Residual Chlorine Decay In Water Distribution Network

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Residual Chlorine Decay In Water Distribution Network

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Abstract: The study was undertaken to measure the variational change in residual chlorine decay in water distribution network. A total of 900 water sample were collected at different period of the day for one month, from different ten water sample locations at water stand taps, at the study area in Calabar South Local Government Area of Cross River State, Nigeria. The effect of various Pipe diameter, water sample point distance, change in chlorine concentration with time on residual chlorine and regression model of residual chlorine as a function of dosage, pipe diameter and temperature were investigated. First order decay equation was used to model and analyst the variational change in residual chlorine concentration. It was observed that, the residual chlorine concentration decreases as pipe diameter increases. The loss of chlorine in water was found to be smaller in larger pipe diameter. The residual chlorine concentration decreases as distance increases. A linear relationship was observed to exist between residual chlorine concentration and change in chlorine concentration with time. Furthermore, from the regression model, the R square value, been the coefficient of correlation of the regression, shows that, for morning period 87%, afternoon period 85% and night period 73% of the total variation of the chlorine concentration at the water stand taps was accounted for by dosage, temperature and pipe diameter. This research offers several options and robust approach in addressing chronic water supply in Cross River State and as a guide in planning, simplifying approaches in predicting residual chlorine in pipe of varying diameter and strategizing proper dosing approach for water treatment plant to attain a desirable and durable residual chlorine at water stand taps.

Keywords: Residual Chlorine, Water Distribution Network, Pipe diameter, Water sample point distance Calabar, Cross River State.

I. INTRODUCTION

Modeling and analyzing residual chlorine in water distribution network is very essential in predicting the Variational change in the dosage of chlorine concentration from the ground level water storage reservoir at Cross River State water board to the public water collection stand taps at different location. Chlorine is rated as one of the regularly used disinfectant by water utilities and water service providers to kill and inactivate microorganisms so that they cannot reproduce and infect human hosts. This disinfectant is readily available, cheap, easy to transport, occur in gaseous, liquid and solid form. However, when injecting Chlorine in water and is transported through water pipes of distribution network; it under goes reactions with the bulk water and with the inner pipe wall naturally along the distance of travel. The reactions result in the dissipation and loss of residual chlorine. These phenomenon pose a major threat in weakening the barriers against water safety and create the chances of recontamination.

According to world health organization standard, a limit for residual chlorine concentration at public water stand taps was set up to be 0.2 – 0.3mg/L at 30 minute contact time, less than this, the water is not fit for direct consumption (WHO, 1993).Similarly, Lious and Kroon (1987) in their work, reported that on the disinfecting action of chlorine, that when chlorine is added to water, it form hypochlorous acid or hypochlorite ion which have an immediate and disastrous effect on most form of microscopic organism.

In a write up by R.O. Connor from Ontario Ministry of the Attorney General report that in May 2000 in Canadian town of Walkerton, that seven people died and more than 2,300 became ill after E-coli and other bacteria related disease infected the town water supply and was concluded that, after the water well was contaminated, the Walkerton disaster could have been prevented if the required residual chlorine had been maintained (Connor., 2002).It was also estimated that 3.4 million people mostly children die every year from water related diseases (World Health Organization., 2002a).The centre for disease control reported that the contamination of the distribution system can occur when water main is broken (CDC., 2002).

In an experimental study conducted on the effect of flow rate and pipe diameter on wall chlorine decay by Risala and Kifah (2011), they observed that chlorine decay rate decreases as pipe diameter increase. A comprehensive study undertook by Ekeng and Agunwamba (2011) on the effect of pipe ageing of different diameter and pressure on residual chlorine, using calcium hypochlorite (HTH) and DPD reagent of N.N. Diethylephenylene – diamine. It was observed that the application of free chlorine on smaller pipe diameter shows relatively large chlorine dissipation than in pipe of larger diameter. They also found that the age and condition of the distribution system account for most losses of disinfectant residual.

