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Assessment and Optimization of Electrochemical Treatment of Typical Raw Water

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ABSTRACT: This article provides a brief report on electrochemical treatment of selected raw water. Raw water samples were collected from selected villages in Katsina and Osun states, Nigeria. These water samples were subjected to electrochemical treatment using statistical methods (orthogonal technique). Selected pollutants were monitored in term of water quality. Operational factors were optimized using steepest ascent technique and environmental engineering application of the findings was provided. The study revealed that factor with significant effects on efficacy of electrochemical treatment plant process at 99 .5 %confidence levels are sedimentation time, treatment time, chlorine added, and turbidity. Model equation for efficacy of the process based on the selected factors can be expressed as $60.68\text{-}2.26T_u+1.30Cl_d+1.10T_s+0.66S_t\text{-}\ 0.22D_b$. Operating cost of the process in US dollar (USD) can be expressed as 0.016 E_s, while size of the required sedimentation tank per unit volume can be expressed in relation to optimum treatment time as 6.538 R_t . It was concluded that the system is cost effective, economical and effective in removing selected pollutants.

Keywords: Statistical techniques, raw water, electrochemical treatment, sedimentation, pollutants

Arıtılmamış Suyun Elektrokimyasal Muamele ile Değerlendirilmesi ve Optimizasyonu

ÖZET: Bu makalede, arıtılmamış suyun elektrokimyasal muamale üzerine kısa bir bilgi vermektedir. Ham su örnekleri Nijeya'nın Katsina ve Osun eyaletlerindeki seçilmiş köylerden toplanıldı. Bu su örnekleri istatistiksel yöntemler kullanılarak elektrokimyasal muamelye tabii tutuldu ve su kalitesi bakımından değerlendirme yapıldı. Operasyonel faktörler en dik çıkış tekniği kullanılarak optimize edildi ve basit çevresel mühendisliği uygulamaları sağlandı. Çalışma, %99.5 güven seviyesinde elektrokimyasal proseslerin etkinliği üzerine sedimantasyon zamanı, muamele süresi, eklenilen klor ve bulanıklık gibi faktörlerin önemli bir etkiye sahip olduğunu gösterdi. Seçilen faktörler baz alındığında prosessin etkinliği için model eşitliği, $60.68\text{-}2.26T_u+1.30Cl_d+1.10T_s+0.66S_t\text{-}\ 0.22D_b$ olarak ifade edilebilir. Seçilmiş kirleticileri kaldırmada sistemin ekonomik ve tasarruflu olduğu sonucuna varılmıştır.

Anahtar kelimeler: İstatistiksel teknik, ham su, elektrokimyasal muamele, sedimantasyon, kirleticiler

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INTRODUCTION

Water is essential for all forms of life. Water covers about 73 percent of the Earth's surface. The quality of our environment is very often defined by the quality of the water set around us. Unfortunately the expanding demands for 'fresh' water of good quality by a growing population and industry have, inevitably, been equaled by an increased discharge of waste products to the nation's water courses. It is well known that environmental issues have become serious social concerns of a global scale. Among these issues, the impact of water pollution is getting more serious because it is closely related to the health and lives of human beings (Yoshida et al., 2007). The 20th century introduced new concerns regarding the environment, highlighting that its contamination and degradation will inevitably have its effects on all living things (Khanniche et al., 2001). Industrial pollution alters this environment in many more ways that were initially thought, interfering with the growth rate of species, the food chain, and with the health of those in contact with it. Current guidelines aim to lower the levels of toxic chemicals, reduce quantities of readily utilizable compounds, and reduce the degree of nutrients that would support microbial growth. Unless a suitable reduction is made, these factors will continue to cause un-repairable damage to the water courses they discharged their wastewater to.

Today, water containing pollution caused substances and microbes are treated to the conventional treatment process, in which microbes are still present in the final product. Conventional water treatment process is visible and practicable, but it has some disadvantages, such as it takes a long treatment time, it requires large-scale treatment facilities with economical issues and the problem of how to get rid of sludge produced by treatment. Advances in technology have resulted in greater water demands by communities and industries. The volume of wastewater from these companies has increased likewise, containing a variety of suspended solids, oils, metals, and organics. The unfortunately cleaning of these wastewaters prior to discharge using existing treatments has yet to improve comparatively.

Modern conventional treatment is often of a high technological nature, using membrane, irradiation, ultra violet, principally electrical technique to reduce the concentration of microbes, organic and inorganic compounds. Limitations of these treatment methods highlighted have included inabilities to cope with fluctuating loads and toxic, often expensive on time, cost, and space unlike electrochemical treatment technique. As a new water treatment method, electrochemical water treatment has been studied (Polcaro et al., 2001; 2002; Rajkumar et al., 2001; Chen, 2004; Oke 2007 a; Oke et al., 2012 a and b). In the electrochemical treatment process, organic pollutants in water are electrochemically oxidized or reduced to non-hazardous inorganic substances. In this water treatment method, electrode material is one of the important factors that affect treatment efficiency. In previous studies, effects of other factors such as chlorine dose, density of bacteria, concentration of dissolved minerals (iron), suspended solids and other pollutants were not addressed. The main focus of this study is to investigate effects of selected factors not previously studied on efficacy of electrochemical treatment process with a particular attention to utilization of orthogonal technique.

