor the control parameters. An oversight in programming was made to the controller on system B and while a data log was sent it contained no information. All of the systems operate without pH control in a range of 8.7 – 8.9 typically. The systems were operated on the bromination program from 7/12 – 8/2/2004 and again during the last week of testing 8/20 - 8/27/2004. Sodium hypochlorite only was used during the period of 8/2-8/20/2004. The systems were

inspected three times each week during the period for any evidence of increased fouling, algae growth or any reported condenser operating problems. Tests for free and total halogen were conducted on site during each visit. During the first bromination period a glycine/free chlorine procedure was used to differentiate free chlorine from free bromine. All residual bromine will test as free halogen so the glycine was used to react with any remaining free chlorine. Any remaining free halogen would then be bromine. Bacterial counts and ATP measurements were performed on samples taken back to the laboratory within a few hours of each visit. Bacterial counts were conducted by making serial dilutions using 9 mL dilution blanks containing Butterfield's buffer and plated using 3M Petrifilm™. This technique provides a more accurate count than using dipslides. Tests for SRB were also conducted three times weekly using Sanicheck™ SRB media. ATP tests were conducted using an AMSALite™ ATP luminometer.

Field Data Results

The systems selected for testing were ideal due to the close proximity to the author's office and laboratory. The systems are also equipped with state of the art internet accessible control equipment capable of feeding halogen based on ORP. There were, however some upsets which interfered with the smooth collection of data. System A experienced a poorly operating hypochlorite pump during the first 2 weeks of the test and was replaced. System A also ran out of hypochlorite on three occasions of less than 24 hours during the test period. System D experienced some initial problems with halogen feed due to a poorly operating pump and System E had a problem with ORP calibration due to a faulty probe. Figure 6 shows the daily average ORP for systems A and C. The averages are derived from readings taken every ten minutes by the controller and emailed in the weekly log in a .csv file. The loss of chlorine feed due to pump problems and supply are evident for system A. The graph for system C indicates the chlorine pump volume is set too high and overshoots the ORP set point. In both cases it does indicate the ORP function of the controller to be capable of maintaining oxidant residuals in a somewhat consistent manner. Figure 7 shows the ORP profile for system A through a 24 hour period on a "spike" day. In figure 7, the wave pattern of the ORP controller can also be seen. It was observed during the study that halogen residuals were the highest as the crest of the wave was approached and with the chlorine pump on. As the ORP approached the trough of the wave the chlorine residuals were much lower as would be expected. While not documented for this study it was of interest to note in some cases the chlorine residual approached zero at the trough of the wave before the dead band was reached and the pump activated. It appears the bigger the overshoot of ORP due to pump settings versus system size, the lower the residual halogen at the trough. Although this was not part of this study one could conclude the best method for controlling the variation in residual and ORP is to maintain a tight deadband (< 5 - 10mv) and to not adjust the chlorine pump to not overshoot the set point.

The visual and tactile results indicate there were no obvious differences in algae growth, film fill fouling, or other evidence of increased microbiological growth in all of the systems tested. These results would be consistent with other similar systems operating on chlorine. The average results of thrice weekly halogen tests and ORP readings at the time of the test are summarized figure 8. The chlorine residuals in systems B and E appear much higher than the residuals reported during the first bromination period. This is due to an ORP adjustment in the "spike" day for system B midway through the first bromine period and a problem with the ORP probe in system E.

Figure 9 summarizes the average ATP, average colony counts, and SRB results for the systems tested. The data show no significant differences in planktonic populations between the time periods when the systems were brominating versus chlorinating.

Laboratory Data

It is well understood the number of planktonic bacteria in a system are not the cause of the problems in cooling water systems and that biofilm organisms are. It is also known the number of planktonic organisms may not reflect the amount of biofilm organisms. With these concepts in mind, it makes more sense to study the effects of microbicides on biofilm organisms rather than the planktonic ones. It is not within the scope of this paper to study the effects of chlorination and bromination on biofilm organisms, but to compare the microbicidal effect of chlorine and bromine in general on bacterial populations at high pH. To demonstrate this, a small scale study on planktonic organisms was conducted.

A sample of cooling water was obtained from the sump of an operating cooling water system known to have a poorly administered microbiological control program. The sample contained some sediment from the sump as well. The sample was delivered to the laboratory and aerated on arrival. To help promote growth and viability, 2 grams of sucrose were added to the 19 liter sample. The water sample was allowed to aerate for 20 hours prior to testing. The pH was adjusted to 8.8 for the test.

