

# Effectiveness of in-Situ Generated Monochloramine for the Control of Legionella in a Real Industrial Cooling Tower

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## Abstract

The aim of the study was to determine the effectiveness of in-situ-formed monochloramine for the control of Legionella growth in a real cooling tower system. The cooling tower utilizes an industrial water (makeup) made of by blending industrial raw water and decarbonated raw water. A generator device injecting in-situ-formed monochloramine into the cooling system was installed. The detection of Legionella, heterotrophic plate count (HPC - 22°C) and continuous monitoring of oxidation reduction potential (ORP) were carried out to check the efficacy of monochloramine. Water samples were monthly collected for 6 months from the makeup, two collecting basins and the blow-down. Monochloramine was injected at 4 mg/L for 60 days to achieve a mean residual concentration of 0.145 mg/L in the blow-down. Over time, at the same pumping rates, a greater monochloramine residual was achieved so the dosage was decreased at 2.5 mg/L. *L. pneumophila* (SG 7-14) decreased from an initial load >10.000 cfu/L to undetectable levels and remained stable till the end of the experimental period while HPC decreased slowly (mean count <10.000 cfu/ml) after the first 60 days.

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**Index terms**— legionella sp.; in-situ formed monochloramine; industrial cooling tower.

Abstract-The aim of the study was to determine the effectiveness of in-situ-formed monochloramine for the control of Legionella growth in a real cooling tower system. The cooling tower utilizes an industrial water (makeup) made of by blending industrial raw water and decarbonated raw water. A generator device injecting in-situ-formed monochloramine into the cooling system was installed. The detection of Legionella, heterotrophic plate count (HPC -22°C) and continuous monitoring of oxidation reduction potential (ORP) were carried out to check the efficacy of monochloramine. Water samples were monthly collected for 6 months from the makeup, two collecting basins and the blow-down. Monochloramine was injected at 4 mg/L for 60 days to achieve a mean residual concentration of 0.145 mg/L in the blow-down. Over time, at the same pumping rates, a greater monochloramine residual was achieved so the dosage was decreased at 2.5 mg/L. *L. pneumophila* (SG 7-14) decreased from an initial load >10.000 cfu/L to undetectable levels and remained stable till the end of the experimental period while HPC decreased slowly (mean count <10.000 cfu/ml) after the first 60 days.

From an initial value of 300-400 mV during the first 60 days, the ORP dropped to around 150 mV, which rather explains why monochloramine residuals in the blow-down increased at the end of the experimental time. The results indicate that insitu-formed monochloramine can control Legionella and HPC growth in industrial cooling towers using industrial raw water and decarbonated raw water. Moreover, the ORP can be useful for monitoring the effectiveness of monochloramine.

Keywords: legionella sp.; in-situ formed monochloramine; industrial cooling tower.

## 1 I. Introduction

ooling towers have been consistently attributed to community-acquired legionellosis outbreaks ??Engelhart et al. 2007; ??u 2008) because Legionella emitted by contaminated cooling towers can be transported over several

### 3 FIGURE 1: A DRAWING OF THE COOLING SYSTEM

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43 kilometers within respirable vesicles ??Walser et al. 2013). Typical operating conditions maintained in a cooling  
44 system, such as temperature range, pH as well as continuous airflow, make it ideal for biological growth or  
45 biofouling. In cooling towers biofouling can interfere with normal system operation (for example, heat transfer  
46 resistance) and it can also enhance corrosion and scaling problems, which may be critical risk factors for Legionella  
47 growth together with stagnant water and nutrient availability in the makeup water (Ludensky 2005). Thus, in  
48 order to minimize the production of contaminated aerosols by Legionella it is necessary to minimize microbial  
49 multiplication.

50 Due to its low cost and high effectiveness, chlorine is the most used biocide as antifouling agent in cooling  
51 towers (Nebot et al. 2007;Rubio et al. 2015). However, it is highly reactive with natural organic matter contained  
52 in water -especially when the cooling tower utilizes wastewater as makeup water (Hsieh et al. 2010;Li et al. 2011a)  
53 -leading to the formation of by-products such as trihalomethanes or haloaceto-nitriles which can have adverse  
54 impact on human health and ecosystems (Schwarzenbach et al. 2006;Nieuwenhuijsen et al. 2000).

