Chlorine Concentration Decay in Water Distribution Systems with Variation of Temperature

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***Abstract*—In this study, the effect of the chlorine concentration rate at various temperatures with slow- and fast-reacting agents was investigated. The results show that temperature affects the rapid and slow decay phases as well as the pipe set, the latter being more susceptible to temperature changes because of higher values for the activation energy parameter. The main goal of this study is to determine how the service age of pipes affects the chlorine concentration in the water distribution system. Moreover, we analyze here the water distribution system with various temperatures as well as with fast and slow-reacting agents.**

***Index Terms*—Temperature, Fast reactant agents, Slow reactant agents, Activation energy**

I. INTRODUCTION

In many water distribution systems, a major distribution goal is to maintain chlorine residual by effectively modeling chlorine concentration. The secondary disinfection of the drinking water distribution system aims at maintaining chlorine residuals from the entry point to the far from the far point of the system (WHO, 2004). The chlorine is lost by the reaction with organic matter and inorganic substances like ammonia, manganese, or iron left in the water after treatment, a higher concentration of chlorine is required at the entry point as compared to the extremities. With the higher concentration of chlorine at the entry point, the odor and change in the taste may be generated at upstream locations that need elimination through downstream booster dosing or lower chlorine concentration at extremities (USEPA, 2006). In the planning and management of system hydraulic performance nowadays software packages are used to simulate flows in complex pipe or reservoir networks.

The chlorine decay in pipes can be divided into two points bulk decay and wall decay. The bulk decay results from the reaction of chlorine substances in the bulk water while on the other hand, well decay occurs due to the reaction of chlorine with the pipe wall and the biofilm as well as corrosion products. The disinfectant residual used most frequently to maintain the microbiological safety of drinking water in supply networks is chlorine. Chlorine concentration must be maintained within a very small range, typically between 0.2 and 1.0 mg/L, to be effective and to prevent the overproduction of toxic disinfection by-products. (WHO, 2011). Because chlorine concentration decreases as water moves through transport and distribution networks, managing chlorine residuals is not an easy task. For the maintenance of water quality in transmission and distribution networks, disinfecting drinking water is essential. Before entering the transportation system, treated water is cleaned and disinfected (Clark and Coyle, 1990). A detectable disinfectant residual should stay in the water because bacterial contamination of water is anticipated in the transmission and distribution system, reducing the risk of waterborne illness and biofilm development. Water Research Centre (1976) had previously recommended some factors to be taken into consideration for controlling the number of bacteria in treatment and distribution systems, including system cleaning, limiting the time and amount of water retained in the network, and alternative disinfectants that may last longer in the water. Chlorine residual modelling is extremely helpful for controlling disinfectant concentrations in transportation and distribution networks, but it heavily depends on how accurately chlorine decay is described. The temperature is one of the most important variables affecting chlorine decomposition rates and needs to be included in decay models (Fisher et al. 2011a). Chlorine degradation rates are significantly influenced by temperature as described in

(Roccaro et al. 2008). In order to the observational Arrhenius equation describes the impact of temperature on chemical reaction rate coefficients.

$k = Ae^{(E_A/RT)}$

where, k is the reaction rate coefficient, A is the frequency factor, E_A is the activation energy, R is the ideal gas constant [8.31 J/(molK)], and T is the temperature. Each chemical process has its own unique Arrhenius parameters (A and E_A). According to the transition state theory, E_A is the minimal amount of energy needed for a reaction to take place to activate the complexes of reactants. High values of E_A typically indicate greater sensitivity of reaction rates to temperature changes. The Arrhenius equation is used to effectively explain how temperature affects the first-order chlorine bulk decay coefficient (Hua et al. 1999). This study examines the impact of temperature on chlorine decay rates for a variety of untreated and treated waters from various sources. The main goal of this study is to gain knowledge about how temperature affects, the chlorine decay in waters with various rapid, slow, and pipe aging factor decay phases in different ways