MATERIALS AND METHOD

As a follow up study on water treatment techniques in villages in Nigeria, water samples were collected from selected water sources in Katsina state (Kurechidutsi, Dogoruwa, Unguwar Mangoro and Kwari) and Osun state (Rivers eru, Igbo and oju nla). Water samples were collected in both rainy and dry seasons. Collected water samples were subjected to electrochemical treatment at fixed selected factors using orthogonal technique. Fixed factors were separation distance between the electrodes, stirring rate, type of electrode (aluminium/aluminium), direct current voltage, contact surface area of the electrodes and volume water sample (750 ml) to be treated. Factors varied under orthogonal technique were sample's turbidity (NTU), chlorine dose, treatment time, settlement time and concentration of bacteria. The quality of raw and treated water were measured using standard methods and procedure as stated in literature (APHA, 1998). Selected parameters (turbidity, suspended solids, iron concentration and density bacteria (most probable number)) were monitored. In the determination of bacterial density examination multiple tubes test technique was used as stated in the standard methods for water and wastewater analyses (APHA, 1998). Effects of selected factors on efficacy of electrochemical treatment process with a particular attention to utilization of standard orthogonal matrix technique were conducted (Table 1). The standard

Table 1. Standard $L_{25}(5^5)$ matrix (Guttman et al., 1971; Gardiner and Gettinby, 1998; Drouichel et al., 2001)

Experiment	Turbidity	Chlorine dose	Treatment Time	Settlement Time	Bacteria	Turbidity (NTU)	Chlorine dose (mg l^{-1})	Treatment Time (minutes)	Settlement Time (minutes)	Bacteria (MPN $100ml^{-1}$)
1	1	1	1	1	1	100	150	10	15	550
2	1	2	2	2	2	100	300	20	30	1100
3	1	3	3	3	3	100	450	30	45	1650
4	1	4	4	4	4	100	600	40	60	2200
5	1	5	5	5	5	100	750	50	75	2750
6	2	1	2	3	4	150	150	20	45	2200
7	2	5	1	2	3	150	750	10	30	1650
8	2	4	5	1	2	150	600	50	15	1100
9	2	3	4	5	1	150	450	40	75	550
10	2	2	3	4	5	150	300	30	60	2750
11	3	1	2	3	4	250	150	20	45	2200
12	3	5	1	2	3	250	750	10	30	1650
13	3	4	5	1	2	250	600	50	15	1100
14	3	3	4	5	1	250	450	40	75	550
15	3	2	3	4	5	250	300	30	60	2750
16	4	5	4	3	1	300	750	40	45	550
17	4	1	1	2	3	300	150	10	30	1650
18	4	4	5	1	2	300	600	50	15	1100
19	4	3	4	5	1	300	450	40	75	550
20	4	2	3	4	5	300	300	30	60	2750
21	5	3	2	5	4	400	450	20	75	2200
22	5	2	3	4	5	400	300	30	60	2750
23	5	1	2	3	4	400	150	20	45	2200
24	5	5	1	2	3	400	750	10	30	1650
25	5	4	5	1	2	400	600	50	15	1100