55 In cooling water bromine is less effective than chlorine against *L. pneumophila*. Nonetheless, with continuous  
56 or semi-continuous low level dosing it can reduce and control Legionella populations as long as the residual  
57 concentrations are maintained in the circulating water (Thomas et al. 1999). Bromine is also used for the  
58 oxidation of biofouling but unfortunately it is toxic for the environment, in which it is released via blow-down  
59 water (Meesters et al. 2003).

60 Among the oxidizing agents, monochloramine seems to be the most materials respectful and to produce the  
61 lowest concentration of by-products in drinking water (Melada et al. 2015). It is also more effective for decreasing  
62 Legionella within the biofilms in drinking water systems (Coniglio et al. 2015) and even at concentrations as  
63 low as 1 ppm it is able to penetrate complex biofilm matrixes like that in cooling towers ??Turetgen 2004;  
64 ??an Schalkwyk et al. 2010). It has been demonstrated that in the presence of organic nitrogen compounds,  
65 like in cooling systems employing secondary-treated municipal wastewater as makeup water, adding pre-formed  
66 monochloramine to reduce biological growth of Legionella species is better than forming monochloramine in-situ  
67 (Chien et al. 2012). Moreover, pre-formed monochloramine was found to be Year 2 015 less aggressive than free  
68 chlorine, while still being an effective biocide (Li et al. 2011b).

69 Thus, as far as we know, at the moment there are few studies on the effectiveness against Legionella of in-  
70 situ-formed monochloramine in cooling systems. For this reason, in the present study the effectiveness of in-situ  
71 formed monochloramine was evaluated for its ability to control biological growth in a cooling system.

## 72 2 II. Materials and Methods

73 A cooling tower system of an Italian industrial plant was considered. The cooling tower system studied has a  
74 flow rate of 270-300 m<sup>3</sup> /h of recirculating cooling water, an average of 6-10 m<sup>3</sup> /h of makeup water and a water  
75 evaporation of about 4 m<sup>3</sup> /h. The water lost by evaporation is reintegrated with an industrial water (makeup  
76 water) made of by blending industrial raw water and decarbonated raw water. A drawing of the cooling system  
77 is depicted in Figure ??.

## 78 3 Figure 1: A drawing of the cooling system

79 Prior to the application of monochloramine, to minimize biofouling, the water of the cooling circuit was success-  
80 fully decontaminated via continuous disinfection with bromine at low levels (assuring a residual concentration of  
81 free chlorine of ~0.1 ppm) added with a scale and corrosion inhibitor. To prevent legionellae growth additional  
82 periodic chlorine shock was made with 5 ppm free chlorine for 5h.

83 In order to verify the effectiveness of in-situ formed monochloramine for the control of Legionella growth  
84 in the cooling tower considered for the study, on July 2014 the injection of bromine was stopped and water  
85 samples were collected every 15 days till the detection of Legionella (> 100 cfu/L). When, on September 2014, *L.*  
86 *pneumophila* SG7-14 was recovered in the cooling tower (makeup water, the two collecting basins and the blow-  
87 down) at high concentrations (>10.000 cfu/L), a patented generator device continuously injecting in-situ-formed  
88 and heterotrophic plate count (HPC) at 22°C was carried out to check the efficacy of the water treatment with  
89 insitu formed monochloramine.

90 The makeup water and water samples taken from the cooling tower collecting basins and the blowdown were  
91 collected weekly from September 2014 to March 2015. At the time of each sampling, the cooling system was  
92 operating. As shown on Table 1, for the makeup water and the blow-down physical and chemical parameters  
93 (DPD Free and Monochlor-F methods, Nitriver and Nitriver, HACH Company, USA) were determined. For  
94 Legionella determinations, 1L water samples were collected, taking care to gently resuspend the fluffy sediment  
95 at the bottom of the collecting basins. Effectiveness of in-Situ Generated Monochloramine for the Control of  
96 Legionella in a Real Industrial Cooling Tower monochloramine into the cooling system was installed. A regular  
97 testing program for the detection of Legionella suggestive for Legionella were confirmed on the basis of cultural  
98 testing and serogrouped by slide agglutination using commercial antisera (Oxoid and Biogenetics). Results were  
99 expressed in cfu/L and the counts referred

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## 100 4 \*oxidation reduction potential