A. AL-Jasser (2007) conducted a study on chlorine decay in drinking water transmission and distribution systems. He concluded that distance travelled on larger transmission line with minimum chlorine concentration increases bacterial growth. According to K. Gotoh (1988), Lu et al (1999), Sharp et al (1991), Residual chlorine concentration decreasing rate coefficient for various pipe materials shown that, the root causes of bacterial growth in distribution network is distance traveled in larger transmission lines and showed the problem to be very dangerous to human health.

Based on previous work done by Wableetal (1991), Sharp et al (1991) on modeling chlorine concentration in network and applications to Paris distribution network, they concluded that it appears reasonable to assume that, the disappearance of chlorine in water flowing through pipe is governed by first order decay equation.

$$K = \frac{K_w K_f}{R_n (K_w + K_f)} \qquad 1.1$$

K = chlorine decay coefficient (l/T)
Kw = wall coefficient (L/T)
Kf= Mass transfer coefficient (L/T)
Rn= Hydraulic radius

Geldreish (1996) carried out a research on microbial quality of water in distribution system; he found that the residual chlorine concentration was within 1.2- 0.3 mg/L, which can control a number of microbial organisms below 100 to 500 milliliter of water sample.

II. MATERIAL AND METHOD

STUDY AREA

The study area is located in Calabar, Cross River State, Nigeria. The scope of the area is denominated by two major rivers, Calabar River in the north-west and the Great kwa River in the eastern part of calabar. The study area is located between latitude 4^{o}55’15” and 4^{o}58’30” North and longitude 8^{o} 18 30” and 8^{o} 21’00” East, with a population of 100, 585 in 1991 population census. It has a population of 191, 630 in 2006 National population projection. It occupies an area extent of 270 sqkm (Antigha, 2002).

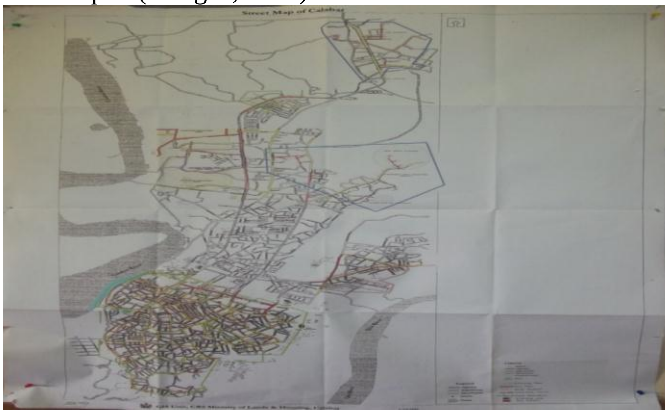


Figure 3.2: Map of study Area

The analysis was conducted using colorimeter color-wheel test kit, a free chlorine measurement equipment that uses a powder chemical DPD (N, N. diethylenediamine) that causes colour change to pink in the presence of chlorine. It also used to ascertain the quantity of free chlorine available in the collected water sample. Hanna H199100 PH/Temperature was used to measure the ph and temperature of the collected water sample. A stop watch was used to read the residence time for distance of the collected water sample from one location to another. The pipe types use in the distribution line are of pvc pipes and the pipes diameter are range from 0.0191 -0.9m.A total of 900 water sample were collected from 10 water sample location at water stand taps at different period of the day from the study area. The various period were morning, afternoon and night period. The study area comprises of Cross River State Water Board and Nine Public water sample collection location. The Nine Public Water sample Collection Location are: Goldie, Mount-zion, and yellow-Duke, Ekpo-Abasi, New-Airport, Abitu, Jebs, Imman and Mbukpa. The source of water is from Cross River State water board, which extract its main collection source from a fresh water river located at lemna road at Ikot-Effangha, Calabar. The topography of the study area is slightly steep with slope of about 1.700 m (Edet and Ntekin,1996).

