

Smart Mathematical Model for Chlorine Concentration Decay in Water Pipe Line Network

Rakesh Chandra Bhadula, Amit Kumar Mishra, Deepak Kholiya, Satyajeet Singh, V. N. Kala

Abstract: Water is the critical need of today world. Clean and drinking Water is made drinkable by water chlorination in repositories and water conveyance framework distribution system. To obstruct the bacterial growth a base measure of minimum amount of residual chlorine should remain in the water. It is a serious challenge for the checking point of view about residual chlorine to ensure the quality of water in the distribution system, as there are numerous factors which affect its concentration decay process. At the point when chlorine starts mixing with water it reacts with pipe wall and various other elements present in the water prompting to its concentration decay. This problem makes it necessary to investigate the behavior of chlorine decay pattern. In this paper we investigate that chlorine reducing with increment of the time period and various samples was collected from old age and newly built colony.

Keywords: Chlorination, framework, investigate

I. INTRODUCTION

Chlorine plays an important and essential role in purification of water, which is the need of every house hold. The pioneered researchers (Wable et al., 1991; Biswas et al., 1993; Rossman et al., 1994; Clark et al., 1995) gave zero-order and first-order reaction for CCD and validated that the first-order reaction gives a better result. Later researchers (Hua et al. (1999), Al Heboos et al. (2017)) gave two reactant agent (2R) models of first and second-order reaction in which the prediction given by second-order reaction was better. Hua et al (1999) suggested that decay constant was proportional to reciprocal of initial concentration and CCD is a function of temperature having exponential nature. The second-order model given by Al Heboos et al. (2017) was dependent on initial chlorine concentration but Ozdemir et al. (2018) experimental result showed that there is no relationship between chlorine bulk decay and initial chlorine concentration. The result obtained by using water from three sources by Fisher et al. (2012) through 2RA model seems to be in good agreement with Hua et al. (1999) and Al Heboos et al. (2017). He used the single value of activation coefficient, E_a/R with a slow and fast-reacting agent. Monteiro et al. (2015) applied 2RA model on raw and treated water. He predicted that CCD was fast with raw water and the slow reacting agent is very sensitive to temperature change than the fast-reacting agent.

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He suggested that the effect of temperature on CCD cannot be predicted accurately by a single value of the activation coefficient. The CCD depends on temperature change (Courtis et al. 2009). Ozdemir et al. (2018) found that the value of bulk decay constant varies with the water residence time in the pipe and temperature change. Fluid flow velocity is also one of the important parameters on which bulk decay constant depends on low-velocity high dispersion and high-velocity low dispersion. (Tzatchkov et al. 2002). Pipe service age is an important parameter in determining the CCD for all pipe material. Clark et al.(1994, 1995) through experimentation and simulation observed the effect corrosion on CCD and suggested that aged pipe have high chlorine demands. This study was further done by Al-jasser (2007) who suggested that the wall decay constant shows a decrease of -92% to an increase of +431% from the corresponding values of a newly installed pipe which shows that aged pipe due to corrosion in internal surface consumes more chlorine.

Many researchers had developed different mathematical models for chlorine concentration decay in water pipeline network. They discussed various parameters, which are directly related to chlorine concentration decay in water distribution pipeline network system, that affect the water quality. But there is requirement for a mathematical model which have bulk decay coefficient, wall reaction coefficient and mass transfer coefficient that can calculate the chlorine concentration decay for various time period, various temperatures with corrosion effect. In such a case, our model plays an significant role. The basic idea behind of this model is that, we can calculate the chlorine concentration decay at temperature and distance with galvanized iron (GI) traditional old pipe and new technology equipped galvanized iron pipes or widely used chlorinated polyvinyl chloride pipes (CPVC) so that gradually chlorine is injected on the distribution system to make safe and to maintain the limit of it so that it remain at a fair point. In this model chlorine concentration decay is calculated with the concept of temperature with different value values of E/R i.e 6000 C to 7000 C as Monteiro et al. (2015) taken different value of E/R and this is one of the most important parameter that is ageing factor of the pipe.

