Determination of Residual Chlorine In Water Distribution System of Dhule City Using EPANET

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Abstract- *The purpose of this study is to predict the level of chlorine residual in a drinking water distribution system of Dhule City and to help operators to determine chlorine dose in a drinking water using EPANET 2.0. Residual chlorine tests were performed for each zone on the day of water supply. Three set of readings were conducted and total 90 values were observed on-site using chloroscope. By comparing the observed readings with predicted values from EPANET by trial and error method The chlorine decay coefficients are found. This type of study is useful in understanding the movement of foreign particles in the water distribution system, to optimise the chlorine dosage at the water treatment plant and water storing facilities, to maintain limiting 0.2 mg/L of residual chlorine throughout the system. In water treatment process, chlorination is very important stage where disinfection of water is done by mixing chlorine in water. The level of chlorine in drinking water is thus of great importance. Lower values less than 0.20 mg/L may lead to pathogen formation in water and higher values greater than 1 mg/L may lead to produce DBP (disinfection by products) like trihalomethanes which may have some adverse effects on health. However, maintaining this residual is a complicated task because chlorine consumption is different according to the season, flow and pipe networks.*

Keywords- Residual Chlorine, Disinfection, EPANET, Water Quality.

I. INTRODUCTION

Water quality is a prime concern in the world. Many transmittable diseases are waterborne. Water distribution networks serve many purposes in addition to the provision of water for human consumption, which often accounts for less than 2% of the total volume supplied. People in rural areas obtained water from unprotected ponds or tanks, wells, cisterns and sometimes streams and rivers. Mostly this water is unsafe for consumption. Consequently, the populations suffer from frequent epidemics. The objective of any water distribution system is to make water available to the consumer in proper quantity and pressure, with acceptable quality in terms of flavour, odour, appearance and sanitary security. Preserving the water quality throughout the distribution system is, therefore, one of the most challenging technological issues for suppliers. Therefore, source concentration must be large enough to maintain adequate residual free chlorine as minimum 0.2 mg/L (Drinking Water Specification IS: 10500, 2012). Chlorine disinfection presents the advantages of efficiency and durability. To guarantee the water supply system's disinfection, we need a residual concentration disinfectant to prevent recontamination by pathogenic or indicator micro-organisms, which can originate in the biofilm formed inside the system, as well as in negative pressure areas. There is a problem when water distribution systems have considerable proportions. Chlorine residual concentration disappears along the system. Knowing the aspects behind chlorine decay is in order if we are to develop a strategy capable of disinfecting a water supply system and, at the same time, preserving water quality until the point of use, without using more disinfectant than necessary. Typically, chlorine is added near the final stages of drinking water treatment plants to disinfect. A certain residual amount is added to disinfect against any pathogens found in the inside walls of the distribution system piping. This residual chlorine is consumed on its journey through the piping system and the chlorine concentration should be at low concentrations at the point of consumption.. Computer-based mathematical models that able to predict the time history and the spatial distribution of constituents in water distribution networks are useful in network design and operation. Chlorine disinfectants interact with the natural organic matter in treated water to form disinfection by-products (DBP). Raising the pH of treated water may assist in controlling the corrosion but will increase the formation of trihalomethanes (by products of chlorine disinfectant). Since the THMs are carcinogenic, this is not desirable. There is a trade-off between providing enough residual to ensure the micro-biological safety of the water supplied, and adding too much disinfectant, which can lead to taste, odour, or by-product problems (Jea et al., 2012). Long retention times are very significant with regard to the concentrations of various contaminates and substances as they propagate through the system.

1.1 EPANET

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. EPANET was developed in 1993 with some kinetic models describing the decay of chlorine using data collected in field sampling studies (Vasconcelos., 1997). In this paper, the EPANET software developed by the USA Environmental Protection Agency is adopted because it is for general public and educational use and it is available online. It is not only free but it requires relatively small computer space to operate. It has unlimited number of pipes that can be analyzed. In addition, the User manual to guide the users understands the software can also be downloaded free. These are advantages for students, researchers and professionals of the developing economies who may not have the financial means to acquire other sophisticated tools. EPANET has become a very popular tool in analyzing complex and simple water distribution networks in both the developed and developing countries of the world.

II. OBJECTIVES

- The objective of any water distribution system is to make water available to the consumer in proper quantity and pressure, with acceptable quality in terms of flavor, odor, appearance and sanitary security.
- To understand the movement of foreign particles in the water distribution system, to optimize the chlorine dosage at the water treatment plant and water storing facilities, to maintain limiting 0.2mg/L of residual chlorine throughout the system.
- Knowing the aspects behind chlorine decay and to develop a strategy capable of disinfecting a water supply system, and at the same time preserving water quality until the point of use, without using more disinfectants than necessary.