101 The biocide effect of monochloramine towards Legionella and HPC is shown on Figure 2. At the beginning of  
102 the disinfection program, one week after the continuous injection of monochloramine, the load of *L. pneumophila*  
103 SG7-14 decreased at undetectable levels, with the exception of the makeup water, where Legionella was recovered  
104 at a concentration of 200 cfu/L. Effectiveness of in-Situ Generated Monochloramine for the Control of Legionella  
105 in a Real Industrial Cooling Tower to water samples concentrated 100 times (1L in 10 ml of the water sample).  
106 The detection limit of the culture procedure was 10 cfu/L. The HPC at 22°C was detected in accordance with  
107 ISO 6222 (International Standard Organization 1988) to provide information on the disinfection process with  
108 monochloramine. For HPC, 100 ml of water were sampled. Sampling bottles for Legionella and HPC were steam  
109 sterilized and contained sufficient sodium thiosulfate to neutralize chlorine. All samples were stored at 4°C and  
110 analyzed within 12 h.

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## 113 6 III. Results and Discussion

114 After the start of the cooling water in-situ monochloramination, a total of 32 water samples were monthly  
115 collected for 6 months from the same sites of the cooling tower: the makeup, the two collecting basins (named  
116 BASIN 1 and BASIN 2, respectively) and the blow-down.

117 An interesting phenomenon was observed when the response of monochloramine residuals was tracked over  
118 time. As shown on Table 1, at the beginning of the experimental period monochloramine had to be injected  
119 into the cooling water system at an average concentration of 4 mg/L for about 60 days in order to achieve a  
120 mean residual concentration of 0.145 mg/L in the blow-down. Over time, at the same pumping rates, a greater  
121 monochloramine residual could be achieved. For this reason, subsequently the dosage was regulated to obtain a  
122 continuous concentration of 2.5 mg/L monochloramine. We attributed this increase in residual to at least two  
123 main reasons: i. the monochloramine biocide effect towards Legionella, and ii. the monochloramine reaction with  
124 biofilm constituents that probably bromine could not get to.

125 Year 2 015 Further analyses showed that in the makeup water entering the cooling system Legionella was  
126 absent, while the bacterium was isolated by means of swabs in the tap from where the makeup water had been  
127 collected, showing that it was a local contamination instead of makeup water contamination. In fact, two weeks  
128 after the sanitization of the tap and the monochloramination of the entire cooling system, the load of Legionella  
129 decreased at undetectable levels also in the sampling site of the makeup water and remained stable in all the  
130 sampling sites till the end of the experimental period. On the contrary, during the entire experimental period  
131 the HPC load decreased slowly, with a mean count ranging lower than 10.000 cfu/ml after the first 60 days.

132 The interaction between monochloramine and the biofilm is probably confirmed by the minimal algae growth  
133 on the partially wetted structure of the cooling tower at the end of the experimental time. In fact, to get an idea  
134 of how well algae growth was being controlled, the cooling tower was visually inspected three times during the  
135 experimental time. As shown on Photographs 2 and 3, two months after the start of the disinfection program  
136 (Photograph 2) with monochloramine and at the end of the experimental period (Photograph 3) small amount  
137 of green algae growth was observed on collecting basins, much less than when bromine was used (Photograph 1).  
138 3 shows the response of ORP with time during the entire experimental period. The monochloramine field trial  
139 and the continuous monitoring of ORP started on September 18 th , 2014. On November 13 rd , the probe was  
140 found incorrectly calibrated but it was recalibrated on November 20 th . Anyway, from an initial value of 300-400  
141 mV during the first 60 days, the ORP dropped to around 150 mV, which rather explains why monochloramine  
142 residuals in the blow-down increased at the end of the experimental time. One week after the continuous injection  
143 of monochloramine, the load of *L. pneumophila* SG7-14 decreased at undetectable levels from an initial value  
144 >10.000 cfu/L and remained stable in all the sampling sites till the end of the experimental period. This data  
145 probably show that in-situ formed monochloramine can adequately control Legionella growth in industrial cooling  
146 towers using blended industrial raw water as makeup water. Nonetheless, the high load of HPC observed during  
147 the first 60 days, when residual concentrations of monochloramine were low and in turn ORP was high, probably  
148 suggests that at the beginning of the disinfection program some bacteria may require higher concentrations of  
149 the disinfectant to be completely killed. Anyway, our data suggest that ORP values and HPC measurements can  
150 play an important role in verification of treatment cooling tower procedures with monochloramine.