When chlorine is reacting with old pipe surface for that less chlorine is used to purify the water in the distribution system. While, in the case of newly aged pipe it is more effective for purification of water since less chlorine is react with the pipe's wall, and remaining chlorine react to purify the water. Similar experiment was done by Clark et al. (1994, 1995).



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This model is additionally useful for calculating chlorine concentration decay in galvanized iron (GI) traditional old pipe and new technology equipped galvanized iron pipes or widely used chlorinated polyvinyl chloride pipes (CPVC).

II. MATHEMATICAL MODELLING

Residual of chlorine concentration decay in water pipe line networks is depend on the following factors (i) Bulk reactions with chemical substances present in water distribution system. i.e. (ii) Wall reaction with material. i.e. (iii) Residual of chlorine by mass transfer (iv) Natural evaporation process in the water tank. Above factor can be written mathematically with help of differential equations

$$\frac{dc}{dt} = -k_b c \quad (i)$$

$$\frac{dc}{dt} = -k_w c \quad (ii)$$

Considering over all decay coefficient that is $k = k_b + k_w$.

$$\frac{dc}{dt} = -k c \quad (iii)$$

The wall reaction rate depends on the various factor like flow velocity, wall rate constant, pipe dia. Then Over all wall decay constant for pipe line network can be written as

$$k_w = \frac{2k_f k_w}{r(k_f + k_w)} \text{ .Where mass transfer coefficient}$$

$$k_f = S_h \frac{\text{Diffusivity}}{\text{Diameter of pipe}}$$

Thus equation (iv) can be solved analytically with the following initial and boundary conditions.

$$c(x, t) = 0 \quad t=0, x>0 \quad (v)$$

$$c(x, t) = c_0 \quad x=0, t \geq 0, \quad (vi)$$

Hence

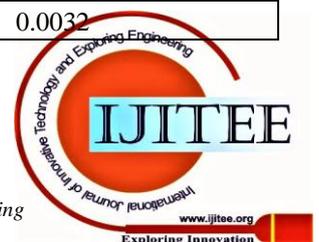
$$c = c_0 e^{-kt}, \text{ where } k = k_b + k_w \quad (vii)$$

III. RESULT AND DISCUSSION

In order to accomplish this study more than 500 water samples were collected from the various water distribution pipe line networks. This was either old distribution pipe line network or newly installed pipe line network. A generalized mathematical model was solved analytically and results were displayed with the help of MATLAB software. These results also compare with the actual samples which were taken from various distribution systems.

Table 1: Chlorine Decay for Old and Newly Built Pipe Line Network .

Serial No.	t (Time per second)	c (chlorine concentration PPM), where $k_b = 0.000005983$ per second & $k_w = 0.0000060300$ per second	c (chlorine concentration PPM), where $k_b = 0.0005983$ per second & $k_w = 0.00060300$ per second
1	0	3	3
2	300	2.9892	2.0922
3	600	2.9785	1.4591
4	900	2.9677	1.0176
5	1200	2.9571	0.7097
6	1500	2.9464	0.4949
7	1800	2.9358	0.3452
8	2100	2.9253	0.2407
9	2400	2.9147	0.1679
10	2700	2.9043	0.1171
11	3000	2.8938	0.0817
12	3300	2.8834	0.0569
13	3600	2.873	0.0397
14	3900	2.8627	0.0277
15	4200	2.8524	0.0193
16	4500	2.8421	0.0135
17	4800	2.8319	0.0094
18	5100	2.8217	0.0066
19	5400	2.8116	0.0046
20	5700	2.8015	0.0032



21	6000	2.7914	0.0022
22	6300	2.7813	0.0015
23	6600	2.7713	0.0011
24	6900	2.7614	0.0008
25	7200	2.7514	0.0005

