Predictive Model for Lime Dosage in Water Treatment Plant

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***Abstract*-** A predictive model for determining the quantity of lime required for water treatment was developed by considering the inter-relationship between water quality parameter such as pH and the quantity of lime required for water treatment. The model constants were obtained using least square regression method and solving the resultant equation using MATLAB program. The resultant model equation was found to be Q= -1.5402+ 1735.539(⟦10⟧^(-ΔpH)). Comparison of the results from the simulation of the model and experimental data showed a good prediction with a correlation coefficient of 89%.

***Index Terms*-** predictive model, lime, dosage, pH, water treatment.

I. INTRODUCTION

Water treatment can be defined as the manipulation of a water source to achieve a quality that meets the specified goals or standards set by the community through its regulatory agency [1]. It involves physical, chemical and biological changes that transform raw water into potable water. The choice of treatment process depends on the quality and nature of the raw water. Water treatment processes can be simple, as in sedimentation, or may involve complex physicochemical changes, such as coagulation [2].

An important water quality variable that must be considered when selecting or configuring the water treatment sequence is the pH [3]. This variable has major effects on the chemistry of constituents in water and on the treatment process performance. It is therefore important to routinely monitor and control the pH profile in all water treatment stages. The effectiveness of coagulants and polymers varies greatly depending on the pH of the water. pH also affects corrosion and water quality in the distribution system and thus must be controlled to minimize water quality impacts [1,3].

Lime is an odourless white powder which is soluble in water. The principal component of lime is calcium hydroxide ($Ca(OH)_2$) [4]. Lime is used to adjust the pH of drinking water and is added at various stages of the process. These include adjustment of water pH to prepare it for further treatment and combating "red water" by neutralizing the acid water, thereby reducing corrosion of pipes and mains from acid waters. The corrosive waters contain excessive amounts of carbon dioxide. Lime precipitates the CO_2 to form calcium carbonate, which provides a protective coating on the inside of water mains [5]. Lime is used in conjunction with alum or iron salts for coagulating suspended solids incident to the removal of turbidity from "raw" water. It serves to maintain the proper pH for most satisfactory coagulation conditions. In some water treatment plants, alum sludge is treated with lime to facilitate sludge thickening on pressure filters [6]. A diagram of typical water treatment plant is shown in Figure 1.

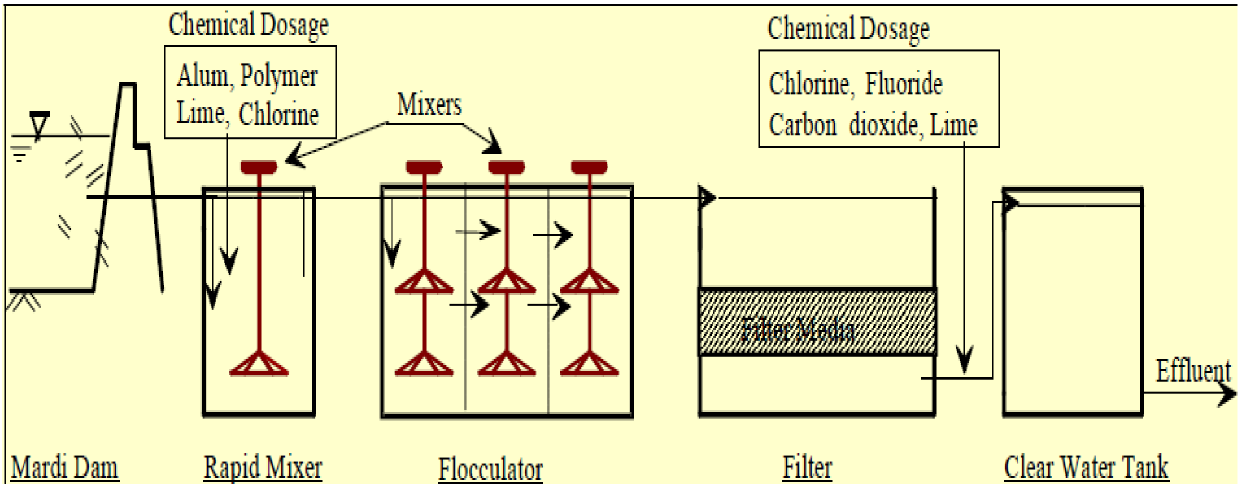

Figure 1: Typical water treatment process [2]