III. LITERATURE REVIEW

Following are the literature papers referred for this thesis:

- Shreedhar (2015) designed the residual chlorine concentration decay in distribution network for three villages in northern part of Karnataka state, India. A constant concentration of 1mg/L was maintained in the tank. The reaction occurring in the bulk, as well as pipe wall reactions have been modeled with first order decay laws. The chlorine concentration was determined for three times moments i.e. at 3am, 6am and 8am. The minimum residual chlorine concentration of pilot village distribution was 0.60mg/L. Thus chlorine residual concentration values remain quite high (≥ 0.60 mg/L). For the considered water distribution network, the residual chlorine concentration values computed during the last 2 days of the simulation remain greater than the minimum admissible range of 0.3mg/L
- Goyal and Patel (2014) studied the amount of chlorine required for disinfecting the water supply with and without booster stations in Baroda, India. Incorporation of the booster station further reduced the amount of chlorine required for variable demand pattern as compared to constant demand pattern. The total required chlorine was considerably reduced by about 31.84%. Hence , the adoption of booster station is not only economical it would not pose any adverse health impact.
- Monteiro (2014) studied the performance of the 2R model as well as of first and nth order decay kinetics for full scale modeling of chlorine in a transmission system. Results have shown that a similar level of accuracy can be achieved with the three tested kinetic models, provided that a good calibration of the wall decay coefficient is accomplished. Although with improved modeling capabilities, the use of the standalone EPANET MSX was less user friendly than normal EPANET application by the lack of a graphical interface allowing for the visualization of chlorine concentration profiles along the system.
- Sivakumar et al. (2013) studied the effect of booster disinfection on water quality behaviour in distribution networks for Nirjuli, India. After adopting the three booster locations with the input concentrations of 0.5mg/L and modified dose of chlorine of 2mg/L at source node 49 and 1.5mg/L at source node 50, the total amount of chlorine required per day was 29kg. Hence, total required chlorine was considerably reduced by about 63%. Further, the amount of chlorine required per day reduced to about 76% for the variable demand pattern with booster station in comparison with the conventional disinfection process having constant demand pattern. The adoption of booster station is not only economical it would not pose any adverse health impact. Also found that variable demand patterns have many advantages over the constant demand pattern including water saving and disinfectant consumption for water quality analysis.
- Babaei et al. (2012) studied performance of pump, its operational cost and its optimization. Also studied that water quality of the network would not be less than such a certain amount and the possible increase. So that with lower costs and reduced energy consumption quality standard is maintained. To achieve this goal simulation program such as EPANET was used which has the ability to analyze hydraulic properties and water quality.

IV. METHODOLOGY

Total three zones of Dhule city are selected for the study. Water samples are periodically collected on the day of water supply, taken at 10 random locations where chlorine concentration is to be analyzed on-site with chloroscope.

4.1 Hydraulic Data Required

- Underground Pipe network layout map.
- Length, Diameter, Roughness coefficients of each pipe, material of pipe.
- Elevation of nodes, demand at nodes.
- Information about dead ends, loops.
- Type of valve, diameter

4.2 Analysis of Residual Chlorine

First the system hydraulic model (EPANET) is set up with all of the pipe, reservoir and junction data. All the data is obtained from Municipal Corporation, while bulk chlorine decay coefficient is obtained from literature and some model runs. Details of the network layout and hydraulics are fed to the software. Network of the selected zone is prepared. Value of the bulk decay coefficient -1.0 d-1 is selected from the literatures [(Mohammed et al., 2009), (Rossman 2000)]. The wall decay coefficient is found out by trial and error method by analyzing the residual chlorine values in the system (Toru et al., 2008). It is done by computing least square error between the data obtained from observed values and software predicted values. These coefficients are applied for the other zones also, and their validation purpose and good results are obtained. Water samples are periodically collected on the day of water supply, taken at 10 random locations of the zone where chlorine concentration is to be analyzed on-site with chloroscope. Orthotolidine solution is used in the analysis. For this, 10 ml water sample is taken in clean glass tube. 1-2 drops of orthotolidine solution is mixed in the sample. The yellow colour would form if residual chlorine is present. Then, this tube colour is compared with the comparator tubes in the chloroscope and the reading is noted down. Two sets of readings are collected on each day of analysis of which one set contains 10 readings starting from ESR to the 10th selected node of the study area zone. After collection of 1st set of readings which takes 1 to 1.5 hour, 2nd set of readings is taken from ESR to 10th selected node.