The sample was divided into 7, 1,000 mL aliquots. One was used as a control and the remaining for the test. A 1% solution of 10% hypochlorite and a 1% solution of 10% hypochlorite plus 0.3% sodium bromide (powder) were used as the biocide stock solutions. A stoichiometric excess of sodium bromide was used to ensure all of the halogen was in the hypobromite form. Both solutions were tested using a Lamotte 7105 hypochlorite test kit and were found to contain equal levels of halogen as % hypochlorite (approximately 0.07%). The halogen stock solutions were added to the aliquots at 1mL per 1000 mL for the low level or approximately 0.7 ppm as Cl_2 , 2mL for the medium level and 3mL for the high level and then thoroughly mixed.

Figure 10 shows the resulting halogen levels for the chlorinated and brominated samples over time. The levels are reported as ppm Cl_2 . Additional halogen equivalent to the original amount was added at 60 and 240 minutes to ensure a continual residual over the test period. From the data it can be seen the residual halogen levels for bromine are significantly lower than for chlorine even though an equivalent amount was added. To ensure this was not an error, equal amounts of chlorine and bromine stock solutions were added to distilled water and tested for total residual and were found to be equal. Therefore it is likely the lower bromine levels are an indication of the greater reactivity of bromine. Since the combined bromine forms are more reactive than combined chlorine forms this would be logical. Figures 11, 12, and 13 summarize the bacterial colony counts over time and the % kill for all levels tested. The % kill is calculated from the colony count at $T=0$. The control bacterial population was also measured at 240 minutes and 1200 minutes to ensure reduction in numbers were strictly from the halogen and not from nutrient limitation. The control colony counts continued to increase significantly over the 1200 minute test period indicating the bacteria present were active and viable. The results show significant reduction in bacterial colony counts at all levels tested with the greatest efficacy shown at the highest levels for both chlorine and bromine. In no case was complete sterilization realized. The tests also indicate given equal amounts of halogen fed, there is no significant difference in microbicidal activity. However, since the chlorine residuals were more stable and persistent, one should also compare similar residuals in which case the brominated high level results can be compared to the chlorine medium level results. In this case the brominated sample results are more favorable as would be expected based on the dissociation chemistry. Figures 14 and 15 show the log and non log graphs of the data in figures 11, 12, and 13. The non log graph provides a more dramatic representation of the bacterial population reduction than the log graphs.

Discussion and Conclusions

If one were to review marketing literature or technical papers presented by sellers of bromine one would assume bromine to be far superior to chlorine in alkaline cooling water environments. One can also find papers that indicate chlorine and bromine are ineffective in controlling biofilm and biofilm organisms. By digging deeper into the literature one can find a great deal of evidence to support these positions as well as to contradict them. In reviewing the literature it can be concluded that chlorine, and likely bromine, are both capable of oxidizing the extracellular polysaccharides that comprise a major part of surface biofilms. This is independent of pH. It can also be found that chloramines are more effective than free chlorine for killing biofilm organisms, likely since free halogen will be consumed oxidizing the extracellular material. This poses an interesting question: Since combined bromine is inherently unstable and behaves more like free bromine would the more stable chloramines actually make chlorine more effective than bromine at killing biofilm organisms as well as providing longer term inhibition in intermittently applied programs? While this is an intriguing question, most of us applying bromine to cooling water systems do so in a manner that results in the existence of both chlorine and bromine in the system simultaneously by applying a higher stoichiometric ratio of chlorine to bromine. When testing for free and combined forms of chlorine in a cooling water system we generally find both forms present while chlorine is being fed. Once the feed of chlorine is discontinued most often only combined chlorine remains. We may assume from this while there is free chlorine in the system, reaction and removal of extracellular biofilm components is likely taking place but once oxidant feed is discontinued, combined chlorine may continue to slowly kill both planktonic and biofilm organisms. If brominating at a molar ratio resulting in only bromine being present (1:1) on a non-continuous basis we might expect to see the halogen level diminish rapidly and provide no lingering beneficial effects. It may be a possibility the typical chlorine to bromine molar ratios used in cooling water systems are actually more effective and certainly less costly than generating only bromine. The literature also suggests that within biofilms pH gradients do exist, with the pH in the biofilm being typically lower than a higher pH environment in the bulk water. If this is the case, more of the chlorine or bromine would shift to the hypohalous acid form and efficacy would be increased at the biofilm level. When possible, it is the author's preference to feed supplemental bromine as a portion of the total halogen residual in high pH systems.