Table 2a. Individual efficacies of the water treatment process

Experiment	Efficacies (Run 1)				Efficacies (Run 2)				Efficacies (Run 3)				Efficacies (Run 4)			
	Turbidity	Suspended Solid	Bacteria	Iron	Turbidity	Suspended Solid	Bacteria	Iron	Turbidity	Suspended Solid	Bacteria	Iron	Turbidity	Suspended Solid	Bacteria	Iron
1	41.45	36.89	59.91	45.12	43.56	37.96	86.41	45.66	45.79	39.06	72.89	46.21	50.30	46.73	81.18	51.72
2	43.45	49.89	64.18	52.19	45.67	51.34	65.32	52.82	47.99	52.83	59.24	53.45	48.95	57.91	54.36	58.37
3	68.67	61.23	74.91	63.56	72.17	63.01	76.86	64.32	75.85	64.83	69.82	65.09	77.36	71.08	64.46	71.08
4	68.45	88.83	96.86	82.34	71.94	91.41	99.76	83.33	75.61	94.06	90.72	84.33	77.11	103.12	83.95	92.09
5	71.67	73.95	99.87	74.86	77.77	76.38	96.90	79.44	81.74	78.60	88.11	80.39	83.36	86.17	83.39	87.79
6	56.78	56.89	42.08	66.78	59.68	58.54	43.59	67.58	62.72	60.24	39.27	68.39	63.96	66.04	36.88	74.68
7	63.45	61.46	87.25	61.23	66.69	63.24	89.46	61.96	70.09	65.08	80.81	62.71	71.48	71.35	74.97	68.48
8	45.34	58.79	53.60	58.99	47.65	60.49	56.41	59.70	50.08	62.25	50.81	60.41	51.08	68.25	48.46	65.97
9	48.76	51.23	75.32	63.45	51.25	52.72	79.13	64.21	53.86	54.24	71.35	64.98	54.93	59.47	67.86	70.96
10	43.67	49.34	29.75	62.12	45.90	50.77	32.51	62.87	48.24	52.24	29.20	63.62	49.20	57.28	28.93	69.47
11	44.56	48.78	34.01	59.89	46.83	50.19	36.12	60.61	49.22	51.65	32.18	61.34	50.20	56.63	31.29	66.98
12	42.43	45.67	40.63	60.82	44.59	46.99	43.42	61.55	46.87	48.36	38.70	62.29	47.80	53.02	37.84	68.02
13	43.56	46.21	43.92	59.99	45.78	47.55	47.18	60.71	48.12	48.93	42.08	61.44	49.07	53.64	41.30	67.09
14	45.67	46.34	61.65	58.89	48.00	47.68	66.00	59.60	50.45	49.07	58.99	60.31	51.45	53.79	57.61	65.86
15	46.98	47.87	45.39	53.45	49.38	49.26	49.49	54.09	51.89	50.69	44.15	54.74	52.92	55.57	43.94	59.78
16	33.55	41.23	46.23	45.67	35.26	42.43	51.57	46.22	37.06	43.66	45.40	46.77	37.80	47.86	46.75	51.08
17	37.88	32.34	42.31	31.23	39.81	33.28	45.38	31.60	41.84	34.24	39.70	31.98	42.67	37.54	39.67	34.93
18	41.23	43.44	47.11	56.76	43.33	44.70	51.17	57.44	45.54	46.00	45.24	58.13	46.45	50.43	45.28	63.48
19	40.67	44.55	60.70	39.87	42.74	45.84	66.68	40.35	44.92	47.17	58.92	40.83	45.82	51.72	59.62	44.59
20	31.23	38.97	24.88	41.30	32.82	40.10	29.11	41.80	34.50	41.26	25.42	42.30	35.18	45.24	27.57	46.19
21	41.81	44.56	21.26	57.88	43.94	45.85	24.41	58.57	46.18	47.18	21.24	59.28	47.10	51.73	22.73	64.73
22	38.99	47.89	20.47	35.45	40.98	49.28	24.13	35.88	43.07	50.71	20.86	36.31	43.92	55.59	22.99	39.65
23	41.23	42.34	9.14	42.34	43.33	43.57	10.64	42.85	45.54	44.83	9.10	43.36	46.45	49.15	10.02	47.35
24	43.33	38.79	43.83	37.54	45.54	39.91	47.10	37.99	47.86	41.07	42.31	38.45	48.81	45.03	37.12	41.98
25	33.45	56.78	45.41	59.82	35.16	58.43	49.61	60.54	36.95	60.12	43.54	61.26	37.68	65.91	44.12	66.90

orthogonal matrix (L_{25}) which involves 5 factors and 5 levels is as obtained from literature such as Gardiner and Gettinby (1998); Guttman et al. (1971); Drouichel et al. (2001). Efficacy of the treatment process was based on ability to reduce selected parameters (suspended solids, bacteria density, turbidity and concentration of iron). Significant operational factors (settlement time, treatment time and chlorine dose added) were optimised using steepest ascent technique, while sample based factors (concentration of iron, suspended solid concentration and bacteria density) were kept constant. In steepest ascent technique factors with negative effects were decreased at a constant step in relation to the ratio of the effects as compared to the smallest significant factor, while factors with positive effects were increased in the same manner. Engineering applications of the results were provided using standard literature such as Tebbutt (1991), Steel and McGhee (1979); Vieessman and Hammer (1993); Chin (2000). Figure 1 presents typical sources of water in the selected villages. Computations of the efficacy based on ability to remove these selected parameters were conducted using the following expressions:

$$R_i(\%) = 100\left(\frac{C_o - C_1}{C_o}\right) \qquad (1)$$

Overall efficacies were computed using geometrical means as follow:

$$R_{all}(\%) = \left(R_i \times R_j \text{ ---------- } \times R_n\right)^{\frac{1}{n}} \qquad (2)$$

RESULTS AND DISCUSSION

In this study, results are discussed in following categories: orthogonal experiments, hypothesis and statistical analysis, optimization and engineering applications.