II. MATHEMATICAL MODELLING

The mass transfer equation for the chlorine decay in water distribution for the three-reactant model can be given as

$$\frac{dC}{dt} + Ae^{(E_A/RT)}\ \mathrm{C} = = - k_f C C_f - k_s C C_s \qquad (1)$$

where Cis the amount of free chlorine (mg/L), C_f and C_S are the amounts of fast and slow reducing agents (mgCl-equiv/L), respectively, and k_f and k_S, are the amounts of fast and slow response rates, respectively and T is the temperature, A is the frequency factors.

III. RESULT AND DISCUSSION

This model uses the service rate coefficient to compute the rate of change in chlorine concentration degradation concerning temperature. It also considers the effects of slow- and fast-reacting agents. PYTHON software is used to create the graphs. The mathematical model developed by Bhadula et al. (2021) provided that the service rate coefficient. Chlorine concentration data were gathered from the Pithuwala water box in Dehradun at various temperatures according to the rate of chlorine decomposition.

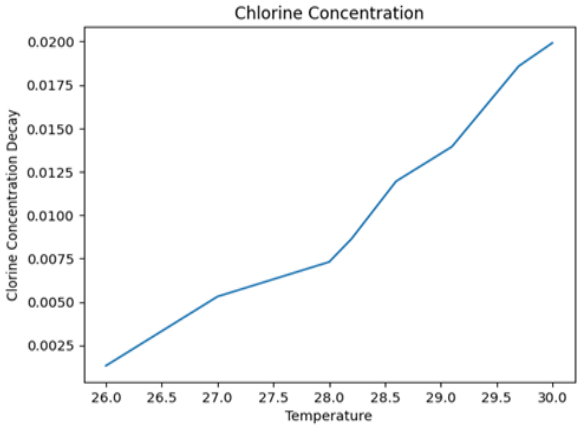

Figure 1: Variation between chlorine decay rate and temperature.

In Figure 1. When the temperature was 30 degrees Celsius, the chlorine decay rate was 0.02 mg per second with respect to the same concentrations of the fast-reducing agent and slow-reducing agent taken as 0.001 with a service rate coefficient value of 0.000000001. When the temperature is 28.2 degrees Celsius, the chlorine decay rate is 0.007. This graph demonstrates how the rate of change in concentration with respect to temperature will slow down when temperature drops.

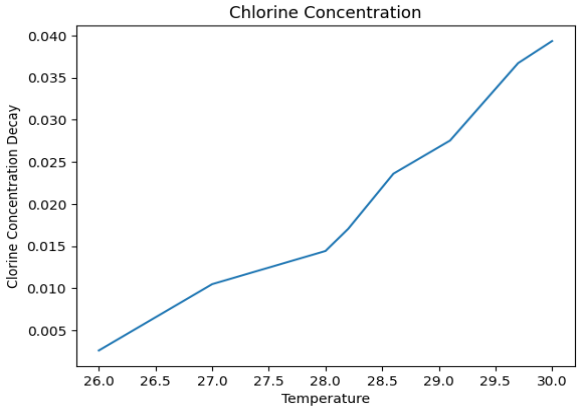

Figure 2: Variation between chlorine decay rate and temperature when amount of fast reactant agent increased

In Figure 2. for different temperatures and varied chlorine concentrations, the concentration of the fast-reacting agent is taken to be 0.002, whereas the concentration of the slow-responding agent is taken to be 0.001. This graph illustrates how the rate of change

of concentration with respect to time will rapidly drop if the concentration of a fast-reducing chemical is increased and the temperature decreases. The rapid reaction rate coefficient is 6.47 at 20 ^{0}C, while the slow reaction rate coefficient value is -0.17, and 0.000000001 is the service rate coefficient. Figures 1 and 2 show that when the fast reaction rate is increased by two, the chlorine concentration rate increases by two.