In theory, bromine should and likely does have an edge over chlorine as a microbicide at high pH in a laboratory setting; however, the laboratory and field data presented in this paper do not indicate any significant differences in results for either halogen form. The laboratory kill study results do point to a slight advantage in the planktonic results based on the residual carried, but do not show an advantage based on an equal use amount basis. It has been the author's observation and experience over many years that it is difficult to distinguish any clear differences in the field for either program. It is likely success for either chlorination or bromination programs comes from exposing the biofilm and biofilm organisms to enough halogen for a long enough period of time. This approach will ensure not only removal of extracellular material and the death of organisms, but also to prevent their recovery. Performance in the field with either approach is greatly improved by having properly functioning feed and control equipment capable of maintaining the necessary residuals. It should also be stated successful halogen (both chlorine and bromine) programs administered by the author most often are accompanied by the use of a biodispersant and less frequently a non-oxidizing microbicide. The unsuccessful halogen programs observed; both chlorine and bromine are typically poorly controlled or applied to infrequently to be effective.

The information presented in this paper neither proves or disproves the question posed in the title. It should however provide those considering the option of chlorinating some assurance that

they can successfully control biofilm related problems if they properly apply and manage a chlorination program.

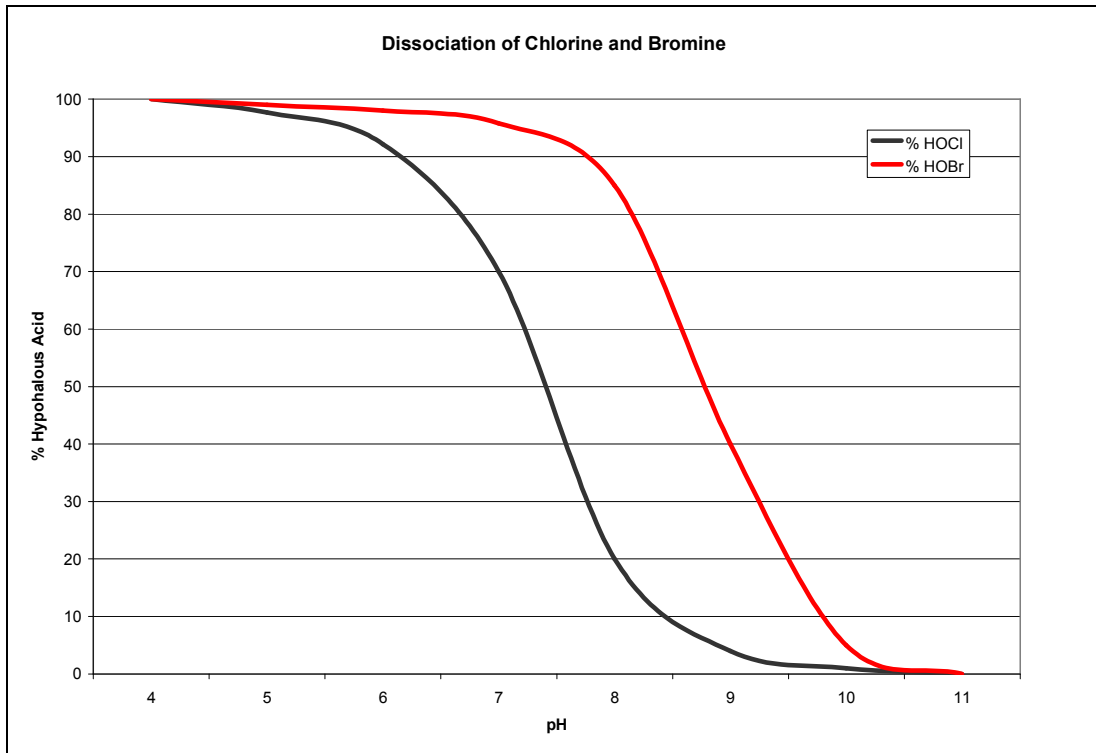


Fig. 1: Percent hypochlorous acid versus pH.



Fig 2: Clean cooling water systems operating at high pH using chlorine.