Two principal methods of lime dosing can be employed. The first is fixed rate dosing of variable strength lime solution. In this case, the amount of powdered lime mixed into solution is controlled, thus regulating the strength of the lime solution, once mixed in this manner the lime is dosed into the water stream at a fixed rate. Changes in the pH of the water are adjusted by changing the amount of lime powder introduced into the lime solution, the lime is mixed on a continuous basis in accordance with pH of the incoming water. High-level corrections are made using stronger lime solutions and low-level corrections are made using weaker lime solutions [7]. The second principle is variable rate dosing of fixed strength lime solutions. The lime is mixed at a set strength in a bulk batch and is then dosed into the water stream at a flow rate which is controlled in relation to the pH of the water. Introducing higher volumes of lime solution makes high-level corrections; low-level corrections are made introducing lower volumes of lime solution. For the first method, fixed speed fixed flow pumps are employed while for the second method variable speed variable flow pumps are utilised [7].

The water industry is facing increased pressure to produce higher quality treated water at a lower cost. The efficiency of a treatment process is closely related to the operation of the plant [2].The high cost of chemical analysis of raw water to determine the quantities of chemicals required for water treatment has necessitated the need for various researches into finding alternative methods such as models. Model equations allow quantities of chemical to be predicted from the existing water quality parameter data [8]. Compared to other water research fields not much development was documented in the field of water treatment dosing models [2]. The use of artificial neural networks for process modeling and control in the drinking water treatment industry is currently on the rise [2,9,10], however, reports on the application of statistical methods such as linear regression, multi-variable regression etc are scarce.

Kaduna North water treatment being the largest water supplier in Kaduna-Nigeria spends millions of Naira annually in producing potable water on chemicals which constitutes a significant operational expense. The chemical budget, despite being influenced by the price of chemicals, is also dependent on several operational variables such as, the volume of water to be treated, the choice of chemical regime and the dosing requirement of each chemical [10]. Owing to such influences, the predictability of chemical spending is challenging. The plant has over the years documented the raw water quality, the treatment plant performance as well as the treatment chemicals used. This study is aimed at developing a model that can be used to predict the quality of lime required for neutralization of pH in the water treatment plant. This was done by using statistical procedures to establish whether a significant relationship exists between water quality and required chemical dosages.

II. MODELING PROCESS

The following assumptions were made to facilitate the development of the model equation.

i. The amount of lime used is only influenced by the changes in water quality
ii. There is uniform distribution of the lime in the water (ideal, well mixed)

Water becomes slightly acidic after passing through the clarifier and the filter [5,6]. Lime is therefore added to neutralize the pH (i.e. pH value of 7). A large difference between the pH of the water medium and the pH value of 7 (iso-electric point (pH_{is})), means more quantity of lime (Q) will be required for the neutralization and vice versa.

This can be represented as follows:

$$Q \propto pH - pH_{is} \quad (1)$$

Taking ΔpH as the positive value of pH – 7,

$$Q \propto -\Delta pH \quad (2)$$

Since pH is a log function of hydrogen ion concentration, $[H^+]$, Equation (2) can be rewritten as

$$Q \propto 10^{-\Delta pH} \quad (3)$$

Introducing constant,

$$Q \propto K_1(10^{-\Delta pH}) \quad (4)$$

To correct variations from other factors not accounted for, a constant (K_2) is introduced.

$$Q = K_2 + K_1(10^{-\Delta pH}) \quad (5)$$

The constants are determined by least square regression method [11].

Let Q_{1i} be an observed value of quantity of chlorine and predicted value of the model is

$$K_2 + K_1(10^{-\Delta pH})i \quad (6)$$

Then the error of prediction E will be given by

$$E_i = Q - K_2 + K_1(10^{-\Delta pH})i \quad (7)$$

And the square of the error is

$$E_i^2 = [Q_i - K_2 - K_1(10^{-\Delta pH})i]^2 \quad (8)$$

And for all set of data,

$$\sum_i^2 E_i^2 = \sum [Q_i - K_2 - K_1(10^{-\Delta pH})i]^2 \quad (9)$$

And expanding gives,

$$\sum_i^2 E_i^2 = \sum Q_i^2 - 2K_2 \sum Q_i - 2K_1 \sum Q_i(10^{-\Delta pH})i + K_2^2 + 2K_2K_1 \sum (10^{-pH})i + K_1^2 \sum (10^{-\Delta pH})^2 i \quad (10)$$