151 Finally, our data show that monochloramine was effective also at controlling algae growth. In fact, comparison  
152 of visual inspections of the collecting basins (Photographs 1-3) showed a decrease in green algae growth at  
153 the end of the experimental period. This could also explain why as time passed the residual monochloramine  
154 concentration that could be achieved in the blow-down increased.



Figure 1: C

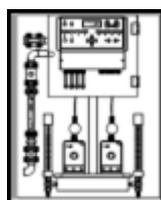


Figure 2:

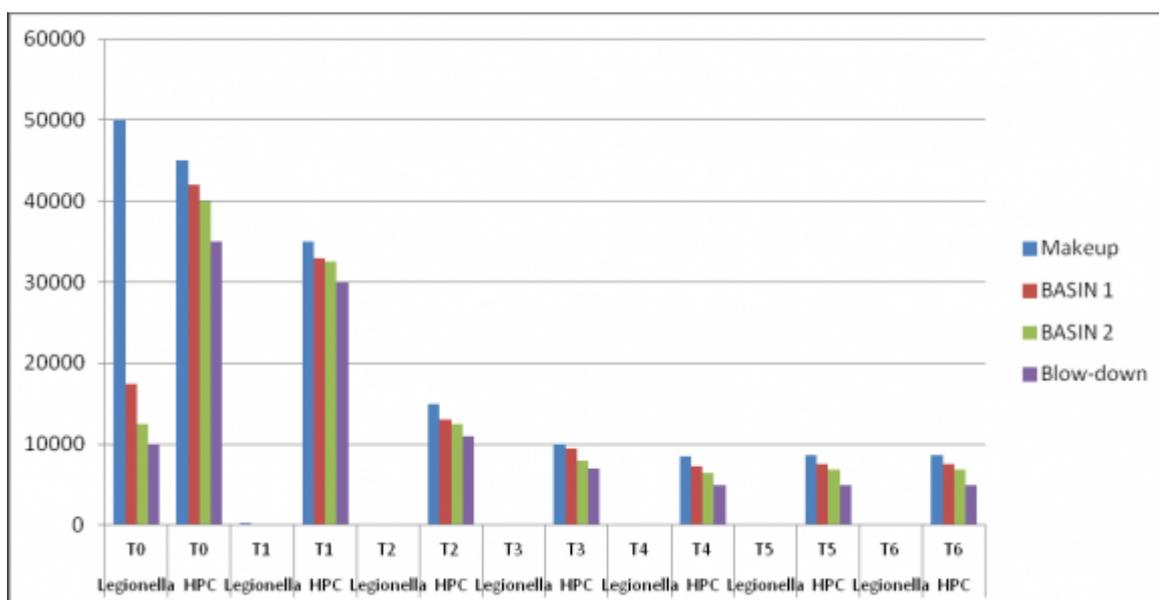


Figure 3:



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Figure 4: Figure 2 :



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Figure 5: Photograph 1 : 015 Photograph 2 : Photograph 3 :



Figure 6: Figure 3 :

Figure 7:

1

	Makeup			Blow-down		
	Nov 2014	Nov 14	Dec 14	Jan 15	Feb 15	Mar 15
Free chlorine (mg/l)	0.02	0.04	0.04	0.02	0.03	0.09
Total residual chlorine (mg/l)	0.03	0.33	0.11			
Monochloramine (mg/l)	0.00	0.35	0.23	0.17	0.11	0.38
Ammomium ion (mg/l)	0.00	0.08	0.13	0.09	0.06	0.08
Nitrite (mg/l)	0.011	0.121	0.234	0.066	0.138	0.217
Nitrate (mg/l)	15.4	26.6	100.8	21.3	26.8	31
Chloride (mg/l)				390	320	
pH	7.4	7.5		7.8	7.7	7.8
Conductivity (?S)	890	1727		1870	1790	
ORP * (mV)			174	180	160	152

Figure 8: Table 1 :

155 .1 Conflict of interest statement

156 Dr Stefano Melada, responsible for the Research & Development department of Sanipur Srl, contributed with a  
157 scientific and technical support necessary for the development of the management plan. He did not participate  
158 to the samplings of the water, isolation and identification of legionellae. No financial support was given to the  
159 authors.

160 [Rubio et al. ()] ‘Assessment of the antifouling effect of five different treatment strategies on a seawater cooling  
161 system’. D Rubio , J F Casanueva , E Nebot . *Appl Therm Eng* 2015. 5 p. .

