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Residual Chlorine Decay in Juja Water Distribution Network using EPANET Model

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Abstract*: The current study was carried out to analyze the residual chlorine decay analysis within the existing Juja water distribution network. The study used EPANET as a simulation tool. From the field samples, the first-order bulk decay coefficient Kb was found equal to - 0.047 h^{-1}. The wall coefficient Kw was assumed to - 4.0 mg/m^2/day as guided by literature. The analysis shows that the entire supply area of the existing distribution network faces higher residual chlorine concentration (0.70 to 0.8 mg/l) from 9 am. The study recommended the reducing of the initial chlorine added at the treatment plant and the optimization of the network, which will provide a proper residual chlorine dosage to reduce Juja consumers exposure to health risk and also to be economically reasonable for the water company in charge

Keywords: Residual Chlorine, Distribution System, Bulk decay coefficients, Wall decay coefficients, EPANET.

I. INTRODUCTION

In most developing countries, the water distribution network failed to satisfy the demand in terms of flow, pressure and ideal quality during daily consumption. Especially in Juja water distribution network, a semi-urban town located in central Kenya, the residual chlorine concentration seems to be higher in the distribution network. The world health organization standard limits the residual chlorine concentration at public water stand taps to be 0.2 – 0.3mg/l at 30 minute contact time, less than this, the water is not a good fit for direct consumption[1]. Residual chlorine should also be limited to a reasonable dosage to minimize water taste and odor inconvenience [2]. EPANET model chlorine decay thought two coefficients (the reactions in the water mass k_b and wall reactions k_w). For residual Chlorine decay analysis, the chlorine concentration is assumed to decay exponentially[3]. k_b and k_w are set to negative values because of the actions of decomposition. EPANET model the reactions in the water mass with a kinetic order 1, which means that the instantaneous speed of the reaction (in mass/volume/time) depends on concentration. The k_b coefficient of order one reactions is usually assessed by water samples chlorine analysis after a time of presence. The k_b coefficient can be evaluated using the expression: Ct= $Coe.^{-Kbt}$ (1)

Where k_b is a coefficient of bulk flow, Ct the concentration at the time t and Co the initial concentration. Most often, the coefficients of reactions in the water mass increase with temperature. It is recommended to take into account the temperature variation while evaluating k_b. The speed of a reaction that occurs on the wall of a pipe can be considered a dependent of the concentration in the bulk flow. The contribution of wall reactions is introduced into the Epanet through another constant k_w zero-order kinetics constant. The wall reaction decay also depends on temperature, organic content in the water, and initial disinfectant concentration[4]. The wall reaction decay coefficient of each pipe depends on the coefficient used to describe its roughness. k_w is usually adjusted to take into account the limitations on the transfer of mass of reactants and products between the water mass and the wall [5]. This study, therefore, seeks to Model the residual chlorine decay in The Juja water distribution system using EPANET.

II. MATERIALS AND METHODS

2.1 Hydraulic modelling

EPANET quality simulation in a given distribution system is based on a hydraulic model on which to apply the quality model. The hydraulic model supporting this study was developed for Juja (central Kenya) water distribution network main [6].

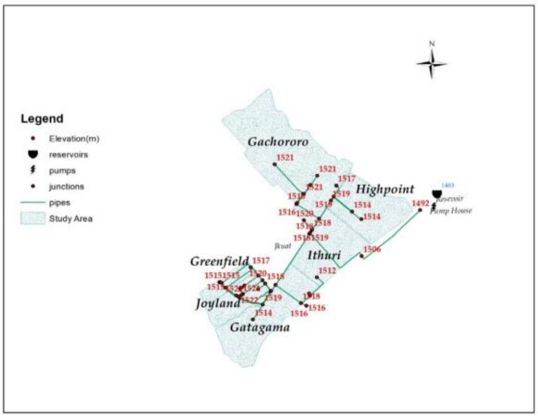

Figure 2.1: Juja Town Distribution Main [6]