4.3 Steps in using EPANET

- Draw a network representation of your distribution system or import a basic description of the network placed in a text file.
- Edit the properties of the objects that make up the system.
- Describe how the system is operated.
- Select a set of analysis options.
- Run a hydraulic/water quality analysis
- View the results of the analysis

V. RESULTS AND DISCUSSION

Total 3 number of zones: - Zone-1 Pirachi Tekadi GSR, Zone-3 Chakkarbardi ESR, Zone-9 Ashok Nagar ESR of the Dhule city are studied and analyzed for the prediction of residual chlorine in the water distribution system. The residual chlorine is found out on site using Chloroscope instrument. The results obtained from the field tests and that of EPANET software are calibrated and the coefficient of wall decay is obtained for all these zones along with the minimum initial required chlorine dosage in the ESR. The data obtained from observed values and that of EPANET software is calibrated to find the K_w value. This K_w value is then validated by applying it to the other zones and satisfactory results are obtained. From literatures it is found that in most cases, the ideal calibration is to be done by comparing the predicted and observed data by use of Root Mean Square Error Method (RMSE). The predicted values for all zones are obtained by varying the value of K_w as -0.45/day, -0.50/day, -0.55/day, -0.60/day and K_b= -1/day is kept same for all zones.

5.1 RMSE Analysis

The root-mean-square error (RMSE) is a measure of the differences between values (sample and population values) predicted by a model or an estimator and the values actually observed. These individual differences are called residuals when the calculations are performed over the data sample that are used for estimations, and are called prediction errors when computed out-of-sample.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}$$

Where, n= number of readings in a set,
y = observed reading
y^ = predicted reading

From the readings given in the Annexure, following RMSE values are obtained

Table 1: RMSE obtained for Zone-1

K_w, K_b	-0.45, -1	-0.50, -1	-0.55, -1	-0.60, -1
%RMSE	3.94	3.81	3.78	3.99

Table 2: RMSE obtained for Zone-3

K_w, K_b	-0.45, -1	-0.50, -1	-0.55, -1	-0.60, -1
%RMSE	3.56	3.22	2.94	3.21

Table 3: RMSE obtained for Zone-9

K_w, K_b	-0.45, -1	-0.50, -1	-0.55, -1	-0.60, -1
%RMSE	3.28	3.07	2.91	3.43

Though the differences between the errors for different K_w values are small, the K_w corresponding to the least RMSE is of great importance. Thus from the above data, the value of coefficient of wall decay K_w= -0.55/day is determined for the Dhule City.

5.2 Minimum Initial Required Residual Chlorine at ESR

The minimum initial required residual chlorine at the ESR is also found out with the help of EPANET software with the condition to have minimum 0.20 mg/L residual chlorine at the tap of consumer of the zone with K_b = -0.55/day, K_b= -1/day. If the below concentrations are maintained at the respective ESR, then there will be atleast 0.20 mg/L of residual chlorine in each house of the zone which is the minimum requirement according to Indian Standard Drinking Water Specification (Second Revision IS:10500,2012).

Table 4: Minimum Initial Required Residual Chlorine at ESR

ZONE	MINIMUM INITIAL REQUIRED RESIDUAL CHLORINE AT ESR
1- Pirachi Tekadi GSR	0.8 mg/L
3- Chakkarbardi ESR	0.5 mg/L
9- Ashok Nagar ESR	0.4 mg/L

VI. CONCLUSION

Controlling the residual chlorine in drinking water is a very important aspect, since the decrease of chlorine concentration below a minimum level may cause secondary development of microorganisms and excessive chlorine concentration may cause formation of dangerous DBP. Mathematical modeling of chlorine decay along the water supply system is thus necessary from public health point of view. The water quality model of the water distribution system gives well calibrated quality model to be used along with the specific reaction rate. The reaction occurring in bulk as well as pipe wall reactions are modeled with first order decay laws. The water quality analysis is performed in EPANET, to obtain K_w value and chlorine residual concentration in the network. The following conclusions can be drawn from the study:

- The initial minimum residual chlorine at the ESR for Zone-1 is found out to be 0.8 mg/L.
- The initial minimum residual chlorine at the ESR for Zone-3 is found out to be 0.5 mg/L.
- The initial minimum residual chlorine at the ESR for Zone-9 is found out to be 0.4 mg/L.
- The decay is faster for higher values of initial residual chlorine at ESR than those of lower values.
- EPANET incorporated first order model is found to be satisfactory in terms of prediction of residual chlorine.

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