Improvement of Trihalomethanes Removal for Water Distribution System

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Abstract — *Potable water good quality should be a priority for the worldwide population distribution systems. The agency that distributes the majority of the water in the island of Puerto Rico, the Puerto Rico Aqueduct and Sewage Authority. The United States Environmental Protection Agency (USEPA) has made, since the 1970's, different regulations to improve the quality of the water of human consume with the SDWA which is the guide of the PRHD to regulate the PRASA and non-PRASA potable water systems. This government agency ensures the public safety of the drinking water they receive in their homes. The daily water monitoring enrolls pH, chlorine, turbidity and nutrients tests. There are another tests related to TOC and THM's concentration. The case studied exhibits an excess on THM's concentration into the distribution system. The filter plant has been dealing with an almost high THM concentration of the outflow which increases during the distribution, so the parameter exceeds when arrives to the consumer. The THM's can cause different health effects such as cancer and reproductive problems. The principal cause of THM's in water is the TOC and Chlorine mixture. The water disinfection creates byproducts that are not safe in high concentration to human health. This is why PRASA have to monitor constantly, and specially, to prevent health risks in the public that consumes its water. There were some improvements that were suggested to get better results in the jar test performed, improvement of the calculus and procedure to diminish the errors, the coagulant sample freshness to make the test and the equipment optimization.*

Key Terms — Chlorine, Drinking Water Treatment, THM's, TOC.

INTRODUCTION

Water is essential for every species and activities made around the world. Health and wellness are directly related to what the human consumes, for that reason is essential to drink clean and potable water. Drinkable water should commit the regulations established to assure quality to the consumers. The majoritarian potable water distributor in Puerto Rico (PR) is the Puerto Rico Aqueduct and Sewage Authority (PRASA). They execute the water treatment and quality monitoring from the water source to the distribution system as shows Figure 1. The sources of fresh water available in Puerto Rico are from groundwater, lakes, and rivers. The contamination of the water is treated depending of its source to provide safe drinking water. The Safe Water Drinking Act (SWDA) is an act that was stablished to protect the quality of drinking water in the United States of America (USA) and authorizes the Environmental Protection Agency (EPA) to stablish minimum standards to regulate tap water [1]. The PRASA water distribution parameters are always to be improved to maintain the compliance of the EPA and Puerto Rico Health Department stablished ones. The Puerto Rico Health Department (PRHD) is the government agency which oversees the SDWA compliance of the PRASA and non-PRASA systems in Puerto Rico [2]. In the west region of Puerto Rico, water treatment and distribution system are to be improved by willing to be zero exceedances with the trihalomethanes (THM). The THM are contaminants that are the result of a reaction between the chlorine and total organic carbon (TOC) in the water [3]. The chlorination is the most used water disinfection technique in water treatment and with it comes some chlorine treatment by-products, which are a health risk, the most common are the THM's. If consume excessively or continuously, the THM's, can cause health effects such as cancer, adverse reproductive outcomes, as well as higher blood THM concentration by dermal absorption and inhalation [4]. Treatment plant processes and optimization guaranties a better water quality that could help to reduce and prevent parameters exceedances based in the protection of the human health and life.

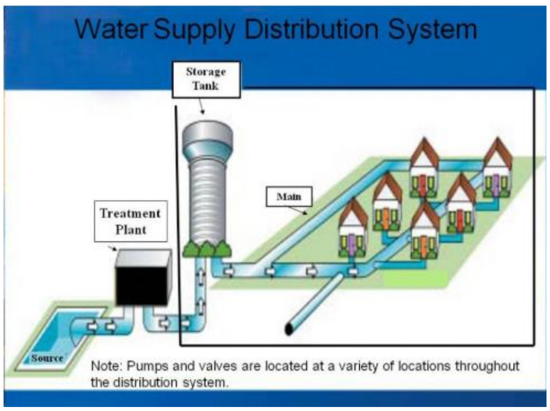

Figure 1
Water Treatment and Distribution System

JUSTIFICATION

The optimization of the water treatment and the diminishment of contaminants that should not exceed the parameters established by the EPA have to be progressive as time goes by. To maintain the water quality is the main focus of PRASA. For better results it is needed to meet an evaluation which provides the improvement opportunities for the Filter Plant and its potable water distribution system in the reduction of trihalomethanes concentrations and the prevention of non-compliances.

