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SMALL WATER DISTRIBUTION SYSTEM DISINFECTION BY-PRODUCT CONTROL: WATER QUALITY MANAGEMENT USING STORAGE SYSTEMS

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ABSTRACT: Disinfection, a vital part of a drinking water treatment, using chlorine is the most widely practiced process in the world. The Stage-2 Disinfectant and Disinfection By-Product regulations force water utilities in the US to be more concerned with their distributed water quality. Compliance requires changes to their current operational strategy. Storage system management is an important part of the operational strategy of small scale utilities. This study quantifies changes in DBP formation and chlorine decay in storage systems under varying operational parameters such as mixing, contact time, and water movement using a physical model (Pipe Loop) of a distribution system. Effective operation of storage systems can yield greater than 30% decrease in DBP formation in distribution systems and maintain chlorine residual for a 50% longer period.

Keywords: Clearwell, Storage Tank, Pipe Loop, Trihalomethanes, Chlorination

1. INTRODUCTION

Disinfection and distribution of treated water are vital parts of a drinking water utility's operation. Though they may seem like two completely different processes, their operation strategy needs to be complementary in order to maintain minimum disinfectant residual as part of the distribution system water quality management. Chlorination is one of the most widely used disinfection processes in water treatment plants because chlorine is a very effective disinfectant and is relatively easy to handle; the capital costs of installation are low; it is cost effective, simple to dose, measure and control; and, it has a reasonably prolonged residual [1]-[3]. Despite the benefits of chlorine, halogenated disinfection by-products (DBPs) are formed due to the interaction of aqueous free chlorine with natural organic matter (NOM), like humic substances, present in water [4], [5].

Small-scale water utilities are known to use different operational strategies to overcome their physical (infrastructure, source water quality, distribution system layout, storage system design etc.) and financial constraints to meet the water demand and provide consistent quality water to all its customers. In other words, though known to have infrastructural constraints small-scale utilities tend to benefit a lot by making necessary changes to the way they operate each of their units based on site-specific conditions and the formation kinetics of the contaminant in question. Water treatment process operation to maintain water quality with respect to numerous contaminants in distribution systems irrespective of seasonal changes and fluctuating water demand is a complex process and hence requires a balanced approach. With the Stage-2 Disinfectants and Disinfectant By-Product Rule regulation compliance date approaching (October 2014) many small-scale utilities in US are adopting techniques to balance protection against microbial risks with the risks posed by harmful by-products [6]-[8].

Storage tanks are an important part of infrastructure as well as the operational strategy of small scale utilities [9]-[15]. Many small scale water utilities are shut down for a part of the day and these tanks act as a reservoir of treated water at the treatment plant (clearwell) or in the distribution system (tower or stand-pipe) to meet the water demand of the town. They hold immense potential to either improve or degrade the water quality provided by the utility. External factors like atmospheric temperature, mixing conditions, size and shape of the tank, location of inlet and outlet valves, wall coating etc. play a vital role in quality of water coming out of the storage tanks [9]-[15]. The volume of water entering and leaving the tank and timeline of these events are the most important factors that dictate successful operation of storage tanks. Therefore understanding the changes in chemistry of water while in the storage systems can help utilities utilize these structures to maintain or improve the quality of water provided to their customers.

2. METHODS

This research was conducted using a physical model of distribution system (Pipe Loop) built at the City of Columbia, Missouri (USA) Water Treatment Plant using 10.16 cm (4 in) PVC pipe [16]. The scenarios discussed in this paper are: Normal Run, Storage Tank in Distribution System Run, Clearwell with proper mixing and fill-drain cycles Run and Clearwell without mixing and fill-drain cycles Run.

Normal run is used as the control or baseline for comparing other scenarios and is based on typical operation of a drinking water treatment process which involves treated water with disinfectant residual entering the distribution system. In order to simulate a Normal Run (NR), finished water from the City of Columbia water treatment plant (chlorinated water before ammonia addition) is allowed to enter the Pipe Loop via the Water Tank attached to it (Fig. 1). The water was recirculated in the looped system for 7 days with water samples collected at daily intervals.

In order to simulate storage tank in a distribution system scenario in the Loop, the finished water was allowed to fill the Loop via a storage tank attached to it. Once both tank and Loop were full, the valve between them was shut and the water was allowed to stay in the tank and recirculate in the Loop for 2 days. On day 2, the valve between tank and Loop was opened and one-third of volume of the tank was drained through the loop. The tank was filled to its full capacity at high pressure to ensure proper mixing. The process of draining one-third volume and refilling it with new water was continued for 4 more days before the Loop and the tank were drained completely to start the process all over again. Water samples were collected from the tank as well as the Loop at regular intervals. Samples were collected before draining and after refilling at both locations.