Orthogonal Experiments: In this L_{25} orthogonal experiments 5 factors with 5 levels were selected based on literature and importance in water and wastewater purification. The factors selected are sample's turbidity (NTU), chlorine dose, treatment time, settlement time and concentration of bacteria. The levels are numbered 1as the lowest level, through 3 to 5 as the highest level. Orthogonal experiments were repeated and the results are as presented in Table 2(a and b). Table 2a presents individual efficacies, while table 2b shows overall efficacies. From the results minimum responses occurred in all cases at experiment number 23 and the maximum values occurred at experiment number 5. The minimum responses occurred when chlorine dose added is at the lowest level and other factors are at high levels. This indicates that the other factors are combination of both positive and negative effect factors or influence of the chlorine dose added is so high that it neutralizes positive effects of other factors. Maximum responses occurred in all cases when chlorine dose added is at the highest level, turbidity of the water used at the lowest level, treatment time, settlement time and density of the bacteria in the water sample used are at high levels. This means that chlorine dose used, treatment time and settlement time with bacteria density in water used are likely to be positive factors the influence of which increases efficacy of electrochemical treatment of water with turbidity of water sample used as the only negative factors. These results are similar to the observation made concerning effects of separation distance of electrode, current density, and contact surface area on efficacy of electrochemical treatment process (Chen 2004; Oke, 2007), which indicates that efficacy of electrochemical treatment of water reduces with an increase in the turbidity of the water, increasing bacteria density of the water sample, decrease in treatment time, settlement time and chlorine dose used.

Hypothesis and Statistical Analysis: In order to analyze the data from the orthogonal experiments, the results were subjected to hypothesis tests with an objective of testing whether the factors and interactions have significant effect on the pollutants removal electrochemically. It is therefore necessary at this point to define the concepts and the issues such as replication (which is the process of repeating the entire procedure), two way interactions (involves combination of two factors), three and four way factors (combination of three and four factors respectively), main factors or main effects (these are the five factors mentioned, namely: chlorine dose used; turbidity of the water used; treatment time, settlement time and density of the bacteria) and hypothesis (statistical expression). The concept behind test of hypothesis is based on the need to decide whether a statement concerning a parameter or a set of parameters is true or false. It is to ascertain the truth in a claim. It is well known that in testing a statistical hypothesis *H* specific requirements are needed. Table 3 presents a summary of the requirements. The explanations of the summary are that:

* if hypothesis H is true and accepted or false and rejected, the decision is in either case correct;

* if hypothesis is true but rejected, it is in error (Type I error, with probability of α);

* if hypothesis is false but accepted, it is in error (Type II error, with probability of β).

The term null hypothesis is used for any hypothesis set up primarily to see whether it can be rejected and the term significant test is used when the test is based on checking if the difference error is too large to be reasonably attributed to chance. The specification of the probability of Type I error which is called the level of significance is usually set at α = 0:05 or α = 0:01. This value of probability should not be too small (Oke and Awofeso, 2006). Based on the sampling distribution of an appropriate statistics, the author constructed a criterion for testing the null hypothesis against the given alternative. Then calculations from the data were made and the values of the statistical parameters on which the decision was based were obtained. The analysis of orthogonal experimentation proceeds with using the formulae and sum of squares of analysis of variance. Tables 1; 2b and 4 show the standard orthogonal matrix, sum of the response, sum of squares (SSQ), K values of the factors, sum of squares of K values (SSQK), difference between the sum of squares (DFSSQK) and significant test. SSQ, coefficients (K) and SSQK were calculated using standard equations.

Table 1 is a standard orthogonal matrix (L_{25}) which involves 5 factors and 5 levels is as obtained from literature such as Gardiner and Gettinby (1998); Guttman et al. (1971); Drouichel et al. (2001). Efficacy of the treatment process was based on ability to reduce selected parameters (suspended solids, bacteria density, turbidity and concentration of iron). In this L_{25} orthogonal experiments 5 factors with 5 levels were selected based on literature and importance in water and wastewater purification. The factors selected are sample's turbidity (NTU), chlorine dose, treatment time, settlement time and concentration of bacteria. The levels are numbered 1as the lowest level, 2 as low level through 3 as the medium level, 4 as high to 5 as the highest level. The first five columns in the table are the code and level (1 to 5). The last 5 columns are the actual concentration of the parameters. In the 6^{th} column turbidity (NTU), the actual turbidity as follows: 100 NTU (lowest), 150 NTU (low); 250 NTU (medium); 300 NTU (high) and 400 NTU (highest). For the 7^{th} column chlorine dose (mg L^{-1}) is the parameter with 100 mg L^{-1} (lowest), 300 mg L^{-1} (low); 450 mg L^{-1} (medium); 600 mg L^{-1} (high) and 750 mg L^{-1} (highest). For the 8^{th} column treatment time (minutes) is the parameter with 10 minutes (lowest), 20 minutes (low); 30 minutes (medium); 40 minutes (high) and 50 minutes (highest). Columns 9^{th} and 10^{th} are for settlement time (minutes) and bacteria density (MPN/100ml) respectively in the same level as columns 6^{th} ; 7^{th} and 8^{th}.