To minimize the error i.e. to obtain those values of constants that give best prediction by finding the derivatives of the $\sum_i^2 E_i^2$ with respect to the constants K_1 and K_2 and equating to Zero.

$$\frac{\partial \sum E_i^2}{\partial K_2} = 2K_2 - 2\sum Q_i + 2K_1(10^{-\Delta pH})i \quad (11)$$

$$\frac{\partial \sum E_i^2}{\partial K_1} = 2K_1 \sum (10^{-\Delta pH})_i^2 + 2K_2 \sum (10^{-\Delta pH})i - 2\sum Q_i (10^{-\Delta pH})i \quad (12)$$

The water quality data were collected from the daily records kept by the Kaduna north water treatment plant for a period of two years. Using MATLAB, the values of the constants K_1 and K_2 were determined using weekly average for a period of one year. All the daily readings were not used directly since the data generated will be cumbersome. The model was verified using different set of data from another period of one year.

III. RESULTS AND DISCUSSION

a. Quantity of lime and pH data from the water works.

The weekly average quantities of lime dosage and pH values obtained from the water treatment plant are shown in Figures 2 and 3 below. The pH of the water of the filtered water was observed to have values between 6.2 and 6.3 (slightly acidic). This was because the clarified water contains more CO_2 which forms weak acid (H_2CO_3) with water. This makes the water corrosive and can lead to the corrosion of the pipes [6,7,12]. Seasonal variations also affect the quantity of alum dosage because the raw water has higher turbidity during rainy season due to run off water addition to the main water body. This also affects the acidity of the clarified water and hence the quantity of lime dosage.