LITERATURE REVIEW

A distribution system with high THM results may indicate certain conditions that could be improved. The problems that a drinking water treatment plant and the distribution system could have varies but three of the conditions that may affect it are a) the distribution tanks are not in optimum conditions, b) the filtration plant TOC removal is not as effective as it should be or c) the chlorine disinfectant dose may be reduced. It is normal to observe an increasing of the THM's concentration as water travels through the distribution pipes and tank, but this is not a reason to exceed the 0.08 mg/L parameter established by EPA. Storage tanks are commonly used to ensure that there is enough water for short or long term. Water storage tanks have their own impact on water quality, one of the common problems they present are the loss of disinfectant residual, bacteria re-growth, poor turnover, and excessive detention time. The study, realized in an Ethiopian location called Jimma, was conducted on piped-water supply before entering the tank and after leaving the water storage tanks found in the town. The sampling included 19 storage tanks with volume ranges from 2,500 to 25,000 L filled with tap water. The samples were collected and then analyzed its physicochemical, as pH, temperature and turbidity, and bacteriological properties. The pH values were between 7.13 and 7.41, the temperature was between 21.3 and 23.1 °C, and turbidity range was from 2.08 to 2.93 NTU. The bacteriological count made this water unhygienic as it shown in the following Table 1 [5].

Table 1
Mean Bacterial Count of Water Samples in Storage Tanks

Storage Tanks	TC cfu/100 mL		FC cfu/100 mL	
	Before storage	After storage	Before storage	After storage
B	2.6	4	1.3	4.6
AJ1	8.33	8.36	6.33	7.66
AJ2	8.33	14.33	6.33	9.33
AJ3	8.33	12	6.33	7.33
Gate 4 A	5.66	7.33	4.6	7
Gate 4 B	5.66	10.6	4.6	7.33

Storage tanks conditions of this area had different structural deficiencies shown in the Figure 2. This study revealed that the analyzed physicochemical properties of water were between the established parameters of the World Health Organization (WHO) but not all of them were enough to EPA parameters as happened with the turbidity. The physical conditions of the water tanks also affected the bacterial loads of total coliforms (TC) and fecal coliforms (FC) as well as its conditions could be affected by contamination or inadequate treatment. The TOC removal has a relationship with the turbidity parameter.

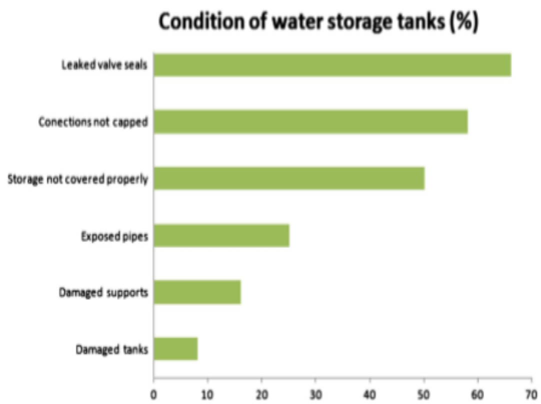

Figure 2
Conditions of Water Storage Tanks (%)

The turbidity parameter is important referring to microbial risk management on drinking water treatment because of turbidity spikes are considered potential for breakthrough of pathogens. As mentions Rizzo, L., et al, for raw water with high turbidity (10-20 NTU) and relatively high TOC concentration (5-6 mg/L) with a pH range of 7.2-8.5, and alkalinity between 46 and 50 mg $CaCO_3$/L, the simultaneous removal of TOC and turbidity was demonstrated by means of TOC and turbidity removal domains overlapping in alum coagulation diagram (Amirtharajah's diagram) [6]. Figure 3 suggests that the coagulation conditions for conventional treatment would be in the region of $Al(OH)_3$ precipitation and optimum sweep floc formation. The TOC removal would likely be in a region of charge neutralization with $Al(OH)_3$ species and/or highly charged polynuclear species [7]. This study of the THM's and turbidity was done at Italy, they took water samples from an artificial basin which was constructed for the compensation of water deficit in vacations season. They used two coagulants, one of alum base and the other of ferric chloride base.

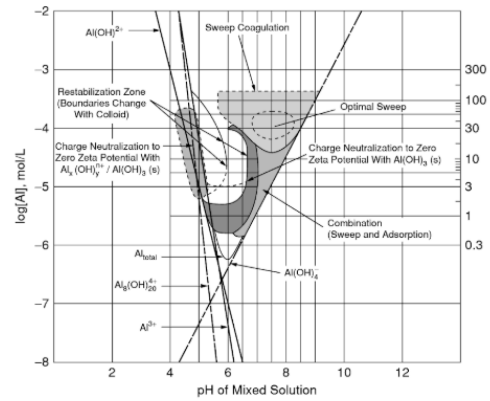

Figure 3
Coagulation Domain Diagram for Alum

They used a jar test to identify and compare the coagulants potency at different concentrations as shows the following Table 2.