Table 2a presents efficacies of the treatment in removing selected parameters (sample's turbidity (NTU), suspended solid, iron concentration and bacteria). The first 5 columns are individual efficacies for run1 (first set experiments), the next 5 columns are for run 2 till the last 5 columns for run 4. From the table the lowest efficacy occurred at experiment 23 (turbidity at the highest level, chlorine concentration at the lowest level, treatment time at the low level, settlement at medium level and bacteria density at high level). The highest efficacies occurred at experiment 5 when turbidity at the lowest level, chlorine concentration at the low level, treatment time at the low level, settlement at low level and bacteria density at low level). This indicates that turbidity contributes negatively, chlorine concentration contributes positively, treatment time contributes positively, settlement contributes positively and bacteria density contributes negatively to efficacies of the water treatment process.

Table 3. Summary of statistical requirement

Test	Accept H	Reject H
H is true	Correct decision	Type I error
H is false	Type II error	Correct decision

Table 2b shows a standard matrix L_{25} (5^5), overall efficacies computed using equation (2) and statistical data (mean; minimum, maximum and standard deviation). The first column is for experiment number, the next 5 columns are for the L_{25} matrix code, the next 7 columns are for the runs (runs 1 to 4 are as presented in Table 2a). From the table the lowest efficacy occurred at experiment 23 (turbidity at the highest level, chlorine concentration at the lowest level, treatment time at the low level, settlement at medium level and bacteria density at high level). The highest efficacies occurred at experiment 5 when turbidity at the lowest level, chlorine concentration at the low level, treatment time at the low level, settlement at low level and bacteria density at low level). This indicates that turbidity contributes negatively, chlorine concentration contributes positively, treatment time contributes positively, settlement contributes positively and bacteria density contributes negatively to efficacies of the water treatment process.

The values of these variables are as presented in Table 4. In the computations of effects, the methods used were based on literature such as (Gardiner and Gettinby, 1998; Lei et al., 2006; Oke, 2009) were followed (Table 4). From Table 4 it can be concluded that turbidity of the water used; chlorine dose used; treatment time and settlement time are significant factors that influence efficacy of electrochemical treatment of water at 99.5%confidence level with F-ratios of 537.58; 177.47; 127.69 and 46.15 respectively. Although, density of the bacteria of water used has effects on efficacy of the electrochemical treatment of water, its significance was not as high as that of the other four factors. F-ratio of the factor (density of the bacteria of water used) was 5.26. This can be attributed to causes of turbidity in water, which are colloidal particle, suspended solid and organic materials. These materials require more chemicals to neutralize their negative effects. Figure 2(a to e) presents responses of these selected factors to efficacy of electrochemical treatment of water at various levels. From the figure it can be identified that two

Table 4. Statistical Analysis of the efficacies and other data

Level of the factors (K)	Turbidity	Chlorine dose	Treatment Time	Settlement Time	Bacteria
$K_1 = \sum_{i=1}^{7} K_{1i}$	352.02	235.17	259.72	264.48	269.88
$K_2 = \sum_{i=1}^{7} K_{2i}$	302.47	238.66	243.19	262.21	266.97
$K_3 = \sum_{i=1}^{7} K_{3i}$	264.78	288.02	255.00	260.22	278.55
$K_4 = \sum_{i=1}^{7} K_{4i}$	225.61	301.26	306.66	272.95	277.48
$K_5 = \sum_{i=1}^{7} K_{5i}$	215.31	297.07	295.62	300.33	267.31
$SSQK = \left(\sum_{i=1}^{7} K_{1i}\right)^2 + \left(\sum_{i=1}^{7} K_{2i}\right)^2 + \left(\sum_{i=1}^{7} K_{3i}\right)^2 + \left(\sum_{i=1}^{7} K_{4i}\right)^2 + \left(\sum_{i=1}^{7} K_{5i}\right)^2$	382770.8	374230.1	373049.4	371115.5	370145.7
$SST = \sum_{i=1}^{25} R_i^2 - C = 4246$	$C = \frac{T^2}{25} = 74004.21$			$T = \sum_{i=1}^{25} R_i = 1360.19$	
$DFSSQK = \frac{SSQK}{5}$	76554.16	74846.03	74609.87	74223.1	74029.14
$SSQ = DFSSQK - C$	2549.95	841.82	605.66	218.89	24.94
Degree of freedom (df) = 4	$MSSE = \frac{SSE}{4}$		$SSE = SST - \sum_{i=1}^{n} SSQ_i = 4.76$		
$MSSQ = \frac{SSQ}{df}$	637.49	210.46	151.42	54.72	6.23
$F = \frac{MSSQ}{MSSE} = \frac{MSSQ}{1.19}$	537.58	177.47	127.69	46.15	5.26
$Effects = \left(\frac{SSQ}{5^{y-2}}\right)^{0.5}$	-4.52	2.60	2.20	1.32	-0.45
Coefficients = 0.5 x Effects	-2.26	1.30	1.10	0.66	-0.22

(**a**) Source of water with plant cover;

(b) Source of water (shallow well) at a river bed

(c) source of water with plant and trees in it

(d) source of water with flowing stream

Figure 1. Typical sources potable water at the villages

factors (turbidity and density of bacteria) decrease with increasing levels, which indicates that these two factors have negative effects on the efficacy of the treatment technique. Also, from the figure it was revealed that the response of three factors (settlement time, treatment time and chlorine dose used) increases with increasing levels. These factors have positive effects on efficacy of electrochemical treatment of water.