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2.2 Water quality modeling

2.2.1 Bulk Decay Coefficient

The bulk flow reactions depend only on the chemical composition of distributed water and are not affected by the pipe characteristics or formed biofilm. A laboratory test was conducted to calculate its value, as described in the literature[7], [8],[9]. To estimate the bulk decay coefficient k_b, a water sample was taken from the distribution network. The water sample was subdivided into 6 separated sub-samples, each of 10 ml (non-reacting glass bottles). After that, the 6 sub-samples were subjected to residual chlorine test successively using the DPD procedure[10]. The first sub-sample was tested just after it was taken (at t=0) followed by the other 5 sub-samples with a time gap of one hour between each, t1, t2, t3…tn, as shown in Figure 2.2. The field chlorine concentrations plotted versus time.

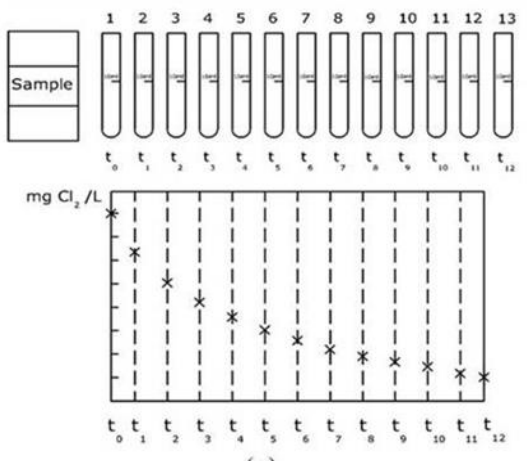

Figure 2.2: Diagram of the method used in calibrating Kb [9]

2.2.2 Wall decay coefficient $\mathbf{k_w}$

Wall decay coefficient depends on water temperature and actual pipe wall conditions; therefore, it is challenging to evaluate on a laboratory. To overcome this difficulty in the present study, the wall coefficient was assumed to be the same for all network pipes as guided by literature. As the modeled network consists mainly of PVC pipelines, k_w was assumed initially to ***- 4.0 mg/m²/day*** and will be adjusted further [11].

Once k_b and k_w coefficients were estimated, they were introduced to the model, and an extended water quality analysis was run for 24 hours.

2.2.3Model validation

This study used a questionnaire to validate the model. Juja consumer was subject to question about how they feel the taste and the odor. From the level of satisfaction, the chlorine concentration was estimated. A total of 100 houses were assessed during the questionnaire process. Most of the house assessed was located at Gachororo and Gate C (Joyland and greenfield) due to their high population density.

III. RESULT AND DISCUSSION

3.1 Calibration wall and bulk coefficient (and)

From the methodology described in section **2.2.1**, the bulk coefficient k_b was calculated and was found to be -0.047 hour^{-1} , as shown in Figure 3.1 below.

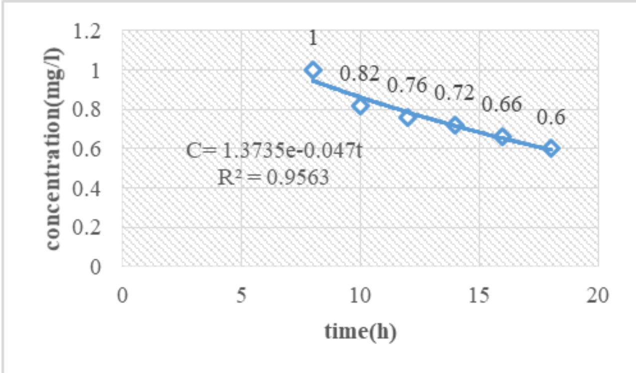

Figure 3.1: Calibrated bulk coefficient k_b

The wall coefficient k_w doesn't have any significant impact on the chlorine decay in this study during the adjusting process. Then it was taken to be ***- 4.0 mg/m²/day*** as guided by literature.

3.2 Chlorine concentration throughout the system

The chlorine takes time to reach all the nodes located in the distribution network. It was found out that by 9 am there was presence of constant chlorine in all the nodes with value between 0.70 and 0.80 mg/l, as shown in Figure 3.2 below.