Table 2
Characteristics of the Samples Taken from the Basin and Coagulant used for Jar Test

Sample	pH	Alkalinity (mg/L)	Turbidity (NTU)	TOC (mg/L)	DOC (mg/L)	UV_{254} (1/cm)	SUVA (1mg/m)	Coagulant
S1	7.4	183.4	29.0	3.32	3.22	0.123	3.82	Alum
S2	7.4	190.9	15.0	2.80	2.79	0.108	3.87	Alum
S3	7.4	190.9	10.0	2.80	2.72	0.099	3.64	Alum
S4	7.4	188.5	9.0	2.76	2.60	0.100	3.85	$FeCl_3$
S5	7.5	189.4	8.0	2.71	2.66	0.102	3.83	Alum
S6	7.4	193.5	8.0	2.80	2.77	0.128	4.62	$FeCl_3$
S7	7.3	192.2	8.0	2.90	2.86	0.112	3.92	Alum
S8	7.5	189.7	12.4	2.84	2.75	0.098	3.56	$FeCl_3$
S9	7.7	191.9	8.0	2.66	2.59	0.102	3.94	Alum
S10	7.7	193.2	4.7	2.61	2.56	0.102	3.98	Alum
S11	7.7	190.0	5.3	2.72	2.64	0.097	3.67	$FeCl_3$
Average	7.49±0.14	190.3±2.79	10.66± 6.74	2.81±0.19	2.74±0.18	0.11±0.01	3.88±0.28	
Range	7.3-7.7	183.4-193.5	4.7-29.0	2.61-3.32	2.56-3.22	0.1-0.13	3.56-4.62	

The study of microbial contamination, turbidity and TOC provided the next table that demonstrates that there are correlation coefficients between the TC and FC concentration at the before and after storage of the potable water system. The turbidity and TOC compliance realized by the different coagulants had high natural organic matter (NOM) removal efficiency but were not enough for provide turbidity values lower than 2 NTU for alum and 1.2 NTU for ferric chloride at the targeted pH of 7.0. The experiment was also realized with a maximum coagulant dose.

The next two tables (Table 3 and Table 4), shows the TOC and turbidity removal at the conditions of target pH and maximum coagulant dose.

Table 3
Correlation Coefficients Among Water Quality Parameters Before and After Storage

Parameters	Turbidity	pH	Temp	TC	FC
Turbidity	1.00				
7	0.74	1.00			
Temperature	0.33	0.87	1.00		
TC	0.61	0.98	0.94	1.00	
FC	0.73	0.99	0.88	0.98	1.00
After storage					
Turbidity	1.00				
pH	0.60	1.00			
Temperature	0.00	0.68	1.00		
TC	0.41	0.96	0.76	1.00	
FC	0.38	0.90	0.78	0.89	1.00

Table 4
TOC Removal at Both Target pH and Maximum Coagulant Dose

Coagulant	Samples	Target pH removal		Max. dose removal	
		Dose (mg/L)	TOC removal (%)	Dose (mg/L)	TOC removal (%)
Alum	S1-S3, S5, S7, S9, S10	30-50	16-36	80	33-46
FeCl2	S4, S6, S8, S11	30-40	22-30	80	36-46

The process of coagulation can be effective for the simultaneous control of organic precursors of THM's and pathogen breakthrough. “The relation of the NOM with the development of THM's and the evidence of the relation of turbidity and the pathogens it is important to evaluate the approach simultaneous compliance for THM's precursors and turbidity removal. This study demonstrated that at target pH the removal percent of TOC, see table 5, was in compliance with the percent established by EPA but turbidity removal was rather a limiting parameter than TOC removal for compliance, and, thus, for pathogen control” [6].