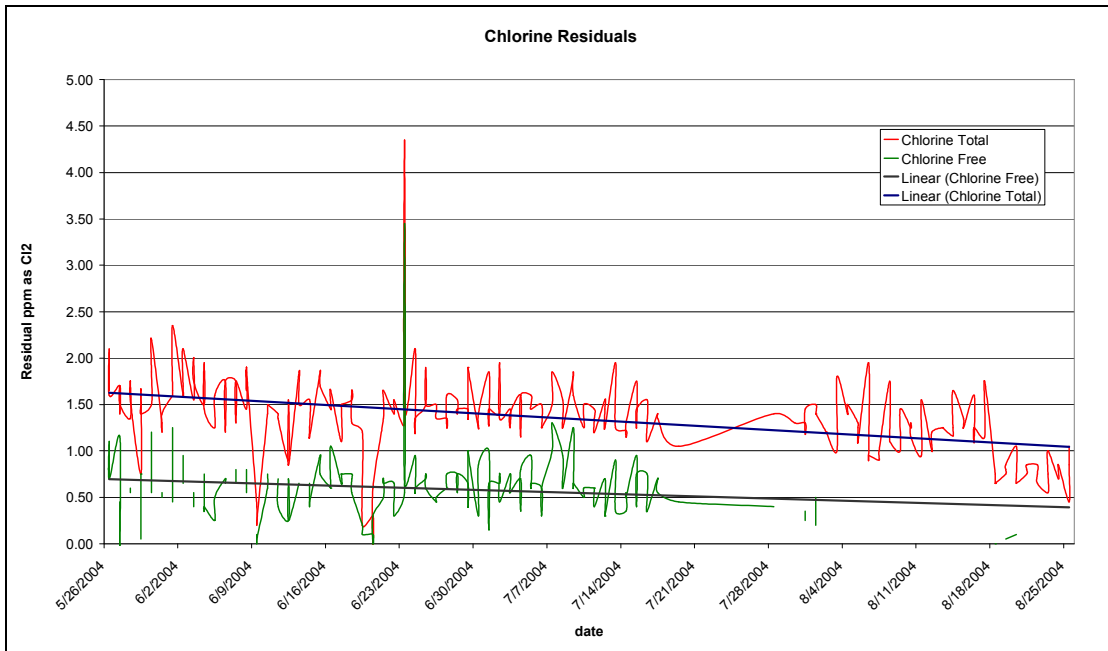


Fig. 3: System free and total chlorine levels over a 3 month period.

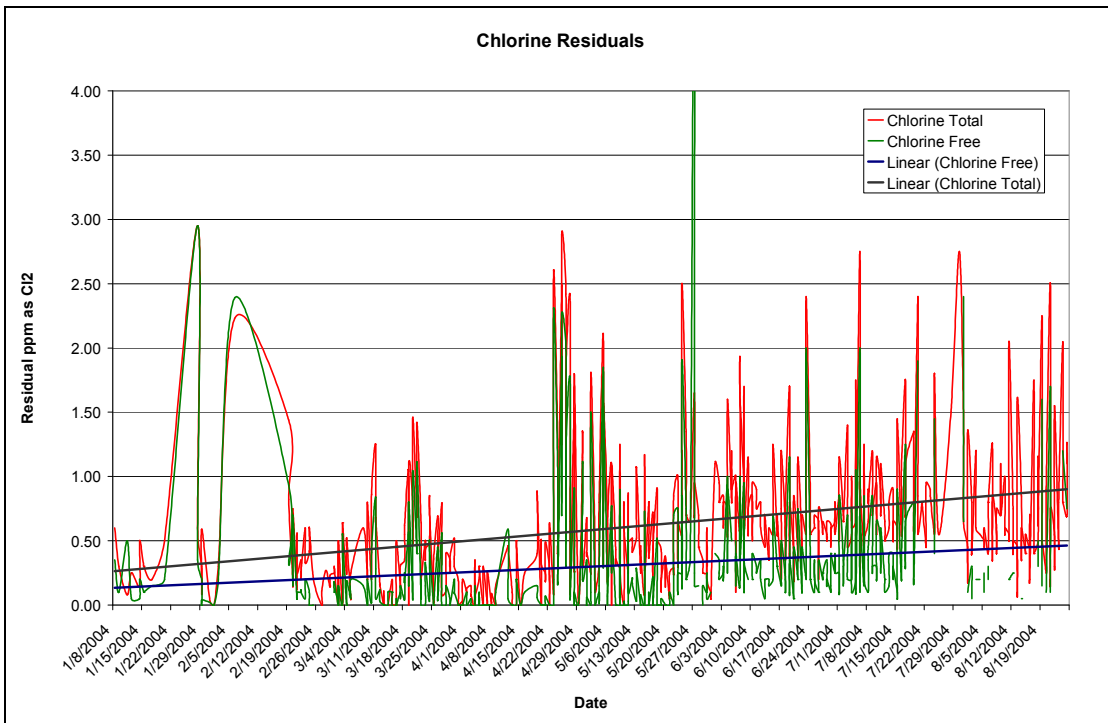


Fig. 4: System free and total chlorine levels over 8 month period.