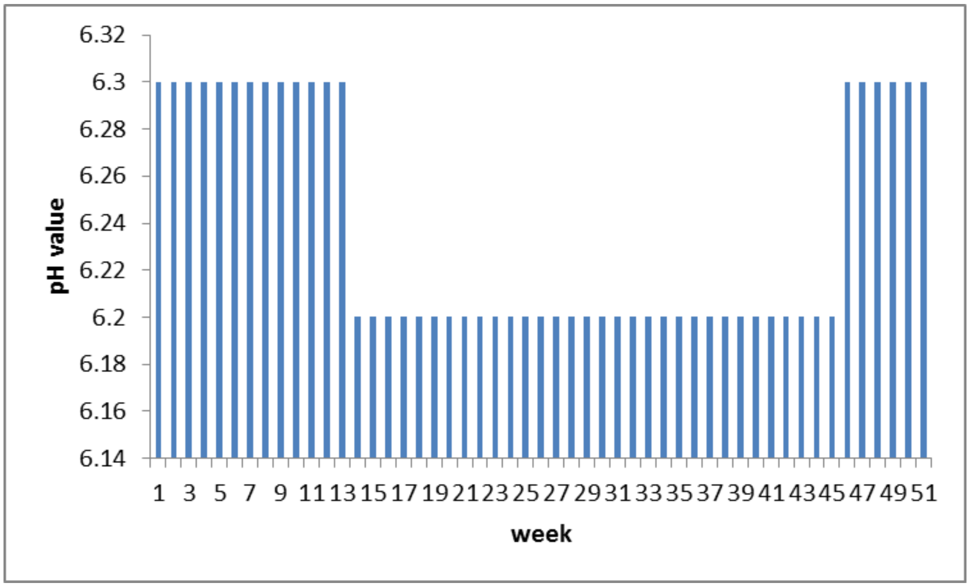

Figure 2: Weekly average values of pH

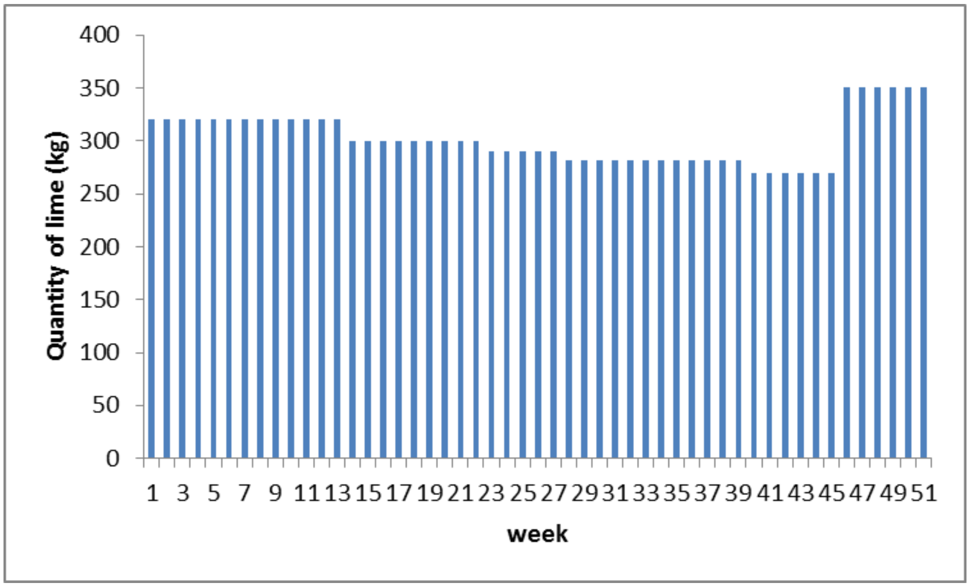

Figure 3: Weekly average values of quantity of lime

b. Model result and Verification

Substituting the values of the constants, K_1 and K_2 into equation (5) gives the model equation for predicting the quantity of lime required for water treatment.

$$Q = -1.5402 + 1735.539(10^{-\Delta pH}) \qquad (13)$$

The model was simulated using another set of data obtained for a period of 52 weeks. A good program is measured by its robustness in performance against the changes of the problem properties. And its accuracy is a measure of a nearness of a value to the true value [13]. Figure 4 gives a comparison of the Weekly average of the model and actual quantities of lime. An observation of the results shows a very good prediction of the quantity of lime. However, slight deviations were observed in week 4, 6 and 7 which can be attributed to human errors during the measurement of parameters, the solution technique and incomplete mixing which leads to the consequent presence of dead zones. A statistical analysis of the model performance gives a correlation coefficient of 89%.

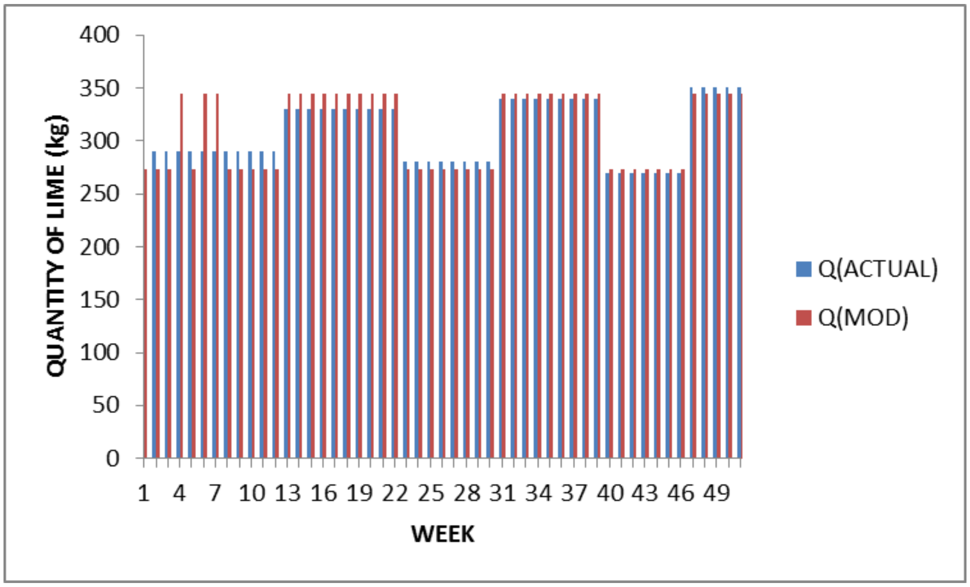

Figure 3: Comparison of the Weekly average of model and actual quantities of lime.

IV. CONCLUSION

A predictive model of lime dosage has been successfully developed using operational and water quality data from Kaduna-North water treatment plant. The model was able to correctly predict the dosing rates of lime required for pH neutralization. Further studies are hereby recommended for lime application in conjunction with alum or iron salts for coagulating suspended solids from raw water.

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