For clearwell with proper mixing and fill-drain cycles, the finished water was allowed to fill only the tank attached to the Loop on day 0 with high pressure and 1/3rd of the tank was drained after 24 hours using a valve at the bottom of the tank. The tank filled to its full capacity at high pressure to ensure proper mixing. The process of draining one-third volume and refilling it with new water was continued for 4 more days before the tank was drained completely to start the process all over again. Water samples were collected before draining and after refilling the tank at regular intervals.

For clearwell without mixing and fill-drain cycles, the finished water was allowed to fill only the tank attached to the Loop on day 0 and the water was allowed to sit in the tank for 7 days without any mixing or draining and filling with new water. Water samples were collected from the tank at regular intervals.

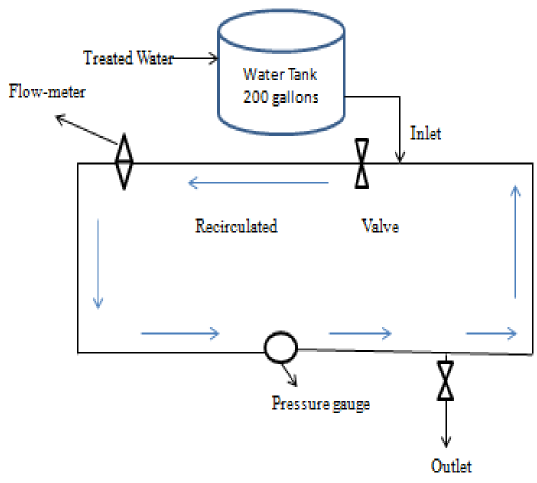

Fig. 1 Schematic of the Pipe Loop used in experiments to determine effects of distribution system management. Water tank shown was used to simulate clearwell and storage tank

All of the collected samples were tested for free and total chlorine residual, total organic carbon (TOC), pH, UV254 and TTHM as a function of time over a period of 10 months. The TTHM concentration entering the Pipe Loop averaged 40 µg/L (half of MCL limit of 80) and pH averaged 8.5, which is considerably high for a chlorinated system. UV_{254} was measured using Varian Cary 50 UV-Visible Spectrophotometer following Standard Method 5910 B [17]. Free and total chlorine residual was measured using appropriate DPD methods (Hach methods 8021 and 8167 [18] equivalent to Standard Method 4500-Cl G [17] and a Hach pocket Colorimeter II (Cat # 5870000) designed for collecting on-site measurements. TTHM concentrations were analyzed with a Varian 3800 Gas Chromatograph (GC) equipped with a Saturn 2000 Mass Spectrometer (MS) for detection following an analysis method similar to that described by EPA method 524.2 [19] and Standard Method 6232 C [17] was used. Total Organic Carbon (TOC) was measured using the combustion Infrared Method (Standard Method 5130B [17]). Statistical analysis of the data collected was done using MiniTab to ensure soundness of the conclusions. Analysis of Variance (ANOVA) and Paired t-tests were conducted on all the data with 90-99% level of significance.

3. RESULTS AND DISCUSSION

3.1. Normal Run Vs. Storage Tank In Distribution System Run

Water chemistry in storage systems is unique in many ways. Therefore, results are explained as comparisons with a Normal Run (Fig. 2). This analysis is intended to statistically explain the effect of storage tank operation on water quality in terms of chlorine residual and trihalomethane concentrations.

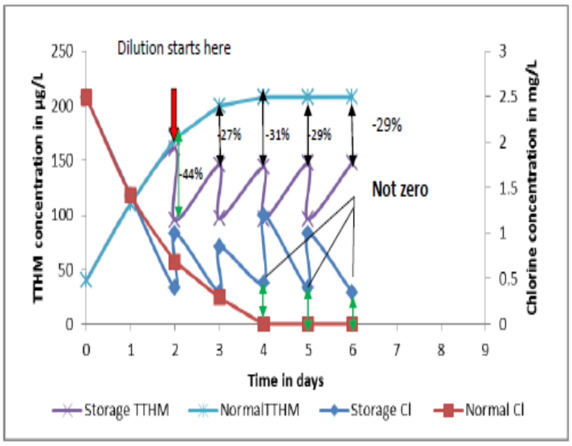

Fig. 2 Storage Tank run vs. Normal run chlorine residual and TTHM trends. The percent differences between the TTHM formation and chlorine decay values are also noted.