Two sets of water sample were used, sample A containing the treated water collected from different water sample location. Sample B contain distilled water used for controlled of the experiment. A sachet reagent pillow Haclpermachen DPD (N.N. diethylphenylene) is dissolved in 10 mg of test-tube containing the treated water sample A, the both water sample were thoroughly shake to ensure homogeneity in mixture before putting in place on the color-wheel test kit apparatus. The test kit has an adjustable scale which is adjusted for both water sample A and B to change to pink in the presence of free chlorine. Observation was made and the concentration of residual chlorine recorded in mg/L. The procedure is repeated for each water sample collected. However, for each measurement carried out on each water sample collected, the time t_2, t_1 is recorded. The PH and Temperature of the treated water sample A was measured and reading noted from the Hanna H1991001 PH/Temperature meter.

The Mathematical model of chlorine decay along water distribution Network were computed using first order decay equation.

$$\frac{dc}{dt} = K_b C + \frac{4}{d} K_w \qquad 1.2$$

In which dc = change in chlorine concentration, dt = change in residence time,

Kb =first-order bulk decay coefficient, C=chlorine concentration (mg/l),d=pipe diameter(m),

kw = zero-order wall decay coefficient .

For analysis purposes, the above data was interpolated as:

C_1=Free chlorine concentration at ground level water storage reservoir in Cross River State Water Board. (Mg/l).

Co=Residual chlorine concentration at public water collection sample location stand taps (mg/l).

t_2 = Residence time at ground level water storage reservoir in Cross River State Water Board (min).

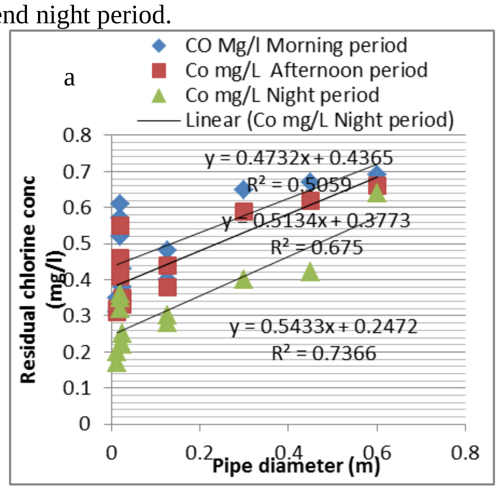
t_1 = Residence Time at public water collection location (m)

$$dc/dt = \frac{\text{change in chlorine concentration}}{\text{change in residence time}} = \frac{c_1 - c_o}{t_2 - t_1}$$

$$C = c_1 - c_o$$

III. RESULTS AND DISCUSSION

Figure 4.1 present results of variation of residual chlorine concentration with pipe diameter for data collected during morning, afternoon and night period. It was observed that, the residual chlorine concentration decreases as pipe diameter increases. The loss of chlorine in water was found to be smaller in larger pipe diameter. Since the major aim of the research work is to ensure the adequacy and to attain a desirable durable residual chlorine concentration, to meet WHO standard, larger pipe is recommend. Analytically, the R square values for all the period were found high, indicating goodness of fit of the analysis. Furthermore, a linear relationship was observed to exist in the plot of residual chlorine concentration with pipe diameter for all the days investigated. As label in fig 4.1, a-d represent selected days and weeks of the research work in a month. The blue legend represents morning period, red legend afternoon period and green legend night period.