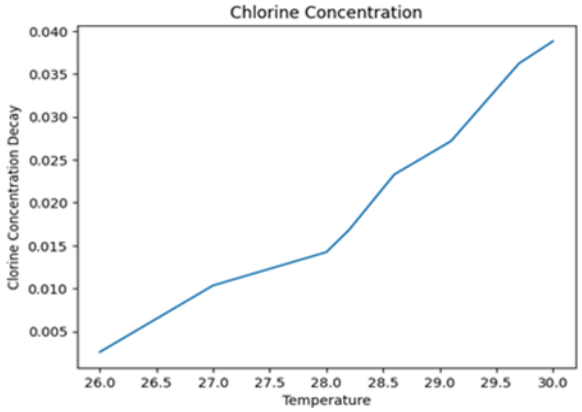

Figure 3: Variation between chlorine decay rate and temperature when the pipe is new.

In Figure 3, it is assumed that the service rate coefficient is 0.001with respect to the concentrations of the fast and slow reducing agents, which depends on temperature and chlorine concentration, the coefficients of fast reaction rate and slow reaction rate are -6.47 and 0.001 respectively. At 30 degrees Celsius, chlorine decomposes at a rate of 0.016, whereas at 27 degrees Celsius, it decomposes at a rate of 0.005. However, in Figure 1, chlorine decomposes at a rate of 0.02 at 30 degrees Celsius and 0.05 at 27 degrees Celsius.

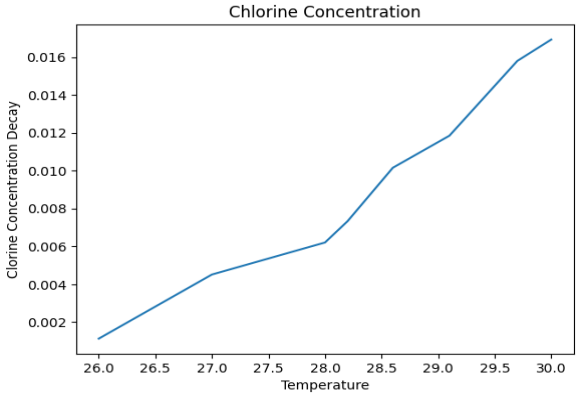

Figure 4: Variation between chlorine decay rate and temperature when slow reaction coefficient decreased

This graph demonstrates how the rate of change of concentration with respect to time will gradually decrease as the temperature decreases and a service rate coefficient rises. which is acceptable given the rapid decline in chlorine content in the old distribution system. When the slow reaction coefficient is decreased, chlorine concentration decay occurs quickly, and when the slow reaction agent is increased, chlorine concentration decay occurs slowly which can be seen clearly in Figures 1 and 4.

IV. CONCLUSION

The aging of infrastructure and biofilm can have an impact on the rate at which chlorine in water distribution systems degrades overtime. There may be some additional places for chlorine to interact with pollutants or be consumed through other chemical reactions as pipes and other system components get older and develop rough surfaces or corrosions. As a result, the pace at which chlorine decomposes may decrease, causing chlorine to disintegrate more slowly over time. The pace of chlorine decay can be accelerated by the presence of quick-acting substances in the water, such as organic waste or ammonia. These substances easily interact with chlorine, producing by-products of disinfection or engaging in other chemical processes that deplete chlorine. As a result, when fast-reacting chemicals are present compared to when they are not, the concentration of free chlorine declines more quickly.

On the other hand, the presence of slow-acting substances, like specific kinds of bacteria or inorganic chemicals, may have a relatively lower effect on the pace of chlorine degradation. Slow-reacting substances interact with chlorine more slowly, resulting in a more progressive drop in free chlorine concentration over time. Slow-reacting substances can nonetheless contribute to chlorine degradation and reduce the effectiveness of disinfection over time, despite the potential for a less noticeable effect.

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