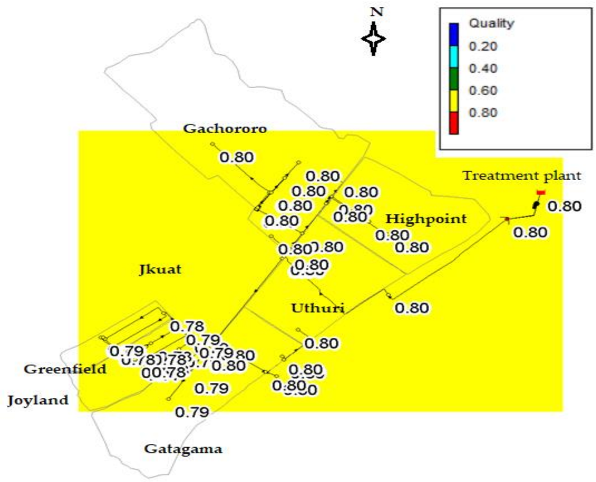

Figure 3.2: Concentration tie-lines of chlorine throughout the system from 9 am

From figure 3.2 above, it is evident that the Juja distribution network presents a higher concentration of residual chlorine in the entire network from 9 am (0.70-0.80 mg/l). High residual chlorine in drinking water may produce apart from taste and odor another effect on consumer health. However, chlorine is used to combat microbial contamination; it can react with organic matter in the water and form dangerous carcinogenic Trihalomethanes [12].

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Therefore, It is crucial to provide only the necessary chlorine dosage to avoid recontamination and, higher residual chlorine concentration may not be economically justified. The distribution network's residual chlorine decay rate may be explained by the low velocity of water in the pipes (95% of the pipes have a velocity of 1 m/s and less). As demonstrated by [13] in some pipes, disinfectant residual losses increased with velocity.

3.3 Model validation

From figure 3.3 below, we can notice that the target consumers for the survey denied the chlorine concentration between [0.2-0.4 mg/l] or [0.8-1 mg/l]. 90% indicated the chlorine between [0.6-0.8 mg/l], which seems to be approximately what the model has given, as shown in section 2.2.3. Only 10% has indicated the chlorine between [0.4-0.6 mg/l].

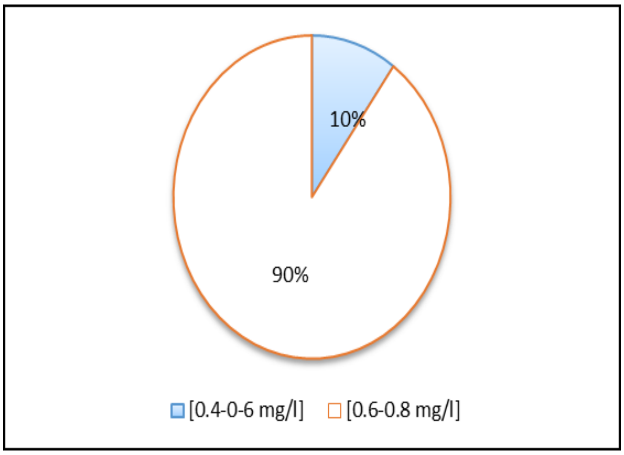

Figure 3.3: Residual chlorine from customers level of satisfaction

IV. CONCLUSION

From the above study, it is evident that the Juja water distribution system presents higher residual chlorine (0.70 to 0.8 mg/l) from 9 am. It is important to notify that high residual chlorine in drinking water may result in poor taste and form dangerous carcinogenic Trihalomethanes. It's then crucial to provide only the necessary chlorine dosage to avoid recontamination. The distribution network residual chlorine decay rate may be explained by the poor hydraulic state of the actual distribution network (velocity in pipes less than 1 m/s) and, also by the water age in the system since it was treated (direct pumping). A higher residual chlorine concentration may not be economically justified. Thus**,** it is crucial to reduce the initial chlorine added at the treatment plant while trying to optimize the hydraulic properties of the network as a new investment to maintain a safe supply throughout the entire network.

The future work will focus on optimizing the network for an efficient supply.

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