Table 5
Turbidity Removal at Both Target pH and Maximum Coagulant Dose

Type.	Samples	Target pH removal			Max. dose removal		
		Dose (mg/L)	NTU (%)	Final NTU	Dose (mg/L)	NTU (%)	Final NTU
Alum	S1-S3, S5, S7, S9, S10	30-50	50-83	1.9-6	80	33-46	0.8-2
FeCl2	S4, S6, S8, S11	30-40	37-81	1.2-5	80	36-46	0.6-2

VALIDATION/OPTIMIZATION GUIDE

The optimization of a drinking water treatment plant will require to collect data. The information obtained from the plant will be the base for the improvement of itself. It will be necessary to collect the daily data of turbidity, chlorine concentration and contact time, manganese, iron, alkalinity and pH. The jar test is an essential procedure to determine the level of TOC removal during the process of coagulation and flocculation in the drinking water plant by the relation of turbidity measure it has. It is necessary to expand the focus not only to the TOC removal also to the chlorine dose at the influent and at the effluent. The inflow of the plant will be tested with the primary and secondary coagulants that are actually at the plant in a jar test and the turbidity of the different jars will be measured. The turbidity measure obtained from this test will be compared with the turbidity of the two plants that treats the water at the treated water level of the plants, where the water has not been filtered yet. With those results the visualization of the situation. The equipment of the jar test should be in optimum conditions to realize a successful test. Equipment adjustments would also improve the plant TOC removal. The changes that would do a difference are the filters backwash time execution, the velocity of the mixers, the pre-chlorine dose, and the sedimentation tanks periodic cleaning time.

METHODOLOGY

The methodology of this investigation will be based on the analysis of the TOC values that were taken on a monthly and quarterly basis. Also, the chlorine concentration at the different sampling points of the filtration plant to determine the dosing effectiveness. The plant reserve tank is important for the distribution system and it may be evaluated and verified to assure a good chlorine contact time. For the TOC removal, the turbidity measure will be a guide. The turbidity will be measured at the plant influent with a jar test to verify the coagulant/flocculant dose is optimum to the NOM removal and at the treated not filtered water step of the plant. This result will establish if the TOC removal is failing or not in the plant. The chlorine contact time will have also to be monitored as it is the chlorine concentration at the plant effluent. The distribution tank water level must be monitored, the water needs to be oscillating. Although there are always ways to improve the system, the first step is to identify the drinking water treatment plant amelioration opportunities. This will collaborate with the actual status of the plant and help with the implementation of new ideas for the amelioration of the process.

CASE STUDY

A PRASA Filter Plant and its distribution system is willing to minimize the results of high THM's according to EPA regulations. The plant has two treatment plants, "planta vieja" and "planta nueva" which joins at the outflow. The "planta vieja" inflow is 2 MGD at its maximum, and "planta nueva" inflow maximum is of 4 MGD. The filtration plant water source is a lake, the water gets in the plant by open channels. The "planta vieja" has rapid mixing phase at which is injected the coagulants. The "planta nueva" does not have a rapid mixing phase, the coagulants are added to the inflow of the plant. The difference at the inflow treatment of both plants can indicate that there is an improvement opportunity. Flocculation and sedimentation processes runs normal on both plants, as it does filtration and disinfection processes. Jar test has been executed to ensure the coagulant/flocculant effectiveness, but the test was not as favorable as expected. The next Table 6 presents obtained the values.

The jar test coagulant/flocculant verification may suggest that there is a problem with the equipment or the coagulant. This test is key to understand the THM's excess during the last semester of the past year in the filtration plant, by the relation between turbidity and TOC concentration in water, so it was scheduled another jar test with the adjustments of the calculations and the clarified theory given to the plant operator.

Table 6
Jar Test Coagulant Effectiveness Evaluation (02/09/19)

Primary solution	Secondary solution	Turbidity (NTU)	pH	T °C
0	0	16.5	8.05	25.5
2.8	0.4	1.87	7.87	25.6
3.0	0.4	6.92	7.91	25.6
3.2	0.4	6.11	7.89	25.6
3.4	0.4	6.14	7.89	25.6
3.6	0.4	4.3	7.87	25.6

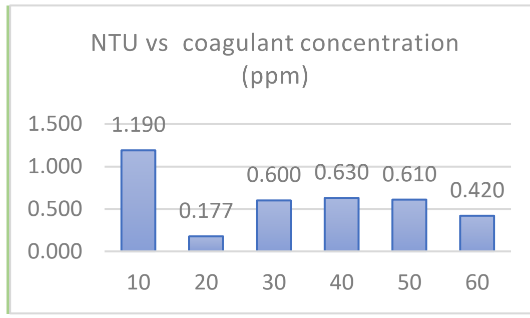

Figure 4
Turbidity Removal Potential of the Actual Coagulant (03/08/19)

This new jar test revealed that the optimum dose of the actual flocculant was 20 ppm per 2 L of entering raw water for the turbidity removal, results are shown in Figure 4. Also were tested different coagulants in the jar test, this test revealed that there are better results on other coagulant than the one used in the plant, as shows the next Table 7.