162 [Meesters et al. ()] ‘Biofouling reduction in recirculating cooling systems through biofiltration of process water’.  
163 Kph Meesters , J W Van Groenestijn , J Gerritse . *Water Res* 2003. 37 p. .

164 [Jenner et al. ()] ‘Chlorination by-products in chlorinated cooling water of some European coastal power stations’.  
165 H A Jenner , Cjl Taylor , M Van Donk , M Khalanski . *Mar Environ Res* 1997. 43 p. .

166 [Nieuwenhuijsen et al. ()] ‘Chlorination disinfection byproducts in water and their association with adverse  
167 reproductive outcomes: a review’. M J Nieuwenhuijsen , M B Toledano , N E Eaton , J Fawell , P Elliot .  
168 *Occup Environ Med* 2000. 57 p. .

169 [Microorganisms] *Colony Count by Inoculation in or on a Solid Medium*, Microorganisms . Geneva. 6222.

170 [Chien et al. ()] ‘Control of biological growth in recirculating cooling systems using treated secondary effluent as  
171 makeup water with monochloramine’. S H Chien , I Chowdhury , M H Hsieh , V A Dzombak , R D Vidic .  
172 *Water Res* 2012. 46 p. .

173 [Li et al. ()] ‘Control of mineral scale deposition in cooling systems using secondary treated municipal wastewater’.  
174 H Li , M K Hsieh , S H Chien , J D Monnell , V A Dzombak , R D Vidic . *Water Res* 2011b. 45 p. .

175 [Hsieh et al. ()] ‘Corrosion control when using secondary treated municipal wastewater as alternative makeup  
176 for cooling tower systems’. M K Hsieh , H Li , S H Chien , J D Monnell , I Chowdhury , V A Dzombak , R  
177 D Vidic . *Wat Envir Res* 2010. 82 p. .

178 [Li et al. ()] ‘Escalating water demands for energy production and the potential for use of treated municipal  
179 wastewater’. H Li , S H Chien , M K Hsieh , V A Dzombak , R D Vidic . *Environ Sci Techn* 2011a. 45 p. .

180 [Engelhart et al. ()] ‘Hospital-acquired legionellosis originating from a cooling tower during a period of thermal  
181 inversion’. S Engelhart , S Pleischl , C Lück , G Marklein , S Martin , A Simon , M Exner . *Int J Hyg Environ*  
182 *Health* 2008. 211 p. .

183 [ISO (International Standard Organization) 1988. Water Quality Detection and Enumeration of Legionella ISO]  
184 ‘ISO (International Standard Organization) 1988. Water Quality Detection and Enumeration of Legionella’.  
185 *ISO 11731*.

186 [ISO (International Standard Organization) 1988. Water Quality. Enumeration of Viable] *ISO (International*  
187 *Standard Organization) 1988. Water Quality. Enumeration of Viable*,

188 [Thomas et al. ()] ‘Laboratory observations of biocide efficiency against Legionella in model cooling tower  
189 systems’. W M Thomas , J Eccles , C Fricker . *ASHRAE Trans* 1999. 105 p. .

190 [Ludensky ()] *Microbiological Control in Cooling Water Systems. Directory of Microbiocides for the Protection*  
191 *of Materials: A Handbook*, M Ludensky . 2005. p. .

192 [Nebot et al. ()] ‘Model for fouling deposition on power plant steam condensers cooled with seawater: effect of  
193 water velocity and tube material’. E Nebot , J F Casanueva , T Casanueva , D Sales . *Int J Heat Mass Tran*  
194 2007. 50 p. .

195 [Coniglio et al. ()] ‘Monochloramine for controlling Legionella in biofilms: how much we know?’. M A Coniglio ,  
196 S Melada , H Mohamed , Yassin . *J Nature and Science* 2015. 1 p. e44.

197 [Melada and Coniglio ()] ‘Monochloramine for Remediation of Legionella Only in Domestic Hot Water Systems:  
198 an Iron Fist in a Velvet Glove’. S Melada , M A Coniglio . *OJPM* 2015. 5 p. .

199 [Schwarzenbach et al. ()] ‘The challenge of micropollutants in aquatic systems’. R P Schwarzenbach , B I Escher  
200 , K Fenner , T B Hofstetter , C A Johnson , U Von Gunten , B Wehrli . *Science* 2006. 313 p. .