Systems																	
Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
9/02	-	+	+	-	+	-	+	-	+	+	+	-					
9/02		+	+		-		-		+	-	-						
10/02		+	-						+								
10/02		-							-								
12/02	-	-	-	-	-	-	-	+	-	-	-	+					
4/03	-	+	-	-	-	-	-	-	-	-	-	-					
6/03	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
7/03														-			
10/03	-	+	-	-	-	-	-	-	-	-	-	-					
12/03	-	-	-	-	-	-	-	+	-	+	-	+					
3/04	-	-	-	-	-	-	-	-	-	-	-	-					
7/04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Fig. 5: *Legionella* results for 17 systems. Systems highlighted in yellow using bleach/bromide(11,13 – 17). Systems 2 – 10 in blue initially on BCDMH 3 times weekly transitioned to bleach only prior to 12/02.

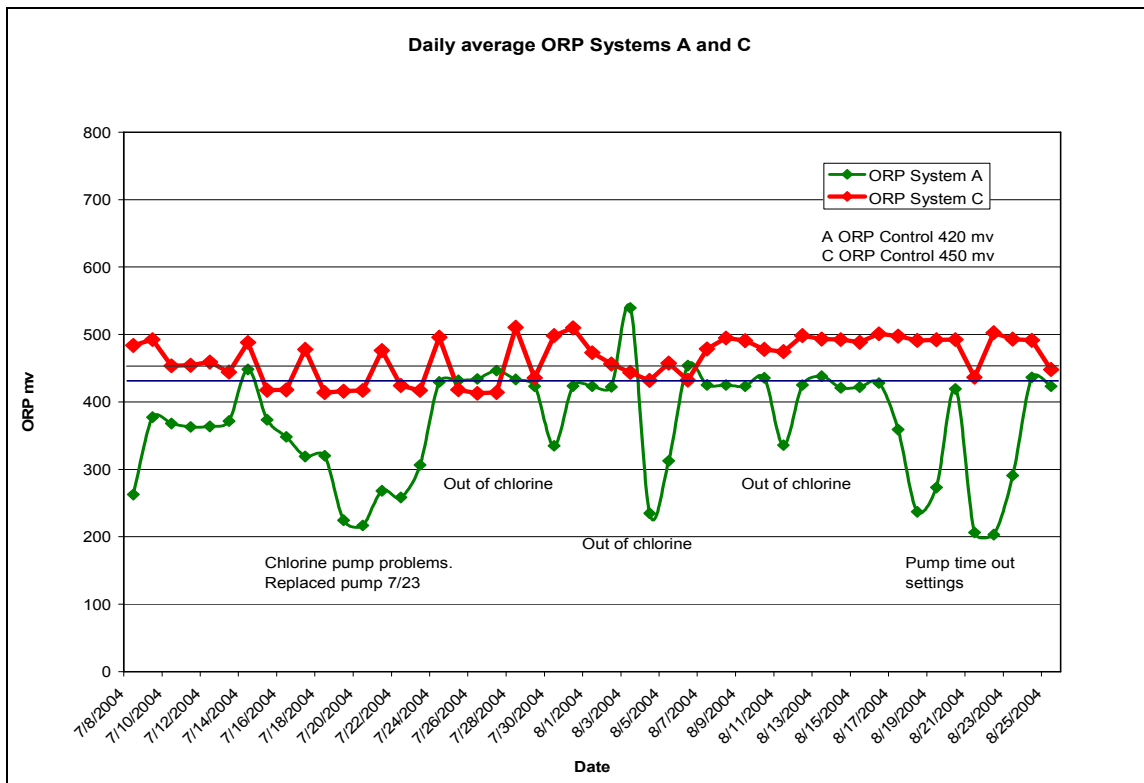


Fig. 6: System A and C daily average ORP readings.