Figure 2(a) revealed that minimum turbidity for effective electrochemical treatment of water is 250 NTU. Figures 2(b) to 2(e) revealed that minimum effective treatment time for electrochemical treatment technique is 30 minutes, minimum effective time for floc settlement (settlement time) is 45 minutes, minimum supporting disinfection concentration using calcium hypochlorite is 0.8 mg l^{-1}. ml and minimum bacteria density was found to be 3 MPN/ 100ml. ml.

Optimization of operational Factors: Figures 3 (a - c) show optimization results and influence of these factors on pollutants removal during electrochemical treatment. Figure 3a shows that chlorine dose is a significant factor that influence efficacy of the electrochemical treatment of water positively (turning points above the mean). This result indicates that the higher the chlorine dose during electrochemical process the more the pollutants will be removed. This can be attributed to many factors such as reduction in the resistance of the electrolyte due to lowering organic matters (oxidation of organic component of the water by chlorine added), increase in conductivity of the electrolyte due to addition of ionic material (calcium hypochlorite), and increase in the flow of current due to high electrical conductivity. The optimum value obtained from the graph is 1481 mg l^{-1} of calcium hypochlorite, which indicates that change in efficacy of the system above 1481mg l^{-1} compared to efficacy of the system at 1481 mg l^{-1} of calcium hypochlorite will not be significant. Although it might be argued that 1481 mg l^{-1} of calcium hypochlorite is a small amount of chlorine compared to concentration of pollutants in some raw water samples, but transforming the value to equivalent chlorine dose gives 1.97 mg l^{-1} . ml of raw water which is adequate for wastewater and raw water (Steel and McGhee, 1979; Metcalf and Eddy, 1993).

From Figure 3b influence of treatment time (retention time in the reactor) on the efficacy of electrochemical process is positive (turning point above the mean). This indicates that higher retention time increases efficacy of the electrochemical treatment. This positive effect can be attributed to more electro-migration of ions from anode into the electrolyte, more collusion of unlike charges with colloidal particles, more of attraction forces and more dissolution of aluminum electrode into the electrolyte, which can be expressed as follows:

$$M(g) = IVT \quad (3)$$

$$Al - 3e^{(-)} = Al^{3+} \quad (4)$$

Optimum retention time was 99.6 minutes, which equivalent to 0.13 minutes ml^{-1}. Although, the retention time looks higher than necessary, but due to low direct voltage source (6 volt) and low current rating (600 mA) energy loss and cost will be small, which will make the process inexpensive and attractive.

Figure 3c shows that settlement time (sedimentation time) is among the factors that influence efficacy of the electrochemical treatment process positively (turning points above the mean). This result indicates that the higher the sedimentation time for the flocs more efficiency of electrochemical process. This phenomenon can be attributed to reduction in the suspended solid, higher time for flocculent particles (type II settling) , zone settling (type III settling) and compressive settling (type IV settling). The optimum value obtained from the graph was 148.0 minutes, which is equivalent to 0.20 minutes ml^{-1} of raw water sample.

Engineering Applications: Engineering applications of the technique are as follows:

❖ **Efficacy of the technique**: A model that relate efficacy of the technique to the selected factors was developed and the model is as follows:

$$Y(\%) = 60.68 - 2.26T_u + 1.30Cl_d + 1.10T_s + 0.6\ S_t - 0.22D_b$$

❖ **Design Parameters**: The main function of environmental engineers is to design an effective environmental pollution control devices using design parameters. For the section required design parameters are:

❖ **Retention time:** Retention time was defined as effective time required reducing pollutant optimally. For this technique effective time (detention time) can be expressed as: $R_t(h) = 0.13Q_n$

❖ **Chlorine dose:** The study conducted on the technique revealed that chlorine is require to reduce microorganism and effective concentration can be related to flow rate as $C_l(g) = 1.97Q_n$