Data from the Loop and storage tank shows that the decay of chlorine residual and formation of TTHMs over time is dramatically different in Storage Tank run when compared to Normal Run. Relative to a Normal Run dilution by adding new water to the Storage Tank tends to decrease the concentration of TTHMs formed on average by 34% over a 6-day operation. In addition to that, this dilution helped maintain minimum residual in the system without additional chlorine unlike during the Normal Run when by the end of day 3, chlorine residual in the system decreased to zero. The TTHM concentration during the Storage Tank Run seems to be between 143 and 148 µg/L after 24 hours following the dilution for 4 days (compared to 200 µg/L for the Normal Run). This range depends on the concentration of TTHMs formed in the system before starting the dilution on day 2, which in turn depends on number of days the water is stored before the dilution process started. It is statistically proven with 99% level of confidence that these two strategies produce different trends in chlorine decay and TTHM formation over time under constant wall conditions.

The adverse effect of increased contact time and chlorine dosage on TTHM formation in the distribution system is explained in detail in our previous research [16], [20]. Therefore, storage time before the dilution process takes effect and contact time in the tank play an important role in water quality management in storage tanks. The stabilization effect of the dilution process is unique and can be a blessing to utilities if the tank is operated properly. The adverse effects of biofilm formation, dead spots in the tank due to stratification and inappropriate positioning of inlet and outlet on water quality are extensively studied subjects. Hence it can be concluded that operation of the tank which involves constant mixing to avoid temperature stratification issues, proper maintenance in terms of coating to ensure absence of biofilm, optimal location for inlet and outlet, minimizing storage time by draining a considerable volume of water at short and regular intervals can be the difference between tanks improving versus degrading water quality in distribution systems.

3.2. Clearwell With And Without Mixing And Fill-Drain Cycles

Clearwell is a storage tank located on the premises of a treatment facility and is used to store finished treatment water before it is allowed to enter the distribution system. Though the concept of storage time before dilution does not apply to clearwell as the finished water from the filtration unit directly enters the clearwell. Rather the effect of mixing, fill-drain cycles, and physical condition of the clearwell become predominant. For a large clearwell at any given time the mixed age of the water in the clearwell can be 2 to 4 days which demonstrates the adverse effect of increased contact time with the disinfectant. The difference between having and not having proper mixing and fill-drain cycles during storage time is shown using the data produced by two scenarios (Fig. 3). Storage tank data of Normal Run represents a system with no mixing and filling cycles whereas Tank Storage Run represents a system with complete mixing and regular filling cycles. Constant physical conditions are maintained in both systems.

Comparison of data from the two runs shows that the decay of chlorine residual and formation of TTHMs over time is dramatically different. Dilution with new water in the Storage systems Run tends to decrease the concentration of TTHMs formed on average by 30% over the 6-day operation relative to the Normal Run. The dilution process helped increase the chlorine residual in the Storage systems Run by 65% on day 4 and by 113% on day 5 relative to the Normal Run. On day 6 chlorine residual in the Normal Run decreased to zero when about 1.4mg/L is still left in the Storage system Run. It is statistically proven with a 99% level of confidence that these two strategies produce different trends in chlorine decay and TTHM formation over time under constant wall conditions.

These differences in TTHM concentration and Chlorine residual between these two strategies are solely due to mixing and filling conditions. Therefore, it can be concluded that, in the case of clearwells, the mixing and filling conditions play an important role in management of water quality. Storage time before entering clearwell depends on the contact time of disinfectant requirements during filtration, therefore, it cannot be included in clearwell management. When operated under proper mixing and filling conditions, the clearwell can provide better water quality in terms of TTHM formation and chlorine residual without additional chlorine.

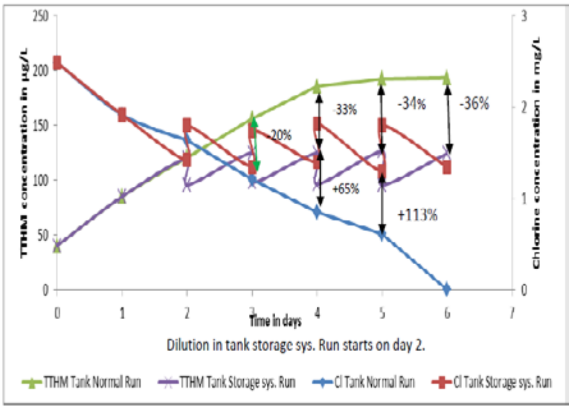

Fig. 3 Tank Normal run vs. Tank Storage run chlorine residual and TTHM trends. The percent differences between the TTHM formation and chlorine decay values are also noted.

The change in TTHM formation and chlorine decay kinetics between a high chlorine dosage scenario and usage of chlorine boosters scenario is explained in detail in our previous research [16], [20].