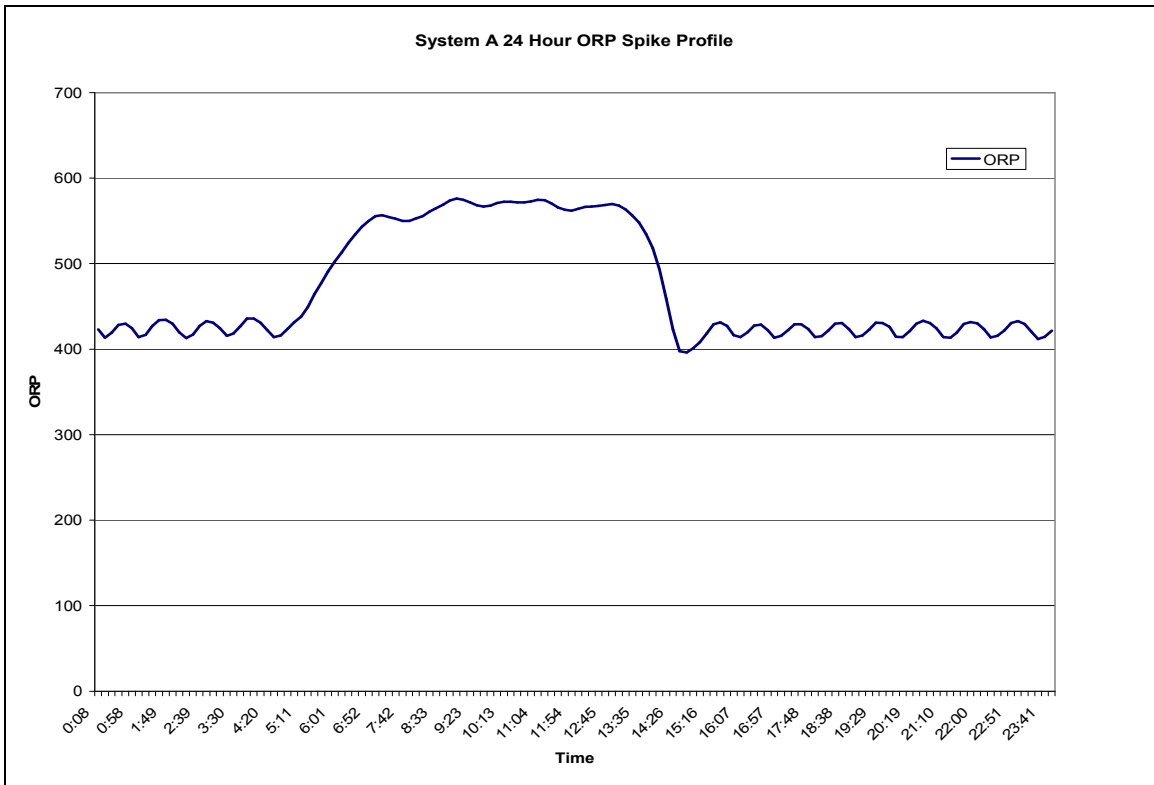


Fig. 7: System A 24 hour ORP profile on a spike day.

System	Halogen	Dates	ORP	TRO	FRO	FRO (glycine)
A	Bromine	7/12 – 8/2	335	0.39	0.09	0.02
A	Chlorine	8/4 – 8/20	394	0.55	0.19	
A	Bromine	8/23 – 8/27	390	0.33	0.15	
B	Bromine	7/12 – 8/2	414	0.45	0.18	0.14
B	Chlorine	8/4 – 8/20	505	1.31	0.68	
B	Bromine	8/23 – 8/27	502	1.13	0.68	
C	Bromine	7/12 – 8/2	472	0.46	0.18	0.15
C	Chlorine	8/4 – 8/20	505	0.66	0.33	
C	Bromine	8/23 – 8/27	498	1.33	0.73	
D	Bromine	7/12 – 8/2	483	0.74	0.40	0.29
D	Chlorine	8/4 – 8/20	494	1.33	0.96	
D	Bromine	8/23 – 8/27	489	1.37	0.97	
E	Bromine	7/12 – 8/2	449	0.65	0.39	0.36
E	Chlorine	8/4 – 8/20	619	1.09	0.68	
E	Bromine	8/23 – 8/27	605	0.87	0.43	

Fig 8: Average ORP and halogen levels for systems A – E. Halogen levels are as ppm Cl₂.

System	Halogen	Dates	ATP	CFU/mL	2 day SRB	7 day SRB
A	Bromine	7/12 – 8/2	778	1.78E+03	1	1
A	Chlorine	8/4 – 8/20	938	2.34E+03	0	2
A	Bromine	8/23 – 8/27	1609	2.49E+04	0	NA
B	Bromine	7/12 – 8/2	684	6.81E+03	0	2
B	Chlorine	8/4 – 8/20	887	1.05E+03	0	0
B	Bromine	8/23 – 8/27	959	3.09E+03	0	0
C	Bromine	7/12 – 8/2	654	7.63E+03	1	1
C	Chlorine	8/4 – 8/20	632	6.56E+03	0	0
C	Bromine	8/23 – 8/27	923	1.96E+02	0	NA
D	Bromine	7/12 – 8/2	790	3.46E+03	0	0
D	Chlorine	8/4 – 8/20	807	3.88E+03	0	0
D	Bromine	8/23 – 8/27	798	2.62E+03	0	0
E	Bromine	7/12 – 8/2	434	4.72E+03	1	1
E	Chlorine	8/4 – 8/20	493	3.10E+03	0	1
E	Bromine	8/23 – 8/27	643	5.10E+03	0	NA

Fig.9: Average ATP and colony counts for the testing periods. Number of positive 2 day and 7 day SRB tests.