Here we took the value of Bulk reactions coefficient $k_b = 0.000005983$ per second and wall reactions coefficient $k_w = 0.0000060300$ per second as pioneer researcher Ozdemir et. al (2010) was taken and chlorine concentration was taken 3 PPM and time was taken from 0 second to 7200 seconds then result was analyzed with the help of table 1 that chlorine is decaying slowly with respect to time. From table 1 it is also concluded that when $k_b = 0.0005983$ per second & $k_w = 0.00060300$ per second was taken chlorine is decreasing rapidly, which is happen in old aged colonies. In these colony most of the chlorine react with the pipe wall and rest of the chlorine purify the water, in such a case we have to inject the chlorine at some earlier point. This mathematical model will

help us to find such location and time period, in which we have to inject chlorine concentration in distribution system. Then we compare the results which has shown by mathematical model and collected samples, these samples were collected from newly built colony Turner Road and old age colony Clement Town, Dehradun. That was taken from different locations and time period from 0 second to 7200 second with the interval of 300 seconds. These compared results were shown in figure 1.

It was analyzed that the both mathematical model and collected data was similar. From these results it is observed that chlorine is decreasing with respect to the time and when chlorine is decreasing and its level reaches near to zero then we have to inject the chlorine to the distribution system for which we may use our mathematical model to identify the location where we have to inject the chlorine.

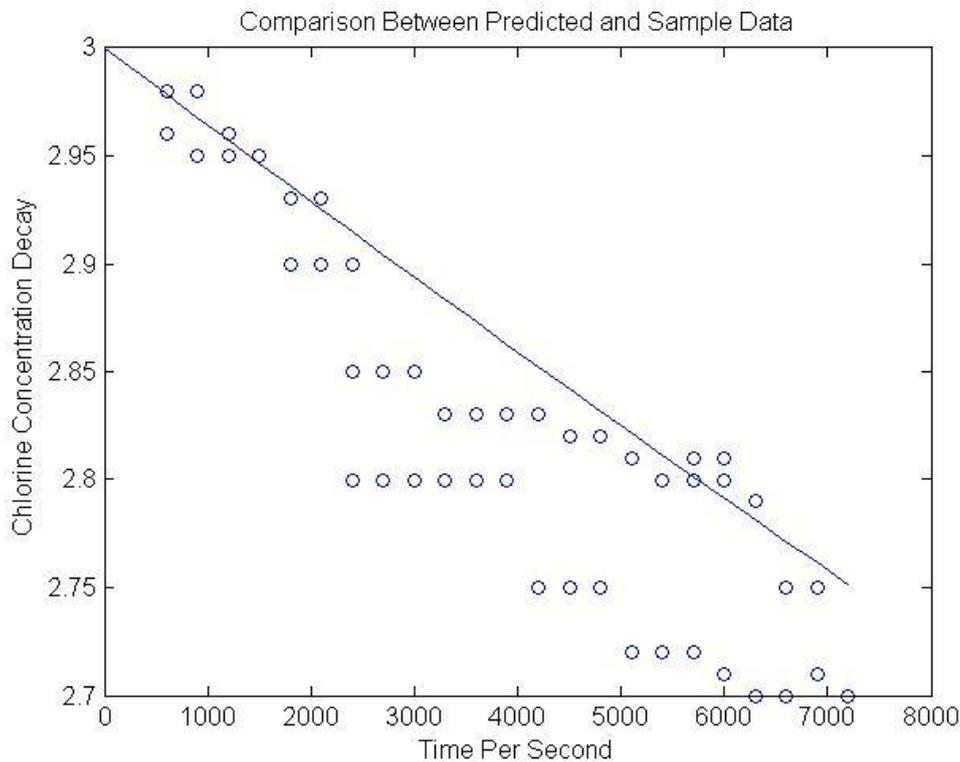


Figure 1 (Comparison Between Predicted And Sample Collected Data From A New Colony)

Another sample was collected from 50 year old colony Clement Town. Effect of age of cast iron pipe through which water is flowing plays a significant role in chlorine decay process. With time the pipe material quality degrades due to presence of bio-films and corrosion-erosion of pipe internal surface (Al-Jasser (2007)). For observing the influence of pipe service age, is introduced in the first order reaction. The sample collected from Clement Town was consistent with the result of Al-Jasser(2007). Here chlorine is decreasing very as fast. This phenomenon could be explained on the basis that in the newly installed pipes there is less chance of bio-films and corrosion of internal surface

hence the flow remains steady. But with increase in pipe service age, the thickness of bio-film increases, also due to oxidation and water hammering effect on internal surface that lead to corrosion-erosion and deterioration of pipe material (Kiéné et al. (1998)). This increases the chlorine consumption rate in pipe flow. Consumption pattern is shown in the figure 2.. After analyzing consumption pattern, it is observed that when chlorine is less than the amount prescribed by WHO.