4. CONCLUSIONS

Operational strategies affect water quality in terms of chlorine residual and TTHM formation in distribution systems. In the case of storage systems management, it is statistically proven that storage time before entering the tank, mixing conditions and fillings cycles play an important role in maintaining water quality in storage tanks located in distribution systems as well as clearwells located at the treatment facility. Storage time before entering the clearwell cannot be considered as a part of clearwell management as it is not controlled by the operation of the clearwell. Rather the primary disinfectant contact time requirements of the state directly influence this storage time. Proper mixing and fill-drain cycles can alone hold the potential to dictate whether a storage structure will improve or degrade the water quality in terms of chlorine residual and TTHM formation. Operators need to realize that any given operational strategy has potential to improve water quality with respect to one parameter and degrade it with respect to another. Finding a right balance requires knowledge of system-specific conditions and factors of variability of water chemistry in distribution systems.

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6. REFERENCES

[1] Sadiq R, and Rodriguez MJ, “Disinfection by-products (DBPs) in drinking water and predictive models for their occurrence: a review”, J. of Science of the Total Environment, Vol. 321, 2004, pp. 21–46.

[2] U.S. Environmental Protection Agency, “National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts”, Federal Register, Vol. 63, 1998, pp. 69390-69476.

[3] Warton B, Heitz A, Joll C, and Kagi R, “A new method for calculation of the chlorine demand in natural and treated waters”, J. of Water Research, Vol. 40, 2006, pp. 2877–2884.

[4] Adams C, Timmons T, Seitz T, Lane J, and Levotch S, “Trihalomethane and Haloacetic Acid Disinfection By-Products in Full-Scale Drinking Water Systems”, J of Environmental Engineering, Vol. 131, 2005, pp. 526-534.

[5] Rook J, “The chlorination reactions of fulvic acids in natural waters”, J of Environmental Science and Technology, Vol. 11, 1977, pp. 478–482.

[6] Carrico B, and Singer PC, “Impact of Booster Chlorination on Chlorine Decay and THM Production: Simulated Analysis”, J. of Environmental Engineering, Vol. 135, 2009, pp. 928-935.

[7] Clark RM, and Sivaganesan M, “Predicting Chlorine Residuals and Formation of TTHMs in Drinking Water”, J of Environmental Engineering, Vol. 124, 1998, pp. 1203-1210.

[8] Clark RM, Adams JQ, and Lykins BW, "DBP Control in Drinking Water; Cost and Performance", J. of Environmental Engineering, Vol. 120, 1994, pp. 759-782.

[9] Besner MC, Gauthier V, Barbeau B, Millette R, Chapleau R, and Prevost M, “Understanding distribution system water quality.”, J. of American Water Works Association, Vol. 93, 2001, pp. 101-114.

[10] Clark R, Abdesaken F, Boulos P, and Mau R, “Mixing in Distribution System Storage Tanks: It’s Effect on Water Quality”, J. of

Environmental Engineering, Vol. 122, 1996, pp. 814-821.

[11] Germeles AE, "Forced plumes and mixing of liquids in tanks." J. of Fluid Mechanics, Vol. 71, 1975, pp. 601–623.

[12] Grayman WM, and Clark RM, "Using computer models to determine the effect of storage on water quality", J. of American Water Works Asssociation, Vol. 85, 1993, pp. 67–77.

[13] Kennedy MS, Moegling S, Sarikelli S, and Suravallop K, (1993). "Assessing the effects of storage tank design on water quality" J. of American. Water Works Association, Vol. 85, 1993, pp. 78-88.

[14] Mau R, Boulos P, Clark R, Grayman W, Tekippe R, and Trussel R, (1995). "Explicit mathematical models of distribution system storage water quality", J. of Hydraulic. Engineering, ASCE, Vol. 121, 1995, pp. 699–709.

[15] Zachár AA, and Aszódi AA, "Numerical Analysis of Flow Distributors to Improve Temperature Stratification in Storage Tanks", J of Numerical Heat Transfer: Part A -- Applications, Vol. 51, 2007, pp. 919-940.

[16] Poleneni SR, "Analysis and management of disinfection by-product formation in distribution systems", M.S. Thesis, University of Missouri. 2013, ch. 3.

[17] APHA, AWWA, WEF, "Standard Methods for the Examination of Water and Wastewater," 20th ed. United Book Press: Baltimore, MD. 1998.

[18] Hach, "Water Analysis Handbook." 3rd ed. Hach Company: Loveland, CO. 1997.

[19] Munch JW, "EPA Method 524.2: Measurement of Purgeable Organic Compounds in Water by Capillary Column Gas Chromatography/Mass Spectrometry", Rev. 4.1, US EPA, Office of Research and Development: Washington, D. C. 1995.

[20] Poleneni SR and Inniss EC, "Small Water Distribution System Operations and Disinfection By-Product Fate" J. of Water Resource and Protection, Vol. 5, pp. 35-41.

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