Time	Low				Medium				High			
	FCI ₂	TCI ₂	FBr ₂ *	TBr ₂	FCI ₂	TCI ₂	FBr ₂	TBr ₂	FCI ₂	TCI ₂	FBr ₂	TBr ₂
T=15	0.09	0.38	0.09	0.13	0.32	0.78	0.16	0.28	1.17	1.9	0.51	0.72
T=30	0.08	0.33	0.08	0.12	0.15	0.66	0.15	0.21	0.82	1.58	0.32	0.54
T=45	0.11	0.29	0.08	0.11	0.15	0.53	0.09	0.16	0.52	1.33	0.19	0.41
T=60*	0.07	0.28	0.06	0.09	0.06	0.46	0.07	0.14	0.23	1	0.09	0.34
T=120	0.14	0.27	0.14	0.25	0.52	1.07	0.22	0.46	1.83	2.5	0.55	1.15
T=240*	0.15	0.3	0.05	0.13	0.15	0.45	0.09	0.12	0.41	1.3	0.15	0.3
T=1200	0	0.15	0.05	0.1	0.11	0.35	0.04	0.09	0.07	0.5	0.09	0.12

Fig 10: Laboratory test chlorine and bromine residuals over time. All results reported as Cl₂. *Additional halogen dose added at 60 and 240 minutes.

Low Level Halogen					
Time	Control	Cl ₂	% Kill*	Br ₂	% Kill
T=0	4.80E+05				
T=15		1.56E+05	67.5	2.60E+04	94.6
T=60*		3.90E+04	92	2.50E+04	94.8
T=120		2.90E+4	94	2.00E+05	58.4
T=240*	5.90E+05	3.60E+3	> 99	1.30E+04	97.3
T=1200	7.20+E05	1.9E03	> 99	8.00E+03	98.3

Fig 11: Low level halogen laboratory results. % kill calculated from T=0.

Medium Level Halogen					
Time	Control	Cl ₂	% Kill*	Br ₂	% Kill
T=0	4.80E+05				
T=15		4.70E+04	90.2	3.30E+04	93.1
T=60*		1.80E+03	> 99	2.60E+04	94.6
T=120		1.50E+04	96.9	1.10E+03	> 99
T=240*	5.90E+05	2.20E+04	95.4	1.40E+04	97.1
T=1200	7.20+E05	1.10E+02	> 99.9	1.20E+04	97.5

Fig 12: Medium level halogen laboratory results. % kill calculated from T=0.

High Level Halogen					
Time	Control	Cl ₂	% Kill*	Br ₂	% Kill
T=0	4.80E+05				
T=15		1.00E+03	97.9	1.8E+02	> 99.9
T=60*		1.50E+03	96.9	1.4E+02	> 99.9
T=120		1.60E+02	> 99.9	8.00E+02	> 99
T=240*	5.90E+05	6.00E+02	> 99	5.00E+02	> 99
T=1200	7.20+E05	1.10E+02	> 99.9	1.30E+02	> 99.9

Fig 13: High level halogen laboratory results. % kill calculated from T=0.