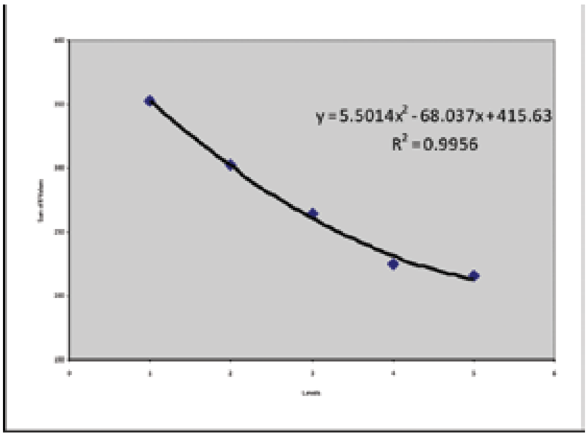

Figure 2a. Turbidity of the water used

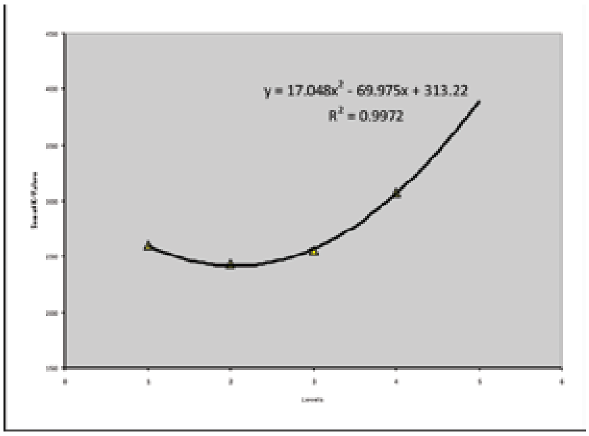

Figure 2b. Treatment Time of electrochemical

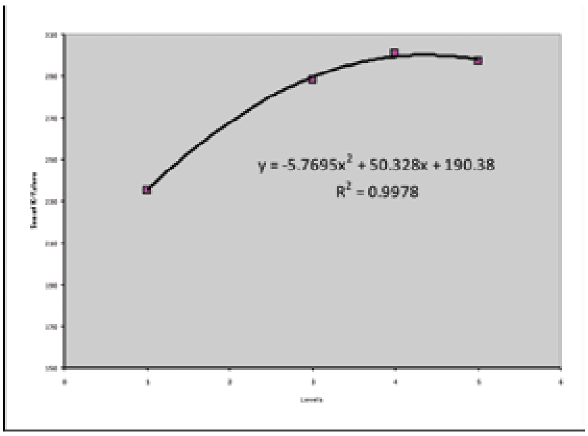

Figure 2c. Chlorine dose Used

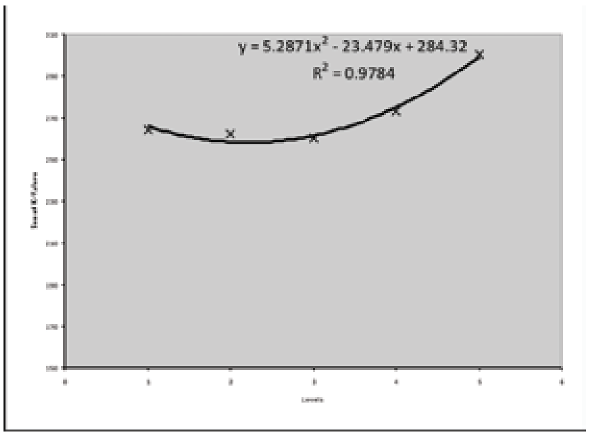

Figure 2d. Settlement Time

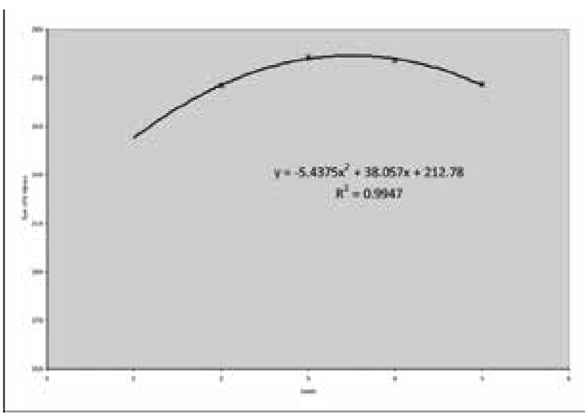

Figure 2e. Density of bacteria in water used

❖ **Sedimentation tank:** Size of sedimentation tank is important in water and wastewater treatment plant to remove effectively suspended solids, flocs and floating solids. Size of sedimentation tank can be expressed in relation to flow rate as:

$$V_{st}(m^3/h) = 0.80Q_n = 6.538R_t$$

❖ **Energy Required:** For the electrical energy is required. The amount of energy required can be expressed in relation to flow rate, voltage of the electrical source and retention time as:

$$E_s(Kwh) = Q_n V T_s$$
$$= 0.13 V Q_n^2$$

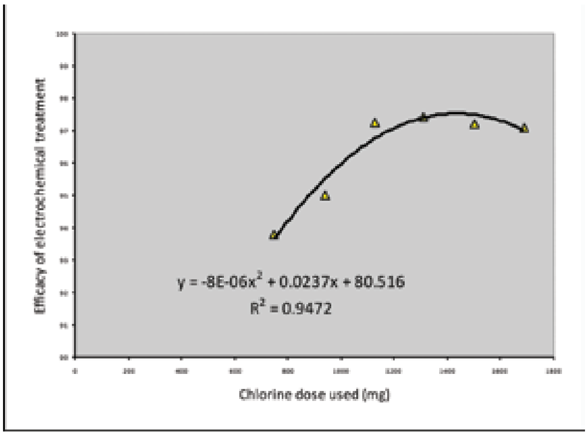

Figure 3a. Optimization of chlorine dose using sleepest ascent

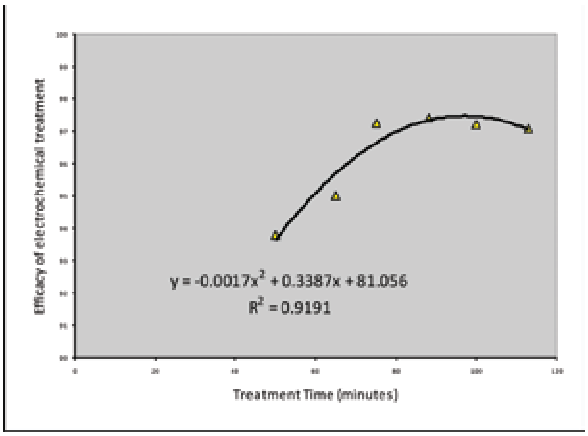

Figure 3b. Optimization of Treatment time using sleepest ascent

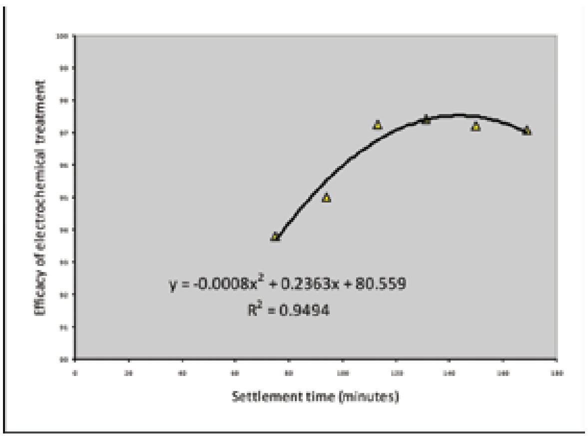

Figure 3c. Optimization of settlement time using sleepest ascent

Cost of energy required for the treatment: The cost of treatment using the technique can be expressed in relation to energy required as:

$$C_t\,(Nigeria\ Naira) = 12.56\,E_s$$

$$C_t\,(US\$) = 0.016\,E_s$$

CONCLUSION

In this study, L_{25} orthogonal experiments, which involves 5 factors with 5 levels were selected based on literature and importance in water and wastewater purification were studied. The factors selected are sample's turbidity (NTU), chlorine dose, treatment time, settlement time and concentration of bacteria. Effects of selected factors on efficacy of electrochemical treatment in purification of typical raw water were conducted using statistical technique (L_{25} orthogonal experiments). Raw surface water samples were collected from selected sources of water in Nigeria. These water samples were subjected to electrochemical treatment at various factors using orthogonal technique. The study revealed that electrochemical treatment of raw water supported by electrolyte (chlorine dose) is promising in removing turbidity, suspended solid, bacteria and iron concentration. It was concluded that the technique is cost effective and selected factors are significant in the efficacy of the system. It was concluded that the technique can be used to replace conventional water treatment technique at household level based on the cost and efficacy.

ABBREVIATIONS AND SYMBOLS

C_i	influent concentration of the pollutant (mg L^{-1})
C_o	effluent concentration of the pollutant (mg L^{-1})
df	degree of freedom
C	statistical constant
y	number of levels
K_{1i}	K value for level 1 and factor i
K_{2i}	K value for level 2 and factor i
K_{3i}	K value for level 3 and factor i
K_{4i}	K value for level 4 and factor i
K_{5i}	K value for level 5 and factor i

$DFSSQK = \frac{SSQK}{5}$

SSQK	sum of square of K
SST	Sum of square of T
SSQ	sum of square of factor Q
Q_n	flow rate ($m^3\ d^{-1}$)
T_u	Turbidity of the water used (NTU)
Cl_d	chlorine dose used ($mg\ l^{-1}$)
T_s	Treatment time (minutes)
S_t	Settlement time (minutes)
D_b	bacteria density (MPN $100ml^{-1}$)
R_t	Optimum time (h)
R_i	Individual efficacy (%)
R_{all}	overall efficacy (%)
E_s	Energy required for the treatment (K w h)
C_t	energy cost (US dollar)
V	voltage used (v)
I	current used (A)

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