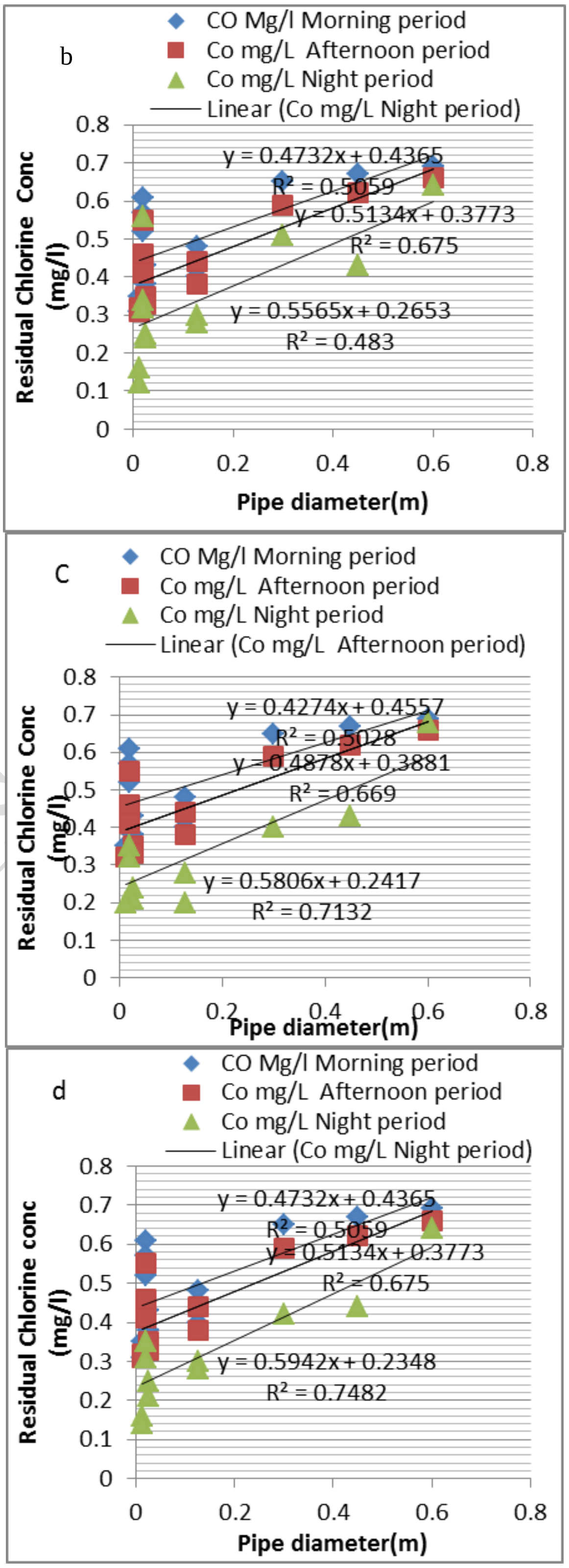
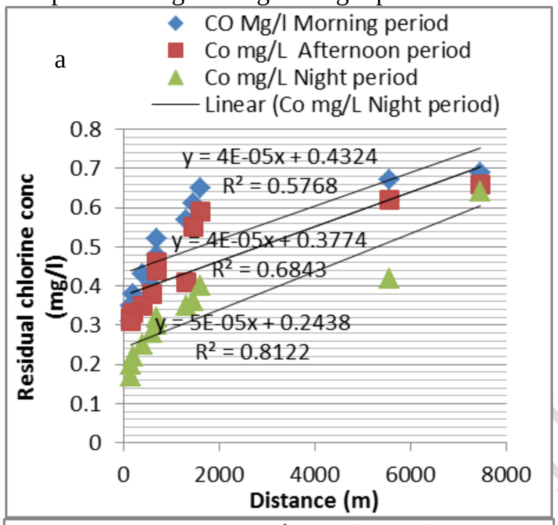


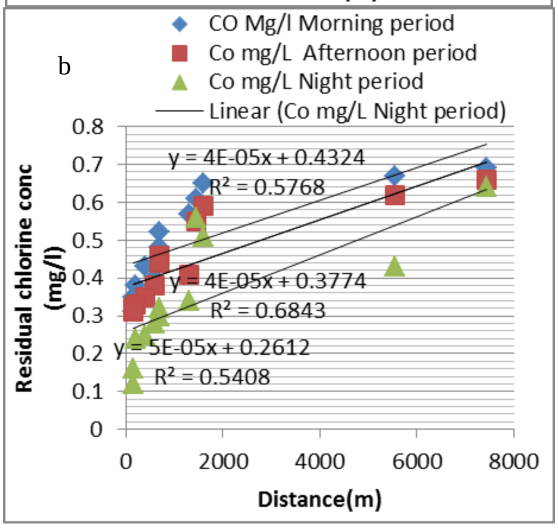
Figure 4.1: (a) Day one of week one, (b) day eight of week two (c) Day 15 of week three and (d) Day 28 of week four.