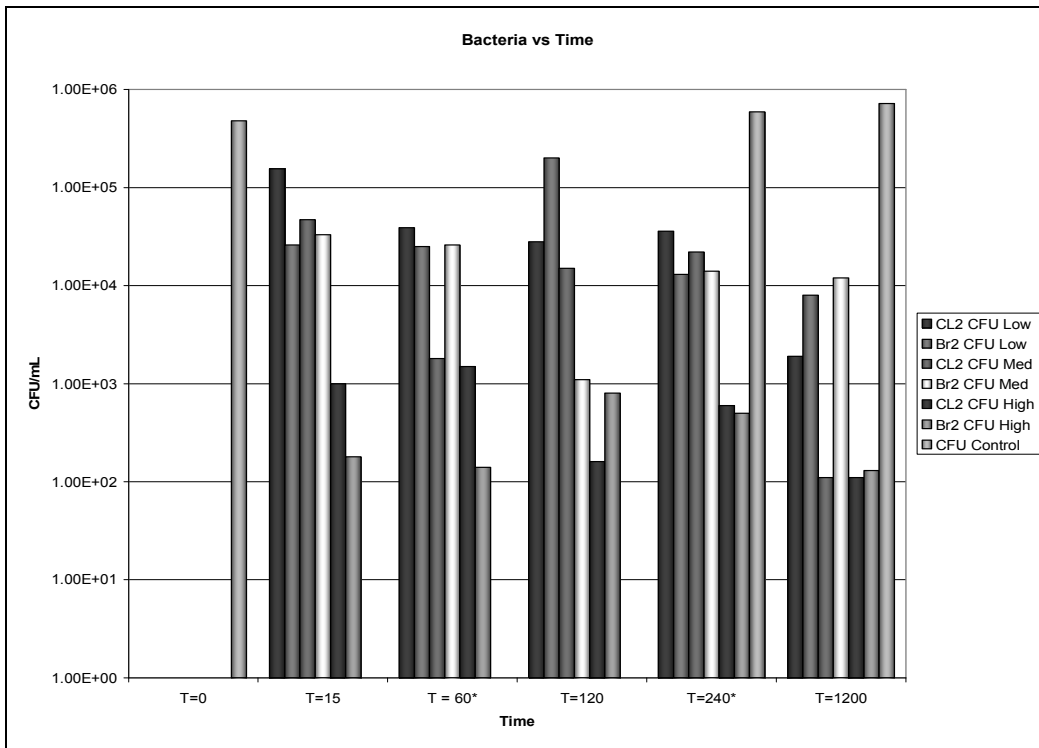


Fig. 14: Log scale graph of bacterial colony counts versus time.

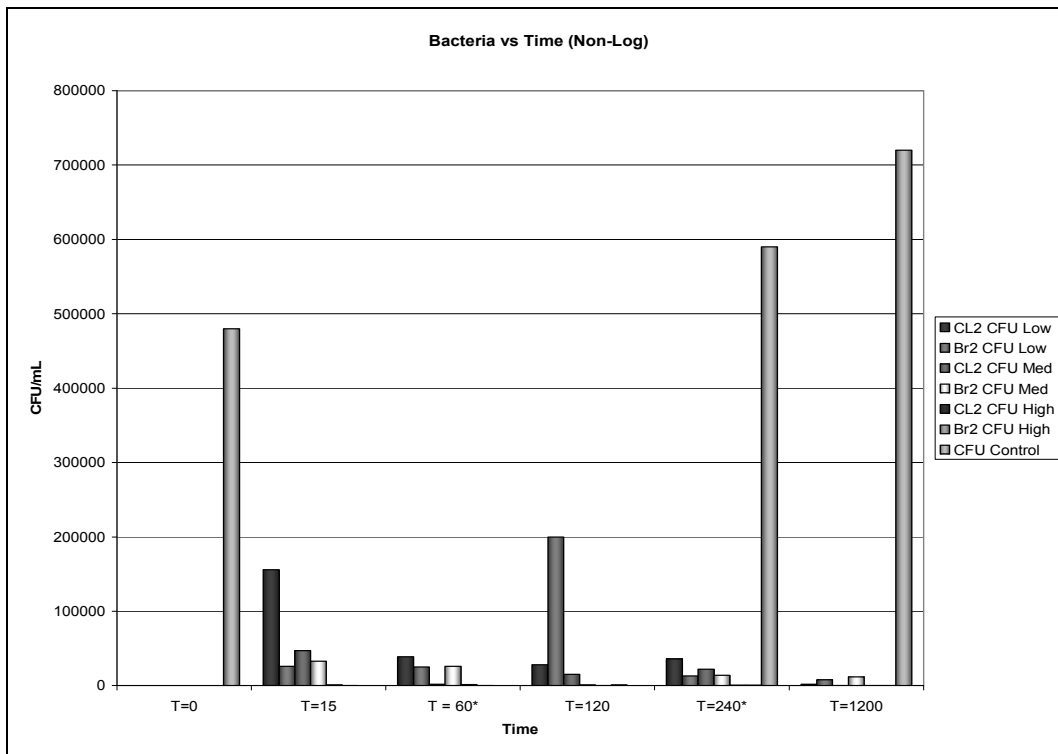


Fig 15: Non log graph of bacterial colony counts versus time.

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