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Then we have to inject to chlorine at that point like in figure 2.

In figure 2 chlorine .2 PPM at 3500 seconds which is the initial requirement of chlorine for purification of the water. Then after this point we have to inject chlorine to maintain

safe limit, so that it will be safe and consumer can not affect by impure water. With the help of our mathematical model we can find out the location where the chlorine is need to inject for this purpose our mathematical model plays a role as a smart device.

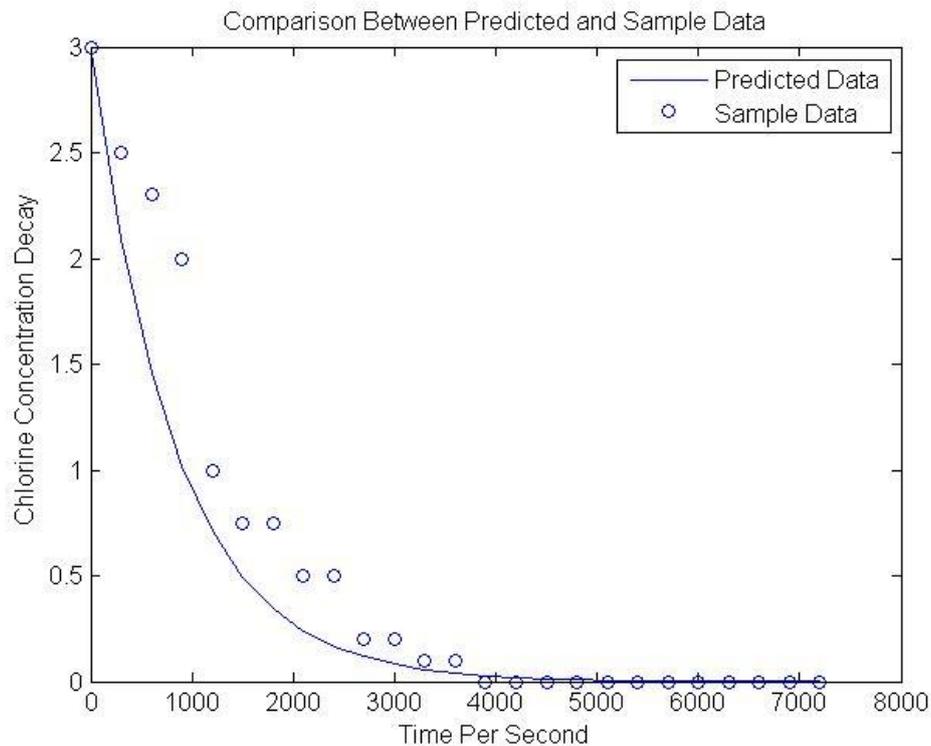


Figure 2 (Comparison Between Predicted And Sample Collected Data From A Old Colony)

IV. CONCLUSION

Mathematical model is solved analytically and result was plotted with help of MATLAB software and samples collected from two different sites i.e. Turner Road and Clement Town. An observation is made that chlorine consumption rate is very fast in old aged colony while It is very slow in newly built colony. It has observed that wall reaction rate is very high in old aged pipeline system and less chlorine remains for purification of the water. And it is concluded that there is very small error between predicted and sample collected values. These representation shows that newly built colony chlorine is reducing very slowly, which is due to the fact that pipe wall of new pipe line take less chlorine for wall reaction and rest of the do reaction with the water to purify it so that every house hold get pure water for his household activity.

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