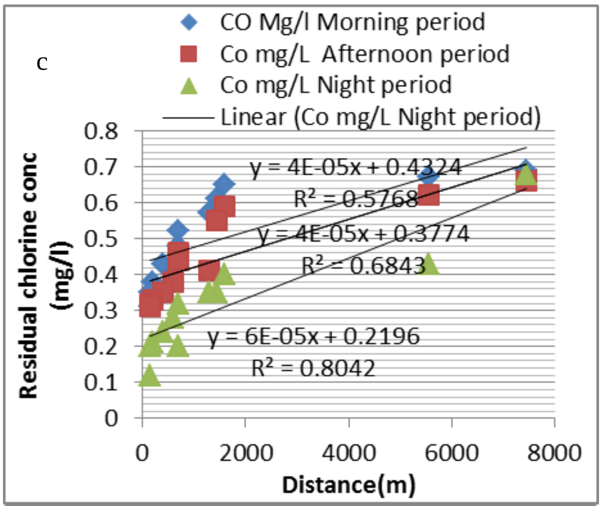
Figure 4.2: Present results of variation of residual chlorine concentration with distance for data collected during morning, afternoon and night period. It was observed that, the residual chlorine concentration decreases as distances increases. Base on previous work done by Hossein et al (2012) on effect of

residence time to water quality in large water distribution systems, they observed that ,bacteria growth (HPC) has direct relationship with water age, distance travelled and residence time, it was concluded that distance travelled increase bacteria growth, chlorine consumption and hydraulic change in the distribution system. Hence, according to the comparison of the work done by Hossein et al and this research work on residual chlorine decay in water distribution network, it was concluded that the distance travelled had been the major causes of decrease in residual chlorine concentration, increase bacteria growth, chlorine consumption, which led to the outbreak of cholera and typhoid. To offset this problem of distance, the chlorine concentration at the ground level water storage reservoir should be stepped up to ensure a durable residual chlorine that will go round circulation. Label in figure 4.1, a-d represent selected days and weeks/month of the research work.

The blue legend represents morning period, red legend afternoon period and green legend night period.







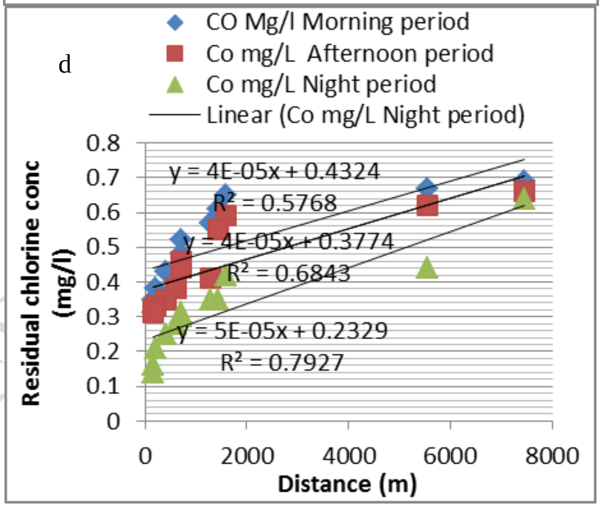
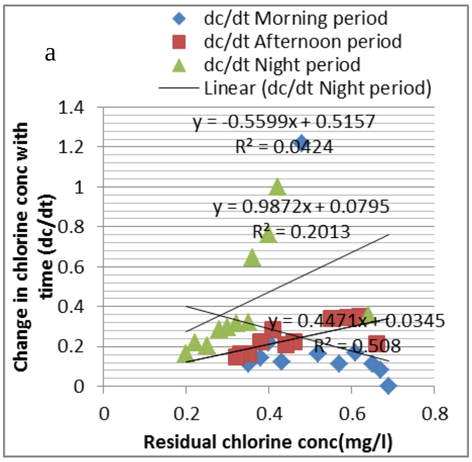