Table 7
Jar Test Coagulants Comparison (03/08/19)

Coagulant	Concentration (ppm)	NTU
680325014	10	2.51
680325014	20	1.03
680325014	30	0.96
6803	20	0.92
2800	20	1.42
M-4000	20	1.75

The results of the second semester of year 2018 demonstrates that the THM's are in alarming levels during July and October, but in November the results had exceeded the maximum of the EPA parameter as shown in the next Table 8.

Table 8
THM's Results of the 2018's Last Semester

Date	Res. Chlorine	pH	Total THM
6/2/2018	1.8	7.56	0.04
6/20/2018	2.2	7.49	0.05
7/11/2018	2.4	7.46	0.06
8/8/2018	1.85	7.66	0.04
9/1/2018	1.87	7.72	0.05
10/10/2018	1.92	7.61	0.06
11/28/2018	1.83	7.53	0.09

The marked value of 0.08 mg/L of total THM's by EPA is a parameter that has to complain at the sample point individually and in average. The determination of the THM's compliance at the tap water is evaluated with the regulation that is based in collect samples at different points of the distribution system. The samples concentration of THM's is measured by two steps. The first stage in which the value of the average and the individual one has to comply is called running annual average (RAA). The second stage changes sampling the locations and the method to calculate compliance. In this stage the average must be below of the maximum contaminant level (MCL). [2] A possible high chlorine dose may also affect the plant effluent if the TOC removal is not as effective as expected. The application of the chlorine dose may vary during the day, by temperature or pH commonly. This filter plant distributes water to Lajas and San German municipalities and may affect the consumers of the area.

Conclusion and Future Works

The Lajas drinking water plant system have been dealing for the last six months of last year with a problem of THM's. The plant operation is overall in a good performance. The first coagulant/flocculant reaction test was not as effective as it should be. The coagulant/flocculant dose analyzed at the jar test was not congruent with the literature, the calculations and the equipment had ameliorations opportunity. The second jar test was more accurate than the first one. The values given by the test showed better procedural application and results. This test validated the optimum dose of the actual coagulant used at the plant and also it was tested a comparison of the actual coagulant and other coagulants turbidity removal capacity. It is possible that the chemicals added to the coagulation/flocculation process are not removing enough TOC as requires the plant for distribute the drinking water. A sample for TOC removal was requested to an external lab but they are waiting for the result in which it will be known the real capacity of the TOC removal of the different coagulants and which one is the best one for the potable water plant. The comparison of the results between both the actual chemicals and the introduced ones will determine if the plant needs to change the chemicals used for those steps. Those coagulants could work different in the process of the filtration plant. The plant inflow system of open channels should be verified and maintained in good conditions to prevent the organic matter excess. The water source of the inflow is a lake that should be dragged any time soon to diminish the possibility of contamination or organic matter transportation. There are some other recommendations that could improve the plant system as the chlorine adjustment during the operation to lower the risk of the creation of THM's at the distribution system. Another application that could be considered are the micro-sand filtration and granular activated carbon adsorption. Those applications could be helpful if the coagulant/flocculant dose are high during the plant process.

References

[1] EPA. (n. d.). *The Safe Drinking Water Act* [Online]. Available: https://www.epa.gov/sdwa. [Accessed: January 2019].

[2] "P. del S. 843", *Puerto Rico Water Purity Protection Law*, Law 193 from December 26, 1997.

[3] M. L. Davis, et al., “Disinfectants and Disinfectant By-Products”, in *Introduction to Environmental Engineering*, Fifth Edition, 2013, pp. 265-266.

[4] National Center for Biotechnology Information (NCBI). *Environmental Health Perspectives, Tap Water Trihalomethanes: Flow of Concerns* [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1257669. [Accessed: January 2019].

[5] D. Chalchisa, et al., “Assessment of the quality of drinking water in storage tanks and its implication on the safety of urban water supply in developing countries”, in *Environmental Systems Research*, 2017.

[6] L. Rizzo, et. al., “Simultaneous Compliance of TOC and Turbidity Related to Pathogen Breakthrough and THM's Control by Enhanced Coagulation”, in *Global Nest Journal*, vol. 7, 2005, pp. 145-153.

[7] J. Bratby, “Treatment with metal coagulants”, in *Coagulation and Flocculation in Water and Wastewater Treatment*, Second Edition, 2006, pp. 85-86.