Figure 4.2: (a) Day one of week 1, (b) day eight of week two (c) Day 15 of week three and (d) Day 28 of week four.

Figure 4.3: Present results of change in residual chlorine concentration with time (dc/dt) against residual chlorine concentration for data collected during morning, afternoon and night period. A linear relationship was observed and also as the residual chlorine concentration increases, the change in chlorine concentration with time also increases. As depicted in figure 4.1, a-d represent selected days and weeks of the research work in a month. The blue legend represents morning period, red legend afternoon period and green legend night period.



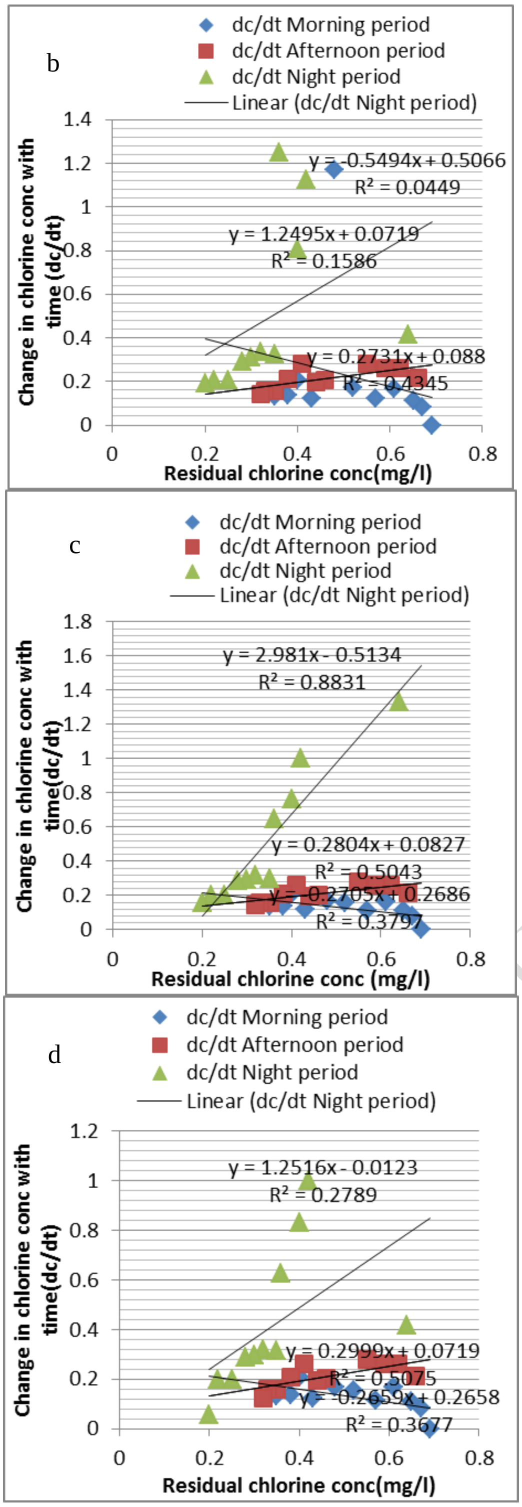


Figure 4.3: (a) Day one of week one, (b) day eight of week two (c) Day 15 of week three and (d) Day 28 of week 4

Figure 4.4: Present results of regression analysis of residual chlorine as a function of dosage, pipe diameter and temperature for morning, afternoon and night period. From the regression model, the R square value, being the coefficient of correlation of the regression, showed that 87% for morning period, 85% for afternoon and 73% for night period .The total variation of the chlorine concentration at the water stand taps is accounted for by dosage, temperature and pipe diameter. The dosage, temperature and pipe diameter are the independable variable indicated as X1, X2, X3 and Y as the dependable variable being the residual chlorine at the stand tap. In conclusion, since the R square values of the regression model was considered high, it indicate the goodness of fit of the analysis.

Regression Statistics	
Multiple R	0.9234114
R Square	0.8526886
Adjusted R Square	0.8199528
Standard Error	0.0008811
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	4.04402E-05	2.02E-05	26.04754	0.000180744
Residual	9	6.98649E-06	7.76E-07		
Total	11	4.74267E-05			

Figure 4.4: Regression analysis of residual chlorine as a function of dosage, diameter and temperature for morning period in day one.

Regression Statistics	
Multiple R	0.9234114
R Square	0.8526886
Adjusted R Square	0.8199528
Standard Error	0.0008811
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	4.04402E-05	2.02E-05	26.04754	0.000180744
Residual	9	6.98649E-06	7.76E-07		
Total	11	4.74267E-05			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	1.446E-05	0.011776642	0.001228	0.999047	-0.02662615	0.026655	-0.02157345	0.021602379
X Variable 1	0.0002773	0.00045163	0.614093	0.554358	-0.000744315	0.001299	-0.00055055	0.001105231
X Variable 2	0.008479	0.002257398	3.75611	0.004512	0.003372446	0.013586	0.00434097	0.012617099

Figure 4.5: Regression analysis of residual chlorine as a function of dosage, diameter and temperature for afternoon period in day one.

Regression Statistics	
Multiple R	0.859607261
R Square	0.738924643
Adjusted R Square	0.680907897
Standard Error	0.001449476
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	5.35178E-05	2.68E-05	12.7364	0.0023738
Residual	9	1.89088E-05	2.1E-06		
Total	11	7.24267E-05			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0.005917937	0.006566626	0.901214	0.390953	-0.0089368	0.0207727	-0.00611943	0.017955304
X Variable 1	-3.90856E-05	0.000258878	-0.15098	0.883321	-0.0006247	0.0005465	-0.00051364	0.000435467
X Variable 2	0.011215676	0.002383478	4.705593	0.001111	0.0058239	0.0166075	0.00684649	0.01558486

Figure 4.6: Regression analysis of residual chlorine as a function of dosage, diameter and temperature for night period in day one.

IV. CONCLUSION

From the study undertaken to measure the variational change in residual chlorine decay in water distribution network, a number of conclusions were drawn that will help water board and water service providers in planning, simplified approach to predict residual chlorine in pipe of varying diameter and formulating proper dosage approach for water treatment plant to attain a desirable and durable residual chlorine at the consumer water outlet. The residual chlorine concentration increases as pipe diameter increases. The loss of chlorine in water was found to be smaller in larger pipe diameter. The residual chlorine concentration decreases with distance increasing. Distance travelled was found to be the major cause of decrease in residual chlorine concentration, increase bacteria growth and chlorine consumption, which led to the outbreak of cholera and typhoid. A linear relationship was observed between residual chlorine concentration and change in chlorine concentration with time. From the regression model, the R square value, been the coefficient of correlation of the regression, shows that, for morning period 87%, afternoon period 85% and night period 73% of the total variation of the chlorine concentration at the water stand taps is accounted for by dosage, temperature and pipe diameter. The dosage, temperature and pipe diameter are the independable variable indicated as X1, X2, X3 and Y as the dependable variable being the residual chlorine at the stand taps. Since the R square values of the regression model was considered high, it indicate the goodness of fit of the analysis. Hence, this research will help water board and water service providers in planning, simplified approach to predict residual chlorine in pipe of varying diameter and formulating proper dosage for water treatment plant to attain a desirable and durable residual chlorine at water stand taps.

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